# Development and Documentation of Geomorphic Characteristics in Support of a Cultural Resources/Archaeological Favorability Model for Death Valley National Park | 2015-01

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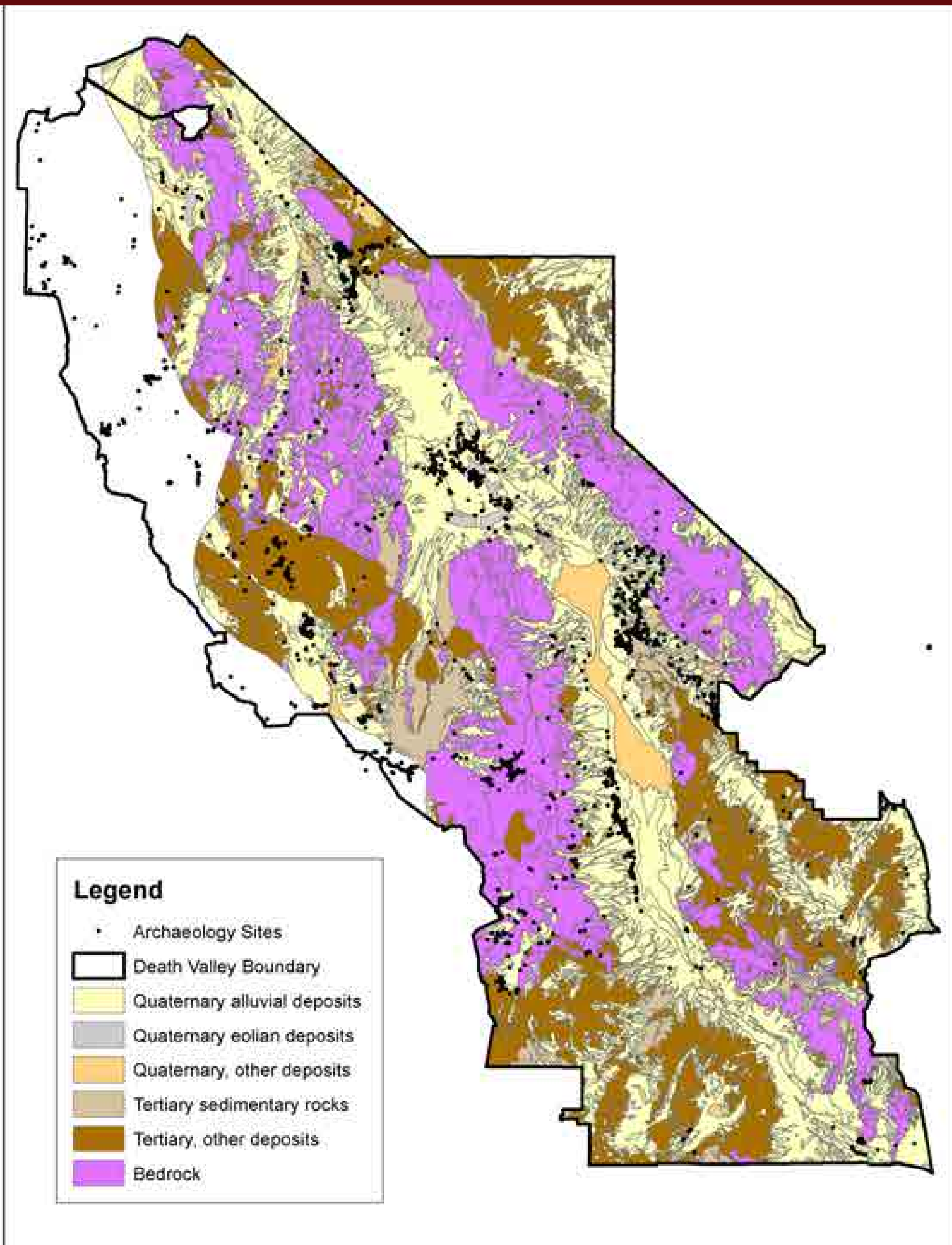


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# Interim/Final Progress Report

## Development and Documentation of Geomorphic Characteristics in Support of a Cultural Resources/Archaeological Favorability Model for Death Valley National Park

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Submitted to:
NPS Grants and Agreements Officer:
Catherine C. Schroeder
National Park Service MWRO
601 Riverfront Drive
Omaha, NE 68102

Submitted by:
T.F. Bullard, S.N. Bacon, and H.L. Green
Desert Research Institute
Reno, NV

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# Interim/Final Progress Report

Development and Documentation of Geomorphic Characteristics in Support of a Cultural Resources/Archaeological Favorability Model for Death Valley National Park

T.F. Bullard, S.N. Bacon, H.L. Green
Desert Research Institute, Reno, NV

[Great Rivers CESU Task Agreement #P13AC000904 under Cooperative Agreement #P13AC00763]

The following report sections contain 1) a comparison of actual project accomplishments with the goals and objectives for the reporting period as set forth in the agreement; 2) a discussion of the project background; 3) project progress on objectives during the reporting period; 4) specific project results and pertinent details; 5) recommendations for future work.

## 1. COMPARISON OF ACTUAL ACCOMPLISHMENTS WITH GOALS AND OBJECTIVES FOR THE REPORTING PERIOD

As per the agreement, the following presents a comparison of goals and objectives with actual accomplishments during the project period. If goals were not met, a short description is given.

**Objective 1:** Compile geologic, hydrologic, and tectonics information to determine the age, origin, and spatial distribution of different landscape units and hydrology: *Completed*

The following tasks were part of Objective 1 and the first performance period:

- Conduct a literature and records search on the geology, Quaternary geology, geomorphology, soils, and paleoenvironment of the Death Valley region: *Completed*
- Gather available digital geologic maps, including maps of active faults: *Completed*
- Acquire maps and/or digital data of known springs and natural water sources in Death Valley National Park: *Completed*
- Organize archaeological site catalog: *this was conducted by the research team at University of Illinois Champagne-Urbana*

**Objective 2:** Integrate the geologic, geomorphic, and hydrologic information with archaeological site information to develop site associations with geomorphology:

- Determine the relationship of archaeological site and site types to landform, landform age, geologic parent materials, active and inactive springs, and active faults: *Initial determination has been completed.*
    - *Map scale is an important element of any attempt to integrate and correlate archaeological sites with the geomorphology in Death Valley National Park.*

*Until high resolution geomorphic maps are available, assignment of meaningful geomorphic attributes to prehistoric archaeological sites and correlation between the prehistoric archaeology and geomorphology will not be possible.*

- *To demonstrate the influence of map scale on the correlation of archaeology and geomorphology, site type inventory was determined for each Pleistocene and Holocene surficial geologic unit at three available map scales (1:250,000, 1:100,000, and 1:50,000) for a small portion of Death Valley National Park where overlapping geologic map coverage is available. As a further test, a small area at site-specific scales within the overlapping coverage were mapped at 1:3,000- and 1:10,000-scales and site inventories were compared between them, as well as the site inventories for the same small test area, but using the available surficial geologic maps at scales of 1:250,000, 1:100,000, and 1:50,000. The results of the test underscore the need for high resolution geomorphic and surficial geologic maps at site-specific scales for developing geomorphic-based models for archaeology.*

- Examine site locations relative to geology using Quaternary geologic and bedrock geologic maps and assign attributes to sites that include: landform, relative age of geomorphic surface, slope aspect, and parent material. *This could not be accomplished at the scale of currently available geologic maps and digital elevation models in addition to poor age control for most existing geologic units.*

## 2. INTRODUCTION

Applying geomorphic principles to help understand human prehistory in the context of desert landscape evolution has been an integral part of archaeological investigations for many decades (Waters, 1992). The use of geomorphology to define and characterize landscape components conducive to preserving archaeological materials, also has been in use for several decades; however, it is only in recent years that soil-geomorphology has been applied to characterize landform surface dynamics and the relative age of deposits to assist with cultural resource management strategies. Intensified research efforts on American Southwest desert geomorphic systems in the 1970s and 1980s began to shed light on landscape evolution and the associations among landscape stability, landscape age, desert soils, and the development and significance of desert pavements (Wells et al., 1984; McFadden et al., 1987; McFadden et al., 1989). In recent years, application of this knowledge in archaeology has led to increased use of geomorphic-based archaeological models in cultural resource management programs on U.S. Department of Defense (DoD) installations (e.g., McDonald and Bullard 2003; Peter et al., 2004; Miller et al., 2009; Bullard et al., 2009; Brewster et al., 2011). However, the proper effective use of geomorphology in modeling, particularly in desert environments, is still developing.

The Desert Research Institute (DRI) began working with the U.S. Army Corps of Engineers, University of Illinois, Champagne-Urbana (UICU), and Fort Irwin Cultural Resources Department in 2001 to develop a conceptual, geomorphic-based archaeological model (Ruiz, 2002; McDonald and Bullard, 2003; McDonald et al., 2004; Ruiz et al., 2007). Since that time we have expanded the concept of geomorphic-based favorability models to other DoD installations including U.S. Marine Corps installations at Twentynine Palms (Brewster et al., 2011) and Camp Pendleton (Bullard and Bacon, 2010), as well as the U.S. Army Yuma Proving Ground (Bullard et al., 2010). The study plan at Death Valley National Park (DEVA) was to expand upon existing conceptual frameworks built around the role of geomorphology in archaeological modeling and to provide necessary geologic and geomorphic input for a comprehensive predictive model being developed with researchers at UICU.

Previous geomorphic-based archaeological models were based on straightforward associations of geology, geomorphology, and archaeology, and estimates the relative favorability (i.e., potential) of particular landscape components to contain surface and/or buried archaeological sites. For example, at Fort Irwin, a region characterized by a mix of geologic rock types, relatively intact lithic scatters, campsites, and quarry sites are commonly found preserved on stable geomorphic surfaces formed on parent materials derived from fine-grained volcanic rock sources and Tertiary-age deposits containing cobbles of lithic material suitable for procurement and tool making. The same types of sites (i.e., lithic scatters, campsites, and quarry sites) were rarely found on landscapes formed on deposits derived from coarse-grained igneous rock sources, such as granite and quartz monzonite.

The absence of lithic scatters, campsites, and quarry sites in landscapes associated with granitic rocks does not necessarily mean they did not exist; the coarse-grained igneous rocks tend to weather rapidly and are commonly associated with relatively unstable landscapes. In general, associated landscapes commonly have surfaces that are bioturbated by flora and fauna, and are relatively unfavorable areas for preserving intact surface archaeological sites. On the other hand, sites formed in areas containing abundant coarse-grained igneous rock may be more conducive to producing relatively thick deposits that could support different vegetation types (e.g., grasses) than areas containing abundant fine-grained volcanic rocks. Areas containing abundant coarse-grained igneous rock and weathering products also have the potential for containing buried sites. In addition, other site types, such as natural rock shelters and long-term habitation sites, which were rarely observed in fine-grained volcanic rock terrain at Fort Irwin, tended to be more frequently associated with coarse-grained igneous rocks. These same concepts were used at DEVA.

## Current Study

The focus of the research was to evaluate existing Quaternary geologic maps of the DEVA landscape and attempt to refine them as a basis for assessing the geomorphic context of archaeological resources for modeling purposes. The plan was to develop a hierarchical framework for site favorability to be used in a comprehensive archaeological predictive model developed by UICU. In simple terms, understanding the history and evolution of the landscape helps determine whether or not an artifact or an archaeological site is *in situ*. For example, if a 10,000 year old stone tool is found on a 2,000 year old alluvial fan surface, then it is likely that the tool is not in place and was transported to its current location long after the tool was created. Conversely, knowing the age of landscape units (i.e., landform) can help to constrain otherwise unknown age artifacts or activities such as quarrying or construction of stone alignments. Mapping the landscape into discrete geomorphic units based on relative surface age and landscape genesis can help develop the framework for archaeological favorability maps that can be used in the search for potential archaeological sites of particular ages.

The most thorough and efficient way to gain an understanding of landscape history in a region like DEVA is to integrate surface geologic or geomorphic map analysis with site-specific studies of natural surface and subsurface exposures of Pleistocene and Holocene alluvial and eolian deposits. The principle objectives of the project were to:

- Identify relations among archaeological site type and landform type, landform age, geologic parent materials, active and inactive springs, and active faults;
- Integrate the geology, hydrology, and tectonics to determine the age, origin, and spatial distribution of different geomorphic features; and
- Develop an archeological favorability map based on the integrated geology, geomorphology, springs, and active faults.

## Methods

Development of a geomorphic-based favorability model relies on the cultural resource inventory digital database (i.e., site catalogs), Quaternary geologic maps prepared at scales meaningful to the archaeologist, and the application of geospatial analyses.

**Geospatial Analysis.** The geospatial analyses consisted of intersecting DEVA's GIS database of archaeological sites with different geologic, terrain, and environmental (e.g., hydrology, springs) data layers in Environmental Systems Research Institute (ESRI) ArcGIS platform. Terrain data layers include standard ESRI imagery, NAIP color DOQs, available 10-meter digital elevation models, 1-meter, digital light detection and ranging (LiDAR) models, digital data for locations of springs, and active faults, as well as existing bedrock and Quaternary geologic maps.

**Cultural Resources Inventory Database.** A requirement of a geomorphic-based archaeological model is an archaeological site catalog that has reliable site location information, site type, and geomorphic data. Most catalogs commonly contain discrepancies in site location and inconsistencies in site records because of evolving developments in technology, methods, and protocols used throughout management history. Under normal circumstances, sites can be checked on maps and imagery against site records, compared with geomorphic data, and specific geomorphic attributes (e.g., landform, landform age, deposit, soil development) can be assigned to sites and site types. The necessary high-resolution geomorphic and surficial geologic maps are currently not available, thus determination of site location with respect to geomorphic units and landforms, both critical parts of the analysis, could not be undertaken to provide meaningful results.

As initially anticipated, archaeological sites were to be attributed with geologic, geomorphic, and relative age data. Then, as necessary, sites would be examined on ESRI/NAIP DOQ imagery alongside existing surficial geologic maps to confirm landform type, relative age of the deposit, and parent material type. Landforms and their relative ages can be identified and characterized by landscape position (e.g., terraces and other fluvial features parallel to stream channels; recognizable morphology of different age alluvial fans), surface feature characteristics (e.g., surface roughness resulting from original depositional relief, such as bar-and-swale topography, fluvial dissection, degree of desert pavement development), and cross-cutting relations with adjacent and different-aged landforms similar to classification schemes employed elsewhere in the desert southwest (e.g., Peterson, 1981; McFadden et al., 1989). Ultimately, geomorphic data and soil information can be spatially joined to each archeological site in

ArcGIS. The low resolution of existing geomorphologic and surficial geologic map data for DEVA makes any association among geomorphology and archaeology near meaningless.

**Geomorphology and Parent Material.** Developing the relations among archaeological sites, geomorphology, and geology is an important component of a geomorphic-based archaeological favorability model. The relations between landform morphology, age, and associated soil characteristics are dependent in large part on the parent material (i.e., geologic rock type) that comprises the deposits of individual landforms upon which soils develop (e.g., Birkeland, 1999). As expected, the occurrence and preservation of archaeological sites has a large dependence on the geology and landscape evolution of an area. Despite the challenge presented by lack of sufficient map resolution, the influence of scale on geomorphic and archaeological associations was tested for an area of the South Funeral Mountains where the surficial geology had been mapped by the U.S. Geological Survey (USGS) at three scales (1:250,000; 1:100,000; and 1:50,000) and archaeology site occurrence could be compared.

**Active Faults, Springs, and Archaeology.** Direct and indirect effects of tectonics, such as active faulting, can influence the spatial distribution of landform types, archaeological sites, and locations and activity of groundwater discharge (e.g., springs and seeps). The DEVA region is a well-documented zone of Pleistocene and Holocene faulting along the Death Valley fault zone (Machette et al, 2001; Workman et al., 2002a, b; Frankel and Dolan, 2007; Fridrich et al., 2012a, b). As indicated in the DEVA database of springs and USGS fault maps, many mapped springs are present where surface faults occur.

***Active faulting*.** Pleistocene and Holocene active faults can exert control on the location and integrity of archaeological sites, whereas, archaeological sites that are displaced by faults can help constrain fault slip rates. Faults that produce vertical as well as horizontal displacement can result in substantial topographic relief that may provide concealment and shelter, vantage points, and associations with water and vegetation. Studies in coastal northern California have demonstrated the importance of documenting archaeological sites displaced by Holocene active faults for purposes of determining, elucidating, and extending the paleoseismic record (e.g., Noller et al., 1993; Kelson et al., 2005). For example, the slip rate of a strike-slip fault can be determined if it passes through and displaces an archaeological site containing assemblages of known age. Because fault slip-rate determinations require the linear measurement of the horizontal, vertical, or both (i.e., oblique) fault displacement vectors, recognizable archaeological features of known age that are displaced across a fault can be useful strain indicators. Conversely, if the ages of fault-displaced geomorphic surfaces or subsurface deposits are known and fault slip rates have been determined, these data can be used to constrain or estimate ages of archaeological sites. In some cases, particularly quarrying sites and lithic scatters where little archaeological context is available for estimating age, cross-cutting relationships of faults and geomorphic surfaces can be used to place bounding limits on the age of the archaeology. Because fault slip rates are documented for many of the principal active faults in DEVA (e.g., Machette et al., 2001; Frankel et al., 2007), fault slip rates could be used to estimate the age of fault-displaced surface archaeological sites of unknown age.

***Springs and faults***. The occurrence of springs in desert regions is commonly associated with fracture systems in bedrock and both active and inactive faults. Fracture systems, fault zones, and fault planes can provide pathways for groundwater to reach the surface. Recent faulting in DEVA and the surrounding region has fragmented landforms and affected the local hydrogeology and surface hydrology (e.g., Faunt, 1997; Machette et al, 2001; Workman et al., 2002). Archaeological site location often has a spatial connection with water, which includes active and formerly active springs. Many of these natural water sources may be associated with fault traces and juxtaposed geologic units of contrasting hydraulic conductivity, which can result in the upwelling of groundwater and discharge onto the surface. In many cases, sites of former, long-term groundwater discharge are recognized by deposits of calcium carbonate in the form of travertine.

The predominantly strike-slip and normal faulting associated with the Death Valley – Furnace Creek fault systems are manifested in the DEVA landscape. Landforms associated with faulting within Death Valley include active and abandoned stream channels and stream terraces offset across strike-slip (horizontal), normal, and oblique-slip faults. Strike-slip and oblique-slip faults can result in the translation of small topographic ridges that block stream outlets (shutter ridges) and can also result in topographically low, elongated marshy areas associated with springs. For example, if an active strike-slip fault cuts across a stream channel or a channel developed from spring discharge, that stream channel eventually will be abandoned as fault displacement increases. The channel's former presence may be preserved in the landscape as a subtle, but recognizable topographic feature. If the fault slip rate is known and the distance between the two offset channels is measurable, then it is possible to estimate the age of an archaeological site that was displaced by faulting.

**Geomorphic-Based Archeological Favorability Map.** The ultimate goal of a geomorphic characterization for archaeology is to provide data for the development of a geomorphic-based archaeological favorability map and the eventual integration into the comprehensive archaeological predictive model developed by UICU. A geomorphic-based archaeological favorability map relies heavily on a detailed geomorphic map. Once a detailed geomorphic map is generated, derivative maps can be developed to portray the geomorphology – archaeology associations with a classification of relative likelihood (favorability) of encountering *in situ* archaeological materials; these types of maps are commonly portrayed as red, yellow, green representing levels of likelihood of finding archaeological sites. The detailed derivative maps can be used as a tool to identify certain archaeologically-sensitive landscape elements or areas that may be exposed to surface disturbance, such as when determining access points and routes to specific places within the park.

# 3. PROGRESS FOR THE PROJECT

Tasks and milestones completed for the reporting period and project include:

- Conducted a literature search on the geology, Quaternary geology, geomorphology, soils, and paleoenvironment of the Death Valley region;
- Gathered available digital geologic maps, including maps of active faults;
- Acquired maps of known springs and natural water sources in DEVA;
- Organized and began the analyses by intersecting archaeological sites and site types to landform, landform age, geologic parent materials, active and inactive springs, and active faults; and
- Compared and analyzed the effect of map scale on the ability to interpret site type association with geomorphology and geology.

**Literature Search**

A broad selection of recent literature on the geology, Quaternary geology, geomorphology, soils, and paleoenvironmental information exists for the Death Valley region and areas adjacent to DEVA. Some of the most relevant material is contained in U.S. Geological Survey regional geologic and hydrologic technical reports related to characterization studies at and around Yucca Mountain and the Nevada National Security Site (previously known as the Nevada Test Site), as well as papers contained in various professional journals such as the Geological Society of America (GSA) Bulletin, the GSA journal Geology, GSA Special Papers, Journal of Quaternary Science, Geomorphology, Quaternary Research, and Journal of Geophysical Research. The following publications represent relevant and up-to-date material on the Quaternary geology, geomorphology, soils, tectonics, and hydrology of the Death Valley region.

Enzel, Y., Knott, J.R., Anderson, K.C., Anderson, D.E., and Wells, S.G., 2002. Is there any evidence of mega-Lake Manly during Isotope Stage 6? Quaternary Research, v. 57, p. 173-176.

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Enzel, Y., Wells, S.G., and Lancaster, N., (editors), 2003. Paleoenvironments and paleohydrology of the Mojave and southern Great Basin deserts. Geological Society of America Special Paper 368, 249 p.

Wrucke, C.T., Stone, P., and Stevens, C.H., 2007. Geologic map of the Warm Spring Canyon area, Death Valley National Park, Inyo County, California. U.S. Geological Survey Scientific Investigations Map 2974, Scale 1:24,000.

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## Digital Geologic and Fault Maps

The publication of Workman et al. (2002a, b) contains the most up-to-date, comprehensive geologic and surficial geologic map for the majority of DEVA. Although the digital geologic map provided by DEVA does not cover the entire Park, the majority is covered, especially the principal valleys and along the broad piedmonts. The greatest drawback of the digital geologic map is the relatively small scale of 1:250,000, which required the mappers to lump (i.e., consolidate) important Pleistocene and Holocene alluvial units into map units that encompass broader time spans. Despite the small scale, the Holocene and Pleistocene geologic mapping shown on the 1:250,000 scale map is more detailed than the larger scale maps at 1:50,000 of the southern Funeral Mountains and at 1:100,000 of Death Valley Junction, because the surficial geology was mapped at finer scales (less than 1:100,000 scale), but compiled at 1:100,000 scale, and presented at 1:250,000 (C. Menges, pers. communication September, 2014). The map and report by Fridrich et al. (2012a, b) provide a greater detail of bedrock geologic map units (scale at 1:50,000), but the area covered by the map limits the usefulness to a relatively small area of the southern Funeral Mountains. We were, however, able to assess the relative usefulness of three scales of geologic mapping at 1:50,000; 1:100,000; and 1:250,000 for the southern Funeral Mountains area covered by the Fridrich et al. map (2012 a,b).

The U.S. Geological Survey maintains the most up-to-date compilation of Quaternary Fault and Fold database of the United States (http://earthquake.usgs.gov/hazards/qfaults/). The georeferenced fault map was imported into ArcGIS and underlaid with the Quaternary geology and the archaeological database for DEVA to assess the relation of archaeological site occurrence to mapped faults.

**Spring Sites and Water Resources**

Watershed boundaries and stream networks are available as geodatabases and were downloaded from the National Resources Conservation Service (NRCS) and USGS National Hydrography Dataset (NHD) and imported as layers in ArcGIS. The NHD also contains data for known seeps and springs. DEVA provided existing point shapefiles for springs and these were used in ArcGIS for analyzing spatial associations among springs, seeps, and archaeological site location. The digital geologic map of the southern Funeral Mountains (Fridrich et al., 2012a) also provides locations of important springs and seeps and shows a strong correlation of springs and seeps with fault traces.

**Archaeological Sites, Geomorphology, Springs, and Faults**

The archeological site catalog for DEVA was imported into ArcGIS for an initial assessment of the possible relations among archaeological sites and site types to landform, landform age, geologic parent materials, active and inactive springs, and active faults. For the initial assessment, only archaeological sites listed as prehistoric were used and only those sites that fall within the area of the digital geologic map.

There are approximately 1628 prehistoric archaeological sites within DEVA, and for each site there is possibility of 16 individual site types that can be recorded. As Table 1 illustrates, the majority of site types represented at the 1628 prehistoric sites are comprised of lithic scatters (AP2; ~40%) followed by cairns/rock features (AP8; ~18%), hearths and pits (AP11), ceramic scatters (AP3), rock shelter/cave (AP14), and habitation debris (AP15).

Prehistoric archaeological sites were overlain on the 1:250,000-scale geologic map of DEVA (Fig. 1) to illustrate the archaeological and geological associations. Table 2 shows the predominance of prehistoric sites occurring in areas mapped as Quaternary alluvial deposits (64%) although these types of deposits comprise only about 43% of the map area. When the prehistoric archaeological sites are associated with individual Quaternary alluvial deposits (Table 3), nearly 50% associate with unit Qay, which has an age of Holocene to latest Pleistocene; similarly, 22% of the sites are associated with Qayf/Qayfe (fine-grained alluvium and thin evaporite crust) with an age of Holocene to latest Pleistocene. In all, nearly 75% of archaeological sites situated in areas mapped as Quaternary alluvium can only be constrained in age to the period from the latest Pleistocene to Holocene.

There is clear association of prehistoric archaeological sites with springs and Quaternary active faults (Figs. 2, 3, 4), although the percentage of sites located on or within a few hundred meters of springs and faults is relatively low. The number and percent of prehistoric archaeological sites associated with natural springs and Quaternary active faults was determined using the detailed fault data set (USGS and California Geological Survey, 2010). About 22% of prehistoric archaeological sites in DEVA lie within 500 m of springs. Almost 20% of the springs at DEVA are located within 100 m of Quaternary active faults. The number and percentage of springs within 100 m of Quaternary active faults declines by almost 5% when using the general data set provided to us by DEVA. Similarly the number of sites located within 100 m of Quaternary active faults declines from about 11% to about 7% from the detailed fault data set to the more general data set.

**Analyzing the Effect of Map Scale on Site Type and Geomorphology Associations**

The preceding discussion of prehistoric sites associated with surficial geology illustrates the effect of map scale on the associations among archaeological sites, site types, and geomorphology. Useful associations, such as the age of geomorphic surfaces relative to the age of archaeological materials found on the surfaces are often diminished by coarse-scale maps that by necessity generalize or group map units. The effect of map scale on site type and geomorphology association was analyzed to provide comparisons between the number of sites and site types occurring in a common map area in the southern Funeral Mountains at the three map scales available for DEVA. To demonstrate the scale effect, the geomorphology of a small area of several hundred square meters was mapped at two larger and site-specific scales to show the archaeological site-geomorphic map unit association at different scales of 1:10,000 and 1:3,000 and compared to the surficial geologic map at 1:250,000; 1:100,000; and 1:50,000 for the same map area. The results are discussed in the following section.

# 4. SPECIFIC PROJECT RESULTS FOR THE REPORTING PERIOD

In addition to acquiring literature and digital maps for geology, faults, and springs, an initial assessment of the archaeological site-geomorphic associations was conducted. For the initial assessment, the 1:250,000-scale geologic map (Workman et al., 2002a) was simplified prior to analyzing associations. In order to quickly gain an understanding of the distribution of archaeological sites, the geologic map units, in particular the Quaternary deposits, were lumped (with age associations) into the six categories below and shown in Figure 1:

- Quaternary alluvial deposits comprised of Qc (channel alluvium – *Holocene*), Qay (young alluvium – *middle Holocene to latest Pleistocene*) and Qayf (young fine-grained alluvium – *Holocene to latest Pleistocene*), Qayo (intermediate-age alluvium – *middle Holocene to latest Pleistocene*), Qao (old alluvium – *late to middle Pleistocene*), Qau (undifferentiated alluvium – *Holocene to Pleistocene*), QTa (oldest alluvium – *middle Pleistocene to late Tertiary*), and QTau (undifferentiated older alluvium – *Holocene to latest Tertiary*);
- Quaternary eolian deposits (*Holocene* sand sheets and dune fields, relict sand ramps – *Holocene to middle Pleistocene)*;
- Quaternary other includes Qayfe (Evaporite surface crusts of salts and carbonate – *Holocene to latest Pleistocene*), QTd (deposits associated with modern or past groundwater discharge – *Holocene to late Tertiary*), QTls (landslide block – *Holocene to late Tertiary*), QTsf (old alluvial, paludal, or lacustrine sediments – *Pleistocene to late Tertiary*), and Qlc (old lacustrine deposits – *late to middle Pleistocene*);
- Tertiary sedimentary rocks;
- Tertiary, other deposits comprised of lava flows, ash flow tuffs, tuffs, and intrusive igneous rocks; and
- Bedrock, comprised of sedimentary, metamorphic, and intrusive igneous rocks (*Proterozoic to* Cretaceous)

Figure 1 also shows the prehistoric archaeological sites within DEVA superimposed on the generalized geology. Table 2 shows the distribution of the sites within the geologic map area by geologic map unit and relative percentage of the archaeological sites that fall within each map unit. Archaeological sites included on the map and preliminary results include only sites in the database identified as having prehistoric components. The site types do not include the "AP1 (unknown)" site type in the DEVA database and the distribution analyis did not include sites in the areas of DEVA that are not covered by the USGS digital geologic map. It is important to note that nearly 66% of prehistoric sites in DEVA are found in association with Quaternary alluvial deposits, which represent 43% of the map area.

**Map Scale and Interpreting Landscape Age.** As noted by Workman et al. (2002a,b), because of the map scale, units such as Qay (Holocene alluvium) may actually include, or lump, many subunits of Holocene age alluvium as well as older, but too small to map, remnants of late Pleistocene age alluvium and alluvial fan remnants. The lumping of many ages of landforms and deposits, although necessary for map presentation, limits our ability to discriminate discrete land surfaces of differing ages where archaeological sites may be situated, thereby limiting the strength of developing landscape and archaeology relations. For example, in Figure 5 the Quaternary geologic map on the left, which is used in this study, is from the USGS Death Valley region ground-water model (Workman et al., 2002a, 1:250,000 scale). It depicts one Holocene alluvial unit, two older alluvial units, and one fluvial unit. The map on the right of Figure 5 is the same map area, but mapped in detail at a scale of 1:6,000 by Green (2009); Green's map shows four Holocene alluvial units, two older alluvial units, two fluvial units, and four lake deposits. Further demonstration of the importance of scale is shown in Table 3. Nearly half of 1034 prehistoric sites found in areas mapped as Quaternary or Tertiary surficial deposits occur within a map unit Qay that has an age that spans the entire Holocene. For the purposes of determining the age of geomorphic surfaces and site associations and geomorphic modeling, such a broad age for the unit contributes little to the effort. Obviously, the detail of the 1:6,000-scale map is preferred for the ability to accurately associate archaeological sites with the most correct representation of the geomorphology, and ultimately strengthen performance of models.

The importance of working with detailed maps is further illustrated by the broad range of ages obtained for different alluvial fan units using $^{10}$Be cosmogenic surface exposure age dating from numerous studies in DEVA and compiled by Owen et al. (2011). All the locations of numerical surface age sites from numerous studies in Death Valley presented in Owen et al. (2011) were spatially joined to the 1:250,000-scale USGS geologic map to show how small-scale or coarse resolution mapping results in a wide range of ages for each map unit (Fig. 6). Figure 6 shows ages for the Qay map unit of Workman et al. (2002a) that span a range of ages from the latest Holocene to nearly 150,000 years.

A study by Frankel and Dolan (2007) along the Grapevine Mountains piedmont in northern DEVA demonstrates the utility of mapping using Light Detection And Ranging (LiDAR) Digital Elevation Model (DEM) data initially gathered along fault zones in Death Valley to create highly detailed Quaternary geologic maps (Figs. 7, 8). Although not entirely perfected, a process that could potentially automate geomorphic mapping is available in ArcGIS if one has high resolution (sub-meter) digital elevation data. Regmi et al. (2014) have demonstrated very good correlation of automated mapping based on surface roughness with standard geomorphic mapping techniques for a small same area in southern Arizona (Figs. 9, 10).

We attempted the same technique with 10-meter resolution DEMs to generate geomorphic maps. The difference between the 1-meter LiDAR and the 10-meter DEM is so great that the 10-meter resolution DEM serves no practical purpose in terms of geomorphic mapping in developing an archaeological favorability model (Fig. 11). Thus, a requirement for applying automated surface roughness mapping in DEVA is sub-meter digital elevation data, which is currently not available beyond the areas bounding fault zones.

As discussed previously, the greatest drawback of using the digital geologic map for DEVA in archaeological studies is the small scale of 1:250,000. Although the mapping was performed at scales of 1:100,000 or smaller, units were eventually compiled at 1:100,000 and presented at 1:250,000 scale (C. Menges, personal communication, September 2014). The 1:50,000 scale map and report by Fridrich et al. (2012a, b) provides greater detail of bedrock map units, but the area covered by the map limits the usefulness to a relatively small area of the southern Funeral Mountains. The Quaternary map units are actually less detailed than the 1:250,000 scale map.

**Assessing the effect of map scale.** Despite the challenge presented by lack of sufficient map resolution, we were able to assess the relative usefulness of three scales of geologic mapping (1:50,000; 1:100,000; and 1:250,000) because the Death Valley Junction 30’ x 60’ geologic map (scale 1:100,000) of Slate et al. (2009) overlaps with the Fridrich et al. (2012a) geologic map (scale 1:50,000), for the southern Funeral Mountains area and the 1:250,000-scale USGS geologic map (Figs. 12, 13, 14).

The assessment was accomplished by clipping the 1:100,000-scale map coverage to the 1:50,000-scale map of the southern Funeral Mountains, intersecting the areas with the archaeology site catalog and the 1:250,000-scale map, and comparing the numbers of site types (Tables 5 and 6) among map units. Geologic and geomorphic attributes for the 1:50,000-scale map were derived from the intersection of the two data sets, whereas, the geomorphic attributes for the 1:100,000-scale map were manually inspected by determining the surficial geology and geomorphology underlying each archaeological site data point.

Results of site type association with geologic map units for this relatively small area (Tables 7, 8, 9) indicate minor differences in the distribution of archaeological sites types with latest Pleistocene and Holocene deposits. For example, about 60 to 65% of prehistoric archaeological sites are situated in areas mapped as Holocene alluvium. Some minor differences are apparent in the age assignments for surficial map units and map unit detail was lost on the smallest scale map. Greatest differences in the three small-scale maps were the detail of the bedrock geology. The map of Slate et al. (2009) did not map the bedrock detail; whereas, the 1:50,000-scale map of Fridrich et al. (2012a) showed the greatest level of detail for bedrock units.

***Test of mapping scale.*** Two small areas were mapped at site-specific scales on NAIP imagery in ArcGIS in the overlapping map areas in the southern Funeral Mountains (described above). The location of the test area is shown on Figures 12, 13, and 14, and was chosen because it represented an area of relatively complex geomorphology with a small number (10) of archaeological sites within two broad categories of surficial geologic map units as shown on the three small-scale (1:250,000-, 1:100,000, and 1:50,000 scale) geologic maps. Figures 15-17 show the surficial geologic maps for the small area for the three small-scale maps and Figures 18-19 show the geomorphic mapping that was performed at 1:10,000 and 1:3,000 scales, respectively. Tables 10 and 11 summarize the distribution of archaeological sites and archaeological site types by map units for the various mapping scales. To further illustrate the effect of map scale, the detailed, large-scale mapping was compared and contrasted with the small-scale geologic maps for the same site-specific map area.

The surficial geologic map units represented by the small-scale maps in the site-specific map area consist of two units: Qay and Qayo. Table 10 shows that there is a similar distribution of archaeological sites with surficial geologic units among the small-scale geologic maps, although there is some variability in the assignment of map units. This likely reflects a loss of precision in map unit contact positioning at the different small scales.

The large-scale geomorphic maps (1:10,000 and 1:3,000 scale) show very similar distributions of archaeological sites. Exceptions occur where map unit contacts were refined at the finer detail and only possible at 1:3,000 scale. For example, a lithic scatter located on Qfy1 on the 1:10,000-scale geomorphic map is associated with a younger Qfy2 map unit on the 1:3,000-scale geomorphic map. Similarly, three sites mapped in the active channel at the 1:10,000 scale, whereas, at 1:3,000 scale the three sites are located on a young fan unit (Qfy4) that was able to be identified and mapped at this larger map scale.

# 5. Recommendations for Future Work in Geomorphic-Based Modeling

The ultimate goal of this project was to begin development of a model that could serve as a decision support tool to help address archaeological inventory strategies and fiscal resource allocation. Should the project continue, future products will eventually include a digital favorability map with some predictive capabilities, and an accompanying database that could be utilized and manipulated to address questions pertaining to the age and distribution of different archaeological site types. Future work could also provide paleoenvironmental context for known sites, as well as those that have yet to be discovered within the study area.

Although a comprehensive geomorphic-based favorability model could not be developed, areas were identified where enhanced data and information are necessary. These include:

- The association among bedrock types and archaeological site types, such as rock shelters (AP14) and habitation sites (AP15) needs to be better understood. At the National Training Center at Fort Irwin, which is located immediately south of the Avawatz Mountains and adjacent to the southern boundary of DEVA, rock shelters and habitation sites were found to be associated with coarse-grained granitic igneous rocks (quartz monzonite). At Fort Irwin, many documented natural rock shelters are formed through the cavernous weathering phenomena (e.g., tafoni) associated with coarse-grained igneous rock (McDonald and Bullard, 2003). These rocks also weather and disintegrate to their coarse mineral constituents (quartz, feldspar, mica) to produce abundant, loose very-fine gravel to fine-grained sand (known as grus). The grus is highly permeable and often supports distinctive vegetation, including native grasses, and is also easily transported by overland flow thereby raising the potential for burying archaeological sites (McDonald and Bullard, 2003; McDonald et al., 2004). In contrast, bedrock rock shelters and habitation sites at DEVA occur primarily in areas mapped as being underlain by calcareous bedrock (limestone and dolomite) and various sedimentary rocks including sandstone, conglomerate, and travertine (Table 12). Few if any rock shelters in DEVA are associated with coarse-grained igneous rocks. Understanding why the difference may be an important aspect of the prehistory of DEVA. It may also reflect the spatial relation of coarse-grained igneous rocks to natural resources as well as overall geography, or simply that those areas containing granitic rocks have yet to be surveyed.
- There is a strong need for more detailed (larger scale, higher resolution) Quaternary geologic and/or geomorphic maps than currently exists for DEVA. The bedrock geology, in large part, is sufficient for assessing the general geologic contribution to surficial geologic deposits comprising geomorphic features. Geomorphic maps of sufficient detail

could be generated for those parts of DEVA containing surficial geology and geomorphology (e.g., alluvial fans, terraces, lacustrine features, and eolian features) using existing LiDAR coverage. New methods and techniques for automating mapping alluvial fan terrain using surface roughness derived from 3-meter LiDAR data have been developed and initial results show great promise (e.g., Regmi et al., 2014). In the meantime, traditional mapping methods using ArcGIS and high-resolution LiDAR in concert with high-resolution imagery (e.g., NAIP) as demonstrated by Frankel and Dolan (2007) can provide the level of surface detail required to produce meaningful map units that can be correlated to archaeological site types in DEVA. The mapping-scale test suggests that for the landforms found in DEVA, a map scale between 1:3,000 and 1:10,000 would be sufficient to provide additional age constraints for undated archaeological sites that currently can only be constrained to the Holocene.

- Careful assessment on a site by site basis will be required to determine accurate locations and the level of site geomorphology detail in developing a robust model of the geomorphic association to archaeology.
- Strengthening of the UICU model will benefit from the integration of the associations of site types to geomorphology, soils, and geology.

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Tables

**Table 1.** Prehistoric archaeological site types at DEVA

| Site Type | Description | Count |
|---|---|---|
| AP1. | Unknown | 122 |
| AP2 | Lithic scatter | 1199 |
| AP3 | Ceramic scatter | 216 |
| AP4 | Bedrock milling feature | 142 |
| AP5 | Petroglyphs | 145 |
| AP6 | Pictographs | 38 |
| AP7 | Architectural feature | 91 |
| AP8 | Cairns/rock features | 552 |
| AP 9 | Burials | 20 |
| AP10 | Caches | 4 |
| AP11 | Hearths/pits | 233 |
| AP12 | Quarry | 19 |
| AP13 | Trails/linear earthworks | 66 |
| AP14 | Rock shelter/cave | 117 |
| AP15 | Habitation debris | 112 |
| AP16 | Other | 77 |

**Table 2.** Distribution of prehistoric archaeological sites by grouped geologic map unit and relative area of grouped map unit in the Death Valley National Park studyarea covered by the 1:250,000-scale geologic map.

| Map Unit | Archaeological Sites [n, (% total)] | Relative Map Area (%) |
|---|---|---|
| Quaternary alluvial deposits | 1034 (64%) | 43% |
| Quaternary eolian deposits | 66 (4%) | 1% |
| Quaternary, other deposits | 39 (2%) | 2% |
| Tertiary sedimentary rocks | 94 (6%) | 6% |
| Tertiary, other deposits | 158 (10%) | 20% |
| Bedrock | 237 (15%) | 28% |
| **TOTAL** | 1628 | 100% |

**Table 3**. Summary of discrete Quaternary alluvial units and their ages, prehistoric archaeological sites associated with each unit, area, and the percent total area represented by each unit shown on the 1:250,000-scale surficial geologic map of Death Valley National Park (does not include sites situated in areas mapped as bedrock).

| Map Unit Symbol | Description | Age | Arch. Sites (n) | Area (km$^2$) | Relative Area: Alluvial Units |
|---|---|---|---|---|---|
| **Qc** | channel alluvium | Holocene | 17 (2%) | 75 | 1% |
| **Qay** | young alluvium | Holocene to latest Pleistocene | 509 (49%) | 2533 | 48% |
| **Qayf** | young fine-grained alluvium | Holocene to latest Pleistocene | 223 (22%) | 477* | 9% |
| **Qayo** | intermediate-age alluvium | middle Holocene to latest Pleistocene | 31 (3%) | 301 | 6% |
| **Qau** | undifferentiated alluvium | Holocene to Pleistocene | 41 (4%) | 373 | 7% |
| **Qao** | old alluvium | late to middle Pleistocene | 136 (13%) | 1099 | 21% |
| **QTa/QTau/ QTsf** | older undifferentiated alluvium/old alluvial, paludal, lacustrine | Holocene to Tertiary | 77 (7%) | 382 | 7% |
| **TOTAL** | | | 1034 (100%) | 5240 | 100% |

*includes 183 km$^2$ of thin evaporate crust (Qayfe) that covers parts of Qayf

**Table 4.** Number and percent of prehistoric archaeological sites associated with natural springs and Quaternary active faults. Detailed fault data set (USGS and California Geological Survey, 2010) used for determining springs and sites within 100 m of faults. The difference in using the fault data set provided by DEVA is about 6% for sites within 100 m of faults and about 3% for springs situated within 100 m of faults.

| Distance | Springs (n=997) at Faults (DEVA fault data set) | Sites (n=1628) at springs | Sites (n=1628) at Faults (DEVA fault data set) |
|---|---|---|---|
| <100 m | na | 15 (<1%) | na |
| 100 m | 185 [19%] (153 [15%]) | 39 (~2.5%) | 185 [11%] (110 [7%]) |
| 200 m | na | 110 (~7%) | na |
| 500 m | na | 356 [~22%] | na |

**Table 5.** Area distribution of Pleistocene and Holocene alluvial map units containing prehistoric archaeological sites in the southern Funeral Mountains study area, 1:250,000-scale map.

| Map Unit Symbol | Description | Age | Arch. Sites (n) | Area ($km^2$) | Relative Area Alluvial Units (Holocene) |
|---|---|---|---|---|---|
| **Qc** | channel alluvium | Holocene | 7 | 13 | 8% (11%) |
| **Qay** | young alluvium | Holocene to latest Pleistocene | 94 | 70 | 41% (62%) |
| **Qayf** | young fine-grained alluvium | Holocene to latest Pleistocene | 27 | 7 | 4% (6%) |
| **Qayo** | intermediate-age alluvium | middle Holocene to latest Pleistocene | 9 | 6 | 3% (5%) |
| **Qau** | undifferentiated alluvium | Holocene to Pleistocene | 10 | 18 | 11% (16%) |
| **Qao** | old alluvium | late to middle Pleistocene | 29 | 32 | 19% |
| **QTa/QTau** | older and undifferentiated older alluvium | Holocene to Tertiary | 16 | 23 | 14% |
| **TOTAL** | | | 192 | 169 | 100% (100%) |

**Table 6.** Area distribution of Pleistocene and Holocene alluvial map units containing prehistoric archaeological sites in the southern Funeral Mountains study area, 1:50,000-scale map.

| Map Unit Symbol | Description | Age | Arch. Sites (n) | Area [$km^2$] | Relative Area Alluvial Units (Holocene) |
|---|---|---|---|---|---|
| **Qayy** | annually active alluvial fan | late Holocene | 0 | 4 | 2% (3%) |
| **Qayo** | recently active, low terraces | early Holocene | 6 | 9 | 5% (8%) |
| **Qay** | recently active channels | Holocene (<12ka) | 125 | 102 | 61% (89%) |
| **Qai** | mid-level terraces | Late Pleistocene | 61 | 30 | 18% |
| **Qao** | high terraces | Pleistocene | 5 | 18 | 11% |
| **Qc** | colluvial deposits | Holocene and Pleistocene | 1 | 4 | 2% |
| **TOTAL** | | | 198 | 167 | 100% (100%) |

**Table 7.** Summary of archaeological site type association to surficial geologic units for the 1:50,000-scale geologic map in the common overlapping area in the southern Funeral Mountains. Numbers of each site type and percent of site type occurring in specified map units. Final column shows total site types and percent by map unit; final row shows total number of site types occurring in map area. See Table 1 for site type definition.

| Map Unit | AP1 | % | AP2 | % | AP3 | % | AP4 | % | AP5 | % | AP6 | % | AP7 | AP8 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qc | 0 | 0.0 | 1 | 0.8 | 0 | 0.0 | 1 | 6.3 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 |
| Qay | 4 | 36.4 | 52 | 41.9 | 29 | 85.3 | 14 | 87.5 | 3 | 37.5 | 1 | 50.0 | 5 | 62 | 49.6 |
| Qayo | 0 | 0.0 | 6 | 4.8 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 1 | 0.8 |
| Qai | 3 | 27.3 | 30 | 24.2 | 2 | 5.9 | 1 | 6.3 | 2 | 25.0 | 0 | 0.0 | 6 | 29 | 23.2 |
| Qao | 0 | 0.0 | 1 | 0.8 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 5 | 4.0 |
| QTf/TBx (9) | 3 | 27.3 | 21 | 16.9 | 0 | 0.0 | 0 | 0.0 | 2 | 25.0 | 1 | 50.0 | 2 | 28 | 22.4 |
| PxBx (5) | 1 | 9.1 | 13 | 10.5 | 3 | 8.8 | 0 | 0.0 | 1 | 12.5 | 0 | 0.0 | 1 | 0 | 0.0 |
| **n/%** | 11 | 100.0 | 124 | 100.0 | 34 | 100.0 | 16 | 100.0 | 8 | 100.0 | 2 | 100.0 | 16 | 125 | 100.0 |

| Map Unit | % | AP10 | % | AP11 | % | AP12 | % | AP13 | % | AP14 | % | AP15 | % | AP16 | % | n, Total | %by unit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qc | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.5 |
| Qay | 49.6 | 0 | 0.0 | 11 | 61.1 | 3 | 37.5 | 7 | 70.0 | 1 | 7.7 | 4 | 28.6 | 5 | 41.7 | 201 | 48.8 |
| Qayo | 0.8 | 0 | 0.0 | 1 | 5.6 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 8 | 1.9 |
| Qai | 23.2 | 0 | 0.0 | 4 | 22.2 | 3 | 37.5 | 2 | 20.0 | 0 | 0.0 | 0 | 0.0 | 2 | 16.7 | 84 | 20.4 |
| Qao | 4.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 8 | 1.9 |
| QTf/TBx (9) | 22.4 | 1 | 100.0 | 2 | 11.1 | 2 | 25.0 | 1 | 10.0 | 4 | 30.8 | 4 | 28.6 | 4 | 33.3 | 75 | 18.2 |
| PxBx (5) | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 8 | 61.5 | 6 | 42.9 | 1 | 8.3 | 34 | 8.3 |
| **n/%** | 100.0 | 1 | 100.0 | 18 | 100.0 | 8 | 100.0 | 10 | 100.0 | 13 | 100.0 | 14 | 100.0 | 12 | 100.0 | 412 | 100.0 |

**Table 8.** Summary of archaeological site type association to surficial geologic units for the 1:100,000-scale geologic map in the common overlapping area in the southern Funeral Mountains. Numbers of each site type and percent of site type occurring in specified map units. Final column shows total site types and percent by map unit; final row shows total number of site types occurring in map area. See Table 1 for site type definition.

| Map Unit | AP1 | % | AP2 | % | AP3 | % | AP4 | % | AP5 | % | AP6 | % | AP7 | % | AP8 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Qayy** | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| **Qay** | 5 | 45.5 | 54 | 43.5 | 29 | 85.3 | 14 | 87.5 | 4 | 50.0 | 0 | 0.0 | 6 | 37.5 | 68 | 54.4 |
| **Qayo** | 0 | 0.0 | 4 | 3.2 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| **Qai** | 0 | 0.0 | 9 | 7.3 | 1 | 2.9 | 1 | 6.3 | 0 | 0.0 | 1 | 50.0 | 2 | 12.5 | 13 | 10.4 |
| **Qao** | 1 | 9.1 | 5 | 4.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 4 | 25.0 | 13 | 10.4 |
| **QTa** | 0 | 0.0 | 5 | 4.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 9 | 7.2 |
| **Bx (1)** | 5 | 45.5 | 47 | 37.9 | 4 | 11.8 | 1 | 6.3 | 4 | 50.0 | 1 | 50.0 | 4 | 25.0 | 22 | 17.6 |
| **n/%** | 11 | 100.0 | 124 | 100.0 | 34 | 100.0 | 16 | 100.0 | 8 | 100.0 | 2 | 100.0 | 16 | 100.0 | 125 | 100.0 |

| Map Unit | AP10 | % | AP11 | % | AP12 | % | AP13 | % | AP14 | % | AP15 | % | AP16 | % | n Total | % by unit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Qayy** | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| **Qay** | 0 | 0.0 | 10 | 55.6 | 3 | 37.5 | 7 | 70.0 | 2 | 15.4 | 5 | 35.7 | 6 | 50.0 | 213 | 51.7 |
| **Qayo** | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 4 | 1.0 |
| **Qai** | 0 | 0.0 | 5 | 27.8 | 0 | 0.0 | 1 | 10.0 | 0 | 0.0 | 0 | 0.0 | 1 | 8.3 | 34 | 8.3 |
| **Qao** | 0 | 0.0 | 1 | 5.6 | 0 | 0.0 | 1 | 10.0 | 0 | 0.0 | 0 | 0.0 | 1 | 8.3 | 26 | 6.3 |
| **QTa** | 0 | 0.0 | 1 | 5.6 | 0 | 0.0 | 1 | 10.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 16 | 3.9 |
| **Bx (1)** | 1 | 100.0 | 1 | 5.6 | 5 | 62.5 | 0 | 0.0 | 11 | 84.6 | 9 | 64.3 | 4 | 33.3 | 119 | 28.9 |
| **n/%** | 1 | 100.0 | 18 | 100.0 | 8 | 100.0 | 10 | 100.0 | 13 | 100.0 | 14 | 100.0 | 12 | 100.0 | 412 | 100.0 |

**Table 9.** Summary of archaeological site type association to surficial geologic units for the 1:250,000-scale geologic map in the common overlapping area in the southern Funeral Mountains. Numbers of each site type and percent of site type occurring in specified map units. Final column shows total site types and percent by map unit; final row shows total number of site types occurring in map area. See Table 1 for site type definition.

| Map Unit | AP1 | % | AP2 | % | AP3 | % | AP4 | % | AP5 | % | AP6 | % | AP7 | % | AP8 | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qc | 0 | 0.0 | 5 | 4.0 | 0 | 0.0 | 0 | 0.0 | 1 | 12.5 | 0 | 0.0 | 0 | 0.0 | 2 | 1.6 |
| Qay | 5 | 45.5 | 33 | 26.6 | 11 | 32.4 | 8 | 50.0 | 2 | 25.0 | 0 | 0.0 | 4 | 25.0 | 52 | 41.6 |
| Qayf | 0 | 0.0 | 17 | 13.7 | 18 | 52.9 | 7 | 43.8 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 3 | 2.4 |
| Qayo | 0 | 0.0 | 7 | 5.6 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 1.6 |
| Qau | 0 | 0.0 | 2 | 1.6 | 0 | 0.0 | 0 | 0.0 | 2 | 25.0 | 0 | 0.0 | 1 | 6.3 | 8 | 6.4 |
| Qao | 2 | 18.2 | 7 | 5.6 | 1 | 2.9 | 0 | 0.0 | 0 | 0.0 | 1 | 50.0 | 6 | 37.5 | 18 | 14.4 |
| QTa/QTau | 0 | 0.0 | 6 | 4.8 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 11 | 8.8 |
| QTd | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| TBx (3) | 4 | 36.4 | 33 | 26.6 | 1 | 2.9 | 1 | 6.3 | 2 | 25.0 | 1 | 50.0 | 4 | 25.0 | 28 | 22.4 |
| PzBx (3) | 0 | 0.0 | 14 | 11.3 | 3 | 8.8 | 0 | 0.0 | 1 | 12.5 | 0 | 0.0 | 1 | 6.3 | 1 | 0.8 |
| **n/%** | 11 | 100.0 | 124 | 100.0 | 34 | 100.0 | 16 | 100.0 | 8 | 100.0 | 2 | 100.0 | 16 | 100.0 | 125 | 100.0 |

| Map Unit | AP10 | % | AP11 | % | AP12 | % | AP13 | % | AP14 | % | AP15 | % | AP16 | % | n Total | % by unit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qc | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 8 | 1.9 |
| Qay | 0 | 0.0 | 12 | 66.7 | 1 | 12.5 | 8 | 80.0 | 1 | 7.7 | 2 | 14.3 | 5 | 41.7 | 144 | 35.0 |
| Qayf | 0 | 0.0 | 1 | 5.6 | 0 | 0.0 | 1 | 10.0 | 0 | 0.0 | 2 | 14.3 | 0 | 0.0 | 49 | 11.9 |
| Qayo | 0 | 0.0 | 1 | 5.6 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 10 | 2.4 |
| Qau | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 13 | 3.2 |
| Qao | 0 | 0.0 | 2 | 11.1 | 1 | 12.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 8.3 | 39 | 9.5 |
| QTa/QTau | 0 | 0.0 | 0 | 0.0 | 1 | 12.5 | 1 | 10.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 19 | 4.6 |
| QTd | 0 | 0.0 | 0 | 0.0 | 1 | 12.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.2 |
| TBx (3) | 1 | 100.0 | 2 | 11.1 | 4 | 50.0 | 0 | 0.0 | 4 | 30.8 | 4 | 28.6 | 5 | 41.7 | 94 | 22.8 |
| PzBx (3) | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 8 | 61.5 | 6 | 42.9 | 1 | 8.3 | 35 | 8.5 |
| **n/%** | 1 | 100.0 | 18 | 100.0 | 8 | 100.0 | 10 | 100.0 | 13 | 100.0 | 14 | 100.0 | 12 | 100.0 | 412 | 100.0 |

**Table 10.** Summary of prehistoric archaeological sites by map scale and map units represented in the site-specific map area.

| | Map Units | | Map Units | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Scale** | **Qao** | **Qay** | | | | | | | |
| 1:250,000 | 4 | 6 | | | | | | | |
| 1:100,000 | 3 | 7 | | | | | | | |
| 1:50,000 | 4 | 6 | **Qfi** | **Qfy1** | **Qfy2** | **Qfy3** | **Qfy4** | **Qac** | **Qc** |
| 1:10,000 | | | 3 | 1 | 0 | 3 | na | 3 | na |
| 1:3,000 | | | 3 | 0 | 1 | 2 | 3 | 1 | 0 |

Note: ages of map units for 1:250,000-; 1:100,000-; and 1:50,000-scale geologic maps are shown on Figures 12-14; Qay is latest Pleistocene to Holocene; Qao is latest to middle Pleistocene. Ages for the units shown on the 1:10,000- and 1:3,000-scale maps (Figs. 18-19) are estimates based on experience in similar terrain and similarly mapped and described units in areas adjacent to DEVA.

**Table 11.** Summary of prehistoric archaeological site types by map unit in the site-specific map area.

| | Map Units: 1:250,000 1:100,000 1:100,000 | | Map Units 1:10,000 and 1:3,000 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Site Type** | **Qao** | **Qay** | **Qfi** | **Qfy 1** | **Qfy2** | **Qfy3** | **Qfy4** | **Qac** | **Qc** |
| **AP2 (lithic scatter)** | 2 | 1 | 4 | 1 | 1 | 0 | 3 | 0 | 0 |
| **AP7 (architecture feature)** | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **AP8 (cairns/rock feature)** | 1 | 3 | 2 | 0 | 0 | 5 | 2 | 2 | 0 |
| **AP16 (unknown)** | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |

Note: ages of map units for 1:250,000-; 1:100,000-; and 1:50,000-scale geologic maps are shown on Figures 12-14; Qay is latest Pleistocene to Holocene; Qao is latest to middle Pleistocene. Ages for the units shown on the 1:10,000- and 1:3,000-scale maps (Figs. 18-19) are estimates based on experience in similar terrain and similarly mapped and described units in areas adjacent to DEVA.

**Table 12.** Summary of rock shelter (AP14) and habitation site (AP15) associations with bedrock and bedrock lithology.

| Site Type | 1:50,000 map | | 1:100,000 map | | 1:250,000 map | | Map unit Geology |
|---|---|---|---|---|---|---|---|
| | Rock unit | Count | Rock unit | Count | Rock unit | Count | |
| **AP14** | Bedrock | 12/13 | Bx | 11/13 | Bedrock | 12/13 | • DSh, DShv – Hidden Valley Dolomite (Devonian)<br>• Oe/Op – Eureka Quartzite (quartzite), Pogonip Formation (limestone; Ordovician)<br>• PxnbcNopah, Bonanza King, Carrara formations, (limestone, dolomite, siltstone; Cambrian)<br>• Ts4 – sedimentary rocks (sandstone, conglomerate; Pliocene and Miocene)<br>• Ttf/Tnm – travertine (Ttf; Pliocene) and Artists Drive Formation (Tnm; Miocene)<br>• Bx – undifferentiated bedrock older than Quaternary (1:100,000 scale map) |
| (n=13) | DSh | 6/13 | | | DShv | 7/13 | |
| | Oe/Op | 2/13 | | | Pznbc | 1/13 | |
| | Ttf/Tnm | 4/13 | | | Ts4 | 4/13 | |
| | | | | | | | |
| **AP15** | Bedrock | 10/14 | Bx | 9/14 | Bedrock | 10/14 | |
| (n=14) | Tertiary | 4/14 | | | DShv | 6/14 | |
| | Pre-Tertiary | 6/14 | | | Ts4 | 4/14 | |

# Figures and Captions

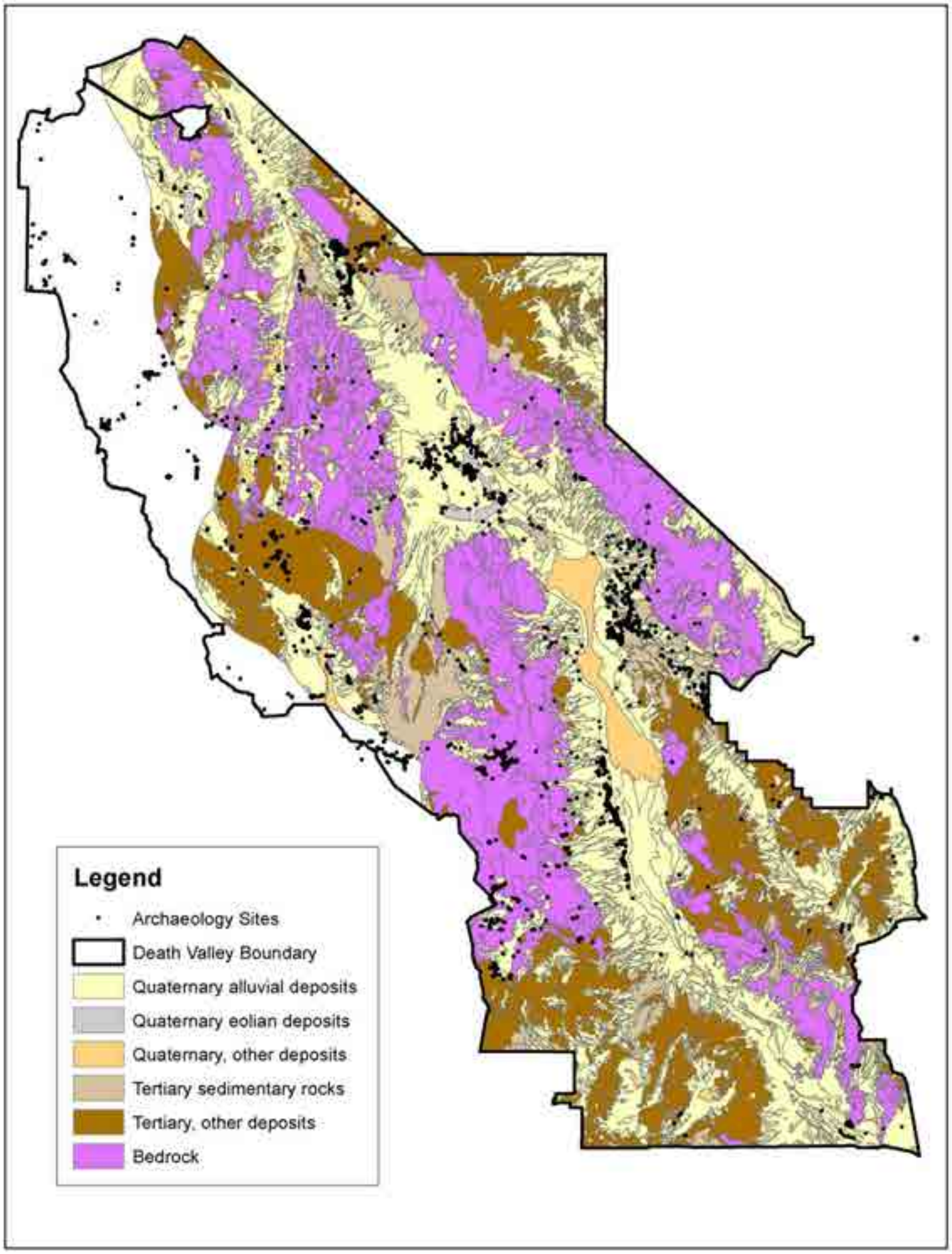


**Figure 1.** Archaeological sites having prehistoric components within Death Valley National Park superimposed on grouped Quaternary and bedrock geologic map units of the USGS groundwater model geologic map (original mapscale = 1:250,000).

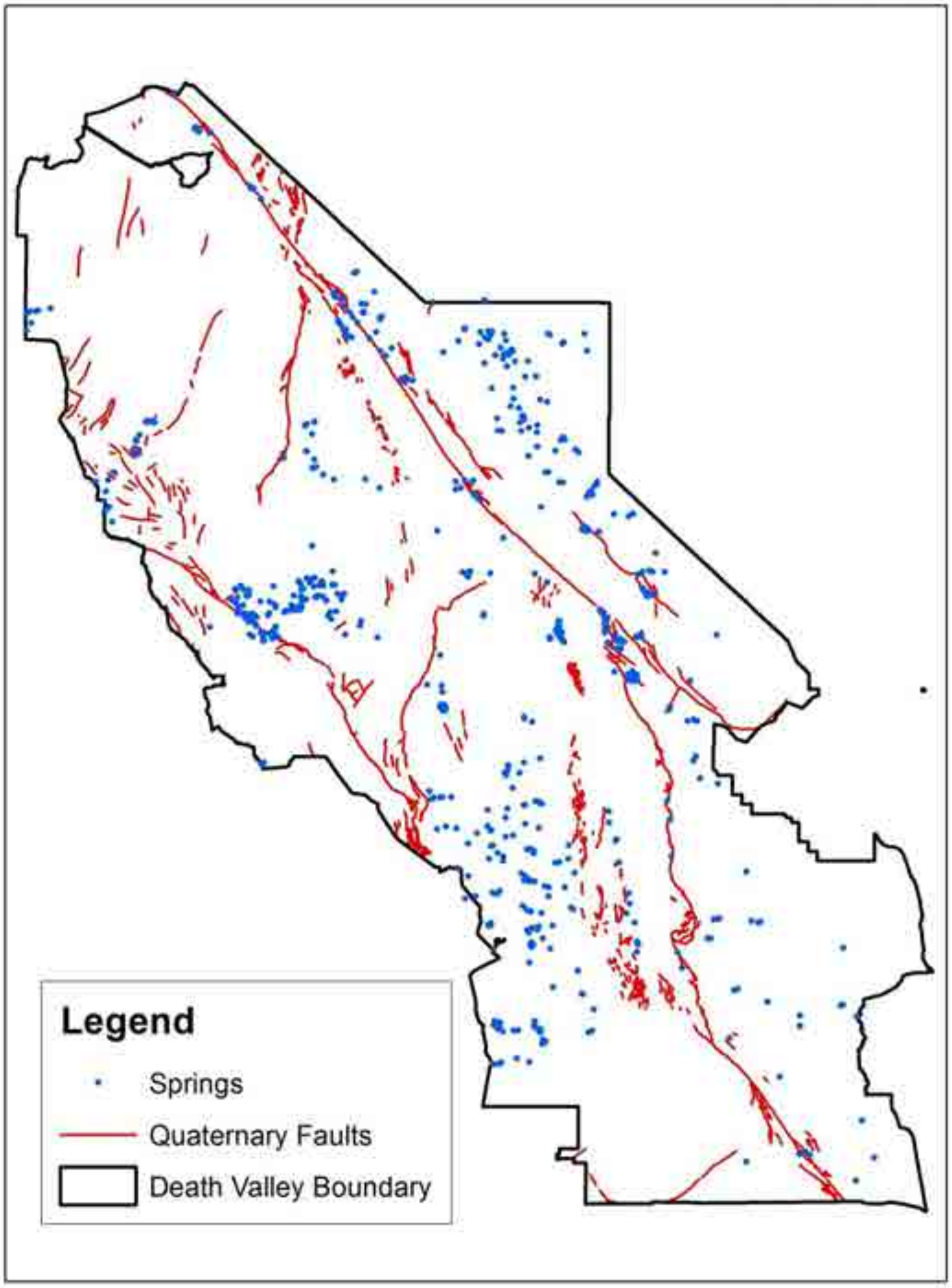


**Figure 2**. Map of DEVA showing spring locations relative to Quaternary faults.

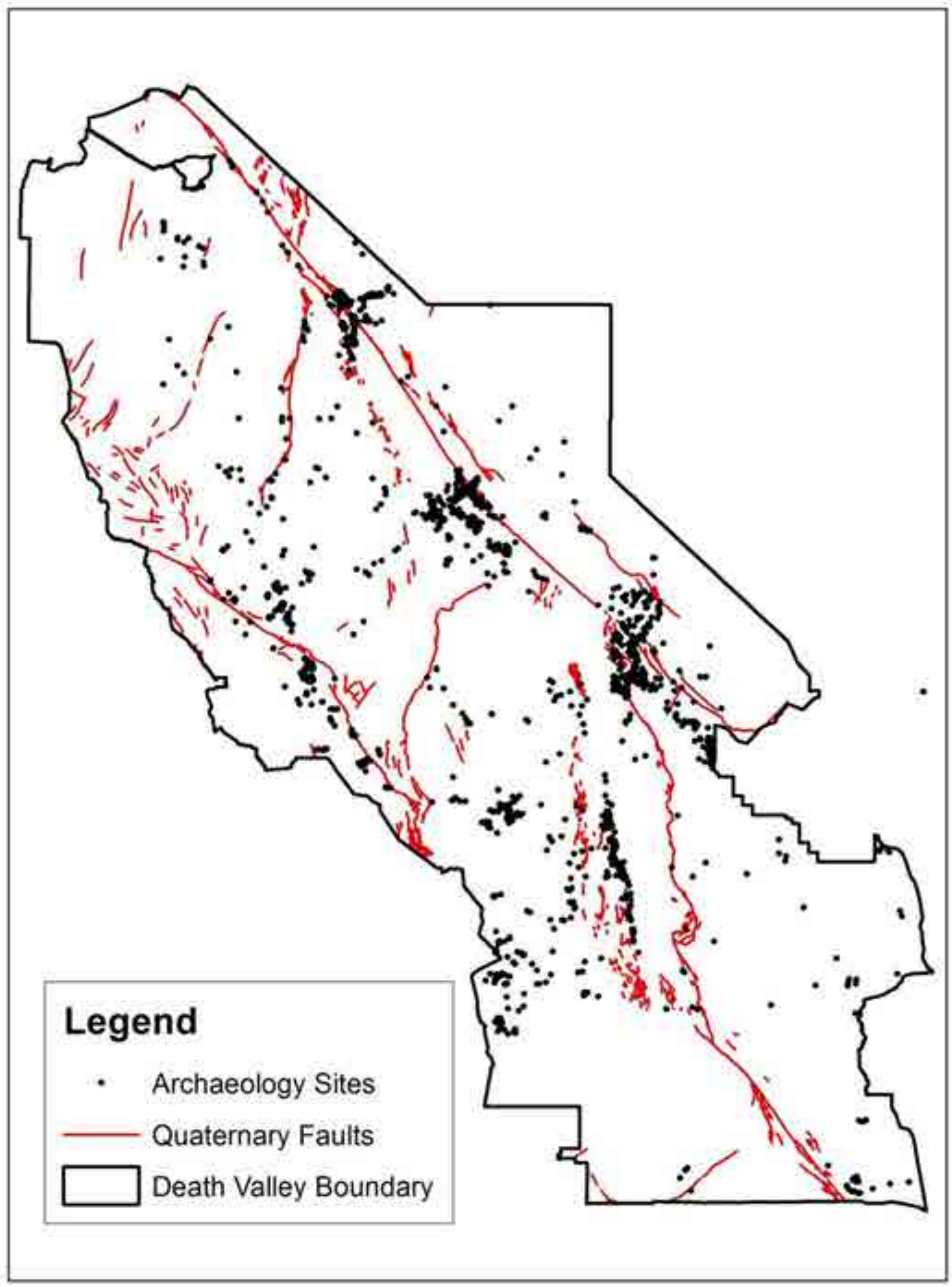


**Figure 3**. Map of DEVA showing prehistoric archaeological sites relative to Quaternary faults.

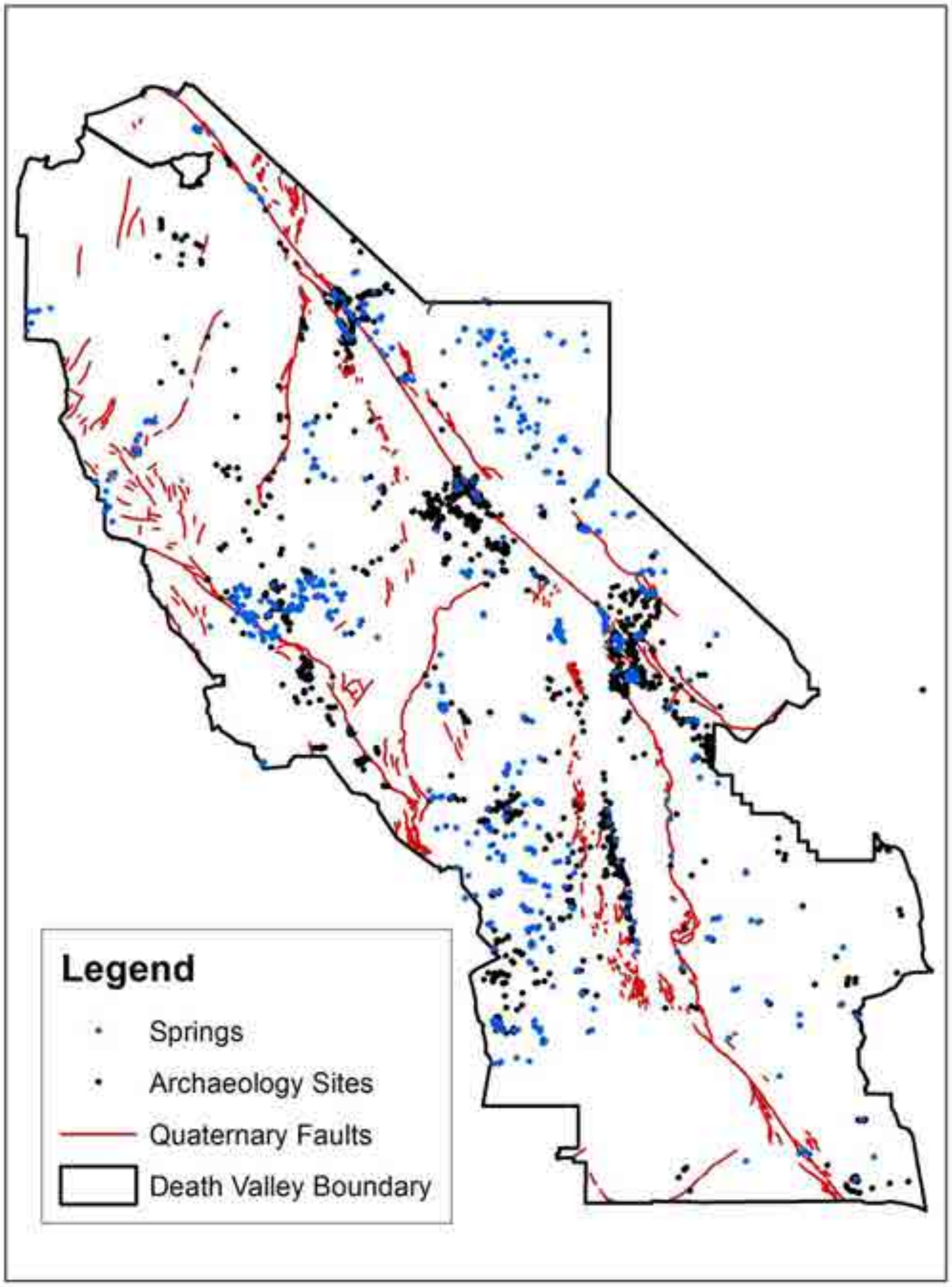


**Figure 4.** Map showing distribution of archaeological sites in DEVA relative to springs and Quaternary faults.

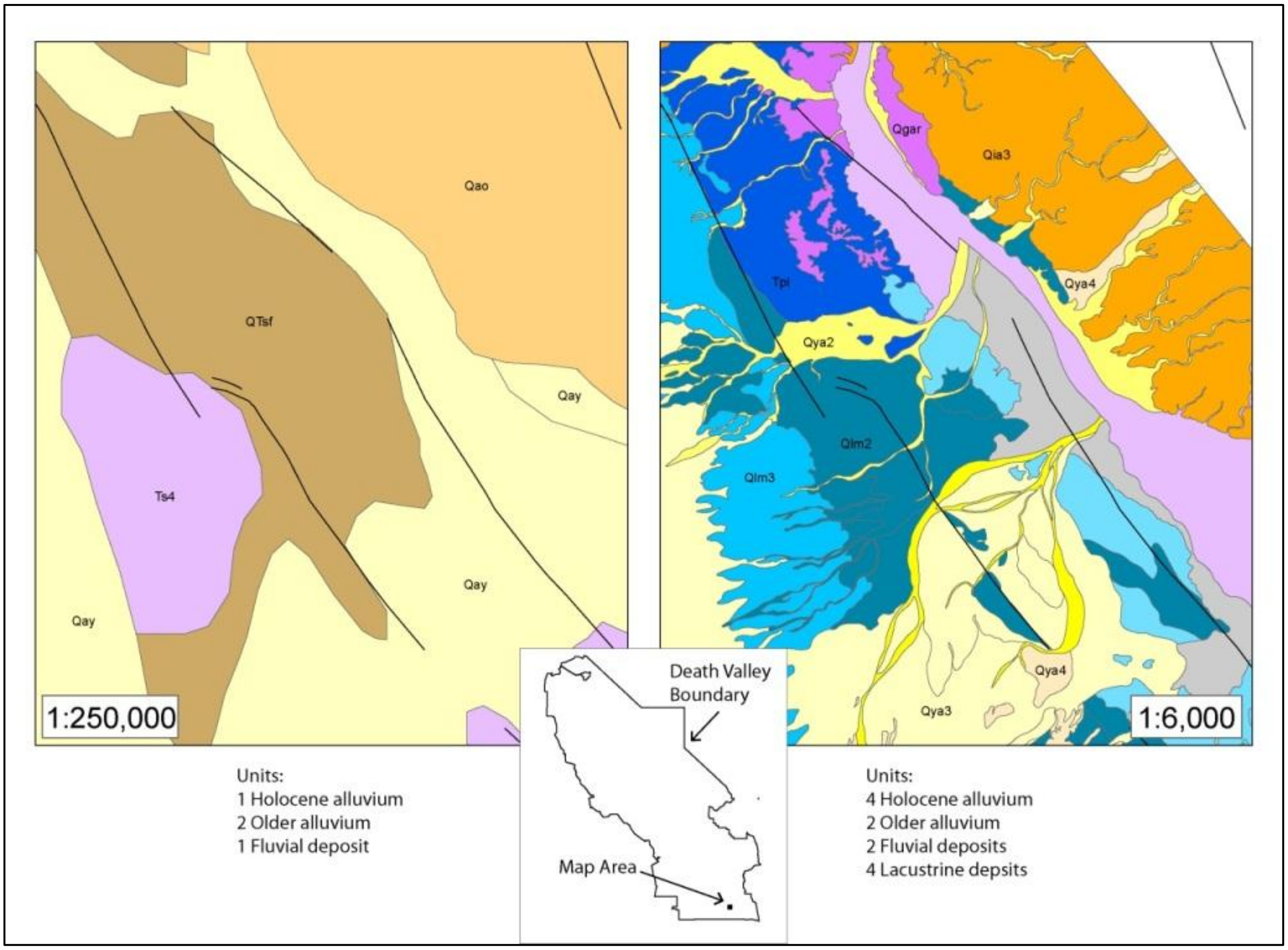


**Figure 5.** Two different surficial geologic maps demonstrating the effect of mapping scale on the detail of geologic map unit boundaries for the same mapped area of Death Valley National Park. Left map is from the 1:250,000-scale USGS geologic map of the Death Valley ground-water model area (Workman et al., 2002a) and the right map is a detailed Quaternary geologic map from Green (2009) mapped at a scale of 1:6,000.

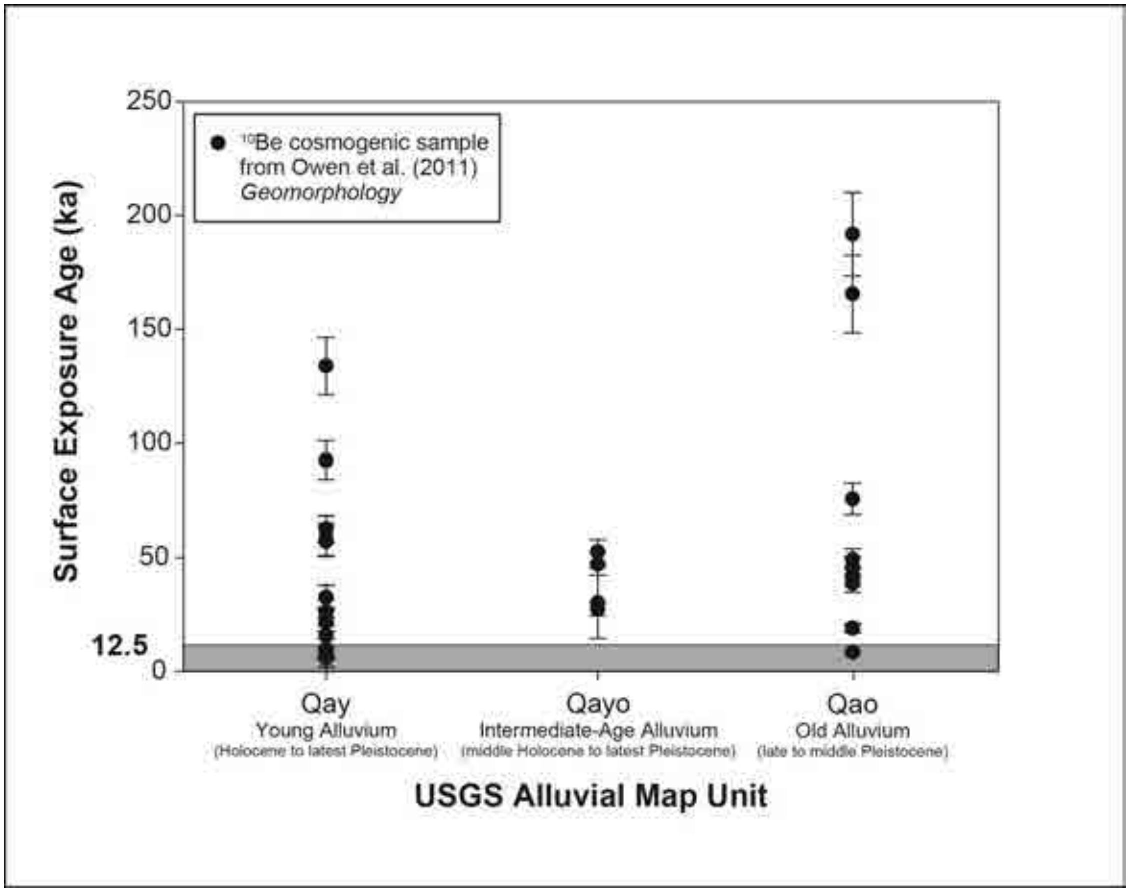


**Figure 6.** Plot showing the wide distribution of surface exposure age versus three alluvial map units from the 1:250,000-scale USGS geologic map for Death Valley. The numerical ages are from cosmogenic surface exposure age dating of different alluvial fan units from numerous studies in Death Valley and compiled in Owen et al. (2011). The plot demonstrates that the small scale 1:250,000 USGS geologic map units results in the inclusion of a wide range of alluvial fan units that have numerical ages that do not correspond to the designated age shown for the USGS map units. The plot demonstrates the limited utility of the small-scale maps in determining archaeological site associations with landscape components. The gray bar represents the general period of archaeological interest and spans the period from 0-12.5 ka (historical to Younger Dryas). Of particular note is that Qay, young alluvium, is a prominent, undifferentiated Holocene age map unit that is associated with many archaeological sites. The wide range of ages obtained in areas mapped as young alluvium underscores the importance of having maps with greater detail for purposes of constraining ages of the archaeology and developing predictive models.

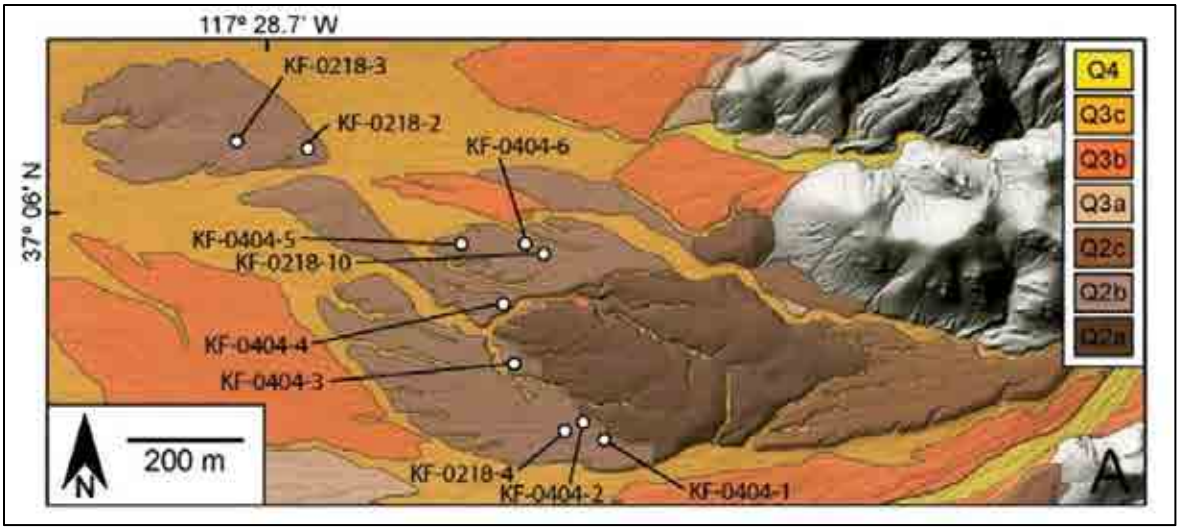


**Figure 7.** Portion of Death Valley National Park showing a detailed Quaternary geomorphic map with 7 map units and site locations where samples were taken for cosmogenic surface-age determinations.

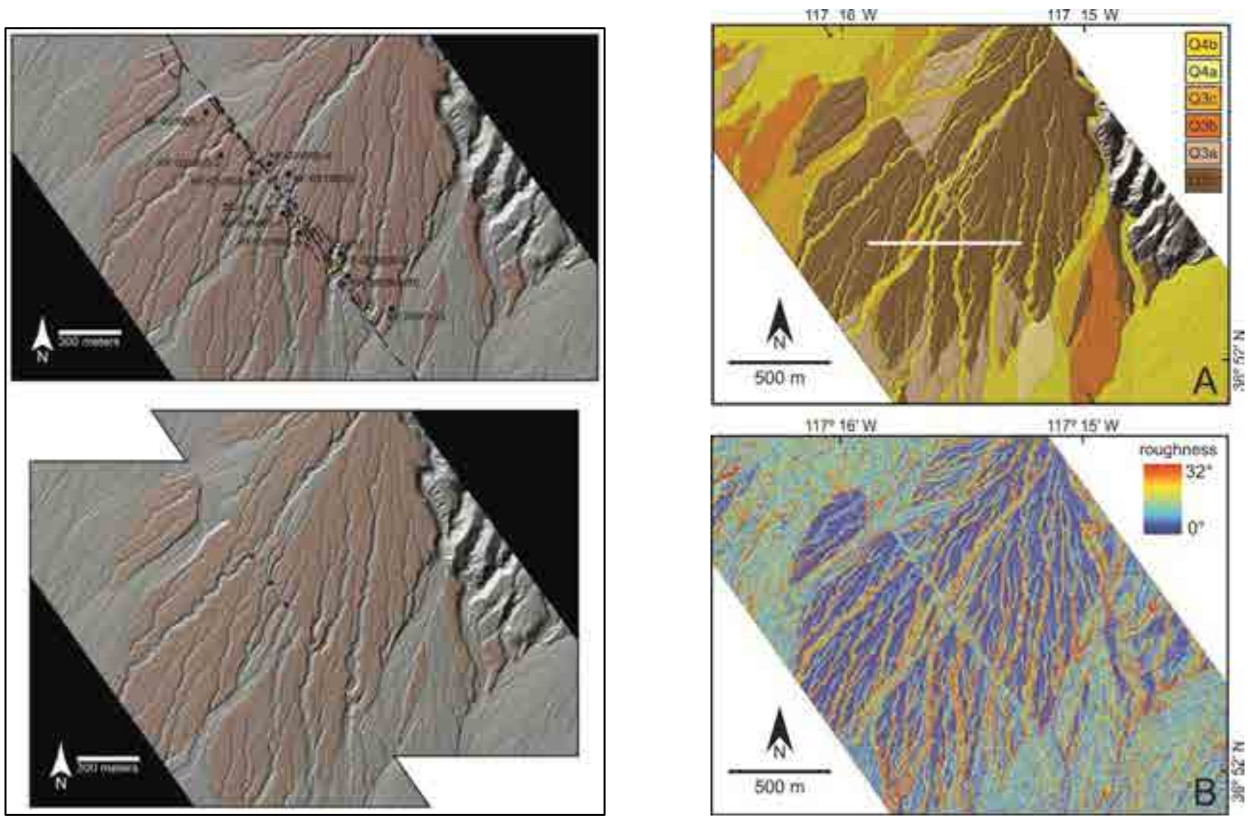


**Figure 8.** Examples of geomorphic maps based on surface roughness developed from ALSM and DEM data (figures from Frankel et al., 2007 (left) and Frankel and Dolan (2007) (right). Left figures show color-coded ALSM image of Red Wall Canyon alluvial fan on the Grapevine Mountains piedmont; top left shows the fan surface displaced across strike-slip faulting and the lower left shows the restored alluvial fan prior to faulting. The figures at the right show a detailed geomorphic map of the same alluvial fan (top) and a surface roughness map using standard deviations of slope that very closely represents the mapped geomorphic units.

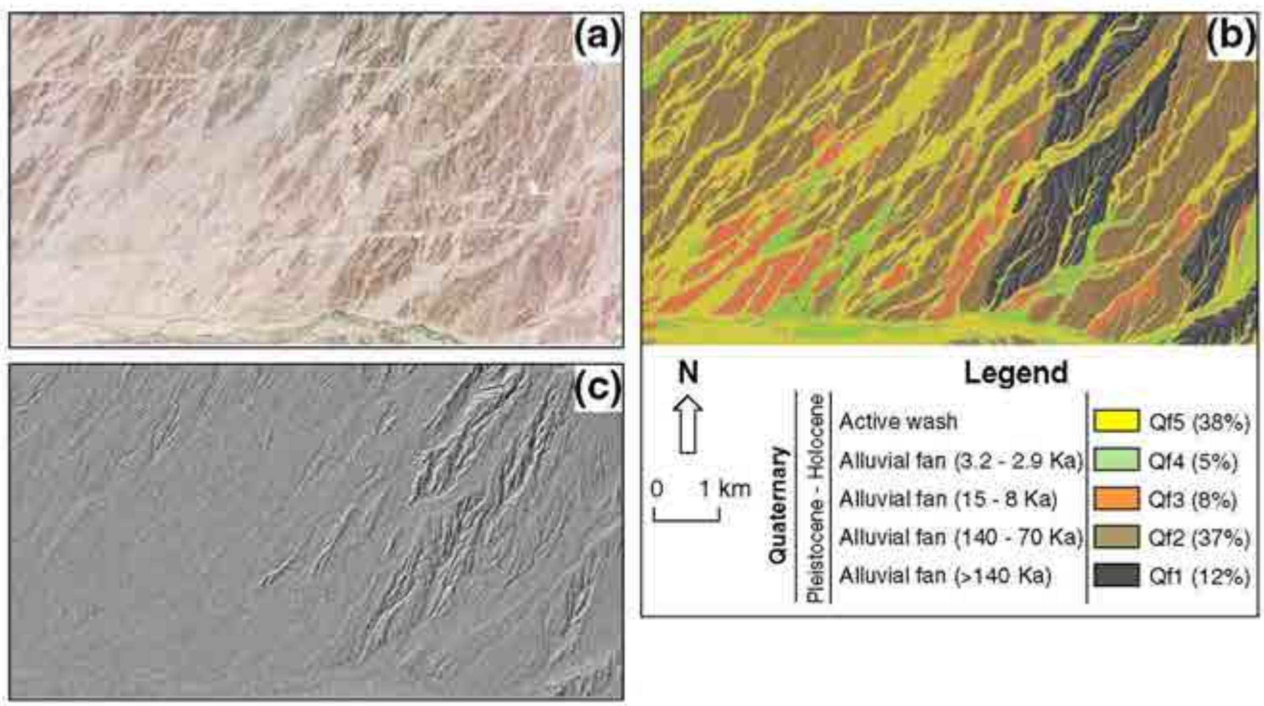


**Figure 9.** Example of development of a geomorphic map (b) using standard mapping techniques using both (a) satellite imagery and (c) LiDAR data. The expert-based map was used to evaluate automated mapping results based on multi-parameter surface attributes of roughness, slope, and dissection calculated from 3-meter LiDAR data (from Regmi et al., 2014).

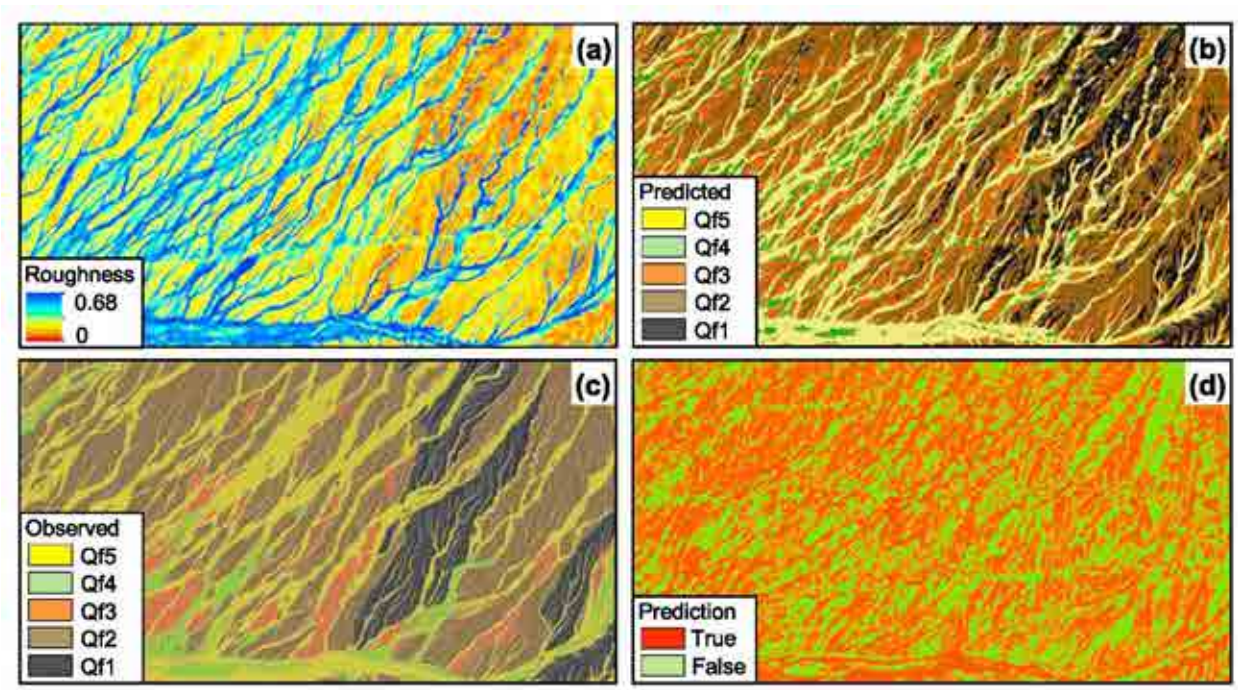


**Figure 10.** Example of automated mapping results using (a) LiDAR and surface roughness, (b) predicted geomorphic map units, (c) geomorphic map, and (d) test of the predicted map against the geomorphic map (from Regmi et al., 2014).

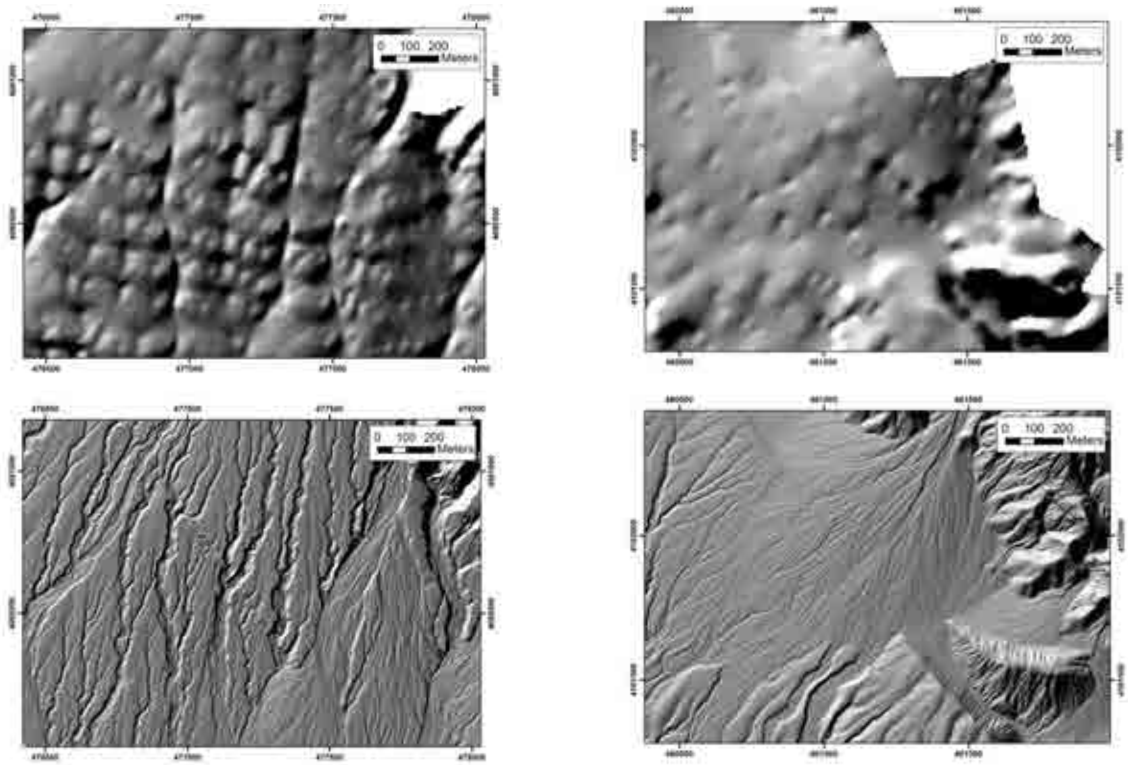


**Figure 11.** Examples of hillshade slope maps for the same areas in DEVA derived from the available 10-meter digital elevation model (top images) and 1-meter LiDAR data for a narrow strip map along the Death Valley fault zone in the northern part of Death Valley. The available DEM is insufficient for developing automated geomorphic maps using surface roughness routines in ArcGIS. The high quality LiDAR data is sufficient for automated mapping to develop geomorphic maps using surface roughness, as well as providing sharp detail of the surface topography to apply standard geologic and geomorphic mapping methods.

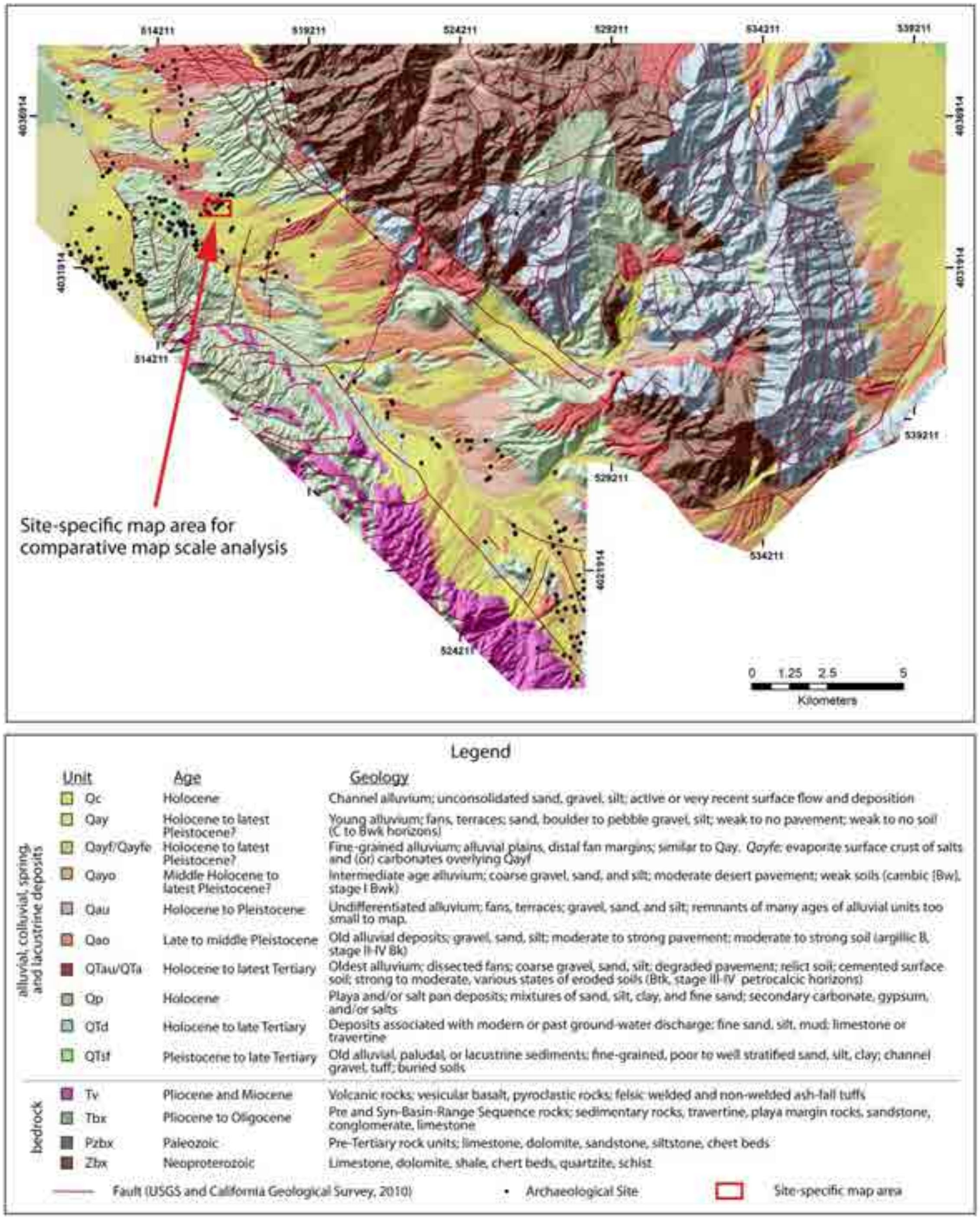


**Figure 12.** 1:250,000-scale geologic map for a part of the southern Funeral Mountains. Small orange box is the location of the test area for detailed mapping shown in Figure 15. (modified from Workman et al., 2002).

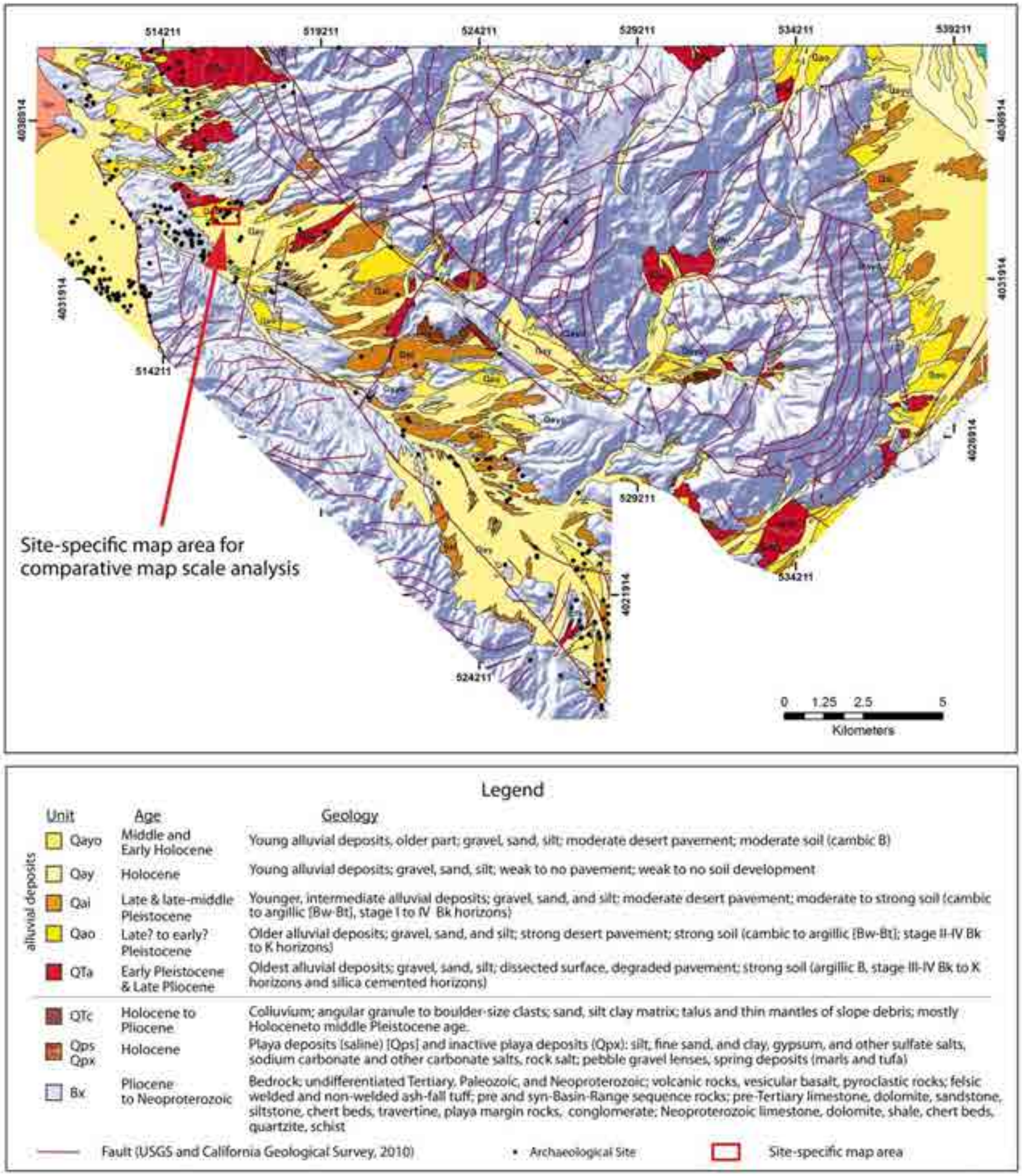


**Figure 13.** 1:100,000-scale geologic map for a part of the southern Funeral Mountains. Small orange box is the location of the test area for detailed mapping shown in Figure 15. (modified from Slate et al., 2009).

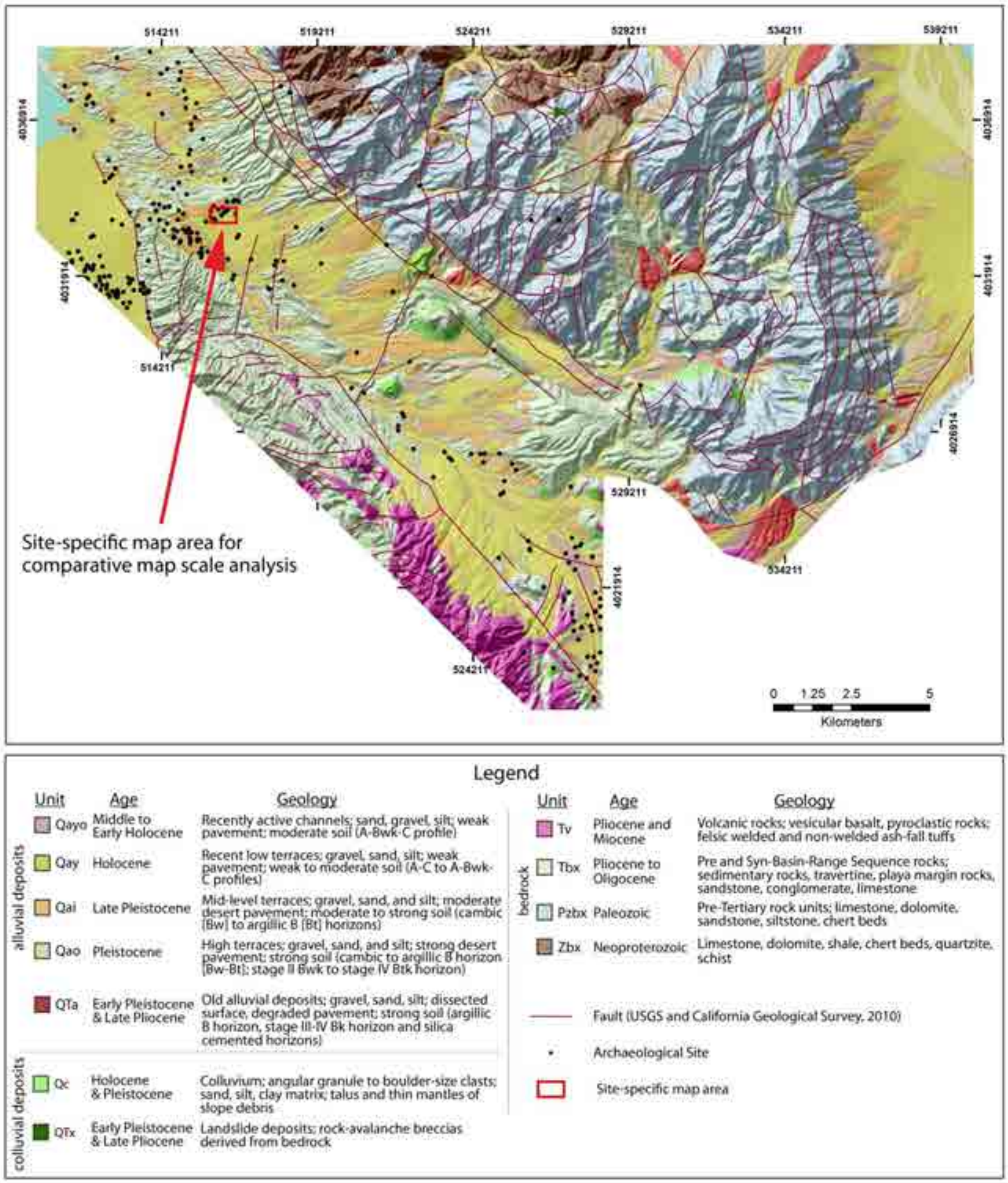


**Figure 14.** 1:50,000-scale geologic map for a part of the southern Funeral Mountains. Small orange box is the location of the test area for detailed mapping shown in Figure 15. (modified from Fridich et al., 2012a).

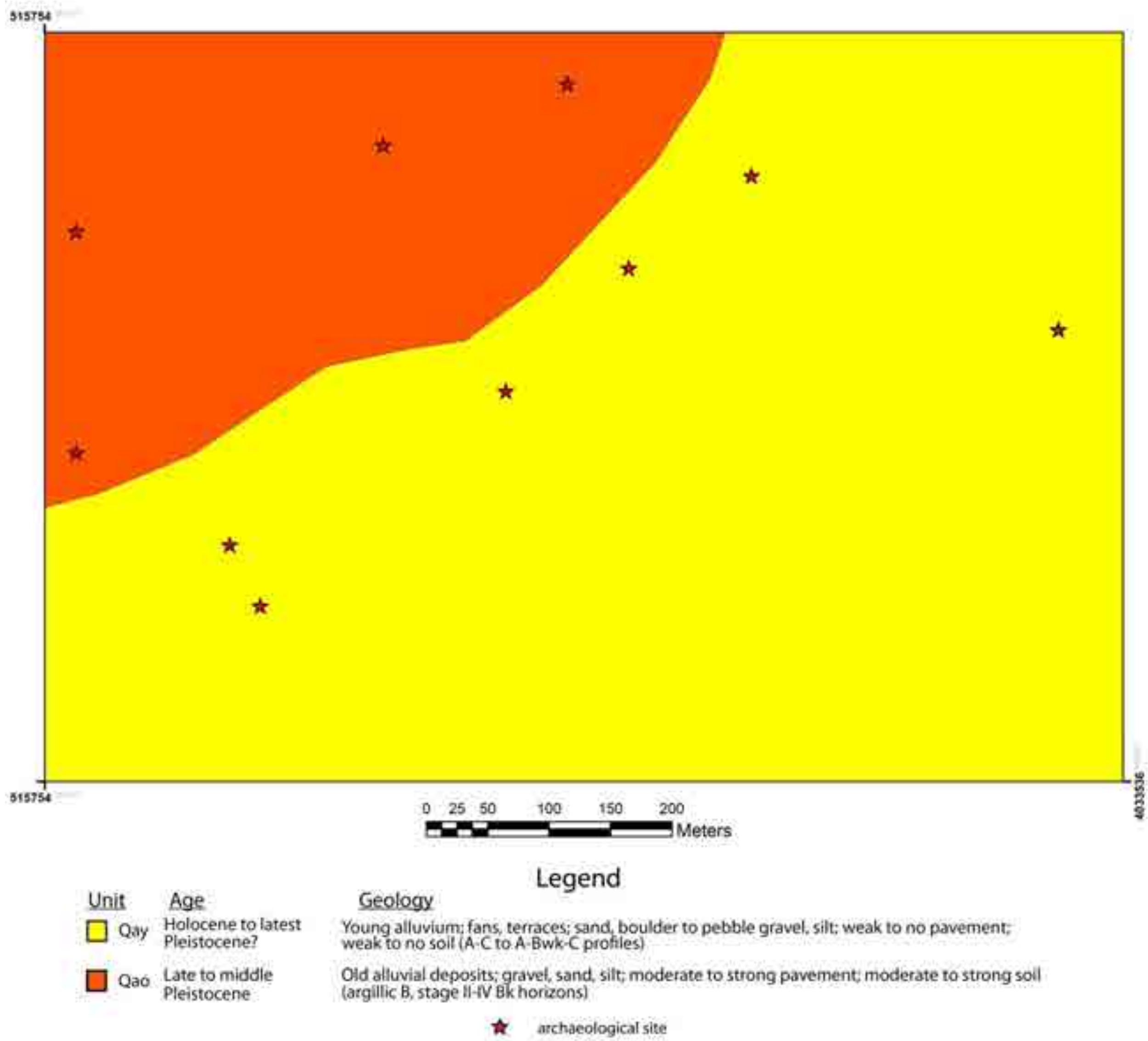


**Figure 15.** Site-specific geomorphic map at 1:50,000 scale from USGS map (Workman et al., 2002a) demonstrating the effect of map scale on landscape interpretation for purposes of geoarchaeology for the same area in the southern Funeral Mountains map area. Note that archaeological sites fall within only two map units: Qao (Pleistocene) and Qay (Holocene) map units. The small map scale limits the usefulness of the geologic maps in terms of providing geomorphic context and geologic information at archaeological sites.

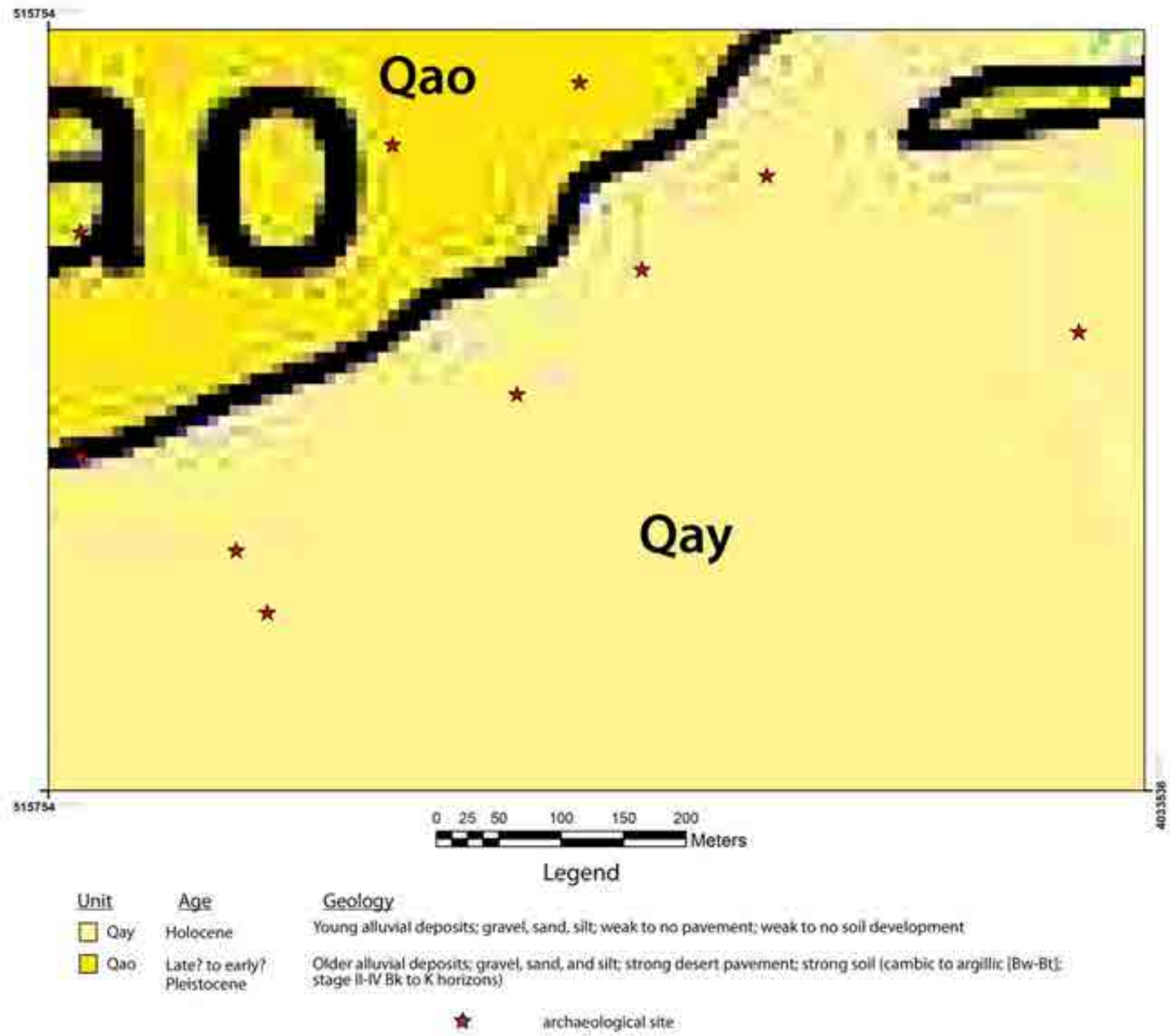


**Figure 16.** Site-specific geomorphic map at 1:100,000 scale from USGS map (Slate et al., 2009) demonstrating the effect of map scale on landscape interpretation for purposes of geoarchaeology for the same area in the southern Funeral Mountains map area. Note that archaeological sites fall within only two map units: Qao (Pleistocene) and Qay (Holocene) map units. The small map scale limits the usefulness of the geologic maps in terms of providing geomorphic context and geologic information at archaeological sites.

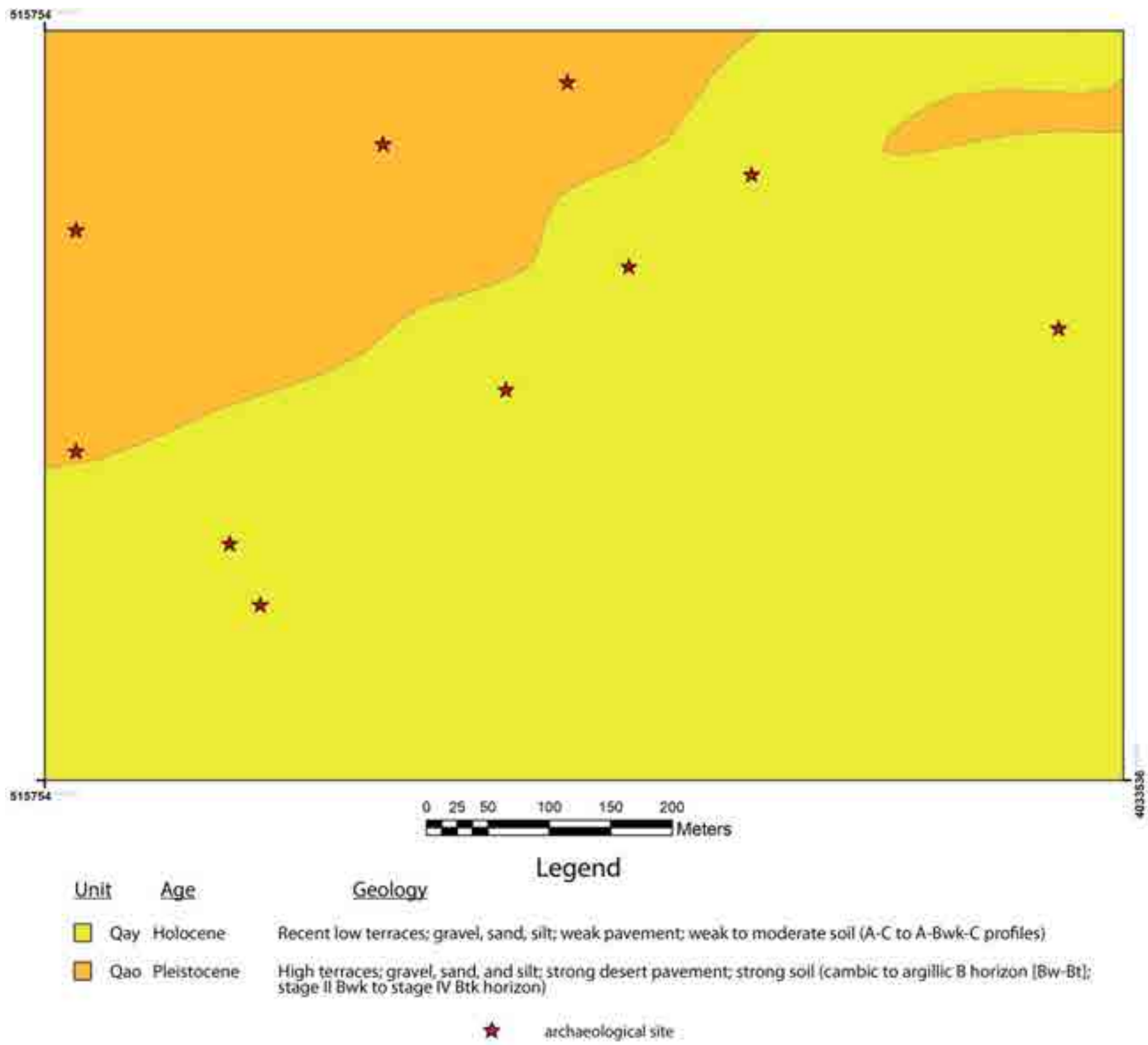


**Figure 17.** Site-specific geomorphic map at 1:50,000 scale from USGS map (Fridrich et al., 2012) demonstrating the effect of map scale on landscape interpretation for purposes of geoarchaeology for the same area in the southern Funeral Mountains map area. Note that archaeological sites fall within only two map units: Qao (Pleistocene) and Qay (Holocene) map units. The small map scale limits the usefulness of the geologic maps in terms of providing geomorphic context and geologic information at archaeological sites.

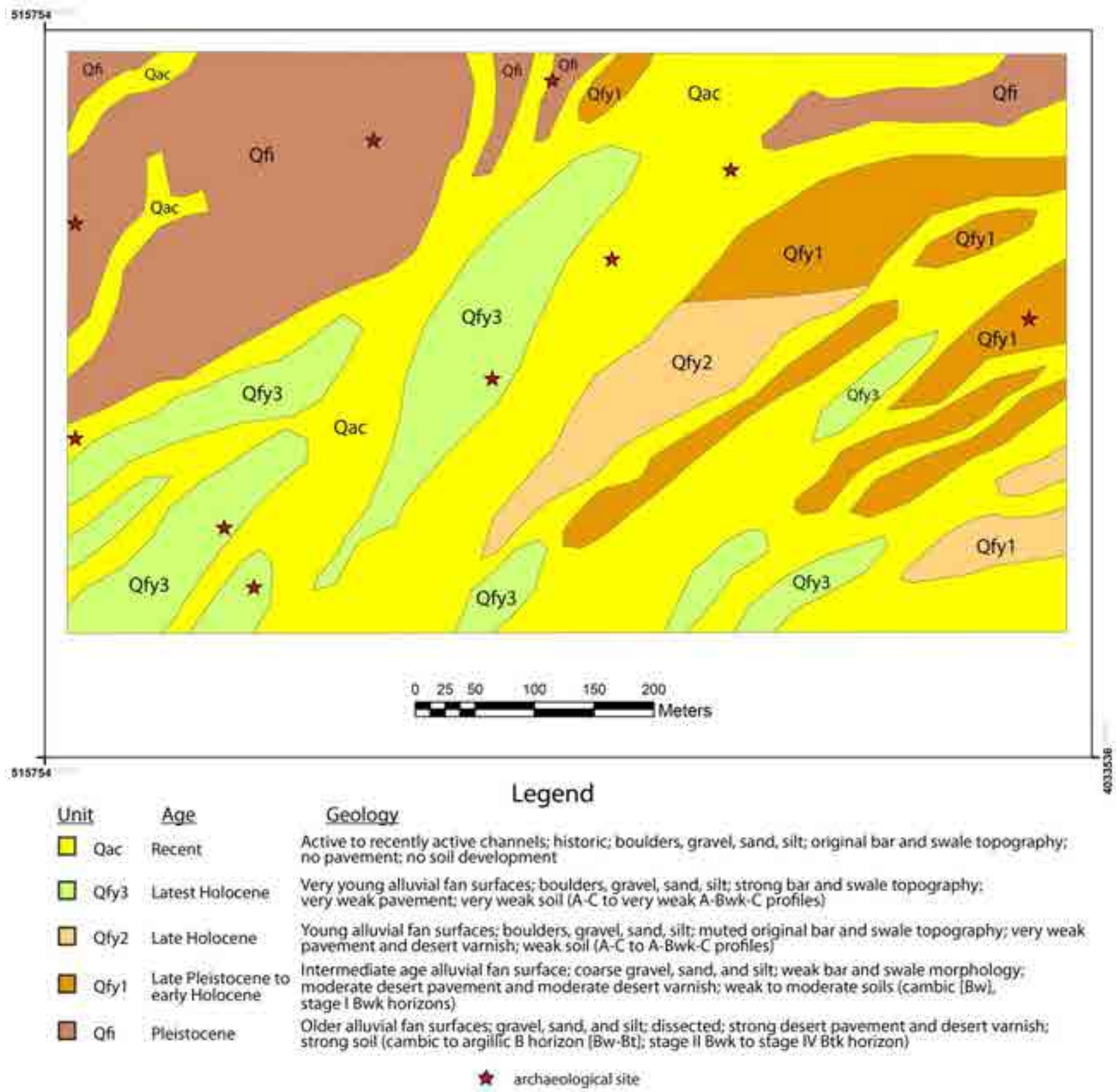


**Figure 18.** Site-specific geomorphic map generated at 1:10,000 scale from NAIP imagery. Example of the effect of map scale on landscape interpretation for purposes of geoarchaeology for the same area in the southern Funeral Mountains map area. In contrast to smaller scale maps, which show only one map unit (Qay) representing the entire Holocene epoch, detailed large-scale mapping of the Holocene units results in three additional Holocene map units. The detail provides refinement of the geomorphic context for archaeological site interpretation.

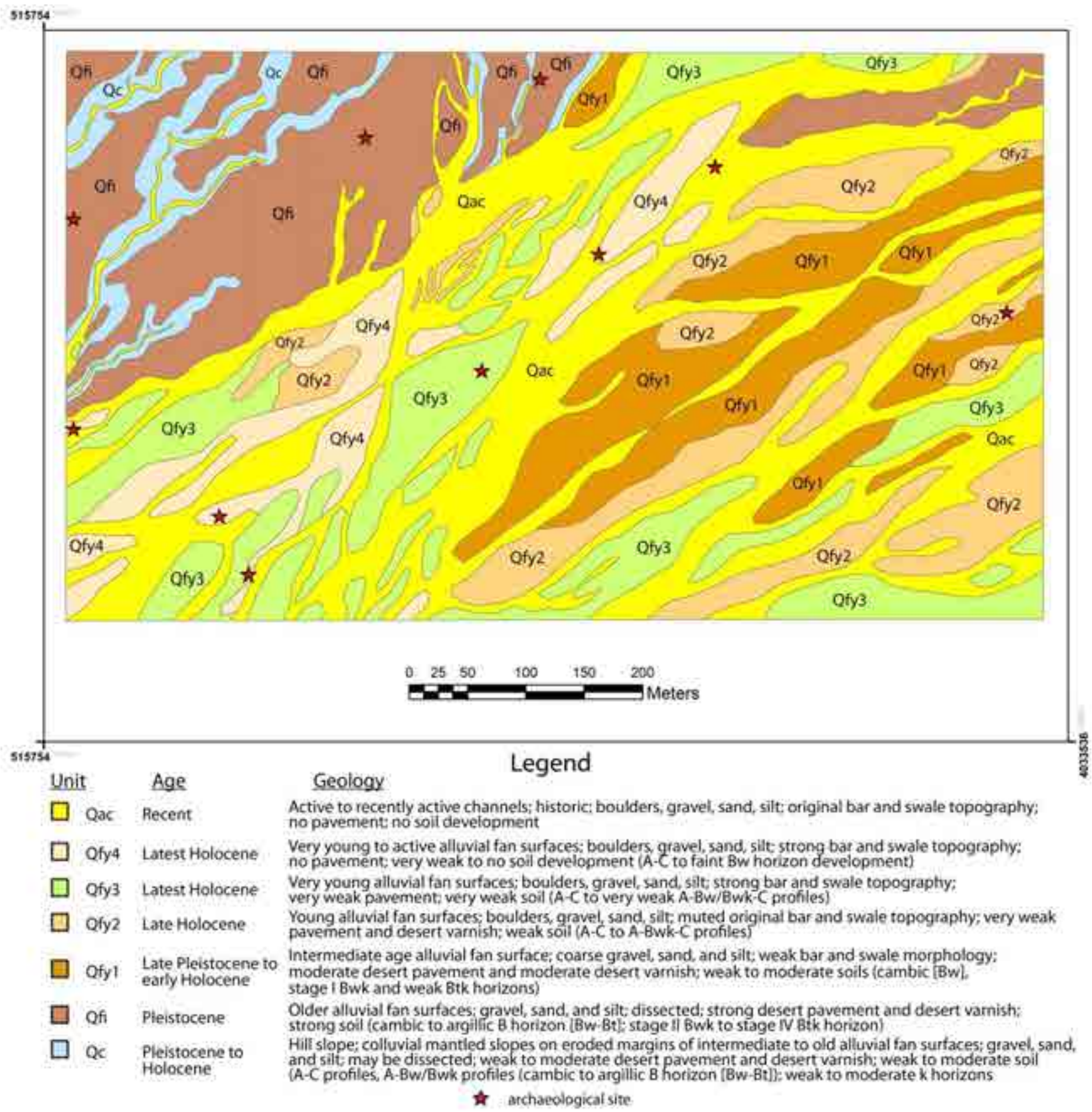


**Figure 19.** Site-specific geomorphic map generated at 1:3,000 scale from NAIP imagery. Example of the effect of map scale on landscape interpretation for purposes of geoarchaeology for the same area in the southern Funeral Mountains map area. In contrast to smaller scale maps, which show only one map unit (Qay) representing the entire Holocene epoch, detailed large-scale mapping of the Holocene units results in four additional Holocene map units. The detail provides refinement of the geomorphic context for archaeological site interpretation.