U.S. DEPARTMENT OF THE INTERIOR
U.S. Geological Survey

Surficial and Bedrock Geologic Map Database of the Kelso 7.5 Minute Quadrangle, San Bernardino County, California

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CONTENTS

Section I - Description of this report

About This Report

This report consists of three primary components: documentation, a digital geologic map database, and a printable map plot file. This text serves to provide a discussion and interpretation of the geology, as well as introduce and describe the digital data. There is no paper map included in the report. The report includes PostScript and PDF plot files that can be used to plot images of the geologic map.

The geologic map database delineates map units that are identified by general age, lithology, and clast size following the stratigraphic nomenclature of the U.S. Geological Survey. For descriptions of the units, their stratigraphic relations, and sources of geologic mapping, consult Part II of this report, or the geologic map plot files described later in this report. The scale of the mapping limits the spatial resolution (scale) of the database to 1:24,000 or smaller.

Parts Of This Report

This report consists of four components: a revision list, the report text, the digital geologic map database, and digital plot files of the geologic map.

1. Documentation

A list of the parts of the report and at what version number of the report each was last revised (if at all) followed by a chronologic list that describes any revisions:

a. of03-501revs.txt	ASCII file

The text of the report (this document), which describes the database, how to obtain it, and description of the geology and findings:

b. of03-501_1a.txt	unformatted ASCII text
c. of03-501_1a.pdf	PDF file

FGDC formatted metadata is included in the documentation and database portions of this report:

d.	of03-501_1b.txt	FGDC ASCII text formatted metadata
e.	of03-501_1b.html	FGDC HTML formatted metadata
f.	of03-501_1bfaq.html	FGDC 'FAQ' formatted html file

2. Geologic Map Database

The geologic map is compiled and structured in a spatial database. The spatial database is available as a set of two ESRI formatted coverages, and is distributed as uncompressed ARC/INFO export files, described below.

ARC/INFO export file	Size of file	Resultant Coverage	Description of Coverage
of03-501_2a.e00	1.96 MB	kls-geol	Map unit contacts, faults and unit labels
of03-501_2b.e00	77 KB	kls-str	Structural (strike and dip) measurements
of03-501_2.tar	2.1 MB		Tar file containing all of the above files, including import.aml (see below) and metadata (of03-501_1b.txt)

Resultant coverage names are suggested names, and are created using the included import.aml, and Arc/Info Macro Language file for importing the database from export files to coverages.

3. PostScript and PDF plot files

The geologic map plot files can be viewed on-screen or printed out. When printed at 1:24,000 scale, the page size dimensions are 45 x 30 inches.

The geologic map of the Kelso Quadrangle plot files are described below: (the PDF files are not compressed):

Plot file	Size of plot file	Description of plot file
of03-501_3a.eps	51.9 MB	Geologic map of the Kelso Quadrangle (PostScript)
of03-501_3a.pdf	15.3 MB	Geologic map of the Kelso Quadrangle (Acrobat Ver. 4 PDF)

How To Get This Report

Obtaining the geologic map database or digital plot files

This report can be obtained in two ways:

1. On the World Wide Web from the Western Region Geologic Publications Website, Geopubs.

The U.S. Geological Survey supports a set of graphical pages on the World Wide Web from which digital publications such as this one can be obtained. The URL for this report is: http://geopubs.wr.usgs.gov/open-file/of03-501/. Should this URL become unavailable, it is recommended to try the Western Region Geologic Publications page (http://geopubs.wr.usgs.gov/), or the U.S. Geological Survey main page (http://www.usgs.gov/). Click on '**Open-File Reports 2003**' from the main web page, then scroll down to the link '**Open-File Report 03-501',** which will take you to the web page for this report.

2. Anonymous ftp over the Internet

The files in these reports are stored on the U.S. Geological Survey Western Region FTP server. The Internet ftp address of this server is:

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Connect to this address directly using ftp or through a browser, log in with the user name `anonymous', and enter your e-mail address as the password. This will give you access to all the publications available from the server.

The files in this report are stored in the subdirectory:

pub/open-file/of03-501

If you are obtaining a plot file to give to a vendor to plot, make sure your vendor is capable of reading PostScript and/or PDF plot files.

Obtaining Paper Maps from the USGS

The U.S. Geological Survey will make plots on demand from map files such as those described in this report. The U.S. Geological Survey's Map on Demand website can be found at: http://rmmcweb.cr.usgs.gov/public/mod/

Be sure to include with your request the publication number and the exact names, as listed in the Parts of this Report section above, of the plot file(s) you require. A publication number and its letter alone are not sufficient, unless you are requesting plots of all the plot files in this report. You may wish to determine the price before placing an order.

Also note that not all parts of this report (such as this text and the spatial data) are plot files, and may not be provided by the Map on Demand service.

Order plots from:
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Section II: Results

Introduction

This geologic map database describes geologic materials for the Kelso 7.5 Minute Quadrangle, San Bernardino County, California. The area lies in eastern Mojave Desert of California, within the Mojave National Preserve (Figure 1). Geologic deposits in the area consist of Proterozoic metamorphic rocks, Cambrian-Neoproterozoic sedimentary rocks, Mesozoic plutonic and hypabyssal rocks, Tertiary basin fill, and Quaternary surficial deposits. Bedrock deposits are described by composition, texture, and stratigraphic relationships. Quaternary surficial deposits are classified into soil-geomorphic surfaces based on soil characteristics, inset relationships, and geomorphic expression.

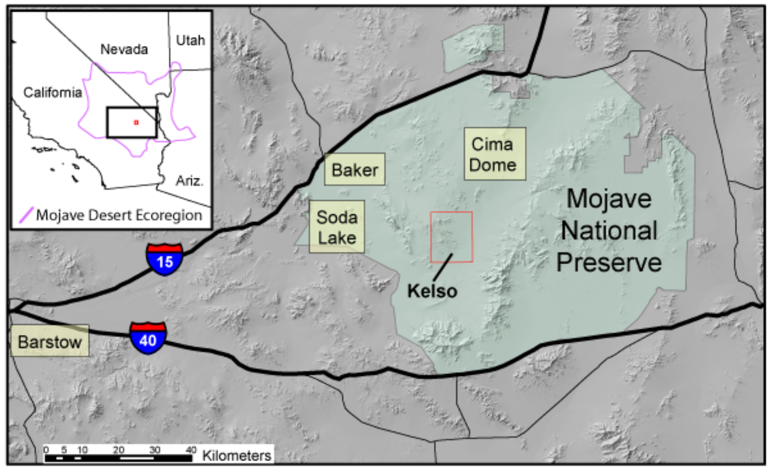

Figure 1. Location of the Kelso Quadrangle and surrounding area.

The surficial geology presented in this report is especially useful to understand, and extrapolate, physical properties that influence surface conditions, and surface- and soil-water dynamics. Physical characteristics such as pavement development, soil horizonation, and hydraulic characteristics have shown to be some of the primary drivers of ecologic dynamics, including recovery of those ecosystems to anthropogenic disturbance, in the eastern Mojave Desert and other arid- semi-arid environments (Belnap and others, 2001; McAuliffe and McDonald, 1995; Steiger and Webb, 2000)

Acknowledgements

I wish to thank David Miller for numerous discussions of Mojave geology, as well as his invaluable help in understanding field relations. David Miller and Phil Stoffer reviewed the map and manuscript, and provided greatly to the evolution of this work. Stephanie Dudash provided a technical review of the digital spatial data and documentation.

Previous Work

D.F. Hewett (1956) first mapped the geology of the Kelso area in the early 1920's as part of 1:125,000 scale mapping of the Ivanpah 1x1 degree quadrangle. Dunne (1972) mapped much of the bedrock area, which was recompiled with additional mapping by Dunne and others (Curry and Reseigh, 1983). A compilation for the East Mojave National Scenic Area (now the Mojave National Preserve), by Miller and others (1991) constituted the most recent bedrock mapping in the Kelso Quadrangle. Wilshire (1992) mapped bedrock and surficial geology in the Marl Mountains Quadrangle adjacent to the Kelso Quadrangle to the north, and along with 3 adjacent maps compiled detailed information of development of the Cima Volcanic Field area. Numerous authors such as Hazzard and Mason (1936); Hazzard (1954); Stewart (1970); Stone and others (1983); Cooper and Fedo (1992); Cooper and others (1994) have studied the late Proterozoic-Cambrian sedimentary strata in the map area, and in the surrounding areas.

This is the first surficial geology map for much of the area, although Curry and Reseigh (1983) mapped some surficial deposits in part of the quadrangle. Previous surficial geology mapping and soil studies in the area is primarily the work of Eric McDonald along the southwestern Providence Mountains (McDonald, 1994; McDonald and others, 1995). This work developed a detailed alluvial and eolian chronosequence for the western Providence Mountains, incorporating the effects of desert dust and lithology into variability of the soil sequence. Eolian sands in the alluvial deposits allowed for thermoluminescence dating of the soils, which further defined timing on the chronosequence. Several authors have also worked on dating and sand provenance of the Kelso Dunes (Clarke, 1994; Lancaster, 1995; Ramsey and others, 1999; Sharp, 1966) and the associated Devil's Playground eolian system. Sharp (1966) performed the first detailed studies of Kelso Dunes and developed a model in which the dunes were derived from sands transported by the Mojave River following deposition as the Mojave River exits Afton Canyon and loses carrying capacity, with minor inputs from local alluvial fans. Local sand sources from fans of the Providence Mountains and Kelso Wash are recognized, but are fairly minor (Lancaster, 1995; Ramsey and others, 1999). The eolian system dates as early as 17 ka (Clarke, 1994) and is presently active. Lancaster (1995) has established a chronology of five dune activation events: 25 to 16.8 ka, 12.5 to 3.5 ka, 3 to 1.5 ka, 0.8 to 0.4 ka, and 0.25 to 0.15 ka. Studies of Quaternary climate change have recently focused on the combination of lacustrine and eolian deposits to elucidate wet and dry climates respectively.

Physiographic and Historical Setting

The Kelso quadrangle lies near the transition from the tectonically active Mojave Desert block and the inactive Eastern Mojave Desert block defined by Dokka and Travis (1990). Results of Mojave Desert block tectonics (see below) include northwest-trending mountain ranges, while Eastern Mojave Desert block tectonics results in more northerly trending mountain ranges. Both types of landscapes can be seen in the region, and some evidence exists for the influence of both styles of tectonics in the map area.

Broad physiographic features around the map area consist Old Dad Mountain to the west, Kelso Dunes and the Granite Mountains to the south, Kelso Wash and Cima Dome to the east, and the Marl Mountains and the Cima Volcanic Field to the north (Figure 2). The entire map area eventually drains to Soda (dry) Lake, the majority of the map area via Kelso Wash through the Devils Playground, and the northwestern map area.

Physiographic features in the map area consist of Kelso Peak in the northwestern corner of the quadrangle, with a low ridge of hills informally named the Kelso Mountains extending south from Kelso Peak and occupying a large portion of the western map area. Gently sloping piedmonts extend from the Kelso Mountains and drain to the southeast and south. The south facing piedmont tends to be steeper than the gently sloping southeast facing piedmont. A large integrated wash system, Kelso Wash, crosses the southeastern corner of the map area and is the drainage outlet for nearly all of the map area, with the exception being the extreme northwestern corner of the map area (Figure 2). Physiographic values for the quadrangle, calculated from the USGS Digital Elevation Model for the quadrangle, are as follows: elevations range from 614 to 1451m, and slopes range from 0 to about 42 degrees. The climate is arid to semi-arid with the majority of annual precipitation falling in the winter months.

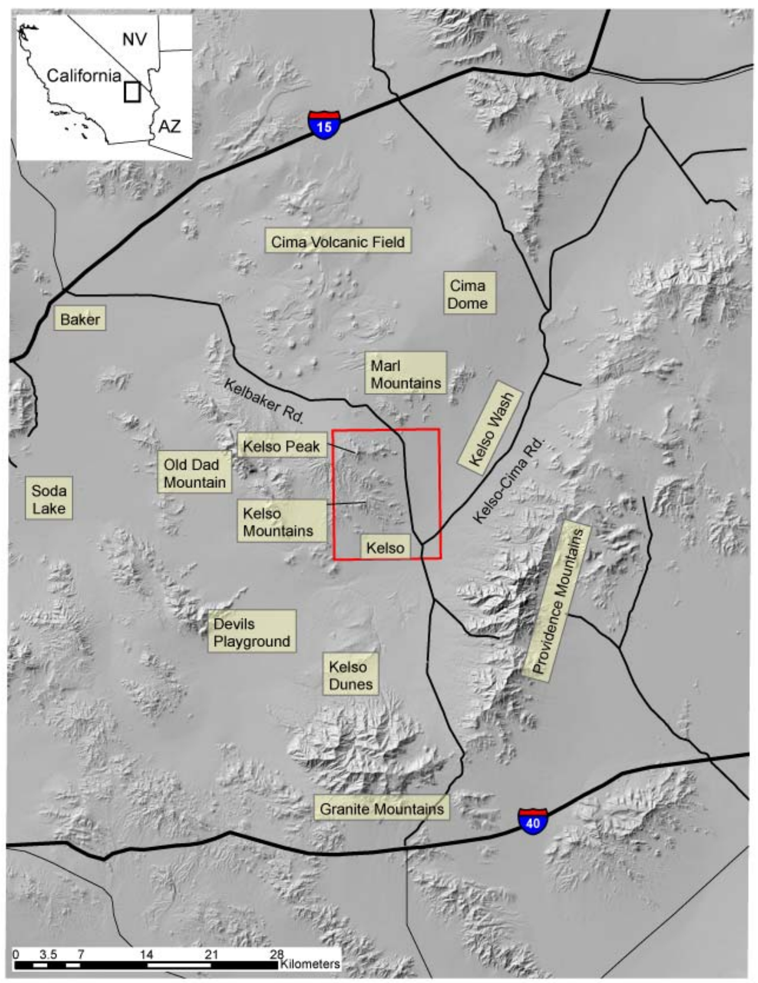

Figure 2. Physiographic features in the Kelso 7.5 Minute Quadrangle area

The Kelso quadrangle contains the town of Kelso, which is located at the intersections of two major through-roads in the Mojave National Preserve: the north-south running Kelbaker Road and the southwest-northeast running Kelso-Cima Road. The town originated as a watering station for the Los Angeles and Salt Lake Railroad (later the Union Pacific) in 1912. The Kelso Depot is currently a rest area and is a being remodeled to serve as the interpretive center for the Mojave National Preserve. Much of the western portion of the map area is wilderness as designated in the 1992 Desert Protection Act.

Biology

Highly variable flora and fauna are found in the Kelso area. Vegetation on Holocene alluvial deposits poor to moderately dense, and is dominated by creosote bush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*), along with numerous types of cacti (barrel, beavertail, cholla, pincushion, among others), flowering forbs, and annual grasses. Ephedra (*Ephedra spp*.) is not uncommon. Joshua tree (*Yucca brevifolia*) and Mojave yucca (*Yucca schidigera*) are also found at higher altitudes, and are commonly associated with Pleistocene aged surficial deposits. Pleistocene age deposits are typically very poorly vegetated, and tend to be mixed creosote and Joshua tree/Mojave yucca, and prolific small cacti such as pincushion cactus. Kelso Wash and disturbed areas, such as roads, are commonly vegetated with cheesebush (*Hymenoclea salsola*), as well as creosote/white bursage and annual grasses. Datura (*Datura wrightii*) is common in washes and along roadsides. Wildlife observed in the area includes desert tortoise, bighorn sheep, bobcat, quail, jackrabbit, Mojave green rattlesnakes, and many other common birds and rodents found in the east Mojave Desert.

Cryptobiotic soil crusts are found on many materials in the Mojave, with the exception of highly mobile or active sediments. Cryptobiotic soil crusts stabilize soil, are important nitrogen and carbon fixers, and are associated with enriched nutrient levels in vascular plants (Belnap and others, 2001).

Geologic Setting

Many authors have summarized the geologic history of the Mojave Desert, one of the most recent for tectonics in the central Mojave Desert being Glazner and others (1994). The Kelso area is approximately 35 km east from the tectonically active Mojave Desert block and the inactive Eastern Mojave Desert block defined by Dokka and Travis (1990), with the approximately western quarter of the map included in this report within the Mojave Desert block. The Mojave Desert block is typified by northwest striking right-lateral strike-slip faults active in the Late Cenozoic which have accommodated a significant fraction of the Pacific-North American plate translation as part of the greater San Andreas Fault System (Dokka and Travis, 1990). Faulting was active into the Quaternary in the Mojave Desert block, and commonly produced northwest-trending mountain ranges. The Eastern Mojave Desert block, or Sonoran block of Howard and Miller (1992) is typified by the lack of Quaternary faults and more northerly trending mountain ranges, and is structurally similar to the Basin and Range province geology of southern Arizona. Recent work, including findings in this report, has suggested that the boundary between the Mojave Desert block and the eastern Mojave Desert block, long thought to be the Bristol-Granite Mountains Fault to the west of the map area, may not be as sharp as previously assumed, and that a broad zone of mixed tectonic styles may exist in the western portions of the Eastern Mojave Desert Block (Brady, 1992; Skirvin and Wells, 1990).

Geologic Discussion

Surficial Deposits

Surficial deposits in the Kelso Quadrangle, much like the rest of the Mojave Desert, represent a diverse spectrum of geologic materials. Surficial deposits, including geomorphic surfaces, are generally classified by their depositional process and soil development characteristics. Geomorphic surface are considered to be depositional or erosional surfaces formed in a distinct time interval. Geomorphic surfaces and their underlying deposits are classified according to geomorphic relationships, microtopographic features, amount of soil development, pavement development, weathering characteristics, and clast composition and size distribution, and sedimentological features (Bull, 1991). Many surfaces and deposits are found commonly in alluvial fan settings, while axial valley, wash, playa, and eolian sand depositional environments are also common desert landscapes.

Surficial deposits in the map area occupy two primary environments: piedmonts and axial valleys (Peterson, 1981), with varying amounts of eolian sand influence in each environment. Based on surfaces found in the map area, these two environments are logically split into three main geomorphic provinces: gently sloping low relief granite-sourced alluvial fan deposits, steeper sloping and moderate relief mixed source lithology and age alluvial fan deposits, and a very gently sloping moderately incised complex wash/axial valley system with varying amounts of eolian sand activity. These three provinces have significant differences in the surficial processes acting on them, and thus have different geomorphic expressions and characteristics.

Relative ages of geomorphic surfaces are based on well-understood observable criteria, but techniques for directly dating Quaternary deposits are evolving, and many deposits in the eastern Mojave Desert are difficult to date. Relative ages of alluvial fan deposits in the Mojave Desert are based largely on infilling or diffusive muting of bar and swale microtopography, depth on inset channels, flattening or rounding of stranded surfaces between channels, degree of soil development, desert pavement development, degree of varnishing of clasts, and decrease in overall grain-size as clasts weather with time (Bull, 1991; McDonald, 1994; Yount and others, 1994). Until recently, very little has been known about the numeric ages and processes controlling rates of soil development on desert surfaces. Recent studies in the Providence Mountains, Soda Mountains, and Silver Lake areas have provided much needed insight into the ages and controlling factors influencing development of surficial materials in the Eastern Mojave Desert (e.g. McDonald, 1994; McDonald and others, 1995; Reheis and others, 1989; Wells and others, 1985; Wells and others, 1995).

Alluvial materials in the eastern Mojave Desert typically have been classified by their erosional, depositional, and soil development characteristics into soil-geomorphic units. Detailed description of soil development factors along with direct dating methods allow for the development of a soil chronosequence, which describes the rate of soil development, or a soil development characteristic, through time for a set of deposits (Birkeland, 1999). In the east Mojave Desert, well-dated deposits at Silver Lake were used to calibrate changes in pedogenic factors among a sequence of late Pleistocene to modern deposits (Reheis and others, 1989). Several later studies have extrapolated results from the Silver Lake chronosequence to other areas in the east Mojave, and have greatly added to the understanding of the timing of landscape change, factors influencing soil development, and rates of soil development (McDonald, 1994; Wells and others, 1985; Yount and others, 1994). Various soil classifications have been applied to desert fans in the region and correlations, among the classification schemes by various authors, and to the Silver Lake chronosequence, have been fairly successful (Wells and others, 1990). The classification used in this report is based largely on Yount and others (1994), and has three main types: old alluvial fan deposits (OA), intermediate age alluvial fan deposits (IA), and young alluvial fan deposits (YA). The three main types are fairly easily distinguished in the field and by remote sensing methods, and therefore comprise a convenient mapping classification. Subdivisions within these types of surfaces are generally based on degree of soil development, pavement development, inset relationships, amounts of degradation of original landform, or burial of surfaces. An idealized schematic cross section, showing soil-geomorphic characteristics for alluvial deposits is presented in Figure3.

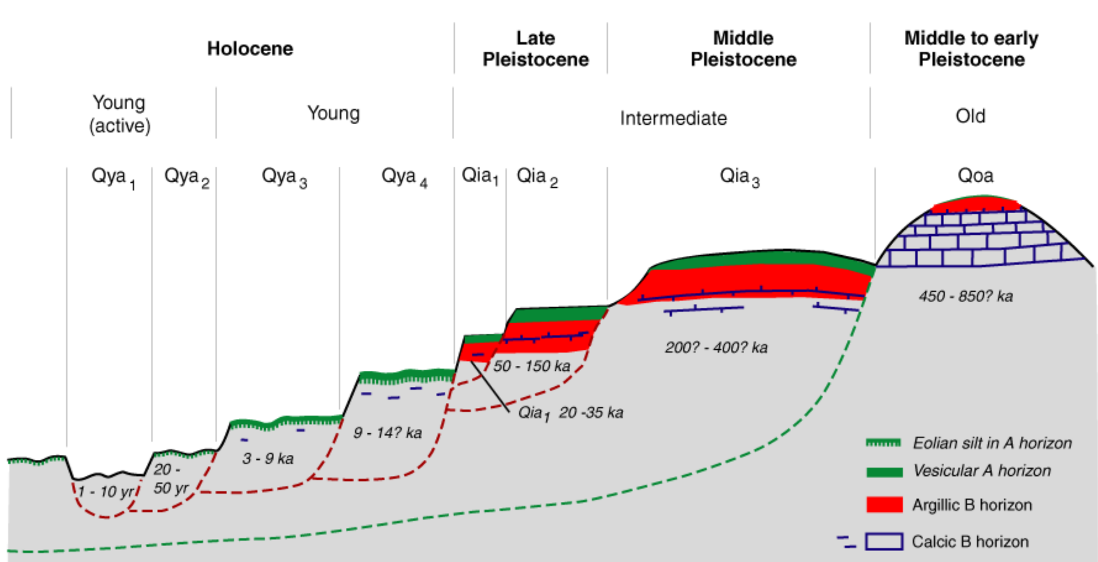

Figure 3. Idealized schematic cross section, showing soil-geomorphic characteristics and approximate age ranges for alluvial deposits in the eastern Mojave Desert (image courtesy of D.M. Miller)

Deposits classified as old alluvial fan deposits (OA) typically form linear whaleback ridges, or ballenas (Peterson, 1981), with strongly rounded shoulders, that may be found at varying heights above active channels (Yount and others, 1994). These surfaces are remnants that have had the upper soil layers stripped off, occasionally leaving a lag of boulders, cobbles, and pedogenic calcic horizon chips on the surface. Remaining soil horizons are usually well-developed with stage IV (Gile and others, 1966) or higher petrocalcic horizons (Machette, 1985), and occasional thin, degraded red-brown argillic horizons (McDonald, 1994; Yount and others, 1994). OA deposits commonly appear light toned on air photography from the common chips of petrocalcic carbonate at the surface, have rounded surfaces, are perched above surrounding surficial deposits, and tend to be found in proximal fan environments near the bedrock to alluvial transition. Age control for OA deposits is largely through the use of tephrochronology methods. The 0.74 Ma Bishop ash is often the most diagnostic tephra layer observed in OA deposits (e.g., McDonald, 1994). These deposits are not directly exposed at the surface in the map area, but occur at one locality in the southwest portion of the map area. This locality is an extremely strong pedogenic calcium carbonate horizon equivalent to stage IV (Gile and others, 1966; Machette, 1985). Exposed in wash cuts, this 3 to 5 m thick calcrete is the dominant fabric, separating and strongly cementing clasts, indicating that the calcium carbonate is pedogenic, and not from another source such as faulting, local stream input, or groundwater discharge. This calcrete deposit is overlain by a relatively thin well-developed argillic B horizon capped by a well-developed desert pavement surface. Due to the long development times of both the OA surfaces, and the overlying IA surface (see below) containing desert pavement and B horizon, this deposit is inferred to be very old, possibly in the range of several hundreds of thousands of years. Through time erosion has eroded the surface down to the calcic horizon, and then have subsequently developed soils on top of the erosional surface, which are of IA type characteristics.

Intermediate age (IA) alluvial fan deposits are most readily identified by the presence of desert pavements. These surfaces consist of a mantle of clasts from pebble to boulder in size that frequently interlock, and typically is one clast in thickness. Clast size often depends on source lithology, but is also affected by age of the surface and climatic factors (Bull, 1991). Surface clasts may be varnished in varying degrees based on age and source lithology. Below desert pavement surfaces is typically a vesicular A horizon, or A_v. McFadden and others (1998) show that A_v horizon development is strongly linked to pavement development, and that A_v horizons grow through accumulation of eolian fine-grained material, which is augmented by the dust-trapping characteristics of the overlying pavement (or surface clasts in undeveloped pavements) clasts. This horizon varies in thickness and amount of silt, which is often used as a criterion for defining a relative age of the surface. Older surfaces tend to have well-developed vesicles and are silt dominated and platy with ped faces, while younger A_v horizons tend to contain more sand and not express well-developed ped faces. The thickness of A_v horizons can be used to determine the relative degree of pedogenesis, or age. B horizons are found below the A_v horizon tend to consist of infiltrated (illuviated) fine sand, silt and clay. Varying amounts of red to brown clay accumulation and iron oxidation tend to change soil color (Bw to Bt horizon), which is also a general diagnostic of more advanced soil development. Stage I to III calcium carbonate development is also common, and is expressed as calcium carbonate undercoatings, rinds, nodules and accumulations between clasts (Gile and others, 1966). Vegetation is typically very sparse with Mojave Yucca, Creosote, White Bursage, and varieties of cholla found on surface shoulders and in inset channels with occasional individual plants isolated in a pavement. Smaller plants, such as pincushion cactus and annual grasses are not uncommon on the pavement surfaces. IA deposits are typically dark toned on air photography from the presence of varnish, and are found more commonly in proximal fan positions, are not uncommon in medial and distal environments, but do tend to decrease in abundance away from mountain fronts. In plan form they are stranded, elongate to diamond shaped, which is typically a reflection of the pattern of incision on the fan into the IA deposits. Degree of separation between surfaces and the slope transitions between younger inset surfaces tend to vary with timing of incision and the apparent age of the deposit, and range from very rounded and diffuse to vertical cut banks to the active channel.

IA deposits are often considered to be Pleistocene, and correlation to dated deposits in the Providence Mountains and in other nearby piedmonts has confirmed and refined this designation as largely late Pleistocene (McDonald, 1994; Wells and others, 1995). Dating in the Mojave Desert and throughout the southwest United States has shown several pulses of aggradation events, each large enough to be locally preserved as Pleistocene surfaces (Bull, 1991). Most surfaces retaining desert pavements have been dated as late Pleistocene, with some falling in the range of late-middle Pleistocene age range (Bull, 1991; McDonald and others, 1995). McDonald (1994) has shown through direct dating and through age correlations that there have been two intervals of fan development during the late and middle Pleistocene: 22,000 to 90,000 years B.P. and 36,000 to 130,000 years B.P. Tentative correlations can be made with unit Qia1 of this report and the fan aggradation periods of 22 to 90 ka, and unit Qia2 with the fan aggradation period between 36 to 130 ka. On the Cima Volcanic Field, just north of the map area, cumulic soils with similar characteristics have been dated by their position on a ~450 ka lava flow (Wells and others, 1985; Wells and others, 1995).

Young Alluvial (YA) fan deposits typically consist of sand- and gravel- sized material with well- to moderately-developed bar and swale microtopography and little soil profile development. Bar deposits tend to be coarser grained than swale deposits, and the size of clasts in bar deposits can be used to calibrate the intensity of flooding events affecting the immediate area. Soil development (where present) is usually restricted to the oldest surfaces, and consists of incipient A_v development and incipient reddening in the subsurface (cambic horizon), and stage I to II calcic development. YA deposits are typically light-toned on air photography, with varying amounts of tonal changes due to source lithology, incipient clast varnish, and vegetation density. YA deposits composed of grus-weathering materials may be darker toned on air photography due to dense cryptobiotic soil crusts. YA deposits are found throughout the alluvial fan environment. A typical model of an alluvial fan in equilibrium prescribes YA deposits in proximal fan environments be typically restricted to narrow channels inset into older stranded surfaces, and generally becoming more prolific down-fan as older surfaces are stripped or buried. This is not always the case, as local variations in base level and sediment production and delivery rates affect the timing and location of sedimentation.

Data collected on ages of YA deposits range from latest Pleistocene through modern and active. The younger set of YA surfaces can often be relatively dated by the amount of degradation or burial of anthropogenic impacts. Stripping or burial of old roads, tin cans, glass, and equipment often associated with mining operations give indications as to the magnitude, timing and frequency of alluvial activity. In the map area, degradation of tank tracks associated with Patton's Desert Training Center (1942 through 1944) or Desert Strike (1966) maneuvers (Prose and Wilshire, 2000), mining roads, trash, and an airstrip indicate that alluvial activity has been intense and widespread over the last 100 years. Much of this activity can reasonably be considered to be less than 50 years in age when widespread military and mining activities in the area decreased. Since the establishment of much of the area as Wilderness Area under the California Desert Protection Act in 1992, many washes and very young surfaces now show little evidence of past disruption by automobiles.

The classification of YA surfaces used in this report distinguishes 4 subdivisions: Qya1, Qya2, Qya3, and Qya4. The oldest deposits, Qya4, are small in areal extent and show less soil development characteristics than IA surfaces. Bar and swale topography is still present, although subdued, and small patches of flat incipient pavement surfaces are common. Vegetation is usually sparse with a mixture of typical assemblages found on IA surfaces, as well as creosote/ambrosia assemblage. Amount of vegetation varies with incipient pavement development, with vegetation often relegated to the unpaved portion of the surface. YA deposits mapped as unit Qya4 are somewhat difficult to identify in remote sensing, and usually require field observations to identify areas containing these deposits. On air photography, they are generally darker toned but often mottled in overall color due to patchy incipient pavement formation and varnishing. Due to their generally more pronounced soil development, they require some degree of stranding above the more active middle to late Holocene deposits they are associated with, and thus are found typically in proximal and medial fan environments. When present in distal environments, they typically are at-grade with younger deposits. These deposits are dated at 10 ka in Fenner Wash near the town of Fenner (Shannon Mahan, written communication, 2003), and lie on 13 ka groundwater discharge deposits in lower Kelso Wash near Soda Lake (Shannon Mahan, written communication, 2000).

Deposits set into Qya4 deposits, Qya3, are the most areally widespread of all surficial deposits in the map area, and likely throughout most areas of the East Mojave. They are typically sand- and gravel- covered surfaces with pronounced bar and swale microtopography. There is often an incipient A_v horizon, minor B horizon (cambic horizon), and calcic development, when present, is typically stage I to II. Qya3 deposits are typically moderately vegetated with creosote, ambrosia and annual grasses, and host a wide variety of typical east Mojave Desert flora. Biotic soil crusts are very common and can form thick mats or 'carpets' of lichens, particularly on sediments derived from granitic source areas. These deposits are typically light toned on air photography, have undulating terrain, and show varying tonal changes due to lithology and vegetation density. Correlative deposits have been dated in the Providence Mountains at 4 to 5.5 ka (McDonald and others, 1995), roughly 3 to 6 ka in the Silver Lake area (Wells and others, 1990), and 6.5 ka at Valjean Valley (Miller and others, 2001).

Qya2 deposits consist largely of narrow gravelly to sandy bar or terrace deposits and are typically inset along the margins of Qya3 deposits. These bars and terraces are the first surface above active alluvial channels and tend to be a few centimeters to a meter below Qya3 surfaces. Bar and swale topography is largely intact and well-developed, and the surfaces lack desert pavements and clast varnish. There is very little to no soil development, which may be expressed as fine sand and silt accumulations in the upper 10 cm, but may also be attributed to overbank fine deposition in flood events. Qya2 deposits tend to be heavily vegetated, which may reflect the proximity to water sources in active channels, and by soil stabilization above active channels. Qya2 deposits are found across the entire fan environment, and tend to be prevalent in more active portions of the fan. On air photography they tend to be darker toned (likely from vegetation effects), elongate in the down-fan direction, and have rough microtopography when visible.

Ages of Qya2 deposits are uncertain, although evidence for minimum ages of these deposits exists in the form of burial or erosion of dateable anthropogenic impacts. In the map area, tank tracks and an old airstrip have been buried by Qya2 surfaces. In other areas of the Mojave, similar deposits bury trails and roadways established in the 1800's as part of emigration and mining activities. Qya2 surfaces can be considered to be active on centennial scales.

The youngest alluvial fan deposits classified in this report, Qya1, is found in active to recently active channels and consist of moderately sorted sand and gravel. There is no soil development, desert pavements, or clast varnish. These deposits are largely unvegetated, even by annual grasses. There are found in all areas of the alluvial fan environment, and generally are more constricted in proximal environment, and may anastomose and become wider in medial and distal fan positions. On air photography and other remote sensing platforms, they are very light toned to white (high albedo). In the map area, and in many places throughout the Mojave, Qya1 surfaces often bury or erode recently graded roads. Many of these events are anecdotally attributed with El Nino generated storm events. In the map area several Qya1 channels were observed to have reoccupied channels that had been diverted due to road grading during the 1997 and 1998 winter seasons. Frequency of sediment movement on Qya1 surfaces leads to the interpretation that they are typically deposited on decadal or smaller time intervals. Thus, most of these deposits are probably 20 to 0 years in age.

Wash deposits are found primarily along Kelso Wash in the southeastern corner of the map, and in more integrated drainages in the southeastern map area. Wash deposits have similar soil development characteristics as alluvial fan units, and are separated based on sedimentologic differences and differences in eolian processes and vegetation assemblages. The wash environment consists of a complex mosaic of active and inactive wash deposits, distal alluvial fan, and eolian sand. At the surface the deposits consist of moderate- to well-sorted, fine-grained sand approximately 20 to 40 cm deep and exhibit moderate-sized eolian coppice dunes at the base of perennial vegetation. Although much of the sand is eolian, distal alluvial processes also occur in this system as evidenced by the presence of active alluvial channels and diffuse transitions between the two environments. Cutbanks in active washes expose deposits that are largely medium- to fine-grained moderately sorted sand and are well bedded. The depositional environment for the sediments below the eolian/alluvial cap is interpreted to be a mixture of braided fluvial/wash and distal alluvial deposits. Consistent stratigraphic sections along Kelso Wash suggest that more pronounced beds in the wash system may be correlated along at least 3 km stretch of the valley. This suggests consistent fluvial processes occurring in Kelso Wash. Buried A_v horizons below the eolian/alluvial cap indicate the presence of at least early to mid Holocene deposits in Kelso Wash. Vegetation communities associated with wash deposits is the typical creosote/ambrosia assemblage. The presence of cheesebush (*Hymenoclea salsola*) and smoke tree (*Psorothamnus spinosus*) is often diagnostic of a wash environment.

Modern and active wash channels and sediments are inset into the mid-Holocene wash deposits, and most often exhibit braided channels approximately 1 to 1.5 m deep. Near the town of Kelso, and southwest along the railroad, the channels have been stabilized by levees where channels tend to be much deeper, from 2 to 4 meters. It is likely, but not positive, that drainage diversion has caused deeper incision.

Lithologic Controls on Alluvial Fan Geomorphology

Lithology of clasts in alluvial fan deposits in the map area controls a large portion of the geomorphologic character of the deposits (Bull, 1991; McDonald, 1994). The primary sources for alluvial fans in the map area can be separated into 2 main lithology categories: grus-weathering granitoids, and a mixture of gneiss, limestone, dolomite and minor shale. A small portion of fan deposits has a source of coarse gravel (basin fill) deposits.

In the southwest map area, alluvium is derived predominately from gneiss, limestone, dolomite, shale, minor coarse gravel deposits, and diorite. Proximal alluvial fans in this area are typified by distinct intermediate alluvial (IA) surfaces inset by narrow younger alluvial (YA) channels and surfaces. As this alluvial environment decreases in slope distally, to the south, incision decreases and YA surfaces become more pronounced and areally significant. Clasts in the IA deposits tend to be moderately- to poorly-sorted, often cobble to boulder sized, and have well-developed varnish. Based on sedimentology, the majority of these deposits are interpreted to have originated as debris-flows emanating from canyons to the north. In the more poorly sorted surfaces, cryptobiotic crust populations tend to thrive on patches of elevated silt accumulation in the A_v horizon between large cobbles and boulders.

Holocene channels in proximal fans of the southwestern map area are narrow, ranging in depth from 1 to 4 meters. Channels in more distal portions of the fans with gentler slopes are progressively less deep, until eventually incision is replaced by burial of Pleistocene surfaces by Holocene deposits. This pattern of incision in upper fans and burial in lower fans is common on desert alluvial fans. It is unclear if the transition from stranded debris-flow dominated IA surfaces in proximal environments to distally dominated YA deposits is a geomorphic expression of a change in depositional styles from debris flow to fluvial processes over time.

In the eastern map area, alluvium is almost entirely sourced from granitoid rocks or second-generation granitoid sediments derived from Tertiary basin fill deposits. Both of these materials weather to grus, which is a grain-by-grain weathering product to predominately sand- to gravel- sized grains. This part of the map area is characterized by relatively few late Pleistocene surfaces and by poor geomorphic surface diagnostic indicators such as pavements, clast varnish, and vertical separation of inset surfaces. Small remnant Pleistocene surfaces (Qiag3) are restricted to proximal fan environments, and are rarely over 0.5 m above younger surfaces. The grain-by-grain weathering style of the granitoid materials produces sediments that tend to show little grain size variation horizontally across fan surfaces, and vertically in weakly developed soil profiles (Bedford, 2001). Ongoing research of these granitic alluvial fan deposits is aimed at characterizing the spatial distribution and variability of grain size distributions in order to create physical properties models for these types of alluvial systems.

Continuing studies of grus-derived alluvial fan sediments may elucidate causes of the relatively uniform grain sizes and unique characteristics of these fans. Possible explanations for the lack of extensive IA deposits from grus sources are: (1) that a moderately sorted sandy deposit has little cohesive strength, is repeatedly eroded, and thus surfaces are rarely preserved to form older soils, (2) differences in sediment production rates for lithologies in the hillslopes, resulting in variations in timing of sediment availability for aggradation events, and (3), that the grus material fans are a result of punctuated, ephemeral alluvial processes which continually erase older deposits and/or deposit sediments in small amounts that may not be preserved or recognized, while more consistent fluvial and debris flow processes tend to occur in other fan environments. This final explanation could be further modified in that grussy sediments produce less debris flows due to the lack of fine-grained material to act as a debris flow matrix, and instead may only produce sieve and more traditional alluvial deposits.

Eolian History

Eolian deposits are widespread directly south of the map area in the Kelso Dunes and Devils Playground (Figure 2). Sharp (1966) recognized that the majority of the sand supplied to the dunes came from ~50 km to the west where the Mojave River exits Afton Canyon and loses sediment carrying capacity. Compositional similarity to Mojave River sand, and the large volume of eolian sediments supports the theory that sands of Kelso Dunes are derived from the Mojave River, although local minor sources from fans of the Providence Mountains and Kelso Wash are also recognized (Lancaster, 1995; Ramsey and others, 1999). The Kelso Dunes are a part of a larger long-lived eolian system which dates as early as 17 ka (Clarke, 1994) and is presently active in minor amounts. Lancaster (1995) has established a chronology of five dune activation events: 25 to 16.8 ka, 12.5 to 3.5 ka, 3 to 1.5 ka, 0.8 to 0.4 ka, and 0.25 to 0.15 ka.

Recent studies of Quaternary climate variability have focused on lacustrine and eolian deposits to elucidate the timing of wet and dry climatic periods. Tchakerian and Lancaster (2002) have linked the histories of Lake Manix and eolian systems in several parts of the Mojave Desert, and have determined that many of the eolian pulses are tied to periods of very low lake levels (dry periods) when lake sediments can be desiccated. In wetter and semi-arid periods, sediment production is high and is concentrated in many environments, including lake basins, while vegetation serves to stabilize eolian deposits to form paleosols. Although the system is complex, linkages between lacustrine and eolian systems are compelling.

Quaternary deposits south of the Kelso Mountains contain relic alluvial and eolian sediments. Surfaces of unit Qia2, Qia1, Qya4, and Qya3 (mapped as Qiae2, Qiae1, Qyae4, Qyae3) all contain pronounced accumulations of fine sand in the upper soil horizons that progressively get thicker and more pronounced to the south, towards Kelso Dunes. This indicates contribution of eolian sand to the fan deposits during and after deposition. Surface expressions of these deposits do not show influence of modern eolian processes such as coppice mounds, subdued topography, or higher albedo in remote sensing. Additions of eolian sand to deposits as old as Qia2, which may date to ~150 ka suggests greater antiquity to the eolian system than dated at Kelso Dunes. Field observations are required to determine the extent of the eolian influence due to the lack of surface expression on remote sensing images. Qya2 and Qya1 surfaces in the area do not contain any indications of active or recent eolian influence, which suggests that eolian features in Kelso Valley may be somewhat transient in time and space, and may be a reflection of changing sediment supplies or wind regimes. Qya2 deposits are no older than ~150 ya, then this also corroborates the terminus of eolian deposition at Kelso Dunes at ~150 ya (Lancaster, 1995).

Mixed alluvial and eolian deposits also crop out immediately south of the Proterozoic-Cambrian carbonate dominated landslide spurs in the southern Kelso Mountains. These deposits (unit Qiae1) are high (2 to 4 meters), are moderately sloping into the hillside, and consist of gravel and coarse sand mixed with considerable amounts of very fine sand. These deposits likely represent sand ramp deposits that abutted up against the carbonate spur. The deposits grade to the southeast where they are inset into Qia2 deposits. Active channels truncate the deposits, and geomorphic relationships suggest that a significant amount of the deposit has been eroded. Deposits of Qya4 crosscut the location where the toes of the sand ramps would have graded to. Small, unmappable deposits of Qyae4 are inset into the deposit approximately 3 meters at the highest portion (~4 meters) of the surface, suggesting that the removal of the toes and incision into the sand ramps occurred prior to the time that Qya4 units were deposited. These deposits likely correspond to unit 'Qe1' of McDonald (McDonald, 1994) which has an IRSL date of 17 ka (Clarke, 1994). Ages on Qia1 and Qiae1 deposits are rare, and there is a possibility that the deposits may be somewhat older, on the range of 20-35 ka, which would predate known major eolian deposits associated with Kelso Dunes.

Climatic influences on Geomorphology

Work throughout the southwest United States has revealed that many surfaces were most likely deposited in large fan aggradation events in interglacial periods, as a result of wet to dry climatic changes, that may have changed vegetation dynamics, destabilizing hillslope materials that had developed during glacial stages (Bull, 1991; McDonald and others, 1995; Reheis and others, 1996). If this model holds true, then a few inferences can be made about climatic influences on alluvial fan deposition in the Kelso area. The magnitude of climate shifts in the Late Pleistocene to early Holocene may be the cause of widespread aggradation in the early and mid Holocene, resulting in deposition Qya4 deposits. Miller and others (2001) dated debris-flow deposits in the Silurian Lake area that correlate to unit Qya3, and suggested at least one climatically induced sedimentation pulse at about 6.3 to 6.5 ka. Wide spread deposition of unit Qya3 on alluvial fans in the region apparently began around 6 ka, and continued until approximately 3 ka, which corresponds to the transition the drier altithermal (~4 to 7 ka) period.

Bedrock Deposits

Four primary types of bedrock deposits are found in the Kelso Quadrangle: Proterozoic metamorphic rocks, Late Proterozoic/Cambrian sedimentary rocks, Jurassic/Cretaceous/Tertiary intrusive rocks, and Miocene basin fill. Planimetric areas of the deposits as mapped reveal that the late Mesozoic/Tertiary rocks are the predominate rock type in the quadrangle, followed in order of decreasing area by the Proterozoic metamorphic rocks, Miocene gravels, and the Late Proterozoic/Cambrian sedimentary rocks. Each of these rock types will be discussed beginning with the oldest.

Metamorphic Rocks

Proterozoic metamorphic rocks are widespread in the southwestern United States. Prior to the middle 1980's these rocks had received little attention in the eastern Mojave Desert. Wooden and Miller (1990) discussed Early Proterozoic rocks in the New York Mountains and surrounding areas, approximately 30 km east of the Kelso quadrangle. Detailed studies of mineral assemblages and internal relationships for these rocks in the map area were not performed for this study, however megascopic and regional relations will be presented here.

Rocks identified as Early Proterozoic age are divided into three types in the map area. The most common is medium-grained, foliated, biotite gneiss. Second in abundance is a biotite-poor fine- to medium-grained granofels, and the third is medium-grained biotite schist that crops out in small areas but is commonly too small in outcrop to map. Foliation in all units, when present, typically strikes north-to-south.

Aplite, pegmatite, felsite dikes and irregular small bodies intrude all of the Proterozoic rock units, and are in turn intruded by Mesozoic and Cenozoic plutons and dikes. Nearly equigranular texture, and the lack of foliation in many intrusions indicate that many post dated metamorphism and deformation that created the gneiss and schist.

Medium- to coarse-grained biotite gneiss comprises most of the Proterozoic rock in the map area. Mapped as the undifferentiated Proterozoic map unit (Xgu), it may contain locally small out crops of granofels or schist. This unit is typically gray to light tan or pink, and consists mainly of biotite gneiss of 0.5 to 1cm thick bands of biotite and 1 to 3cm bands of gray to pink feldspars and quartz. Foliation is well developed and often is accompanied by a strong lineation that results in the mafic minerals occupying needle-shaped zones up to 1 cm wide and several cm long. Approximate mineral volumes are 10 to 20 percent biotite, 25 to 40 percent quartz, and 40 to

50 percent feldspars. No distinctive metamorphic minerals were observed by the author, although Hewett (1956) reported that sillimanite, quartz and biotite schist occur within the study area. These rocks are similar to the ~1710 Ma “Preorogenic to Synorogenic Granitoids” of Wooden and Miller (1990), to which they are loosely correlated.

Fine- to medium-fine-grained granofels crops out in the southeastern portion of the Proterozoic exposures and is mapped as unit Xgg. Texture ranges from microgranitic to fine- to weakly medium-grained equigranular. Composition is primarily granitic, with approximately 45 percent plagioclase, 35 percent potassium feldspar, 20 percent quartz and 0 to 1 percent biotite. These rocks may correlate to the1690 to 1670 Ma “Postorogenic Granitoids” of Wooden and Miller (1990), based on leucocratic, low biotite specimens. Faint jointing strikes from 250 to 10 degrees, and may indicate localized foliation. The granofels is intruded by very coarse-grained pegmatite, fine-grained rhyolitic dikes, and hornblende-biotite granodiorite of indeterminate ages, as are most of the Proterozoic units.

Proterozoic rocks with high mafic mineral content occur throughout the Proterozoic section of the map area and are mapped as unit Xgs. These rocks range from 20 to 30 percent biotite gneiss to biotite schist. One outcrop consisted of biotite gneiss with most of the biotite occurring in 3 to 7 cm diameter rounded masses that are interpreted as replacement of large garnet phenocrysts with biotite, indicating that some portions of the map area were at one time at fairly high metamorphic grade. These rocks tend to be well foliated and lineated. The aluminous composition of the rocks leads to the interpretation that the protolith may have been sedimentary in origin, perhaps as much older sedimentary rocks caught up in intrusion and metamorphism of the Proterozoic granitoids. Wooden and Miller (1990) suggest protoliths for biotite-garnet gneiss in the eastern Mojave region based on composition may be immature clastic sedimentary rocks, volcaniclastic rocks, or shallow intrusive rocks. Direct stratigraphic relations were not observed by the author, making relative age determinations difficult. Interpretations of protolith materials allow two possible scenarios: 1) unit Xgs sedimentary protoliths deposited on top of existing plutonic or volcanic units (Xgu and Xgg materials), or 2) units Xgu and Xgg protolith materials intruding older Xgs materials. The latter is most likely, based on higher degree of metamorphism and correlations to rocks described by Wooden and Miller (1990). If correlations to rocks described by Wooden and Miller (1990) are correct, rocks mapped as unit Xgs would be the oldest (but indeterminate in maximum age), rocks mapped as unit Xgu would have intruded unit Xgs rocks at ~1710 Ma during the Ivanpah orogeny, followed by intrusion of unit Xgg rocks at ~1690 Ma.

Sedimentary Rocks

Sedimentary rocks crop out in three topographic ridges, or spurs, in the south central map area, near Kelbaker Road. These rocks consist primarily of limestone and dolomite, along with quartzite, shale, and conglomerate beds. In places they are slightly metamorphosed. Numerous authors have identified these rocks as Neoproterozoic-Cambrian continental margin deposits (Bahde and others, 1997; Cooper and Fedo, 1992; Cooper and others, 1994; Dunne, 1972; Hazzard, 1954; Hazzard and Mason, 1936; Hewett, 1956; Stewart, 1970; Stone and others, 1983). The local and regional stratigraphy and depositional environments of these deposits and their correlatives throughout the Mojave, is widely debated in the literature. Due to the limited stratigraphic exposure, and structural disarticulation of these deposits in the Kelso Quadrangle, detailed descriptions and regional interpretations are outside the scope of this investigation. Stratigraphic work by the author is intended to give an overview of the deposits, and to aid in the understanding of the structural orientation of the spurs in which the rocks crop out. The stratigraphy presented here is based upon work by Hazzard and Mason (1936), Hazzard (1954), Stewart (1970), and are compiled and described in the map area by Dunne (1972), with modifications based on more recent work by Cooper and Fedo (1992), Cooper and others (1994), and Bahde and others (1997) .

Although highly faulted and disarticulated, the sedimentary rock sequence shows a general trend of older, clastic sediments in northern outcrops, and younger carbonate-dominated sediments in southern outcrops. These rocks dip to the south as well, revealing sequences of sediments that young to the south. The deposits are highly structurally complex. They are cut by numerous faults, and in many places are highly brecciated. Repetition of units or sequences of units is not uncommon and tend to consist of fault-bounded blocks of the Latham Shale and Chambless Limestone. Debate has arisen concerning the origin and emplacement mechanism for these monolithologic breccia deposits that are fairly common in the eastern Mojave region. Two emplacement mechanisms that have been proposed are catastrophic avalanches, or slow, gravity-driven glide blocks (Friedmann, 1999). This author interprets the deposits in the study area as avalanche landslide megabreccia deposits similar to those described in detail in Shadow Valley by Friedmann (1999) and in the Halloran Hills by Bishop (1996). Evidence for a catastrophic emplacement of several sets of landslides (possibly each one representing one a morphological spur), consists of intense brecciation, and fracturing and faulting of units. Friedmann (1999) also described gravity glide blocks in Shadow Valley, to which the deposits in Kelso also share similarities such as basal brecciation, and that many of the repeated sections are along anisotropies of lithologies at the base of the Latham Shale. This author favors the avalanche landslide megabreccia interpretation, although further work is needed to make a definitive interpretation.

One problem with either interpretation is the lack of highlands from which the landslides or gravity slides may have originated. The northwest trending fault zone northwest of each of the spurs of sedimentary rocks is most likely indicative of the provenance for the slides. I interpret the slides to have originated from the north, emplaced following normal down to the southwest slip on the fault zone, which created the grade for the slides. Following sliding, the highlands from which the slides originated, likely the top of the Teutonia Pluton, was either lowered through erosion, or structurally lowered.

Igneous Rocks

Intrusive igneous rocks are the most abundant class of rocks throughout the Mojave Desert. The majority of these rocks have their origins in magmatic arcs that swept the North American Cordillera during the Mesozoic. Triassic plutons are known in the west Mojave Desert, while Jurassic plutonic and volcanic rocks comprise the oldest significant magmatic arc to affect the eastern Mojave Desert region. The Jurassic magmatic arc was then overprinted by Cretaceous magmatic arc-related rocks (Fox and Miller, 1990). Tertiary volcanic rocks, plutons and dikes are also widely distributed in the Mojave Desert and are commonly associated with large extensional tectonism.

In the Kelso area, plutonic and intrusive igneous rocks have been assigned Jurassic, Cretaceous, and early Cenozoic ages by correlating with dated rocks in the area (Beckerman and others, 1982; Dunne, 1972; Fox and Miller, 1990; Miller and others, 1991). No volcanic rocks crop out in the quadrangle, although there are Cenozoic volcanic deposits in the Providence Mountains (Miller and others, 1991), Old Dad Mountain area (Dunne, 1972) and extensive Tertiary and Quaternary basalts in the Cima volcanic field to the north (Wilshire, 1992). There is evidence that Miocene volcanic rocks once cropped out in the map area, but have since been eroded into the basin fill deposits (see below).

Nine mappable intrusive rock units have been identified in the Kelso quadrangle. The author interprets many of these rocks as belonging to the Teutonia batholith of Beckerman and others (1982). This correlation is largely based on similarity of composition and texture. Correlations to the Teutonia batholith and other major intrusive suites are presented in Table 1 and are discussed further below. No thin section petrology, chemical analysis, or isotopic dating was done as part of this study. Ages of intrusive rocks have been designated through correlation with dated plutons elsewhere in the east Mojave Desert.

Table 1. Correlation of mapped plutonic units to regional plutonic units

Map Unit	Correlated Unit	Correlated Age
Kgd	Live Oak Canyon Granodiorite of Beckerman and others (1982)?	79 Ma (Beckerman and others, 1982)
Ktgd	Live Oak Canyon Granodiorite of Beckerman and others (1982)?	79 Ma (Beckerman and others, 1982)
Kte	Mid Hills Adamellite of Beckerman and others (1982)	93 Ma (Miller and others, 1991)
Ktp	Mid Hills Adamellite of Beckerman and others (1982)	93 Ma (Miller and others, 1991)
Ktk	Teutonia Adamellite of Beckerman and others (1982)	97 Ma (Miller and others, 1991)
KJag	indeterminate	~155 Ma (Fox and Miller, 1990)
KJmd	Rock Springs Monzodiorite of Beckerman and others (1982)	97 Ma (Miller and others, 1991)
	‘mafic intrusive rocks' of Fox and Miller (1990)	> 155 Ma (Fox and Miller, 1990)
	Hornblende-biotite Monzodiorite of Miller and others (1985)	> 157 Ma (Miller and others, 1985)
KJd	Rock Springs Monzodiorite of Beckerman and others (1982)	97 Ma (Miller and others, 1991)
	‘mafic intrusive rocks' of Fox and Miller (1990)	> 155 Ma (Fox and Miller, 1990)
	Hornblende-biotite Monzodiorite of Miller and others (1985)	97 Ma (Miller and others, 1991)

Jurassic to Cretaceous Plutonic Rocks

Three plutons (units KJmd, KJd, and KJag) I interpret to be of Jurassic, or possibly Cretaceous in age. The rocks in each pluton are compositionally variable ranging from melanocratic to mesocratic, and albitized leucocratic. Compositions in hand sample are monzodiorite, diorite, and albitized granite. Many studies in the eastern Mojave Desert region have identified similar compositionally variable rocks, including albitization, as Jurassic in age which tend to cluster around 155 Ma (Beckerman and others, 1982; Fox and Miller, 1990). Dating of some of the melanocratic rocks (the Rock Springs Monzodiorite of Beckerman and others (1982)) at 97 Ma suggests that some of these rocks may be as young as Early Cretaceous (Miller and others, 1991). Because these plutons are not locally dated, and possibly could be Cretaceous in age, I follow past assignments by (Dunne, 1972) and consider them to be Cretaceous to Jurassic. Due to possible overprinting of thermal histories by younger Cretaceous and Tertiary intrusion events, dates may have wide ranges.

The two mafic phases of the Cretaceous to Jurassic intrusive rocks (units KJmd and KJd) crop out only in the southern map area. They intrude Proterozoic metamorphic rocks and are in turn intruded by the plutons assigned Cretaceous ages based on compositional and texture. These rocks contain abundant biotite and hornblende phenocrysts, commonly showing foliation. In outcrop, both plutons tend to be dark gray to light blue-gray in color. Intrusive relationships between plutons mapped as KJmd and KJd are not present, and the only age relationships that can be interpreted is the tendency of Jurassic to Cretaceous plutons to become more mafic or melanocratic with age (Fox and Miller, 1990). Thus, unit KJd is interpreted here to be possibly older than unit KJmd.

Regional correlatives of these mafic plutons may be the Rock Springs Monzodiorite of Beckerman and others (1982) in the Mid Hills area, the 'mafic intrusive rocks' of Fox and Miller (1990) in the southern Providence and Bristol Mountains, 'Mafic member of Teutonia batholith**'** in the Cima Dome area (Wilshire, 1992), and may also be related to diorite sills that crop out in the Cowhole Mountains (Wadsworth and others, 1995). These authors have described Mesozoic intrusive rocks in their respective areas that have similar characteristics to those in the Kelso area, along with younger, more voluminous granitoid suites. More detailed petrologic and chemical studies of the suite of Mesozoic intrusive rocks in the Kelso and Providence Mountains may allow positive correlations, and perhaps identification a single, larger intrusive suite of Jurassic to Cretaceous rocks than previously recognized.

Rocks mapped as 'Albitized Granite,' (unit KJag) crop out in the western center of the map area. This unit consists largely of granite, which has undergone varying degrees of albitization. This type of alteration consists of replacement of alkali feldspars with albite, and localized chloritization of biotite (Fox and Miller, 1990). In central portions of the outcrop area, rocks mapped as this unit are nearly entirely white. The degree of alteration decreases away from the central portion of the outcrop area, where it commonly occurs as meter-scale patches of altered granite, and as tabular masses that create a banded outcrop appearance. This banding can occur on scales ranging from less than one centimeter to several meters. Fox and Miller (1990) describe this type of alteration as locally common in the Providence and Bristol Mountains, which exhibit both pronounced zones of alteration in which mesocratic rocks are white in color, as well as more common widespread mottling or spotted alteration. This type of alteration appears to be widespread in Jurassic plutonic rocks eastern Mojave Desert, and much of the southern Cordillera, and is believed to represent late to post magmatic alteration (Fox and Miller, 1990). Dates of similar plutons in the Providence and Bristol Mountains cluster around 155 Ma, suggesting that rocks in the Kelso area exhibiting this style of alteration should likely be similar in age. However, the albitized granite pluton in the Kelso quadrangle is intruded by a pluton correlated with the 97 Ma (Miller and others, 1991) Teutonia Adamellite of Beckerman and others (1982), allowing for the possibility that the pluton is Cretaceous to Jurassic.

Cretaceous Plutonic Rocks

Four granitoid plutons in the map area are confidently correlated with plutons in the Cretaceous Teutonia batholith of Beckerman and others (1982), although other plutons in the map area have affinities to the Teutonia batholith. The Teutonia batholith is one of the largest intrusive suites in the eastern Mojave Desert region. Units confidently correlated to the Teutonia Batholith as part of this study are: Equigranular Quartz Monzonite (Kte), Porphyritic Quartz Monzonite (Ktp), Biotite Granodiorite (Ktgd), and Quartz Monzonite of Kelso Peak (Ktk). With the exception of unit Ktgd, all of these map units have very similar composition and texture to plutons in the Teutonia batholith. Intrusive relations suggest that they are likely comagmatic or closely spaced in emplacement age.

Units Kte and Ktp are the plutons most similar to plutons in the Teutonia batholith. Both plutons are leucocratic quartz monzonite. Both units are megascopically tan to light brown, with unit Kte being lighter toned than unit Ktp. In hand sample the two units are both medium to coarse-grained and typically contain 8 to 10 percent biotite phenocrysts often in disaggregated masses. The two are distinguished by grain size and texture. Unit Kte is equigranular to semi-equigranular, and tends to have between 8 and 10 percent biotite phenocrysts. Unit Ktp is porphyritic, tends to be coarser grained overall with larger potassium feldspar phenocrysts, and more disseminated and smaller biotite phenocrysts ranging from 10 to 12 percent. Biotite content decreases near many contacts between these two rock types. Intrusive relationships suggest that unit Ktp is intruded by the Kte pluton, in that the Kte pluton is topographically emplaced below the Ktp pluton. This is identified at a distance by a megascopic change in color from lighter tan tones for unit Kte to darker tans and brown tones for unit Ktp. This contact style is observed from the northern straight away section of Kelbaker Road looking southwest at approximately two-thirds up from the base of the hill, as illustrated in Figure 4. Units Kte and Ktp are correlated (see Table 1) to the 93 Ma (Miller and others, 1991) Mid Hills Adamellite of Beckerman and others (1982) based on composition and texture. Beckerman and others (1982) describe large-scale texture trends within the Mid Hills Adamellite to be porphyritic in northern and southern outcrops and equigranular in central outcrops. This pattern holds true for outcrops in the Kelso Mountains, although on a somewhat smaller scale.

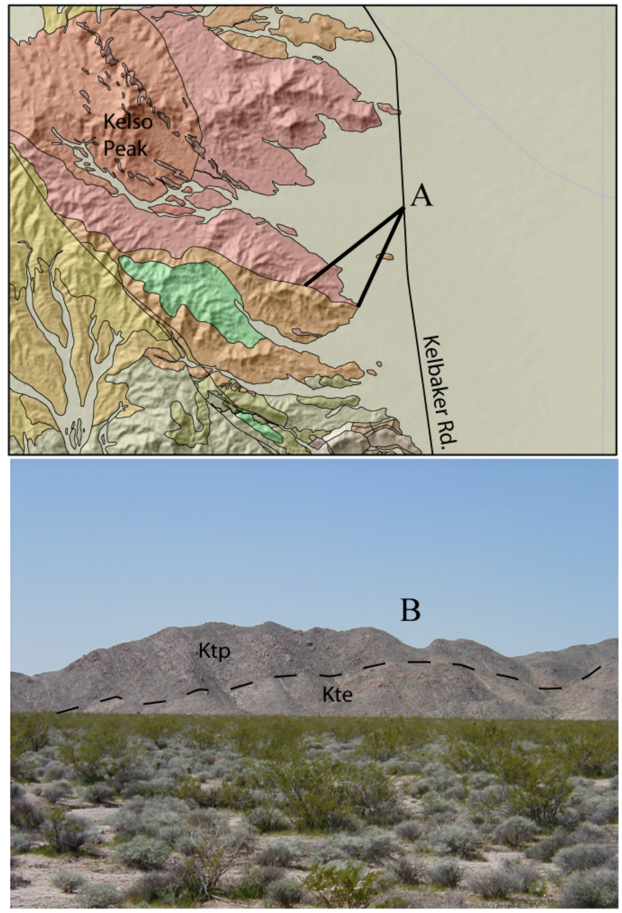

Figure 4. Intrusive relations between Porphyritic Quartz Monzonite (unit Ktp) and Equigranular Quartz Monzonite (unit Kte) near Kelbaker Road

Unit Ktgd crops out in the northeastern map area, adjacent to the Marl Mountains, and is mesocratic to leucocratic. In hand sample it is a medium-coarse-grained porphyritic biotite granodiorite. Biotite phenocrysts typically form 0.5 to 1.5 cm booklets comprising approximately 15 percent rock volume. The pluton weathers to large boulders and cobbles and is typically moderately to well varnished. No intrusive relationships with other intrusive plutons are visible in the limited outcrop extent, although the unit intrudes Proterozoic gneiss and a quartzite correlated to the Sterling Quartzite or possibly a quartzite member of the Johnny Formation. Correlation with the Teutonia Batholith is based on its proximity within plutons correlated to the batholith, although a there is not a direct correlation to a pluton in the Teutonia.

Unit Ktk, named in this report as the Quartz Monzonite of Kelso Peak, makes up the Kelso Peak massif. The pluton is leucocratic. In hand sample the rocks are medium-grained equigranular biotite quartz monzonite. Biotite content ranges from 4 to 8 percent and is usually in isolated phenocrysts. This pluton can be distinguished from the megascopically similar Kte pluton by finer, more equigranular texture, and lesser potassium feldspar and biotite content. Along the contact between the Ktk and Kte pluton, clasts of the Ktk pluton are observed in the Kte body, suggesting that the Kte pluton is older and intruded by the Kte pluton (which intrudes the Ktp pluton). This pluton is correlated to the 97 Ma (Miller and others, 1991) Teutonia Adamellite of Beckerman and others (1982) based composition and texture, as well as intrusive relations with plutons (units Kte and Ktp) correlated to the 93 Ma Mid Hills Adamellite. The Ktk pluton also resembles the Mid Hills Adamellite in its tendency to contain more plagioclase than potassium feldspars.

Unit Kgd crops out in the southern map area and is not easily correlated with the Teutonia batholith plutons, although it has similar affinities with the Teutonia batholith rocks. It is leucocratic and is the only Mesozoic pluton in the map area that is jointed. In hand sample it is a subequigranular medium- to coarse-grained biotite granodiorite, and contains approximately 10 percent biotite in small (2 to 5mm), widely dispersed crystals. Dunne (1972) classified this rock as biotite-hornblende granodiorite based on thin section studies, although hornblende was not observed in outcrop by this author. It intrudes Proterozoic gneiss, and Jurassic to Cretaceous diorite (unit KJd) along its southern margin forming 30 to 70 cm wide banding of granodiorite and diorite. While similar to the Live Oak Canyon Granodiorite of Beckerman and others (1982), this granodiorite is tentatively separate from the Teutonia batholith, based on its isolation from the Teutonia batholith plutons. Its distinguishing features from the plutons correlated to the Teutonia batholith in this report are the smaller biotite crystals, and jointing, which may be post-magmatic.

Cretaceous and Tertiary Dikes

Numerous dikes intrude the bedrock units in the map area. Most dikes are porphyritic felsite, porphyritic andesite (unit TKa), and green basaltic (?) composition. All phases of dike rock intrude rocks correlated to the Teutonia Batholith. Only the andesitic dikes (unit TKa) crop out in mappable areas; these are displayed on the map as lines and polygons. Pegmatitic, aplitic, felsite, rhyolitic dikes, and white-colored dike of uncertain composition are also found in the map area but are volumetrically minor. The porphyritic felsite phase intrudes the sedimentary rocks in the map area, forming thin (10 to 50 cm) dikes and sills but show no cross cutting relationships with other dikes. Apparent absence of this phase intruding the Jurassic-Cretaceous suite may indicate its age as Jurassic or older, and may correlate to Jurassic dikes and sills in the Cowhole Mountains (Wadsworth and others, 1995), although the structural complexities of the sedimentary rocks may obscure true intrusive age relations.

Although the andesitic dikes (mapped locally as unit TKa) are the most abundant, they have the smallest geographic extent of the dikes. Andesite dikes only intrude igneous rocks, and mainly just the Quartz Monzonite of Kelso Peak (unit Ktk), although a few intrude other Cretaceous plutons. The northwest-striking andesite dikes are melanocratic with a dark gray to black fine-grained aphanitic groundmass and phenocrysts sizes ranging commonly from 5 to 8 mm and sparsely up to 20 cm. Zoned feldspar phenocrysts are common as phenocrysts. Wilshire (1992) reported K-Ar ages of 88.2 and 90.7 Ma for similar dikes in the Granite Spring quadrangle, approximately 23 km north of the dikes in the Kelso quadrangle. Though dikes in each area are petrologically similar and have similar outcrop patterns, andesite is a common composition for Miocene volcanic rocks, and a Tertiary age cannot be ruled out at Kelso until the dikes are dated. As a result, these dikes are assigned a Tertiary and Cretaceous age.

Basin Fill Deposits

Semi-consolidated- to unconsolidated coarse-grained deposits (gravel) crop out over much of the western map area. Sedimentary structures in the gravel deposits consist of poor- to moderately-sorted, angular to subangular clasts, exhibiting moderately developed bedding, and cut-and-fill structures. Clast sizes in the map area range from silt and fine sand to boulders up to 7 m, with the dominant clast size being coarse gravel (2 to 10 cm). Sorting is generally poor, exposures of well-sorted sands are observed in more western and basal locations. Several inset channels ranging in sizes from 1 to 3 meters are also observed. Basal deposits 5 km northwest of the map area include massive fine-grained silt, clay, and sand that may be lacustrine in origin.

Depositional processes are inferred to be typically proximal alluvial fan deposits of fluvial and debris-flow in origin, grading westward (and down-section) to more distal alluvial fan to playa or lake environments, therefore these deposits are interpreted to be basin fill deposits dominated by fanglomerates. In addition to a 1000 to 2000 foot thick section of fanglomerate, Dunne (1972) describes volcanic flows and tuffs near the base of the basin fill at the far western portion of the basin, as well as limited exposures of lacustrine deposits within the fanglomerate. Several large blocks of Paleozoic sedimentary rock are also found in the western basin, which are interpreted to be avalanche blocks emanating from Old Dad Mountain during later stages of basin development (Dunne, 1972; Wilshire, 1992).

Current distribution of the basin fill deposits is that of an elongate north- to northwest-trending basin flanked by the Kelso Mountains on the east and by Old Dad Mountain on the west. The northern edge of the basin has no definitive boundary, although the Cima volcanic field appears to be the northern edge of the exposure.

The fanglomerate deposits have two distinct source rocks: Mesozoic granitoids and Proterozoic metamorphic rocks, and are subdivided by clast type on the geologic map (units Tfg and Tfgn respectively). Overall exposures are poor due to cover by colluvial and alluvial deposits, however the source material is commonly visually apparent in air photos with metamorphic sourced gravel having a very dark color tone. On the ground, characterization of the gravels is done by analyzing boulder and cobble clasts in colluvial material, and in rare outcrops in steep gullies and wash cuts. In the eastern basin, the fanglomerate deposits closely mirror compositions of nearby rocks, which are presumed to be the sources.

The most abundant composition of clasts in the fanglomerate deposits is Mesozoic granitoids (unit Tfg). Most of the granitoid gravels in the eastern part of the basin have similar compositions and grain size characteristics to granites mapped in the Kelso Mountains. However, outcrops in the basin near the Radar Ridge radio towers to the west of the Kelso quadrangle, and in some places along the eastern edge of the basin, have granitoid clast compositions of rocks that were not identified in the Kelso quadrangle, and have no reported source by other authors who have studied deposits in the basin fill outcrop area. This rock is a leucocratic granitoid with 2 to 4 cm diameter phenocrysts of fleshy pink alkali feldspars. A correlation with the Kessler Springs Adamellite of Beckerman and others (1982), which crops out in a small pluton nearly 30 km to the east-northeast on the northeast side of Cima Dome, can be made based on the hand sample comparison. This leaves the possibility that either some of the sediments near the top of the fanglomerate section were derived from current exposures of the Kessler Springs Adamellite and transported to the southwest across what is now the elevated Cima Dome, or that the Kessler Springs Adamellite or similar rock previously cropped out in the area and has since been completely eroded or buried.

The second main type of composition of gravel clasts mapped in the eastern part of the basin is metamorphic gneiss with lesser amounts of schist (unit Tfgn). These clasts are interpreted to have come from sources directly to the east, where gneiss and schist of the same compositions crop out at present.

Changes in clast composition in the fanglomerate deposits are often easily recognizable and sharp on air photography, and sharp, within approximately 5 meters in outcrop. The map units are contemporaneous, as observed at one 10 m thick section of granitoid dominated sediments (unit Tfg) interfingering with metamorphic dominated sediments (unit Tfgn) that thins to the south. This may reflect a minor change in the location of the basin depocenter for a short time during basin development, and may be tectonically related.

Dunne (1972) considered these basin fill gravels to be Miocene or Pliocene in age by correlating them to the Avawatz Formation, a unit described in the Soda and Avawatz Mountains by Grose (1959). The Avawatz Formation has been determined to be nearly entirely Miocene in age from a tuff dated at 11 Ma near the top of the section (Spencer, 1990). Skirvin and Wells (1990) identified *in situ* deposits and clasts of the 18.5 Ma Peach Springs Tuff in basal sections of the basin fill deposits. The Peach Springs Tuff has been dated at 18.5 Ma by Nielson and others (1990), and is considered a regional marker unit in the Eastern Mojave region. I identified clasts of the Peach Springs Tuff in the fanglomerate in the vicinity of Radar Ridge. These clasts were observed *in situ* in upper portions of the fanglomerate section, suggesting that the basin drained a source area of the Peach Springs Tuff during later stages of basin development. Other clasts were identified on colluvium-covered slopes in lower sections of the fanglomerate, which I interpret to likely represent local movement along hillslopes from upper sections. In northern portions of the basin, Wilshire (1992) described the Peach Springs Tuff as being nonconformably deposited on top of Mesozoic granitic rocks, or locally interbedded with basal conglomerate. Skirvin and Wells (1990) and Wilshire (1992) both described sections immediately above the Peach Springs Tuff as containing clasts of Peach Springs Tuff, and upper sections typically contain clast of other materials. This leaves an enigmatic middle section containing little or no clasts of Peach Springs Tuff. Three hypothesis to explain this could be: 1) late exposure and erosion of previously uneroded Peach Springs Tuff, 2) late stage reworking of basin fill gravels containing clasts of Peach Springs Tuff, and 3) late stage introduction of new sediment sources and/or complete erosion of Peach Springs Tuff from the basin source terrain. Each of these hypotheses suggests tectonism persisted through basin deposition (roughly 18 to 11 Ma), perhaps with tectonic maintenance of highland source areas.

Source lithology correlations and local proximity of sediments along the southeastern portion of the basin, and north of the Kelso Quadrangle along Kelbaker Road, suggest local sources in the Kelso Mountains. However, these deposits are observed to presently dip up to 24 degrees to the east, toward their source areas, suggesting approximately 20 to 30 degrees of eastward tilting on the Kelso Mountains Fault in order to create the current configuration of the fanglomerates.

The basin containing the fanglomerates is a fault-bounded graben with the Kelso Mountains Fault (see map sheet) being the eastward bounding fault, and the Old Dad Fault (approximately 4 km west of the map area) being the westward basin-bounding fault. The basin-bounding faults are most likely coeval with basin formation and were likely active as normal faults through deposition of the fanglomerate deposits.

Deposits of similar characteristics and structural relationships are prolific through the eastern Mojave region (Brady, 1992, 1993; Brady and Troxel, 1999; Prave and McMackin, 1999; Reynolds, 1991; Spencer, 1990; Wilshire, 1991). These deposits are typically separated into 2 main informal members, the oldest begin around 18 Ma and continues through 12 to 11 Ma. The Peach Springs Tuff is occasionally deposited at the base, or as detritus at the base of the sections. The basal unit deposits are terminated by regional scale unconformity that is occasionally associated with mafic volcanism (Skirvin and Wells, 1990; Wilshire, 1991) dated at 12.1 to 12.8 Ma, at or near the top of the older unit. The upper unit is typically monolithologic with similar clast compositions to modern nearby source terrains, and often contains large (100 m to km scale) megabreccia landslide deposits. In the Avawatz Formation, the upper unit contains a 11 Ma Tuff (Spencer, 1990). Termination of basin deposition is uncertain, but is generally assumed to be at around 10 Ma, although continued in other basins to at least 8 Ma (Brady, 1992). The deposits in the map area must have been deposited prior to erosion and subsequent deposition of

7.5 Ma basalts of the Cima Volcanic Field (Turrin and others, 1985). Regionally, initiation of extension and basin filling tends to young from south to north and from west to east, beginning at about 26 Ma in the Bristol Mountains (Brady, 1993), ~21 Ma in the southern Avawatz Mountains (Spencer, 1990), 18.5 Ma in the Kelso-Old Dad Mountain area (Skirvin, 1990), 18.5 Ma in the Halloran Hills (Reynolds, 1991), less than 14 Ma in the northern Avawatz Mountains Military Canyon Formation (Brady and Troxel, 1999), and finally at 13.4 Ma in the Shadow Valley basin (Friedmann, 1999). Termination of basin deposition tends to follow similar patterns.

Faults mapped southwest of the Kelso Mountains Fault, geomorphic expression of lineaments along the strike of those faults, and source lithology patterns suggest that the basin fill deposits were faulted after basin deposition ceased. Timing for these faults is uncertain but is likely Pliocene or possibly Quaternary, as evidenced by suggestions of tectonic geomorphology along the lineaments (sharp, steep lineaments in easily erodible material). These faults may also have right lateral offset, suggested by apparent 1.5 km or greater offset of metamorphic source clast fanglomerate from present day outcrops of source material along the Kelso Mountains Fault on the western edge of the map area. Skirvin (1990) reported Quaternary right-lateral strike-slip offset on faults on the west side of Old Dad Mountain. No evidence for Pleistocene aged offset was seen in exposures in the map area, but it is permissible based on map geometry.

Summary of Geologic History

The earliest geologic event inferred for the Kelso area was the intrusion of Proterozoic magmas into unknown country rock, possibly sedimentary cover. This event may have been followed by additional deposition of sedimentary materials. Regional metamorphism followed during the 1.7 Ga Ivanpah Orogeny (Wooden and Miller, 1990), which may have emplaced some of the Proterozoic rocks in the area. During the Neoproterozoic, regional erosion gave way to sedimentary deposition on a continental margin setting. Shallow marine sedimentation continued regionally into the Permian to early Triassic (Dunne, 1977; Stone and others, 1983) although only Neoproterozoic and Cambrian strata representing this depositional period crop out in the map area. Clastic sedimentation and volcanism along with east-vergent folding and thrusting deformed much of the area in the early to middle Jurassic (Dunne, 1972), and was quickly followed by intrusion associated with a Jurassic magmatic arc. Arc magmatism was accompanied by or followed by albitization of some areas by late-magmatic hydrothermal fluids (Fox and Miller, 1990). In the late Cretaceous, the Teutonia batholith and other plutons were emplaced as a Cretaceous magmatic arc swept across the eastern Mojave region. Cretaceous and/or Cenozoic dikes and other regional volcanism and extensional tectonics occurred in the Miocene and possibly earlier. A thick sequence of coarse gravel was deposited in Miocene basins synchronous and following extension. Tectonism and minor volcanism continued through Miocene basin development, maintaining or recreating highland areas as sources of megabreccia blocks emplaced in later stages of basin deposition. Extensive erosion and formation of pediments began prior to 7.6 Ma as Quaternary lava flows of the Cima Dome area were deposited on pediment surfaces (Dohrenwend and others, 1984) During and after eruptions, alluvial fan deposition, soil development and stripping occurred locally. There is a potential for strike-slip movement along the Kelso Mountains Fault, and the fault to the west in the Miocene-Pliocene, possibly related to tectonics in the eastern California shear zone. Several periods of late Pleistocene fan aggradation may be loosely tied to interglacial climate and vegetation changes, followed by respites of soil development during glacial periods as landscapes were stabilized by vegetation. Eolian sand sheets and dunes began to accumulate in the Kelso Valley during the late Pleistocene, probably as a result of falling lake levels and declining river flow at Afton Canyon. Pleistocene to Holocene climate transitions likely caused widespread fan aggradation again in the early to mid Holocene. Fluvial incision of older alluvial and wash geomorphic surfaces, along with minor deposition (backfilling or terrace deposition) occurs at present in the all portions of the Kelso piedmont, with incision highest near mountain fronts and accentuated in non-granitic source piedmonts. Incision and backfilling is prolific, but shallow in granitic sourced piedmonts. Soil development continues on stranded surfaces. Eolian deposition at present is restricted to the area of Kelso Wash and distal piedmonts along Kelso Wash.

Description of map units

Surficial geologic units commonly exist as thin (<2 m) veneers over older units. In areas where this relationship is common the unit designators are shown on the map separated by a slash (/). The younger, or overlying, unit is indicated first. Thus, Qya/Qia indicates an area where a veneer of young alluvial fan deposits overlies old alluvial fan deposits.

The lateral extent of individual deposits is commonly so small that each deposit cannot be shown individually at the database map scale. Areas made up of deposits too small to show individually (representing more than 20 percent of the area) are indicated by deposits separated by a plus sign (+), with the most common deposit listed first. Thus, Qya3+Qya1 indicates an area with both Qya3 and Qya1 deposits and associated surfaces, and that Qya3 is more common than Qya1; other deposits in the area compose less than 20 percent. Many Quaternary surfaces, particularly Holocene surfaces, are incised by and contain deposits of younger geomorphic surfaces that contribute less than 20 percent area. For instance, an area mapped as Qya3 will also contain units Qya2 and Qya1, which will not be noted unless the amounts of Qya2 or Qya1 exceed 20 percent.

Ages of alluvial, eolian and wash deposits are classified as young, intermediate and old based on surface micromorphology, pattern and degree of channel dissection of alluvial fan surfaces, degree of soil development, desert pavement development, and intensity of rock varnish developed on surface clasts. Correlations with locally dated deposits provide age control.

Soil A_v and B horizon descriptions are after Birkeland and others (1991). Carbonate stage morphology is from Gile and others (1966), modified after Machette (1985).

af **Artificial Fill (Latest Holocene)** – Loose sand and gravel constructions by humans such as railroad beds, levees, berms, diversion channels, and settlements. Unit denotes areas where natural drainages may be sufficiently altered to change runoff patterns

Wash surfaces and underlying deposits

Qyw **Young Wash Deposits, Undifferentiated (Holocene)** – Moderately- to well-sorted, moderately bedded loose sand and gravel. Grains generally subangular to poorly rounded. Occupies large integrated drainages and valley centers. May be prone to flooding during heavy rain

Qyw1 **Youngest Wash Deposits (Latest Holocene)** – Moderately- to well-sorted, moderately bedded loose sand and gravel occupying major ephemeral stream channels. Sediments are typically derived from granitoids and deposited in active channels by flow within the last few decades. Active channels inset 0.5 to 2.5 meters into older wash and alluvial deposits. Very sparse to no perennial vegetation with occasional annual grasses. Prone to flooding during heavy rain

Qyw2 **Younger Wash Deposits (Late Holocene)** – Lithologically and morphologically similar to unit Qyw1. Surface lies 15 to 30 cm above active wash channel. Well-developed bar and swale topography, lacks soil development. Vegetation is commonly denser than found on active channels and older wash surfaces, with creosote brush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa)*. Cheesebush (*Hymenoclea salsola*) and Smoke tree (*Psorothamnus spinosus*) are generally restricted to Qyw deposits, and tend to be a diagnostic vegetation assemblage. Prone to flooding during heavy rain

Qyw3 **Young Wash Deposits (Holocene)** – Lithologically and morphologically similar to unit Qyw2. Surface lies 20 to 75 cm above active wash channel, and 10 to 40 cm above Qyw2 surfaces. Surfaces commonly have subdued bar and swale topography. Weak to incipient 0.5 to 2 cm thick Av horizon, very weak B horizon, stage I- to I calcic development. Partially vegetated with annuals and perennials such as creosote bush, white bursage, and cheesebush

Alluvial fan surfaces and underlying deposits

Qya **Young Alluvial Fan Deposits, Undifferentiated (Holocene and latest Pleistocene)** – Moderately- to poorly-sorted sand and sandy gravel. Coarser-grained especially near non-granitic mountain fronts where boulders and cobbles are common. Light tan to brown, but varies according to source material. Loose to slightly compact. Abundant bar and swale topography up to 1 m in relief near mountain fronts and less developed toward toe of fans. Deposits lack well-developed desert pavements and varnish. Soils exhibit weakly developed Av, cambic horizons, and stage I to II calcic development on older surfaces. Deposits grade from active channels incised into older alluvial fan surfaces near mountain fronts, to undulating surfaces with age determinations made on degree of soil development away from mountain fronts. Sparse perennial vegetation with localized abundant annual grasses. During and following heavy rains, deposits may be prone to channelized floods near mountain fronts and shallow but possibly wide sheet floods away from mountain fronts

Qya1 **Youngest Alluvial Fan Deposits (Latest Holocene)** – Moderately- to poorly-sorted sand and sandy gravel. Coarser grained especially near non-granitic mountain fronts where boulders and cobbles are not uncommon. Light tan to brown, but varies according to source material. Active channel deposits in channels receiving sediments on decadal time scales. Abundant bar and swale topography and vertical cutbanks along channel margins near mountain fronts and rounded transitions to older deposits toward toe of fans. No soil development, varnished clasts, or desert pavement. Rarely occupied by annual grasses, lacks perennial vegetation and cryptobiotic crusts. During and following heavy rains, deposits may be prone to channelized floods near mountain fronts and shallow but possibly wide sheet floods away from mountain fronts

Qya2 **Younger Alluvial Fan Deposits (Late Holocene)** – Lithologically and morphologically similar to Qya1 with similar trends in grain sizes with proximity to mountain fronts as unit Qya. Surfaces lie 10 to 40 cm above washes and more active areas of unit Qya1. Bar and swale microtopography is prevalent, and lacks varnished clasts or desert pavement. Minor soil development expressed as very incipient Av horizons or accumulations of very fine sand and silt in upper portions of the soil profile. Unit tends to be moderately to well vegetated with perennial shrubs such as creosote and white bursage, and is commonly densely populated with cryptobiotic crusts. Prone to flooding and sheet flow during and after heavy rains. Active on centennial time scales

Qya3 **Young Alluvial Fan Deposits (Holocene)** – Moderately- to poorly-sorted sand and gravel, with similar trends in grain sizes with proximity to mountain fronts as unit Qya. Surface lies approximately 30 cm to 2 m above Qya1 surfaces and 15 cm to 1 m above Qya2 surfaces. Loose. 20 to 60 cm of rounded bar and swale microtopography, no desert pavement or varnish. Soil development consists of 1 to 3 cm thick fine sand and silt A_v, and occasional reddening of subsurface (cambic B) horizons, stage I calcic development. Incised by active channels, which are commonly 10 to 30 m apart, with on less active channels and higher surfaces. Moderately vegetated with perennial shrubs creosote and white bursage, dense cryptobiotic crusts

Qya4 **Young Alluvial Fan Deposits (Early Holocene and latest Pleistocene)** – Lithologically and morphologically similar to Qya3, with similar trends in grain sizes with proximity to mountain fronts as unit Qya. Surfaces lie 10 to 60 cm above Qya3 surfaces, bar and swale topography typically very subdued with 1 to 5 m^2 patches of incipient pavement and clast varnishing. Soil development consists of 1 to 4 cm thick A_v horizon, weak cambic to Btw horizon, stage I to II calcic. Dated at 10 ka in Fenner Wash near the town of Fenner, and lies on 13 ka deposits in lower Kelso Wash near Soda Lake (Shannon Mahan, written communications)

Qyad **Young Alluvial Fan Deposits Dominated by Debris Flows (Holocene and latest Pleistocene)** – Lithologically and morphologically similar to Qya, but primarily consisting of bouldery, matrix-supported material. Bar and swale microtopography is well pronounced on the order of 0.5 to 1 m high. Mapped only where determined from field study; deposits are much more widespread than shown

Qyag **Young Alluvial Fan Deposits Composed of Grus, Undifferentiated (Holocene and latest Pleistocene)** – Characteristics similar to unit Qya, with the exception that inset surface relations are more subdued and commonly less that 50 cm from active wash to the highest surfaces. Also tends to be less incised near mountain fronts. Coarsest grain size fraction is rarely larger than fine gravel, and tends to be moderately sorted at the medium to coarse sand fraction. Soil development weaker that unit Qya, commonly with sandy A_v, weaker cambic, and less developed, but deeper calcic horizons

Qyag1 **Youngest Alluvial Fan Deposits Composed of Grus (Latest Holocene)** – Characteristics similar to unit Qya1but with subdued channeling. Also tends to have less significant fining of clast size away from mountain fronts

Qyag2 **Younger Alluvial Fan Deposits Composed of Grus (Late Holocene)** – Soil characteristics similar to unit Qya2 with subdued channeling and very subdued to no bar and swale morphology. Tends to have less significant fining of clast size away from mountains

Qyag3 **Young Alluvial Fan Deposits Composed of Grus (Holocene)** – Characteristics similar to unit Qya3 with subdued channeling and microtopography. Soil development weak with sandy incipient to weak A_v, poorly-developed cambic horizons, stage I to I+ calcic horizons

Qyag4 **Young Alluvial Fan Deposits Composed of Grus (Early Holocene and latest Pleistocene)** – Characteristics similar to unit Qya4 with subdued soil development. Surfaces lack clast varnishing and generally lack moderately developed desert pavements. Soil development is typically consists of a weak

A_v and cambic to argillic B horizon, and stage I to II calcic horizon. Deposits tend to be incised by unit Qyag3 and younger surfaces in proximal fan environments and buried or at grade with unit Qyag3 surfaces in distal fan environments

Qia **Intermediate Age Alluvial Fan Deposits (Pleistocene)** – Light to dark brown poorly- to moderately-sorted sand and gravel. Clasts mostly subangular to sub-rounded and coarsen toward mountain fronts. Moderate-to well-developed interlocking desert pavement containing moderate to strong varnish coating on clasts, with the exception of granitoid clasts, which rarely varnish. Moderately developed soil profile, with moderate- to well-developed A_v horizon that is as much as 6 cm thick, distinct argillic B horizons up to 50 cm thick and with weak to moderate stage II to III calcic horizons. Surfaces lie 1 to 3 meters above young alluvial fan surfaces (Qya). Surface remnants flat to slightly rounded between incised younger channels. Sparse and stunted vegetation, typically along shoulders of incised channels or isolated on the surface

Qia1 **Intermediate Age Alluvial Fan Deposits (Latest Pleistocene)** – Poorly- to moderately-sorted sandy gravel. Surfaces commonly compact with moderately developed desert pavement consisting of non-interlocking mosaics of mixed size clasts. Relic bar and swale microtopography remains in some areas. Surface is light brown to dark brown to black depending on source lithology and degree of varnish. Varnishing of clasts variable, with granitic clasts having little or no varnish, to quartzite and other sedimentary rocks being very well varnished. Moderately- to well-developed soil profiles consisting of 2 to 6 cm thick silt and fine sand vesicular A_v horizon above 25 to 30 cm reddish argillic Bt horizon, with stage II to III- calcic development. Surfaces lie 1 to 2 m above active stream channels and younger deposits, inset 30 to 100 cm into unit Qia2. Sparsely vegetated. Deposit uncommon or indistinguishable from unit Qia2 in remote sensing, mapped where visited in field

Qia2 **Intermediate Age Alluvial Fan Deposits (Late Pleistocene)** – Similar characteristics to unit Qia1, with more pronounced soil development especially in thickness and degree of A_v horizon development, which ranges from 2 to 8 cm. Argillic Bt horizon with stage II to III calcic development. Pavement surfaces often very flat with well varnished, compact interlocking clasts. Surface is light brown to black. Vegetation is very sparse and tends to be isolated perennials such as creosote or Mojave Yucca (*Yucca schidigera)*, or concentrated along shoulders of incisions. Surfaces are the most common of those of intermediate age

Qiag **Intermediate Age Alluvial Fan Deposits Composed of Grus (Pleistocene)** – Characteristics similar to those for unit Qia, although soil development is less pronounced: sandy weak- to moderately-developed A_v and weak cambic horizons with stage I to II calcic. Generally lacks varnish and pavements. Pavements and varnish, when present, often composed of igneous dike material. Absence of diagnostic inset relationships and soil-geomorphic characteristics generally prevent correlation to unit Qia and its subdivisions, as well as subdivisions within unit Qiag

Qiag3 **Intermediate Age Alluvial Fan Deposits Composed of Grus (Late – Middle Pleistocene)** – Distinct rounded surfaces in areas between young incised channels, with argillic horizons exposed in channels indicating that surface is being degraded. Pavement less extensive than on younger Qia surfaces with A_v and B horizon exposed at the surface or along shoulders, reflecting erosion of the landform. Varnish coatings moderate to strong on clasts that develop varnish. Soil development consists of moderately developed A_v horizon ranging in thickness from 2 to 8 cm, moderately developed Btw horizon with stage I to II calcic development, when present. Associated with Mojave Yucca, which is sparse to moderate in density, and generally suggests the presence of unit Qiag3 at the surface or shallowly (< 1 m) buried. Correlated to unit Qia3 of Yount and others (1994) based on evidence for surface degradation and soil development

Qoa **Old Alluvial Fan Deposits (Pleistocene)** – Unit identified by 2 to 5m thick deposits of stage IV calcic horizons exposed in sides of washes, and correlated to deposits described by McDonald (1994) and Yount and others (1994). Found in the southern Kelso Mountains where top of unit not exposed due to erosion and subsequent deposition and soil development of intermediate age alluvial fan deposits (Qia2) above unit

Mixed alluvial fan and eolian surfaces and underlying deposits

Qyae **Young Mixed Alluvial and Eolian Deposits (Holocene and latest Pleistocene)** – Alluvial and eolian sediments that are thoroughly mixed, with alluvial processes dominating. Forms flatter surfaces than alluvial systems lacking significant eolian sand because eolian sand additions mute topography. Gravelly sand with vague to well-defined thin bedding. Soil development similar to or less pronounced than correlative alluvial units. Contacts with alluvial and eolian dominated units are gradational. Sparsely vegetated, generally supporting creosote bush, white bursage, and annual grasses.

Qyae3 **Young Mixed Alluvial and Eolian Deposits (Holocene)** – Characteristics similar to unit Qya3, particularly in surface morphology. Shows addition of very fine sand and silt in upper 30 cm of soil profile suggesting eolian contribution to the original deposit or as illuvial material prior to deposition of inset units Qya1 and Qya2. Younger inset surfaces in the map area lack eolian contribution features. Lacks eolian features at the surface such as coppice mounds

Qyae4 **Young Mixed Alluvial and Eolian Deposits (Early Holocene and latest Pleistocene)** – Characteristics similar to unit Qya4, particularly in surface morphology. Shows addition of very fine sand and silt in upper 30 cm of soil profile, suggesting eolian contribution to the original deposit or as illuvial material prior to deposition of inset units Qya1 and Qya2

Qiae1 **Intermediate Age Mixed Alluvial and Eolian Deposits (Late Pleistocene)** – Similar in characteristics to unit Qia1, particularly in surface morphology. Shows addition of very fine sand and silt in upper 30 to 40 cm of soil profile, suggesting eolian contribution to the original deposit or as illuvial material prior to deposition of units Qya1 and Qya2. In the outcrops in the southern Kelso Mountains immediately south of the carbonate breccia landslide 'spurs', unit is approximately 3 m thick and consists of reworked eolian and alluvial sediments consistent with a sand ramp depositional setting

Qiae2 **Intermediate Age Mixed Alluvial and Eolian Deposits (Late Pleistocene)** – Similar in characteristics to unit Qia2, particularly in surface morphology. Shows addition of very fine sand and silt in upper 30–40 cm of soil profile, suggesting eolian contribution to the original deposit or as illuvial material prior to deposition of inset units Qya1 and Qya2

Eolian and mass wasting deposits

Qye **Young Eolian Sand Deposits (Holocene)** – Well-sorted light-brown very fine-grained sand and silt forming sand sheets and dunes. Massive to weakly cross-bedded. Develops sandy coppice dunes around perennial vegetation with dune morphology and volume of sand indicating degree and relative age of eolian influx. Weak to no soil development

Qyc **Colluvial Deposits (Holocene)** – Poorly sorted angular to subangular boulders, cobbles and sand. Talus or rockfall below areas of steep bedrock areas that obscures underlying bedrock. Weak soil development, similar to unit Qya

Older Semi Consolidated Deposits

Tbr **Breccia (Pliocene-Miocene)** – Moderately well cemented breccia containing clasts of granodiorite, cross-bedded quartzite, schist, amphibolite, siltstone, and minor gneiss. Clasts as large as 1 to 5 m in diameter. Age limited by Cretaceous age of youngest clasts, and inferred from localized faulting related to Miocene to possibly Pliocene tectonics

Tfg **Granitoid Fanglomerate (Miocene)** – Unconsolidated boulder gravel and coarse sand alluvial dominated deposits derived largely from local granitic sources. Generally poorly bedded, although lower sections can be well bedded, including cross-beds. Large (1 to 2 m) partially rounded volcanic boulders identified as Peach Springs Tuff give a maximum age of 18.5 Ma (Nielson and others, 1990). Deposits commonly highly colluviated, with bedding exposed in active wash or road cuts. Interfingered with unit Tfgn

Tfgn **Gneissic Fanglomerate (Miocene)** – Unconsolidated boulder gravel and coarse sand alluvial dominated deposits derived from local Proterozoic gneiss. Generally poorly bedded, although lower sections can be well bedded, including cross-beds. Boulders of Chambless Limestone as large as 2 to 3 m also observed. Deposits on hilltop surfaces commonly have well-developed desert pavements, equivalent to a Qia2 surface

Intrusive rocks of Mesozoic and Tertiary age

TKa **Andesite (Tertiary and Cretaceous)** – Porphyritic andesite dikes and small intrusive bodies in Cretaceous granitoids. Fine-grained dark-gray to black aphanitic groundmass with 8 to 10 percent zoned feldspar phenocrysts, generally 5 to 8 mm diameter, but up to 1 to 2 cm. Contains 0 to 1percent biotite

Kgd **Granodiorite (Cretaceous)** – Medium- to coarse-grained subequigranular biotite granodiorite. Biotite in small phenocrysts constitutes approximately 10 to 12 percent rock. Tan to gray plagioclase and potassium feldspar. Jointed at 0.3 to 1 m intervals. Intrudes units KJd and Xgu

Granitoids of the Teutonia Batholith

Ktgd **Biotite Granodiorite (Cretaceous)** – Medium- to coarse-grained porphyritic biotite granodiorite. Biotite phenocrysts in 0.5 to 1 cm booklets comprise approximately 15 percent of rock. Tan to light brown on fresh surfaces, moderate dark brown varnish common. Minor chloritized injection breccia observed at contacts where it intrudes Proterozoic rocks. Intrudes unit Xgu and Zs?

Kte **Equigranular Quartz Monzonite (Cretaceous)** – Equigranular- to subequigranular medium- to coarse-grained biotite quartz monzonite. Approximately 30 percent tan, flesh colored, and occasionally salmon pink colored potassium feldspar crystals up to 3 cm diameter, small 8 to 10 percent biotite crystals, 35 percent tan to milky gray plagioclase, 10 to 15 percent milky quartz. Weathers to light tan color, occasionally to rounded dark brown varnish or rinds, often in very large boulders. Intrudes unit Ktp

Ktp **Porphyritic Quartz Monzonite (Cretaceous)** – Medium- to coarse-grained porphyritic biotite quartz monzonite. Phenocrysts consists of 30 percent potassium feldspar up to 4 cm wide, 10 to 12 percent 1 to 5 mm wide disseminated biotite crystals. Groundmass consists of 35 percent plagioclase, 15 percent 2 to 6 mm milky quartz crystals. Light tan to brown in color, weathers to dark tan to brown, occasionally with dark brown to black weathering rinds

Ktk **Quartz Monzonite of Kelso Peak (Cretaceous)** – Equigranular medium-grained biotite quartz monzonite. Biotite approximately 4 to 8 percent in isolated, small 5 to 10 mm phenocrysts, 30 to 35 percent white to light gray potassium feldspars, very rarely pink colored. 15 percent translucent to milky white quartz crystals and 40 percent light gray to white plagioclase feldspars. White to light tan in color, weathers to grus and occasional 1m high pinnacles and boulders. Unit distinguished from unit Kte by uniform medium grain size, whiter color. Intruded by unit Kte: enclaves of unit Ktk are present in unit Kte along southeastern contacts of the pluton

KJmd **Hornblende Biotite Monzodiorite (Cretaceous and Jurassic)** – Medium-grained equigranular hornblende biotite monzodiorite, approximately 1 to 5 percent hornblende, 25 to 30 percent biotite, 5 to 10 percent milky quartz, 15 percent potassium feldspar, and 40 percent light to dark gray plagioclase feldspar. Salt-and-pepper colored (dark gray with flecks of white crystals) on fresh surfaces, light gray on weathered surfaces. Consists of two phases, which are not individually mapped: a northerly leucocratic phase with less biotite, and a southerly more mafic, or melanocratic, phase

KJd **Diorite (Cretaceous and Jurassic)** – Fine-grained porphyritic biotite-hornblende diorite, dark gray aphanitic groundmass, 1 to 4 percent biotite, 5 to 10 percent hornblende, 8 percent milky white plagioclase phenocrysts. Dark gray on fresh surfaces, light blue-gray on older weathered surfaces, commonly dark-brown to black varnished and pitted on highly weathered surfaces. Commonly intrudes Proterozoic gneiss along foliation creating 30 to 70 cm wide interlayered bands

KJag **Albitized Granite (Cretaceous and Jurassic)** – Medium- to coarse-grained granite with various degrees of alteration of alkali feldspars to albite. In central portions of map unit, albitization is pervasive enough to give the rock an entirely white color. Along margins of map unit, albitization occurs in nearly horizontal bands ranging from centimeters to meters in thickness, and also occurs in irregular patches. Host rock appears to be granitic in composition with 1 to 5 percent biotite content, and occasional large quartz crystals up to 2 cm in length. Pink to light tan in unaltered phases, light gray to cream colored in albitized phases

Paleozoic and Late Proterozoic sedimentary rocks

Cbk **Bonanza King Formation (Late and Middle Cambrian)** – Dark-blue to smoky-gray fine-to medium-grained mottled limestone and dolomite. Brown silty mottling generally less than 1 cm thick, indistinct bedding approximately 10 cm to 2 m. Heavily fractured with white recrystallized calcite in fractures. Rocks closely resemble lower "Member No. 1" of the Bonanza King Formation (Stone and others, 1983), but correlation is difficult based on structural complexity. Thickness indeterminate due to faulting

Carrara Formation (Middle and Early Cambrian) – Divided into:

Ccc **Chambless Limestone (Early Cambrian)** – Light-gray fine-grained limestone containing 10 to 30 percent 2 to 3 cm dark blue gray concentric algal nodules (*Girvenella*). Bedding 1 to 2 meters thick. Heavily fractured with white recrystallized calcite in fractures, typically more fractured in lower sections. Thickness indeterminate due to faulting

Ccl **Latham Shale (Early Cambrian)** – Dark-green to locally brown and red shale, containing sporadic 1 to 3 cm beds of buff fine-grained quartzite. Marker bed at approximately 2 to 3 m below top of unit consists of buff sandy limestone, 0.7 to 1.5 m thick, locally contains shell fragments. Thickness of unit approximately 8 to 15 m

Cz **Zabriskie Quartzite (Early Cambrian)** – Light pink, yellow and white medium- to coarse-grained massive to faintly planar cross-bedded quartzite. Contains vertical 1cm diameter trace fossil burrows (Scolithus), white in color, commonly with a black hematite ring around the outside edge. Bedding 0.4 to 1 m thick. Thickness of unit approximately 18 to 20 m. Contacts with Latham Shale and Wood Canyon Formation are sharp at 1 m scale

CZwc **Wood Canyon Formation, undivided (Early Cambrian and Late Proterozoic)** – Interbedded fine- to medium-grained dark-colored quartzite and fine-grained green shale. Locally divided into:

CZwcu **Upper member (Early Cambrian)** – Fine-grained green shale and silty shale rhythmically interbedded with 0.10 to 0.4 m thick beds of fine-grained quartzite

CZwcm **Middle member (Early Cambrian)** – Fine- to coarse-grained dark-colored quartzite with occasional beds of dark green to black shale. Basal 1 to 3 m consists of distinctive quartz and jasper pebble conglomerate. Above pebble conglomerate is medium to coarse-grained massive quartzite overlain by red-brown trough cross-bedded quartzite

CZwcl **Lower member (Early Cambrian to Late Proterozoic)** – Fine-grained medium- to thick-bedded dark green shale with occasional interbeds of fine-grained quartzite

Zs **Sterling Quartzite (Late Proterozoic)** – Divided into:

Zsu **Upper member** – Dark-gray to black medium-grained poorly sorted quartzite with rare discontinuous lenses of 1cm pebble conglomerate

Zsm **Middle member** – Thin-bedded green-gray shale, poorly exposed in saddles. Approximately 20 m thick

Zsl **Lower member** – Basal reddish to white basal pebble conglomerate grades up to well-sorted white fine-grained quartzite. Weathers to red-brown in color. Approximately 30 m thick

Zj **Johnnie Formation (Late Proterozoic)** – Consists of predominately 3 to 5 m thick beds of fine-grained white, gray, and buff quartzite interbedded with minor 0.2 to 0.5 m thick beds of pebble conglomerate, 1 to 10 cm thick shale, and 0.5 to 0.75 m thick buff dolomite beds. Locations where init is queried consist of thick, heavily fractured massive buff dolomite similar to that in the Johnnie Formation. Outcrops that are stratigraphically displaced from all other units may also be part of the Cambrian Nopah Formation

CZp **Phyllite and Phyllitic Schist (Late Proterozoic and Cambrian?)** – Black and dark-green fine-grained phyllite and phyllitic schist. Structural complexity and metamorphism makes correlations difficult, but may include portions of the Johnnie, Wood Canyon, Nopah, or Cadiz Formations. Thickness indeterminate

CZcb **Carbonate Breccia (Late Proterozoic and Cambrian?)** – Blocks of tan and blue-gray limestone and dolomite, thoroughly brecciated and displaced from stratigraphic context. Thoroughly brecciated and cemented, forms ridge crests and prominent spurs. May include Johnnie Formation, Chambless Limestone, Bonanza King, and possibly portions of the Nopah Formation, Noonday Dolomite, or Pahrump Group

Proterozoic Metamorphic Rocks

Xgg **Granofels (Early Proterozoic)** – Micrograniitic to fine- to medium-grained granofels containing very few mafic minerals. Composition is approximately 45 percent plagioclase, 35 percent potassium feldspar, 20 percent quartz, and 0 to 1 percent biotite. Faint jointing strikes from 250 to 10 degrees, and may indicate localized foliation. Intruded by very coarse-grained pegmatite, fine-grained rhyolitic dikes, and hornblende-biotite granodiorite of indeterminate ages

Xgu **Granitic Gneiss Undivided (Early Proterozoic)** – Medium-grained well-foliated biotite gneiss. Biotite content ranges from 10 to 20 percent. Mafic minerals segregated into needle shaped compositional banding leading to a distinctive weathering pattern, which is informally described as 'tiger striped gneiss'. Intruded by very coarse-grained pegmatite, fine-grained rhyolitic dikes, and hornblende-biotite granodiorite of indeterminate ages

Xgs **Biotite Schist and Biotite Gneiss (Early Proterozoic)** – Medium-grained well-foliated biotite gneiss with biotite content typically greater than 20 percent. Mafic minerals occasionally segregated into needle shaped compositional banding. In one outcrop, biotite has replaced 3 to 7 cm garnet phenocrysts. Biotite schist is common in small outcrops, which contain 15 to 10 percent quartz and 5 to 10 percent feldspars. Intruded by very coarse-grained pegmatite, fine-grained rhyolitic dikes, and hornblende-biotite granodiorite of indeterminate ages

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Section III: Description of the Database

The geologic map database is presented as two ESRI ARC/INFO formatted coverages, which are distributed as ARC export (.e00) files. These files, as coverages represent two layers of a traditional geologic map. The coverage named 'kls-geol' (if naming conventions suggested in this report are used) represents polygon and line features representing map units, and faults and contacts, respectively. The coverage named 'kls-str' (if naming conventions suggested in this report are used) represents structural point measurements (such as bedding, dips of faults, etc) and their associated values (strike, dip). The nature of each feature (e.g. map unit label) is encoded in a database item(s), or field(s). The structure and content of each of the coverages, and their database items are presented below. Users may also consult the included FGDC metadata for more formal treatments of the database specifics.

Converting ARC export files

ARC export (.e00) files typically need to be converted into a format usable by GIS packages. Two common methods of converting ARC export are converted to ARC coverages using the ARC command IMPORT with the option COVER, and by stand-alone conversion applications. A stand-alone conversion application is available from ESRI (http://www.esri.com/), as well as from other places on the Internet. For ARC Workstation users, we have included an ASCII text file in ARC Macro Language that will convert all of the export files in the database into coverages and create the associated INFO directory. With the Workspace set to the directory containing the Arc Export files, from the ARC command line type:

```
Arc: &run import.aml
```

ARC export files can also be read by some other Geographic Information Systems. Please consult your GIS documentation to see if you can use ARC export files and the procedure to import them.

Note: consult the metadata or the Database Specifics section of this Report for details of the format and content of the digital database

Digital Compilation

The map was digitized 'heads-up' in ArcMap (Environmental Systems Research Institute, http://www.esri.com) versions 8.0-8.2. Mapping was primarily done on stereo air photos, and was transferred to GIS using Digital Orthophoto Quadrangles (DOQ's). Extensive use of GPS during field observations aided in determining positions and extents of geologic features during the compilation process.

The following Quality Control measures were taken: Geologic lines attributed as any type of 'contact' we checked so as to not separate geologic map units of the same type. No lines attributed as contacts are 'dangles'. All geologic polygons are attributed with map unit designators found in the original Report.

Base Maps

The base map presented on the geologic map images in this Report is the 1:24000 scale U.S. Geological Survey Digital Raster Graphic (DRG) for the map area. DRGs are available from the U.S. Geological Survey, as well as other data providers, and are not distributed with this Report.

Spatial Resolution

Uses of this digital geologic map should not violate the spatial resolution of the data. Although the digital form of the data removes the constraint imposed by the scale of a paper map, the detail and accuracy inherent in map scale are also present in the digital data. Plotting at scales larger than 1:24,000 will not yield greater real detail, although it may reveal fine-scale irregularities below the intended resolution of the database. Similarly, where this database is used in combination with other data of higher resolution, the resolution of the combined output will be limited by the lower resolution of these data.

Database Specifics

Digital Database Format
The map databases consist of ARC/INFO formatted coverages and supporting INFO files, which are stored in a UTM (Universal Transverse Mercator) projection (Table 1). Digital tics define a 7.5-minute grid of latitude and longitude in the coverages

Projection
Table 1 - *Map Projection*
The maps are stored in UTM projection

PROJECTION UTM	
UNITS METERS	-on the ground
ZONE 11	-UTM zone
DATUM NAD83	
PARAMETERS	

The content of the geologic database can be described in terms of the lines, points, and the areas that compose the map. Descriptions of the database fields use the terms explained in Table 2.

Table 2 - *Field Definition Terms*

ITEM NAME	Name of the database field (item)
WIDTH	Maximum number of digits or characters stored
OUTPUT	Output width
TYPE	B-binary integer, F-binary floating point number, I-ASCII integer, C-ASCII character string
N. DEC.	Number of decimal places maintained for floating point numbers

Lines

The lines (arcs) are recorded as strings of vectors and are described in the arc attribute table (AAT) described in Table 3. They define the boundaries of the map units, faults, and the map boundaries. These distinctions, including the geologic identities of the unit boundaries, are recorded in the LTYPE field according to the line types listed in Table 4.

Table 3 – *Structure of the Arc Attribute Tables*

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	Description
FNODE#	4	5	B		starting node of arc (from node)
TNODE#	4	5	B		ending node of arc (to node)
LPOLY#	4	5	B		polygon ID to the left of the arc
RPOLY#	4	5	B		polygon ID to the right of the arc
LENGTH	4	12	F	3	length of arc in meters
<coverage>#	4	5	B		unique internal control number
<coverage>-ID	4	5	B		unique identification number
LTYPE	35	35	C		geologic line type (see Table 4)

Table 4 - *Line Types Recorded in the LTYPE Field of Arc Attribute Tables for Coverage kls-geol*

contact, approximately located
contact, certain
contact, concealed, queried
contact, eolian gradational
contact, gradational
dike, TKa
fault, approximately located
fault, certain
fault, concealed
fault, concealed, queried
levee
map boundary, certain
normal fault, approximately located
normal fault, certain
normal fault, concealed

Areas

Map units (polygons) are described in the polygon attribute table (PAT) described in Table 5. The identities of the map units are recorded in the PTYPE field by map label, listed in Table 6. A complete Description of Map Units is available in Section II of this report.

Table 5 - *Structure of the Polygon Attribute Tables*

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	Description
AREA	4	12	F	3	area of polygon in map units (meters)
PERIMETER	4	12	F	3	length of perimeter in map units (meters)
<coverage>#	4	5	B		unique internal control number
<coverage>-ID	4	5	B		unique identification number
PTYPE	35	35	C		map unit label

Table 6 - *Map Units Recorded in the PTYPE field of Polygon Attribute Tables (listed by coverage name)*

CZcb	CZwcm	Ccc?
CZp	CZwcu	Ccl
CZwc	Cbk	Cz
CZwcl	Ccc	KJag

KJd
KJmd
Kgd
Kte
Kte+Ktk
Ktgd
Ktk
Ktp
Qia
Qia+Qyae
Qia1
Qia2
Qia2+Qya
Qia2/Qoa
Qiae1
Qiae2
Qiag
Qiag3
Qiag3+Qyag3
Qiag3?
Qya+Qia
Qya1+Qya3
Qya3
Qya3+Qia
Qya3+Qya1
Qya3+Qya2
Qya3+Qya2+Qya1
Qya3+Qya4
Qya3+Qya4+Qya2+Qya1
Qya4
Qya4+Qya3
Qyad
Qyae
Qyae+Qiae
Qyae3+Qya1+Qya2
Qyae3+Qya2+Qya1
Qyae3+Qyae4
Qyae3+Qyae4+Qya2+Qya1
Qyag1+Qyag3
Qyag2
Qyag3
Qyag3+Qiag3
Qyag3+Qiag3+Qyag4
Qyag3+Qyag1
Qyag3+Qyag2
Qyag3+Qyag4
Qyag3/Qia
Qyag3/Qiag
Qyag3/Qyag4
Qyag4
Qyag4+Qiag3+Qyag3
Qyag4+Qyag3
Qyc
Qyc/CZp
Qyc/CZwc
Qyc/Cz?
Qyc/Zj
Qye
Qye/Qia
Qye/Qya
Qye/Qya+Qia
Qye/Qya3
Qye/Qya3+Qya1
Qye/Qyae3+Qyae4+Qya2+Qya1
Qye/Qyag3
Qye/Qyag3+Qyag1
Qye/Qyw
Qyw1
Qyw2+Qyw1
Qyw3
Qyw3+Qyw1
Qyw3+Qyw2
TKa
Tbr
Tfg
Tfgn
Xgg
Xgs
Xgu
Zj
Zj?
Zs?
Zsl
Zsm
Zsu
af

Points
Data gathered at a single locality (points) are described in the point attribute table (PAT) described in Table 7. The identities of the points describing the type of structural measurement taken are recorded in the PTTYPE field. Strike and Dip values of the structural measurement are recorded in the STRIKE AND DIP fields, respectively.

Table 7 – *Structure of the Point Attribute Table for Structural measurements*

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	Description
AREA	4	12	F	3	NA
PERIMETER	4	12	F	3	NA
<coverage>#	4	5	B		unique internal control number
<coverage>-ID	4	5	B		unique identification number
PTTYPE	35	35	C		type of structural measurement
DIP	3	3	I		dip of measurement
STRIKE	3	3	I		strike of measurement (right hand rule)

Table 8 – Content of the PTTYPE field in the Point Attribute Tables for Structural Measurements

bedding
crumpled bedding
fault dip
fold axis
foliation
joint

slickenside
small anticline
small syncline
vertical bedding
vertical foliation