U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division

Death Valley National Park

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for Death Valley National Park

deva_geology.pdf

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Geologic Resources Inventory Map Document for Death Valley National Park

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Geologic Resources Inventory Map Document

Death Valley National Park, California and Nevada

Document to Accompany Digital Geologic-GIS Data

deva_geology.pdf

Version: 9/3/2014

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Death Valley National Park, California and Nevada (DEVA).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

National Park Service (NPS) Geologic Resources Inventory (GRI) Program staff have assembled the digital geologic-GIS data that accompanies this document.

For information about the status of GRI digital geologic-GIS data for a park contact:

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About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the Earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: http://irma.nps.gov/App/Reference/Search. To find GRI data for a specific park or parks select the appropriate park

(s), enter “GRI” as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: http://www.nature.nps.gov/geology/inventory, or contact:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.

GRI Digital Maps and Source Map Citations

The GRI digital geologic-GIS map for Death Valley National Park, California and Nevada (DEVA):

GRI Digital Geologic Map of Death Valley National Park and Vicinity, California and Nevada (*GRI MapCode DEVA*)

Workman, J.B., Menges, C.M., Fridrich, C.J., Thompson, R.A., 2014, Geologic map of Death Valley National Park, California and Nevada: U.S. Geological Survey Scientific Investigations Map SIM-XXXX, unpublished digital data, scale 1:150,000. (*Geologic Map of Death Valley National Park*) (*GRI Source Map ID 75945*).

Additional information pertaining to each source map is also presented in the GRI Source Map Information (DEVAMAP) table included with the GRI geology-GIS data.

Map Unit List

The geologic units present in the digital geologic-GIS data produced for Death Valley National Park, California and Nevada (DEVA) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qay - Young alluvium). Units are listed from youngest to oldest. Information about each geologic unit is also presented in the GRI Geologic Unit Information (DEVAUNIT) table included with the GRI geology-GIS data. Some source unit symbols, names and/or ages may have been changed in this document and in the GRI digital geologic-GIS data. Unit symbols, names and/or ages in unit descriptions, or on a correlation of map units or other source map figure were not edited. If a unit symbol, name or age was changed by the GRI the unit's source map symbol, name and/or age appears with the unit's source map description.

Cenozoic Era

Quaternary and Tertiary Periods

Alluvial Deposits

Qayy - Youngest alluvium along active channels
Qay - Young alluvium
Qayf - Young fine-grained alluvium
Qayo - Intermediate-age alluvium
Qau - Undifferentiated younger alluvium
Qao - Old alluvium
QTau - Undifferentiated alluvium
QTa - Oldest alluvium

Mass Wasting Deposits

QTls - Landslide block

Fine-Grained Deposits

Qp - Playa and (or) salt pan deposits
Qe - Eolian deposits
QTd - Deposits associated with modern or past ground-water discharge
Ql - Old lacustrine deposits
QTp - Old paludal or lacustrine deposits

Volcanic Deposits

QTvmB - Mafic volcanic deposits of the Badwater assemblage
TvsF - Silicic volcanic deposits of the Furnace Creek assemblage
TvmF - Mafic volcanic deposits of the Furnace Creek assemblage
TvsN - Silicic volcanic deposits of the Navadu assemblage
TvsNy - Younger silicic volcanic deposits of the Navadu assemblage
TvsNo - Older silicic volcanic deposits of the Navadu assemblage
TvmN - Mafic volcanic deposits of the Navadu assemblage
TvmNy - Younger mafic volcanic deposits of the Navadu assemblage
TvmNo - Older mafic volcanic deposits of the Navadu assemblage
TvsO - Silicic volcanic deposits of the Owlshead assemblage
TvmO - Mafic volcanic deposits of the Owlshead assemblage

TvsH - Silicic volcanic deposits of the Hells Gate assemblage
TvmH - Mafic volcanic deposits of the Hells Gate assemblage

Intrusive Rocks

TisF - Silicic intrusive rocks of the Furnace Creek assemblage
TimF - Mafic intrusive rocks of the Furnace Creek assemblage
TisN - Silicic intrusive rocks of the Navadu assemblage
TimN - Mafic intrusive rocks of the Navadu assemblage
TisO - Silicic intrusive rocks of the Owlshead assemblage
TimO - Mafic intrusive rocks of the Owlshead assemblage

Tectonic Mélanges

TfxF - Tectonic melange of the Furnace Creek assemblage
TfxN - Tectonic melange of the Navadu assemblage
TfxT - Tectonic melange of the Titus Canyon assemblage

Basin-Fill Deposits

QTs - Post-basin-range sedimentary basin-fill deposits
QTsx - Post-basin-range rock-avalanche breccia deposits
QTsB - Sedimentary basin-fill deposits of the Badwater assemblage
TsF - Sedimentary basin-fill deposits of the Furnace Creek assemblage
TsvF - Sedimentary and volcanic basin-fill deposits of the Furnace Creek assemblage, undifferentiated
TsxF - Rock-avalanche breccia deposits of the Furnace Creek assemblage
TsN - Sedimentary basin-fill deposits of the Navadu assemblage
TsvN - Sedimentary and volcanic basin-fill deposits of the Navadu assemblage, undifferentiated
TsxN - Rock-avalanche breccia deposits of the Navadu assemblage
TsO - Sedimentary basin-fill deposits of the Owlshead assemblage
TsH - Sedimentary basin-fill deposits of the Hells Gate assemblage
TsvH - Sedimentary and volcanic basin-fill deposits of the Hells Gate assemblage, undifferentiated
TsT - Sedimentary basin-fill deposits of the Titus Canyon assemblage
TsxT - Rock-avalanche breccia deposits of the Titus Canyon assemblage

Mesozoic Era

Cretaceous Period

Kis - Younger Mesozoic silicic intrusive rocks

Jurassic Period

Jis - Older Mesozoic silicic intrusive rocks

Jurassic and Triassic Periods

JTRis - Oldest Mesozoic silicic intrusive rocks
JTRsv - Sedimentary and volcanic rocks, undivided

Paleozoic Era

PZu - Paleozoic sedimentary rocks, undivided
PSu - Permian to Silurian sedimentary rocks, undivided

Permian Period

Pov - Owens Valley Group

Permian and Pennsylvanian Periods

PPNb - Bird Spring Formation
PPNkc - Keeler Canyon Formation

Pennsylvanian Period

PNt - Tihvipah Limestone

Mississippian Period

Mu - Mississippian sedimentary rocks, undivided

Devonian Period

Dlb - Lost Burro Formation

Devonian and Silurian Periods

DShv - Hidden Valley Dolomite

Ordovician Period

Oes - Ely Springs Dolomite
Oe - Eureka Quartzite

Ordovician and Cambrian Periods

OCu - Ordovician and Cambrian sedimentary rocks, undivided
OCp - Pogonip Group

Cambrian Period

Cnbc - Nopah, Bonanza King, and Carrara Formations, undivided
Cn - Nopah Formation
Cb - Bonanza King Formation
Cm - Monola Formation
Cc - Carrara Formation
Cms - Mule Spring Limestone
Csv - Saline Valley Formation
Cz - Zabriskie Quartzite
Ch - Harkless Formation
Cpo - Poleta Formation
Ccam - Campito Formation, Montenegro Member

Paleozoic and Proterozoic Eras

Cambrian and Neoproterozoic Periods

CZws - Wood Canyon Formation and Stirling Quartzite, undivided
CZw - Wood Canyon Formation
CZca - Campito Formation, undivided
CZcaa - Campito Formation, Andrews Mountain Member

Proterozoic Era

Neoproterozoic Period

Zd - Deep Spring Formation
Zs - Stirling Quartzite
Zr - Reed Dolomite
Zw - Wyman Formation
Zj - Johnnie Formation
Zn - Noonday Dolomite
Zk - Kingston Peak Formation
Zb - Beck Spring Dolomite
Zh - Horse Thief Spring Formation

Neoproterozoic and Mesoproterozoic Periods

ZYp - Noonday Dolomite and Pahrump Group, undivided

Mesoproterozoic Period

Yc - Crystal Spring Formation

Paleoproterozoic Period

Xmi - Metamorphic and igneous rocks, undifferentiated

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below.

Qayy - Youngest alluvium along active channels (Holocene)

Typically unconsolidated gravel, sand, and (or) silt; generally associated with zones of active to very recent surface flow and deposition. Differetiated only within selected major drainages where appropriate at map scale. No significant weathering or modification of the original depositional surface. May locally include braided channel systems with small inclusions of Qay, Qayf, Qayo, and (or) Qao alluvium. Thickness varies from 0 to 30 m, commonly from 1 to 10 m. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Qay - Young alluvium (latest Pleistocene? to Holocene)

Mostly medium- to coarse-grained alluvium consisting of boulder to pebble gravel and sand, but may locally include fine-grained deposits of sand and silt. Typically unconsolidated to poorly consolidated. Commonly located in the proximal and distal positions of alluvial fans flanking basins, but also may include gravel- and sand-dominated axial drainages and fluvial terraces. Typically has no or weak soil development, no to moderate varnish development on clasts, and no to moderately modified surfaces characterized by prominent to indistinct relict depositional landforms (for example, bar and swale) with at most localized and incipient surface pavement development. Typically low surface relief related mainly to primary depositional features with at most minor dissection, although latter may increase adjacent to incised major drainages. Variable thickness commonly ranging from 0 to 20 m; possibly as much as 30 m adjacent to tectonically active mountain fronts. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Qayf - Young fine-grained alluvium (latest Pleistocene? to Holocene)

Mostly sand and (or) silt, locally with minor pebble gravel. Unconsolidated to poorly consolidated. Mostly associated with alluvial plains along the axial drainages of basin interiors, but may include fine-grained distal fan margins where clearly distinguishable from coarser-grained facies on aerial photography or image maps. Typically gentle surface gradients and minimal local relief. Has soil and surface characteristics similar to unit Qay, with some variation related to topographic position and finer-grained character (for example, minimal bar and swale development and fine-textured soil characteristics). Variable thickness from 0 to 10 m; possibly as much as 30 m in the interiors of tectonically active subsiding basins. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Qayo - Intermediate-age alluvium (latest Pleistocene? to middle Holocene)

Mostly medium- to coarse-grained gravel (boulder to pebble) and sand deposits in proximal and medial basin positions. Poorly consolidated to unconsolidated. Generally has weakly developed soils, weak to moderate varnish development on clasts, and weak to moderate surface modification characterized by no to incipient pavement development with strong to weak relict bar and swale landforms. Local relief similar to that of unit Qay. Unit mapped where sufficiently large older elements of unit Qay may be differentiated on images or aerial photography and (or) are identified in field or on existing maps; otherwise unit is included within Qay. Variable thickness ranges from 0 to 10 m, with possibly as much as 20 m adjacent to tectonically active mountain fronts. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Qau - Undifferentiated younger alluvium (middle Pleistocene to Holocene)

Mainly used to delineate areas with intermixed Qay, Qayf, and (or) Qao deposits, with at most minor inclusions of QTa that cannot be depicted individually at map scale. Generally consists of various alluvial units of recent to middle Pleistocene age that individually comprise from 20% to 80% of area, with at most 5-10% inclusions of unit QTa. Commonly used on piedmonts with complex suites of alluvial deposits, or along drainages with narrow suites of terraces or inset surfaces, within that age range. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Qao - Old alluvium (middle to late Pleistocene)

Typically medium- to coarse-grained gravel (boulder to pebble gravel dominated) and sand deposits in proximal and medial basin positions, but may locally include regions with fine-grained sand and silt at surface in some closed-basin settings. Variable induration but generally moderately consolidated to unconsolidated below potentially cemented well-developed soils. Has moderately to well-developed soils, moderate to strong varnish development on clasts, and moderate- to well-developed surface pavements with no detectable bar-and-swale landforms. Variable local relief, ranging from undissected to well incised, depending on local base-level conditions, but typically with at least some local incision; unit typically contains at least some varnished pavement surfaces preserved on flat to broadly rounded interfluves even where strongly dissected. Thickness of individually mapped units at surface typically from 0 to 30 m, but may increase to 50-100 m along tectonically active range-fronts. Aggregate thickness of all Pleistocene-age alluvial units adjacent to tectonically active range fronts may exceed 500 m in subsurface. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

QTau - Undifferentiated alluvium (latest Tertiary to Holocene)

Mainly used to delineate areas of mixed Qay, Qayf, Qayo, Qao, QTa or QTsf (lithology unknown) units that are too small or too complexly intermingled to depict individually at map scale. Commonly identified where complex suites of deposits of widely mixed ages are located in proximal piedmonts or range-front embayments, interiors of dissected basins, or small narrow intramontane valleys or basins. In contrast to unit Qau, older QTa and QTsf comprise a significant component of unit QTau (commonly >10-20% of unit area). Also used to indicate areas where one or more of the Quaternary or Quaternary and Tertiary deposits listed above are complexly intermingled with dissected tracts of unconsolidated to poorly consolidated Tertiary sediments in patterns too complex or small to discriminate individually at map scale. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

QTa - Oldest alluvium (latest Tertiary to middle Pleistocene)

Generally medium- to coarse-grained gravel (boulder to pebble) and sand. Variable induration, from poorly consolidated beneath cemented surface soils to well cemented throughout. Mostly associated with old dissected fans and (or) gravel-sand dominated basin fill deposits, commonly located at basin margins. Typically has strongly developed or eroded relict soils (usually dominated by variably degraded cemented petrocalcic to petrosalic horizons). Generally strongly incised into ballena (ridge-ravine) topography with little or no preservation of pavements or original surfaces on narrow interfluves. Thickness generally from 0 to 100 m, but may increase to 300 m locally. Generally not preserved at surface on basin side of tectonically active range-front faults. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

QTls - Landslide block (late Tertiary to Holocene)

Generally brecciated but coherent (commonly recemented) bedrock outcrop, typically emplaced above or interstratified within surficial materials or upper basin-fill sediments in basin piedmonts or along range fronts. Thickness variable and poorly determined, as base of slide blocks generally are not exposed and thus basal depths must be estimated mainly from geophysical data. Exposed thicknesses commonly from 10 to 100 m, but may range to more than 500 m in subsurface. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Qp - Playa and (or) salt pan deposits (Holocene)

Variably consolidated mixtures of silt, clay, and fine sand. May contain varying proportions of secondary carbonate, gypsum, and (or) salts in very arid basins. Generally restricted to sites of active deposition in the interior of closed to poorly drained basins. No significant surface modification or soil development, although salt crusts of variable hardness and thickness may develop on surface. Deposit thickness is poorly constrained, but may vary from 1 to 10 m for deposits of this age; commonly underlain by poorly constrained and potentially thicker accumulations of older playa or lacustrine deposits of middle to early Holocene and Pleistocene age. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Qe - Eolian deposits (middle Pleistocene to Holocene)

Generally loose, but locally consolidated sand and silt, with local concentrations of gravel on stabilized surfaces commonly associated with buried paleosols. Typically consists of Holocene sand sheets or dune fields sufficiently thick and continuous to be mapped and (or) large individual dunes. May also locally include large relict late to mid-Pleistocene sand ramp deposits that are banked along the flanks of some ranges and may contain one or more variably developed calcic to petrocalcic relict or buried soils. Generally restricted to areas with sufficient sand accumulation to form discrete eolian landforms. Thickness of most sand sheets and dune fields vary from 0 to 10 m, but deposits in individual large dunes and sand ramps may increase locally from 30 to 200 m (for example, northern Amargosa Desert and southeastern Eureka Valley). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

QTd - Deposits associated with modern or past ground-water discharge (late Tertiary to Holocene)

Typically fine-grained deposits of fine sand, silt, and mud, but may locally include dense crystalline deposits of limestone or travertine. Variably indurated, from unconsolidated to cemented. Generally associated with variable amounts of organic material, phreatophytic or wetland fauna, and (or) secondary precipitates of carbonate or silica commonly derived from ground-water. Commonly consists of fossil deposits (latest Pleistocene or older in age) that formed in paludal to lacustrine environments associated with formerly expanded sites of ground-water paleodischarge that are entirely or largely inactive under current climatic conditions, although unit locally is associated with areas of active seepage or spring discharge. May include older fine-grained (inactive) playa or lacustrine deposits locally. Thickness of unit variable, depending on age range of exposed units. Commonly from 0 to 10 m for exposed deposits, but possibly as much as 100 m or more in subsurface or in some dissected basin interiors (for example, southwestern Pahrump Valley; Page and others, 2005). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Ql - Old lacustrine deposits (middle to late Pleistocene)

Generally fine- to meidum-grained gravel (mostly pebble to cobble, some small boulder) and sand, related primarily to pluvial lakes formed in closed basins such as central Death Valley (Machette, Klinger, and Knott, 2001). May locally include fine-grained sand and silt beds and (or) variably cemented tufa deposits. Generally moderately consolidated to unconsolidated beneath surface soils, except where associated with cemented densely crystalline tufa. Has moderate- to well-developed soils, moderate to strong varnish development on surface clasts, and moderate- to well-developed surface pavements with no detectable bar and swale landforms. Variable local relief, ranging from undissected to deeply dissected, depending on local base-level conditions, but typically with at least some local incision; unit typically contains at least some varnished pavement surfaces preserved on flat to broadly rounded interfluves even where strongly dissected. Unit similar in many respects to unit Qao, but is differentiable based on generally finer gravel texture, better sorting and rounding of coarse fraction, and common association with lacustrine depositional features and landforms (for example, shorelines; spits and bars; forset, backset, or deltaic stratification). Thickness variable, but typically from 0 to 20 m; locally as much as 50 m. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

QTp - Old paludal or lacustrine deposits (late Tertiary to Pleistocene)

Typically fine-grained paludal, lacustrine, or fluvial basin-fill sediments consisting of mixtures of poorly to well stratified silt, clay and fine sand. Variable induration, from unconsolidated to well consolidated. May contain local gravel-dominated channels and interbeds, paleodischarge deposits, interbedded tuffs, and (or) buried soils. Deposits are typically exposed in bluffs, ridges, or badland areas in dissected basin interiors (for example, beds of Lake Tecopa Allogroup of Morrison, 1999) or in uplifted fault blocks (beds of Confidence Hills Formation of Beratan and others, 1999), although unit locally includes fine-grained primarily lacustrine deposits as young as late to middle Pleistocene related to pluvial lakes within enclosed basins (for example, northern Death Valley; Klinger and Sarna-Wojcicki, 2001). Variable thickness from 0 to greater than 100 m in exposed sections. Total thickness in basin subsurface may exceed 300 m. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

QTvmB - Mafic volcanic deposits of the Badwater assemblage (Pliocene to Holocene)

Basalts and much lesser andesite erupted from widely scattered, mostly isolated centers in the Black Mountains and Greenwater Range in the central part of the map area (andesite and basalt member of the Funeral Formation of Drewes [1963]). Fridrich and others (2012) report an Ar/Ar age of 4.5 Ma near Furnace Creek Wash where maximum thickness is about 175 m. Along western side of map area unit includes unrelated deposits of Saline Valley, the Cottonwood Mountains, the Argus Range and the Emigrant pass area of the northern Panamint Range. Andesite and basalt of the Saline Range (2.5–3.5 Ma; Ross, 1970) is more than 300 meters thick. In the Cottonwood Mountains, includes the Tuff of Mesquite Spring (3.2 Ma) and an unnamed basalt (3.7 Ma) at the base of the section (Snow, 1990). Olivine basalt flows conformably overlying basaltic lapilli tuff, scoria, volcanic breccia, and cinder deposits with minor andesitic flows in the northern Argus Range and Darwin Plateau area are of uncertain age, but Hall and MacKevett (1962) indicate that the highest flows may be as young as Pleistocene, although much of the section is likely Pliocene in age. In this area, individual basalt flows vary from 3 to 30 meters thick with a composite thickness of approximately 180 meters with as much as 275 meters of pyroclastic deposits below. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvsF - Silicic volcanic deposits of the Furnace Creek assemblage (Miocene to Pliocene)

Lava flows and related tuffs erupted from volcanic fields active in the Furnace Creek tectonic stage; mainly biotite-rich dacites (5.5–6.5 Ma) of the northern Black Mountains and Greenwater Range in the central part of the map area. Locally these deposits include intercalated basaltic to andesitic lava flows and minor low-silica rhyolite lava flows and tuffs of the central Death Valley volcanic field, and sparse phenocryst-poor rhyolite tuff units (2.9–3.5 Ma), such as the tuff of Mesquite Spring (approximately 3.2 Ma). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvmF - Mafic volcanic deposits of the Furnace Creek assemblage (Miocene to Pliocene)

Basalt and lesser andesite flows and related (co-eruptive) scoria deposits, with ages ranging from approximately 2.9 to 6.5 Ma. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvsN - Silicic volcanic deposits of the Navadu assemblage (Miocene)

Undifferentiated TvsNy and TvsNo. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvsNy - Younger silicic volcanic deposits of the Navadu assemblage (Miocene)

In southern part of map area, consists of Shoshone volcanic sequence, a stack of mainly dacite to rhyolite lavas and related tuff ring deposits of the central Death Valley volcanic field. In northern part of map area, consists of Stonewall Tuff (7.5 Ma) and rhyolite of Sarcobatus Flat (approximately 7.5–9.9 Ma) erupted from the southwest Nevada volcanic field to the northeast of the map area. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvsNo - Older silicic volcanic deposits of the Navadu assemblage (Miocene)

In southern part of map area and as scattered remnants along the eastern flank of the Panamint Mountains, consists of Rhodes Tuff (approximately 10.4 Ma), an early product of the central Death Valley volcanic field. In northern part of map area, unit includes several eruptive units of the southwest Nevada volcanic field, including lavas and tuffs of the rhyolite of Rainbow Mountain (10.7–11.3 Ma), Ammonia Tanks Tuff (11.45 Ma), and Rainier Mesa Tuff (11.6 Ma). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvmN - Mafic volcanic deposits of the Navadu assemblage (Miocene)

Undifferentiated TvmNy and TvmNo. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvmNy - Younger mafic volcanic deposits of the Navadu assemblage (Miocene)

Basaltic flows mainly dating from 7.5 Ma, but ranging from 7–10 Ma. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvmNo - Older mafic volcanic deposits of the Navadu assemblage (Miocene)

In southern part of map area and along the eastern flank of the Panamint Mountains, consists of Sheephead Andesite (approximately 11 Ma), an early product of the central Death Valley volcanic field. In the northern part, consists of several packages of basalt and trachytic andesite flows, ranging in age from about 10.4–11.5 Ma interbedded with older silicic volcanic deposits of the Navadu assemblage (TvsNo). Within Furnace Creek basin and northern Black Mountains, unit is equivalent to basaltic rocks of Artist Drive Formation of McAllister (1970). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvsO - Silicic volcanic deposits of the Owlshead assemblage (Miocene)

Rhyolitic and dacitic lava domes and ash-fall and ash-flow tuffs that are part of the mainly andesitic Owlshead volcanic field in the southwest part of the map area west of southern Death Valley. Luckow and others (2005) report Ar/Ar ages on mostly rhyolite to trachyte and trachyandesite volcanic rocks in the southern Panamint Range, Wingate Wash, and eastern Owlshead Mountains ranging from 13.26–13.94 Ma. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvmO - Mafic volcanic deposits of the Owlshead assemblage (Miocene)

Andesitic and lesser basaltic flows, flow-breccias, and scoria that constitute the major products of the Owlshead volcanic field in the southwest part of the map area with some deposits preserved to the east of Death Valley in the vicinity of the Ibex and Saddle Peak Hills. Luckow and others (2005) report Ar/Ar ages on basalt to trachybasalt and basaltic trachyandesite volcanic rocks in the northern Owlshead Mountains and upper Wingate Wash area ranging from 12.56–12.79 Ma. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvsH - Silicic volcanic deposits of the Hells Gate assemblage (Miocene)

Mapped only in the area of the Titus Canyon paleobasin in the Amargosa Range where the upper part of the section consists mainly of several thick welded ash-flow tuffs of the southwest Nevada volcanic field, including the Tram (13.45 Ma), Bullfrog (13.35 Ma), Topopah Spring (12.8 Ma), and Tiva Canyon (12.7 Ma) Tuffs. Also includes a large complex of dome-flows of the 15.1 Ma rhyolite of Daylight Pass located immediately northeast of Daylight Pass in the Amargosa Range. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TvmH - Mafic volcanic deposits of the Hells Gate assemblage (Miocene)

Andesitic lava flows and associated breccias (approximately 14.0 Ma) that underlie the Lithic Ridge Tuff (13.9 Ma) of the southwest Nevada volcanic field to the northeast of the map area. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TisF - Silicic intrusive rocks of the Furnace Creek assemblage (Miocene to Pliocene)

Small fine-grained granitic to coarse-grained quartz monzonitic stocks exposed near Last Chance Peak at the north most edge of the map area; McKee (1985) reports 7.3–7.9 Ma from K-Ar. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TimF - Mafic intrusive rocks of the Furnace Creek assemblage (Miocene to Pliocene)

Basaltic dikes that are the underpinnings of mafic volcanic rocks of the Furnace Creek assemblage (TvmF). Includes 6.3–7.5 Ma diorite of Last Chance Range (McKee, 1985). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TisN - Silicic intrusive rocks of the Navadu assemblage (Miocene)

Granitic and granodioritic intrusions exposed mainly in the south-central part of the map, including the Little Chief granite (10.6 Ma; McKenna, 1986) of the central Panamint Range and granitic intrusions of the central Black Mountains and Greenwater Range (approximately 9–10 Ma). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TimN - Mafic intrusive rocks of the Navadu assemblage (Miocene)

Mainly consists of the Willow Spring Gabbro (11 Ma) exposed in the central Black Mountains, but also includes minor, widely scattered basaltic and gabbroic dikes within source areas of associated mafic volcanic rocks of the Navadu assemblage (7–12 Ma). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TisO - Silicic intrusive rocks of the Owlshead assemblage (Miocene)

Hypabyssal granitic intrusions exposed across the southern part of the map area. The Granite of Kingston Peak exposed in the Kingston Range at the southeast corner of the map area is approximately 12.1–12.4 Ma (Calzia and others, 2000). Luckow and others (2005) report a minimum age of 13.65 Ma from microgranite in the southern Panamint Range Sugarloaf volcanic center within the suspected primary source area of the Owlshead volcanic field. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TimO - Mafic intrusive rocks of the Owlshead assemblage (Miocene)

Dikes and other small hypabyssal intrusions related to mafic volcanic rocks of the Owlshead volcanic field in the southwestern corner of the map area. Luckow and others (2005) report two ages from basalt dikes in the Radio Tower Range of the Owlshead Mountains at 13.35 and 13.56 Ma. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TfxF - Tectonic melange of the Furnace Creek assemblage (Miocene to Pliocene)

Packages of faulted rocks that are too tectonically distended and faulted to show at map scale other than as a mélange. Associated with faults inferred to have been most active during the time of the Furnace Creek assemblage. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TfxN - Tectonic melange of the Navadu assemblage (Miocene)

Packages of faulted rocks that are too tectonically distended and faulted to show at map scale other than as a mélange. Associated with faults inferred to have been most active during the time of the Navadu assemblage. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TfxT - Tectonic melange of the Titus Canyon assemblage (Eocene to Miocene)

Packages of faulted rocks that are too tectonically distended and faulted to show at map scale other than as a mélange. Present only along the broad damage zone of the Titus Canyon fault system, especially the westernmost very low-angle segment along and south of Titus Canyon. Most sliver fault blocks in this mélange are of Bonaza King (Cb) or Carrara (Cc) Formations or Zabriskie Quartzite (Cz). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

QTs - Post-basin-range sedimentary basin-fill deposits (Pliocene to Pleistocene)

Dominantly desert alluvium conglomerates, gypsum-bearing playa claystones, and playa margin sandstones and siltstones. Base of unit defined as the horizon at which significant faulting and related tilting is buried upsection throughout the vast majority of a basin. The base of this sequence varies from approximately 12 Ma in the easternmost part of the Death Valley region to as young as approximately 2 Ma in the central part of the region, immediately east of central Death Valley. The post-basin-range sequence is absent, by definition, from Death Valley physiographic feature to the eastern front of the Sierra Nevada because basin-range tectonism is ongoing in this western part of the region, where even the Holocene deposits are syn-basin-range. Unit may include deposits as young as early Pleistocene, but is generally restricted to older rocks of dominantly Pliocene age. Quaternary and Quaternary to latest Tertiary surficial deposits are mapped as surficial deposits regardless of whether they are post-basin-range (east of Death Valley) or syn-basin-range (west of Death Valley). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

QTsx - Post-basin-range rock-avalanche breccia deposits (Pliocene to Pleistocene)

Megabreccias with the characteristic features of rock-avalanche deposits, including local lithologic homogeneity and strong internal shattering of megaclasts. May locally include isolated landslide deposits. Unit is defined similarly to post-basin-range sedimentary deposits described above. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

QTsB - Sedimentary basin-fill deposits of the Badwater assemblage (Pliocene to Pleistocene)

Dominantly desert alluvium conglomerates, gypsum-bearing playa claystones, and playa margin sandstones and siltstones deposited within structural basins formed during the late stages of basin-range extension across the map area from present to approximately 4.5 Ma. Well exposed in the southern Funeral Mountains, northern Greenwater Range and northern Black Mountains in the central part of the map area. Thickness is highly variable. Maximum thickness from well log data in Furnace Creek basin is approximately 300 m (Fridrich and others, 2012). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TsF - Sedimentary basin-fill deposits of the Furnace Creek assemblage (Miocene to Pliocene)

Dominantly desert alluvium conglomerates, gypsum-bearing playa claystones, and playa margin sandstones and siltstones deposited within extensional structural basins formed during the Furnace Creek tectonic stage (2.9–7 Ma) of Fridrich and Thompson (2011). Thickness is highly variable. Maximum exposed thickness in Furnace Creek area is approximately 2.2 km (Fridrich and others, 2012). Includes the Furnace Creek Formation of Hunt and Mabey (1966) in the central part of the map

area in the northern Greenwater Range, northern Black Mountains and Furnace Creek drainage. Also preserved in the southern Funeral Mountains, southern Black Mountains northern Cottonwood Mountains, and northern Owlshead Mountains. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TsvF - Sedimentary and volcanic basin-fill deposits of the Furnace Creek assemblage, undifferentiated (Miocene to Pliocene)

Interbedded volcanic and sedimentary rocks mapped in the northern Grapevine Mountains where detailed mapping does not exist and exposure is limited due to extensive mantling by thin, unmapped Quaternary deposits. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TsxF - Rock-avalanche breccia deposits of the Furnace Creek assemblage (Miocene to Pliocene)

Megabreccias with the characteristic features of rock-avalanche deposits, including local lithologic homogeneity and strong internal shattering of megaclasts. Generally interstratified with other sedimentary deposits of the Furnace Creek assemblage of Fridrich and Thompson (2011) or displaying similar degree of tilting as these deposits. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TsN - Sedimentary basin-fill deposits of the Navadu assemblage (Miocene)

Desert alluvium, lacustrine claystones and lesser freshwater limestones, playa margin sandstones and siltstones, and fluvial conglomerates in which larger clasts are generally subangular. Locally contains numerous thin volcanic interbeds. Basin-fill deposits formed throughout the area of basin-range extension during the Navadu tectonic stage (7–12.5 Ma) of Fridrich and Thompson (2011), including deposits broadly distributed over the entire map area. Includes the Navadu Formation of Snow and Lux (1999) in the Cottonwood Mountains, the Artist Drive Formation of McAllister (1970) in the Furnace Creek basin and Black Mountains, China Ranch beds of Mason (1948) within the Alexander, Dumont, and Sperry Hills, and the Military Canyon Formation of Brady and Troxel (1999) in the Avawatz Range in the southern part of the map area. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TsvN - Sedimentary and volcanic basin-fill deposits of the Navadu assemblage, undifferentiated (Miocene)

Interbedded volcanic and sedimentary rocks preserved prominently in the footwall of the northwestern Black Mountains where extremely steep slope angles prevent differentiation at map scale. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TsxN - Rock-avalanche breccia deposits of the Navadu assemblage (Miocene)

Megabreccias with the characteristic features of rock-avalanche deposits, including local lithologic homogeneity and strong internal shattering of megaclasts. Clasts derived from different source rocks in different locales. Generally interstratified with other sedimentary deposits of the Navadu assemblage of Fridrich and Thompson (2011) or displaying similar degree of tilting as these deposits. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TsO - Sedimentary basin-fill deposits of the Owlshead assemblage (Miocene)

Mainly fluvial conglomerates and sandstones, and lacustrine freshwater limestones, siltstones and claystones. Formed during earliest stages of basin-range extension (approximately 11.5–16 Ma), within the Pahrump, Kingston, Wingate Wash, and Opera House detachment basins and the central Death Valley rhombochasm, and related rocks (Fridrich and Thompson, 2011). Deposits are generally faulted and tilted to a much greater degree than overlying deposits of the Navadu assemblage. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TsH - Sedimentary basin-fill deposits of the Hells Gate assemblage (Miocene)

Fluvial conglomerates with large (gravel to cobble) subrounded clasts, and lacustrine claystones and lesser freshwater limestones; late (12–16 Ma), pre-basin-range fill of the Titus Canyon and Ubehebe paleobasins that postdates the 16–19 Ma lacuna of Fridrich and Thompson (2011). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TsvH - Sedimentary and volcanic basin-fill deposits of the Hells Gate assemblage, undifferentiated (Miocene)

Interlayered sedimentary and volcanic deposits of the lower (13.5–16 Ma) part of the Hells Gate section within the Titus Canyon paleobasin along the northeastern side of the Grapevine Mountains, consisting mostly of numerous, thin, mainly rhyolitic volcanic units interbedded with dominantly fine-grained, typically strongly tuffaceous sedimentary rocks such as claystones, siltstones and sandstones. Includes numerous bedded tuffs and thin ash-flow tuffs derived from the southwest Nevada volcanic field just northeast of the map area, including deposits derived from the Tolicha Peak-Sleeping Butte volcanic center (14.1–14.3 Ma). Also includes the rhyolite of Daylight Pass (15.1 Ma), which was erupted from a center located approximately 1 km northeast of Daylight Pass in the Grapevine Mountains. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TsT - Sedimentary basin-fill deposits of the Titus Canyon assemblage (Oligocene? To Miocene)

Fluvial cobble to boulder conglomerates, lacustrine freshwater limestones and claystones, and much lesser basal talus breccias with dark red lateritic clay matrix; deposited primarily as early fill of the Titus Canyon and Ubehebe paleobasins, but also as rare, isolated paleocanyon fills beyond the main paleobasin margins. Unit predates the 16–19 Ma lacuna of Fridrich and Thompson (2011); Stock and Bode (1935) describe lower Oligocene fossils near the base of the section, but Fridrich and Thompson (2011) indicate the presence of possible Eocene (approximately 40 Ma) age fossils within the section; Snow and White (1990) define an Early Miocene to Late Oligocene age in the Ubehebe paleobasin based upon dated tuffs within the section. These rare, interbedded distal tuffs include Monotony Tuff (27 Ma), three tuffs of the Pahranagut Formation (21–24 Ma), and an unidentified tuff dated at approximately 19.8 Ma (Cemen and others, 1999). Cobbles and boulders in fluvial conglomerates are characteristically very well rounded and include granitoid and metavolcanic lithologies from source areas along and outside the western edge of the map area. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

TsxT - Rock-avalanche breccia deposits of the Titus Canyon assemblage (Oligocene? To Miocene)

Megabreccias with the characteristic features of rock-avalanche deposits, including local lithologic homogeneity and extreme internal shattering of megaclasts. Clasts mainly derived from Bonanza King (

Cb) and Carrara (Cc) Formations. Occurs within the Titus Canyon paleobasin in proximity to the Titus Canyon fault system where it is interbedded with other sedimentary deposits of the Titus Canyon assemblage of Fridrich and Thompson (2011). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Kis - Younger Mesozoic silicic intrusive rocks (Cretaceous)

Granite and quartz monzonite intrusions in the Panamint and Owlshead Mountains; includes the granite of Rabbitt Holes Spring in the southeast corner of the map area interpreted by Calzia and Troxel (2002) to be a roof pendant of the Teutonia batholith (93 Ma; Miller and others, 1994) and quartz monzonite of Papoose Flat (83 Ma; Miller, 1996) in the Inyo Mountains just west of the Saline Range in the northwestern part of the map area. Intrusions in the Panamint Mountains include granodiorite of Hall Canyon (66–83 Ma; Labotka, 1985), Skidoo Granite (81 Ma; Lanphere and Dalrymple, 1965), and monzogranite to quartz monzonite of the Manly Peak pluton which may be as old as upper-most Jurassic (142 Ma—Andrew, 2002; 144–151 Ma—Wrucke and others, 2007). Granitic rocks within the Owlshead Mountains are poorly studied and may include undifferentiated silicic to intermediate intrusive rocks of Jurassic or even Triassic age, but includes adamellite pluton (98–103 Ma) of Gastil and others (1967). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Jis - Older Mesozoic silicic intrusive rocks (Jurassic)

Mostly quartz monzonite with local monzodiorite and diorite intrusions along the western part of the map area; includes quartz monzonite in the Sylvania Mountains pluton (155 Ma; McKee, 1968) at the northern-most edge of the map area; quartz monzonite of Joshua Flat (153–184 Ma; McKee and Nash, 1967) and diorite of Marble Canyon (Nelson, 1971) in the southern White Mountains near the northwest corner of the map area; quart monzonite of the Hunter Mountain batholith (175 Ma; Dunne and Walker, 2004) and closely associated intrusive rocks throughout the southern Inyo Mountains, Nelson Range, northern Argus Range, southern Cottonwood Mountains, Ubehebe Peak region, and Hunter Mountain area; diorite intrusions within the Owlshead Mountains (141 Ma minimum cooling age; Guest, 2000) which Pavlis and others (2012) describe as Jurassic; quartz monzodiorite to granodiorite to granite intrusions of the Avawatz Mountains quartz monzodiorite complex of Spencer (1981) underlying most of the Avawatz Mountains, and exposed as fault slices near the Garlock fault and in the Owlshead Mountains along the southern edge of the map area; DeWitt and others (1984) report U/Pb zircon age of 177 Ma from an exposure south of the map area; unit also includes undated granodiorite and granite in the Avawatz and Granite Mountains which intrudes the Avawatz Mountain quartz monzodiorite and is intruded by the Late Jurassic Independence dike swarm. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

JTRis - Oldest Mesozoic silicic intrusive rocks (Triassic to Jurassic)

Medium-grained, equigranular to porphyritic, leucocratic biotite granite exposed at Avawatz Peak which is intruded by the Avawatz Mountain Quartz Monzodiorite and intrudes metavolcanic and metasedimentary rocks of Jurassic to Triassic age (Spencer, 1981). Also includes oldest intrusive rocks in the Cottonwood Mountains; leucosyenite of Dry Bone stock (226 Ma) and White Top stock (228 Ma) mapped by Snow (1990). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

JTRsv - Sedimentary and volcanic rocks, undivided (Jurassic and Triassic)

Exposed in the southern and western parts of the map area including the southern Inyo Mountains, southern Panamint Range (Warm Spring Canyon), and Avawatz Mountains. Interbedded andesitic volcanic rocks frequently metamorphosed by shallow, silicic Mesozoic intrusive rocks. In the southern

Panamint Range, includes the Jurassic Warm Spring Formation composed of mostly andesitic lava flows above minor tuff and massive sandstone bed at base (Wrucke and others, 2007) gradationally overlying the Triassic Butte Valley Formation composed of banded calc-silicate hornfels, silty limestone, and calcareous argillite (Johnson, 1957; Cole, 1986). In Avawatz Mountains, age is poorly constrained and unit includes undifferentiated strongly metamorphosed volcanic and sedimentary rocks widely intruded by small bodies of granitic rock, not mapped separately (Brady, 1986b; Spencer, 1990). Thickness varies considerably, and is poorly studied in many exposures. Greater than 1,600 m thick in southern Panamint Range. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

PZu - Paleozoic sedimentary rocks, undivided (Paleozoic)

Exposed within and along the edges of the Hunter Mountain batholith where altered and isolated exposures cannot easily be identified or differentiated. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

PSu - Permian and Silurian sedimentary rocks, undivided (Silurian to Permian)

Mapped in southern part of map area where isolated exposures of Paleozoic wall rocks or inclusions within Mesozoic intrusive rocks have dramatically altered the parent rocks, or attenuation along the Garlock and associated faults has removed stratigraphic context. In Awawatz Mountains consists of rocks correlative with parts of the Owens Valley Group, Keeler Canyon Formation, Perdido Group, Tin Mountain Limestone, Lost Burro Formation, and Hidden Valley Dolomite from top to bottom. Also mapped in northeastern part of map area within Bullfrog Hills where hydrothermally altered exposures of upper Paleozoic rocks within fault zones are difficult to differentiate and include units not present in other parts of the map as described by Slate and others (1999) to the northeast on the Nevada Test Site. Up to 2,370 m thick. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Pov - Owens Valley Group (Lower Permian)

Exposed in the Dry Mountain area, Cottonwood Mountains, Darwin Plateau, and Panamint Range. In the Dry Mountain area, unit consists of the Lone Pine Formation, composed of thin-bedded calcareous mudstone, shale, and siltstone. Exposures in the Cottonwood Mountains and Panamint Range consist of the Darwin Canyon Formation, composed of well-bedded very fine grained sandstone, calc-arenite sandstone, and subordinate calc-arenitic, bioclastic limestone, and limestone conglomerate underlain by the Osborne Canyon Formation, composed of calcareous mudstone, bioclastic limestone, limestone conglomerate, and subordinate calcareous siltstone (Burchfiel, 1969; Stone, 1984; Stone and Stevens, 1987; Stone and others, 1987; Wrucke and others, 2007). The Osborne Canyon Formation and underlying Tihvipah Limestone have been incorrectly mapped as the Keeler Canyon Formation by Streitz and Stinson (1974) within the map area (Stone and others, 1987). Hall (1971) reported 730 m of unit exposed in Panamint Butte area but Stone (1984) remapped much of this unit as Bird Spring Formation. Burchfiel (1969) reported 180 m of the unit in the Dry Mountain area. Wrucke and others (2007) report approximately 650 m in the southern Panamint Range. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

PPNb - Bird Spring Formation (Lower Permian and Pennsylvanian)

Exposed in eastern part of the map area in the northern Nopah Range and in the central part of the map area in the Cottonwood Mountains and Panamint Range. Bird Spring Formation consists of limestone, silty limestone, dolomite, chert, quartzite, siltstone, and shale. Common layers and nodules of brown-weathering chert. Contains abundant macrofossils including brachiopods, ostracods, colonial and solitary corals, bryozoans, sponges, pelmatozoan fragments, and fusulinids. Burchfiel and others (1982)

report a partial thickness of 336 m in the northern Nopah Range where the top of the unit is not preserved. Wrucke and others (2007) report a maximum thickness of 525 m in the Warm Spring Canyon area in the southern Panamint Range. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

PPNkc - Keeler Canyon Formation (Middle Pennsylvanian to Lower Permian)

Exposed in the Dry Mountain area, southern Inyo Mountains, and Cottonwood Mountains. Time equivalent to the Bird Spring Formation mapped to the east. Lower part of mapped unit may be equivalent to Tihvipah Limestone as described below (Stone and others, 1987). Composed of silty, bioclastic limestone and siltstone and a basal micritic limestone with abundant chert nodules; fossils include fusulinids, pelmatozoans, bryozoans, and brachiopods. Unit is differentiated from the partly age-equivalent Bird Spring Formation by an abundance of turbidite facies. Conformably overlain by the Lone Pine Formation of the Owens Valley Group and conformably underlain by the Rest Spring Shale. (Ross, 1967; Streitz and Stinson, 1974; Stone and Stevens, 1987). Unit 1,164 m thick in Dry Mountain area (Burchfiel, 1969). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

PNt - Tihvipah Limestone (Lower to Middle Pennsylvanian)

Exposed in the west central part of the map area in the northern Argus Range and northern Cottonwood Mountains. Probable equivalent to the lower part of the Bird Spring Formation in the southern Cottonwood Mountains and lower part of the Keeler Canyon Formation in the southern Inyo Mountains as mapped (Stone and others, 1987), but only used where clearly differentiated on previous mapping. Consists of micritic limestone with interbedded thin, lenticular chert beds, silty and shaly limestone beds, and abundant, diagnostic, “golf-ball” chert nodules. Basal pebble conglomerate above unconformable contact with underlying Mississippian rocks (Snow, 1990). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Mu - Mississippian sedimentary rocks, undivided (Upper and Lower Mississippian)

Exposed throughout the northern and central parts of the map area. Revised stratigraphy of Stevens and others (1996) describes three separate facies belts across the area. Exposures in the northern parts of the map area (northern Last Chance Range, southern Inyo Mountains, northern Saline Range, and northern Grapevine Mountains) are within the northwestern-facies belt. This facies is more siliciclastic and includes the Rest Spring Shale and underlying Kearsarge Formation (previously mapped as Perdido Formation by Nelson [1971], McKee [1985], and Wrucke and Corbett [1990]). Exposures in west-central parts of map area (southern Last Chance Range, southern Saline Range, Dry Mountain, northwestern Cottonwood Mountains, southeastern Inyo Range, and southern Funeral Mountains) are within the central-facies belt. This facies is transitional between siliciclastic and carbonate assemblages and includes the Rest Spring Shale, underlying Perdido Group of Stevens and others (1996) (former Perdido Formation of McAllister [1952]), and Tin Mountain Limestone. Exposures in the central and eastern part of the map area (southeastern Cottonwood Mountains, northern Argus Range, Panamint Butte, Panamint Range, Nopah Range, and Montgomery Mountains) are within the southeastern-facies belt. This facies is dominantly carbonate and includes the Indian Springs Formation and either the underlying Monte Cristo Group of Nevada or equivalent Santa Rosa Hills Limestone and Perdido Formation limestone facies of southeastern California.

Rest Spring Shale of the northwestern-facies is thin-bedded black siltstone, shale, and mudstone, with minor, dark-gray limestone. The Kearsarge Formation is a heterogeneous sequence of thin-bedded limestone, chert, brown sandstone, siltstone, black shale, and a basal limestone and chert pebble

conglomerate. Rest Spring Shale of the central-facies is olive-gray shale containing distinctive concretions near the base with thin-bedded siltstones and sandstones near middle and minor limestone beds near top. Stevens and others (1996) redefine the Perdido Group as containing the Mexican Spring Formation composed of mostly siltstone strongly bioturbated (grazing trails parallel to bedding) with turbidite beds of graded bioclasts (brachiopods, gastropods, foraminifera) and conglomerate and the underlying Leaning Rock Formation composed of thin-bedded, micritic, argillaceous limestone, and minor mudstone and conglomerate. Tin Mountain Limestone is composed of cherty and bioclastic (horn corals and crinoids) limestone with distinctive pale-red to purple argillaceous partings. Indian Springs Formation consists of interbedded gray to yellowish-brown bioclastic limestone, shale, and quartzite. Monte Cristo Group consists of bioclastic limestone and minor dolomite and chert beds divided into (from top to bottom) Yellowpine Limestone, Bullion Limestone, Anchor Limestone, and Dawn Limestone. Yellowpine Limestone contains unusually large solitary rugose corals, Lithostrotionella colonial corals, and pelmatozoan ossicles, Bullion Limestone contains encrinitic limestone (grainstone to wackestone), Anchor Limestone consists of alternating thin-bedded limestone and chert beds, and Dawn Limestone is abundantly fossiliferous limestone with common dark-brown-weathering chert beds. The Santa Rosa Hills Limestone consists of gray, coarse-grained limestone with abundant pelmatozoan fragments and minor chert nodules. The Perdido Formation limestone facies consists of gray, fine-grained limestone interstratified with reddish-brown bedded and nodular chert layers.

Unit is more than 250 m thick in the Last Chance Range where it is highly faulted (McKee, 1985), 400 m thick in the Dry Mountain area of the Cottonwood Mountains (Burchfiel, 1969), about 140 m thick in the Panamint Butte area (Hall, 1971), as much as 420 m thick in the Warm Spring area in the Panamint Range (Wrucke and others, 2007), and 300 to 480 m thick in the Nopah Range and Montgomery Mountains (Burchfiel and others, 1982; Page and others, 2005). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Dlb - Lost Burro Formation (Upper and Middle Devonian)

Exposed throughout map area. Uppermost 10 m of unit includes calcareous, laminated to thin-bedded sandstone and sandy dolomite (Quartz Spring Sandstone Member). Remainder of unit consists of dolomite and limestone, sandy dolomite, quartzite and sandstone beds; dolomite and limestone beds contain Amphipora sp. and silicified stromatoporoids. Includes quartzitic basal Lippincott Member. Equivalent to Devils Gate Limestone and Nevada Formation as previously mapped in Last Chance Range of Nevada and northern Nopah Range (Zenger and Pearson, 1968). Unit about 500 m thick in the Dry Mountain area (Burchfiel, 1969) and 457 m thick in the Panamint Range (Hall, 1971). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

DShv - Hidden Valley Dolomite (Lower Devonian and Silurian)

Mapped in the Cottonwood Mountains, Panamint Mountains, Funeral Mountains, Nopah Range, and Montgomery Mountains. Consists mostly of massive dolomite, but includes minor quartzite beds and brown-weathering chert at base in the Panamint Range area (Hall, 1971). Generally lacks macrofossils but age equivalent with parts of the Sevy and Laketown Dolomites based on fossils collected by McAllister (1952). Contact with underlying Ely Springs Dolomite is gradational. Unit is 440-460 m thick in southeastern Funeral Mountains (McAllister, 1974) and in the Dry Mountain area (Burchfiel, 1969), about 120 m thick in Panamint Range, and about 100 m thick in the Nopah Range (Burchfiel and others, 1982). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Oes - Ely Springs Dolomite (Upper Ordovician)

Widely exposed in map area. Upper 20-25 m consists of slope-forming, finely crystalline dolomite with sparse pelmatozoan fragments. Most of the Ely Springs (lower two thirds to three quarters) is cliff-

forming, burrow-mottled, irregularly thin- to thick-bedded dolomite with common planar laminations; includes nodules and lenses of dark-gray to dark-brown chert. Fossils include brachiopods, colonial (Halysites sp. and favositids) and solitary corals, gastropods, pelmatozoan ossicles, and stromatoporoids. Lower contact with Eureka Quartzite is disconformity; upper contact with Hidden Valley Dolomite is gradational and conformable (Hall, 1971). Unit is 50-200 m thick. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Oe - Eureka Quartzite (Upper and Middle Ordovician)

Widely exposed in map area. Consists of fine- to medium-grained orthoquartzite and sandstone. Beds contain tabular-planar and trough crossbed sets and Skolithos burrows. At some locations, unit has sandy carbonate beds and collophane nodules (Ross, 1964); in Panamint Mountains, lower part contains silty and sandy dolomite, argillaceous quartzite, and minor shale. Unit is 6-150 m thick. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

OCu - Ordovician and Cambrian sedimentary rocks, undivided (Ordovician and Upper Cambrian)

Mapped in the southern Cottonwood Mountains north of Panamint Butte by Hall (1971) where alteration of the thick dolomite-rich section along the southern edge of the Hunter Mountain batholith prevents differentiation of individual units. Possibly includes parts of the Ely Springs Dolomite, Eureka Quartzite, Pogonip Group, and the Nopah and Bonanza King Formations. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

OCp - Pogonip Group (Middle and Lower Ordovician and Upper Cambrian)

Widely exposed across map area. Consists of (from top to base) the Antelope Valley Limestone, Ninemile Formation, and the Goodwin Limestone (Ross, 1964). Antelope Valley Limestone is finely to coarsely crystalline limestone and silty limestone; beds are commonly burrowed and have yellowish-orange to pale-red tracks and trails on bedding planes; contains orthocone cephalopods, gastropods (Maclurites sp. and Palliseria sp.), pelmatozoans, Receptaculites sp., and trilobites; also contains ooids and oncoids. Ninemile Formation is shaly siltstone, silty limestone, and dolomite. Goodwin Limestone is limestone and dolomite with dark-brown-weathering chert layers and distinctive intraclastic conglomerate; contains trilobite and brachiopod fragments and sparse ooids. Base of Goodwin contains Late Cambrian conodonts in the Spring Mountains east of the map area (Page and others, 2005). Group is about 410 m thick in the Dry Mountain area (Burchfiel, 1969), 384 m thick in the Panamint Range (Hall, 1971), 670 m thick in the Funeral Mountains (Fridrich and others, 2012), and 320 m thick in Nopah Range (Burchfiel and others, 1982). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Cnbc - Nopah, Bonanza King, and Carrara Formations, undivided (Upper, Middle, and Lower Cambrian)

Mapped in the Kingston Range at southeast corner of map area. Undivided Cn, Cb, and Cc. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Cn - Nopah Formation (Upper Cambrian)

Widely exposed across map area. In central part of the map area unit includes, from top to base, Smoky, Halfpint, and Dunderberg Shale Members. Smoky and Halfpint Members consist of alternating

light- to dark-gray cliff-forming dolomite that gives these rocks a banded appearance; members contain common stromatolites, oncoids, and brachiopod fragments, and less common pelmatozoan fragments. Dunderberg Shale Member consists of thin-bedded silty limestone, shale, and some siltstone; Dunderbergia sp. trilobite fragments are common. Formation is 365 m thick in the northern Last Chance Range (McKee, 1985), 457 m thick in the Panamint Range area (Hall, 1971), 520 m thick in the Funeral Mountains (Fridrich and others, 2012), and about 530 m thick in the Nopah Range and in the Cottonwood Mountains (Burchfiel and others, 1982; Burchfiel, 1969). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Cb - Bonanza King Formation (Upper and Middle Cambrian)

Banded Mountain and Papoose Lake Members recognizable in most parts of the map area. Banded Mountain Member is fine- to medium crystalline dolomite and limestone; alternating light- to dark-gray colors of beds give the member a distinctive banded appearance. Orange burrow mottling is prevalent, and several layers have dark-brown-weathering chert beds and nodules. Base of the member is marked by the regionally extensive “silty unit” (Barnes and Palmer, 1961). The underlying Papoose Lake Member is dolomite with distinctive orange burrow mottles; sparse limestone and silty dolomite beds. Formation is about 1,000 m thick in the Dry Mountain area (Burchfiel, 1969), 1,150-1,350 m thick in the Montgomery Mountains and Nopah Range, respectively (Burchfiel and others, 1982), up to 1,100 m thick in the Funeral Mountains (Fridrich and others, 2012), and about 610 m thick in the northern Last Chance Range of California (McKee, 1985). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Cm - Monola Formation (Middle Cambrian)

Interbedded limestone, silty limestone, siltstone, and shale. Upper part is mostly limestone with minor siltstone and shale interbedded, and lower part is mostly shale and siltstone with minor limestone interbedded. Unit occurs in northwestern part of map area (McKee and Nelson, 1967; Nelson, 1971) where named by Nelson (1962); transitional assemblage of Stewart (1980); time equivalent to upper part of Carrara Formation to southeast (Nelson, 1962) and the lithologically different Emigrant Formation in Esmeralda County, Nevada (Stewart, 1970); conformably overlain by Bonanza King Formation and conformably overlies Mule Spring Limestone. No thickness reported (Nelson, 1971). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Cc - Carrara Formation (Middle and Lower Cambrian)

Interbedded limestone, silty limestone, siltstone, sandstone, and shale. Eastern assemblage of Stewart (1980); equivalent to the lower part of the Monola Formation, Mule Spring Limestone, and upper Saline Valley Formation (Stewart, 1970). Upper part is mostly cliff-forming silty limestone, and lower part contains mostly clastic rocks. Limestone beds contain ooids, oncoids, and stromatolites. Contact with overlying Bonanza King Formation is commonly marked by a change from slope-forming limestone of the Carrara to more massive cliff-forming limestone and dolomite of the Bonanza King Formation. Unit is 420 m thick in the Montgomery Mountains (Burchfiel and others, 1982) and 490 m thick in the Funeral Mountains (Fridrich and others, 2012). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Cms - Mule Spring Limestone (Lower Cambrian)

Exposed in northwest part of map area where named by Nelson (1962). Thin- to medium-bedded, aphanitic to finely-crystalline limestone with trilobite fragments; thicker beds have oncoids; calcareous siltstone and silty limestone are in lower part. Transitional assemblage of Stewart (1980); limestone

beds in lower Carrara Formation separated by clastic intervals coalesce towards the northwest across map area to become the carbonate dominated laterally equivalent Mule Spring Limestone (Stewart, 1970). Total thickness estimated at 120-150 m (Albers and Stewart, 1972). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Csv - Saline Valley Formation (Lower Cambrian)

Exposed in northwest part of map area where named by Nelson (1962). Laterally variable quartzite, siltstone, and minor limestone with abundant trilobites. Transitional assemblage of Stewart (1980); equivalent to lower-most Carrara Formation and upper Zabriske Quartzite (Stewart, 1970). Conformable with overlying Mule Spring Limestone and underlying Harkless Formation. Heterogeous lithology of the Saline Valley Formation distinguishes unit from overlying carbonate dominated Mule Spring Limestone and underlying detrital rich Harkless Formation; about 250 m thick at type locality (Nelson, 1962). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Cz - Zabriskie Quartzite (Lower Cambrian)

Laminated to thick-bedded orthoquartzite, commonly cross-bedded and well-cemented; has skolithos. Eastern assemblage of Stewart (1980); crops out as prominent cliff forming unit or as distinctive hogbacks throughout the area of exposure; equivalent to the lower Saline Valley Formation and the upper part of the Harkless Formation (Stewart, 1970). Unit is 70 m thick in the Montgomery Mountains (Burchfiel and others, 1982), 250 m thick in the Funeral Mountains (Fridrich and others, 2012), and 106 m thick in the Dry Mountain area (Burchfiel, 1969). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Ch - Harkless Formation (Lower Cambrian)

Exposed in northern part of map where named by Nelson (1962). Upper member contains interbedded siliceous siltstone and shale. Lower member contains interbedded sandstone, siltstone and thin-bedded limestone. Unit contains Olenellid trilobites and archaeocyathids, especially in lower member. Transitional assemblage of Stewart (1980); upper member is equivalent to middle and lower Zabriskie Quartzite and lower member is equivalent to top of Wood Canyon Formation (Stewart, 1970). Conformable with overlying Mule Spring Formation and underlying, carbonate-rich Poleta Formation; about 760-1,066 m thick (Albers and Stewart, 1972; McKee, 1985). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Cpo - Poleta Formation (Lower Cambrian)

Exposed in the north part of the map area where named by Nelson (1962). Three informal members are recognized. Upper member is thin-bedded limestone with some poorly preserved archaeocyathids. Middle member is closely interlayered siltstone, shale, phyllitic siltstone, limestone, and sandstone or quartzite with abundant trilobites in the lower half of the member. Lowest member contains oolitic limestone and abundant archaeocyanthids. Olenellid trilobites common in siltstone, and archaeocyanthids in limestone. Transitional assemblage of Stewart (1980); equivalent to carbonates within the upper member of the Wood Canyon Formation (Stewart, 1970). Contact with overlying Harkless Formation is sharp but conformable. Unit is greater than 600 m thick (McKee, 1985). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Ccam - Campito Formation, Montenegro Member (Lower Cambrian)

Siltstone, shale, and sandstone. Olenellid trilobites and archaeocyathids are rare in the shaly units. Unit is 315 m thick (Albers and Stewart, 1972). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

CZws - Wood Canyon Formation and Stirling Quartzite, undivided (Lower Cambrian and Neoproterozoic)

Shown in various areas across map where units not mapped separately. Undivided CZw and Zs. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

CZw - Wood Canyon Formation (Lower Cambrian and Neoproterozoic)

Quartzite, sandstone, siltstone, shale, and dolomite. Shaly and silty units increase in abundance in the upper part of the formation and formation thickens significantly to the west across the map area. Eastern assemblage of Stewart (1980); equivalent to the lower Harkless Formation, and Poleta, Campito, and Deep Spring Formations (Stewart, 1970). Consists of three recognizable informal members. Upper and lower members consist of interbedded quartzite, micaceous siltstone, and minor silty dolomite which generally for slopes, particularly in contrast to the resistant overlying Zabriske Quartzite and underlying Stirling Quartzite. Middle member is generally more resistant and consists of interbedded quartzite and siltstone, with minor distinctive arkosic conglomerate. Unit is locally metamorphosed to subgreenschist and lower greenschist facies in Funeral Mountains (Slate and others, 2000). Unit is about 1,200 m thick in the Funeral Mountains (Fridrich and others, 2012), 788 m thick in the Panamint Mountains (Hunt and Mabey, 1966), about 600 m thick in the Montgomery Mountains (Burchfiel and others, 1982), and 640-820 m thick in the northwest Spring Mountains (Vincellette, 1964). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

CZca - Campito Formation, undivided (Lower Cambrian and Neoproterozoic)

Exposed in the northern part of the map area. Composed of very fine to fine-grained quartzite and siltstone; transitional assemblage of Stewart (1980); equivalent to the middle member of the Wood Canyon Formation and parts of the upper and lower members (Stewart, 1970). Divided into upper Montenegro and lower Andrews Mountain Members by Nelson (1962) with a transitional contact. Transitional sequence is mapped as part of the lower member. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

CZcaa - Campito Formation, Andrews Mountain Member (Lower Cambrian and Neoproterozoic)

Thin-bedded quartzite and sparse beds of greenish shale. Sandstone is cross-bedded, and has ripple marks and worm trails. Contains the lowest occurrence of trilobite fossils within the transitional assemblage which is inferred to mark the base of the Cambrian. About 910 m thick (McKee, 1985). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Zd - Deep Spring Formation (Neoproterozoic)

Exposed in northwest part of the map area where Nelson (1962) recognizes upper, middle, and lower informal members. Transitional assemblage of Stewart (1980); equivalent to the lower member of the Wood Canyon Formation which is lithologically very similar, particularly the three distinctive bands of

dolomite (Stewart, 1970). Upper member contains siltstone and fine-grained quartzite in the lower part, and prominent dolomite in the upper part. Middle member contains quartzite, sandstone, oolitic-limestone, and minor siltstone and dolomite; upper quarter of member predominantly limestone with clastic rocks dominating below. Lower member contains limestone and dolomite, with minor siltstone, calcareous sandstone, and quartzite; prominent dolomite beds similar to underlying Reed Dolomite occur at the top and base of lower member. Unit conformable with overlying Campito Formation; transitional contact with underlying Reed Dolomite (Nelson, 1962). Link (1993) assigns a Cambrian age to the unit farther to the east, but the lack of trilobites supports the older Neoproterozoic age. About 487-548 m thick (Albers and Stewart, 1972; McKee, 1985). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Zs - Stirling Quartzite (Neoproterozoic)

Quartzite and sandstone, conglomeratic quartzite, and minor beds of micaceous siltstone. Quartz grains are usually fine- to medium-grained. A 20 m thick white quartzite marks the base of the unit just east of the map area (Page and others, 2005). Locally metamorphosed to sub-greenschist and lower greenschist facies in Funeral Mountains (Slate and others, 2000). Eastern assemblage of Stewart (1980); equivalent to the more carbonate rich Reed Dolomite of the transitional assemblage (Stewart, 1970). Five members of regional extent are recognized across the map area, but are not divided here. Unit forms massive cliffs and is 1,100 m thick in the Montgomery Mountains (Burchfiel and others, 1982), 2,100 m thick in the Funeral Mountains (Wright and Troxel, 1993), over 460 m thick in Panamint Range (Hunt and Mabey, 1966). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Zr - Reed Dolomite (Neoproterozoic)

Exposed only in northwest part of map area. The Reed Dolomite contains medium to coarsely crystalline dolomite, sandy dolomite, and minor amounts of limestone, siltstone, and quartzite; contains ooids and locally is pelletal. Unit is mostly homogeneous massive dolomite, but the Hines Toungue of Nelson (1962) consists of carbonaceous sandstone, quartzite, and siltstone of variable thickness through much of the White and Inyo Mountains, occurring at various levels within the dolomite. Transitional assemblage of Stewart (1980); equivalent to upper part of Stirling Quartzite of eastern assemblage but correlation is poorly constrained (Stewart, 1970); Hines Tougue may be equivalent to the uppermost E member of Stirling. Reed Dolomite is greater than 457 m thick (Albers and Stewart, 1972). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Zw - Wyman Formation (Neoproterozoic)

Exposed in the northwest part of map area. Unit contains phyllitic siltstone, limestone, sandy limestone, and calcareous sandstone. Transitional assemblage of Stewart (1980); fine-grained equivalent to Johnnie Formation. Moderately metamorphosed in all exposures; includes phylite, schist, marble, calc-silicate, and siliceous hornfels. Maximum exposed thickness of the Wyman Formation is 400 m, but the base is not exposed anywhere (Albers and Stewart, 1972). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Zj - Johnnie Formation (Neoproterozoic)

Exposed in the Nopah Range, Resting Spring Range, Montgomery Mountains, Funeral Mountains, Panamint Mountains, and along the Black Mountains where it is generally dramatically attenuated by low-angle normal faults. Unit contains quartzite, conglomeratic quartzite, siltstone, shale, and minor limestone and dolomite beds. Upper part contains Rainstorm Member (Stewart, 1974), which can be

traced regionally across parts of southern Nevada and southeastern California. Rainstorm Member contains mixed clastic and carbonate units and the "Johnnie oolite," a distinctive ooid-bearing dolomite unit in lower part of member. Eastern assemblage of Stewart (1980); equivalent to Wyman Formation; basal contact is unconformity which cuts down section to the northwest removing the underlying Noonday Dolomite across the map area and the entire Pahrump Group in the northern part of the map area. Formation is estimated at 2,000 m thick in the Funeral Mountains (Wright and Troxel, 1993), and 1,220 m thick in Panamint Range (Hunt and Mabey, 1966). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Zn - Noonday Dolomite (Neoproterozoic)

Pink to brownish-yellow to grey dolomite and dolomitic limestone. Contains stromatalites and anomalous tubular structures (Cloud and others, 1974; Corsetti and Grotzinger, 2005) and crystal fans (Corsetti and others, 2004). Upper part contains cross-bedded sandy zones and is coarser-grained than more massive and resistant lower part as described in the southeastern part of the map area (Hazzard, 1937; Wright, 1973; Wright and Troxel, 1984). Petterson and others (2011) redefine unit stratigraphy to include three formal members which include from top to bottom, Mahogany Flats, Radcliff, and Sentinel Peak Members with the later subdivided into two lateral facies, the Ibex Facies, equivalent to the siliciclastic Ibex Formation of Troxel (1982), and the carbonate-dominated Nopah Facies. Unit sits in slight angular unconformity with underlying Kingston Peak Formation. Variable thickness pinching out to the north near the center of the map area. Wright (1973) reports as much as 700 m thick in southern Nopah Range, Mahon (2012) reports as much as 200 m thick in Saddle Peak Hills, and Hunt and Mabey (1966) report 240 m thick in the southern Panamint Range and 305 m thick in the Tucki Mountain area. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Zk - Kingston Peak Formation (Neoproterozoic)

Exposed across the south and central parts of the map area. Unit consists of a thick sequence of dominantly coarse-grained, siliciclastic sediments of variable thickness with minor carbonate beds and extrusive basaltic rocks in the lower part of the unit within the Panamint Range. Diamictite deposits are prominent and along with isolated dropstones and striated and faceted clasts suggest a glacial origin for parts of the unit (Petterson and others, 2011; Corsetti and Kaufman, 2003; Miller, 1985). Exposures in the Panamint Range are the best exposed and most studied within the map area where the unit can be subdivided, from top to bottom, into the formal South Park, Sourdough Limestone, Surprise, and Limekiln Spring Members (Albee and others, 1981; Miller, 1985). The South Park Member is subdivided into the Wildrose, Thorndike, Mountain Girl, and Middle Park sub-members. Exposures in the southeastern part of the map area differ slightly from those in the Panamint Range with coarser sediments derived from the underlying units of the Pahrump Group and subdivisions and correlations within the unit are quite variable between different authors (Mahon, 2012; Macdonald and others, 2013; Mrofka and Kennedy, 2011; Troxel, 1967; Wright, 1973; Wright and Troxel, 1966). Exposures in the Funeral Mountains are not well studied and metamorphosed up to amphibolite grade (Wright and Troxel, 1993). Mahon (2012) reports up to 1,400 m thick in the Saddle Peak Hills in southern Death Valley; Troxel reports an aggregate thickness of 1,100 m in the Salt Spring Hills of southern Death Valley; Miller (1985) reports as thick as 750 m in the Manly Peak area of the southern Panamints and increasing northward to as thick as 1,200 m in the central Panamint Range; Albee and others (1981) describe an aggregate maximum thickness of nearly 1,800 m in the central Panamint Range; Wright and Troxel (1993) report approximately 700 m thick in the Funeral Mountains. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Zb - Beck Spring Dolomite (Neoproterozoic)

Blue gray to tan massive to finely laminated siliceous dolomite to dolomitic mudstone with locally abundant conglomerate, sandstone, and siltstone beds. Algal and stromatolitic structures locally present in dolomitic beds. Metamorphosed to tremolite-dolomite marble in northern Panamint Range and northern Funeral Mountains. Absent in parts of the southern Panamint Range where possibly faulted out by low angle normal faults or missing along disconformity between Noonday Dolomite and/or Kingston Peak Formation and underlying Crystal Springs Formation. Thickness varies from 365 m in the Alexander Hills near the southern Nopah Range (Wright, 1973) to as thin as 200 m in the central Panamint Range (Albee and others, 1981) and 70 m thick in the northern Funeral Mountains (Wright and Troxel, 1993). Pinches out in northern part of map area. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Zh - Horse Thief Spring Formation (Neoproterozoic)

Previously mapped as upper member of Crystal Spring Formation of Hewett (1940) and redefined by Mahon (2012) based upon mapped regional unconformity at base of unit and distinct change in detrital zircon population age and provenance. Older terminology of Hewett (1940) maintained within Panamint Range where unconformity has not been systematically mapped. Andrew (2002) describes an unconformity below the upper siltite member of the Crystal Spring Formation which may correspond to the base of the Horse Thief Springs Formation. Upper member of Crystal Spring Formation of Wright and Troxel (1993) composed of pelitic schist and micaceous quartzite is included in Horse Thief Springs Formation within the northern Funeral Mountains. Unit consists of six regionally extensive marine units of purple to green siliciclastic rocks which fine up section and are capped by a siliceous dolomite bed. Siliciclastic rocks coarsen to the south and thicken to the east. The dolomite beds are sub-meter to meter scale thickness and contain stromatolites, oncolites, microbial laminations, and local grainstones. Mahon (2012) reports approximately 150 m thick in Saddle Peak Hills in southern Death Valley. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

ZYp - Noonday Dolomite and Pahrump Group, undivided (Mesoproterozoic to Neoproterozoic)

Exposed in southern-most parts of map area where units have not be subdivided due to lack of detailed mapping. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Yc - Crystal Spring Formation (Mesoproterozoic)

Extremely heterogeneous unit across map area with local variations in lithology, thickness, and internal stratigraphy over short distances. Composed of interstratified sciliciclastic rocks and siliceous carbonate rocks. Metamorphosed to biotite-grade in the northern Panamint Range and Funeral Mountains with quartzite, argillite, biotite schist, chlorite schist, siliceous marble and in the Funeral Mountains tabular amphibolite layers. Unmetamorphosed exposures in the southern part of the map area include, in descending order, poorly bedded chert and siltstone, stromatolitic limestone, interbedded dolomite and cherty dolomite intruded by diabase sills, purple, massive mudstone, cyclic, upward-fining red feldspathic sandstone, siltstone, and shale, and interbedded, cross-bedded arkosic conglomerate and sandstone. Quartz pebble conglomerate locally present at base sits unconformably on older Proterozoic basement rocks, generally with strong angular discordance to layering of older metasediments. Thick, medium-grained diabase sills (considered part of formation) form large scale talc deposits within overlying dolomite marbles through contact metamorphism. Diabase near Saratoga Spring in southern Death Valley produced a discordant U/Pb age of 1,069 ± 3 Ma while a similar sill in the Kingston Range produced a discordant U/Pb age of 1,087 ± 3 Ma (Heaman and Grotzinger, 1992). Upper part of unit within Panamint Range may include Horse Thief Springs Formation (Zh) where unconformity between

middle and upper Crystal Springs Formation, as previously mapped, has not been clearly identified. Unit is absent in northern parts of map area. Thickness varies; Albee and others (1981) report as much as 1,000 m thick in west-central Panamint Range; Hunt and Mabey (1966) report 564 m thick in Galena Canyon at the southeastern edge of the Panamint Range; Wright (1973) reports approximately 975 m thick in Alexander Hills near southernmost Nopah Range; Wright and Troxel (1993) map approximately 800 m thick in northern Funeral Mountains; Mahon (2012) estimates approximately 500 m thick in the Saddle Peak Hills in southern Death Valley where the base of the unit is not exposed. (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

Xmi - Metamorphic and igneous rocks, undifferentiated (Paleoproterozoic)

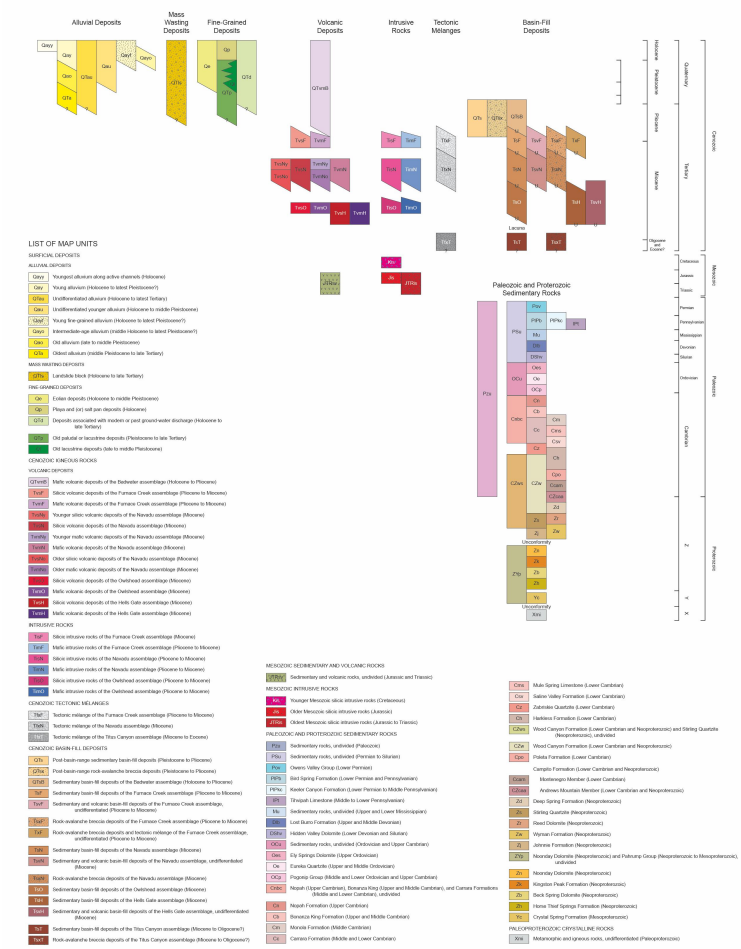
Exposed mainly in the southern and central parts of the map area, in Black Mountains, Greenwater Range, Funeral Mountains, Bullfrog Hills, Nopah Range, and Panamint Range. Isolated exposures in southern Cottonwood Mountains are strongly altered by the Hunter Mountain batholith and may be younger siliciclastic sedimentary rocks. Unit consists of quartz-feldspar augen gneiss, quartzofeldspathic biotite schist, biotite-hornblende-schist, biotite-epidote schist, and minor quartzite, marble, and amphibolite schist comprising a predominantly metasedimentary sequence with indistinct and gradational bedding planes generally parallel to foliation planes. Metasediments are intruded by gneissic monzogranite, pegmatite dikes, and younger diabase dikes. Drewes (1963) described metadiorite intrusions within this sequence which have since been identified as Tertiary mafic intrusions (Otton, 1977; Asmerom and others, 1990). Silicic plutons are generally included within the regional 1.7 Ga plutonic suite (Wasserburg, 1959; Lanphere and others, 1964; Wright and Troxel, 1993) but some porphyritic granitic intrusions are part of the 1.4 Ga plutonic suite (Lanphere and others, 1964). (*GRI Source Map ID 75945)* (*Geologic Map of Death Valley National Park*).

GRI Source Map Information

Geologic Map of Death Valley National Park

Workman, J.B., Menges, C.M., Fridrich, C.J., Thompson, R.A., 2014, Geologic map of Death Valley National Park, California and Nevada: U.S. Geological Survey Scientific Investigations Map SIM-XXXX, unpublished digital data, scale 1:150,000. (*GRI Source Map ID 75945*).

Correlation



Extracted from: [Geologic Map of Death Valley National Park](#).

Note: This figure is part of a draft for the unpublished Geologic Map of Death Valley National Park. It has not been internally reviewed by the U.S. Geological Survey and therefore may contain errors relating to the ages of units and cross-correlation.

Source Index Map 1 - 1:250,000 Scale Maps

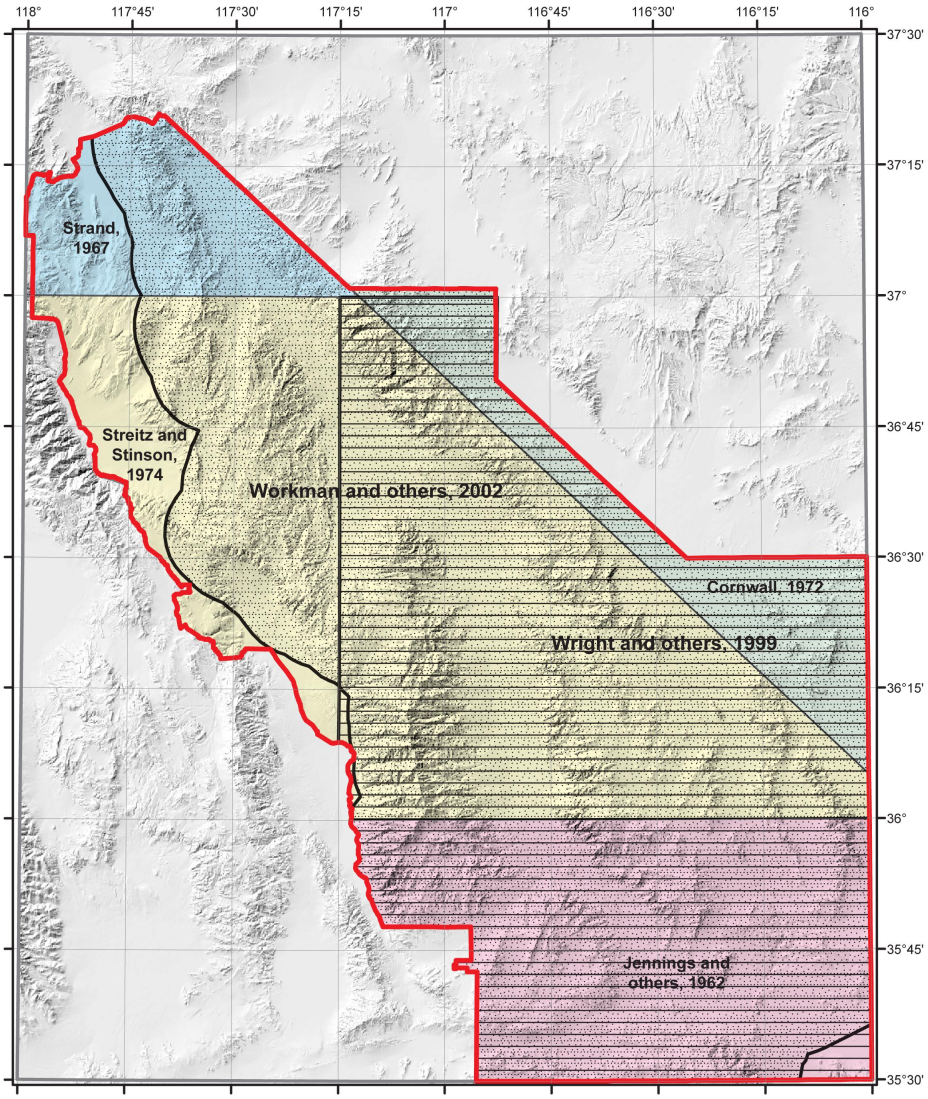


Figure 1A: Sources of geologic map data used in compilation of the Geologic Map of Death Valley National Park. Regional 1:250,000-scale maps.

Extracted from: Geologic Map of Death Valley National Park.

Source Index Map 2 - 1:100,000 to 1:24,000 Scale Maps

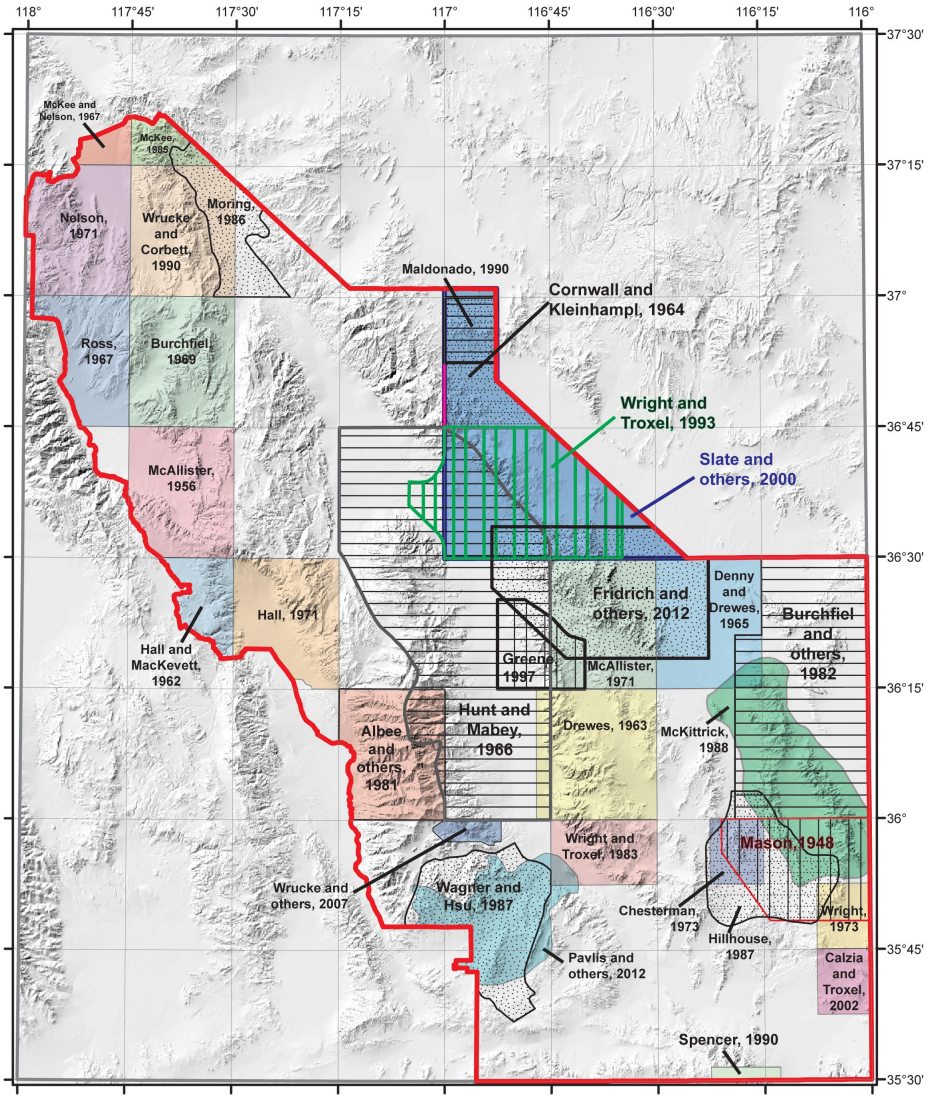


Figure 1B: Sources of geologic map data used in compilation of the Geologic Map of Death Valley National Park. Published maps at various scales ranging from 1:24,000-scale up to 1:100,000-scale.

Extracted from: Geologic Map of Death Valley National Park.

Source Index Map 3 - Theses, Dissertations, or Unpublished Maps

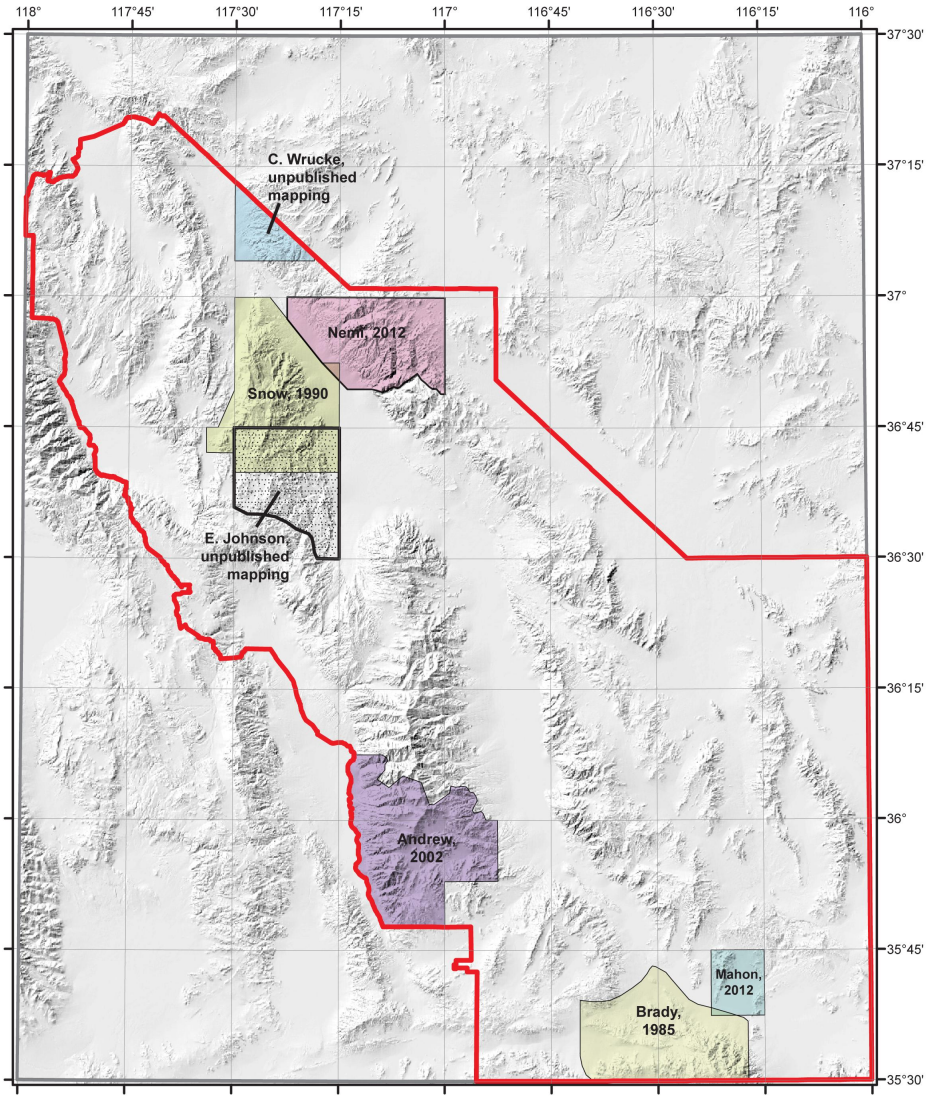


Figure 1C: Sources of geologic map data used in compilation of the Geologic Map of Death Valley National Park. Maps accompanying thesis or dissertation work or incomplete and unpublished mapping provided directly by authors.

Extracted from: Geologic Map of Death Valley National Park.

Report

Introduction

The physical characteristics of Death Valley National Park make it one of the most outstanding geologic parks in the world. The rocks tell the story of early continental crust formation and differentiation, metamorphism, snowball earth, the dawn of life on the planet as well as evolution through time, rifting, the coming and going of ancient seas, foreland folding and thrusting, arc volcanism and intrusion, basin and range extension including crustal-scale detachment fault systems, large-scale silicic to basaltic volcanism, and all manner of surficial processes. The region has drawn geologists for generations both for casual observation, and for detailed study. Some areas of the park have been mapped in tremendous detail. Others have never been mapped at all beyond crude photointerpretation. This mapping effort has drawn together existing published maps, along with substantial amounts of unpublished mapping, combined with more than a decade of detailed field based mapping and reconnaissance mapping by the authors, incorporating a wide range of geophysical data, multispectral imagery, high resolution natural color imagery, and a large collection of new geochemical and radiometric age data. This 1:150,000-scale geologic map therefore represents not only the newest compilation of mapping in Death Valley National Park, but the only existing comprehensive map of the park area.

Death Valley National Park is located in southeastern California and southern Nevada within the Basin and Range province straddling the Great Basin to the north and east, the Mojave Desert to the south, and the southern Sierra Nevada to the west. The park covers 13,747 square kilometers (5,307 square miles) with approximately 95% of that designated as wilderness area. It is the fifth largest national park in the United States, and by far the largest national park outside of Alaska. Badwater, at the eastern edge of Death Valley, is the lowest point in North America at 86 meters (282 feet) below sea level with the adjacent Panamint Mountains rising to 3,368 meters (11,049 feet) above sea level. The highest point in the contiguous United States is Mount Whitney at 4,421 meters (14,505 feet) which is just 137 kilometers (85 miles) to the west of the park. Death Valley is one of the driest places in North America with an annual rainfall of approximately 1.5 inches. The hottest surface air temperature on the planet, 134 °F (57°C), was recorded at Furnace Creek in 1913. The lifeless saltpan environments at the valley floor, give way to scrub and desert woodland up slope, with conifer forests present in the highest elevations which receive snow in the winter months.

Purpose

This regional 1:150,000-scale geologic map compilation provides a new and important foundation for future geologic study in the Death Valley area. Resource management and hazard mitigation are the two largest concerns within the park area. The single most important resource in the region is water and the lack of surface water requires dependence upon fragile groundwater resources. The groundwater system here involves complex interplay between local shallow aquifer systems, and regional, often confined, aquifer systems connected along interbasin flow paths with variable stratigraphic and structural controls. This system requires a comprehensive geologic framework across the area in order to understand. Geologic mapping also provides context for the many mineral deposits in the area. The region has many geologic hazards including active faulting which must be understood to avoid placing people and infrastructure in danger. Future and ongoing geologic studies of a more academic nature also depend upon a strong geologic foundation which this map provides.

Mapping Techniques

This map compilation represents more than two decades of active mapping and research within Death Valley National Park and surrounding areas to the north and east by the authors and their USGS colleagues. All available sources of data have been incorporated into the compilation process with a nominal compilation scale of 1:100,000, reduced to 1:150,000 in order to fit the entire map area on to one printed map plate. Previous compilation efforts in parts of the area by Workman and others (2002) conducted in support of regional groundwater modeling (see Belcher and Sweetkind, 2010 for the most recent progress on these efforts) were limited to a nominal scale of 1:250,000 and based largely upon

older small-scale mapping (see fig. 1A). The current mapping effort, depicted here, utilizes data of all scales in order to represent the most complete and up to date understanding and interpretation of Death Valley geology. This regional mapping effort has been concurrent with new 1:100,000-scale geologic mapping of the Death Valley Junction quadrangle (R.A. Thompson and others, in preparation; Slate and others, 2009), new 1:100,000-scale surficial geologic mapping of the Owlshead Mountains quadrangle (C.M. Menges and others, in preparation) and several 1:50,000-scale geologic maps in specific areas of interest including the southern Funeral Mountains (Fridrich and other, 2012), the southern Grapevine Mountains (C.J. Fridrich and others, in preparation), the Resting Spring and Nopah Ranges and Montogomery Mountains area (J.B. Workman and others, in preparation), along with several USGS topical studies relating to hydrogeology, geophysics, neotectonics, geochronology, drainage basin integration, Cenozoic tectonic basin evolution, and Cenozoic volcanic system evolution.

Where previously published, unpublished, or described map data exist, modifications have been made based upon the following criteria in decreasing order of priority: 1) new detailed mapping on the ground by the authors, 2) prioritizing more recent or robust studies when differences exist in overlapping maps, 3) new reconnaissance level mapping on the ground by the authors, 4) new interpretation by the authors based upon data (geophysics, chemistry, geochronology, etc.) collected since the previous mapping, 5) photo-interpretation particularly in very remote areas based upon new, high-resolution imagery and multispectral imagery where available, and 6) simple edge matching techniques that preserve general geologic interpretations where adjacent or overlapping maps differ in minor ways. Map sources come from a wide range of mapping techniques, and some modifications may reflect an attempt to better register data to more reliable base data where clear shifts or distortions existed because of bad or questionable map bases.

Numerous areas represent entirely new interpretation based upon detailed 1:24,000-scale mapping and generalized 1:100,000-scale reconnaissance mapping where no previous data existed or where older mapping was highly reconnaissance in nature or of an inappropriate scale, scope, or quality to be used in this context. A great deal of previously unpublished, detailed mapping by the authors is represented here. We have attempted to identify all other sources of map data, published and unpublished (see map source figure on map plate). In addition, a tremendous amount of reconnaissance field mapping and photointerpretation using the wealth of new, georectified digital imagery (1 meter resolution, natural-color, USDA National Agriculture Imagery Program and multispectral USGS LandSat7 data) not readily available to geologists before the last few years has been incorporated throughout the map area. Where mapping differs substantially from source maps, the user may assume that intended modifications were made by the authors as described above. However, in a project of this scale and scope, errors are unavoidable, and some modifications to map sources may simply represent unidentified compilation errors. This map is the first attempt to depict the geology of the Death Valley region at a consistent 1:100,000-scale. Our hope is not that future researchers assume the mapping is entirely correct as depicted, but that they use this compilation to focus upon areas that need further study or new interpretation and possibly improved geologic mapping.

Pre-Cenozoic rocks

Proterozoic crystalline rocks are not differentiated across the map area, consistent with most previous mapping in the region. Proterozoic though Paleozoic strataform deposits are grouped into formational level map units consistent with standard use across the region. No new formation names are introduced within this sequence. Proterozoic stratigraphy of the Pahrump Group has been questioned recently by several authors and we adopt the nomenclature of Mahon (2012). Two primary stratigraphic sequences as described by Stewart (1980) are used here. In the northwestern parts of the map area, rocks of the transitional assemblage are present. In the central, southern and eastern parts of the map area, rocks of the eastern assemblage are present. The reader is referred to Sweetkind and White (2001) for more information about Proterozoic to Cambrian stratiform deposits of the region and their significance in regional groundwater studies. Mesozoic arc intrusive rocks are differentiated only based upon sparse age information. Minor exposures of Mesozoic sedimentary and volcanic deposits are undifferentiated.

Cenozoic rocks

The Cenozoic rocks exposed in the Death Valley region consist of shallow intrusive bodies and dikes, local volcanic centers, regional volcanic deposits, and sedimentary basin-fill deposits which include fine-grained lacustrine sediments, coarser-grained alluvial and fluvial sediments, massive, monolithic landslide breccia deposits, and older rocks that are pervasively brecciated at a fine-scale by Cenozoic-age structures (mapped as Cenozoic fault breccia). All pre- and syn-extensional Cenozoic units are mapped using a tectonostratigraphy modified from Fridrich and Thompson (2011). This stratigraphic scheme is based upon detailed study within the central Death Valley area from the Panamint Mountains on the west to the Pahrump Valley on the east and the southern Grapevine Mountains in the north to the southern end of Death Valley. Extensive field study, geochemistry, and geochronology was conducted within this core area on exposures of volcanic and basin-fill deposits by Fridrich and Thompson (2011) and in connection to concurrent projects discussed above. Cenozoic deposits in the northern, western and southern-most parts of the map area have been included within this stratigraphic scheme, but correlations in these areas are more tenuous due to lack of supporting data.

Cenozoic units are divided by tectonic assemblage into five major groupings (Hell's Gate [H], Owlshead [O], Navadu [N], Furnace Creek [F], and Badwater [B]). These tectonic assemblages are time-transgressive across the map area and are defined by structural style, volcanic assemblage, and correlation of bounding unconformities or disconformities. Cenozoic sections of the region generally consist of more than one of these assemblages, and thus are stacks of multiple and distinct basin-fills formed in different tectonic stages. The reader is referred to Fridrich and Thompson (2011) for a more complete description of this nomenclature. Much of the supporting data, especially extensive Ar40/Ar39 age determinations and geochemical fingerprinting of igneous rocks as well as analysis of the volcanic evolution of the central Death Valley volcanic field will be published concurrently by R.A. Thompson and others (written communication, 2014).

Within each assemblage, units are further subdivided by rock type and, where possible, by major lithology. The major rock types include volcanic deposits ([Q]Tv), intrusive rocks ([Q]Ti), sedimentary deposits ([Q]Ts), undivided sedimentary and volcanic deposits (Tsv), tectonic mélange (fx), and undivided interlayered sequences of more than one of these rock types. Volcanic and intrusive rocks are not divided based upon genesis (ash flow vs. lava flow; dike vs. plug; etc.), nor are they divided based upon texture (porphyritic vs. glassy; welded vs. nonwelded; coarse vs. fine; etc.). Volcanic and intrusive rocks are subdivided only by bulk composition into mafic (m) or silicic (s) groupings where possible. Mafic, as used here, includes basaltic to andesitic compositions in volcanic deposits and gabbroic to dioritic compositions in intrusive rocks. Silicic, as used here, includes rhyolitic to dacitic compositions in volcanic deposits and grantic to granodioritic compositions in intrusive rocks. Sedimentary basin-fill deposits are generally composed of interlayered and interfingering alluvial, lacustrine, and fluvial facies, with local mass wasting deposits and undifferentiated volcanic deposits which all vary in percentage from basin to basin and from location to location within individual basins. Therefore, sedimentary deposits are not systematically subdivided at all. Basin fill material composed entirely of large, mappable volumes of rock-avalanche breccia (sx) with only minor interlayered alluvium are subdivided from other sedimentary deposits where possible. Undivided sedimentary and volcanic basin-fill deposits (sv), as used here, do not subdivide volcanic deposit compositions. Tectonic mélanges are defined here as packages of fault slivers that are mapped as a unit, with the pattern of internal faulting shown. The vast majority of individual fault blocks within these packages/damage zones are too small to identify (by the pre-Tertiary formations they consist of) at the scale of the map (1:150,000). This style of generalization of the geology represents a conscious choice to show the external and internal structural geometries of zones of extreme tectonic damage, along with the age of the deformation that formed them, rather than to identify these tectonically mutilated rocks by the pre-Tertiary formations of which they are composed.

The cartographic scheme used on the map is intended to highlight tectonic groupings and lithologies, as both are significant for different users and the overlap of these properties is complex across the map area and within individual basin-fill sequences. Lithology is grouped into different basic colors while tectonic assemblage is grouped into different levels of color saturation. Lithology is listed first in unit symbols on the map, but tectonic assemblage is emphasized by a capital letter at the end of

the unit symbols. Within the database, the different lithologies and tectonic assemblages are further designated by an additional pair of attributes to facilitate differentiation by the user.

Surficial Deposits

The surficial units in this map include some modifications from the standard types of surficial-deposit units encountered in most geologic maps. These modifications are designed to emphasize factors of potential importance to hydrogeologic framework modeling in the Death Valley region, as well as infiltration-recharge and discharge calculations. This includes not only differentiation of specific units, such as modern channels, discharge deposits, and playas, that directly impact these factors, but also identification of generalized textural variations in deposits of potential hydrologic significance. That is, variation in grain size was approximated by differentiating where possible (a) fine-grained deposits on distal alluvial fans and alluvial plains in basin interiors from coarse-grained alluvial deposits in proximal or medial piedmont positions, and (b) fine-grained Quaternary to Tertiary basin sediments from coarse-grained alluvium of similar age range. The latter fine-grained basin sediments typically include Pleistocene to upper Tertiary basin-fill deposits of mixed lacustrine, alluvial, and (or) paludal origin exposed in some dissected basins (Hillhouse, 1987; Morrison, 1999), but locally may delineate primarily lacustrine deposits in a few closed basins (Klinger and Sarna-Wojcicki, 2001). Alluvial units are further subdivided according to more standard age categories that reflect other potentially important hydrologic characteristics such as degree of soil and pavement development, cementation, and amount of internal dissection. Colluvial deposits and minor landslide deposits are not included on this map because (a) they are difficult to systematically identify on aerial imagery, (b) these deposits are commonly thin and discontinuous, especially at map scale, and (c) they typically occur in range blocks and upland areas where they would tend to obscure the hydrogeologically more significant lithology and structure of subjacent bedrock.

Specific characteristics of all units, including physiographic position, dissection, surface and weathering characteristics, and selected soil and sedimentologic properties, are summarized in table 2 of Workman and others (2002). General ranges of unit thickness are estimated below, but are highly variable and poorly constrained due to a lack of basal exposures of most surficial deposits in the area. The typical range of unit thickness given first applies to most surficial deposits located in basins within the central and eastern parts of the map with low to moderate rates of tectonic activity and basin subsidence in localized areas. A larger maximum range is given for some deposits to reflect their likely greater thicknesses adjacent to the fault-bounded margins of basins such as central Death Valley in the western part of the map with high rates of tectonic activity and basin subsidence.

Structural Features

Bedding, foliation, and lineation orientations are not included in this compilation. Abundant structural data exists within the project area, but a systematic synthesis of this information across the area was simply beyond the scope of the current mapping project. Most of the mountain ranges within the map area contain such a complicated structural history, and the folding, faulting, and tilting of rocks has occurred at such a wide range of scales and in such variably overlapping forms, that generalizing this data, in a meaning-full way is quite a complicated task. A wide range of orientations may exist within a small area, and determining the best values to represent these patterns can be highly interpretive. For overlapping reasons, fold axes and fold forms are not represented on this compilation.

In most cases, fault patterns are generalized. Most major fault systems are depicted as a single, continuous line. Where large-scale patterns such as en echelon fractures, stepping faults, bridging faults, conjugate faults, crosscutting faults, large parallel fault strands, etc. exist, an attempt has been made to accurately depict these patterns. Smaller-scale patterns, however, may not be accurately represented where map scale limits detail of the depiction. Offset of faults is not systematically depicted. Offset is commonly variable along length, or over time, and in many situations, offset is not constrained by current data. In some locations, fault kinematic data exists, but has not been included in this compilation. Users are referred to the source maps where much greater mapping detail can be found. On the printed map, fault offset annotations have been included for major fault systems to differentiate dip-slip and strike-slip motions, but this information is not incorporated within the

digital database in the form of attribution or line directionality due largely to the size and complexity of the line networks within the database. In general, fault orientation and offset are not described within the database. Where lower-angle fault planes are observed, either in current attitude, or inferred at time of motion, standard symbols are used to differentiate upper and lower plates. In these cases, thrust faults are differentiated from normal faults and line directionality within the database is consistent (symbolization follows left-hand rule based upon common GIS symbol sets).

Accuracy

Line accuracies on the map and in the database are not differentiated for contacts and only differentiated in a qualitative form for faults. At the compilation scale of 1:150,000, all lines can be considered approximately located. Although a large percentage of lines were digitized at larger scales from more detailed sources (ranging from 1:100,000-scale to 1:24,000-scale), in virtually all cases, the detail was simplified. Even where the locational accuracy of the source data was robust, tight sinuosity was smoothed, vertices along lines were spaced to reduce data clutter, scientifically significant small polygons were enlarged while scientifically unimportant small polygons were removed, and the ability to assess the scientific and locational accuracy of the source data was always limited. In some locations, previous mapping was not modified and unreported levels of accuracy are perpetuated.

Where faults are called inferred, the scientific basis for drawing the fault at all is less than certain and the location is generally approximate. In some cases, the location of a fault might be well constrained, but the identity of the feature drawn may be uncertain. In cases where surrounding geology necessitates a fault, all efforts were made to reasonably locate that fault, unless it was concealed under younger deposits and was shown as such. Where faults are called concealed, again the scientific basis for drawing the fault may be less than certain, but concealed faults connecting well exposed faults across short distances or separating incongruous outcrops across a thin valley may be quite well constrained.

Extracted from: Geologic Map of Death Valley National Park.

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