Facies Analysis of Late Proterozoic through Lower Cambrian Rocks of the Death Valley Regional Ground-Water System and Surrounding areas, Nevada and California

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Introduction

Late Proterozoic through Lower Cambrian rocks in the southern Great Basin form a westward-thickening wedge of predominantly clastic deposits that record deposition on the early western shelf edge of western North America (Stewart and Poole, 1974; Poole and others, 1992). Regional analyses of geologic controls on ground-water flow in the southern Great Basin typically combined lithostratigraphic units into more general hydrogeologic units that have considerable lateral extent and distinct hydrologic properties. The Late Proterozoic through Lower Cambrian rocks have been treated as a single hydrogeologic unit, named the lower clastic aquitard (Winograd and Thordarson, 1975) or the quartzite confining unit (Laczniak and others, 1996), that serves as the hydrologic basement to the flow system. Although accurate in a general sense, this classification ignores well-established facies relations within these rocks that might increase bedrock permeability and locally influence ground-water flow.

This report presents a facies analysis of Late Proterozoic through Lower Cambrian rocks (hereafter called the study interval) in the Death Valley regional ground-water flow system - that portion of the southern Great Basin that includes Death Valley, the Nevada Test Site, and the potential high-level nuclear waste underground repository at Yucca Mountain (fig. 1). The region discussed in this report, hereafter called the study area, covers approximately 100,000 km$^2$ (lat 35°-38° 15' N., long 115°-118° W.). The purpose of this analysis is to provide a general documentation of facies transitions within the Late Proterozoic through Lower Cambrian rocks in order to provide an estimate of material properties (via rock type, grain size, and bedding characteristics) for specific hydrogeologic units to be included in a regional ground-water flow model.

Regional Setting

The oldest sedimentary rocks in the region are Middle and Late Proterozoic carbonate and clastic rocks of the Pahrump Group (including the Kingston Peak, Beck Spring, and Crystal Spring Formations) and the Late Proterozoic Noonday Dolomite. These rocks are as thick as 5 km in an east-west-trending depocenter through southern Death Valley and the Kingston Range, and they become thinner and eventually pinch out away from this east-west trending depocenter (Stewart, 1972; Wright and others, 1974). These rocks were interpreted as having been deposited in a failed rift by Wright and others (1974). In the southern part of the study area these rocks were deposited on an
Figure 1. Regional map showing locations of composite stratigraphic sections, outcrops of Late Proterozoic to Lower Cambrian rocks, and major regional structures. NDVF, Northern Death Valley fault; SDVF, Southern Death Valley fault; FCF, Furnace Creek fault; GF, Garlock fault; SVPFZ, Stewart Valley-Pahrump fault zone; WPT, Wheeler Pass thrust; GPT, Gass Peak thrust. FM, Frenchman Mountain; SM, Spring Mountains; AM, Ash Meadows; PM, Panamint Mountains; LC, Last Chance Range; YM, Yucca Mountain.
older Proterozoic complex of gneiss and intrusive rocks, whereas in the Panamint and Farewell Mountains these rocks are metamorphosed to medium and high grades and intruded by granitic rocks (Labotka, 1980).

The basal sequence within the Cordilleran miogeocline consists of a clastic wedge that thickens from less than 100 m on the east, where basal strata are Lower Cambrian, to more than 3,000 m in western areas, where most of the sequence lies below basal Cambrian beds (fig. 2). The primary lateral facies changes within the study interval includes a transition from quartzite and siltstone in eastern exposures in Clark County and southern Nye County, Nev. (fig. 1) to predominantly shale and carbonate rocks in western exposures in Esmeralda County, Nev. and Inyo County, Calif. (fig. 1) (Stewart, 1970). The westward increase in fine clastics and carbonate within the clastic wedge indicates a transition from shelf to slope-and-rise facies (Stewart, 1972).

In the study area, the Late Proterozoic through Lower Cambrian interval may be subdivided into three broad regions - eastern, central, and western (Stewart, 1970; Nelson, 1978) (fig. 2). Each of these regions was originally mapped using separate stratigraphic nomenclature that reflected regional differences in the lithologic character of the strata; only later were these stratigraphic packages shown to be equivalent.

Throughout much of the central region (fig. 2), the study interval is Late Proterozoic to Lower Cambrian in age and consists of a westward-thickening wedge of fine- to coarse-grained sandstone, conglomeratic sandstone, siltstone, and minor amounts of carbonate rock (Stewart, 1970). The section includes the Late Proterozoic Johnnie Formation and Stirling Quartzite, the Late Proterozoic to Lower Cambrian Wood Canyon Formation, and the Lower Cambrian Zabriskie Quartzite (Stewart, 1970). Interbedded carbonate and clastic rocks of the Lower and Middle Cambrian Carrara Formation represent the transition to an overlying carbonate succession (Palmer and Halley, 1979). Rocks characteristic of the central region are exposed in mountain ranges from the northwestern Spring Mountains (SM, fig. 1) (Burchfiel, 1964; Stewart, 1970) to the Nevada Test Site area (Barnes and Christiansen, 1967; Reso, 1963) and the Death Valley area (Hunt and Mabey, 1966; Diehl, 1974; Wright and others, 1974).

In the western region (fig. 2), strata that are laterally equivalent to those of the central region are thicker, finer grained, and more carbonate rich. They consist of
Figure 2. Total thickness of the Late Proterozoic to Lower Cambrian rocks in Death Valley region. Thickness is in meters; contour interval is 1000 m. A minimum thickness (for example, >1,752 m) is shown for incomplete sections or where base of section is not exposed.
interbedded siltstone, limestone, dolomite, and fine-grained quartzite (Nelson, 1962; Stewart, 1970; Albers and Stewart, 1972). The stratigraphic section of this region includes the Late Proterozoic Wyman Formation, the Late Proterozoic to Lower Cambrian Reed Dolomite and Deep Spring Formation, and the Lower Cambrian Campito, Poleta, and Harkless Formations. Typical exposures are found in the White and Inyo Mountains and Last Chance Range, Calif. (LC, fig. 1) (Nelson, 1962; Signor and Mount, 1986) and exposures in Esmeralda County, Nev. (Stewart, 1970; Albers and Stewart, 1972).

The interpretation of facies trends in the Death Valley region must take into account the structural complexity of the region. Late Proterozoic and Paleozoic rocks throughout the region were affected by south- and southeast-directed shortening in the form of late Paleozoic to Mesozoic regional thrusts and more localized folds (Fleck, 1970; Wernicke and others, 1988; Snow, 1992) (fig. 1). The major thrusts have stratigraphic offsets of several kilometers and horizontal displacements as much as several tens of kilometers, which result in offsets in regional facies trends (Fleck, 1970; Snow, 1992). Thrusts in the western and northwestern parts of the region consistently rocks of the study interval, including the Johnnie Formation, Stirling Quartzite, and Wood Canyon Formation, in their hanging walls.

All of the rocks of the Death Valley region were later deformed by complex Neogene extensional normal and strike-slip faults (Stewart, 1988; Wright, 1989; Wernicke and others, 1988). This deformation is characterized by a variety of structural patterns that overlap in space and time: (1) Basin and Range extension; (2) local extreme extension along detachment faults that currently have gentle dips; and (3) development of discrete strike-slip faults and transtensional basins within the Walker Lane belt. The northwest-trending Walker Lane belt (Stewart, 1988) transects the Death Valley region roughly parallel to the Nevada-California border and contains several large right-lateral faults with northwest orientations (fig. 1), such as the Stewart Valley-Pahrump fault zone, the Furnace Creek-Death Valley fault system and the Las Vegas Valley shear zone (Stewart and others, 1968; Longwell, 1974; Stewart and Crowell, 1992). In the western part of the region, the Walker Lane belt also includes the detachment faults and metamorphic core complexes of the Death Valley region that have accommodated large-magnitude northwest-directed horizontal extension.

Methods of Study

Using existing published data, 14 composite stratigraphic sections from throughout the region were selected (fig. 1) based upon the following criteria:

- the completeness of the section,
- the need for a broad geographic distribution of the locations providing stratigraphic information.
All the stratigraphic data used in this compilation appear in Stewart (1970) and references cited therein (table 1). In a number of cases, individual sections were combined to yield as complete a section as possible.

For each of the 14 composite sections, the following data were compiled: location, total thickness, aggregate thickness of sandstone and coarser units, aggregate thickness of siltstone and shale units, aggregate thickness of carbonate units (limestone and dolomite), and the thickest single bed or continuous interval of either carbonate or coarse clastic unit (table 2). For each section, the measured interval was from the top of the Lower Cambrian Zabriskie Quartzite (or in the northwestern region, the top of the Lower Cambrian Harkless Formation) to the base of the Late Proterozoic Johnnie Formation. Clastic units in the lower third of the Lower and Middle Cambrian Cararra Formation, which overlies the Zabriskie Quartzite, were not included in the measurements. Units below the Johnnie Formation, including the Late Proterozoic Noonday Dolomite and the Middle to Late Proterozoic Pahrump Group, were not considered in the thickness tabulations. These units are rarely exposed at the surface so thickness values are scarce. Moreover, in most places these units are too deep to impact the ground-water flow. In the western part of the region, the base of the sedimentary section is often not exposed and the thickness measurements are minimum values.

**Table 1.** Location of composite measured sections used for facies analysis.

<table>
<thead>
<tr>
<th>Location Number</th>
<th>Location name</th>
<th>Corresponding sections (from Stewart, 1970)</th>
<th>Northing (UTM m)</th>
<th>Easting (UTM m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weepah Hills</td>
<td>Locations 44 and 45</td>
<td>4,195,849</td>
<td>461,318</td>
</tr>
<tr>
<td>2</td>
<td>Northern Last Chance Range</td>
<td>Locations 4, 5 and 6</td>
<td>4,132,338</td>
<td>431,327</td>
</tr>
<tr>
<td>3</td>
<td>Mount Dunfee</td>
<td>Locations 51 and 52</td>
<td>4,133,220</td>
<td>473,080</td>
</tr>
<tr>
<td>4</td>
<td>Quartzite Mountain and Belted Range</td>
<td>Locations 54 and 55</td>
<td>4,151,744</td>
<td>558,349</td>
</tr>
<tr>
<td>5</td>
<td>Groom District</td>
<td>Location 67</td>
<td>4,132,926</td>
<td>607,746</td>
</tr>
<tr>
<td>6</td>
<td>Bare Mountain</td>
<td>Location 57</td>
<td>4,077,943</td>
<td>526,593</td>
</tr>
<tr>
<td>7</td>
<td>Echo Canyon</td>
<td>Locations 11 and 12</td>
<td>4,042,365</td>
<td>528,357</td>
</tr>
<tr>
<td>8</td>
<td>Panamint Mountains (Trail Canyon and Hanaupah Canyon)</td>
<td>Locations 14 and 16</td>
<td>4,005,023</td>
<td>498,366</td>
</tr>
<tr>
<td>9</td>
<td>Desert Range</td>
<td>Locations 70 and 71</td>
<td>4,073,532</td>
<td>645,970</td>
</tr>
<tr>
<td>10</td>
<td>Spring Mountains</td>
<td>Locations 61, 63, 64 and 66</td>
<td>4,029,722</td>
<td>595,984</td>
</tr>
<tr>
<td>11</td>
<td>Northern Resting Spring Range</td>
<td>Locations 20 and 21</td>
<td>4,004,141</td>
<td>566,581</td>
</tr>
<tr>
<td>12</td>
<td>Nopah Range</td>
<td>Location 26</td>
<td>3,966,799</td>
<td>580,695</td>
</tr>
<tr>
<td>13</td>
<td>Las Vegas Range</td>
<td>Locations 73 and 74</td>
<td>4,035,602</td>
<td>668,022</td>
</tr>
<tr>
<td>14</td>
<td>Winters Pass Hills and Winters Pass</td>
<td>Locations 31 and 32</td>
<td>3,958,566</td>
<td>613,038</td>
</tr>
<tr>
<td>Location name</td>
<td>Total thickness (m)</td>
<td>Aggregate thickness, siltstone + shale (m)</td>
<td>Aggregate thickness, sandstone + conglomerate (m)</td>
<td>Aggregate thickness, limestone + dolomite (m)</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>---------------------</td>
<td>--------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Weepah Hills</td>
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<td>366</td>
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<td>Mount Dunfee</td>
<td>1752</td>
<td>744</td>
<td>78</td>
<td>930</td>
</tr>
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<td>Quartzite Mountain and Belted Range</td>
<td>2862</td>
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<td>786</td>
<td>246</td>
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<tr>
<td>Groom District</td>
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<td>942</td>
<td>768</td>
<td>18</td>
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<tr>
<td>Bare Mountain</td>
<td>2052</td>
<td>1218</td>
<td>612</td>
<td>222</td>
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<tr>
<td>Echo Canyon</td>
<td>3180</td>
<td>1752</td>
<td>1170</td>
<td>258</td>
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<tr>
<td>Panamint Mountains</td>
<td>2376</td>
<td>1344</td>
<td>666</td>
<td>366</td>
</tr>
<tr>
<td>(Trail Canyon and Hanaupah Canyon)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desert Range</td>
<td>3150</td>
<td>1752</td>
<td>1062</td>
<td>336</td>
</tr>
<tr>
<td>Spring Mountains</td>
<td>3060</td>
<td>2046</td>
<td>864</td>
<td>150</td>
</tr>
<tr>
<td>Northern Resting Spring Range</td>
<td>2232</td>
<td>1314</td>
<td>816</td>
<td>102</td>
</tr>
<tr>
<td>Nopah Range</td>
<td>2160</td>
<td>1068</td>
<td>876</td>
<td>216</td>
</tr>
<tr>
<td>Las Vegas Range</td>
<td>702</td>
<td>270</td>
<td>432</td>
<td>0</td>
</tr>
<tr>
<td>Winters Pass Hills and Winters Pass</td>
<td>1212</td>
<td>642</td>
<td>426</td>
<td>144</td>
</tr>
</tbody>
</table>
Analysis of Regional Facies Trends

Thickness
The total thickness of the study interval generally increases to the northwest from less than 1 km in the Winters Pass area (location 14, fig. 1) and in the Las Vegas Range (location 13, fig. 1), to between 2 and 3 km in the vicinity of the Nevada Test Site and Death Valley (fig. 2). The base of the stratigraphic section in the northwestern part of the region is poorly exposed, however, Stewart (1970) estimated that the total thickness of this interval might be as much as 5-6 km in the White and Inyo Mountains of California. Abrupt changes in the thickness of the Late Proterozoic through Lower Cambrian section are evident across the major strike-slip faults of the region (fig. 2). These changes have long been used to estimate the magnitude of offset along these faults (Stewart, 1967; Stewart and others, 1968; Prave and Wright, 1986).

Compositional trends
The main compositional trend within the study interval is the decrease of sandstone toward the northwest in conjunction with an increase in finer-grained clastic components, and some increase in the amount of carbonate. The proportion of sandstone and conglomerate within the study interval also decreases to the northwest (fig. 3). Because of the relatively minor amount of carbonate rocks in the section, a northwest decrease in the sand-shale ratio (fig. 4) mimics the proportion of sandstone and conglomerate within the study interval (fig. 3). In general, bedding characteristics mirror the compositional trends; toward the northwest the entire section in characterized by thinner bedding, with fewer thick, continuous intervals of quartzite (see pl. 2 in Stewart, 1970). The relative proportion of carbonate rocks within the section shows a gradual increase from southeast to northwest (fig. 5). Carbonate rocks become thicker and more continuous toward the northwest. In two of the composite sections from the northwestern part of the region, the thickest single intervals are composed of carbonate rocks. Carbonate rocks occur as dolomite interbeds in the Wood Canyon Formation and the upper part of the Stirling Quartzite throughout much of the central part of the study area, and in discrete formations, such as the Reed Dolomite, in Esmeralda County, Nev.

Structural aspect
In addition to regional stratigraphic changes, the rocks within the study interval exhibit differences in structural style across the region. In the eastern part of the region, the study interval is generally exposed in the upper plates of thrust faults or in rotated range blocks associated with normal faults. The interval is exposed in the hanging wall of the Wheeler Pass thrust in the Spring Mountains (WPT, fig. 1) (Burchfiel and others, 1974), the hanging wall of the Specter Range thrust in the Specter Range (small exposures just south of the southern boundary of the Nevada Test Site, fig. 1) (Burchfiel, 1965) and in the rotated range blocks of the Resting Spring (location 11, fig. 1) and Nopah Ranges (Burchfiel and others, 1983) and the Pintwater Range (location 9, fig. 1) (Tschanz and Pampeyan, 1970). The metamorphic grade is low at all of these exposures. For example, the shaly portions of the Wood Canyon Formation are phyllitic
Figure 3. Aggregate thickness of sandstone and conglomerate as a percentage of total thickness for the composite stratigraphic sections. Contour interval is 10 percent.
Figure 4. Sand-shale ratio for composite stratigraphic sections. Sand-shale ratio is computed as aggregate thickness of section that is sand-size or coarser divided by the aggregate thickness of section that is silt-size or finer. Contour interval is expressed as a unitless ratio, in intervals of 0.25.
Figure 5. Three-component diagram for the composite stratigraphic sections.
(sub-greenschist-grade). In general, the rocks in the study interval in the eastern part of the region has been affected by brittle deformation in the upper crust. In contrast, the study interval in the western part of the region is exposed in the lower plates of major regional detachment structures. Examples include Bare Mountain (location 6, fig. 1) (Monsen and others, 1992), the Funeral Mountains (northwest of location 7, fig. 1) (Wright and Troxel, 1993), and the Panamint Mountains (PM, fig. 1) (Hunt and Mabey, 1966; Labotka and others, 1980). In these exposures, metamorphic grade is much higher (as high as amphibolite grade), rocks are foliated, and the deformation is more ductile in nature and characteristic of mid-crustal levels.

Brittle fracturing of clastic rocks in the Late Proterozoic part of the section, particularly the Stirling Quartzite, might result in locally enhanced permeability of the clastic units. The line of springs along the east margin of Ash Meadows (AM, fig. 1) represents discharge from the regional ground-water system (Winograd and Thordarson, 1975). Most of the major springs at Ash Meadows show a limited range of $\delta^{87}$Sr that is interpreted to reflect flow through the regional Paleozoic carbonate aquifer. However, three springs at the very southeast end of the spring line have high $\delta^{87}$Sr (Peterman and Stuckless, 1993; Peterman and others, 1992). These values are interpreted as reflecting travel through rocks with elevated levels of radiogenic strontium and probably reflect local flow through fractured Late Proterozoic quartzites in the northwest end of the Spring Mountains. Flow might be enhanced by fracturing that accompanied extensional faulting along a brittle, low-angle normal fault in the northwest end of the Spring Mountains (Burchfiel, 1965; Abolins, 1999).

**Summary of Material Properties throughout the Region**

On the basis of combined stratigraphic and structural data for the rocks of the study interval in the Death Valley ground-water basin, six broad zones have been delineated (fig. 6) that represent areas with potentially distinct material properties and potentially different hydraulic properties.

**Zone 1:** This zone corresponds to Stewart’s (1970) eastern region and is characterized by a stratigraphic section that is very thin (a few hundred meters) and is similar to the cratonic sedimentary interval exposed in the Grand Canyon.

**Zone 2:** This zone corresponds to Stewart’s (1970) central region and is characterized by a westward-thickening (but generally 2-3 km thick) wedge of fine- to coarse-grained sandstone, siltstone, conglomeratic sandstone, and minor amounts of carbonate rock.

**Zone 3:** This zone corresponds to Stewart’s (1970) western region and is characterized by a thick (greater than 3 km) section of interbedded siltstone, limestone, dolomite, and fine-grained sandstone.

**Zone 4:** In this zone, between localities 12 and 14 (fig. 1) and the south end of Death Valley, the rocks in the study interval are underlain by rocks of the Pahrump Group, a locally thick accumulation of Middle and Late Proterozoic sedimentary rocks.
Figure 6. Regional map showing location of zones that define major regional differences in material properties of Late Proterozoic to Lower Cambrian rocks.
The Pahrump Group includes a significant thickness of dolomite and might locally be important to fluid flow.

Zone 5: In this zone the rocks in the study interval are exposed in the lower plates of major regional detachment structures. In these exposures, metamorphic grade is high, and the rocks are foliated and are potentially impermeable.

Zone 6: In this zone, located in the southwestern part of the region, rocks in the study interval are either missing or their character is completely unknown.

Summary

The main facies transition within the Late Proterozoic through Lower Cambrian stratigraphic section of the Death Valley region is from an eastern region dominated by thick intervals of coarse clastics interbedded with shale, to a more shale-dominated region with significant amounts of carbonate rocks. This transition documented as the boundary between the western facies and the central facies of Stewart (1970), or between the Death Valley facies and the White-Inyo facies of Nelson (1978). Accompanying the regional stratigraphic changes are regional differences in deformational style. Rocks in the east half of the region are affected by brittle deformation that occurs at shallow crustal levels. This brittle deformation affects the sand-rich facies of the Late Proterozoic through Lower Cambrian section and can result in significant fracture permeability. Rocks in the west half of the region are more ductilely deformed. These shale-rich, foliated metamorphic rocks have a tendency to shear and slip rather than fracture. In the western region, the section was deformed ductilely at much deeper crustal levels and did not fracture readily. Late Proterozoic to Lower Cambrian strata in the far northwestern part of the region that contain significant thickness of limestone or dolomite might have primary or secondary (fracture) porosity.
References Cited


