# Mora-Wagon Mound SWCD

# Hydrogeology Project

# Annual Progress Report

# 2014-2015

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# Introduction

This report is Zeigler Geologic Consulting, LLC's (ZGC) annual progress report for the Mora-Wagon Mound Hydrogeology Project, sponsored by the Mora-Wagon Mound Soil and Water Conservation District. During the 2014-2015 fiscal year, ZGC measured static water level in 25 wells in January, mapped the area between Watrous and Colmor, obtained eight water chemistry samples and 10 radiocarbon dating samples, and examined well cuttings from five petroleum wells. Here we describe the progress in each of these tasks. We would like to thank the Soil and Water Conservation Commission for funding this project and we also thank the High Plains Grassland Alliance for additional funding and with helping us to make contact with multiple land owners.

# Static Water Level Measurements

In January of 2015, depth to water has been measured in 25 wells spread across the county to document minimum use water levels. These same wells will all be measured again in August to record maximum use of the local aquifer systems. A 300 ft steel tape is used for most of the wells and a 500 ft steel tape for wells deeper than 300 ft. For open casing wells, we use a well level sounder (maximum length of 300 ft). The measuring point, or height of the entrance to the well above land surface, is subtracted from the total depth measurement such that the final static water level for all wells is calculated relative to the land surface. Measurements are repeated until two values that are within 0.01 ft of one another are obtained. We observed three discrete groupings of water levels in the District area, a shallow zone of water levels between 10' and 40', an intermediate zone between 150' and 300' and a deeper zone with water levels greater than 350'. We hypothesize that the shallow zone is an alluvial aquifer, the intermediate zone corresponds to the Dakota Sandstone and that the deeper zone corresponds to the Morrison Formation. This hypothesis will be tested by further mapping and development of detailed cross-sections across the county.

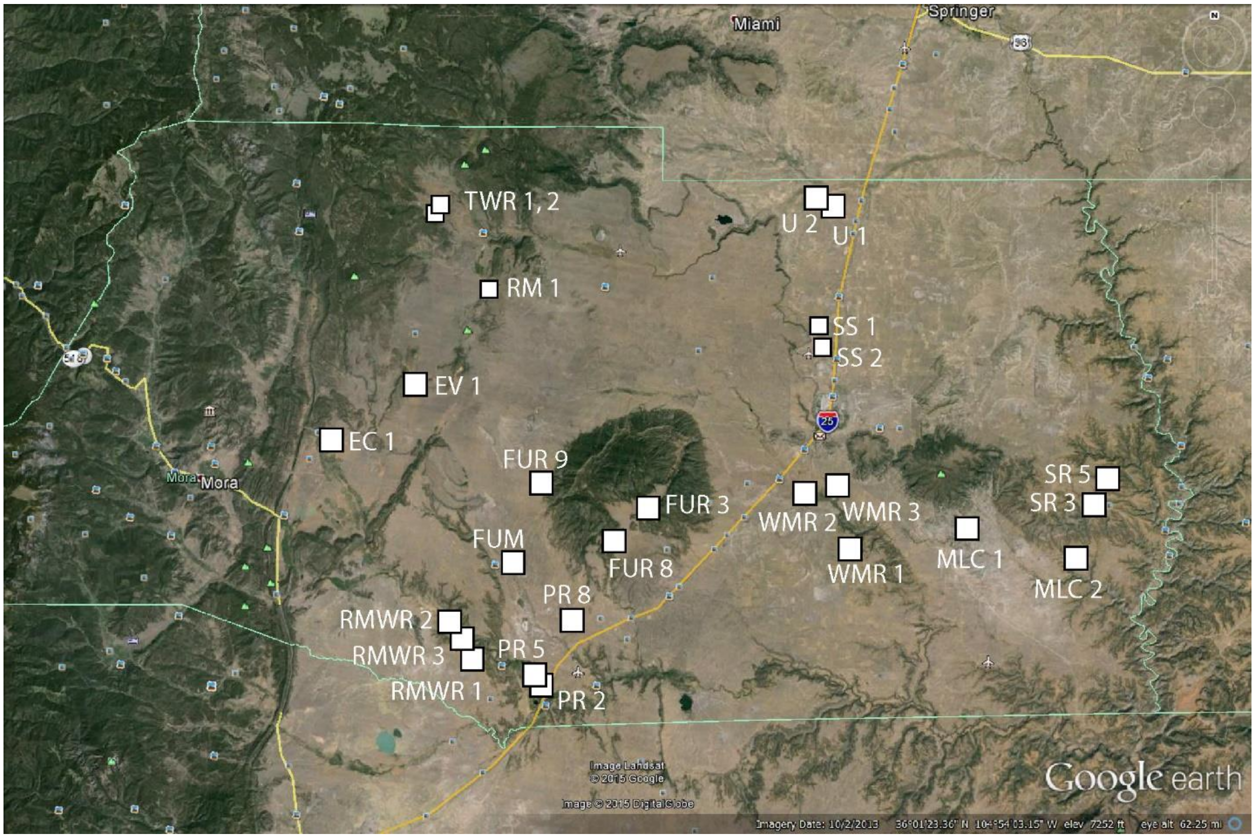



**Figure 1. Location of wells measured in January 2015.**

## Water Chemistry

Approximately two liters of water were collected from each of eight wells distributed across the county for basic water chemistry analyses of major cations and anions (Figure 2). Wells were allowed to flow for 10 minutes prior to collecting a sample if the well was off upon arrival. For stock tanks where the windmill was actively pumping on arrival, a sample was collected within a few minutes. The analytical work was conducted by Hall Environmental of Albuquerque and analyses included the cations calcium (Ca), sodium (Na), magnesium (Mg) and potassium (K), and the anions carbonate ($CO_3$), bicarbonate ($HCO_3$), sulfate ($SO_4$) and chloride (Cl) (Figure 3).

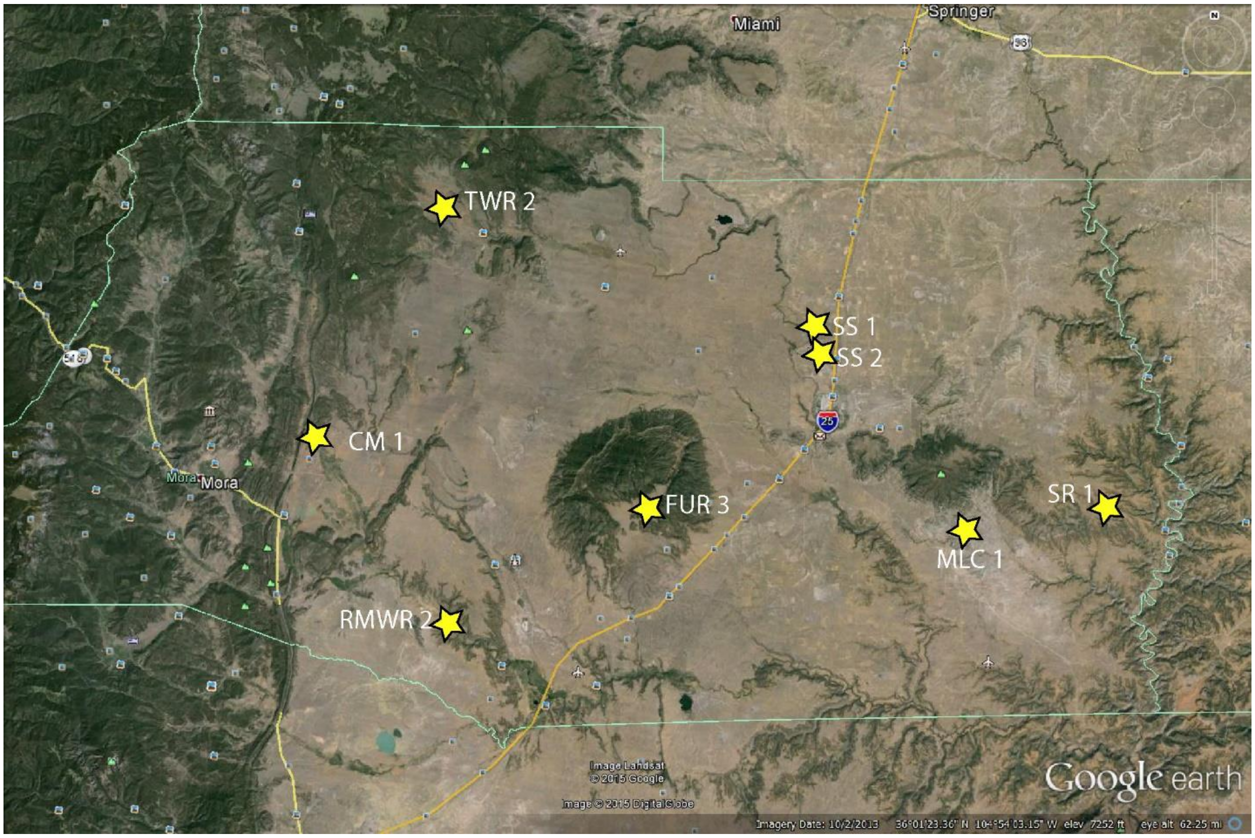



**Figure 2. Well locations with water chemistry samples taken.**

Each of the ions analyzed for can provide information about groundwater-rock unit interactions. A brief overview of each ion follows here (based on Hem, 1985) and we recommend Hem's (1985) *Study and Interpretation of the Chemical Characteristics of Natural Waters* for an in-depth review of groundwater chemistry.

Calcium is the most abundant of the alkaline-earth metals and is an important part of many igneous, metamorphic and sedimentary rocks. In igneous rocks, the minerals pyroxene, amphibole and the feldspar family contain calcium, but in general, groundwater that interacts with igneous rocks has relatively low concentrations of calcium due to the slow decomposition rates of most of these minerals. In sedimentary rocks, calcium occurs most commonly in carbonate rocks, such as limestone and dolomite, and in the sulfate evaporites gypsum and anhydrite. In sandstone, calcium is generally present as a cementing agent and in soils it is present as an adsorbed ion on negatively charged surfaces.

Magnesium is also an alkaline-earth metal that is important in mafic igneous rocks, occurring in minerals such as pyroxene, amphibole and olivine. In sedimentary rocks, magnesium occurs as a carbonate (magnesite) or as a mixture with calcium (e.g., limestone and dolomite). Magnesium carbonates are more soluble than calcium carbonates. Hem (1985) notes that magnesium concentration tends to increase along groundwater flow paths. Sodium is the most abundant of the alkali metals and is an important constituent in igneous and sedimentary rocks in the feldspar mineral family. Feldspars that include a mixture of sodium and calcium tend to be more susceptible to chemical weathering. In sedimentary rocks, evaporites (e.g., rock salt) are important sources of sodium, as well as sodium occurring as part of unaltered minerals, an impurity in a cement or as a residue left over by saline waters that interacted with sediments or sedimentary rocks after depositions. In interbedded shales and sandstones, sodium is often held in the less permeable shales and with long-term groundwater withdrawal and declining water tables, this sodium can be reintroduced into the groundwater from the shales.

Potassium goes into solution less readily than does sodium and tends to be incorporated back into solid weathering products during chemical weathering. It is an important ion in many igneous rock minerals, including the feldspar family and micas. In sedimentary rocks, potassium is a constituent of unaltered feldspar grains, micas, clays minerals and some evaporites. Because it is less soluble than sodium, potassium concentrations tend to be relatively low. Carbonate and bicarbonate are produced as part of the interactions of water and carbonates (e.g., limestone and dolomite). Bicarbonate concentrations are higher in more acidic waters and carbonate concentrations are higher in more basic waters.

Sulfate occurs as a result of the chemical weathering of sulfide minerals with aerated waters. In this reaction, sulfur is oxidized to form sulfate ions. In sedimentary rocks, pyrite is a common mineral host for sulfur that occurs in association with biogenic deposits, such as coal. The most important contributors for sulfate are the evaporite rocks gypsum and anhydrite.

Chloride is the most abundant halogen but conversely has one of the lowest concentrations in rocks. It is generally most common in sodalite (a feldspathoid) and apatite (a calcium phosphate), as well as occurring as an impurity in other minerals. In sedimentary rocks, chloride occurs as inclusions in brine deposits, in cements or as incompletely leached deposits that formed in ocean or closed basins. Chloride tends to be moved through the hydrologic cycle by physical processes, as opposed to chemical processes (Hem, 1985). Generally, where sodium is the dominant cation present, chloride will be the dominant anion (primarily due to the relationship of sodium and chloride ionically bound together as halite, or rock salt).

The chemistry of the water in each well reflects primarily the bedrock unit(s) that the well is drawing water from (Figure 3). These wells appear to be screened along most of their length, such that wells that penetrate more than one geologic unit will have mixed waters. In general, water from wells that are completed in the Dakota Group contain higher abundances of carbonate, bicarbonate, calcium and magnesium. Water from wells completed in the Jurassic Morrison Formation contain significant quantities of sodium and potassium, and water from wells that penetrate units with black shale (Dakota Group, Graneros Shale) contain sulfate.

These differences in chemistry reflect the differences in mineralogy among these bedrock units. Dakota Group sandstones are cemented with calcite, which can dissolve to provide carbonate, calcium and magnesium. Black shales, which are commonly interbedded with sandstone in the Dakota Group, and constitute the primary lithology of the Graneros Shale, contain gypsum, a calcium sulfate, which provides sulfate. The Morrison Formation is rich in feldspars, which can contain sodium and potassium, providing these two cations. Wells that include a mixture of waters from the Dakota Group and the Morrison will thus include some proportion of all the ions expected for those waters. Wells completed in the Triassic Chinle Formation, which is primarily red mudstone and sandstone, contain magnesium, calcium and carbonate.

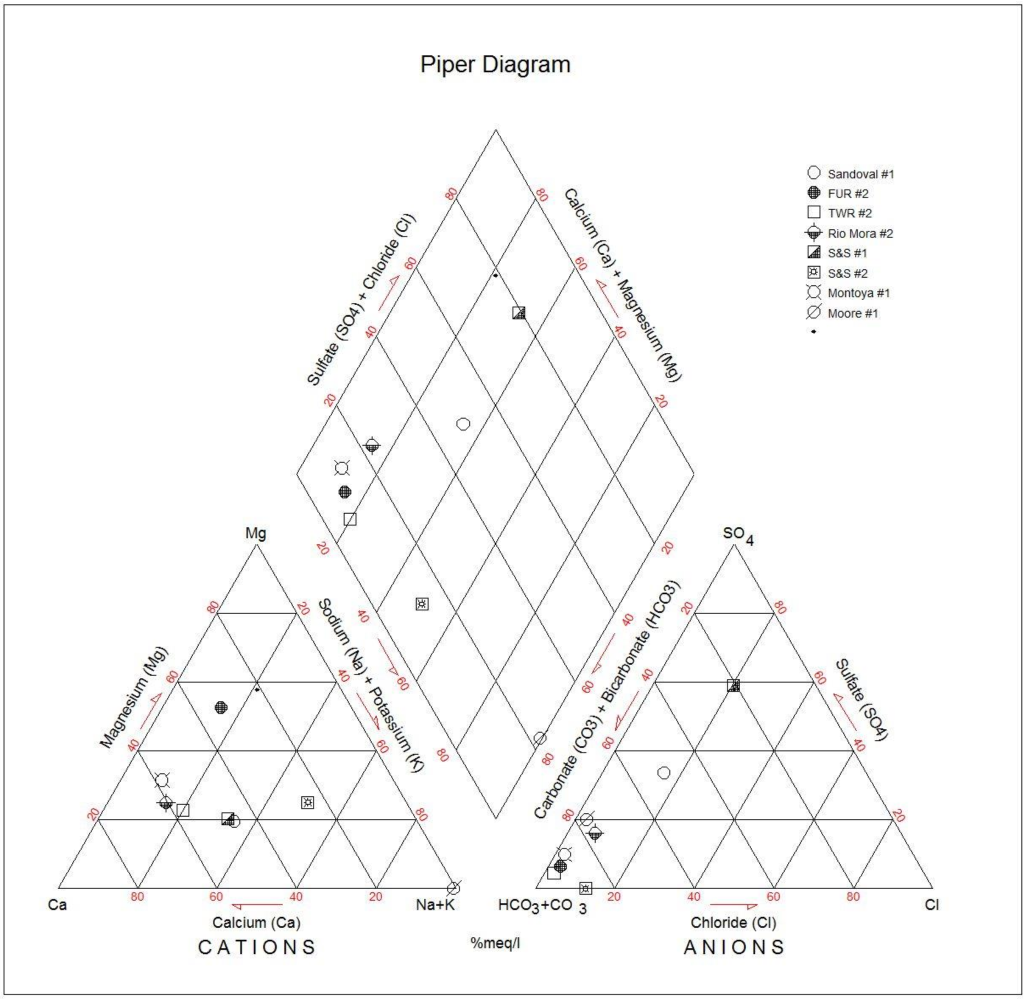



**Figure 3. Piper diagram for water chemistry samples collected January 2015 from Mora-Wagon Mound area.**

## Carbon-14 Dates

We collected one liter of water from each of ten wells around the District (Figure 4). The samples were analyzed by Beta Analytic, Inc. in Miami, Florida. Groundwater age is related to the rate at which water migrates through the subsurface. It is important to remember that water molecules may enter and leave the system via cross-formational flow and that any given mass of groundwater will exchange water molecules with masses of water on all sides of it (Bethke and Johnson, 2008). Hence, a mass of water that entered the groundwater and had a single age associated with it will end up with many of those particles dispersed, rather than traveling entirely as a discrete package. A groundwater sample, therefore, is an average of the ages of all of the molecules of water contained in that sample (Bethke and Johnson, 2008). The distribution of these ages for each sample may include much older molecules and much younger molecules, and may be heavily skewed in one direction or the other. Dating methods, including Carbon-14 ($^{14}C$), generally include the assumption that the groundwater mass is acting as a closed system after it infiltrates below the water table. $^{14}C$ is used for materials that are assumed to be less than 50,000 years old and has a half-life of 5,730 years. It is produced by cosmic rays in the atmosphere and the $^{14}C$ is then dissolved as $CO_2$ in rainfall and as the moisture occurring in roots in the vadose zone. $^{14}C$ is then introduced into the groundwater system by infiltration of surface waters or water migrating downward from the root zone. One complication for the $^{14}C$ method is that the oxidation of ancient organic matter or the dissolution of carbonates (e.g., limestone) will add $^{14}C$-depleted carbon (also called "dead" carbon) into the groundwater (Bethke and Johnson, 2008). This process will create an erroneously old age and so ages of water extracted from systems that are suspected of including carbonate interactions should be corrected for this depleted carbon addition.

For this study, geochemical interactions with the host rocks in the Dakota Group and Morrison Formation are unlikely to contribute significant amounts of "dead" carbon due to a lack of significant quantities of carbonate rocks. The eight samples collected show an apparently random distribution of average ages, with no trend towards younger waters in any particular direction. Average ages range from 0 to around 21,630 years before present (YBP). The youngest water occurs west of Ocate, with an effective age of 0. Very young water also occurs between Wagon Mound and Colmor (approximately 10 years before present) and along the Rio Mora at Watrous. The oldest waters occur in a bench of bedrock northeast of the Rio Mora, within the Turkey Mountains and along the far eastern edge of the study area, on a tributary to the Canadian River. The older age seen in the Turkey Mountains probably reflects a partitioning of groundwater within the Triassic Chinle Formation. The oldest age of 21,630 is anomalous and further analyses are needed.

The very young ages at some of the wells suggests some degree of interaction with younger waters infiltrating from the surface. Future work will include a tritium age analysis for the youngest of the waters sampled. The apparent lack of a trend of younger waters to the west suggest that the aquifer units (Dakota Group, Morrison Formation) are more internally partitioned than might otherwise be expected. In addition, complex folding of the rocks in the subsurface brings older rocks (and thus, older waters) closer to the surface.

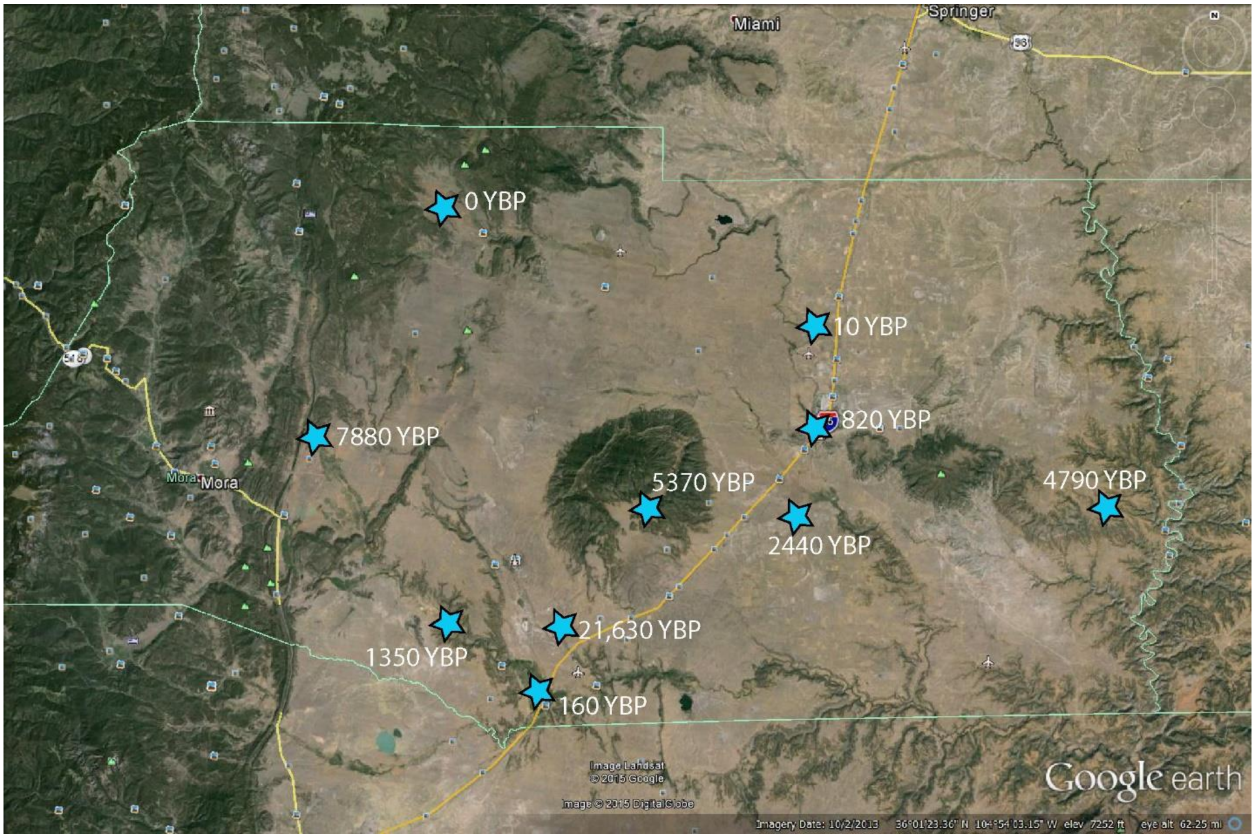



**Figure 4. $^{14}C$ age determinations for four wells sampled in January of 2015.**

## Geologic Mapping

We have mapped an approximately four mile wide strip from Watrous north to Colmor in order to incorporate areas with known groundwater issues, such as declining flows and water quality problems. Bedrock outcrops include (in age order) the Cretaceous Dakota Sandstone, Graneros Shale, Greenhorn Limestone, and Quaternary volcanic deposits and recent eolian sand and alluvial deposits. The Dakota Sandstone is a fine to medium grained quartz sandstone that can range in color from white to orange to dark red or pale gray. The uppermost surface is frequently heavily bioturbated (Lucas, 1990) and weathers unevenly, often producing miniature hoodoos. Low angle crossbeds are common. The lower Dakota Sandstone locally includes rip-up clasts of green mudstone and white caliche.

The Graneros Shale is a pale gray to pale yellowish gray shale with two or three yellow-brown calcarenites that are less than 0.5 m thick and contain abundant fossil material from ammonites and inoceramid clams. The Graneros Shale is frequently covered with debris from overlying basalt flows and so exposures of this unit are not common. On the frontage road of I-25, just south of a Colmor, an igneous dike has preserved a long, low hill of Graneros Shale, which shows well-developed contact metamorphism immediately adjacent to the dike. The Greenhorn Limestone is a pale gray to dark gray shale with interbedded thin micritic limestone beds that occasionally include fossil material. The limestone beds are very pale gray to white and are often bioturbated. Similar to the Graneros Shale, the Greenhorn Limestone is only preserved locally and is generally not well exposed.

The Quaternary basalt flows occur throughout the mapping area and are sourced from vents on the east flank of the Turkey Mountains (Mount Baldy), in the Wagon Mound area and from the west, towards Ocate. These flows are part of the Ocate volcanic field and are 8.3 to 0.8 million years old (Lessard, 1976; Calvin, 1987; O'Niell and Mehnert, 1990). Igneous dikes (vertical to subvertical intrusions of magma) occur sporadically throughout the area and range in composition from basaltic to andesitic. Much of the landscape is covered by variable thicknesses of alluvium and/or eolian sheet sands. Geologic mapping of the county is ongoing. Further revisions will be presented in subsequent reports.

In addition to mapping distribution of different rock types and their orientations, folds, faults and other features, clusters of fractures were also documented. These fractures are presumably pervasive through the underlying bedrock and provide conduits for groundwater to flow along. Fracture sets around Watrous are oriented northwest-southeast to north-south and are actually not in line with the Turkey Mountains, as previously expected. This may indicate that recharge into groundwater south of the Turkey Mountains is not sources from these highlands, but rather from the Ocate anticline to the west (Figure 5, 6).

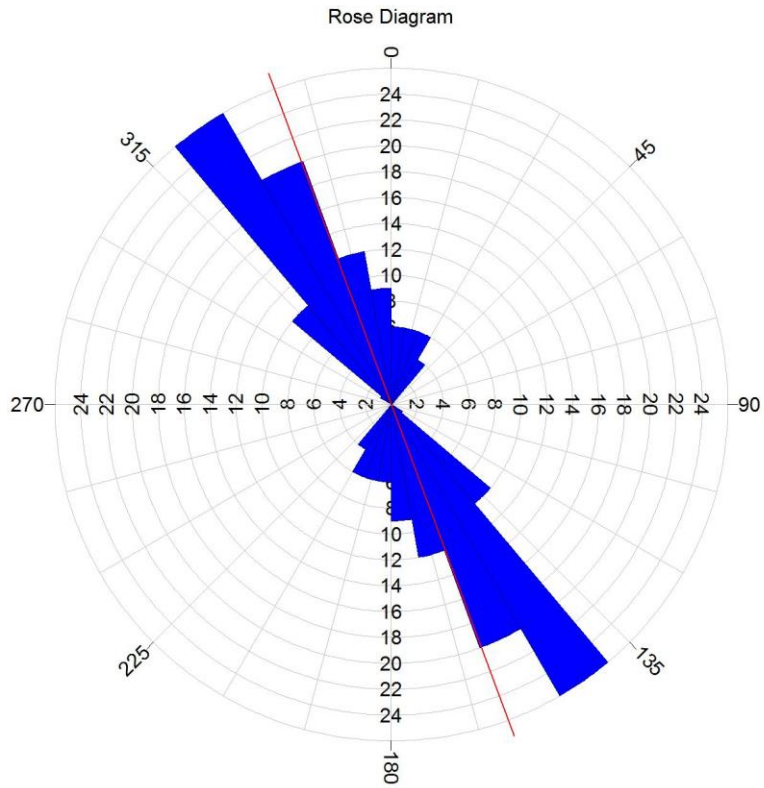



**Figure 5. Rose diagram showing orientation of fractures immediately north of the Mora River, west of Watrous (N = 100).**

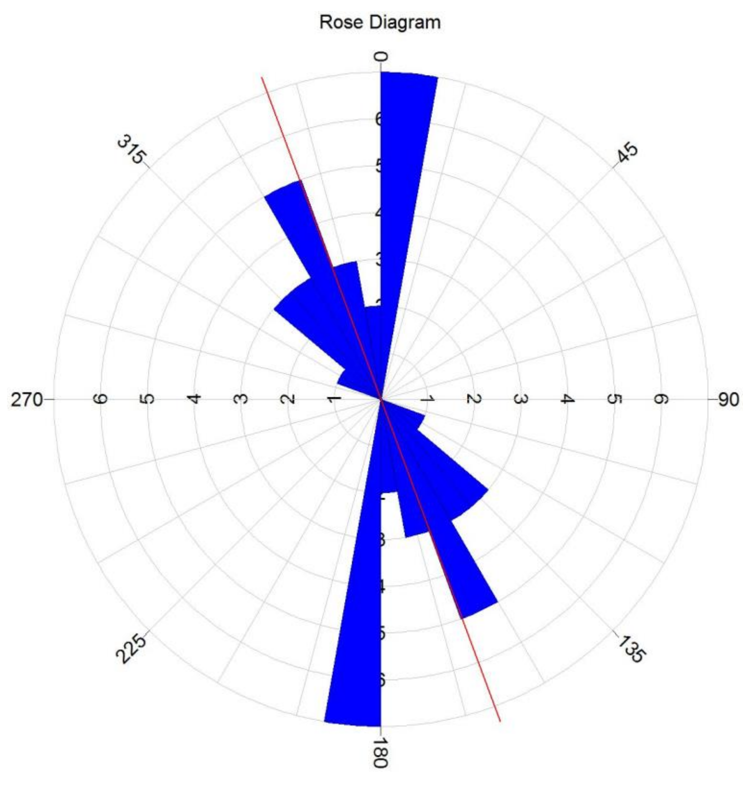
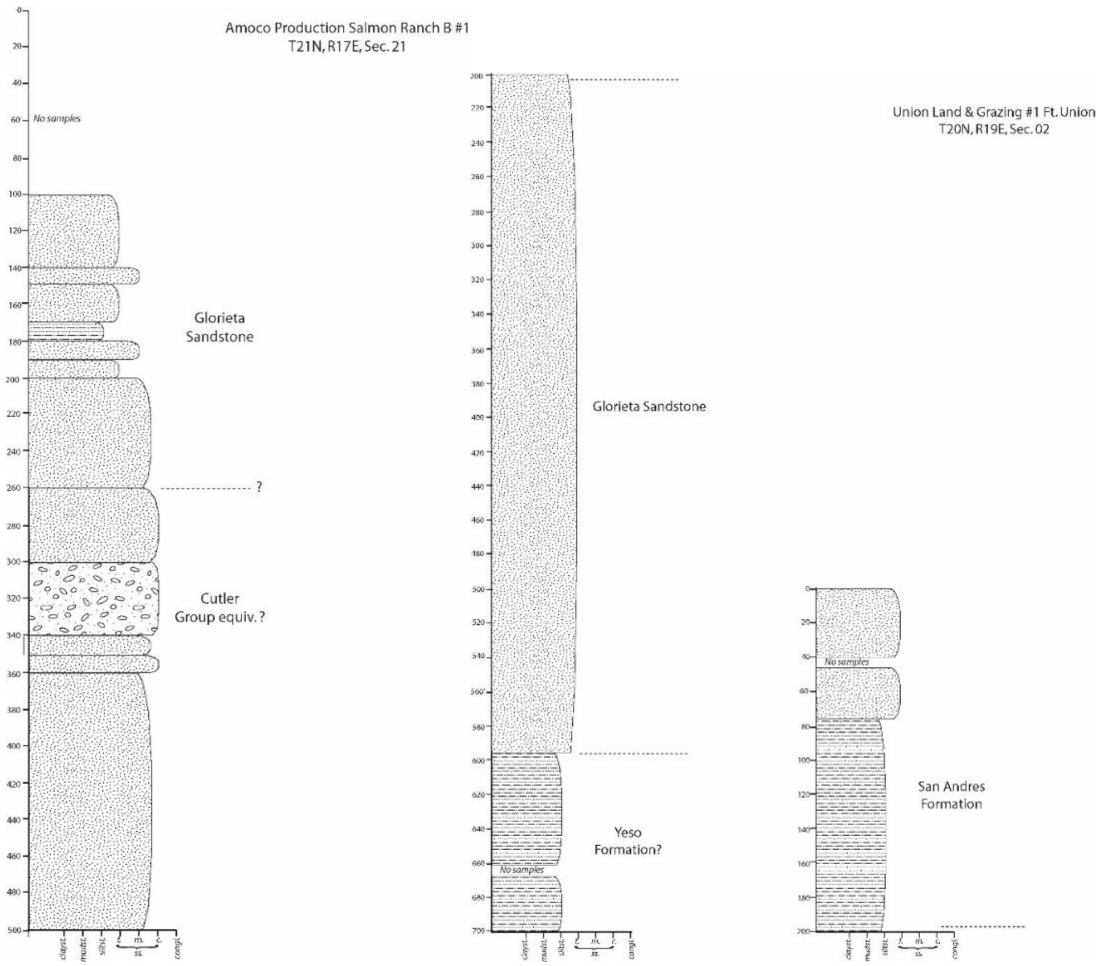
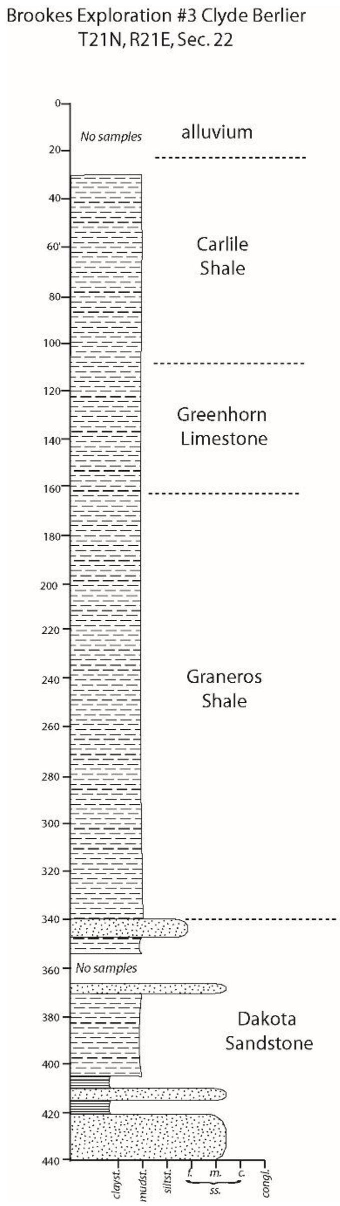


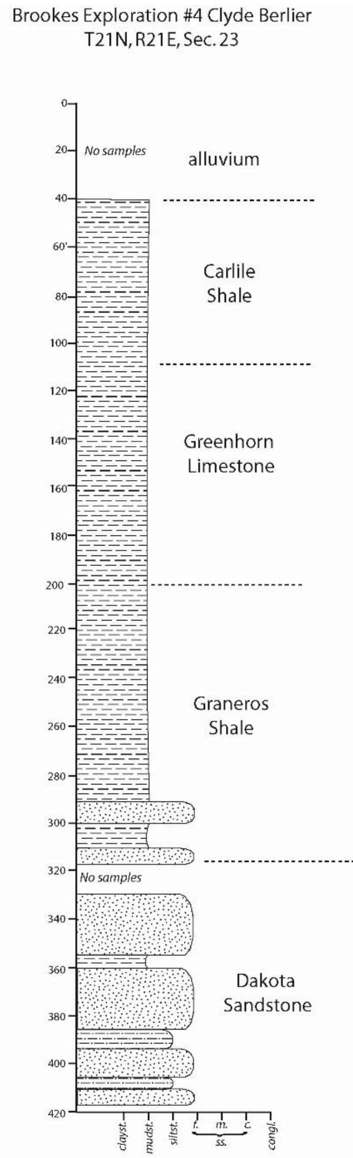

**Figure 6. Rose diagram of fracture orientations taken just south of the Turkey Mountains on Wolf Creek (N = 25).**

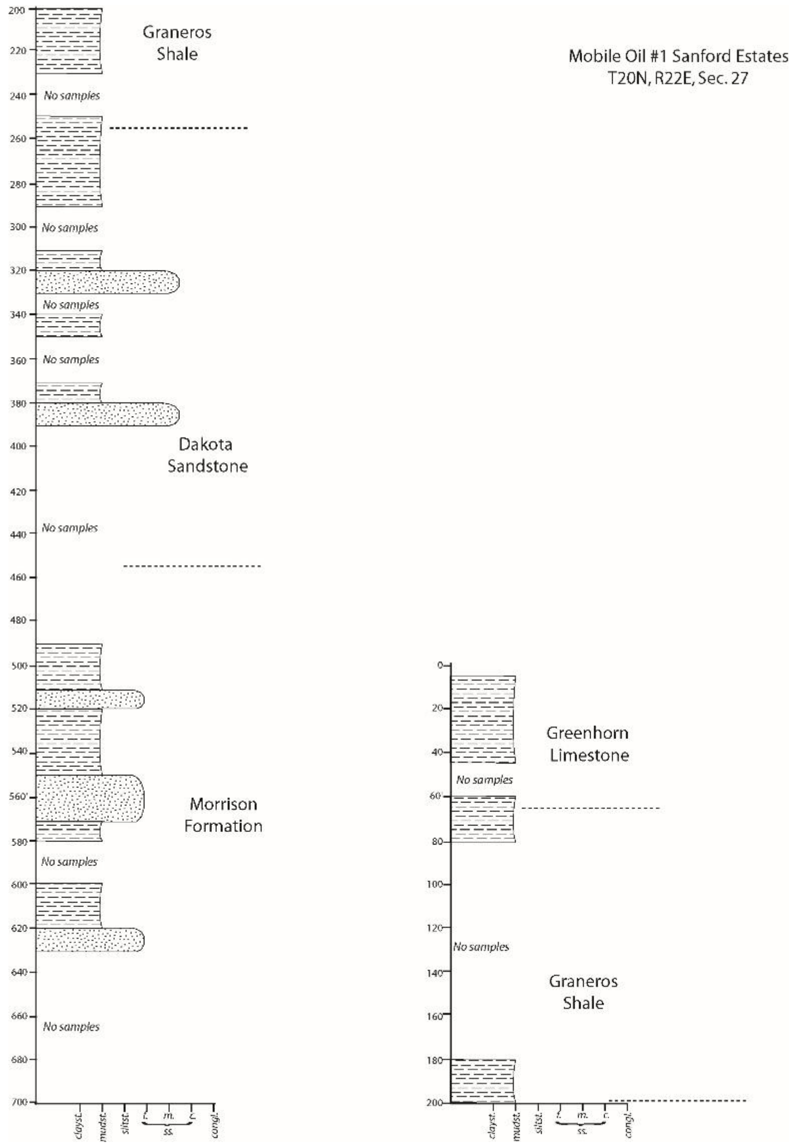
## Petroleum Well Cuttings and Subsurface Analysis

Five petroleum wells have provided a window into the subsurface of the Mora-Wagon Mound area. By examining cuttings and well logs associated with these wells, we are able to construct a picture of where the various bedrock units are in the subsurface (Figure 7). This preliminary east-west transect demonstrates that the subsurface geology is fairly complex. The western most well examined, the Salmon Ranch B #1 lies near the hinge of the Ocate anticline, which brings older Permian strata to the surface near the village of Ocate. The Union Land & Grazing #1 Ft. Union well, drilled near the center of the Turkey Mountains, also shows Permian strata brought to the surface by intrusion of magma, which domed the land surface upward. The Clyder Berlier #3 and #4, to the northeast of the Turkey Mountains, are more representative of the Cretaceous stratigraphy expected in this area. Fairly thick sequences of shale and limestone are preserved above the Dakota Sandstone. The farthest east well, #1 Wooten & Reardon, is interesting as the cuttings have been interpreted to show Morrison Formation rocks in the shallow subsurface and no Cretaceous strata. This may reflect either faulting or folding of Mesozoic strata placing Jurassic rocks adjacent to Cretaceous rocks, or it may indicate paleotopography developed on top of the Morrison such that there are paleo-ridgelines and paleovalleys infilled with younger strata (Figure 8).


Amoco Production Salmon Ranch B #1
T21N, R17E, Sec. 21
No samples
Glorieta
Sandstone
?
Cutler
Group equiv. ?
Glorieta Sandstone
No samples
Yeso
Formation?
Union Land & Grazing #1 Ft. Union
T20N, R19E, Sec. 02
No samples
San Andres
Formation


Brookes Exploration #3 Clyde Berlier
T21N, R21E, Sec. 22
No samples
alluvium
Carlile Shale
Greenhorn Limestone
Graneros Shale
No samples
Dakota Sandstone
clayst.
mudst.
siltst.
f.
m.
c.
ss.
congl.


Brookes Exploration #4 Clyde Berlier
T21N, R21E, Sec. 23
No samples
alluvium
Carlile Shale
Greenhorn Limestone
Graneros Shale
No samples
Dakota Sandstone
clayst.
mudst.
siltst.
f.
m.
c.
ss.
congl.


Mobile Oil #1 Sanford Estates
T20N, R22E, Sec. 27
Graneros Shale
No samples
Dakota Sandstone
Morrison Formation
Greenhorn Limestone
Graneros Shale
clayst. mudst. siltst. f. m. c. ss. congl.

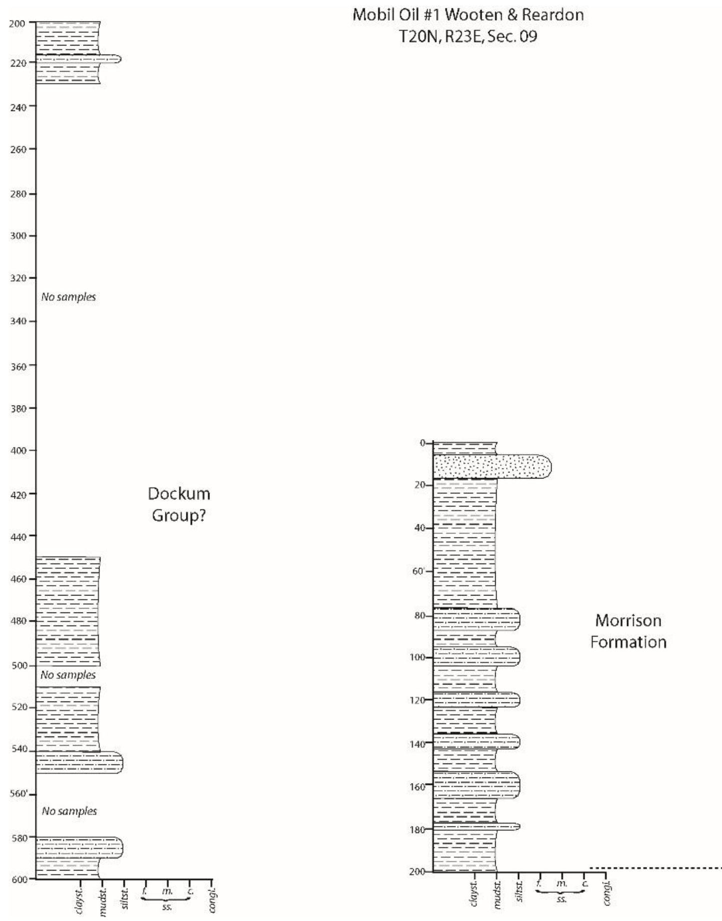



**Figure 7. Interpretive stratigraphic columns developed from petroleum well cuttings. Stratigraphic boundaries are chosen based on both the cutting lithologies, as well as the geophysical logs associated with each well. The primary data for contact placement came from the geophysical logs and is supplemented by the cuttings data.**

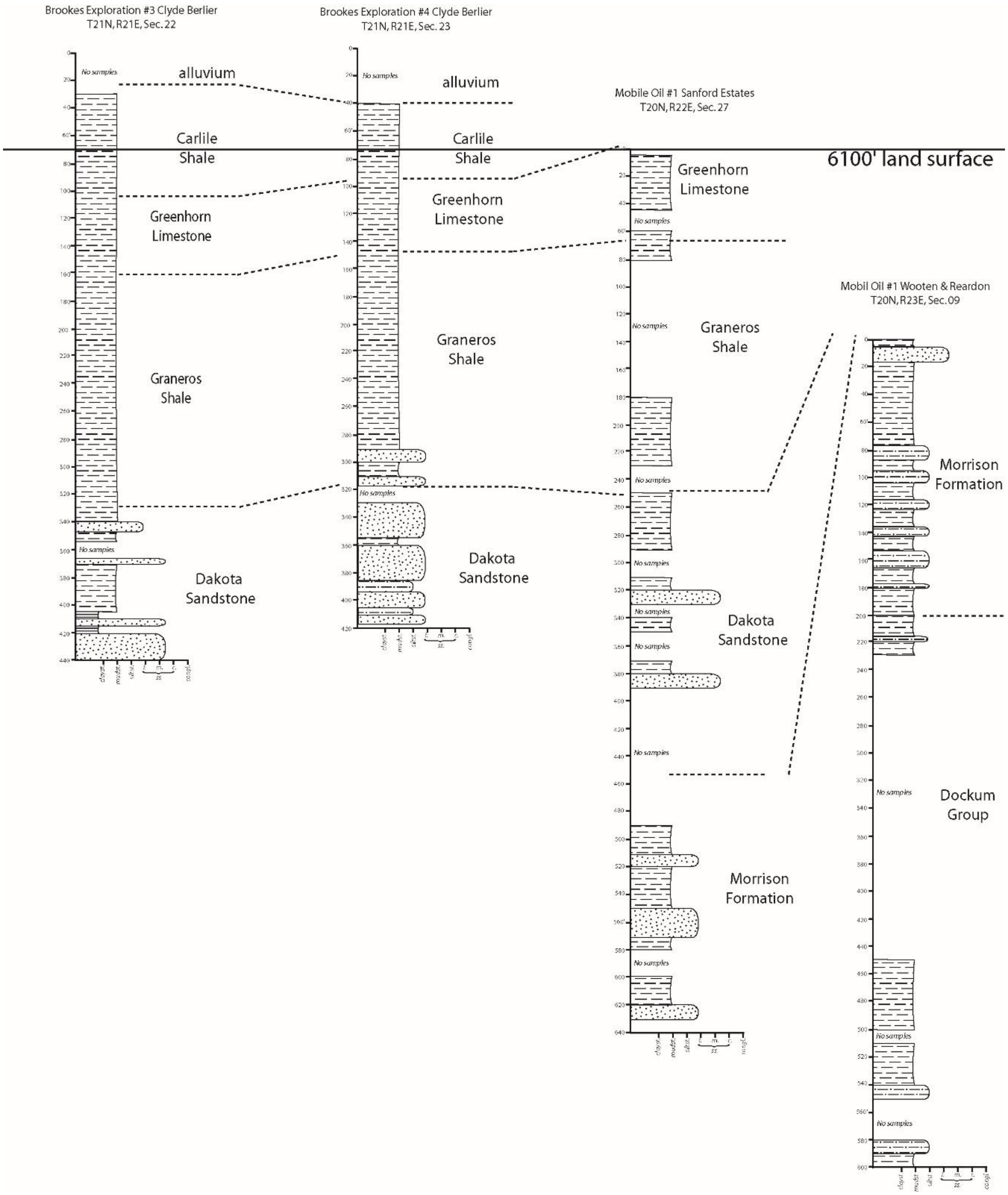



**Figure 8. Stratigraphic correlation diagram from the Wagon Mound area southeast towards the Canadian River valley.**

## Conclusions

Water chemistry, static water levels and surface mapping demonstrate the complexity of the geology in the Mora-Wagon Mound District area. Zones of groundwater appear to occur at discrete elevations: shallow (0 – 40’), intermediate (150-300’) and deep (>350’), which may correlate reasonably well to alluvial (shallow), the Dakota Sandstone (intermediate) and the Morrison Formation (deep). Additional structural complexities, such as the Ocate anticline and the Turkey Mountains, bring deeper and older rock units to the surface, such as the Permian Glorieta Sandstone and Yeso Formation. Radiocarbon dates do not have an obvious trend of younger waters to the west or to the east, although the youngest waters present were taken from the farthest west well. Very old radiocarbon ages, such as the oldest date obtained from south of the Turkey Mountains, may reflect interaction of those waters with carbonates. Ages of water along the Rio Mora are generally older than anticipated, but probably reflect mixing of very young river water with older formation waters, leading to an average age that is older. Examination of petroleum well logs and cuttings continues to demonstrate the complexity of the subsurface, including structural relief or paleotopography affecting the Morrison Formation.

Future work includes static water level measurements in August of 2015 and January of 2016 to begin tracking rates of changes between minimum and maximum use seasons and on an annual basis. Continued geologic mapping and petroleum well log analyses will assist in developing a better picture of the complexities of the subsurface.

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# Appendices

## Appendix I: January Static Water Level Measurements

Individual well static water level measurements for January 2015.

| ID | Date Measured | Water level from land surface (feet) |
|---|---:|---:|
| MLC 1 | 2/12/2015 | 72.54 |
| MLC 2 | 1/19/2015 | 133.7 |
| SR 3 | 1/19/2015 | 233.3 |
| SR 5 | 1/19/2015 | 116.38 |
| FUR 4 | 1/20/2015 | 73.69 |
| FUR 8 | 1/20/2015 | 108.13 |
| FUR 9 | 1/20/2015 | 2.91 |
| TWR 1 | 1/20/2015 | 87.06 |
| TWR 2 | 1/20/2015 | 46.24 |
| RMNWR 1 | 2/8/2015 | 129.51 |
| RMNWR 2 | 2/8/2015 | 28.4 |
| RMNWR 3 | 2/8/2015 | 3.75 |
| PR 2 | 2/8/2015 | 9.04 |
| PR 5 | 2/8/2015 | 3.65 |
| PR 7 | 2/8/2015 | 91.9 |
| WMR 1 | 2/9/2015 | 38.1 |
| WMR 2 | 2/9/2015 | 23.9 |
| WMR 3 | 2/9/2015 | 46.82 |
| RM 1 | 2/9/2015 | 174.83 |
| S&S 1 | 2/10/2015 | 43.82 |
| S&S 2 | 2/10/2015 | 24.52 |
| EC 1 | 2/12/2015 | 393.84 |
| EV 1 | 2/18/2015 | 261.37 |
| U 1 | 5/20/2015 | 51.2 |
| U 2 | 5/20/2015 | 27.23 |

## Appendix II: Well Cutting Descriptions 2015

***Union Land & Grazing #1 Fort Union (2-20N-19E, TD: 4077')***

| | |
|---|---|
| 0-12' | Pale yellow quartz arenite, fine grained, subangular, well sorted, 98% Q, 2 % opaque, >15% clay matrix, silica cement, -HCl. Mostly loose grains. |
| 12-20' | Pale yellow quartz arenite, fine grained, subangular, well sorted, 98% Q, 2 % opaque, >15% clay matrix, silica cement, -HCl. Mostly loose grains. Pale gray mudstone (rip-up clasts?), -HCl. [95% sandstone, 5% mudstone] |
| 20-27' | Ditto 12-20'. Sandstone has some hematite locally. |
| 27-33' | Pale yellow quartz arenite, fine grained, subangular, well sorted, 98% Q, 2 % opaque, >15% clay matrix, silica cement, -HCl. |
| 33-40' | Ditto 27-33'. |
| 40-45' | No samples. |
| 45-53' | Pale yellow quartz arenite, fine grained with some coarse grains, subangular, poorly sorted, 95% Q, 2 % opaque, 3% rip-up clasts, >15% clay matrix, silica cement, -HCl. |
| 53-54' | Ditto 45-53'. |
| 54-61' | Pale yellow quartz wacke, fine to coarse grained, subangular to subround, poorly sorted, 95% Q, 2% opaque, 3% rip-up clasts, ≥15% clay matrix, -HCl. |
| 61-63' | Ditto 54-61', some granules of quartz and rip-up clasts. |
| 63-70' | Pale yellow quartz arenite, fine grained, subangular, well sorted, 90% Q, 6% L (incl. muscovite), 4% rip-up clasts, <15% clay matrix, -HCl. Common manganese staining. |
| 70-74' | Pale yellow quartz arenite, fine grained, subangular, well sorted, 90% Q, 6% L (incl. muscovite), 4% rip-up clasts, <15% clay matrix, -HCl. Hematite common. |
| 74-76' | Pale yellow quartz wacke, fine grained, subangular, well sorted, 90% Q, 6% L (incl. muscovite), 4% rip-up clasts, ≥15% clay matrix, -HCl. |
| 76-82' | Very pale green and pale orange siltstone, locally micaceous (muscovite), -HCl. |
| 82-85' | Ditto 76-82'. Very rare pyrite. |
| 85-86' | Ditto 76-82'. Some goethite. |
| 86-87' | Very pale green and pale orange siltstone, locally micaceous (muscovite), ~HCl. |
| 87-90' | Ditto 86-87'. Common goethite and/or pyrite. |
| 90-95' | Very pale gray siltstone, minor muscovite, some goethite, -HCl. |
| 95-98' | Very pale orange siltstone, minor muscovite and goethite, ~HCl. |
| 98-101' | Ditto 95-98'. Common chips of vein quartz and/or monzonite? |
| 101-104' | Very pale to medium gray and pale orange siltstone, locally micaceous (muscovite), -HCl. |
| 104-110' | Ditto 101-104'. |
| 110-115' | Ditto 101-104'. |
| 115-120' | Very pale gray and pale orange siltstone, locally micaceous (muscovite), +HCl. |
| 120-122' | Very pale green and pale orange siltstone, locally micaceous (muscovite), ~HCl. Some goethite. |
| 122-126' | Ditto 115-120'. |
| 126-133' | Very pale orange siltstone, minor muscovite and goethite, ~HCl. |
| 133-138' | Ditto 126-133'. |
| 138-143' | Pale orange and very pale green siltstone, locally micaceous (muscovite), ~HCl. |

| | |
|---|---|
| 143-150’ | Very pale gray and pale orange siltstone, locally micaceous (muscovite), -HCl. |
| 150-156’ | Very pale pink and very pale green siltstone, locally micaceous (muscovite), +HCl. |
| 156-162’ | Very pale orange, very pale green and reddish purple siltstone, micaceous (muscovite), +HCl. |
| 162-169’ | Ditto 156-162’. Lower proportion of purple siltstone. |
| 169-182’ | Ditto 162-169’. |
| 182-188’ | Very pale green and pale orange siltstone, locally micaceous (muscovite), +HCl. |
| 188-190’ | Very pale orange and rare pale green siltstone, locally very muddy or sandy, +HCl. |
| 190-192’ | Ditto 188-190’. |
| 192-201’ | Very pale orange siltstone, locally muddy or sandy, -HCl. Pale red quartz wacke, fine to medium grained, subrounded, well sorted, 99% Q, 1% opaques, ≤15% matrix, -HCl. [85% siltstone, 15% sandstone] |
| 201-207’ | Pale yellow quartz wacke, fine to coarse grained, subangular to subround, poorly sorted, 95% Q, 2% opaque, 3% rip-up clasts, ≥15% clay matrix, -HCl. Mostly as loose grains. →*Glorieta* |
| 207-210’ | Ditto 201-207’. |
| 210-214’ | Pale yellow quartz wacke, fine grained, subangular to subround, well sorted, 95% Q, 2% opaque, 3% rip-up clasts, ≥15% clay matrix, -HCl. Mostly as loose grains. |
| 214-217’ | Ditto 210-214’. |
| 217-220’ | Pale yellow quartz arenite, fine grained, subangular to subround, well sorted, 95% Q, 2% opaque, 3% rip-up clasts, <15% clay matrix, -HCl. Mostly as loose grains. |
| 220-224’ | Ditto 217-220’. |
| 224-226’ | Ditto 201-207’. |
| 226-228’ | Ditto 217-220’. Very little matrix. |
| 228-232’ | Ditto 217-220’. Very clean, less as loose grains, ~HCl. |
| 232-236’ | Ditto 228-232’. |
| 236-239’ | Ditto 228-232’. |
| 239-244’ | Ditto 228-232’. |
| 244-252’ | Ditto 228-232’. |
| 252-260’ | Ditto 228-232’. |
| 260-262’ | Ditto 228-232’. |
| 262-265’ | Ditto 228-232’. |
| 265-271’ | Ditto 228-232’. |
| 271-274’ | Ditto 228-232’. |
| 274-277’ | “ |
| 277-278’ | “ but mostly as loose grains. |
| 278-279’ | “, mostly loose grains. |
| 279-282’ | Ditto 228-232’. |
| 282-286’ | “ |
| 286-288’ | “ |
| 288-291’ | “ |
| 291-292’ | “, mostly loose grains. |
| 292-293’ | “ “ |
| 293-294’ | Ditto 228-232’. |
| 294-300’ | “ |
| 300-303’ | “ |

| | | | |
|---|---|---|---|
| 303-305’ | “ | | |
| 305-307’ | “, almost white | | |
| 307-309’ | “, almost white | | |
| 309-312’ | “, orthoquartzitic | | |
| 312-315’ | “, almost white, orthoquartzitic | | |
| 315-317’ | “ “ | “ | |
| 317-320’ | “ “ | “ | |
| 320-325’ | “ “ | “ | |
| 325-329’ | “, mostly loose grains. | | |
| 329-332’ | Ditto 228-232’. | | |
| 332-339’ | “, mostly loose grains. | | |
| 339-340?’ | “, almost white, orthoquartzitic | | |
| 343-350’ | “ “ | “ | |
| 350-359’ | “ “ | “ | |
| 359-365’ | “ “ | “, about half is loose grains | |
| 365-370’ | “ “ | “ | |
| 370-375’ | “ “ | “ | |
| 375-381’ | “ “ | “ | |
| 381-385’ | “ “ | “ | |
| 385-393’ | “ “ | “ | |
| 393-398’ | “ “ | “ | |
| 398-405’ | “ “ | “ | |
| 405-410’ | “ “ | “ | |
| 410-417’ | “ “ | “ | |
| 417-425’ | “ “ | “ | |
| 425-430’ | “ “ | “ | |
| 430-435’ | “ “ | “ | |
| 435-440’ | “ “ | “ | |
| 440-445’ | “ “ | “ | |
| 445-450’ | “ “ | “ | |
| 450-457’ | “ “ | “ | |
| 457-465’ | “ “ | “, mostly loose grains | |
| 465-475’ | “ “ | “ | |
| 475-482’ | “ “ | “ | |
| 482-495’ | “ “ | “ | |
| 495-505’ | “ “ | “ | |
| 505-510’ | “ “ | “, some very pale purple | |
| 510-517’ | Ditto 228-232’, mostly loose grains | | |
| 517-527’ | Ditto 228-232’, some very pale purple, generally higher clay matrix content. | | |
| 527-538’ | “ “ | “ | “ |
| 538-550’ | “ “ | “ | “, almost entirely loose sand |
| 550-557’ | “ “ | “ | “ |
| 557-566 | “ “ | “ | |
| 566-576’ | “ “ | “ | |

| | |
|---|---|
| 576-586’ | “ “ “, mostly loose sand |
| 586-595’ | “ “ “ |
| 595-606’ | Pale gray siltstone, somewhat sandy, -HCl. |
| 606-615’ | Ditto 595-606’. |
| 615-625’ | Very paleo orange siltstone, somewhat sandy, -HCl. Some pale purple siltstone (5%). |
| 625-630’ | Ditto 615-625’. |
| 630-642’ | Ditto 615-625’, somewhat higher proportion of pale purple siltstone (15% purple). |
| 642-653’ | Ditto 615-625’. |
| 653-658’ | “ |
| 658-660’ | Very pale orange siltstone, -HCl. |
| 660-663’ | No samples in bag. |
| 663-680’ | Ditto 630-642’. |
| 680-689’ | “, about 50% orange and 50% purple. |
| 689-698’ | “, about 30% purple. |
| 698-704’ | “, about 20% purple. |

***Brooks Exploration #3 Clyde Berlier (22-21N-21E, TD: 440’)***

| | |
|---|---|
| 30-40’ | Medium gray mudstone, +HCl. |
| 40-50’ | “ |
| 50-60’ | “ |
| 60-70’ | “ |
| 70-80’ | “ |
| 80-90’ | “ |
| 90-100’ | “ |
| 100-110’ | “ |
| 110-120’ | “ |
| 120-130’ | “, ~HCl. |
| 130-140’ | “, pale gray micrite, ~HCl. [60% shale, 40% micrite] |
| 140-150’ | Medium gray mudstone, +HCl. |
| 150-160’ | “ |
| 160-170’ | “ |
| 170-180’ | “ |
| 180-190’ | “ |
| 190-200’ | “ |
| 200-210’ | “ |
| 210-220’ | “, ~HCl |
| 220-230’ | “ |
| 230-240’ | “, ~HCl |
| 240-250’ | “ |
| 250-260’ | “ |
| 260-270’ | “ |
| 270-280’ | “, ~HCl |
| 280-290’ | “, -HCl |
| 290-300’ | “, -HCl |

| | |
|---|---|
| 300-310’ | “, ~HCl |
| 310-320’ | “, -HCl |
| 320-330’ | “, +HCl |
| 330-335’ | Medium gray shale, -HCl. Very pale gray quartz arenite, very fine grained, subangular to subround, very well sorted, 98% Q, 2% opaques, <15% clay matrix, +HCl. [85% shale, 15% sandstone] |
| 335-340’ | “ |
| 340-345’ | “, sandstone –HCl. [85% sandstone, 15% shale] |
| 345-350’ | Medium gray shale, -HCl. |
| 350-355’ | “ |
| 355-365’ | No samples |
| 365-370’ | Pale brown loose sand, medium grained, subround to well rounded, very well sorted, 100% Q, fairly muddy. |
| 370-375’ | “, but fine grained. |
| 375-380’ | “, very fine grained. |
| 380-385’ | “ “ |
| 385-390’ | “ “ |
| 390-395’ | “, fine grained |
| 395-400’ | “, very fine grained. |
| 400-405’ | Very pale gray loose sand, medium grained, subround to well round, very well sorted, 100% Q, fairly muddy. |
| 405-410’ | “. Medium gray shale, ~HCl. [80% sand, 20% shale] |
| 410-415’ | Ditto 400-405’. |
| 415-420’ | Ditto 405-410’.[75% sand, 25% shale] |
| 420-425’ | Very pale gray loose sand, medium grained, subround to well round, very well sorted, 100% Q, fairly muddy. |
| 425-430’ | Very pale gray loose sand, medium grained, subround to well round, very well sorted, 100% Q. |
| 430-435’ | “ |
| 435-440’ | “ |

***Brooks Exploration #4 Clyde Berlier (23-21N-21E, TD: 416’)***

| | |
|---|---|
| 40-50’ | Medium gray mudstone, +HCl. |
| 50-60’ | “ |
| 60-70’ | “ |
| 70-80’ | “ |
| 80-90’ | “ |
| 90-100’ | “ |
| 100-110’ | “ |
| 110-120’ | “ |
| 120-130’ | “ |
| 130-140’ | “ |
| 140-150’ | “, ~HCl. |
| 150-160’ | “ |

160-170’ “

170-180’ “

180-190’ “

190-200’ “

200-210’ “

210-220’ “

220-230’ “

230-240’ “

240-250’ “

250-260’ “

260-270’ “, ~HCl.

270-280’ “, -HCl.

280-290’ “, -HCl.

290-300’ “, -HCl. Very pale gray quartz arenite, very fine grained, subangular to subround, very well sorted, 98% Q, 2% opaques, <15% clay matrix, +HCl. [95% mudstone, 5% sandstone]

300-310’ Medium gray mudstone, -HCl.

301-317’ Ditto 290-300’. [85% mudstone, 15% sandstone]

317-330’ No samples.

330-335’ Pale brown loose sand, fine grained, subround to well rounded, very well sorted, 100% Q, -HCl.

335-340’ “

340-345’ “, very fine grained.

345-350’ Medium gray loose sand to silt, fine grained, subround to well rounded, very well sorted, 100% Q, muddy, -HCl.

350-355’ Pale brown loose sand, fine grained, subround to well rounded, very well sorted, 100% Q, -HCl.

355-360’ “, dark gray shale, ?HCl. [95% sand, 5% shale]

360-365’ Pale brown loose sand, fine grained, subround to well rounded, very well sorted, 100% Q, -HCl.

365-370’ “

370-375’ Medium gray loose sand to silt, fine grained, subround to well rounded, very well sorted, 100% Q, muddy, -HCl.

375-380’ “

380-385’ Pale brown loose sand, fine grained, subround to well rounded, very well sorted, 100% Q, -HCl.

385-390’ Medium gray siltstone, mostly as loose silt, -HCl.

390-395’ “

395-400’ Pale brown loose sand, very fine grained, subround to well rounded, very well sorted, 100% Q, -HCl.

400-405’ “, fine grained.

405-410’ Medium gray siltstone, mostly as loose silt, -HCl.

410-415’ Pale brown loose sand, fine grained, subround to well rounded, very well sorted, 100% Q, -HCl.

***Amoco Production Salmon Ranch B#1  (21-21N-17E, TD: 8955’)***

100-110’ Very pale brown quartz wacke/arenite, fine grained, subround to subangular, well sorted, 90% Q, 7% opaques, 3% feldspar, ≤15% matrix in clusters, -HCl. Mostly loose sand, some clay as loose fragments – weathered feldspar?

110-120’ “

120-130’ “

130-140’ “

140-150’ Buff loose sand, fine to coarse grained, subround to well rounded, poorly sorted, 90% Q, 7% opaques, 3% feldspar, loose clay fragments from matrix.

150-160’ Pale red quartz arenite, fine to medium grained, subround, moderately sorted, 90% Q, 7% opaques, 3% feldspar, ≤15% matrix in clusters, +HCl. Small fragments of granite? [97% sandstone, 3% granite]

160-170’ Pale red quartz arenite, fine to medium grained, subround, moderately sorted, 90% Q, 7% opaques, 3% feldspar, ≤15% matrix in clusters, +HCl.

170-180’ Pale reddish orange siltstone, +HCl. Very pale gray quartz arenite, fine grained, subangular, moderately sorted, 95% Q, 5% opaques, ≤15% matrix in clusters, +HCl. Yellow mudstone, +HCl. [50% orange siltstone, 45% arenite, 5% yellow mudstone]

180-190’ “ plus abundant loose quartz sand, fine to coarse grained, rounded.

190-200’ Very pale orange quartz arenite, fine to medium grained, rounded, moderately sorted, 95% Q, 5% opaques, ≤15% matrix in clusters, +HCl.

200-210’ Pale buff loose sand, medium to coarse grained, subround to subangular, poorly sorted, 85% Q, 15% feldspar.

210-220’ “

220-230’ “

230-240’ “

240-250’ “

250-260’ “

260-270’ “, ranging to very coarse/granular.

270-280’ “ “

280-290’ “ “

290-300’ “ “

300-310’ “, granular – some fragments are granitic.

310-320’ “ “

320-330’ “ “

330-340’ “ “

340-350’ Pale buff loose sand, medium to coarse grained, subround to subangular, poorly sorted, 95% Q, 5% feldspar.

350-360’ “, ranging to very coarse/granular.

360-370’ Pale buff loose sand, medium to very coarse grained, angular to subangular, poorly sorted, 95% Q, 5% feldspar.

370-380’ Pale buff loose sand, medium to very coarse grained, subround to angular, poorly sorted, 85% Q, 10% red siltstone rip-up clasts, 5% feldspar.

380-390’ “

390-400’ “

400-410’ “
410-420’ “
420-430’ “
430-440’ “
440-450’ “
450-460’ “
460-470’ “
470-480’ “
480-490’ “
490-500’ “
500-620’ No samples. Stopped at 500’.

***Mobil Oil #1 Sanford Estates (27-20N-22E, TD: 3350’)***

0-10’ Very pale gray mud with medium gray mud rip-up clasts and pale pink ?calcite or dolomite fragments.
10-20’ “
20-30’ Loose medium gray mud rip-up clasts. Very minor ?calcite pieces.
30-40’ “
40-60’ No samples.
60-70’ Medium gray mudstone, +HCl. Some ?calcite fragments.
70-80’ “
80-90’ “
90-180’ No samples.
180-190’ Medium gray mudstone, +HCl.
190-200’ “
200-210’ “
210-220’ “
220-230’ “
230-240’ “
240-250’ “, ~HCl.
250-270’ No samples.
270-280’ Medium gray mudstone, +HCl.
280-290’ “, ~HCl.
290-310’ No samples.
310-320’ Medium gray mudstone, +HCl.
320-330’ Medium gray loose sand, medium to coarse grained, subround, moderately sorted, 90% Q, 10% calcrete? fragments. Medium gray shale, +HCl. [60% shale, 40% sand]
330-340’ No samples.
340-350’ Medium gray mudstone, +HCl. Some sand grains similar to 320-330’. Fragments of vein quartz? [95% shale, 5% sand
350-370’ No samples.
370-380’ Medium gray mudstone, +HCl.
380-390’ Medium gray loose sand, medium to coarse grained, subround, moderately sorted, 90% Q, 10% calcrete? fragments. Medium gray shale, +HCl. [70% shale, 30% sand]

390-490’ No samples.
490-500’ Very pale green and very pale red mudstone, -HCl.
500-510’ Very pale green to grayish green mudstone, +HCl. White quartz wacke, fine grained, subangular, well sorted, 98% Q, 2% opaques, >15% clay matrix, -HCl. [95% mudstone, 5% sandstone]
510-520’ “, sandstone mostly as loose sand. [80% sand, 20% mudstone]
520-530’ Very pale green and very pale red mudstone, +HCl. (?maybe jasper??)
530-540’ Pale green and pale red mudstone, ~HCl.
540-550’ “
550-560’ White quartz wacke, fine grained, subangular to subround, well sorted, 96% Q, 4% opaques, >15% clay matrix, -HCl, mostly as loose sand.
560-570’ “
570-580’ Very pale green to grayish green mudstone, +HCl. White quartz wacke, fine grained, subangular, well sorted, 98% Q, 2% opaques, >15% clay matrix, +HCl. [85% sandstone, 15% mudstone]
580-600’ No samples.
600-610’ Very pale green and very pale red mudstone, -HCl.
610-620’ “, +HCl.
620-630’ White quartz wacke, fine grained, subangular to subround, well sorted, 90% Q, 6% opaques, 4% white clay chips, >15% clay matrix, -HCl, mostly as loose sand.
630-640’ Very pale green and very pale red mudstone, +HCl. White quartz wacke, fine grained, subangular to subround, well sorted, 96% Q, 4% opaques, >15% clay matrix, -HCl, mostly as loose sand. [60% mudstone, 40% sand]
640-650’ Very pale green to grayish green mudstone, +HCl. White quartz wacke, fine grained, subangular, well sorted, 98% Q, 2% opaques, >15% clay matrix, +HCl, mostly as loose sand. [85% sandstone, 15% mudstone]

***Mobil Oil #1 Wooten & Reardon (9-20N-23E, TD: 2127’)***

0-10’ Buff loose sand, fine to medium grained, subangular to subround, moderately sorted, 90% Q, 10% lithics. Pale green and pale red mudstone, +HCl. [85% sand, 15% mudstone]
10-20’ “
20-30’ Pale green and pale red mudstone, ~HCl.
30-40’ “
40-50’ “
50-60’ “
60-70’ “
70-80’ Pale green and pale red mudstone, ~HCl. Very pale orange siltstone, +HCl. [60% mudstone, 40% siltstone]
80-90’ “ [55% siltstone, 45% mudstone]
90-100’ “ “
100-110’ “ “
110-120’ “ [60% mudstone, 40% siltstone]
120-130’ “ “
130-140’ “ “

| | |
|---|---|
| 140-150’ | “ “ |
| 150-160’ | “ “ |
| 160-170’ | “ [70% siltstone, 30% mudstone] |
| 170-180’ | “ [80% mudstone, 20% siltstone] |
| 180-190’ | Reddish brown mudstone, +HCl. |
| 190-200’ | “ |
| 200-210’ | “ |
| 210-220’ | Pale green and pale red mudstone, ~HCl. Very pale orange siltstone, -HCl. [60% mudstone, 40% siltstone] |
| 220-230’ | Reddish brown mudstone, +HCl. |
| 230-450’ | No samples. |
| 450-460’ | Pale red mudstone, +HCl. |
| 460-470’ | “ |
| 470-480’ | “ |
| 480-490’ | “ |
| 490-500’ | “ |
| 500-510’ | No samples. |
| 510-520’ | Pale red and pale green mudstone, ~HCl, locally micaceous. (Green = ++ HCl, red = -HCl.) |
| 520-530’ | “ |
| 530-540’ | “ |
| 540-550’ | Pale red siltstone, micaceous, -HCl. |
| 550-580’ | No samples. |
| 580-590’ | Pale red siltstone, micaceous, -HCl. |
| 590-600’ | Pale red mudstone, +HCl. |