Annual Report: Geology of the northern Seneca, southern Sedan and southernmost 1:50,000 quadrangles, Union County, northeastern New Mexico

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Introduction

This is the 2011-2012 annual report on the surface and shallow subsurface geology of the northern Seneca, southern Sedan and unnamed southern-most 1:50,000 quadrangles in east-central Union County (Figure 1) and has been prepared for the Northeast Soil and Water Conservation District (NESWCD) of Clayton, NM. This report is part of an effort to describe the local geology in order to develop a better understanding of local and regional aquifers for water use planning in eastern Union County. This report is part of the initial, short-term effort to field-check geologic maps made in the 1950s by Baldwin and Muehlberger (published 1959), as well as develop detailed lithologic descriptions of rock units on the surface and in the subsurface, so that more accurate models of the aquifer(s) in eastern Union County can be developed from these maps and descriptions.

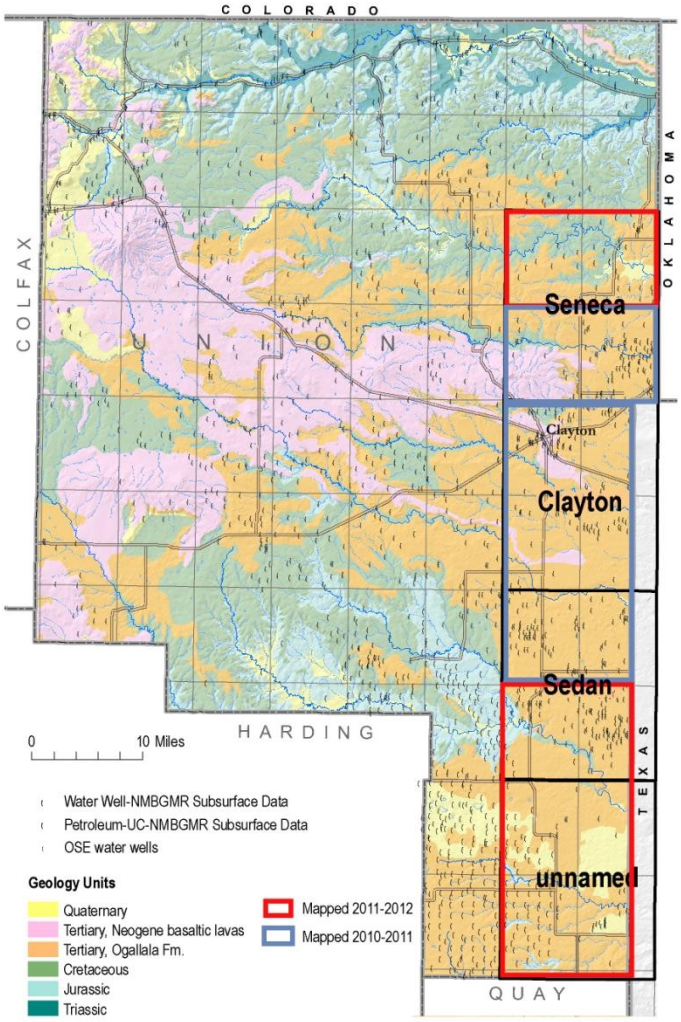

Figure 1. Location of 1:50,000 quadrangles mapped in 2010-2011 and 2011-2012.

Local Geology

For an overview of the geology of Union County, please refer to Baldwin and Muehlberger (1959), assorted technical papers in New Mexico Geological Society Guidebook 38 (1987) and Zeigler (2011). The northern half of the Seneca 1:50k quadrangle includes surface exposures of the Upper Cretaceous Dakota Group, as well as the Oligocene to Pleistocene Ogallala Formation (Figure 2) and Quaternary soils, sand sheets, sand dunes and alluvium. In eastern New Mexico, the Dakota Group consists of a lower thick sandstone unit, a middle shale unit, and an upper sandstone unit (Kues and Lucas, 1987). The lower sandstone is the Mesa Rica Sandstone and represents deposition in a braided river/aggradational fan system. The shale unit, termed the Pajarito Formation, contains oyster shell fragments and most likely was deposited under shallow marine conditions during the late Albian age of the Cretaceous (~100 Ma). The upper sandstone is called the Romeroville Sandstone and is a complex sequence of beach sands, sand bar deposits and thin shales representing slightly deeper water conditions.

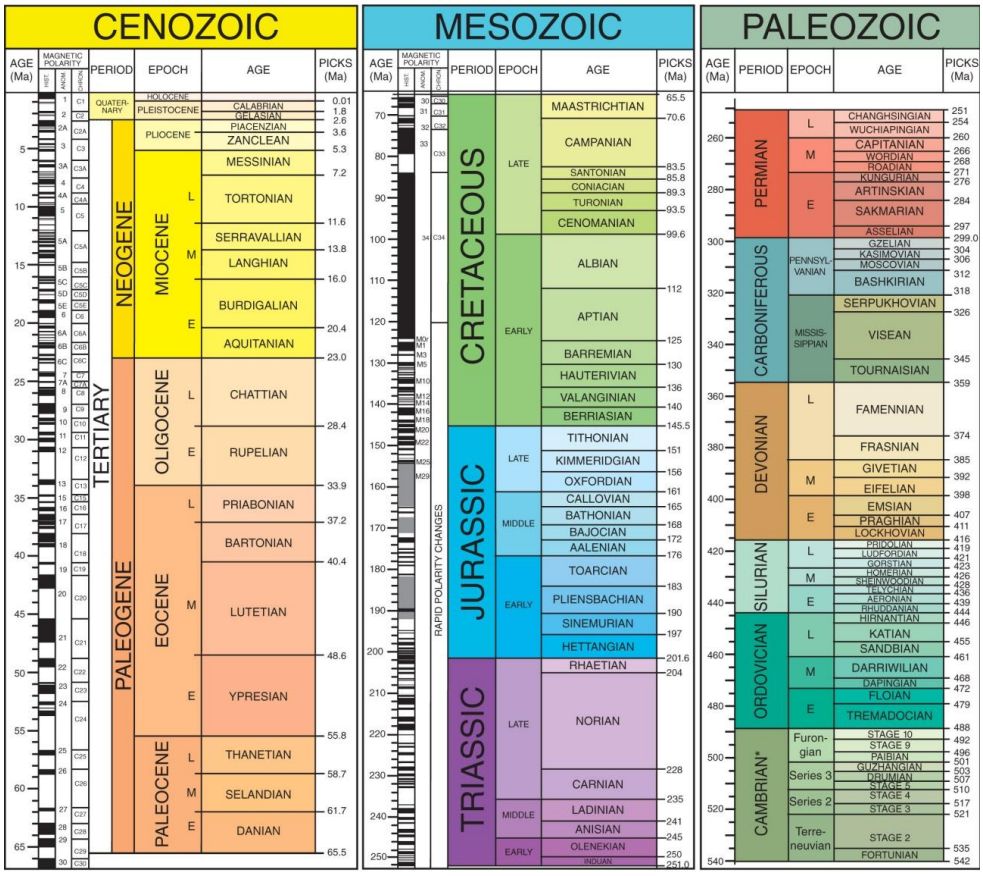

Figure 2. Geologic time scale (2009 version).

The Ogallala Formation (Miocene to Pliocene: 23 – 2.6 Ma) represents deposition by large aggradational fan systems shedding off of the Rocky Mountains, which began to form at the end of the Cretaceous. Thus, the cobble to boulder conglomerates at the base of the Ogallala contain fragments of granite, metamorphic rocks, volcanic rocks and even pieces of the underlying Cretaceous strata as the streams and fans moved material off of the newly uplifted mountains and scoured down into the Cretaceous strata below. The Ogallala also records a trend of climate growing drier in this area. The uppermost deposits of this unit are capped by a thick caliche zone, often termed The Caprock. This zone is a series of calcic soils that developed under very dry conditions (Figure 3). The top of the Ogallala is locally scoured out and then filled with Quaternary stream deposits (Baldwin and Muehlburger, 1959). Large parts of the modern landscape are blanketed with eolian deposits, both as sand sheets and small dunes.

Figure 3. Ogallala Formation exposed in a creek cutbank on the Sedan quadrangle.

At Tramperos Creek, older strata are exposed, including possible Lytle Sandstone (Upper Cretaceous in age) and Middle to Lower Jurassic Morrison Formation. The Lytle Sandstone is a white to very pale pink set of sandstone and siltstone beds that forms a prominent band low in the cliffs of the Dry Cimarron Valley (Kues and Lucas, 1987). At Tramperos Creek, outcrops of a single thick massive bed of sandstone with pebbles scattered throughout and trough crossbedded to planar tabular bedded gold colored sandstones may be either upper Morrison

Formation, or potentially either Lytle Sandstone or lowermost Dakota Group. Due to insufficient exposure and a lack of defining characteristics, we do not explicitly identify this outcrop as pertaining to the Lytle Sandstone. The Morrison Formation consists of different colored low outcrops that are greenish-gray to reddish brown mudstone with some coarse sandstone (Mankin, 1972) (Figure 4, 5). Near the base of the Morrison Formation is a unit termed the “agate bed” which consists of stringers of red chert or jasper. The lower Morrison Formation contains muddy limestones and mudstones that represent deposition in small lakes. The Morrison Formation was deposited in a similar setting to the Chinle Group, with broad, low sinuousity rivers, lakes and aggradational fan systems depositing sediments into a low relief basin.

Figure 4. Morrison Formation mudstones in cutbank of Tramperos Creek.

Figure 5. Channel-form sandstone in the Morrison Formation in Tramperos Creek.

Map Revisions

The northern half of the Seneca quadrangle is predominately covered with either Quaternary and recent sand sheets and sand dunes or the Tertiary Ogallala Formation. In Seneca Creek itself, there are excellent exposures of the Upper Cretaceous Dakota Group. Smaller exposures of Dakota Group sandstones occur in smaller drainages and as low surfaces within Ogallala Formation and sand dune covered areas.

The southern half of the Sedan quadrangle includes a mix of young sand sheets and sand dunes, laterally extensive deposits of Ogallala Formation, as well as outcrops of Dakota Group sandstone in the drainages. Based upon information from water wells and petroleum exploration wells, as well as information in Baldwin and Muehlberger (1959), there is a deep paleovalley in the Sedan area where incision into underlying bedrock was then filled with 300’ or more of Ogallala Formation deposits.

An interesting relationship is shown in Tramperos Creek and near Thomas Highway between the Ogallala and underlying Mesozoic bedrock. At Tramperos Creek, small outcrops of Ogallala Formation locally sits adjacent to Jurassic strata. There is no fault present and this relationship most likely reflects deep incision down into the Jurassic which was then filled with Ogallala sediments. Similarly, near Thomas Highway, the Cretaceous Dakota Group sits beside Ogallala sediments, suggesting the same relationship of a deep scour into the Dakota Group.

The unnamed quadrangle that covers the terrain from south of Sedan to the Quay county line in dominated by young sand sheets and dunes and thick deposits of Ogallala Formation in creek cutbanks. There are very few exposures of older bedrock.

Structure

In general, the eastern part of Union County has few exposures that include structural features such as folds or faults. From northern Seneca south to Sedan, no structural features other than small scale warping of Mesozoic bedrock were observed. At Tramperos Creek, in the southern part of the county, older strata appear in cutbanks rather than the Upper Cretaceous Dakota Group seen to the north.

The Middle to Late Jurassic Morrison Formation appears in outcrops in Tramperos Creek. This somewhat unexpected occurrence is due to the presence of the northwest-southeast

trending Clapham anticline (Baldwin and Muehlberger, 1959). This feature is a nested set of two or three elongate domes that warp the surrounding strata such that Jurassic sedimentary rocks seem to pop up in the midst of Cretaceous strata. Because of these upwarped features, the Cretaceous Dakota Group is eroded in much of the anticline area. To the south, the Clapham anticline merges into another anticline. Baldwin and Muehlberger (1959) suggested that this structural feature may have been active from the Late Jurassic into the Early Cretaceous. Because of this timing of activity, the Lytle Sandstone and Glencairn Formation are either very thin or absent in the area of Tramperos Creek. If this is indeed the case, this would be a remarkable observation, given that there is currently no evidence of tectonic activity during the Late Jurassic to Early Cretaceous. This features is still an area that requires further exploration in order to completely understand the timing of the development of these anticlines.

In addition to the Clapham anticline, there are several small normal faults that are visible in Mesozoic bedrock exposed in cutbanks in some creekbeds, including Tramperos Creek. In general, these faults trend east-northeast, have throw of no more 40 feet and are difficult to trace beyond the creek beds. These faults are probably related to the Laramide orogeny (Late Cretaceous to Middle Cenozoic). The Laramide orogeny is the term used for the uplift of the Rocky Mountains. In general, Baldwin and Muehlberger (1959) noted that the bedrock is more often warped than faulted.

Subsurface observations from petroleum wells (Appendix II) indicate that a possible anticline or fault relationship is present just south of the rim of the Dry Cimarron Valley. The Gregg Oil Northcutt well shows the Morrison Formation just over 20 feet below the surface. Surface observations at nearby outcrops are of Dakota Group, suggesting that the Morrison has been brought close to the surface by either folding or faulting. To the south, the Continental Federal Land Bank well near Tramperos Creek indicates that the Lytle and Glencairn Formations are missing, with Dakota Group sitting directly on Morrison Formation.

These structural features may stem from much older deformation of the High Plains region during the Pennsylvanian and Permian during formation of the Ouachita-Arbuckle deformation. Trends of folds and faults related to this episode of mountain building appear to lie on the same trend as the structural features in southern Union County and may reflect reactivation of these much older faults during the Laramide.

Acknowledgments

ZGC would like to extend our heartfelt thanks to the land owners in eastern Union County who gave us permission to examine outcrops on their property, shared water well logs and stories about the history of water useage in Union County. We are also grateful for the advice and assistance of Barbara and Randy Podzemny, as well as all the members of the NESWC District Board and the NRCS staff. Well log data included in this study also came from Mr. Ben Creighton, Ms. Effie Walker and Mr. Larry Mason, as well as from the NM Bureau of Geology and Mineral Resources petroleum core archive and Dr. Ron Broadhead. We also thank Tim Lite for his conscientious review of previous drafts of this report.

Map Unit Descriptions

Quaternary

Qes: Primarily fine to medium grained silty sand, reworked eolian sheet deposits. Occasionally contains pebbles and cobbles reworked from underlying Ogallala Formation.

Qs/Qsd: Eolian dunes. Most are vegetated.

Qal: Modern alluvium in creek and arroyo bottoms. Primarily coarse sand and pebbles to small boulders of Jurassic and Cretaceous bedrock and clasts from the Ogallala Formation.

Tertiary

To, Ogallala Formation (Miocene-Pliocene): Lower portions of unit comprised of interbedded or intertongued cobble to boulder conglomerate and medium to coarse sandstone. Conglomerates are clast supported and clast size ranges from pebble to small boulder. Clast compositions include siliceous intrusive igneous, metamorphic, Cretaceous sandstone, chert and quartzite. Matrix is coarse sandstone, mostly quartzose with minor feldspar. Sandstones are medium to coarse grained, pebbly, often faintly trough cross-bedded, quartzose and moderately to poorly cemented. The upper Ogallala is semiconsolidated to unconsolidated medium to coarse muddy sand. The uppermost 0.5-3.0 m is a Stage III-IV calcic paleosol (also known as caliche or the caprock). The base of this calcic paleosol is gradational with the underlying muddy sandstone, with stringers of calcareous cemented material and siliceous or calcareous vertically oriented tubules penetrating into underlying unit. Locally, calcic paleosol appears to have developed along a scoured surface. The calcic paleosol is nodular to wavy and laminar with abundant

cylindrical burrow and/or root casts. Concentrically zoned concretions are abundant. Locally, some thin stringers of siliceous materials represent altered air-fall ash beds, which in rare instances have converted to opal.

Cretaceous

Kd, Dakota Group (Late Cretaceous: Albian-Cenomanian): Dakota Group exposures include gold to pale yellow quartz arenite with occasional lenses or interbeds of pale gray shale. Some sandstone beds contain up to 15% lithics (muscovite mica and lithic fragments) and are considered sublithic arenites. Sandstone is fine to medium grained, well sorted, well rounded with trough crossbedding, cross laminations, hummocky bedding or thin planar tabular bedding. Locally, abundant burrows are preserved on bedding plains, or bedding is are intensely bioturbated. Colors range from dark purple to nearly white and cementation ranges from a very well silica cemented orthoquartzite to moderately well cemented. Local manganese staining highlights sedimentary structures. Occasional zones with well developed siderite nodules and boxwork.

Jurassic

Jm, Morrison Formation (Middle to Upper Jurassic): Complex interbedded unit that includes red and green mottle mudstones and claystones, quartz and lithic arenites and wackes, and local lenses of intraclast conglomerate. Mudstone and claystone units are noncalcareous. Sandstone units are white, gold, red and buff in color. They are medium to fine grained with rounded and well sorted grains. Grain composition can include black and red chert. Morrison sandstone bodies have channel forms in outcrop and sedimentary structures include trough crossbedding, cross laminations, medium to thin bedding, and locally planar tabular bedding. Often the sandstones are bioturbated or include complexly shaped, relatively large burrows. Locally there is abundant hematite and limonite cement and white starburst shaped interstitial clays, which result from chemical weathering of feldspar grains. In conglomeratic lenses, clasts are granule to pebble sized and include siltstone and mudstone rip-up clasts and red and black chert. Locally, a discontinuous band of red jasper occurs low in the unit. This jasper bed has not been directly observed as it tends to be covered in colluvial debris on slopes.

References

Baldwin, B. and Muehlberger, W.R., 1959, Geologic studies of Union County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 63, 171 p.

Kues, B. and Lucas, S.G., 1987, Cretaceous stratigraphy and paleontology in the Dry Cimarron Valley, New Mexico, Colorado and Oklahoma: New Mexico Geological Society Guidebook 38, p. 167-198.

Zeigler, K.E., 2011, Preliminary Report: Geology of the Clayton, southern Seneca and northern Sedan 1:50,000 quadrangles, Union County, northeastern New Mexico, unpublished report, 45 p.

Appendix I: Detailed Lithologic Descriptions

This appendix provides detailed lithologic descriptions of different units in eastern Union County by specific location. Locations are listed by unit (e.g., Ogallala or Dakota), then by UTM coordinates (NAD 83 grid). These are in no order geographically. Q = quartz, F = feldspar, L = lithics, used for classification of clastic sedimentary rocks in the Folk (1960) classification system. >15% clay matrix indicates a sandstone should be termed as a wacke, <15% indicates an arenite. This appendix features fewer detailed lithology descriptions compared to Zeigler (2011) due to similarities in features that do not bear repetition in the current report.

Ogallala Formation

Rardin Hills, Seneca Quadrangle

0673706, 4049291: Heavily bioturbated sandstone with extrabasinal pebbles and cobbles, mostly volcanics. Very pale gray in color. ~ 2 m thick.

0673346, 4049366: Coarse quartz sandstone with faint tabular bedding, medium bedded and heavily bioturbated locally. Some extrabasinal pebbles and cobbles, mostly volcanics. Gray brown in color. ~ 4 m thick.

0673130, 4049611: Discontinuous small outcrops of coarse grained quartz sandstone. Thin bedded, planar tabular bedding, heavily bioturbated. ~1 m thick. Locally thin mantle of unconsolidated cobbles weathered down over underlying Cretaceous sediments. Cobbles are rounded and include volcanics, quartzite, quartz and Dakota Group sandstone.

Tramperos Creek, Sedan Quadrangle

0670174, 3987060: Unconsolidated gravel with Dakota Group sandstone, quartzite and chert.

0663320, 3994085: Silt and fine grained sandstone. Some calcrete nodules (some are long, cylindrical and vertical – replacing burrows?). Planar tabular bedding pervasive. Red-orange in color. Lower 6 m is sand to silt that is poorly cemented and includes common calcrete nodules, often as stringers. Upper 3 m is sand to silt with abundant stringers and lenses of pebbles and cobbles that include sandstone, chert, quartzite, siderite, intermediate intrusive igneous rocks.

Cain Creek tributary, unnamed quadrangle

0665752, 4070093: Muddy sandstone, medium bedded with discontinuous stringers of calcrete. Brown in color. ~ 1 m thick. Grades upwards into muddy sandstone with laterally continuous calcrete stringers. Brown in color. ~ 1 m thick. Grades upwards into muddy sandstone with sandstone rip-up clasts and calcrete nodules. Brown in color, ~ 1.5 m thick. Outcrop capped by well-developed caliche horizon. ~ 0.5 m thick. Outcrop becomes poorly consolidated to the east.

Cain Creek???, unnamed quadrangle (or CC tributaries?)

0664074, 4071828: Muddy coarse grained sandstone with granules and subangular pebbles of chert (red-orange, yellow, black). > 1.0 m thick. Massive to somewhat bioturbated. Overlain by caliche horizon. ~ 0.5 m thick.

066347, 4070374: Medium grained sandstone with stringers of nodular calcrete. Few to no pebbles. Upper 2 m has long vertically oriented burrows or groundwater flow structures. ~ 4 m thick. To the west, well-developed caliche horizon occurs that is 0.5 to 1.0 m thick. Underlying sandstone becomes more nodular and bioturbated.

0664447, 4068887: Fine grained sandstone with some calcrete stringers, massive. ~ 7 m thick. Overlain by nodular sandstone. ~ 4 m thick. Overlain by well-developed caliche. ~ 1 m thick.

0675121, 4062525: Heavily bioturbated, well-developed calcrete. ~ 1.5 m thick. Overlain by muddy medium to coarse grained sandstone with calcrete nodules. Becomes laminated in uppermost 6-10 cm. ~ 0.5 m thick.

0676894, 4061615: Medium to coarse sandstone/poorly developed calcrete with vertical groundwater flow structures. ~ 2 m thick. Overlain by well-developed caliche that varies in thickness from 0.5 m to 3.0 m.

0672181, 4066140: well-developed calcrete with black and dark brown chert pebbles that are subangular. Hummocky bedding. ~ 1.5 m thick. Overlain by semi-consolidated medium to coarse sandstone with rare chert pebbles and rip-up clasts of similar sandstone lithology. Massive to nodular, with smooth top surface. Pink in color. ~ 8 m thick. Overlain by discontinuous bioturbated/nodular calcrete. <0.5 m thick.

Cretaceous Dakota Group

Rardin Hills, Seneca Quadrangle

0673256, 4049464: Quartz sandstone, heavily bioturbated. Dark gold-brown in color. Only top of the unit exposed in small outcrop.
0673112, 4049584: Pale gray shale with thin beds of gold-brown, bioturbated quartz sandstone. Some siderite nodules. Probably gradational contact of Dakota Group and Graneros Shale.

Tramperos Creek, Sedan Quadrangle
0670174, 3987060: Medium to fine grained quartz arenite, massive with lenses of trough crossbeds. White to red in color. ~3 m thick.
0665058, 4058814: Medium to coarse grained sandstone with bioturbation. Poorly cemented. Gray in color. ~ 0.5 m thick. Overlain by poorly cemented pinkish tan sandstone. ~ 5 m thick. Overlain by laterally discontinuous poorly developed calcrete. < 0.5 m thick.

Lytle Sandstone?
Tramperos Creek, Sedan Quadrangle
0662387, 3993363: Fine to medium grained lithic arenite with some quartz overgrowths. Massive, includes pebbles of quartzite and chert scattered throughout. Base is planar to slightly scoured. Sits above very fine grained pale buff colored sandstone which is above pink mottled muddy sandstone. Above, flaggy sandstone that is locally bioturbated. Outcrop is capped by medium bedded, planar cross-bedded sandstone. Entire outcrop ~ 6 m thick.

Jurassic Morrison Formation
Tramperos Creek, Sedan Quadrangle
0659031, 4094727: Medium grained sandstone with crossbeds. White and gold in color. ~ 5 m thick. Overlies pale gray shale overlying gold medium grained sandstone. Upper sandstone unit thins to the north as shale thickens.
0658532, 4094571: Mudstone that is greenish gray, gray and very pale red. Includes lenses of 20-30 cm thick dark buff, very well cemented claystone. Locally capped with sparry calcite that preserves cylindrical, 1.0 cm diameter burrows.
0658892, 4093971: Medium grained quartz arenite with crossbeds, and large-scale channel forms. Lenses and thin beds of coarse grained sandstone with rip-up clasts. Locally includes

hematitic concretions. Pale yellow in color. Overlain by gray-green shale. Total outcrop ~ 9 m thick.

0659895, 4093248: Green and red mottled mudstone to claystone that is somewhat bentonitic. Noncalcareous and includes sand-filled complexly shaped burrows. ~ 10 m thick. Overlain by medium grained quartz arenite with a gradational contact (small lenses of sandstone occur in uppermost mudstone). Base of sandstone is a rip-up clast conglomerate. Sandstone contains abundant hematite and limonite cements, up to 10% black and red chert grains and some interstitial mud (<15%). Grains are rounded, well sorted. Sandstone is trough cross-laminated, thin bedded and locally planar tabular bedded. Large complex burrows weathering out of base of sandstone and are up to 5 cm in diameter. ~ 2 m thick.

0660167, 4093840: Fine grained sandstone with abundant hematite and limonite cement. ~ 15% clay matrix. Locally, up to 5% red and black chert grains. Grains overall are rounded, well sorted and locally include rip-up clasts. Small channel forms, low angle crossbeds and cross laminations or thin to medium planar tabular bedded. Some local bioturbation. Thin shale partings and lenses.

0660522, 4093946: Medium to coarse grained sublithic arenite that is calcareous. Rounded and well sorted grains. At base of outcrop, conglomerate with pale green siltstone rip-up clasts (pebble to cobble) and red and black chert granules and pebbles. Abundant pea-sized hematite concretions. Large channel form with crossbeds. At base of outcrop, boulder-size areas of concentrated silica cement (quartzitic). ~ 3 m thick. Across creek, same sandstone channel scours down into red mudstone interbedded with similar sandstones. ~10 m thick.

0664246, 4058722: Medium to coarse grained quartz arenite, locally muddy. 95% quartz, 5% lithics, some mudstone rip-up clasts. Crossbedded. Rubble on slopes includes abundant red silcrete float (= Baldwin's red jasper bed). Brown to white in color. Up to 4 m thick. To the north across the creek, laterally equivalent to red and green mudstone. Locally, Ogallala Formation is at or below same stratigraphic level as Morrison Formation, suggesting paleovalley.

0661852, 3993325: Medium to coarse grained lithic wacke with 10% lithics (incl. black chert). Abundant clay, including kaolinite "stars". Trough crossbedded to ripple laminated and planar tabular. Local small lenses of pinkish red muddy coarse grained sandstone. To the east, lower half of sandstone becomes finer grained, possibly bioturbated, much better cemented and thinly bedded. Locally sandstone is pebbly with rip-up clasts and/or calcrete nodules.

Appendix II: Selected Well Log Lithologic Descriptions

This appendix contains updated lithologic descriptions for five well logs along a north-south transect through eastern Union County. –HCl = negative acid test, ~HCl = moderate acid response, +HCl = vigorous acid response. Both "wacke" and "arenite" are types of sandstone. Wackes have a greater percentage of clay between the grains than do arenites. Sandstone designations follow the classification scheme of Folk (1960). All revised log descriptions end in red beds (interpreted to represent Triassic strata), regardless of total depth of the well. Stratigraphic column representations of these well logs are attached (Figs. 6-10) and represent the author's interpretation of the subsurface stratigraphy. In places, stratigraphic position of various lithologies is interpreted and may not be perfectly representative of subsurface relationships.

Gregg Oil Co. #1 Northcutt (24-30N-36E, TD: 3887)

0-10'	Pale buff, loose very fine to very coarse sand with granules and pebbles, subrounded, poorly sorted, sand fraction is 98% Q, 2 % L, pebble fraction includes fine grained sandstone to siltstone (intraclasts) and rare quartzite. Numerous euhedral quartz grains present.
10-20'	Pale brown, loose silt to very fine sand with occasional caliche pebbles, subrounded to rounded, well sorted, sand fraction is 60% Q, 40% L (calcrete/caliche fragments). Several euhedral quartz grains.
20-30'	Pale red brown and pale gray green mudstone, -HCl; very pale orange quartz wacke, coarse grained, subround, well sorted, 100% Q, >15% clay matrix in clusters or "stars", moderately well consolidated, -HCl. [80% mudst. (~50% red, 50% green), 20% ss]
30-40'	Ditto 20-30. [90% mudst. (60% red, 40% green), 10% ss]
40-50'	Ditto 20-30.
50-60'	Ditto 20-30, sandstone is fine to medium grained. [50% mudst. (50% red, 50% green), 50% ss]
60-70'	Ditto 20-30, red mudstone more grayish red. [60% ss, 40% mudst. (60% green, 40% red)]
70-80'	Ditto 60-70.

80-90’ Pale red brown siltstone, -HCl; very pale green mudstone, -HCl. [70% siltst., 30% mudst.]

90-100’ Ditto 60-70.

100-110’ Pale red brown and gray green claystone, -HCl. [60% green, 40% red]

110-120’ Pale red brown and gray green claystone, -HCl; gold quartz wacke, very fine to fine grained, subangular, moderately well sorted, 95% Q, 5% L (opaques), >15% clay matrix, moderately well consolidated, -HCl. [70% green, 25% red, 5% ss]

120-130’ Pale red brown and pale gray green mudstone, -HCl; very pale gray quartz arenite, fine grained, subangular, well sorted, 100% Q, well consolidated, +HCl. [60% mudst. (50% red, 50% green), 40% ss]

130-140’ Pale red brown and pale gray green mudstone, -HCl; very pale gray quartz wacke, medium grained, subround, well sorted, 100% Q, >15% clay matrix, moderately well consolidated, -HCl. [95% mudst. (~40% red, 60% green), 5% ss]

140-150’ Pale red brown and gray green claystone, -HCl. [60% green, 40% red]

150-160’ Ditto 130-140, sandstone sometimes gold. [85% mudst. (80% green, 20% red), 15% ss]

160-170’ Ditto 150-160. [90% mudst. (60% red, 40% green), 10% ss]

170-180’ Ditto 150-160. [95% mudst. (60% red, 40% green), 5% ss]

180-190’ Ditto 160-170.

190-200’ Ditto 160-170.

200-210’ Ditto 160-170. [95% mudst. (70% green, 30% red), 5% ss]

210-220’ Pale gray green and pale red brown mudstone, -HCl; orange brown quartz wacke, fine to coarse grained, subangular, moderately well sorted, 100% Q, >15% clay matrix (in varying degrees), moderately consolidated, ~HCl; very pale gray quartz wacke, medium to coarse grained, subround, moderately well sorted, 100% Q, >15% clay matrix, moderately consolidated, ~HCl; siderite granules; rare green mudstone granules with jasper stringers; loose granules of monocrystalline quartz, some frosted and rounded, some euhedral and clear. [40% gold ss, 30% pale gray ss, 30% mudst. (60% green, 40% red)].

220-230’ Ditto 210-220, minus mudstone with jasper. [80% mudst. (80% green, 20% red), 15% gold ss, 5% pale gray ss]

230-240’ Ditto 220-230. [40% mudst. (60% green, 40% red), 40% gold ss, 20% pale gray ss]

240-250’ Ditto 230-240.

250-260’ Ditto 220-230. [40% mudst. (80% green, 20% red), 40% gold ss, 20% pale gray ss]

260-270’ Ditto 250-260.

270-280’ Ditto 250-260. Loose quartz grains significant component.

280-290’ Ditto 270-280.

290-300’ Pale gray mudstone, +HCl; orange brown quartz wacke, fine to coarse grained, subangular, moderately well sorted, 100% Q, >15% clay matrix (in varying degrees), moderately consolidated, ~HCl. [85% mudst., 15% ss]

300-310’ Ditto 290-300. [80% mudst., 20% ss]

310-320’ Pale gray mudstone, +HCl; orange brown quartz wacke, fine to coarse grained, subangular, moderately well sorted, 100% Q, >15% clay matrix (in varying degrees), moderately consolidated, ~HCl; very pale gray quartz wacke, fine to medium grained, subround, moderately sorted, 100% Q, >15% clay matrix, moderately consolidated, ~HCl. [80% mudst., 15% pale gray ss, 5% gold ss]

320-330’ Ditto 310-320. Some of very pale gray ss have clay matrix in clusters or “stars”. [80% mudst., 15% pale gray ss, 5% gold ss]

330-340’ Ditto 320-330.

340-350’ Ditto 320-330. [85% mudst., 10% pale gray ss, 5% gold ss]

350-360’ Pale gray mudstone, +HCl; very pale gray quartz wacke, fine to medium grained, subround, moderately sorted, 100% Q (rarely micaceous: biotite), >15% clay matrix sometimes in clusters or “stars”, moderately consolidated, ~HCl. [80% mudst., 20% pale gray ss]

360-370’ Ditto 350-360, plus pale red brown mudstone. Higher amount of loose coarse quartz grains. [80% mudst. (70% gray, 30% red), 20% pale gray ss]

370-380’ Ditto 360-370, plus rare yellow mudstone. [80% mudst. (50% gray, 50% red), 20% pale gray ss]

380-390’ Ditto 360-370. Pale gray sandstone very poorly consolidated.

390-400’ Pale gray and pale red brown mudstone, -HCl; very pale gray quartz wacke/arenite, very fine grained, subrounded, well sorted, 90%Q, 10% L (opaques), some >15% clay matrix, moderately consolidated, ~HCl; loose medium to coarse quartz grains,

some frosted and rounded, others clear and euhedral. [60% loose quartz, 30% mudst. (60% gray, 40% green), 10% ss]

400-410’ Ditto 390-400. [50% mudst. (50% red, 50% gray), 30% loose quartz, 20% ss]

410-420’ Pale gray and pale red brown mudstone, -HCl; orange brown quartz wacke, fine to coarse grained, subangular, moderately well sorted, 100% Q, >15% clay matrix (in varying degrees), moderately consolidated, ~HCl; very pale gray quartz wacke, fine to medium grained, subround, moderately sorted, 100% Q, >15% clay matrix, moderately consolidated, ~HCl; loose medium to coarse quartz grains, some frosted and rounded, others clear and euhedral. [50% mudst. (70% gray, 30% red), 20% gold ss, 15% gold ss, 15% loose quartz]

420-430’ Ditto 410-420. Loose quartz minor component. [80% mudst. (60% gray, 40% red), 15% gold ss, 5% pale gray ss]

430-440’ Ditto 420-430. Gold sandstone also occurs as arenite. No loose quartz. [85% mudst. (50% gray, 50% red), 10% gold ss, 5% pale gray ss]

440-450’ Ditto 430-440. Mudstone + HCl. [80% mudst. (60% red, 40% gray), 15% gold ss, 5% white ss]

450-460’ Ditto 430-440. Mudstone – HCl. [80% mudst. (50% red, 50% gray), 15% white ss, 5% gold ss]

460-470’ White and red siltstone, ~HCl. **CHINLE TOP?**

470-480’ Ditto 460-470.

480-490’ Ditto 460-470.

490-500’ Pale red mudstone with occasional small pale green mottles, ~HCl.

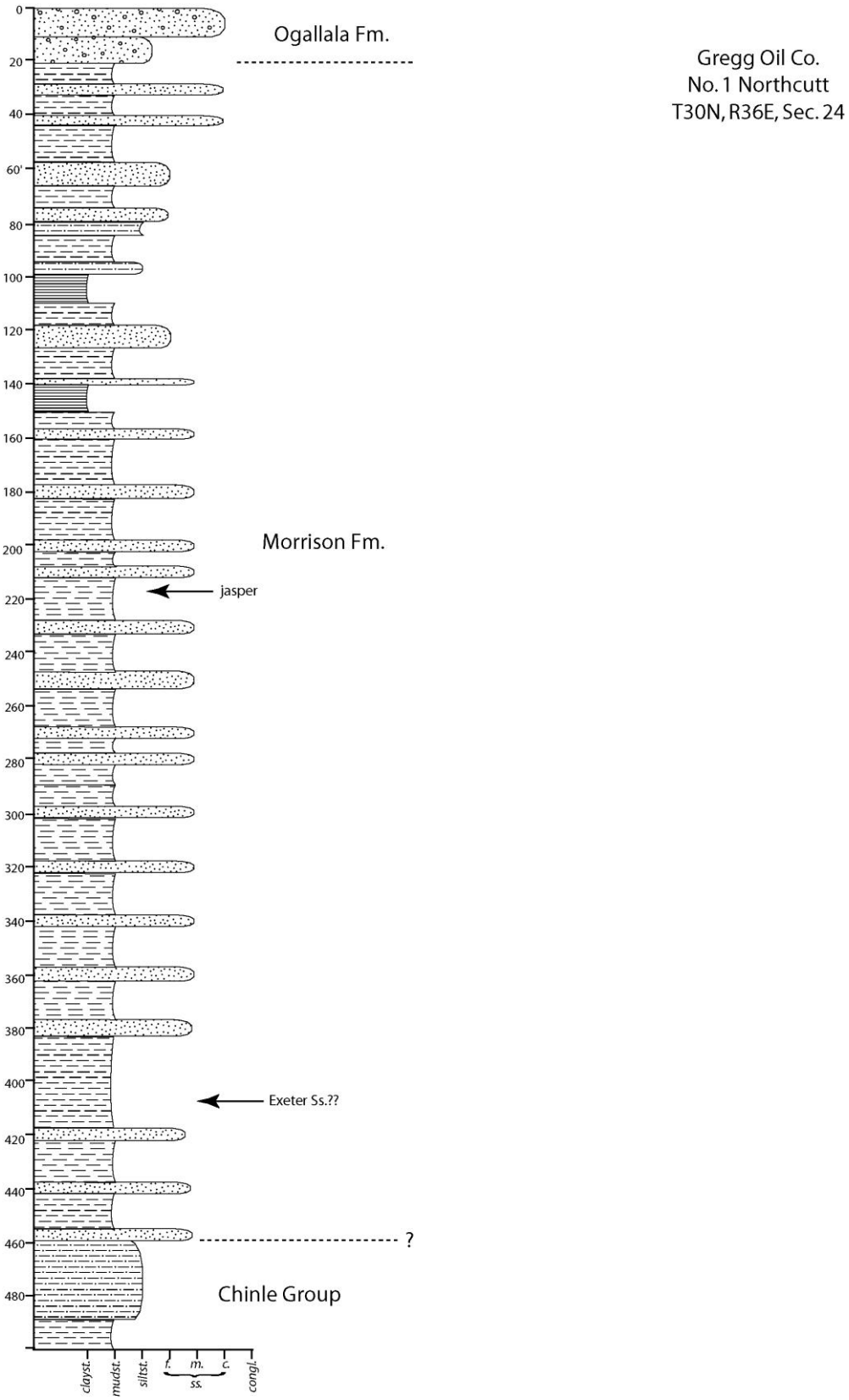

Figure 6. Gregg Oil Co. No. 1 Northcutt interpreted stratigraphic column.

Clayton Water Well #7 (35-26N-35E, TD: 480')

0-10'	Loose sand, caliche and very coarse quartz, angular, moderately poorly sorted.
10-20'	Loose sand and pebbles, sand fraction includes quartz and caliche, coarse grained, subangular to angular, moderately sorted; pebble fraction includes caliche and basalt.
20-30'	Basalt, avesicular to vesicular, aphanitic with ~10% yellow olivine phenocrysts <1 mm.
30-40'	Ditto 20-30.
40-50'	Loose sand and pebbles, sand fraction is quartz, fine to very coarse grained, subangular to angular, moderately poorly sorted, some grains hematite stained; pebble fraction includes basalt from overlying flow (contaminant from drilling), polycrystalline quartz, caliche and sandy mudstone.
50-60'	Loose sand and pebbles, sand fraction is caliche and coarse quartz, medium to coarse grained, angular, moderately poorly sorted; pebble fraction includes basalt from overlying flow, intermediate volcanics and caliche.
60-70'	Loose gravel, rounded to subangular, poorly sorted, includes quartzite, caliche and polycrystalline quartz.
70-80'	Loose sand and pebbles, sand fraction is quartz and some caliche, medium to very coarse grained, subrounded, poorly sorted, some grains hematite stained; pebble fraction includes caliche, quartzite and basalt from overlying flow.
80-90'	Loose sand and pebbles, sand fraction is quartz and some caliche, fine to coarse grained, subrounded, moderately poorly sorted; pebble fraction includes caliche.
90-100'	Ditto 80-90, some quartz grains hematite stained.
100-110'	Ditto 80-90.
110-120'	Loose sand and granules, sand fraction is quartz and some caliche, fine to coarse grained, subrounded, poorly sorted, some grains hematite stained; granule fraction includes quartzite, caliche and basalt from overlying flow.
120-130'	Loose sand and pebbles, sand fraction is quartz and some caliche, medium to very coarse grained, subrounded, poorly sorted, some grains hematite stained; pebble fraction includes caliche and polycrystalline quartz.

130-140’	(Two envelopes) A) Gray shale, petroliferous, ++HCl; loose pebbles including pumice and polycrystalline quartz. [80% shale, 20% pebbles] B) Gray very fine sandstone to siltstone, micaceous, -HCl.
140-150’	Ditto 130-140B, some sandstone pieces ~HCl.
150-160’	Dark gray claystone, micaceous, ~HCl.
160-170’	Ditto 150-160 plus surface contamination.
170-180’	Ditto 160-170.
180-190’	Ditto 160-170, -HCl.
190-200’	Ditto 160-170.
200-210’	Dark gray shale, -HCl; dark brown siderite. [70% shale, 30% siderite]
210-220’	Dark gray shale, +HCl, plus surface contamination.
220-230’	Dark gray shale, -HCl.
230-240’	No samples.
240-250’	Loose sand, quartz, very fine to fine grained, subangular, well sorted.
250-260’	Pale gray quartz wacke, very fine grained, subrounded, well sorted, 90% Q, 10% L (black organic matter), -HCl.
260-270’	Ditto 250-260.
270-280’	Ditto 250-260, plus siderite and small fragments of coal.
280-290’	Ditto 240-250 plus fragments of pale gray quartz wacke, very fine grained, subrounded, well sorted, 90% Q, 10% L (black organic matter), -HCl.
290-300’	Ditto 280-290.
300-310’	Gray siltstone, -HCl.
310-320’	Ditto 280-290, quartz wacke includes some hematite cement; gray shale, -HCl. [40% loose sand, 30% ss, 30% shale]
320-330’	Gray shale, -HCl; gray siltstone, -HCl. [80% shale, 20% siltst.]
330-340’	Gray shale, -HCl.
340-350’	Pale gray quartz wacke, very fine grained, subrounded, well sorted, 90% Q, 10% L (black organic matter), -HCl.
350-360’	Pale gray quartz wacke, very fine grained, subrounded, well sorted, 90% Q, 10% L (black organic matter), -HCl; dark orange brown quartz arenite, medium grained, subrounded, well sorted, 100% Q, abundant manganese staining, + HCl; loose sand,

quartz, very fine to fine grained, subangular, well sorted. [50% arenite, 30% wacke, 20% loose sand]

360-370’ Dark gray shale, -HCl; pale gray mudstone, -HCl. [90% shale, 10% mudst.]

370-380’ Ditto 320-330. [55% shale, 45% siltst.]

380-390’ Pale gray quartz wacke, very fine grained, subrounded, well sorted, 90% Q, 10% L (black organic matter), abundant hematite staining locally, -HCl; Dark gray shale, -HCl; loose sand, quartz, very fine to fine grained, subangular, well sorted. [50% ss, 40% loose sand, 10% shale]

390-400’ Ditto 380-390. [80% loose sand, 15% ss, 5% shale]

400-410’ Ditto 390-400.

410-420’ Loose sand, quartz, very fine to fine grained, subangular, well sorted.

420-430’ Ditto 410-420.

430-440’ Ditto 410-420.

440-450’ Ditto 410-420.

450-460’ Ditto 410-420.

460-470’ Loose sand, quartz, very fine to fine grained, subangular, well sorted; dark gray shale, -HCl. [90% loose sand, 10% shale]

470-480’ Ditto 460-470. [85% loose sand, 15% shale]

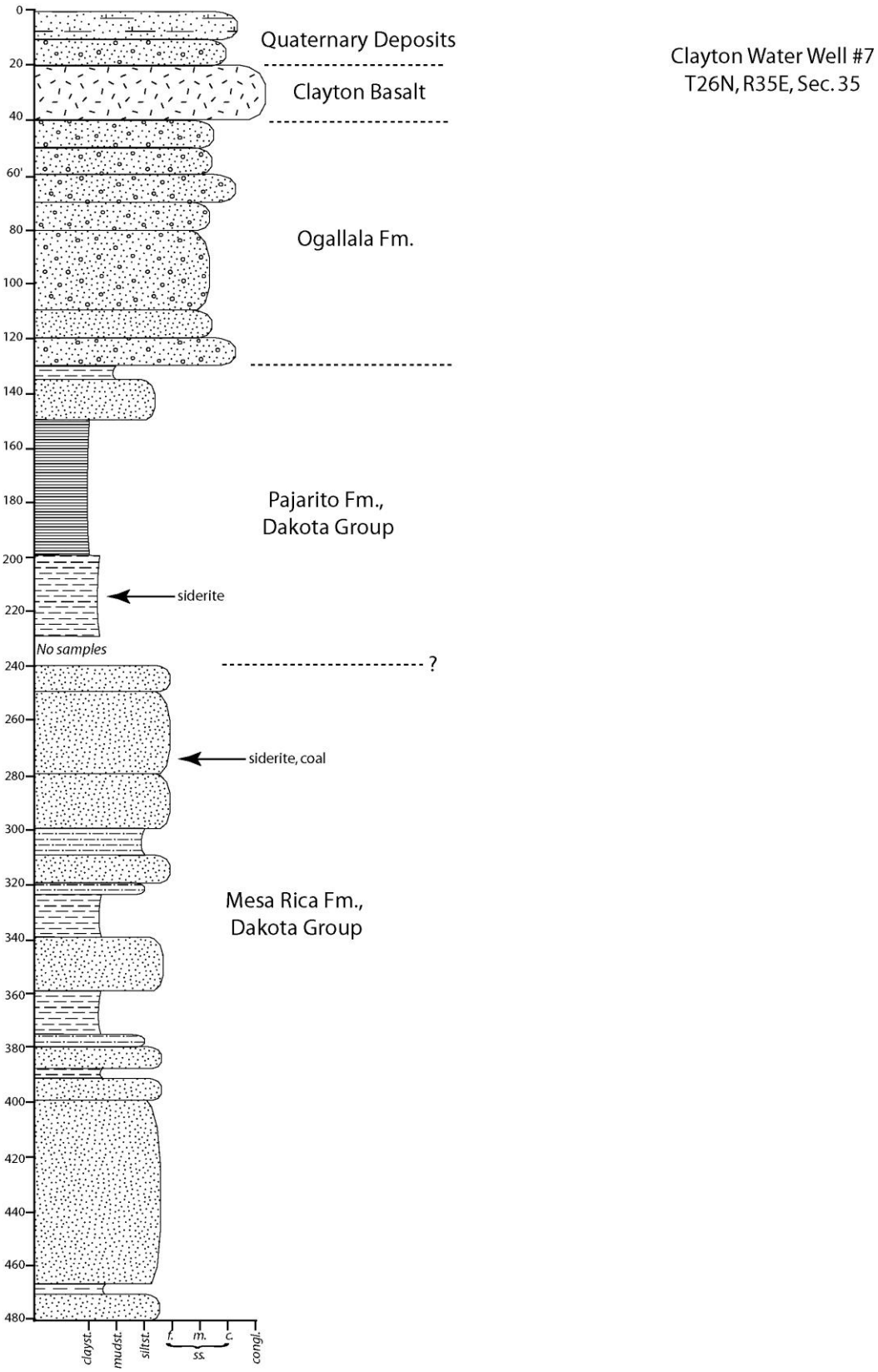

Figure 7. Clayton Water Well #7 interpreted stratigraphic column.

Continental #1 Federal Land Bank "2" (2-24N-36E, TD: 5308')

0-10'	Loose sand, quartz and some caliche, medium to coarse grained, subangular, well sorted, frosted grains.
10-20'	Ditto 0-10, grains are hematite stained.
20-30'	Ditto 10-20.
30-40'	Ditto 10-20.
40-50'	Ditto 10-20.
50-60'	Ditto 10-20.
60-70'	Ditto 10-20.
70-80'	No samples.
80-90'	Ditto 10-20.
90-100'	Ditto 10-20.
100-110'	Loose sand, quartz and some caliche, medium to coarse grained, subangular, well sorted, frosted grains; dark gray siltstone, -HCl. [85% loose sand, 15% siltst.]
110-120'	Ditto 100-110.
120-130'	Ditto 100-110.
130-140'	No samples.
140-150'	Dark gray siltstone, -HCl.
150-160'	Loose sand, quartz and some caliche, fine to medium grained, subangular, well sorted, frosted grains; dark gray siltstone, -HCl; Pale buff quartz wacke, fine to medium grained, subrounded, well sorted, 100% Q, >15% clay matrix in clusters or "stars", moderately consolidated, some hematite staining, -HCl. [50% loose sand, 45% siltst., 5% ss]
160-170'	Dark gray siltstone, -HCl.
170-180'	Ditto 150-160. [50% loose sand, 35% siltst., 15% ss]
180-190'	Ditto 150-160. [60% loose sand, 25% siltst., 15% ss]
190-200'	Ditto 150-160. [80% loose sand, 15% siltst., 5% ss]
200-210'	Ditto 150-160. [70% loose sand, 20% siltst., 10% ss]
210-220'	Ditto 150-160. [70% loose sand, 15% siltst., 15% ss]
220-230'	Ditto 150-160. [60% loose sand, 25% ss, 15% siltst.]

230-240’ Ditto 220-230.

240-250’ Ditto 150-160. [50% ss, 30% loose sand, 20% siltst.]

250-260’ Pale buff quartz wacke, fine to medium grained, subrounded, well sorted, 100% Q, >15% clay matrix in clusters or “stars”, moderately consolidated, some hematite staining, -HCl; pale green mudstone, ~HCl; very pale red and very pale gray siltstone, -HCl. [40% ss, 30% mudst., 30% siltst.]

260-270’ Ditto 250-260. [50% siltst., 30% mudst., 20% ss]

270-280’ Ditto 250-260.

280-290’ Ditto 260-270.

290-300’ Ditto 260-270.

300-310’ Ditto 260-270.

310-320’ Green mudstone, +HCl; Pale buff quartz wacke, fine to medium grained, subrounded, well sorted, 100% Q, >15% clay matrix in clusters or “stars”, moderately consolidated, some hematite staining, -HCl. [90% mudst., 10% ss]

320-330’ Ditto 310-320.

330-340’ Green mudstone, +HCl; red mudstone, ~HCl. [85% green, 15% red]

340-350’ Pale buff quartz wacke, fine to medium grained, subrounded, well sorted, 100% Q, >15% clay matrix in clusters or “stars”, very poorly consolidated, some hematite staining, -HCl; green mudstone, ~HCl; red mudstone, -HCl. [40% ss, 30% green mudst., 30% red mudst.]

350-360’ White siltstone, -HCl; green mudstone, ~HCl. [60% siltst., 40% mudst.]

360-370’ Ditto 350-360.

370-380’ White siltstone, +HCl; green mudstone, -HCl. [70% mudst., 30% siltst.]

380-390’ Pale buff quartz wacke, fine to medium grained, subrounded, well sorted, 100% Q, >15% clay matrix in clusters or “stars”, very poorly consolidated, some hematite staining, -HCl; green mudstone, ~HCl; red mudstone, -HCl. [80% green mudst., 15% red mudst., 5% ss]

390-400’ Ditto 380-390.

400-410’ White siltstone, -HCl; green mudstone, ~HCl. [70% siltst., 30% mudst.]

410-420’ Ditto 400-410. [85% mudst., 15% siltst.]

420-430’ Green mudstone, +HCl.

430-440’	Ditto 420-430.
440-450’	Ditto 420-430 plus red jasper.
450-460’	Ditto 440-450.
460-470’	Ditto 440-450.
470-480’	Red mudstone, +HCl; green mudstone, ~HCl; white siltstone, ~HCl. [80% green mudst., 10% red mudst., 10% siltst.]
480-490’	Ditto 470-480. [70% green mudst., 15% red mudst., 15% siltst.]
490-500’	Pale buff quartz wacke, fine to medium grained, subrounded, well sorted, 100% Q, >15% clay matrix in clusters or “stars”, moderately consolidated, some hematite staining, ~HCl; green mudstone, -HCl; red mudstone, ~HCl. [80% green mudst., 15% red mudst., 5% ss]
500-510’	White siltstone, -HCl; green mudstone, +HCl; red mudstone, ~HCl. [40% green mudst., 30% siltst., 30% red mudst.]
510-520’	Ditto 500-510.
520-530’	Ditto 500-510 plus red jasper.
530-540’	Ditto 520-530 plus loose sand, quartz, fine to medium grained, subrounded, well sorted; pyrite in siltstone. [40% green mudst., 30% siltst., 20% loose sand, 10% red mudst.]
540-550’	Ditto 530-540.
550-560’	Ditto 530-540.
560-570’	Ditto 530-540.
570-580’	Pale green siltstone, very poorly consolidated, +HCl.
580-590’	White siltstone, -HCl; green mudstone, +HCl; red mudstone, ~HCl; loose sand, quartz, fine to medium grained, subrounded, well sorted; pyrite in siltstone. [40% green mudst., 30% siltst., 25% loose sand, 5% red mudst.]
590-600’	White siltstone, -HCl; green mudstone, +HCl; red mudstone, ~HCl. [40% green mudst., 30% siltst., 30% red mudst.]
600-610’	White siltstone, poorly consolidated, +HCl.
610-620’	Green siltstone, poorly consolidated, +HCl; red mudstone, +HCl. [60% siltst., 40% mudst.]
620-630’	Ditto 610-620.

630-640’	Ditto 610-620. [Exeter??]
640-650’	Ditto 610-620.
650-660’	Red brown mudstone, +HCl. [Chinle??]
660-670’	Pale red brown mudstone, +HCl.
670-680’	Ditto 660-670.
680-690’	Ditto 660-670.
690-700’	Ditto 660-670.

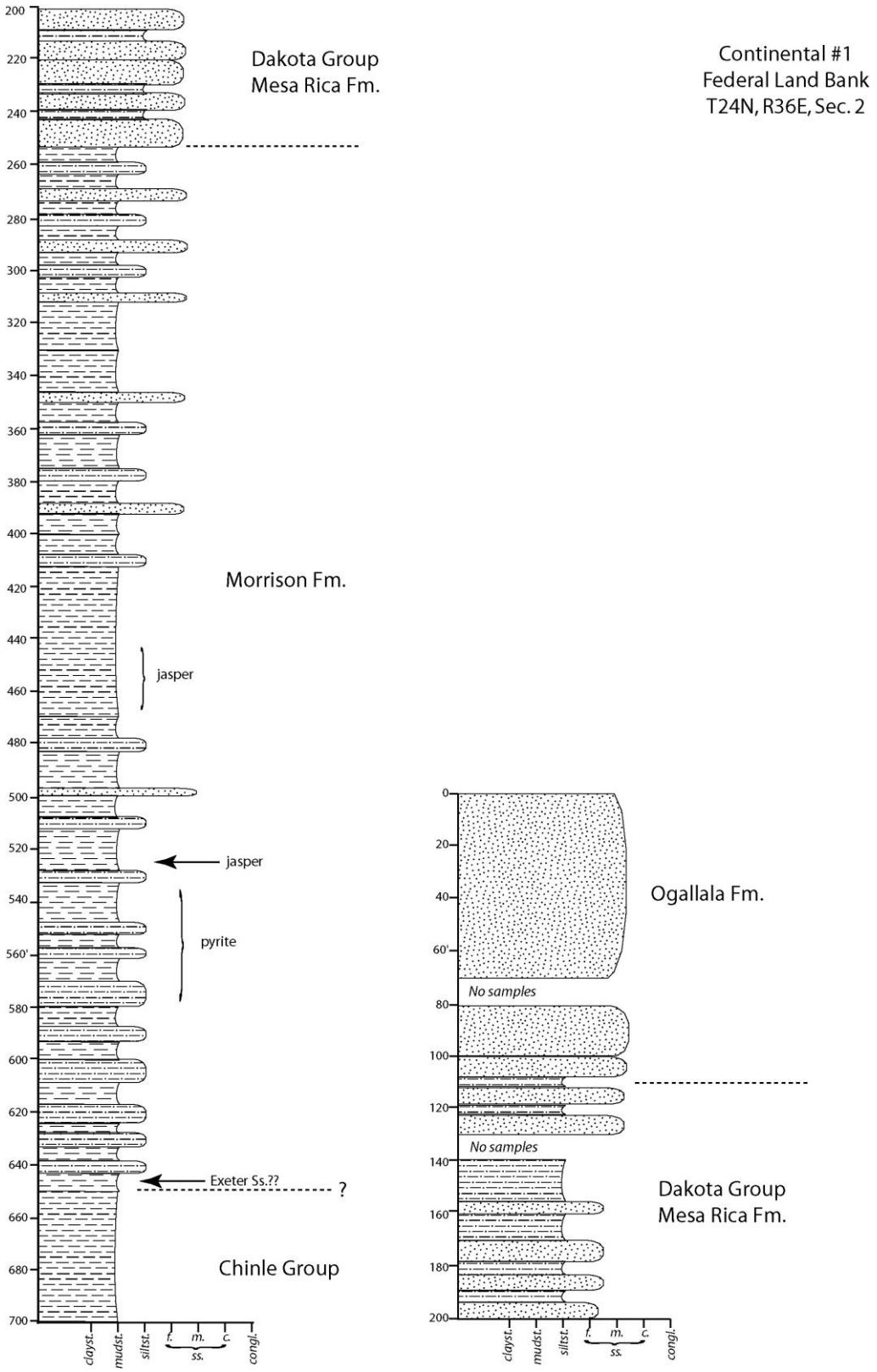

Figure 8. Continental #1 Federal Land Bank interpreted stratigraphic column.

R.L. Nunn & Co. #1 Wallis (30-20N36E, TD: 762')

0-10'	Loose sand and pebbles, sand fraction is quartz and some caliche, very fine to medium grained, subrounded, moderately sorted, frosted grains; pebble fraction is caliche.
10-20'	Gravel and loose sand, gravel fraction is caliche, chert, quartz wacke; sand fraction is quartz and caliche, very fine to very coarse, subrounded, poorly sorted, some grains frosted.
20-30'	Calcrete "caprock".
30-40'	Yellow and very pale yellow quartz wacke, medium grained, subangular, well sorted, 100% Q, >15% clay matrix, locally abundant limonite and hematite cement, well consolidated, +HCl.
40-50'	Ditto 30-40.
50-60'	Yellow and very pale yellow quartz wacke, medium grained, subangular, well sorted, 100% Q, >15% clay matrix in clusters or "stars", locally abundant limonite and hematite cement, well consolidated, +HCl; pale green mudstone, -HCl. [70% mudst., 30% ss]
60-70'	Ditto 50-60.
70-80'	Very pale green claystone, very well consolidated, +HCl.
80-90'	Pale green mudstone, well consolidated, +HCl.
90-95'	Pale green mudstone, well consolidated, +HCl; very pale red mudstone, +HCl. [70% green, 30% red]
95-100'	Ditto 90-95. [60% green, 40% red]
100-110'	Very pale red mudstone, poorly consolidated, +HCl.
110-120'	Ditto 90-95, both very well consolidated. [60% red, 40% green]
120-130'	Red brown siltstone, +HCl; green mudstone, +HCl; red jasper. [70% red, 30% green]
130-135'	Very pale green mudstone, variable consolidation, +HCl.
135-145'	Loose sand, quartz, fine to medium grained, subrounded, well sorted, frosted grains. [Exeter!]
145-155'	Very pale green mudstone, poorly consolidated, +HCl.

155-165’ Red brown siltstone, moderately consolidated, +HCl; green mudstone, well consolidated, +HCl. [70% red, 30% green]

165-175’ Red brown mudstone, well consolidated, +HCl; pale orange mudstone, +HCl. [70% red, 30% orange]

175-185’ Red brown mudstone/mudshale, +HCl; pale green and orange red mottled siltstone to sandy mudstone, +HCl. [60% mudst., 40% siltst.]

185-195’ Red brown mudstone with occasional pale green mottles (<1 cm diameter), well consolidated, +HCl.

195-205’ Red brown mudstone, +HCl; pale green sandy mudstone, +HCl; pale green mudstone, +HCl. [40% red mudst., 40% sandy mudst., 20% green mudst.]

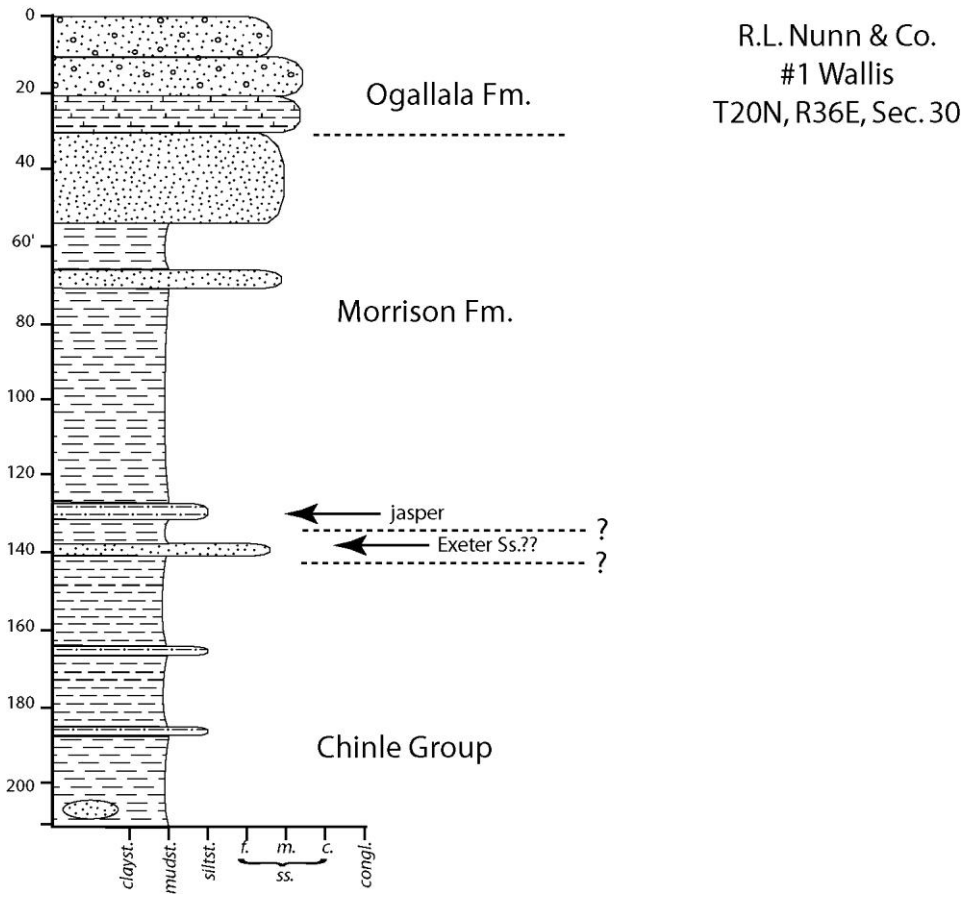

Figure 9. R.L. Nunn & Co. #1 Wallis interpreted stratigraphic column.

Amoco Production Co. 301 BDCD Gas Unit 1835 (30-18N-35E, TD: 2962')

(Samples over-washed.)

0-10' No samples.

10-20' Caliche.

20-30' Caliche.

30-40' Calcrete.

40-50' Calcrete.

50-60' Calcrete and caliche.

60-70' Ditto 50-60.

70-80' Ditto 50-60.

80-90’	Calcrete and caliche; loose sand, quartz, coarse to very coarse grained, subrounded, well sorted, many grains frosted; red brown siltstone, +HCl. [50% loose sand, 40% siltst., 10% calcrete/caliche]
90-100’	Calcrete and caliche; loose sand, quartz, coarse to very coarse grained, subrounded, well sorted, many grains frosted. [90% loose sand, 10% calcrete/caliche]
100-110’	Ditto 90-100. [70% calcrete/caliche, 30% loose sand].
110-120’	Ditto 90-100.
120-130’	Ditto 100-110.
130-140’	Ditto 90-100. [95% loose sand, 5% calcrete/caliche]
140-150’	Ditto 130-140.
150-160’	Ditto 130-140.
160-170’	Ditto 90-100. [70% calcrete/caliche, 30% loose sand]
170-180’	Ditto 90-100. [90% calcrete/caliche, 10% loose sand]
180-190’	Ditto 90-100. [50% calcrete/caliche, 50% loose sand]
190-200’	Ditto 90-100. [70% loose sand, 30% calcrete/caliche]
200-210’	Ditto 90-100. [60% loose sand, 40% calcrete/caliche]
210-220’	Ditto 90-100. [50% loose sand, 50% calcrete/caliche]
220-230’	Ditto 90-100. [90% loose sand, 10% calcrete/caliche]
230-240’	Pale red brown and pale green mudstone, + HCl; loose sand, quartz, coarse to very coarse grained, subrounded, well sorted, many grains frosted. [70% mudst. (90% green, 10% red), 30% loose sand]
240-250’	Ditto 230-240.
250-260’	Ditto 230-240.
260-270’	Ditto 230-240.
270-280’	Ditto 230-240.
280-290’	Pale red brown and pale green mudstone, +HCl. [80% red, 20% green]
290-300’	Ditto 280-290, plus red jasper.
300-310’	Ditto 280-290, plus red jasper.
310-320’	Pale red brown and pale green mudstone, +HCl. [70% red, 30% green]
320-330’	Ditto 310-320. [60% red, 40% green]
330-340’	Ditto 320-330.

340-350’ Ditto 320-330.

350-360’ Ditto 320-330.

360-370’ Ditto 320-330.

370-380’ Ditto 320-330.

380-390’ Ditto 320-330.

390-400’ Ditto 320-330.

400-410’ Ditto 320-330. [Where is Exeter???]

410-420’ Ditto 320-330.

420-430’ Ditto 320-330.

430-440’ Ditto 320-330.

440-450’ Ditto 320-330.

450-460’ Ditto 320-330.

460-470’ Ditto 320-330.

470-480’ Ditto 320-330.

480-490’ Ditto 320-330.

490-500’ Ditto 320-330.

500-510’ Ditto 320-330.

510-520’ Ditto 320-330.

520-530’ Ditto 320-330.

530-540’ Ditto 320-330.

540-550’ Ditto 320-330. Plus red jasper?

550-560’ Ditto 320-330.

560-570’ Ditto 320-330.

570-580’ Ditto 320-330.

580-590’ Ditto 320-330.

590-600’ Ditto 320-330.

600-610’ Ditto 320-330.

610-620’ Ditto 320-330.

620-630’ Ditto 320-330. → clay spike in gamma log [Chinle top?]

630-640’ Ditto 320-330. Plus rare loose sand, quartz, medium grained, rounded, frosted.

640-650’ Ditto 320-330.

650-660’ Red brown mudstone with rare very small pale green mottles, +HCl.

660-670’ Red brown mudstone, +HCl; pale green siltstone, +HCl. [50% mudst., 50% siltst.]

670-680’ Red brown mudstone with rare pale green mottles, +HCl.

680-690’ Ditto 670-680.

690-700’ Ditto 670-680.

[Gamma ray log is suppressed due to casing to 700’, but no variability from 150’ to 630’ where small clay shift occurs, then back by 640’ → No Exeter??]

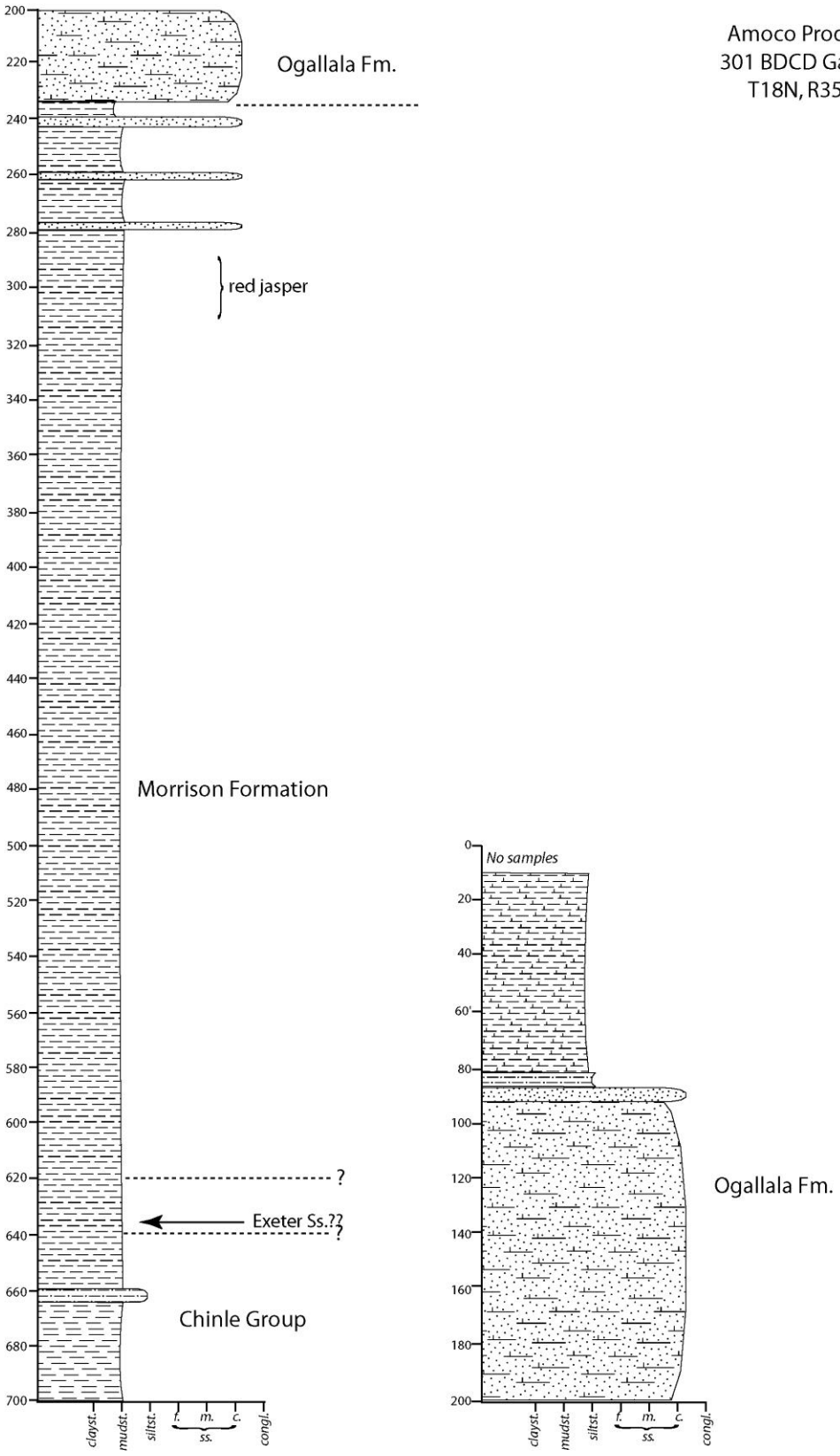

Figure 10. Amoco Production Co. 301 BDCD Gas Unit 1835 interpreted stratigraphic column.