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

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Introduction

This is a preliminary report on the surface and shallow subsurface geology of the Clayton, southern Seneca and northern Sedan 1:50,000 quadrangles in east-central Union County 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 accurate models of the aquifer(s) in the vicinity of Clayton can be developed from these maps and descriptions.

Background Geology

The oldest strata exposed in Union County are found in the Dry Cimarron Valley, are Triassic in age (230-200 million years (Ma)) and referred to as the Chinle Group. During the Late Triassic, New Mexico was a broad, low relief basin with large river systems flowing through from West Texas into Arizona, Utah and on to the shoreline in Nevada. In addition, alluvial fans shedding off of the remains of the Ancestral Rocky Mountains and the Uncompaghre Uplift brought sediments down into the basin. These rocks preserve the remains of some of the earliest dinosaurs and are often brilliant red to purple in color. Triassic rocks exposed in Union County are primarily the upper part of the Chinle Group and include the Sheep Pen Sandstone locally, and the Sloan Canyon and upper Travesser Formation (Baldwin and Muehlburger, 1959; Lucas et al., 1987).

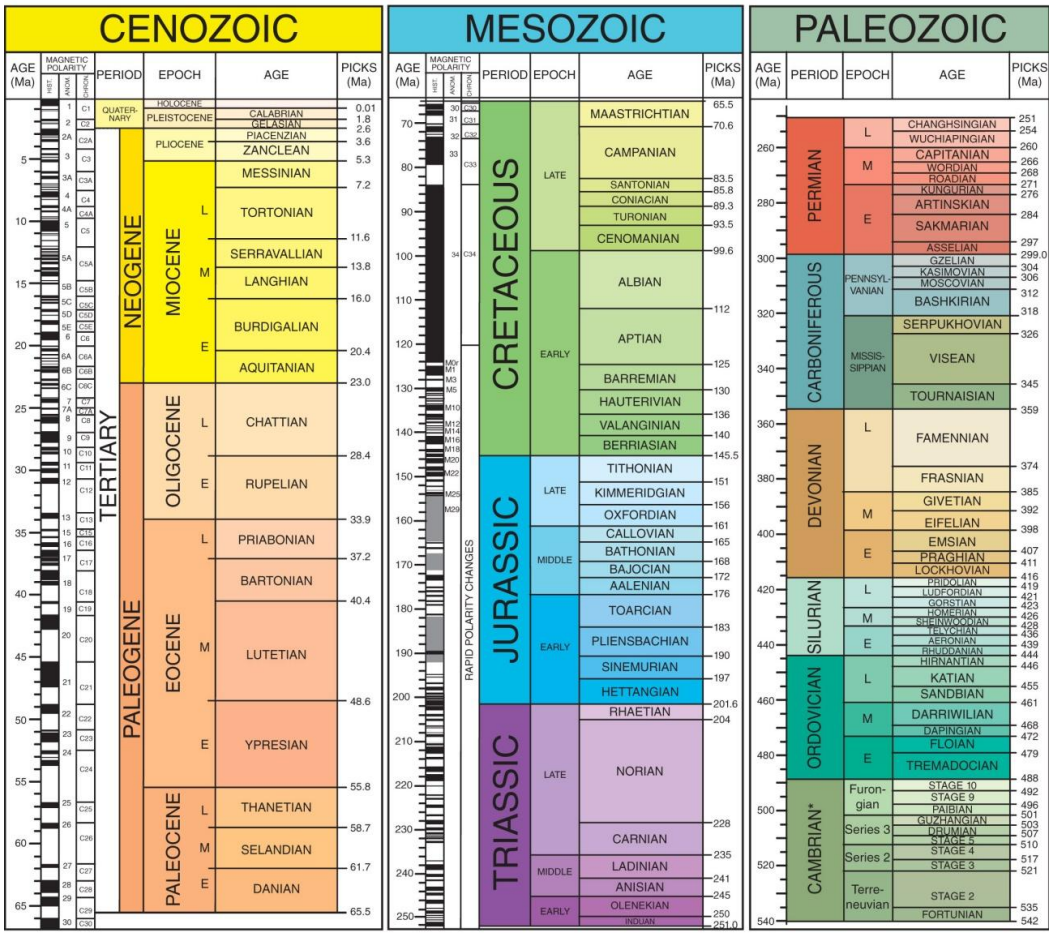


Figure 1. Geologic time scale (2009 version).

There is an interval of time missing at the top of the Triassic rock sequence that represents the Early Jurassic. Thus, rocks of Middle Jurassic (~175-160 Ma) and Late Jurassic (160-145 Ma) rest directly on the Upper Triassic Chinle Group. Middle Jurassic strata include the Exeter Sandstone, a relatively thick sequence of pale red to white quartz sandstone that either lacks features or contains large crossbeds (Mankin, 1972). The Exeter Sandstone is the easternmost extent of a large-scale dune field that covered much of the Four Corners region. Above the cliff-forming Exeter Sandstone are outcrops of the Bell Ranch and Morrison Formations. The Morrison Formation is renowned in the western United States for producing fossil remains of large dinosaurs. Both the Bell Ranch and Morrison Formations consists of different colored low outcrops that are greenish-gray to reddish brown mudstone with some coarse sandstone (Mankin, 1972). 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 fan systems depositing sediments into a low relief basin.

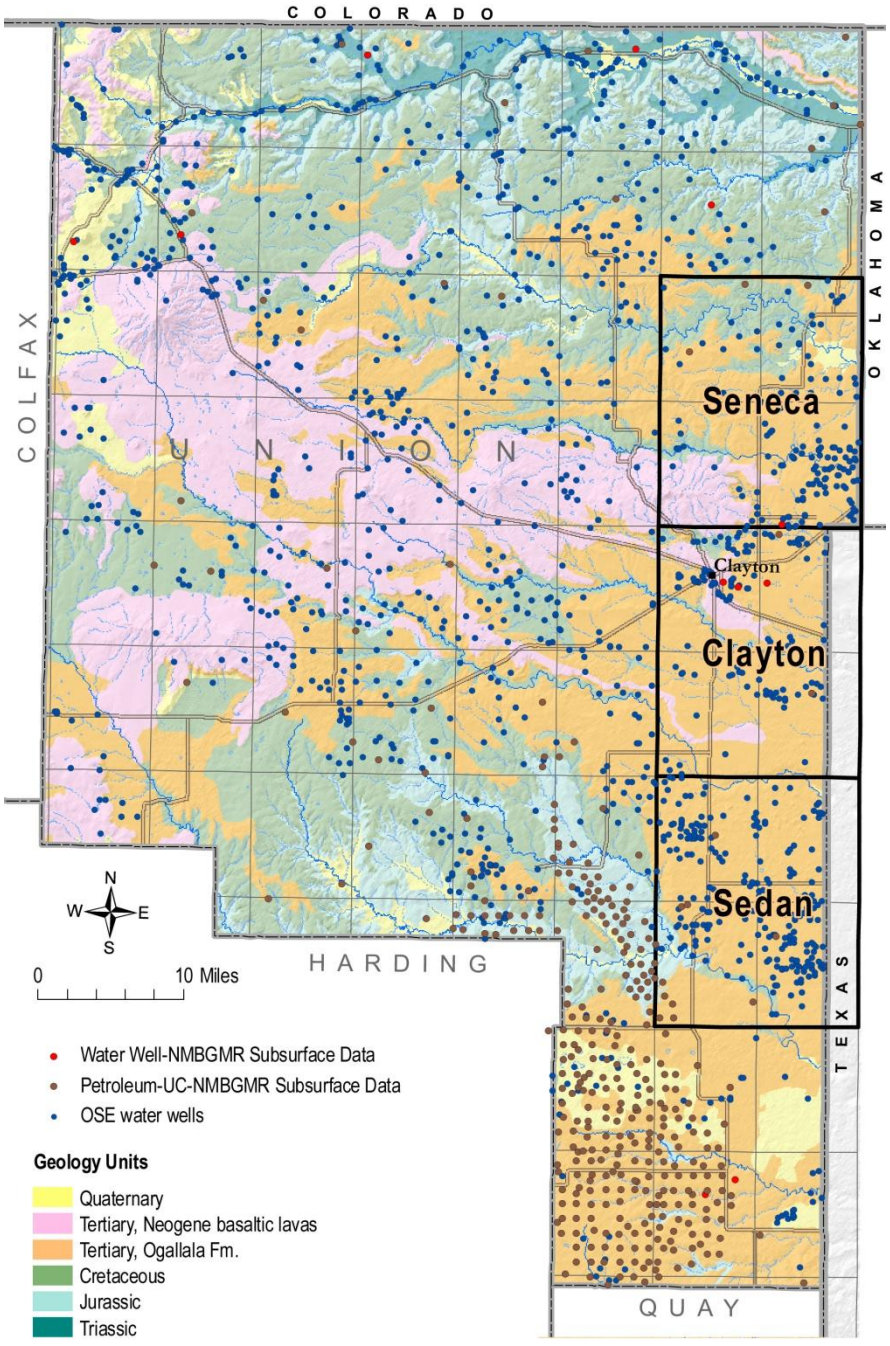


Figure 2. Basic geologic map of Union County with locations of quadrangles discussed in this report (figure courtesy of NMBGMR).

The Morrison Formation is overlain by strata that are Late Cretaceous in age and include the Lytle Sandstone, the Glencairn Formation and the Dakota Group. Rocks that are Early Cretaceous in age are not preserved here. 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). Above the Lytle Sandstone are gray shales and buff-colored sandstones that often contain numerous fossils of small oysters called *Texigryphea* and were deposited under marine conditions (Kues and Lucas, 1987). 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/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, bar deposits and thin shales representing slightly deeper water conditions. Above the Romeroville Sandstone is the Graneros Shale, which consists of dark gray shales and mudstone with thin limestone beds in the middle part of the unit and is also Albian in age (Kues and Lucas, 1987). Often these thin limestone beds are full of oyster shells from inoceramids, shark teeth, and can retain impressions of ammonoid shells.

At the end of the Cretaceous (~65 Ma), the dinosaurs died out in a mass extinction event that also affected many of the organisms living in the world's oceans. In Union County, none of the rocks that record the early to middle Cenozoic are preserved (65 – 23 million years ago). These rocks were either not deposited or were eroded away by some younger phase of degradation of the landscape. The Ogallala Formation, well known on the High Plains for its characteristics as an aquifer (Baldwin and Muehlburger, 1959), is the only record of any part of the Cenozoic preserved in this area (Miocene to Pliocene: 23 – 2.6 Ma). The Ogallala Formation strata represent deposition by large 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. 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.

Local Geology and Revised Maps

The original geologic maps constructed by Baldwin and Muehlberger (1959) are relatively accurate and have needed only a few minor changes. The most prominent change is that more Mesozoic bedrock is exposed in some creek beds than is shown on the compilation map published in Baldwin and Muehlberger's report. Additionally, greater expanses of Quaternary sandy soils and sand dunes are present as compared to what was mapped in the 1950s. In general, the geology of the Clayton 1:50,000 quadrangle is represented by Quaternary basalt flows from the Rabbit Ears vents and vents to the south, Quaternary eolian sands, soils and creek-bed gravels, the Miocene to Pliocene Ogallala Formation, and the Late Cretaceous Graneros Shale and Dakota Group. The basalts are avesicular, except for the top surface, and aphanitic, with no phenocrysts observed, and are up to 10 m (~30 feet) thick. The Quaternary sedimentary deposits are comprised of modern alluvium found in creek beds and arroyo bottoms, reworked eolian sheet sands and sandy soils and modern sand dune fields (mostly vegetated). Modern alluvium includes pebbles to boulders of Dakota Group sandstone, siderite from the Graneros Shale, and reworked quartzite, plutonic and volcanic rocks from the Ogallala Formation. Thickness of eolian sheet sands and soils varies considerably from less than 0.5 m to over 25 m thick. Thickness variations of these soils and older alluvial deposits reflects the erosional surface developed on the top of the Ogallala Formation.

The Ogallala Formation is a complex unit that represents deposition in fluvial, eolian and aggradational fan systems that were carrying material from the newly uplifted Rocky Mountains. The lower Ogallala Formation usually consists of some proportion of cobble to boulder conglomerate and coarse grained sandstone with lenses of sandy mudstone that fines upwards into medium to coarse grained sandstone that becomes pervasively cemented with calcite, forming the hard caliche caprock observed throughout eastern New Mexico and West Texas. Conglomerates contain pebbles to small boulders of quartzite, Dakota Group sandstone, siderite

concretions (Graneros Shale), quartzite, granitic to intermediate intrusive igneous and intermediate to mafic volcanic rocks.

Figure 3. Outcrop of Ogallala Formation, showing complex interfingering of sandstone and conglomerate.

Figure 4. Close-up view of conglomerate lens in outcrop in Figure 1.

The majority of the quartzite and igneous rocks are sourced from exposures in the Rocky Mountains to the west and northwest. Sandstone in the Ogallala Formation ranges from 80% to 90% quartz and 20% to 10% lithic grains. Very rarely, up to 10% feldspar was observed. Most sandstone beds are medium to coarse grained, poorly sorted with subangular to subrounded grains and greater than 15% clay matrix between the sand grains. Many are pebbly and pebbles can be either extrabasinal clasts such as quartzite and chert, or intrabasinal clasts such as mud rip-up clasts and calcrete nodules. Sedimentary structures in most sandstone units have been

obliterated by bioturbation and abundant vertical and horizontal burrowing and/or root casts have been observed. Where sedimentary structures are preserved, they include faint low angle crossbedding, cross-lamination or planar tabular thin bedding. Sandy mudstone units in the Ogallala are laterally discontinuous, red in color, and contain occasional extrabasinal pebbles and do not show signs of bioturbation. The upper 3 to 5 meters of the Ogallala consists of a stage III to IV calcrete horizon (or calcic paleosol) that shows signs of pervasive bioturbation. Locally, thin stringers of chalcedony, locally opalescent, that reflect alteration of ash fall units within the upper Ogallala Formation.

Figure 5. Vertically oriented semi-cylindrical burrows in the uppermost Ogallala Formation.

Figure 6. View of outcrop with intense bioturbation in upper Ogallala Formation.

Figure 7. Brecciated and recemented calcrete caprock in the Ogallala Formation.

The Cretaceous Graneros Shale is observed in some cutbanks along creek beds on the Clayton quadrangle. The Graneros Shale consists of gray to yellowish gray shale with one to three thin sandy limestone beds and laterally persistent sideritized horizons. The sandy limestones locally preserve short, cylindrical burrows and shell material from thin-walled inoceramid clams. In many creek beds, seeps and low-flow springs occur at the sandy limestone horizons. Siderite occurs as individual concretions up to 20 cm in diameter or as laterally continuous beds within the shale. The Graneros Shale is only preserved locally and is often eroded out by either the Ogallala Formation or by Quaternary alluvial deposits. The lack of continuous outcrop reflects a second, and older, erosional surface that was developed on Cretaceous bedrock prior to deposition of the Ogallala Formation. The Ogallala's basal conglomerate does included pieces of Cretaceous bedrock, but the geometry of the basal units suggest a valley fill episode as opposed to active down-cutting and erosion of the Cretaceous by Ogallala streams.

Figure 8. Outcrop of Graneros Shale with sandy limestone bed at top of exposure. Overlain by Quaternary fluvial gravel deposits.

The Dakota Sandstone or Romeroville Formation (sensu Kues and Lucas, 1987) of the Cretaceous Dakota Group is also exposed along cutbanks and in the floor of creeks in some locations. The uppermost Dakota Sandstone is a white to gold to dark purple medium grained quartz arenite with some calcite cement. The grains are well rounded and well sorted. It is thin to medium bedded, and locally contains high angle trough crossbeds, reflecting dune deposition. The uppermost sandstone beds are often pervasively bioturbated. In some places, lenses of gray shale are present in the upper Dakota Sandstone. The contact between the Dakota Sandstone and the Graneros Shale is gradational and the top of the Dakota Sandstone is picked at the last occurrence of a quartz arenite that is laterally continuous.

Figure 9. Outcrop of uppermost Dakota Group (Romeroville Formation sensu Kues and Lucas, 1987).

Figure 10. Small cylindrical burrows oriented on bedding plane in uppermost Dakota Group sandstone.

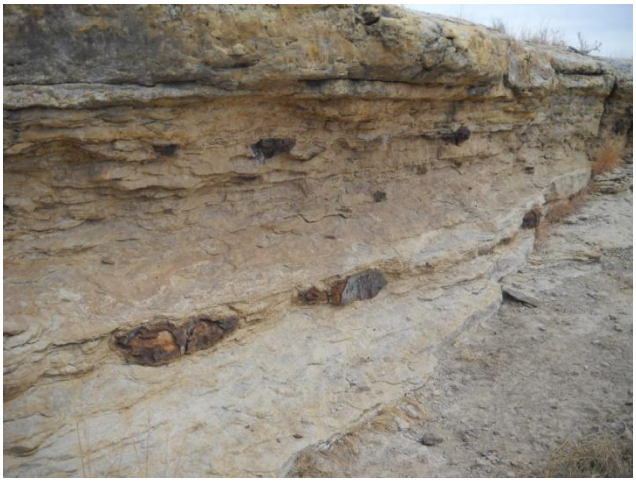


Figure 11. Siderite concretions in uppermost Dakota Group/lowermost Graneros Shale.

The southern half of the Seneca quadrangle is similar to the Clayton quadrangle in terms of the surface geology. Aphanitic basalt flows from the Rabbit Ears vents dominate the southwestern corner of the quadrangle and Quaternary eolian and alluvial deposits cover much of the eastern half. Local outcrops of the Ogallala Formation and the Cretaceous Graneros Shale and Dakota Sandstone are again confined to cutbanks in some creek beds and local exposures along the edges of dune fields. The northern half of the Sedan quadrangle is dominantly Quaternary eolian deposits and alluvium with some exposures of Quaternary basalt, Ogallala Formation and Cretaceous bedrock in creek banks and some poorly developed badland exposures.

In addition to examining surface exposures of rock, five petroleum test wells were chosen that extend from just south of Atencio Road to just north of Sedan. Well cuttings for each well were examined at the core archive facility at the New Mexico Bureau of Geology and Mineral Resources in Socorro. From these well cuttings, interpreted stratigraphic columns can be developed which show what the geology looks like in the subsurface. The well cutting descriptions and stratigraphic columns are in the Appendix to this report. Initial interpretations of the well logs examined indicate that the Cretaceous strata (Dakota Group and Glencairn Formation) are present in the subsurface for much of the extent of these maps areas. To the south, strata interpreted as the Jurassic Morrison Formation are closer to the surface than was expected.

Preliminary Conclusions

Few major changes were made to the compiled map published previously. The only substantial changes include adding observations of Dakota Sandstone along some creek banks and beds where the previous compiled map either showed Quaternary alluvium or Ogallala Formation outcrops. These are relatively minor changes in terms of the geologic map, but they do have an impact on current understanding of the subsurface geology. Common conceptions of the groundwater system in the Clayton area assume that the Ogallala Formation is substantially thicker (200' to over 1000', depending upon the person) and saturated throughout its thickness. However, outcrops of Cretaceous strata in creek bottoms and banks implies that the Ogallala is probably not much over 200' thick in most places. Additionally, the direct contact between the Ogallala and Dakota Sandstone suggests that water percolating down from surface water sources will saturate the Dakota Sandstone at the expense of the Ogallala Formation. There is some Graneros Shale between the two units locally, but it is not laterally extensive enough to act as a true aquiclude and keep surface water within the Ogallala Formation.

The main points to be derived from this preliminary report are the following: 1) geologic maps constructed for Union County are, for the most part, accurate representations of surface exposures, 2) the Ogallala Formation is not as thick as has often been assumed, especially in the Clayton and southern Seneca quadrangles, and 3) the Cretaceous Dakota Formation plays a more important role in the groundwater system than may have previously been expected. Continuation of this effort includes revising the geologic maps for the northern Seneca and southern Sedan 1:50,000 quadrangles, as well as beginning revision of maps to the south (to the Quay County line) and to the west. Continued detailed description of the lithology of older units, including Jurassic and Triassic rocks, in the Dry Cimarron Valley will allow for assessment of these deeper rocks as potential water-producing units. In addition, well cuttings from more petroleum test wells will be examined. Stratigraphic columns will be developed for these test wells and then used to develop a north-south trending fence diagram, which will provide a three dimensional view of subsurface geology.

Detailed 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 Cretaceous bedrock and clasts from the Ogallala Formation.

Qc: Colluvium along escarpments below basalt flows. Consists of basalt boulders and cobbles, as well as eolian soils that have developed among the boulders. Obscures underlying bedrock exposures.

QTb: Quaternary-Tertiary basalt flows. Aphanitic, mostly avesicular, except for top surface of flow. Up to 10 m thick. Individual flows not identified.

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 clast supported and clast size ranges from pebble to small boulder. Clast compositions include siliceous intrusive igneous, metamorphic, Cretaceous sandstone, chert, quartzite. Matrix is coarse sandstone, mostly quartzose with minor feldspar. Sandstones are medium to coarse grained, pebbly, often trough cross-bedded, quartzose, moderately cemented. Middle to upper Ogallala is semiconsolidated to unconsolidated medium to coarse sand. Uppermost 0.5-1.0 m is Stage III-IV calcic paleosol (caliche caprock). Base of calcic paleosol is gradational with underlying sandstone, with stringers of calcareous cemented material and siliceous or calcareous vertically oriented tubules penetrating into underlying unit. Calcic paleosol is nodular to wavy laminar with abundant cylindrical burrow and/or root casts. Concentrically zoned concretions abundant. Locally, some thin stringers of siliceous materials, rarely converted to opal.

Cretaceous

Kg, Graneros Shale (Late Cretaceous: Cenomanian): 0.5 to 4 m of dark gray to pale gray shale. Can contain one to three sandy limestone beds. If limestone beds are present, uppermost one is thickest and fossiliferous (includes thin-shelled inoceramids and molds of

ammonoids/nautiloids). All limestone beds are less than 0.5 m thick, are dark gold-brown in color, can be massive to laminated and are bioturbated. Locally, abundant siderite concretions, up to 20 cm in diameter, as well as laterally persistent horizons that have been sideritized (not more than 20 cm thick).

Kd, Dakota Group – Dakota Sandstone (Late Cretaceous: Albian-Cenomanian): Uppermost unit of Dakota Group, up to 50 m of 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 preserved on bedding plains, or beds are intensely bioturbated. Colors range from dark purple to nearly white and cementation ranges from quartzite to moderately well cemented. Local manganese staining highlights sedimentary structures. Occasional zones with well developed siderite nodules and boxwork.

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.

Mankin, C.J., 1972, Jurassic strata in northeastern New Mexico: New Mexico Geological Society Guidebook 23, p. 91-97.

Appendix: Detailed Lithologic Descriptions

This appendix provides detailed lithologic descriptions of different units in the Clayton area 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.

Ogallala Formation

0662685, 4029032: Pinkish tan, poorly consolidated sandstone. Medium grained, poorly sorted, subangular to subround. 80% Q, 10% F, 10% L, >15% clay matrix = arkosic lithic wacke. Rip-up clasts have been eroded out. Faint horizontal bedding, very bioturbated. Grades upward into a caliche with stringers of caliche and/or chalcedony. Upsection, bedding become thicker, unit is more nodular with vertical burrows and/or root casts. Top is locally very well cemented with advanced calcrete development and some syndepositional deformation and piping.

0662792, 4029686: Base of Ogallala is a boulder to cobble conglomerate with clasts of Dakota Group sandstone, limestone, basalt, quartzite, <1 m thick and as little as 0.2-0.3 m thick.

0659026, 4040452: Basal exposure is orange, unconsolidated sand. Grains are well rounded and sorted, 90% Q, 10% L. Followed by 0.3 m of white, thin bedded, possibly bioturbated quartz wacke with ~10% L, calcite cement, rich in clay matrix with occasional pebbles and cobbles. Local lenses of rip-up clasts of underlying orange sand. Followed by 0.5 m of orange semiconsolidated sandstone that is locally thin bedded to laminated. Grades up into 4-5 m of massive to bioturbated poorly consolidated medium grained sandstone. Local stringers of caliche nodules or calcrete. Occasional horizontally oriented burrows. Top has locally developed into Stage IV-V calcrete. Orange color may be due to overlying basalt flow.

0658947, 4032581: Basal exposure is ~2 m of poorly cemented cobble conglomerate. Cobbles are subround to round, and include calcrete, micrite (Graneros?) and minor quartzite.

0676639, 4064149: 2 m thick exposure of extensively bioturbated, faintly bedded, nodular medium to coarse grained sandstone. Common granule and pebbles of quartzite, etc. Grains are subround to round, poorly sorted. 80% Q, 20% L in sand fraction, >15% clay matrix. Local

lenses of very poorly consolidated fine sand with caliche stringers, burrows and/or root casts and no pebbles.

0634689, 4033498: White to very pale gray coarse grained, subround, poorly sorted, pebbly sandstone. 95% Q, 5% L, >15% clay matrix. Clasts are granule to small cobble and include quartzite, intermediate extrusive and intrusive igneous, ?chert. <0.5 m thick discontinuous calcrete horizons that are moderately developed with some bioturbation. Coarser clasts occur as stringers. Bright orange in color immediately below basalt flow.

0631183, 4031900: Buff coarse sandstone, moderately well sorted, subrounded grains with sparse pebbles of quartzite. 95% Q, 5% L, >15% clay matrix. Faint laminations, moderately bioturbated.

0623939, 4031926: Very pale gray, thin bedded sandstone with faint low angle crossbeds. Very bioturbated and nodular in appearance. Sparse pebbles of quartzite. Upsection, becomes less well-cemented and very bioturbated. Local lenses of non-cemented sand.

0645174, 4021485: ~3 m of faintly crossbedded to laminated sandstone with some bioturbation. Followed by ~6 m of very bioturbated sandstone with long, horizontally oriented "tubes" (cementation along groundwater flow paths).

0671389, 4087097: Bottom 0.5 m is gold massive medium grained sandstone with some localized bioturbation. Occasional pebbles and cobbles of calcrete. Followed by lens of cross-laminated sandy calcrete. Deep scour of cobble conglomerate locally nearly cuts out cross-laminated layer. Conglomerate is 3-4 m thick with lenses of cross-laminated sandstone within – very complex interfingering of conglomerate and sandstone. Conglomerate clasts include quartzite, Dakota sandstone, granite, slate, chert. Clasts are subangular to subround and range from granule to cobble in size.

0676004, 4061656: Poorly consolidated to unconsolidated medium grained sandstone. 85% Q, 15% L, no pebbles. Bioturbated with some calcrete nodules. Capped by ~1 m of slightly better cemented white sandstone that is more heavily bioturbated.

0672392, 4062120: Lowest 1.5 m is massive, poorly consolidated medium grained sandstone with occasional calcrete nodules. Grades upwards into nodular sandstone up to 3 m thick. Also becomes better cemented upsection. Very bioturbated with no extrabasinal clasts.

0648542, 4063458: Lowest 1.0 m is pebbly sandstone with abundant in-situ calcrete nodules, very bioturbated. Clasts are gold-brown and brown-black sandstone pebbles and cobbles.

Followed by 1.0 m of thin bedded pebbly sandstone with pervasive stringers of chalcedony that is locally opalescent. Last 3.0 m are nodular and very bioturbated with faint thin bedding and no pebbles.

0657801, 4027372: 1.5 m thick outcrop of medium to coarse sandstone, buff to gray in color, bioturbated. Top is better cemented than base. No pebbles.

0673402, 4025881: Cemented conglomerate resting on Dakota Group. Clasts include boulders of Dakota sandstone, cobbles of sandstone, quartzite and volcanics. Matrix is coarse grained muddy sandstone with subround grains, 95% Q, 5% L and moderately well cemented. Ogallala seems to be infilling possible tension fractures within Dakota sandstone.

0660727, 4016705: Well cemented and bioturbated sandstone overlain by low ridges of loose gravel that is probably uncemented Ogallala conglomerate. Gravel includes quartzite.

0658735, 4098162: Bioturbated or massive gold sandstone lenses in long low mounds of unconsolidated gravel. Fewer extrabasinal clasts present. Locally, top of outcrop is well developed calcrete that is brecciated and recemented in places. Some silcrete stringers.

0664912, 4027663: Caliche that includes coarse to fine sand grains that are rounded, poorly sorted and mostly quartz with rare red and light gray chert. Mostly massive with pebbles of caliche. Upper 10 cm is nodular.

0665053, 4027681: Base is pebbly sandstone with some siderite. Pebbles are small and angular. Followed by olive green to red coarse to medium sandstone that is very muddy, with some pebbles. Separated by thin red mudstone interval with occasional yellow calcrete nodules. Followed by 2-3 m of bioturbated pebbly, muddy sandstone with vertical burrows. Upper 2-3 m contain abundant vertical burrows, lowest meter of this interval has faint crossbeds.

0665627, 4028050: White moderately well cemented muddy coarse grained sandstone with pebbles and cobbles of volcanics, chert, quartzite, Dakota sandstone, granite. Sandstone grains are subround, moderately sorted, mostly quartz. Followed by less well cemented and bioturbated sandstone with local buff colored sandstone lenses (eolian?).

0666005, 4027626: Base of outcrop is moderately well cemented muddy sandstone with occasional pebbles. Overlain by very bioturbated coarse grained sandstone with some pebbles and calcrete nodules. Local lenses of red-brown sandy mudstone. Upper exposures are better cemented dark gray pebbly sandstone with some cobbles, nodular, local lenses of unconsolidated pebbles and cobbles. Also well cemented “tubes” of groundwater flow paths.

Dakota Group (or "Dakota Sandstone"):
0662792, 4029686: Well sorted, well rounded, medium grained quartz arenite. Interbedded with gray shale. Locally, many large siderite concretions present.
0667658, 4027776: Fine to medium grained pale yellow sandstone that is locally pebbly (pebbles have been eroded out), Thin bedded, planar tabular to crossbedded with very large, low angle crossbed sets. Locally interbedded with gray shale in couplets ~0.5 m thick. Sandstone units are lensoidal over tens of meters.
0660352, 4031900: Uppermost sandstone of Dakota, very bioturbated with some hematitic concretions.
0673530, 4047199: Pale gold to red sandstone, medium to fine grained, well sorted, well rounded, 100% Q, arenite. Faint high angle large scale crossbeds, otherwise bioturbated. Local discrete zones of quartzite that is multicolored and oriented both vertically and horizontally (silica cementation of fractures?).
0677359, 4076723: Fine grained quartz arenite, well sorted and well rounded, bright yellow to buff.
0661077, 4068315: Flaggy exposure, thin to medium bedded with occasional ripple marks and organic debris and rip-up clasts. Bed thickness is irregular. Locally silica cemented to quartzite. Near top of exposure, low angle cross beds up to 1 m tall, thin bedding (almost laminar). Common bioturbation.
0628424, 4030655: Well cemented medium grained quartz arenite, well sorted, well rounded, buff to very pale gray. Ripple marks and abundant burrows. High angle crossbeds dip to the southeast. Becomes thin bedded with shale partings upsection. Irregular bed thickness, with ripple laminations on some bedding planes. Followed by thick bedded sandstone with large sets of very thin bedded, high angle crossbeds with bioturbation towards top. Uppermost exposures are planar tabular bedded above a very thin shale parting. Thin shale partings become more common upsection.
0657143, 4098339: Dark red to purple sandstone and mudstone that is silica cemented almost to a slate. Sandstone locally cemented to a quartzite. Heavily altered with iron and/or manganese. Followed by granular sandstone with concretions and highly altered textures (diagenetic, iron-rich alteration). Granules are quartz, chert and quartzite. Followed by coarse grained to pebbly gold sandstone that is crossbedded and overlain by dark purple mudstone/slate and sandstone/quartzite interbeds.

Graneros Shale:
0661772, 4030996: 5-6 m of dark gray shale, locally capped by a brown fossiliferous sandy limestone. Fossils include nearly complete and fragmented inoceramid pelycopod valves. Shale contains up to 3 limestone beds. Uppermost limestone is <1.0 m thick, others are less than 0.5 m thick. Limestones are sandy with coarse grains of quartz. Uppermost limestone is thin bedded

with planar tabular bedding and long cylindrical burrows oriented horizontally along bedding planes.
0658071, 4032802: ~3 m of yellowish gray shale, floor of creek is micrite.
0659894, 4032042: ~10 m of shale with single sandy limestone bed about 2 m above base of outcrop.
0676959, 4025458: ~6 m of shale that is yellow, green and red (pedogenic or diagenetic alteration?).
0663241, 4029193: Siderite concretions in shale.
0674741, 4027893: Pale yellowish gray laminated to thin bedded noncalcareous sandy shale. Thin sideritized beds, some laterally persistent, less than 0.5 m thick. Burrows on some bedding surfaces. Below is 3.5 m of gray bentonitic shale to silty mudstone with 0.3 to 0.4 m thick laterally persistent siderite zones.
0675386, 4028056: Basal 2 m is bentonitic mudstone, followed by 1.5 m of thin bedded sandy shale.

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 (usually interpreted to represent Triassic strata), regardless of total depth of the well. Stratigraphic column representations of these well logs are attached (Figs. X-Z) 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 – Witt #1 (T29N, R35E, S13; Total Depth: 4283')

0-10' Pale gray fine to v. fine muddy sandstone, 90% Q, 10% L, micaceous, -HCl.

10-20' Ditto 0-10, some small rip-up clasts of same material, -HCl.

20-30' Pale gray shale, -HCl; pale yellow quartz arenite, fine grained, subround-subangular, well sorted, 97% Q, 3% L (incl. muscovite), rare rip-ups of white sandy mudstone, -HCl. [70% ss, 30% shale]

30-40' Pale yellow quartz arenite, very fine to fine grained, subround-round, well sorted, 97% Q, 3% L (incl. muscovite), manganese staining locally, some hematitic banding, -HCl; pale gray shale, -HCl. [50% ss, 50% shale]

40-50' Gray-yellow quartz arenite, fine grained, subround-subangular, well sorted, same composition as above, abundant hematite cement, -HCl; pale gray shale, -HCl. [50% ss, 50% shale]

50-60' Gray to medium gray shale, laminated, -HCl; pale brown-yellow quartz arenite, very fine grained, subround-subangular, same composition as above, some manganese staining, hematite cement, micaceous, -HCl. [70% shale, 30% ss]

60-70' Pale gray sandy mudstone, sand grains are medium to coarse grained, 98% Q, 2% L (muscovite), ~HCl; pale gray shale, ~HCl. [80% mudst., 20% shale]

70-80' Ditto 60-70. [70% mudst., 20% shale]

80-90’ Pale gray sandy mudstone, sand grains are fine to coarse grained, 97% Q, 3% L, micaceous, -HCl.

90-100’ Ditto 80-90; gray shale, -HCl. [90% mudst., 10% shale]

100-110’ Pale gray siltstone, micaceous, quartzose, ~HCl; dark brown-orange quartz arenite, medium-coarse grained, subangular-subround, well sorted, 100% Q, 10% clay matrix, some siderite present, -HCl. [70% siltst., 25% ss, 5% siderite]

110-120’ Medium gray shale, sandy with well rounded quartz grains, -HCl.

120-130’ Dark gray shale, -HCl.

130-140’ Dark gray shale, -HCl; yellow quartz wacke, medium to coarse grained, subround-subangular, poorly sorted, 100% Q, >15% clay matrix, -HCl.

140-150’ Pale tan limestone, sandy with well rounded and well sorted grains, +HCl; medium gray shale, ~HCl; pale yellow quartz wacke, fine grained, subround-subangular, moderately sorted, 100% Q, >15% clay matrix, abundant hematite and manganese, ~HCl; pale yellow quartz arenite, coarse to very coarse grained, subangular-subround, well sorted, 100% Q, ~HCl. [50% limest., 40% shale, 10% ss]

150-160’ ditto 140-150, but no coarse quartz arenite. [70% limest., 25% shale, 5% ss]

160-170’ Pale tan limestone, sandy, +HCl; medium gray shale, ~HCl; pale yellow quartz wacke, fine grained, subround, well sorted, 100% Q, >15% clay matrix, abundant hematite, -HCl; pale gray sandy mudstone with medium grained subangular quartz grains, -HCl. [55% limest., 40% mudst., 3% shale, 2% ss]

170-180’ Pale tan limestone, sandy, +HCl; white chalk, +HCl; medium gray shale, -HCl; pale gray muddy sandstone, medium to fine grained, subround, poorly sorted with granule size angular micrite rip-up clasts, ++HCl; yellow quartz arenite, medium to coarse grained, subangular-subround, well sorted, 100% Q, -HCl. [50% chalk, 15% muddy ss, 15% limest., 15% shale, 5% arenite]

180-190’ Pale tan limestone, sandy, +HCl; medium gray shale, -HCl; yellow quartz arenite, medium to coarse grained, subround-subangular, well sorted, 100% Q, -HCl. [95% limest., 3% shale, 2% ss]

190-200’ Pale tan limestone, possibly sandy, +HCl; Pale gray mudstone with medium grained angular limestone grains, ~HCl. [80% limest., 20% mudst.]

200-210’ Pale tan limestone, some sand grains, +HCl; pale gray mudstone with angular limestone grains, ~HCl; green claystone with rare fine grains of subrounded hematite-stained quartz, -HCl. [60% mudst., 38% limest., 2% clayst.]

210-220’ Pale green sandy mudstone, quartzose, sand grains are fine to medium grained, subangular-angular, moderately sorted, -HCl; white muddy quartz wacke, medium to coarse grained, subround-subangular, moderately sorted, 100% Q, -HCl; yellow-brown muddy sandstone, subround-subangular, moderately sorted, 100% Q, -HCl. [70% sandy mudst., 30% white ss, <1% yellow ss]

220-230’ Pale pink quartz wacke, medium to coarse grained, subround-subangular, poorly sorted, 100% Q, >15% clay matrix, includes pale green mudstone rip-ups, hematite cement, -HCl.

230-240’ Pale red quartz wacke, coarse grained, subround-subangular, well sorted, 100% Q, >15% clay matrix, hematite cement, +HCl; pale green sandy mudstone with fine grained subround quartz grains, -HCl; yellow muddy quartz wacke, fine grained, subround, moderately sorted, 100% Q, >15% clay matrix, -HCl; white siltstone, -HCl. [50% red ss, 40% green ms, 8% gold ss, 2% siltst.]

240-250’ Ditto 230-240, but pale red quartz wacke very fine to fine grained. [Same as 230-240]

250-260’ Ditto 230-240, pale red quartz wacke darker in color. [Same as 230-240]

260-270’ Very pale yellow quartz arenite, coarse grained, subround-subangular, well sorted, 100% Q, hematite cement, ~HCl; pale green sandy mudstone with fine grained quartz, -HCl; very pale yellow quartz arenite, fine to medium grained, subround-subangular, well sorted, 100% Q, minor hematite cement, +HCl; white siltstone with coarse limestone grains, +HCl. [50% coarse yellow ss., 20% fine yellow ss., 20% mudst., 10% siltst.]

270-280’ Ditto 260-270 plus pale tan limestone, +HCl. [40% coarse yellow ss., 30% fine yellow ss., 10% green mudst., 5% siltst., 5% limest.]

280-290’ Ditto 270-280 with white siltstone no longer including coarse limestone grains. [30% limest., 30% siltst., 30% coarse yellow ss., 5% green mudstone, 5% fine yellow ss.]

290-300’ Red-brown mudstone, occasionally color-mottled with pale green, -HCl.

300-310’ Pale red-brown sandy mudstone with fine grained quartz that is subangular-subround, locally mottled with very pale pink, -HCl.

310-320’ Red-brown sandy mudstone with fine grained quartz grains, occasionally mottled very pale pink, -HCl; very pale orange quartz arenite, very fine to fine grained, subround-round, well sorted, 100% Q, some hematite, -HCl; pale green sandy mudstone with fine grained subround quartz grains, -HCl. [50% fine ss., 45% red mudst., 5% green mudst.]

320-330’ Ditto 310-320, minus green mudst. [95% fine ss., 5% red mudst.]

330-340’ Pale red quartz arenite, medium to coarse grained, subround-subangular, well sorted, 100% Q, ~HCl; pale green sandy mudstone with fine grained round quartz, -HCl. [95% ss, 5% mudst.]

340-350’ Very pale pink quartz arenite, very fine grained, rounded, well sorted, 95% Q, 5% L, -HCl.

350-360’ Pale red to buff quartz arenite, medium grained, subround-subangular, moderately sorted, 100% Q, variable hematite cement, +HCl; pale green sandy mudstone with fine grained subround quartz, +HCl. [60% ss, 40% mudst.]

360-370’ Buff quartz wacke, very fine to fine grained sandstone, subangular to subround, moderately sorted, 100% Q, >15% clay matrix, -HCl; green sandy mudstone, -HCl; red-brown mudstone, -HCl. [33% ss, 33% green mudst., 33% red mudst.]

370-380’ Pale red muddy quartz wacke, fine grained, subround, poorly sorted, 100% Q, >15% clay matrix, ~HCl; buff quartz arenite, fine grained, well sorted, 100% Q, quartz overgrowths, ~HCl. [60% buff arenite, 40% muddy ss]

380-390’ Ditto 370-380. Muddy quartz wacke also includes granule size rip-up clasts; also green sandy mudstone, -HCl. [60% muddy ss, 35% buff arenite, 5% green mudst.]

390-400’ Pale red quartz arenite, coarse to medium grained, subangular, well sorted, 100% Q, +HCl; brown micaceous mudstone, -HCl; green sandy mudstone, -HCl; buff quartz arenite, fine grained, well sorted, 100% Q, quartz overgrowths, ~HCl. [60% brown mudst., 30% coarse ss, 5% green mudst., 5% buff arenite]

400-410’ Pale brown sandy mudstone with fine grained subangular quartz, -HCl; brown mudstone, -HCl. [60% sandy mudst., 40% mudst.]

410-420’ ditto 400-410.

420-430’ ditto 400-410. [70% sandy ms., 30% mudst.]

430-440’ Pale red muddy sandstone, fine grained, subangular-subround, moderately sorted, 100% Q, +HCl.

440-450’ Very pale red quartz arenite, fine grained, well sorted, 100% Q, quartz overgrowths, ~HCl; pale gray sandy mudstone with fine to medium grained subangular-subround poorly sorted quartz grains, ~HCl. [70% ss, 30% mudst.]

450-460’ Ditto 440-450. [85% ss, 15% mudst.]

460-470’ Pale red quartz arenite, medium grained, well sorted, 100% Q, quartz overgrowths, ~HCl; very pale green quartz arenite, fine grained, well sorted, 100% Q, quartz overgrowths, -HCl; pale green claystone, -HCl. [60% pale red ss, 35% clayst., 5% pale green ss]

470-480’ Ditto 460-470 plus brown-red mudstone, -HCl. [40% pale red ss, 40% pale green ss, 15% clayst., 5% mudst.]

480-490’ Very pale green muddy sandstone, fine grained, angular-subangular, moderately sorted, 100% Q, ~HCl; green mudstone with biotite, ~HCl. [80% muddy ss, 20% mudst.]

490-500’ Ditto 480-490, with single chip of fine grained quartz arenite with overgrowths and abundant pyrite. [Same % as 480-490, pyrite ss <1%]

500-510’ Pale green sandy mudstone, +HCl; very pale green or pale red muddy sandstone, fine grained subrounded, moderately sorted, 100% Q, -HCl; buff quartz arenite, fine grained, well sorted, 99% Q, 1% L (incl. biotite), quartz overgrowths, -HCl; pale orange quartz arenite, coarse grained, subangular, well sorted, 100% Q, ~HCl. [60% green mudst., 30% muddy ss, 5% buff arenite, 5% coarse ss]

510-520’ Pale green mudstone, +HCl. Rare dark red-brown rounded granules present (chert? jasper?).

520-530’ Ditto 510-520, minus granules.

530-540’ Pale gray claystone, +HCl.

540-550’ Ditto 530-540.

550-560’ Ditto 530-540.

560-570’ Ditto 530-540, plus pale red sandy mudstone with fine grained well rounded hematite coated quartz grains, +HCl. [90% clayst., 10% red mudst.]

570-580’ Pale gray mudstone, +HCl; Buff quartz arenite, very fine grained, well rounded, well sorted, 100% Q, some hematite cement, ~HCl.

580-590’ Pale gray claystone, +HCl; buff quartz arenite, very fine to fine grained, well sorted, 100% Q, quartz overgrowths, +HCl. [60% ss, 40% clayst.]

590-600’ Pale red quartz arenite, very fine to fine grained, well sorted, 100% Q, quartz overgrowths, +HCl; very pale brown claystone, laminated, ~HCl; Pale green sandy mudstone, ~HCl; green mudstone, -HCl. [40% ss, 20% clayst., 20% green sandy mudst., 20% green mudst.]

Nunn and Co. – Jim Hopson #1 (T23N, R35E, S26; Total Depth: 969’)

4-25’ White caliche with occasional medium grained quartz, subround, ++HCl.

25-80’ White caliche; buff sandy mudstone with medium to coarse quartz that are subangular to subround as well as fine grained chert that are subround, poorly sorted, ++HCl; Loose sand, medium to coarse grained, subround-subangular, moderately sorted, 95% Q, 5% L (mostly quartzite). [70% mudst., 25% sand, 5% caliche]

80-118’ Loose sand, fine to very coarse grained, subangular-subround, poorly sorted, 95% Q, 5% L (incl. red and black chert, quartzite, opaques).

118-152’ Loose sand, fine to very coarse grained, surround-subangular, poorly sorted, 85% Q, 15% L (incl. black chert, quartzite, red and gray granite).

152-180’ Buff quartz wacke, fine to medium grained, subround, moderately sorted, 98% Q, 2% L, >15% clay matrix, ++HCl; caliche nodules, rounded, ++HCl; loose sand, fine to coarse grained, subround-subangular, poorly sorted, 90% Q, 10% L (incl. quartzite, opaques).

180-205’ Buff quartz wacke as in 152-180; loose sand, very fine to very coarse with pebbles, subround, poorly sorted, sand fraction is 80% Q, 20% L (incl. quartzite, basalt, andesite, granite, opaques), pebble fraction includes basalt, quartzite, Dakota sandstone, other sandstone, ?obsidian.

205-215’ Buff quartz wacke as in 152-180; loose sand, very fine to coarse, some pebbles, subround, poorly sorted, 85% Q, 15% L (incl. brown chert, quartzite, volcanics, opaques), pebble fraction includes brown and black sandstone, quartzite.

215-240’ Loose sand, very fine to coarse grained, pebbles, subround, poorly sorted, 85% Q, 15% L (incl. quartzite, chert, volcanics, opaques), pebble fraction includes Ogallala rip-up clasts, quartz, quartzite, volcanics (basalt?).

240-260’ Loose pebbles and sand, sand fraction is fine to coarse grained, subround-subangular, 80% Q, 20% L (incl. quartzite, volcanics, opaques), pebble fraction includes angular-subround quartz, fine grained quartzose sandstone, volcanics, chert.

260-285’ Loose sand, very fine to medium grained, subround, moderately sorted, 95% Q, 5% L (incl. muscovite); poorly consolidated buff muddy sandstone, medium grained, subround, moderately sorted, 90% Q, 10% L (incl. muscovite).

285-292’ Gray claystone, +HCl.

292-295’ Gray siltstone, petroliferous, +HCl.

295-310’ Gray siltstone, -HCl.

310-320’ Gray quartz arenite, fine grained, subangular, well sorted, 95% Q, 5% L, -HCl; loose sand with some pebbles, sand fraction is very fine to coarse grained, subangular-subround, poorly sorted, 95% Q, 5% L, pebbles include fine grained yellow sandstone, red chert, quartz, gray mudstone rip-up clasts.

320-340’ Gray quartz arenite as in 310-320; gray mudstone, -HCl.

340-350’ Gray quartz arenite as in 310-320 with 10% L, cross-laminated; yellow quartz arenite, fine to medium grained, subangular-subround, well sorted, 100% Q, -HCl. [90% gray arenite, 10% yellow arenite]

350-355’ Yellow quartz arenite as in 340-350 with abundant iron/manganese staining; gray quartz arenite as in 310-320. [70% yellow arenite, 30% gray arenite]

355-375’ Gray quartz arenite as in 310-320; loose quartz sand, fine to coarse grained, subround.

375-395’ Gray quartz arenite as in 310-320.

395-400’ Pale yellow quartz wacke, medium grained, subangular-subround, well sorted, 100% Q, >15% clay matrix (some kaolinite?), -HCl; gray quartz arenite as in 310-320. [90% yellow wacke, 10% gray arenite]

400-405’ Gray shale, -HCl.

405-413’ Gray siltstone, -HCl.

413-417’ Gray quartz arenite as in 310-320; gray shale, -HCl. [60% arenite, 40% shale]

417-422’ Ditto 413-417, but sandstone not well consolidated.

422-430’ Gray siltstone, -HCl.

430-440’ Ditto 412-422. [50% arenite, 50% shale]

440-450’ Gray mudstone, +HCl.

450-455’ Gray quartz arenite as in 310-320.

455-465’ Gray quartz arenite as in 310-320, more yellowish in color; gray shale, -HCl. [95% arenite, 5% shale]

465-475’ Gray quartz arenite as in 310-320.

475-511’ Yellow quartz arenite, medium grained, subround, well sorted, 100% Q, poorly consolidated, -HCl; gray siltstone, -HCl. [70% ss, 30% shale]

511-517’ Yellow quartz arenite as in 475-511, very poorly consolidated, prominent manganese staining.

517-525’ Pale red quartz wacke, very fine to medium grained, subround-subangular, poorly sorted, 100% Q, >15% clay matrix, ~HCl.

525-530’ Pale gray-green quartz wacke, medium grained, subround-subangular, moderately sorted, 100% Q, >15% clay matrix, rare granules of chert, -HCl; yellow quartz arenite as in 511-517. [50% wacke, 50% arenite]

530-542’ Very pale pink quartz arenite, fine grained, well sorted, 100% Q, quartz overgrowths, ~HCl.

542-545’ Very pale blue sandy mudstone, sand grains are fine grained, subrounded quartz, -HCl.

545-550’ Pale red mudstone with rare coarse grains of chert, -HCl.

550-562’ Pale red mudstone, -HCl; black shale, laminated, -HCl. [<1% black shale]

562-570’ Pale red siltstone, -HCl; pale gray quartz wacke, fine grained, subround-subangular, well sorted, 100% Q, >15% clay matrix, -HCl. [50% siltstone, 50% ss]

570-580’ Pale grayish red mudstone, some granules of micrite, ~HCl; pale gray siltstone with coarse grains of jasper, -HCl. [85% mudst., 15% siltst.]

580-590’ Pale gray and pale red mudstone, +HCl.

590-600’ Loose sand, fine grained to silt, subround-round, well sorted, 95% Q, 15% L (incl. goethite/siderite?, opaques); pale green claystone, -HCl. [90% sand, 10% clayst.]

600-608’ Very pale buff quartz wacke, fine to coarse grained, subround, poorly sorted, 100% Q, >15% clay matrix, very poorly consolidated, -HCl; pale green claystone, -HCl. [95% ss, 5% clayst.]

608-615’ No samples.

615-625’ Loose sand, very fine to fine grained, subround-round, well sorted, 90% Q, 10% L (incl. opaques, goethite?), also silt sized grains.

625-637’ White quartz arenite, medium grained, subround, well sorted, 98% Q, 2% L, -HCl.

637-665’ No samples.

665-670’ Ditto 625-637, some as loose sand.

670-680’ White quartz arenite, fine grained, subround, well sorted, 95% Q, 5% L, discrete round hematite stains, -HCl.

680-690’ Ditto 670-680.

690-700’ Ditto 625-637.

700-710’ Ditto 625-637.

710-718’ Gray quartz wacke, fine grained, subround, well sorted, 100% Q, >15% clay matrix, ~HCl.

718-730’ Gray claystone, laminated, +HCl.

730-740’ Gray claystone, ~HCl; pale gray siltstone, ~HCl. [50% clayst., 50% siltst.]

740-750’ Pale gray granule conglomerate, clasts are gray claystone rip-up clasts (rounded) and red chert, matrix is a coarse sand, poorly consolidated, +HCl.

750-760’ Pale green and pale red-brown siltstone, +HCl.

760-770’ Pale brown mudstone, ~HCl.

770-780’ Brown-red and green mudstone, +HCl.

780-790’ Ditto 770-780.

790-800’ Ditto 770-780.

800-810’ Loose sand, very fine to fine grained, subround, well sorted, 90% Q, 10% L.

810-820’ Red mudstone with granules of micrite, +HCl; pale green mudstone, -HCl.

820-830’ Green and red shale, -HCl.

830-840’ Ditto 810-820.

840-850’ Ditto 820-830.

850-860’ Ditto 820-830.

860-870’ Greenish-gray, brown, very pale gray mudstone, +HCl.

870-880’ Ditto 860-870.

880-890’ Ditto 820-830 plus very pale orange mudstone, -HCl.

890-900’ Ditto 820-830 plus orange sandy mudstone with very coarse grains of rounded quartz.

900-910’ Ditto 810-820 plus red mudstone, +HCl.

910-920’ Ditto 820-830.

920-930’ Ditto 820-830 plus very pale gray shale with loose micrite granules.

930-940’ Ditto 820-830 plus very pale gray shale.

940-945’ Ditto 820-830 plus pale grayish-green quartz arenite, fine grained, rounded, well sorted, 100% Q, hematite cement, jasper stringers.

945-950’ Ditto 820-830 plus gray-brown mudstone, -HCl.

950-960’ Ditto 820-830.

960-969’ Red mudstone, minor green mottles, +HCl.

HH&E Oil Co - #1-A Hughes (T22N, R36E, S33; Total Depth: 1000’)

0-300’ No samples.

300-310’ Very pale red mudstone, -HCl.

310-320’ Very pale red mudstone, +HCl.

320-330’ Very pale red mudstone, +HCl; white and buff siltstone, +HCl [70% siltst., 30% mudst.]

330-340’ Ditto 320-330.

340-350’ Buff quartz wacke, dine grained, subround-round, well sorted, 100% Q, >15% clay matrix, +HCl; green claystone, +HCl.

350-360’ Pale gray shale, +HCl.

360-370’ Ditto 350-360.

370-380’ Ditto 350-360.

380-390’ Very pale red and green mudstone, +HCl; buff siltstone, +HCl. [70% siltst., 30% mudst.]

390-400’ Red and white siltstone, +HCl.

400-410’ Red and white mudstone, +HCl.

410-420’ Pale purple and green mudstone, +HCl.

420-430’ Pale green siltstone, +HCl.

430-440’ Pale green and red siltstone, +HCl.

440-450’ Pale green and pale red mudstone, +HCl.

450-460’ Ditto 440-450.

460-470’ Pale green siltstone, +HCl; red mudstone, +HCl. [70% siltst., 30% mudst.]

470-480’ Pale green claystone, +HCl; red mudstone, +HCl. [70% clayst., 30% mudst.]

480-490’ Red mudstone with minor green mottles, +HCl.

490-500’ Red mudstone, ~HCl.

500-510’ Red and green mottled mudstone, +HCl.

510-520’ Pale red and white mottled mudstone, +HCl.

520-530’ Pale red mudstone, +HCl.

530-540’ Pale red mudstone, some pale green mottles, +HCl.

540-550’ Pale gray and red mudstone, +HCl.

550-560’ Ditto 540-550.

560-570’ Ditto 540-550, red more common.

570-580’ Pale red and green mottled mudstone, +HCl.

580-590’ Ditto 570-580.

590-600’ Ditto 570-580.

600-610’ Ditto 460-470.

610-620’ Ditto 570-580.

620-630’ Ditto 570-580, less green.

630-640’ Ditto 620-630.

640-650’ Pale orange mudstone, +HCl.

650-660’ Pale red mudstone, +HCl; dark green claystone, +HCl. [80% mudst., 20% clayst.]

660-670’ Pale brown mudstone, +HCl.

670-680’ Pale brown sandy mudstone, sand grains are medium grained quartz and rip-up clasts that are subround, +HCl; dark green claystone, +HCl. [60% mudst., 40% clayst.]

680-690’ Ditto 670-680, sandy mudstone very pale brown. [80% mudst., 20% clayst.]

690-700’ Ditto 570-580.

700-710’ Ditto 670-680, with some very coarse grains in sandy mudstone. [60% mudst., 40% clayst.]

710-720’ Ditto 670-680, less well consolidated. [60% mudst., 40% clayst.]

720-730’ Ditto 570-580.

730-740’ Ditto 570-580.

740-750’ Ditto 680-690.

750-760’ Ditto 570-580.

760-770’ Ditto 570-580.

770-780’ Pale brown and green mottled mudstone, +HCl.

780-790’ Ditto 570-580.

790-800’ Loose sand, very fine to medium grained, rounded, moderately well sorted, 90% Q, 10% L; green claystone, -HCl; red mudstone +HCl.

800-810’ Pale red-brown mudstone with green mottles, +HCl.

810-820’ Pale orange muddy sandstone, medium grained, subround, well sorted, 100% Q, poorly consolidated, +HCl.

820-830’ Very pale red mudstone, +HCl; loose sand, fine grained, rounded, well sorted, 100% Q.

830-840’ Pale orange muddy sandstone, fine to medium grained, subround, moderately sorted, 90% Q, 10% L, very poorly consolidated, +HCl.

840-850’ Pale red sandy mudstone with grains of medium to coarse quartz, micrite, claystone and white siltstone (or pumice?), +HCl.

850-860’ Ditto 840-850, minus white siltstone.

860-870’ Ditto 850-860, grains very coarse to granular.

870-880’ Ditto 850-860, slightly less sandy.

880-890’ Ditto 870-880.

890-900’ Ditto 850-860, very poorly consolidated.

900-910’ Ditto 870-880, very little quartz, unconsolidated.

910-920’ Pale red mudstone with coarse grains of green claystone, micrite, white siltstone (pumice?), +HCl.

920-930’ Ditto 910-920, more green claystone.

930-940’ Pale red sandy mudstone with some medium to very coarse grains of green claystone, white siltstone (pumice?) and micrite, +HCl.

940-950’ Ditto 930-940, white siltstone grains are very coarse to granule size.

950-960’ Ditto 940-950.

960-970’ Red mudstone, +HCl; buff muddy sandstone, fine grained, subround, well sorted, 100% Q, poorly consolidated, +HCl. [60% mudst., 40% ss]

970-980’ Pale red mudstone with occasional granules of white siltstone and green mudstone, +HCl.

980-990’ Ditto 970-980.

990-1000’ Ditto 970-980, granules more common.

Skelly - #1 Van Pelt (T28N, R35E, S09; Total Depth: 4387’)

[*Percentages of lithologies are not listed for many intervals due to clear contamination of that sample set with materials from higher in the stratigraphic column (e.g., fragments of Ogallala at 330 feet depth).]

0-10’ No samples.

10-20’ Loose silt, coarse sand and pebbles, rounded, poorly sorted, sand fraction is 80% Q, 20% L (incl. sandst., siltst., volcanics?), pebble fractions includes quartzite and fine grained sandstone.

20-30’ Loose sand, very fine to very coarse grained, some granules, rounded-subrounded, poorly sorted, 90% Q, 10% L (incl. quartzite, sandst., opaques).

30-40’ Loose sand, very fine to coarse grained, subround-round, poorly sorted, 85% Q, 15% L (incl. quartzite, granite, chert?, siltst., sandst., opaques).

40-50’ Loose sand, very fine to medium grained, round, poorly sorted, 90% Q, 10% L (incl., quartzite, granite, chert, pink feldspar, siltst., volcanics?, opaques).

50-60’ Loose sand, very fine to medium grained, round, moderately sorted, 90% Q, 10% L (incl., siltst., granite, quartzite, opaques).

60-70’ Loose sand, very fine to fine grained, rounded, well sorted, 95% Q, 5% L (incl. quartzite, opaques), +HCl on one semi-consolidated chip.

70-80’ Loose sand, fine to coarse sand, round, poorly sorted, 90% Q, 10% L (incl. siltst., quartzite, opaques).

80-90’ Loose pebbles and some sand, sand fraction is fine to medium grained, subround-round, moderately sorted, 90% Q, 10% L, pebble fraction includes Dakota Group?

Sandstone, noncalcareous gray shale, quartzite, metamorphic (garnets?), volcanics, quartz, granite.

90-100’ Loose pebbles, subangular-subround, five are very fine yellow sandstone (Dakota Group?), one quartzite, one limestone.

100-110’ Loose pebbles, angular-subround, include dolomite, fine grained yellow sandstone (Dakota Group?), felsic extrusive with altered biotite, quartzite.

110-120’ Loose silt to coarse sand and pebbles, sand fraction is round, poorly sorted, 85% Q, 15% L, pebble fraction includes caliche, fine grained yellow sandstone (Dakota Group?) and quartzite.

120-130’ Loose sand with some pebbles, fine to coarse grained, subangular-subround, poorly sorted, 90% Q, 10% L, pebbles are fine grained yellow sandstone.

130-140’ Loose pebbles, subangular-subround, Dakota Group sandstone, noncalcareous black shale, quartzite, Ogallala sandstone.

140-150’ Loose pebbles, subround to subangular, Dakota Group sandstone, black shale.

150-160’ Dark gray shale, ~HCl; loose sand, medium grained, rounded, well sorted, 100% Q.

160-170’ Ditto 150-160.

170-180’ Dark red-brown shale, -HCl; yellow sandy mudstone, -HCl. [90% shale, 10% mudst.]

180-190’ Dark gray shale, -HCl; yellow sandy mudstone, -HCl. [95% shale, 5% mudst.]

190-200’ Dark gray shale, -HCl and one pebble quartzite (contamination from up-section?).

200-210’ Gray brown mudstone, -HCl.

210-220’ Black shale, -HCl; rounded pebbles quartzite (contamination?).

220-230’ Pale green mudstone, -HCl; purple-red mudstone, +HCl. [80% green, 20% red]

230-240’ Gray brown quartz arenite, very fine, rounded, well sorted, 100% Q, ++HCl (limey sandstone?).

240-250’ Gray brown quartz arenite as in 230-240 and gold-brown muddy quartz arenite, very fine grained, rounded, well sorted, 100% Q, +HCl. [60% gold-brown, 40% gray-brown]

250-260’ Gray brown quartz arenite as in 230-240, -HCl.

260-270’ Gray brown to dusky red quartz arenite as in 250-260; yellow sublithic arenite, medium grained, subround, well sorted, 90% Q, 10% L, -HCl; dark gray shale, very

well cemented, includes pyrite, -HCl. [90% gray brown arenite, 5% sublithic arenite, 5% shale]

270-280’ Pale green siltstone, -HCl; red mudstone, +HCl; brown-gray muddy sandstone, fine grained, well rounded, well sorted, 90% Q, 10% L, -HCl. [70% siltst., 25% mudst., 5% ss]

280-290’ Gray brown arenite as in 250-260; pale gray mudstone, -HCl [60% mudst., 40% ss]

290-300’ Gray brown arenite as in 250-260; dark red mudstone, -HCl; single pale yellow calcrete nodule, well rounded. [90% ss, 10% mudst.]

300-310’ Very pale gray siltstone, -HCl; dark gray shale, -HCl; dark red siltstone, well cemented, -HCl. [80% gray siltst., 19% shale, 1% red siltst.]

310-320’ Gray brown arenite as in 250-260; very pale gray mudstone, +HCl.

320-330’ Gray brown siltstone, -HCl.

330-340’ Ditto 320-330.

340-350’ Ditto 320-330.

350-360’ Dark gray shale, +HCl; pale red to gray brown quartz arenite, very fine grained, well rounded, well sorted, 100% Q, -HCl. [90% ss, 10% shale]

360-370’ Dark gray mudstone, -HCl.

370-380’ Pale gray mudstone, ~HCl; pale green quartz arenite, fine grained, rounded, well sorted, 95% Q, 5% L, ~HCl. [60% mudst., 40% ss]

380-390’ Ditto 370-380 with arenite also being pale red; dark gray shale, -HCl. [60% mudst., 38% ss, 2% shale]

390-400’ Pale green mudstone, +HCl; tan siltstone, well cemented, ~HCl. [60% mudst., 40% siltst.]

400-410’ Pale green mudstone, -HCl; dark red mudstone, -HCl; pale green muddy sandstone, very fine grained, subround, well sorted, 90% Q, 10% L (incl. chert?), -HCl. [70% green mudst., 15% red mudst., 15% ss]

410-420’ No samples (stratigraphic column interpreted from examples glued to cardboard).

420-430’ Pale gray sandy mudstone with very fine to coarse subround quartz grains, +HCl; dark gray siltstone, well cemented, -HCl. [90% mudst., 10% siltst.]

430-440’ No samples (stratigraphic column interpreted from examples glued to cardboard).

440-450’ Pale gray sandy mudstone with fine grained well rounded quartz, ~HCl.

450-460’ Very pale yellow quartz arenite, very fine grained, well rounded, well sorted, 100% Q, some manganese staining, ~HCl; pale green mudstone, -HCl. [80% ss, 20% mudst.]

460-470’ Dark gray siltstone, well cemented, -HCl; red mudstone, +HCl; sandy mudstone as in 440-450.

470-480’ Ditto 460-470.

480-490’ Ditto 460-470, slightly more red mudstone.

490-500’ Contaminated.

500-510’ Pale gray siltstone, +HCl; brown mudstone, -HCl.

510-520’ Pale gray mudstone, +HCl; red siltstone, +HCl.

520-530’ Gray shale, +HCl; green mudstone, -HCl; buff quartz arenite, medium grained, subround, well sorted, 98% Q, 2% L (incl. green mudstone rip-up clasts), -HCl.

530-540’ Buff quartz arenite as in 520-530, also pale red in color.

540-550’ Red siltstone, well cemented, ~HCl; buff muddy sandstone, fine grained, rounded, well sorted, 100% Q, +HCl.

550-560’ Pale gray muddy sandstone, fine grained, well rounded, well sorted, 100% Q, ~HCl; green mudstone, -HCl; red brown siltstone, -HCl.

560-570’ 550-560, green mudstone is locally micaceous (muscovite).

570-580’ Loose red silt; green and gold quartz arenite, fine grained, rounded, well sorted, 100% Q, -HCl.

580-590’ Red mudstone, ~HCl; green siltstone, ~HCl.

590-600’ Ditto 580-590’.

Herndon - #1 Mock (T27N, R36E, S25; Total Depth: 4555’)

[*Percentages of lithologies are not listed for intervals in this well due to clear contamination of the sample set with materials from higher in the stratigraphic column. Also, these samples were washed thoroughly enough that fine grained materials, such as claystone, are probably not accurately represented. No stratigraphic column has been drawn for this well due to the lack of samples in many intervals.]

0-190’ No samples.

190-220’ Gold quartz arenite, fine grained, rounded, well sorted, 100% Q, -HCl; black shale, -HCl.

220-250’ No samples.

250-280’ Ditto 190-220, plus pale green mudstone, -HCl.

280-310’ Ditto 250-280, plus pale yellow mudstone, -HCl.

310-360’ No samples.

360-390’ Ditto 250-280.

390-420’ Red and green mudstone, -HCl; pale yellow quartz arenite, very fine grained, rounded, well sorted, 100% Q, -HCl.

420-465’ No samples.

465-475’ Red and green mudstone, -HCl.

475-485’ Very pale red to red mudstone, +HCl.

485-490’ No samples.

490-500’ Ditto 390-420, sandstone unconsolidated (loose sand).

500-510’ Pale red, green and very pale green mudstone, +HCl.

510-520’ Ditto 500-510.

520-530’ Ditto 500-510.

530-540’ Ditto 500-510.

540-550’ Ditto 500-510.

550-560’ Ditto 500-510.

560-570’ Pale green and rare red mudstone, +HCl.

570-580’ White siltstone to quartz arenite, very fine grained, +HCl; green and red-brown mudstone, +HCl.

580-590’ Very pale gray quartz arenite, fine grained, rounded, well sorted, ~HCl; red brown mudstone, ~HCl.

590-600’ No sample.

600-610’ No sample.

610-620’ Gray and red-brown shale, ++HCl.

620-630’ Gray and red-brown shale, +HCl; white quartz arenite, very fine grained, rounded, well sorted, 100% Q, +HCl.

630-640’ Gray shale, +HCl.

640-650’ Gray shale, +HCl; white quartz arenite as in 620-630.

650-660’ Gray shale, +HCl.

660-670’ Gray and red-brown shale, +HCl.

670-680’ Pale gray shale, +HCl.

680-690’ Ditto 620-630.

690-700’ Ditto 620-630.

700-710’ Gray shale, red jasper, +HCl.

710-720’ Ditto 700-710.

720-730’ Ditto 700-710, plus brown shale, -HCl.

730-740’ Ditto 720-730, plus green shale, -HCl.

740-750’ Ditto 720-730.

750-760’ Loose sand, very fine to fine grained, rounded, well sorted, 100% Q; jasper; green shale, -HCl.

760-770’ Green and gray shale, +HCl.

770-780’ No samples.

780-790’ Loose sand, very fine to fine grained, rounded, well sorted, 100% Q; jasper; brown shale, -HCl.

790-800’ Ditto 780-790.

800-820’ No samples.

820-830’ Ditto 780-790.

830-840’ Loose sand, very fine grained, rounded, well sorted, 100% Q; red-brown shale, +HCl.

840-920’ No samples.

920-930’ Green, red-brown and pale brown shale, +HCl.

930-940’ Green and red-brown shale, +HCl.

940-950’ Red, red-brown and green shale, -HCl.

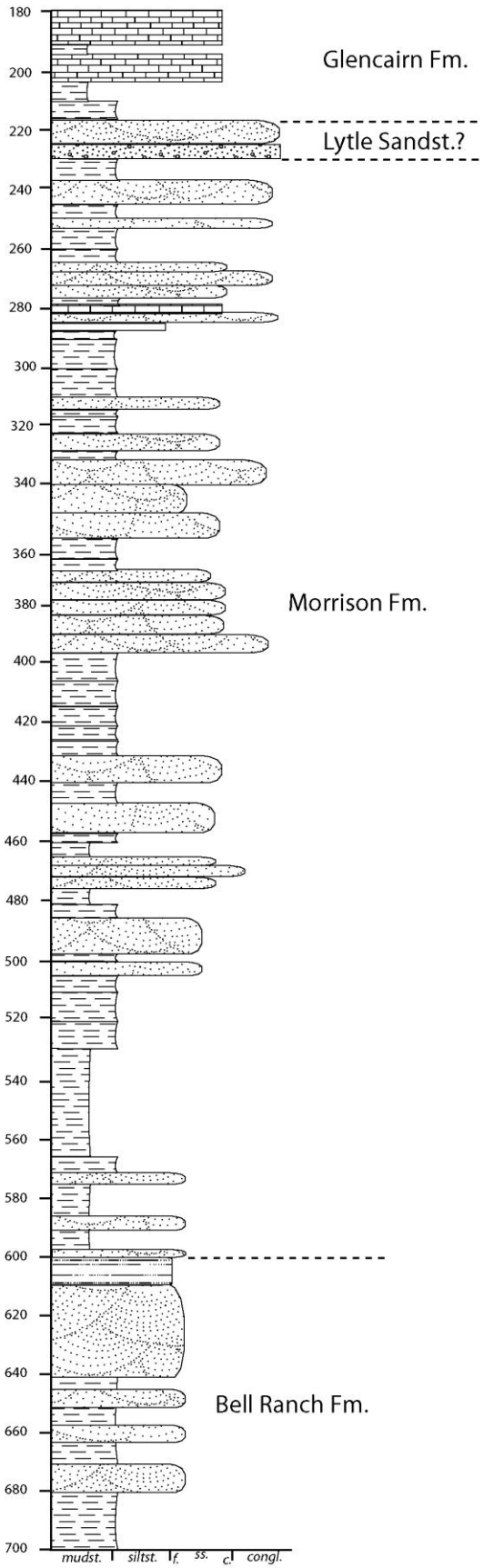
950-960’ Ditto 940-950.

960-970’ Ditto 940-950.

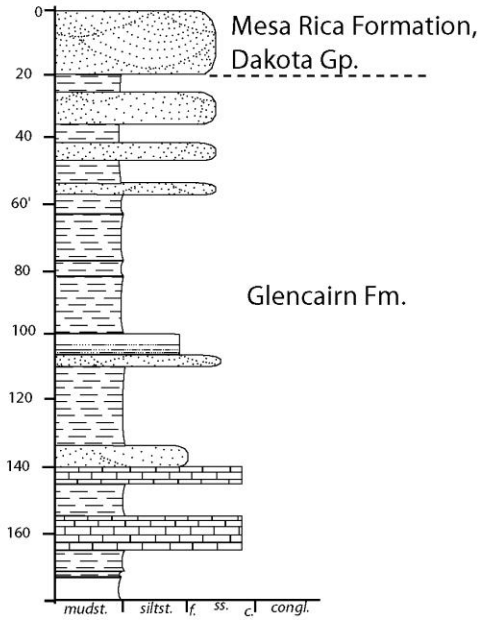
970-980’ Ditto 940-950.

980-990’ Ditto 930-940 (very little sample).

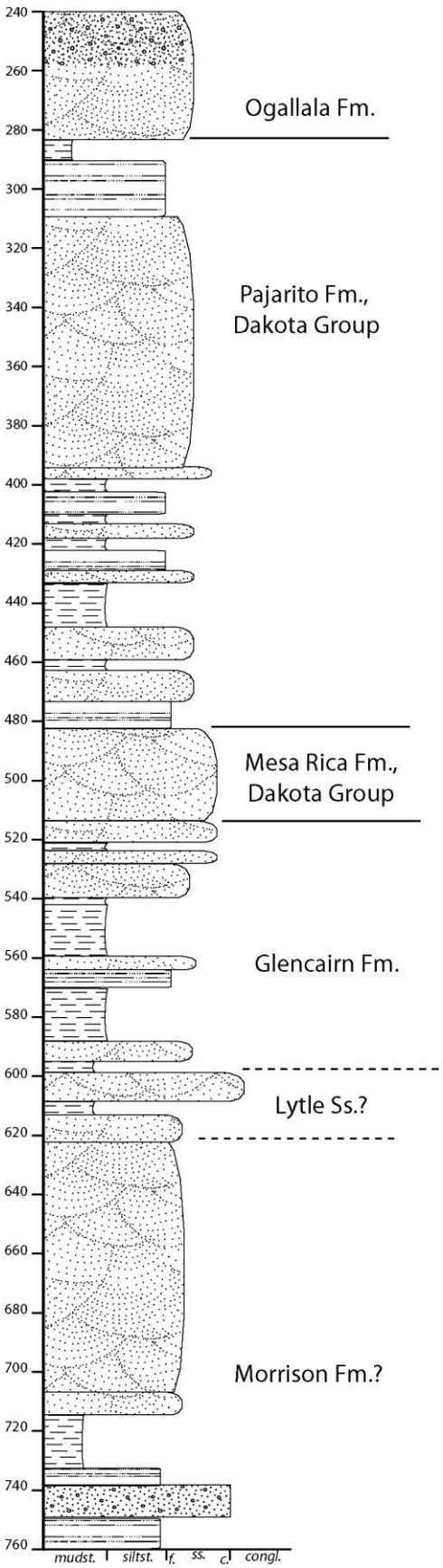
990-1000’ Red, very pale gray and dark gray shale, +HCl.

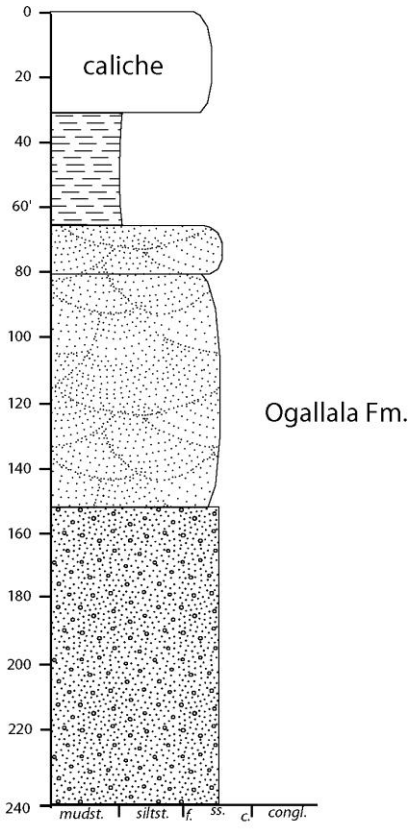


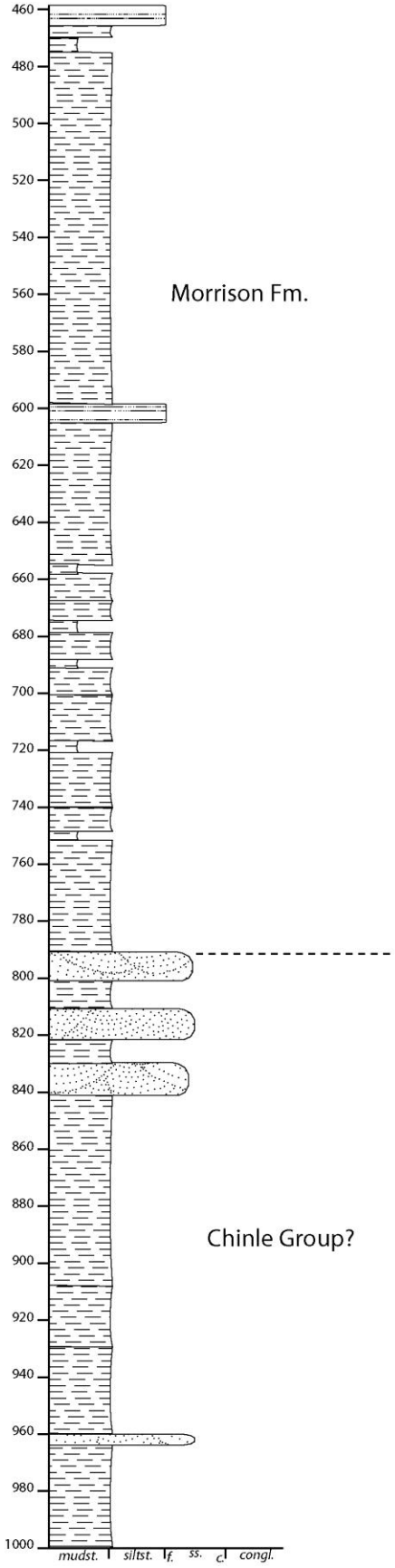
Greg Oil - Witt #1
T29N, R35E, Sec. 13



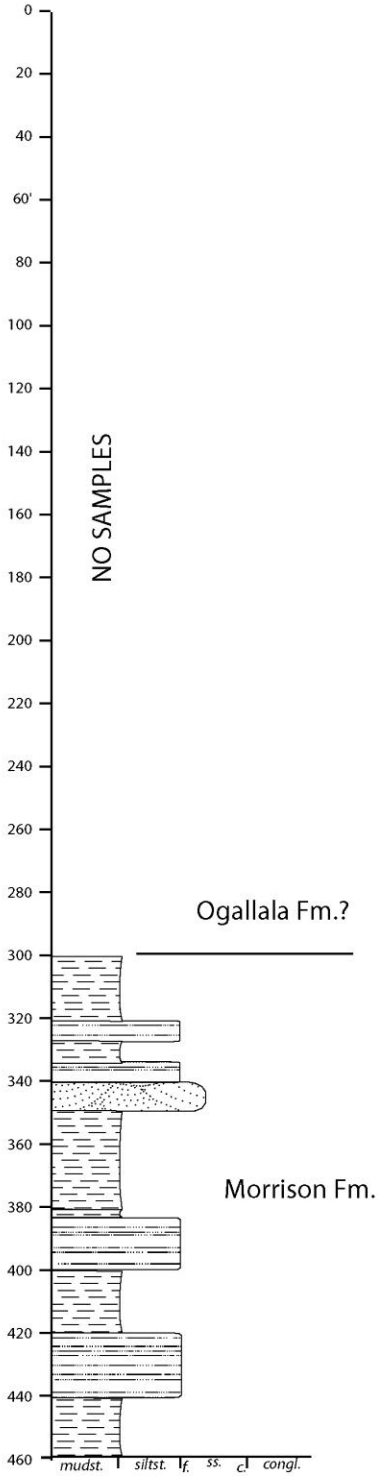
Nunn & Co. - Jim Hopson #1
T23N, R35E, Sec. 26



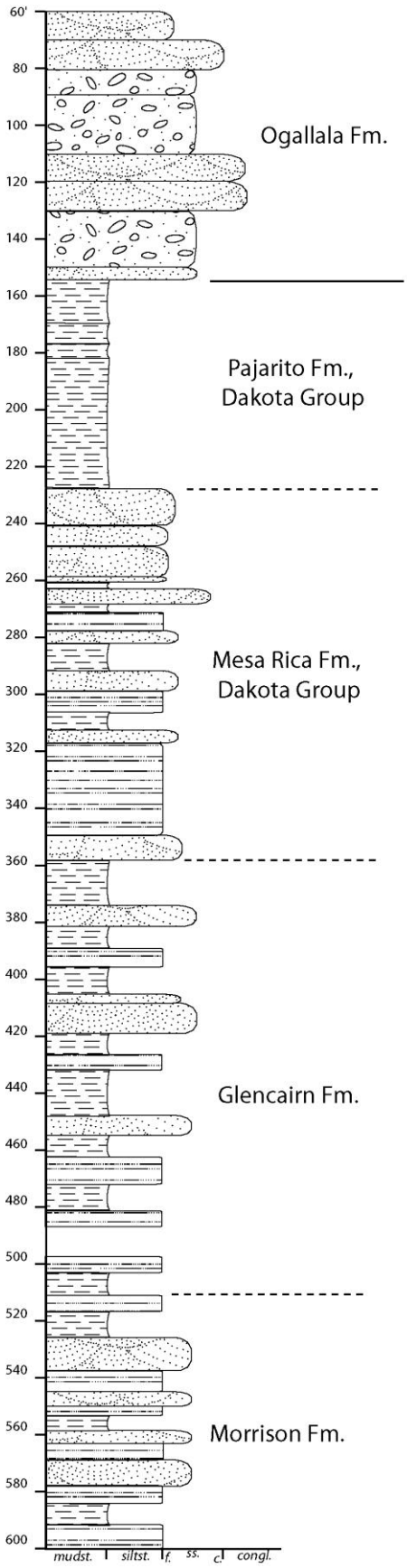


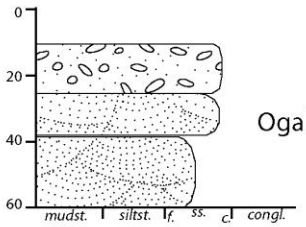


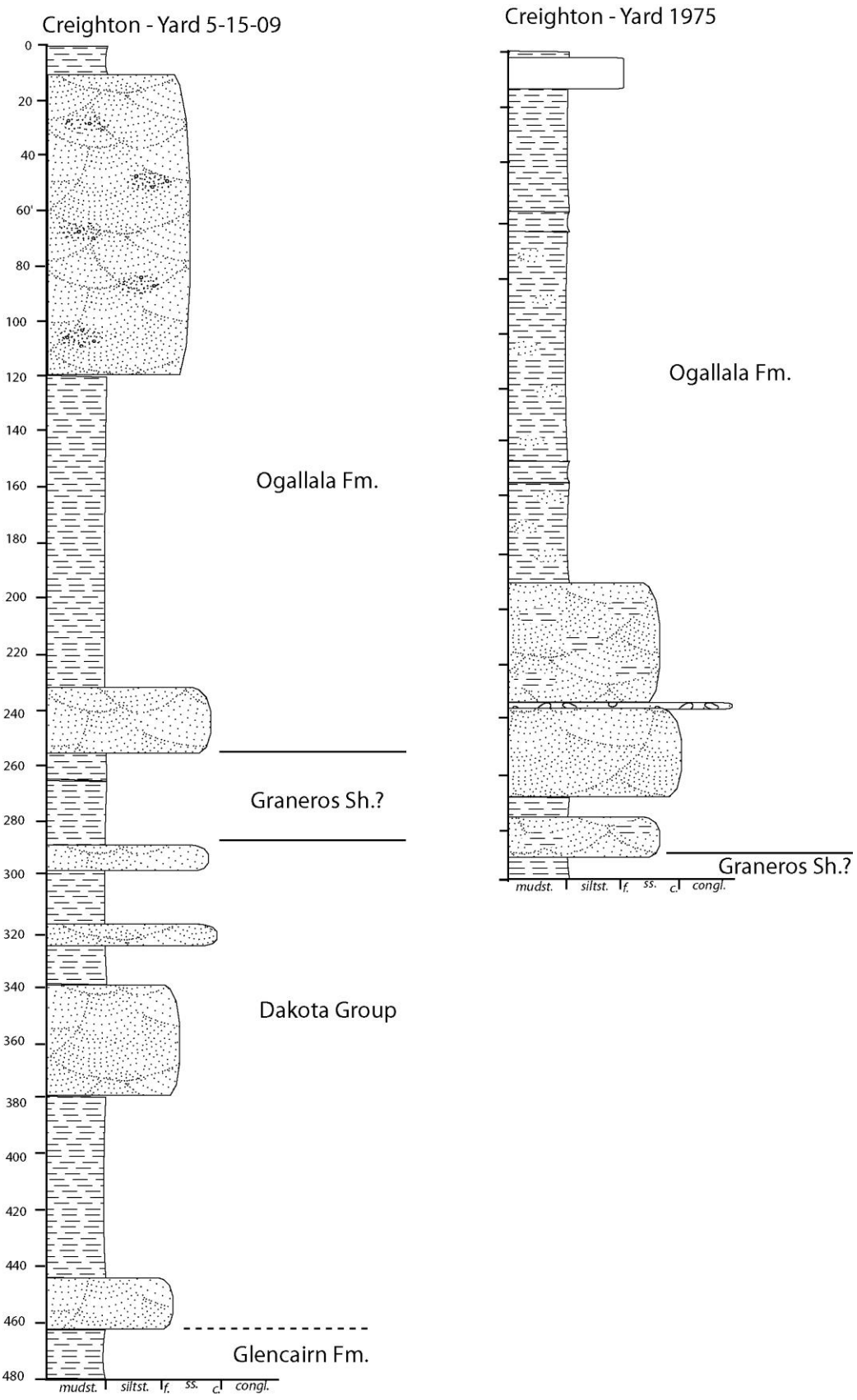
HH&E Oil Co. - #1-A Hughes
T22N, R36E, Sec. 33

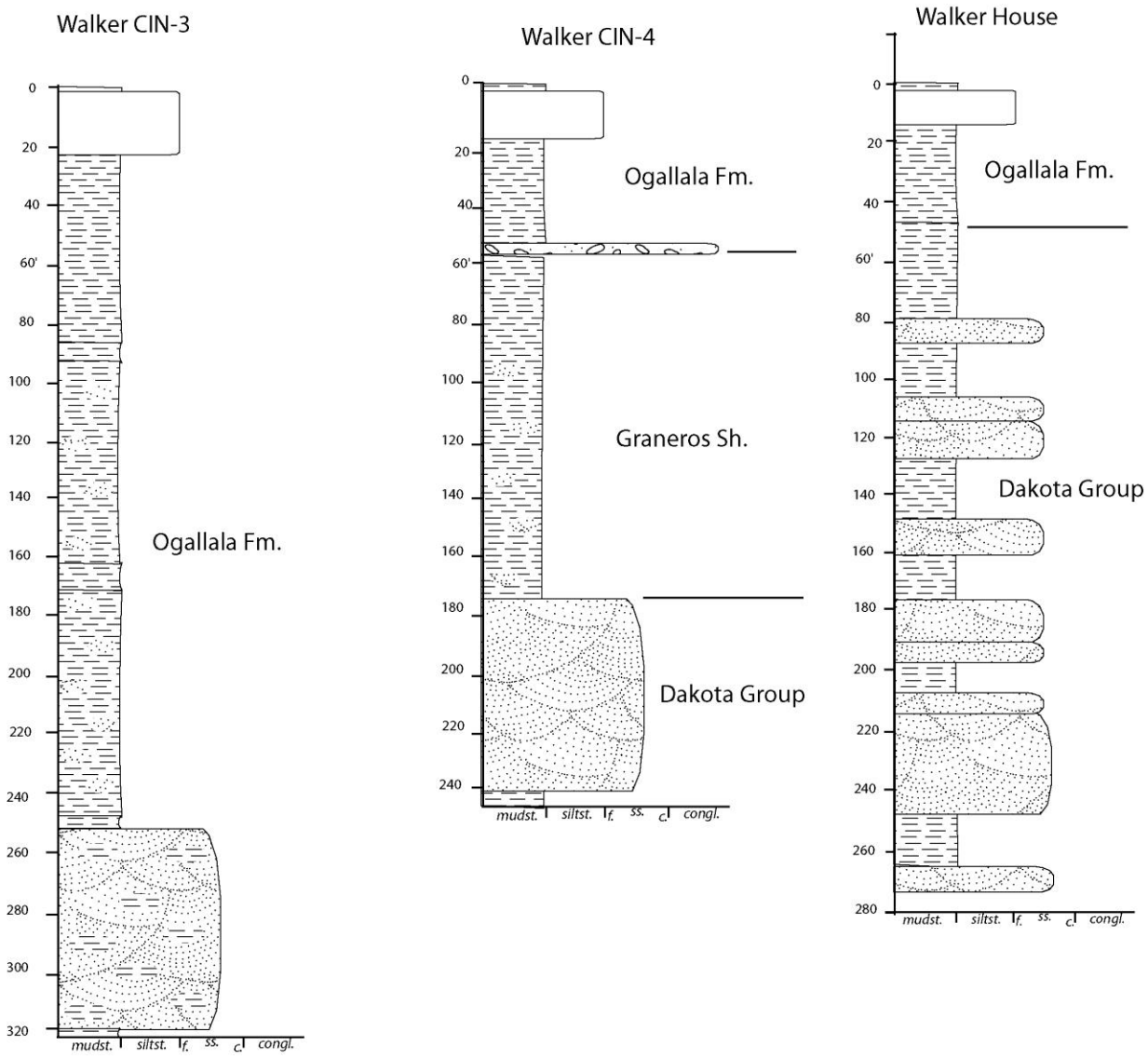


Skelly - #1 Van Pelt
T28N, R35E, Sec. 09






Creighton - Yard 5-15-09
0
20
40
60'
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
Ogallala Fm.
Graneros Sh.?
Dakota Group
Glencairn Fm.
mudst.
siltst.
f.
ss.
c.
congl.
Creighton - Yard 1975
Ogallala Fm.
Graneros Sh.?
mudst.
siltst.
f.
ss.
c.
congl.


Walker CIN-3
Ogallala Fm.
Walker CIN-4
Ogallala Fm.
Graneros Sh.
Dakota Group
Walker House
Ogallala Fm.
Dakota Group
0
20
40
60'
80
100
120
140
160
180
200
220
240
260
280
300
320
mudst.
siltst.
f.
ss.
c.
congl.