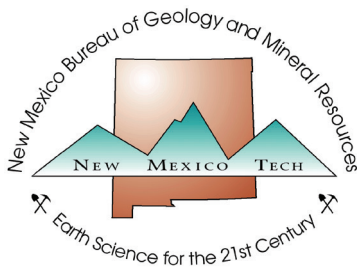


APPENDIX D

Coleman Ranch Well Series: Vertical and lateral heterogeneity and transgressive/regressive cycles in the Lower Permian Yeso Formation

This document describes Kate Zeigler's work with well cuttings in Three L Canyon.



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**Coleman Ranch Well Series: Vertical and lateral heterogeneity and transgressive/
regressive cycles in the Lower Permian Yeso Formation**

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INTRODUCTION

During the spring of 2009, four moderately deep wells were drilled on Coleman Ranch property, located approximately 6 miles east of Cloudcroft, in southeastern New Mexico. The purpose of these wells is not only for water production, but also to conduct groundwater sampling and monitoring operations. During drilling, well cuttings were collected and stratigraphic columns at each well site have been constructed, in order to explore local lateral variation within the Yeso Formation and attempt local correlations between wells. These four stratigraphic columns are also compared to a deep well drilled in Cloudcroft in the fall of 2006.

LOCATION OF WELLS AND METHODS

Location information for the wells used in this study are in Table 1. The Coleman Ranch wells are south to southeast of the Cloudcroft Apache Canyon well (Fig. 1). Coleman #1 is 5.8 miles south of the Cloudcroft well and is near the head of 8 Mile Canyon. Coleman #2 is 1 mile northeast of Coleman #1, near the Coleman Ranch headquarters. Coleman #3 is located in 3 L Canyon, a separate drainage to the southeast

of 8 Mile Canyon. Coleman #4 is located near the junction of 8 Mile Canyon and James Canyon and is about 2 miles northeast of Coleman #2. Coleman #3 is 2.1 miles southeast of Coleman #2 and 1.1 miles southwest of Coleman #4.

For the Coleman Ranch wells, well cuttings were retrieved from consecutive 10 foot intervals. Cuttings for Coleman #1 (CW1) were examined wet and cuttings for Coleman #2, 3 and 4 (CW2, CW3 and CW4) were all examined dry. Lithologies for each interval were identified and described using a hand lens, a standard rock color chart (Geological Society of America Rock-Color Chart, 1991), dilute hydrochloric acid and when necessary, a binocular microscope. For each 10 foot interval, the percentage of bulk rock of each lithology was approximated. For CW2, CW3 and CW4, much of the mudstone fraction was partially washed away so bulk rock percentages for the fine-grained materials in these wells has been underestimated.

Table 1. Location information for wells used in this study. GPS datum is NAD 83.

| Well Name | Easting | Northing | Elevation |
|------------------|----------------|-----------------|------------------|
| CACW | 0432969 | 3646821 | 2584.7 m |
| CW1 | 0439556 | 3640114 | 2488.1 m |
| CW2 | 0441071 | 3640880 | 2421.1 m |
| CW3 | 0444462 | 3640965 | 2323.3 m |
| CW4 | 0444543 | 3642783 | 2276.4 m |

LOCAL GEOLOGY AND STRATIGRAPHY

The Sacramento Mountains are an asymmetrical fault block with a steep west-facing escarpment and a gently dipping eastern slope that reaches the Pecos River about

80 miles east of the escarpment (Pray, 1961). The mountains are primarily comprised of sedimentary strata of Paleozoic age, with some late Precambrian metasedimentary units and Cretaceous sedimentary rocks locally exposed. In addition, numerous Tertiary intrusive units are also an important part of the regional geology. The Paleozoic strata reflect long-term deposition on a regionally stable shelf, though younger Paleozoic units show more lateral variation related to increased tectonic instability (Pray, 1961).

The Yeso Formation, as exposed along the Sacramento escarpment, has been described by Pray (1961) as being a 1200 to 1800 foot thick sequence of limestone, dolomite, shale, siltstone, anhydrite, minor halite and sandstone. Lithology varies widely and rapidly both laterally and vertically. In general, carbonates become more abundant in the upper part of the formation to the south with dolomite being mostly absent from sections examined in the northern part of the escarpment. Red beds are common primarily in the lower and middle Yeso Formation, but can be present at the top of the unit along the crest of the mountain range (Pray, 1961). Evaporites (primarily anhydrite) are also more abundant in the lower and middle Yeso Formation. Regionally, thickness of the Yeso can vary by up to 30%, which probably reflects depositional variation. Thinner sections tend to occur over anticlinal folds in the subsurface (Pray, 1961).

Limestone units in the Yeso Formation are mostly medium to dark gray argillaceous limestone that is thin bedded with interbedded dark shales. Near the base of the unit, the limestones are often recrystallized and contain irregular cavities, suggesting evaporite dissolution (Pray, 1961). A 100 foot thick sequence of limestone in the middle of the Yeso Formation can be traced laterally for up to 10 miles. Sandstone is most

common in the upper Yeso, but is only a minor component of the gross lithology of the formation. Sandstone beds are usually silty, very fine to fine grained quartz sandstones that are yellow in color and moderately sorted. Mudstones, which comprise a third to half of the Yeso Formation are locally very gypsiferous and can be a variety of colors, though they are usually pale red to pink or yellow.

Pray (1961) assigned a Leonardian age to the Yeso Formation based on regional stratigraphic relationships, though there is little fossil evidence to support this age assignment. He interpreted the environment of deposition as a regionally broad marine shelf that at times had restricted circulation, as evidenced by the evaporitic units.

LITHOLOGIC DESCRIPTIONS

Coleman Well #1

Coleman Ranch Well #1 is 280' in depth and includes about 95 feet of the lower unit of the San Andres Formation, the Rio Bonito Member. Here, the Rio Bonito Member is primarily dolomite with some sandy dolomite and fossiliferous limestone. Two thin sandstone beds occur in the upper 50 feet of CW1. These sandstones are medium grained, well sorted, very well rounded quartz arenites with hematitic staining and represent two tongues of the Hondo Sandstone within the Rio Bonito Member. These sandstones should not be referred to the Glorieta Formation, as the Glorieta is stratigraphically above the Yeso and below the San Andres Formation, but not intertonguing with the San Andres Formation (Pray, 1961; Harbour, 1970). The contact between the San Andres Formation and the underlying Yeso Formation occurs within the 90'-100' interval and is designated

by the first occurrence of siltstone or mudstone. In general, the Yeso Formation in CW1 is comprised for tan and brown dolomite, red and less commonly green mudstone and siltstone with some color mottling and yellow medium to fine grained, well sorted, rounded quartz wacke. Mudstone tends to not react to dilute HCl, whereas the sandstones are often effervescent. The lowest 100' of CW1 is dominantly fine grained mudstone and claystone, whereas dolomite is more common in the upper 80' of the Yeso Formation.

Coleman Well #2

The top of Coleman Well #2 is at or immediately below the contact between the San Andres and Yeso Formations based on field observations and geologic map of the area (Hallett, 2007a, b). This well is 80' deep and is the shallowest of the four wells. In CW2, the Yeso Formation includes red and mottled siltstone and mudstone with minor sandy limestone and dolomite. Fine grained siliciclastic materials are sometimes reactive with HCl, but usually not. Some mudstone samples appear to be cross-laminated, though the fragments are too small to determine if these are ripple cross-laminations.

Coleman Well #3

Coleman Ranch Well #3 is 120' deep and consists of only Yeso Formation, with a relatively thick Quaternary alluvium consisting of a dark gray to black silty soil in the upper 20'. The top of the well is approximately 80' below the San Andres-Yeso contact, based on elevation of the well head and projected height of the contact from the geologic map. Here the Yeso Formation includes siltstone, limestone and sandy limestone, minor

bioclastic packstone and sandstone. No dolomite was observed in the well cuttings from CW3. In the upper part of the well, the fine-grained siliciclastics are red in color, whereas they are green in the base of the well. Sandstone units in CW3 are fine grained, well rounded, well sorted quartz arenites.

Coleman Well #4

Coleman Ranch Well #4 is 420 feet deep and also consists only of Yeso Formation with about 15 feet of Quaternary alluvium at the top. The well's top is about 110' below the contact between the San Andres and Yeso Formations. The Yeso Formation in CW4 is predominantly mudstone, claystone and siltstone in the upper third, followed by a thick sequence of bioclastic limestone with minor fine-grained siliciclastic in the middle third, with a relatively short interval of mudstone followed by limestone with minor siltstone in the lower third. In the upper part of the well, the mudstones and claystones are red in color, whereas they are pale yellow with green and red mottling in the lower half of the well. Sandstone units are very fine grained, subrounded and well sorted. The upper sandstone is a micaceous quartz arenite (70-80') and the lower sandstone is a quartz wacke (320-330').

Cloudcroft Well, Apache Canyon

The Cloudcroft well, drilled at Apache Canyon (CWAC) is 1650' deep and the top of this well is at or near the San Andres-Yeso contact, based on field observations. The top 300' of the CWAC well are dominantly siliciclastics, including siltstone, mudstone

and sandstone, followed by approximately 150' of predominantly limestone and dolomite with some sandstone and mudstone. A 100' thick interval of siltstone follows, with a thick sequence of limestone with some siltstone from about 575' to 825'. From 825' to the base of the well at 1650', strata consist of a mixture of dolomitic limestone, siltstone, anhydrite and sandstone.

DISCUSSION

Coleman Well Comparison

The Coleman Ranch well series demonstrates the regional and local heterogeneity of the Yeso Formation, both laterally and vertically. No direct bed-to-bed correlations could be made among any of the four wells. In fact, the four Coleman Wells do not exhibit the same lithology where they overlap one another, despite their relative geographic proximity. Due to this lack of small-scale bed-to-bed correlation, it is difficult to develop a local, composite stratigraphic column that truly depicts the local lithologies of the Yeso Formation that could be used to compare to the Cloudcroft Apache Canyon well. Additionally, correlations are made more difficult within the Yeso Formation because of dissolution collapse due to hydration and dehydration of salts within the Yeso. It is possible to tentatively correlate between the wells based on gross lithologic characteristics of parts of the stratigraphy or by assigning transgressive and regressive cycles to the stratigraphy. If transgression/regressions are used, some correlations can be developed, especially between the middle part of the Cloudcroft Apache Canyon well and CW4. It is important to note that the transgressive events tentatively identified here and

used for local correlations are not first order global sea-level changes, but more likely second or third order localized changes in sea level.

Mack and Dinterman (2002) suggest that the Yeso, Glorieta and San Andres Formations represent a single transgressive event. Mack and Suguio (1991) identified two orders of cyclicity in the Caballo Mountains of south-central New Mexico, including one large transgressive-regressive cycle and several smaller transgressive events that are on the order of 0.5 – 1.0 m in thickness. In the Coleman wells and in the Cloudcroft Apache Canyon well, several thin to moderately thick limestone or dolomitic limestone intervals have been identified. Above and below these limestone intervals are mudstones, sandstones and sandy mudstones. If the limestone/dolomitic limestone intervals represent local maximum marine transgression events, then CW1 contains a single transgressive event, CW2 contains the top of a single transgressive event, CW3 contains the base of a transgressive event and a second transgressive event and CW4 contains evidence of three transgressions. Six possible transgressive events can be identified in the Cloudcroft Apache Canyon well.

The single transgressive event in CW1 does not appear to correlate to a transgressive event in any other well and may represent a local influx of seawater in a small embayment. The transgressive event at the base of CW2 may correspond with the transgressive event at the top of CW3 such that the limestone in CW2 represents the onset of transgressive deposition and the limestone in the top of CW3 records the end of transgressive deposition and the beginning of a regressive event. CW3 also includes a second transgressive event that is not seen in CW4 and is very tentatively correlated with

the uppermost transgressive event in the Cloudcroft well. It should be noted that CW3 is furthest east among the Coleman Ranch wells and is therefore presumably more seaward than the others. CW4 has three transgressive events that may correlate to events in the Cloudcroft Apache Canyon well.

Six transgressive events are identified in the Cloudcroft Apache Canyon well and three of these events are tentatively correlated to the three events identified in CW4. It is of interest that the limestone intervals in the Cloudcroft Apache Canyon well are substantially thicker than their tentatively identified counterparts in CW4. These variations in thickness may relate to local geography along the shoreline, such as embayments, or perhaps to the presence of local high topography.

Lucas and Zeigler (2004) identified six transgressive events in a sequence of Yeso, Glorieta and San Andres Formations in the Lucero uplift of central New Mexico. Ross and Ross (1988) identified a well-defined sequence of large-scale sealevel onlaps during the Leonardian in Permian strata in the Glass Mountains of west Texas. Lucas and Zeigler (2004) suggest that two of the four transgressive events that were identified by Ross and Ross (1988) in the Glass Mountains of West Texas can be correlated to transgressive events in the Lucero uplift sequence and they identify they large-scale transgressive event that encompasses the Yeso to San Andres transition as equivalent to the Roadian transgression which is of early Guadalupian age. However, a lack of biostratigraphic data from Yeso sequences in New Mexico makes exact correlation transgressive cycles between central New Mexico and West Texas difficult (Lucas and Zeigler, 2004).

In addition, the complex relationships between regional tectonics, sedimentation rates and local and global sea level changes may obscure or confuse attempts at regional correlation using these transgressive cycles (Mack and Suguio, 1991; Mack and Dinterman, 2002; Lucas and Zeigler, 2004). The Ancestral Rocky Mountain orogenic event was essentially over by Yeso deposition time, but local highlands were shedding clastic sediments into neighboring basins. If clastic sedimentation rates or subsidence rates were higher than production of carbonate within these same basins, the sedimentary sequence will reflect these differences with a dominantly clastic signature, obscuring smaller transgressive events (Lucas and Zeigler, 2004).

It is tempting to correlate the six transgressive cycles seen in the Yeso Formation in the Lucero uplift with the six transgressive events tentatively identified in the Cloudcroft Apache Canyon Well. However, a lack of biostratigraphic data for both sections makes such correlations tenuous at best. Additionally, the Yeso sequence preserved in the Sacramento Mountains and the Lucero uplift section were both deposited in different basins that were probably experiencing different rates of subsidence, clastic deposition and carbonate production, such that different transgressive episodes were probably preserved in each sequence. Until a more refined biostratigraphic or other geochronologic framework can be developed for these sequences, no direct correlation of sea level cycles between central and southwestern New Mexico should be attempted.

CONCLUSION

The Coleman Ranch well series demonstrate the lack of lateral continuity of lithologies within the Permian Yeso Formation. In spite of the geographic proximity of these four wells to one another, direct correlation between wells and the construction of a composite stratigraphic column for the Yeso Formation could not be attempted. In addition, the lack of local lateral continuity does not allow for direct lithologic comparison of the Coleman Ranch wells to the Cloudcroft Apache Canyon well almost six miles to the north. However, tentative correlations between the Coleman Ranch well group and the Cloudcroft Apache Canyon well can be made using transgressive cycles identified in the stratigraphic columns. These tentative correlations suggest at least six small-scale transgressive events occurred in southeastern New Mexico during the Permian. Three of these events appear to be recorded in CW4 and all six events are recorded in the deeper Cloudcroft Apache Canyon well. Correlation of these six sea level cycles to similar cycles in the Lucero uplift in central New Mexico are not attempted due to a lack of geochronologic control in both sequences.

Acknowledgments: Mr. Michael Coleman graciously consented to the drilling of these wells and collection of the well cuttings. Funding for the drilling was provided by the Otero County Talon Newton, Stacy Timmons and Trevor Kludt assisted with collection of the well cuttings.

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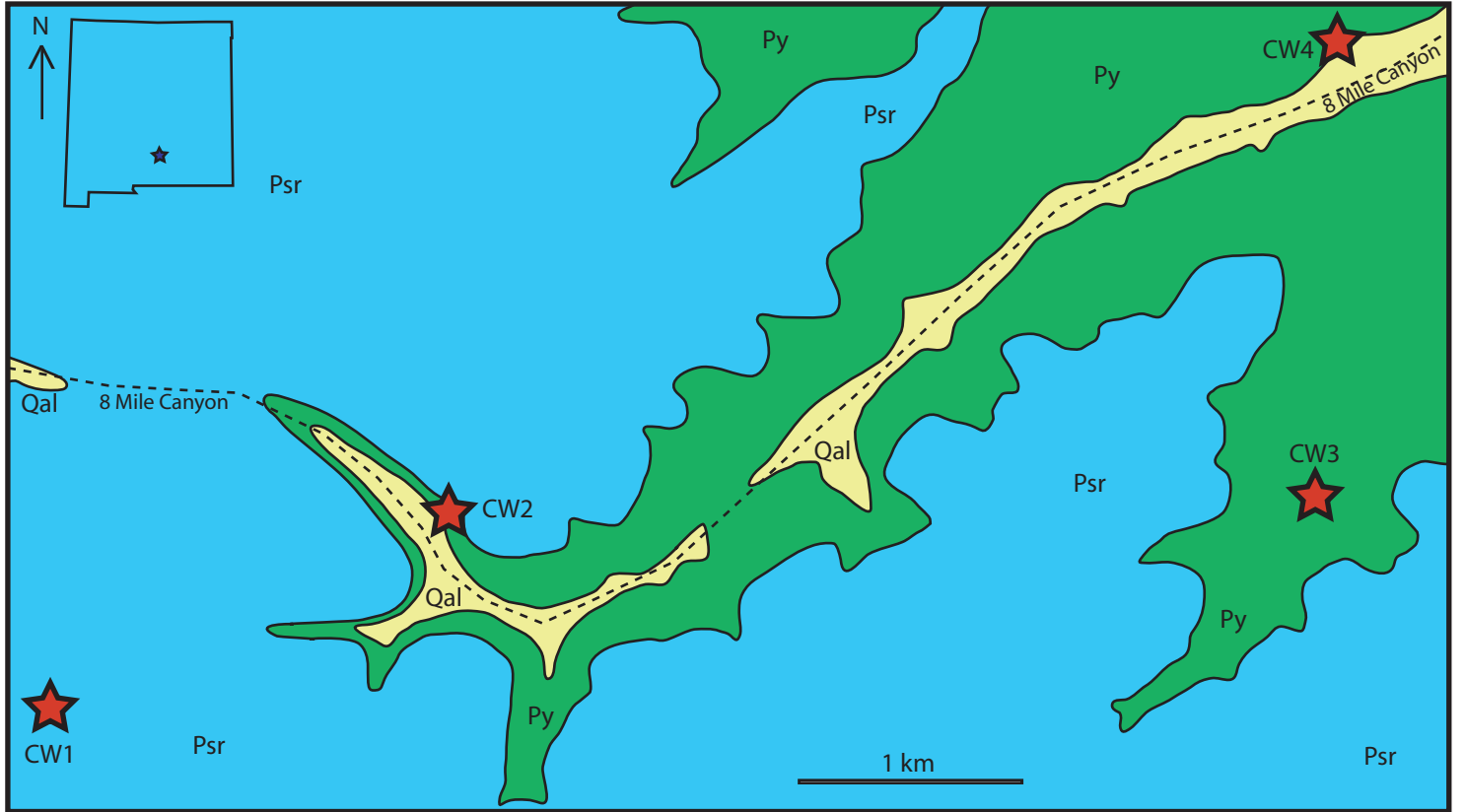


Figure 1. Location of wells used in this study overlaid on local geology (from Hallett, 2007a, b).

Cloudcroft Apache Canyon

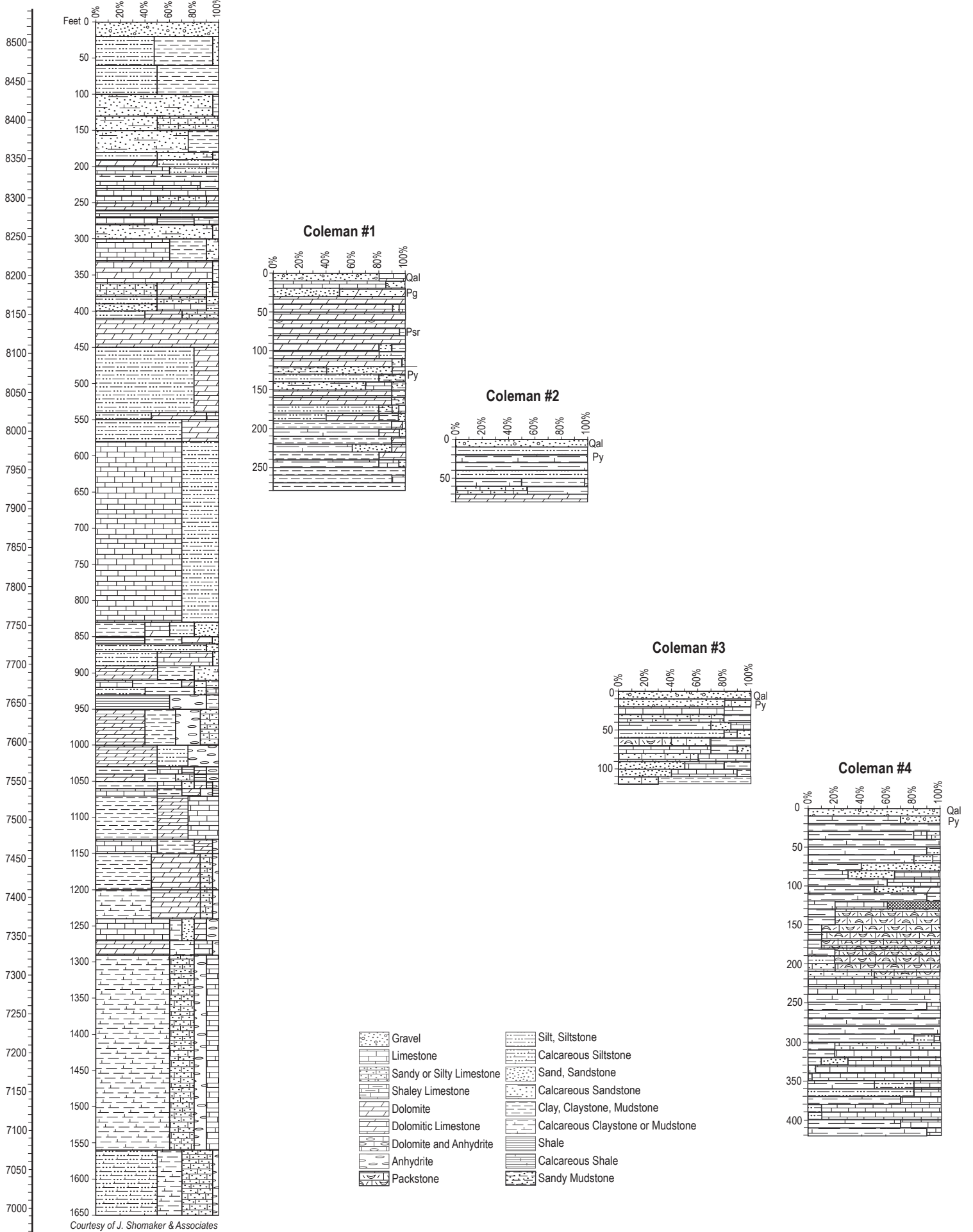


Figure 2. Stratigraphic columns constructed from well cutting data for Coleman Ranch wells 1-4. Columns are placed at their current elevations with respect to the Cloudcroft Apache Canyon well. No corrections for structure or dip have been applied.

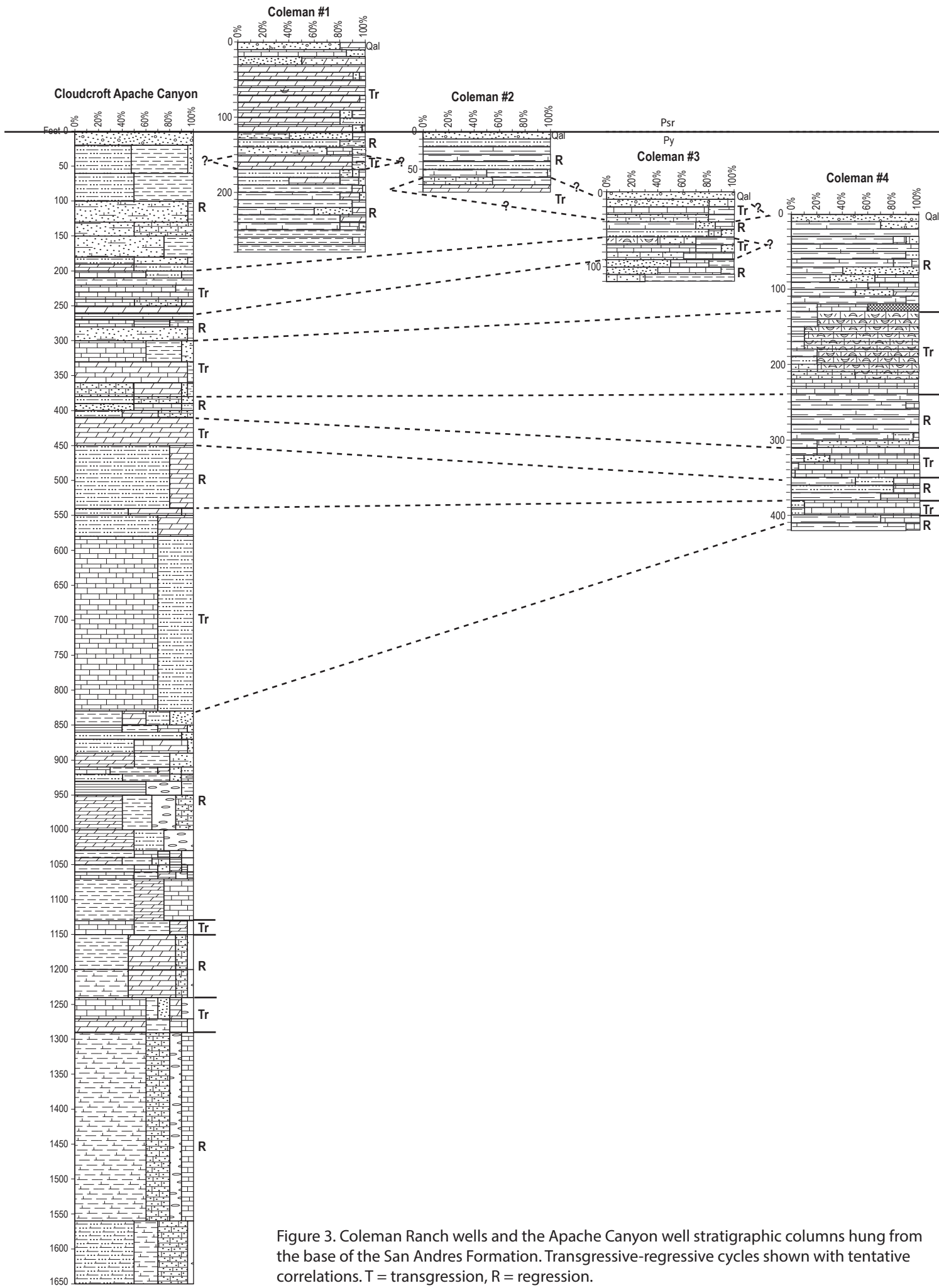


Figure 3. Coleman Ranch wells and the Apache Canyon well stratigraphic columns hung from the base of the San Andres Formation. Transgressive-regressive cycles shown with tentative correlations. T = transgression, R = regression.

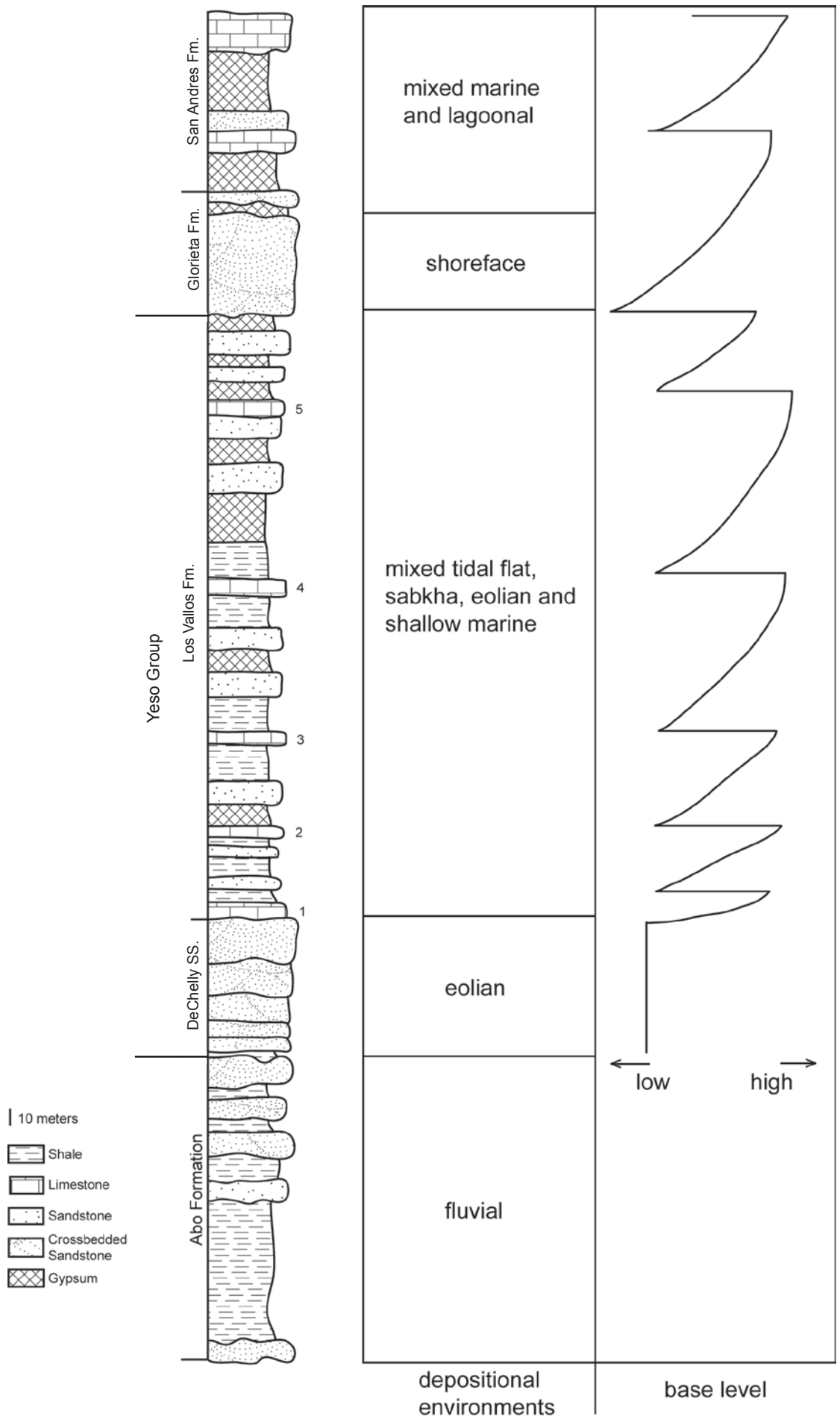


Figure 4. Yeso strata from the Lucero uplift in central New Mexico with depositional environments and interpretation of relative sea level (from Lucas and Zeigler, 2004).