PALEOSOLS OF THE UPPER PENNSYLANIAN-LOWER PERMIAN CUTLER GROUP, NORTHERN NEW MEXICO, PALEOCLIMATIC INTERPRETATION

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ABSTRACT

The Upper Pennsylvanian (Virgillian) to lowermost Permian (Wolfcampian) El Cobre Canyon and Arroyo del Agua formations in the Chama Basin of northern New Mexico are well exposed in a 250+ m section in Canyon El Cobre (Rio Arriba County), northern New Mexico. We studied this succession in an attempt to describe the climate system that existed at the time, and more specifically identify if or when the climate became increasingly arid, as has been proposed.

The section constitutes a red-bed sequence consisting mainly of silty mudstones and sandstones with sheet-like to ribbon geometry and very minor limestones. These sediments represent channel-fill deposition and overbank muds (dominantly), sandy splays and (minor) floodplain ponds. The stratigraphic sequence records an upward transition from mainly braided streams in the El Cobre Canyon Formation to anastomosing streams in the Arroyo del Agua Formation.

We recognized multiple paleosol types within these strata, including mainly calcic Protosols, calcic Argillisols and Calcisols. The Calcisols occur primarily as truncated profiles. Although we observe no distinct difference in paleosol type between the two formations, we note that the calcretes in the Arroyo del Agua Formation are generally thicker than those in the underlying El Cobre Canyon Formation. A significant enrichment of $\delta^{18}O$ also occurs at the transition between these formations. Together, these data suggest climate aridification at the Pennsylvanian-Permian transition, although marine regression and decreasing sedimentation rates may also explain the observations.

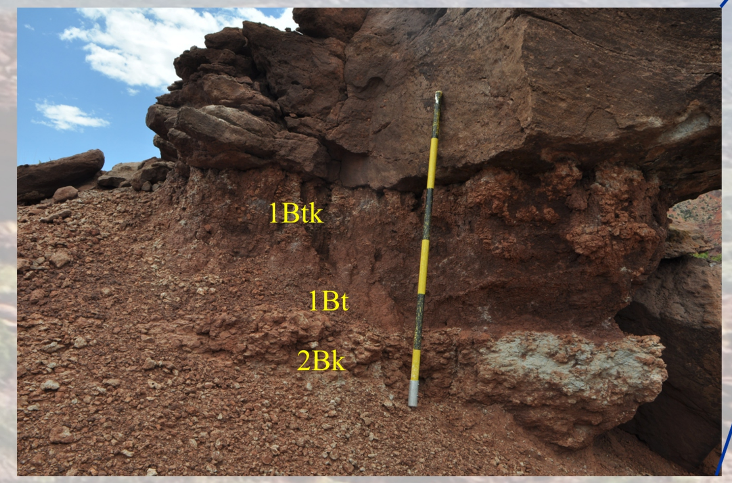
Location of the field area in north-central New Mexico.

GEOLOGIC BACKGROUND

Cañon del Cobre is a large box canyon in southeastern Rio Arriba County, New Mexico, along the southeastern border of the Colorado Plateau, that exposes strata of Pennsylvanian, Permian, Triassic and Cenozoic age. The oldest rocks here are siliciclastic red beds of the El Cobre Canyon Formation of the Cutler Group, strata of Late Pennsylvanian-Early Permian (Virgilian-Wolfcampian) age. The exposed El Cobre Canyon Formation is about 230 m thick (total thickness ~ 640 m) and is mostly siltstone and sandstone deposited in an ephemeral braided stream environment (Eberth and Miall, 1991; Krainer and Lucas, 2010). The overlying Lower Permian Arroyo del Agua Formation of the Cutler Group is as much as 160 m thick, and also consists mostly of siltstone and sandstone, but was deposited on laterally extensive floodplains that developed between relatively stable channels. An extensive unconformity separates Cutler Group strata from overlying Late Triassic strata of the Chinle Group around the rim of Cañon del Cobre.

During deposition of the El Cobre Canyon Formation, broad and shallow channels of a braided river system (major sandstone sheets) developed under semiarid to subhumid climatic conditions. Overbank areas were frequently inundated by sheet floods and splays, causing deposition of minor sandstone sheets and lenses, and stacked sheets and lenses. Small ponds filled with fine-grained lacustrine sediments were common. During deposition of the Arroyo del Agua Formation, channels became narrower and between the channels extensive floodplains developed on which locally pedogenic carbonate horizons formed (Eberth and Miall, 1991; Krainer and Lucas, 2010).

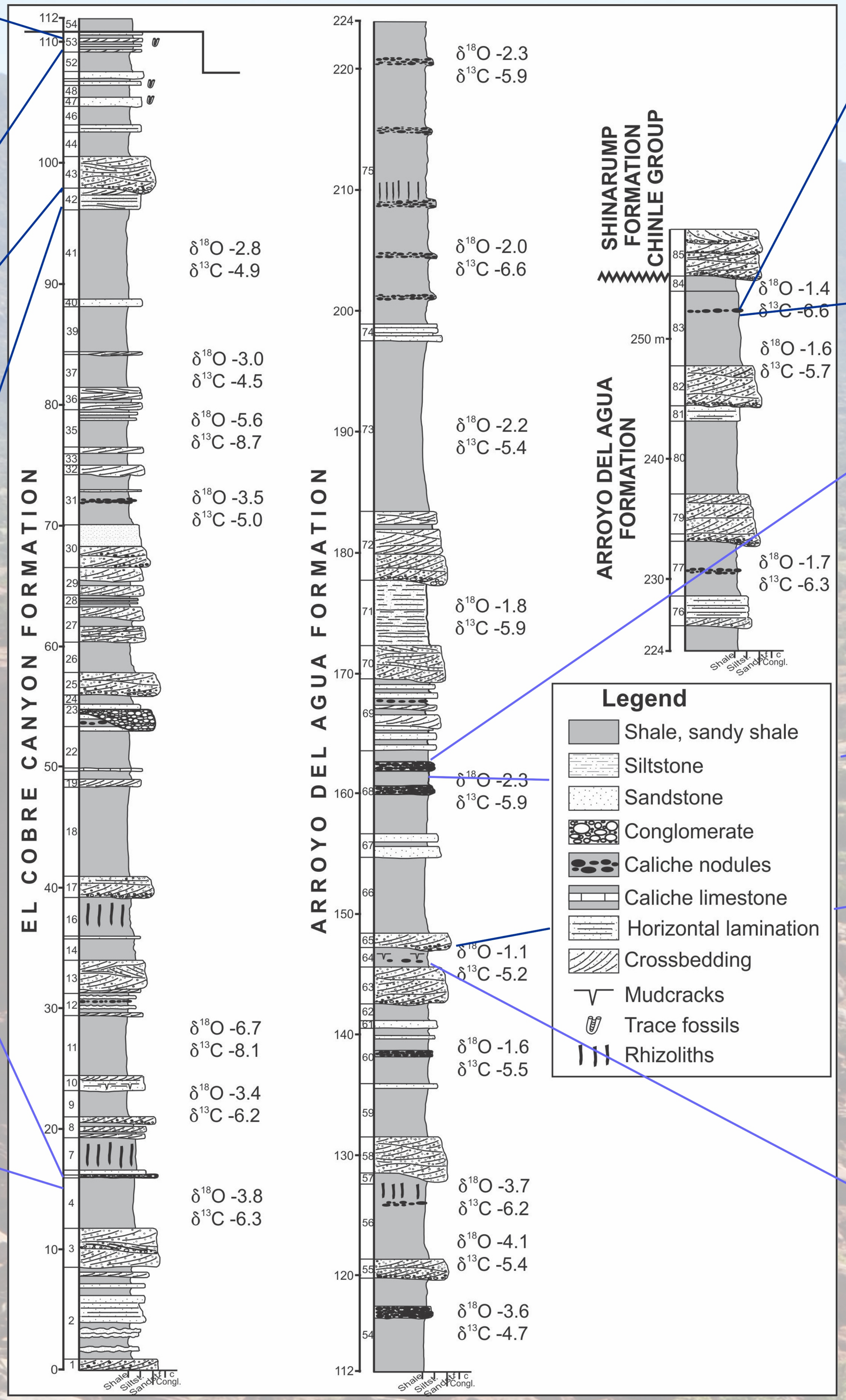
Thin, truncated composite profile of multiple coalesced nodular layers between sandstones.



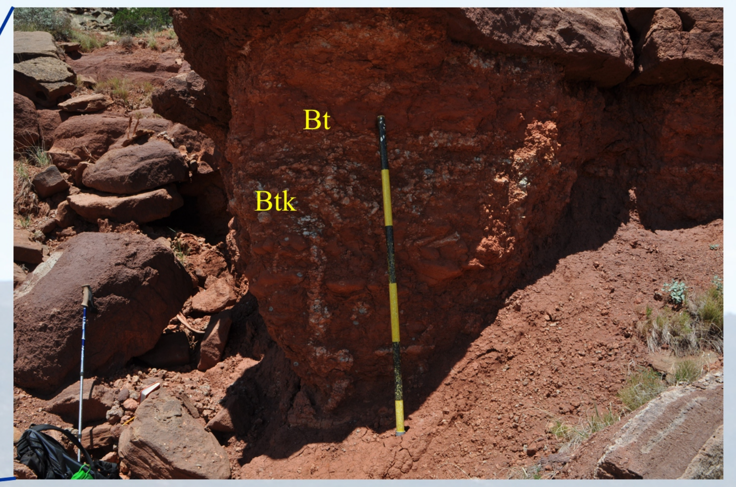
Composite profile comprising 1Btk and 1Bt horizons overlying a truncated 2Bk horizon.

Typical thin argillic calcisol in the lower part of the El Cobre Canyon Formation.

Overview of the measured section, which consistes largely of sheet sandstones and intervening mudstones in the lower part.

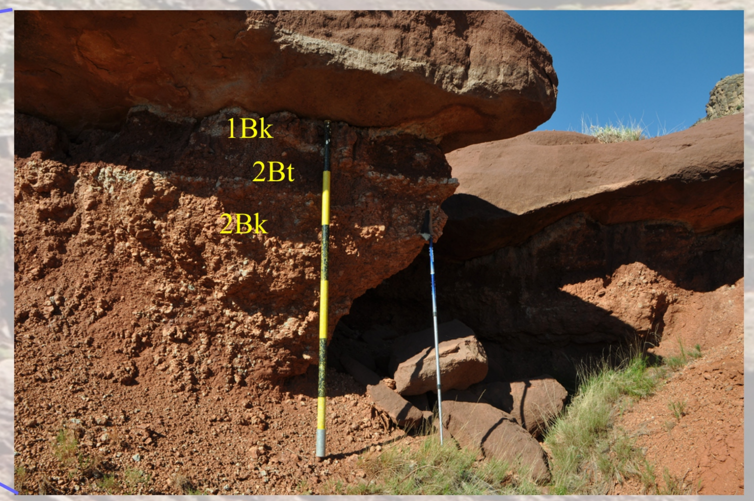


Isotopic analyses by Isotech Laboratories, Inc.



Composite calcic Argillisol near the top of the section.

Thick, truncated profile with Bk horizon weathered to form prominent bench.



Composite, truncated argillic Calcisol with 1Bk, 2Bt, 2Bk horizons, near base of Arroyo del Agua Formation.

Detail of above.

PALEOSOLS

Locally, mudstones display a variety of pedogenic features. Common mudstone fabrics vary from blocky to platey, and less commonly prismatic. Some beds display prominent sand-filled desiccation fractures, rhizoliths and drab root traces. Calcareous nodules are common in most mudstone beds, varying from small (1 to 2 cm) bodies with diffuse boundaries to isolated botryoidal masses. Less common are discrete layers of coalescing nodules. These typically have nodular upper surfaces and bases that are gradational, transitioning downward to vertically-stacked discrete cm-scale nodules (rhizocretions) and isolated nodules. Most of the calcretes in the studied section are immature (Stage I to II), but mature calcrete beds (Stage III to IV), with coalescing nodules forming laterally continuous (K) horizons occur at multiple levels throughout the section.

Where the paleosols in the section display sufficiently distinctive pedogenic features to allow classification, we apply the terminology of Mack et al. (1993) in assigning names of paleosol orders, modified by adjectives describing the most prominent subordinate characteristic. The most common paleosol type we find in the measured section is calcic Argillisol, denoting a paleosol horizon in which the defining characteristic is a clay-rich B horizon that is visibly enriched in $CaCO_3$ in the form of nodules, i.e. a Btk horizon. The calcic Argillisols may also display multiple B horizons, each with distinctive characteristics, such as a Bt horizon underlain by a Bk horizon. In profiles where calcareous B horizons (Bk, or Btk if argillic and calcic) outnumber the argillic (Bt) horizons, we assign the designation Calcisol or argillic Calcisol, as appropriate. Many mudstone beds of varying thickness display pedogenic features, such as calcareous nodules drab and root traces, but lack distinct horizonation. We term these units Protosols, and where they contain calcareous nodules we label them calcic Protosols.

Most paleosol profiles in the section are truncated in that they lack a discernible eluviated upper (A) horizon and display evidence of sediment removal. We also recognize several compound profiles in the section. These are marked by repetition of specific types of B horizons (Bt, Btk or Bk) without an intervening A horizon, suggesting interruption of sedimentation and an erosional episode. This pattern is noted in some Calcisol and argillic Calcisol profiles. We do not find a clear differentiation in paleosol types between the El Cobre Canyon and Arroyo del Agua formations, but note that the calcretes in the latter formation are thick on average than in the older formation. This effect is consistent with an increasingly dry climate with onset near the Virgillian-Wolfcampian boundary. The sedimentology of this section, as described by Eberth and Miall (1991) and Krainer and Lucas (2010) has been interpreted as recording a decreasing sedimentation rate resulting from decreased source-area relief. This could also explain the generally thicker calcretes in the Arroyo del Agua Formation, as compared to the El Cobre Canyon Formation.

ISOTOPE DATA

Sample ID	Stratigraphic Unit #	$\delta^{13}C$ ‰ PDB	$\delta^{18}O$ ‰ PDB
EC-1	4	-6.3	-3.8
EC-2	9	-6.2	-3.4
EC-3	11	-8.1	-6.7
EC-4	31	-5.0	-3.5
EC-5	35	-8.7	-5.6
EC-6	37	-4.5	-3.0
EC-7	41	-4.9	-2.8
EC-8	54	-4.7	-3.6
EC-9	56	-5.4	-4.1
EC-10	56	-6.2	-3.7
EC-11	60	-5.5	-1.6
EC-12	64	-5.2	-1.1
EC-13	68	-5.9	-2.3
EC-14	71	-5.9	-1.8
EC-15	73	-5.4	-2.2
EC-16	75	-6.6	-2.0
EC-17	75	-5.9	-2.3
EC-18	77	-6.3	-1.7
EC-19	83	-5.7	-1.6
EC-20	83	-6.6	-1.4

ISOTOPIC DATA

$\delta^{13}C$ - With the exception of two outliers, the $\delta^{13}C$ data demonstrate substantial consistency across the sampled stratigraphic interval, this supporting the supposition that the sampled carbonate is pedogenic in origin (not lacustrine). Moreover, this consistency likely steady values for the atmospheric pCO_2 across the Virgillian-Wolfcampian.

$\delta^{18}O$ – Of greatest significance is the enrichment in $\delta^{18}O$ that occurs in the pedogenic carbonates of the Arroyo del Agua Formation, relative to those of the underlying El Cobre Canyon Formation, from a mean $\delta^{18}O$ of -4.02 ‰ (PDB) in the older formation to -1.84 ‰ (PDB) in the younger. Tabor and Montañez (2002) cited a mean value of $\delta^{18}O$ = -1.2 ‰ (PDB) for equatorial soils formed in the Virgillian, to $\delta^{18}O$ = 0.5 ‰ (PDB) by the Wolfcampian, which the authors interpret as the result primarily of increased aridity. At least in part, the drying trend may have been related to withdrawal of epeiric seas following the Middle Pennsylvanian (DesMoinesian) highstand. Similarly, we interpret the enrichment observed within the Cutler Group pedogenic carbonates, spanning the Virgillian to early Wolfcampian, as resulting from climatic drying likely coupled with withdrawal of the shallow Pennsylvanian seas.

The depletion of the Cutler Group pedogenic carbonate isotope values relative to those compiled by Tabor and Montañez (2002) likely reflects increased distance from the equator; the authors noted depletion of ca. 0.75 ‰ per degree of latitude from the equator. We note also that the mean $\delta^{18}O$ for the younger (Wolfcampian) calcretes is very enriched relative to slightly younger Wolfcampian values from the Sangre de Cristo Formation reported by Tanner and Lucas (2017). The mean $\delta^{18}O$ = -4.86 ‰ (PDB) for the Sangre de Cristo Formation. We interpret this difference as due primarily to an orographic effect from the upland position at the base of the Ucompahgre Uplift, compared to a lowland position in the Taos Trough for the Sangre de Cristo Formation. The mean $\delta^{13}C$ = -4.86 for the Sangre de Cristo Formation, identical to that for the Cutler Group, again suggesting unchanged pCO_2 across Virgillian through Wolfcampian time.

CONCLUSIONS

- Calcareous paleosols occur throughout the section in Cañon El Cobre. These include calcic Protosols, calcic Argillisols, argillic Calcisols and Calcisols.
- The calcretes (Bk or K horizons) in the Arroyo del Agua Formation tend to be thicker than those of the underlying El Cobre Canyon Formation.
- Isotopic analysis shows consistent $\delta^{13}C$ through the entire section, suggesting steady pCO_2 levels across the Virgilian-Wolfcampian boundary.
- Significant enrichment of $\delta^{18}O$ at this boundary likely indicates the onset of a more arid climate.

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