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Cherty facies of the Late Ordovician Montoya Group, southern New Mexico and western Texas: implications for Laurentia oceanography and duration of Gondwana glaciation

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2002, pp. 159-165. https://doi.org/10.56577/FFC-53.159

in:

Geology of White Sands, Lueth, Virgil; Giles, Katherine A.; Lucas, Spencer G.; Kues, Barry S.; Myers, Robert G.; Ulmer-Scholle, Dana; [eds.], New Mexico Geological Society 53rd Annual Fall Field Conference Guidebook, 362 p. https://doi.org/10.56577/FFC-53

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New Mexico Geological Society Guidebook, 53rd Field Conference, Geology of White Sands, 2002, p. 159-165.

CHERTY FACIES OF THE LATE ORDOVICIAN MONTOYA GROUP, SOUTHERN NEW MEXICO AND WESTERN TEXAS: IMPLICATIONS FOR LAURENTIA OCEANOGRAPHY AND DURATION OF GONDWANA GLACIATION

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ABSTRACT.— The Late Ordovician Montoya Group in southern New Mexico and western Texas records predominantly subtidal carbonate deposition on a gently dipping ramp. Rocks of the Montoya Group are almost entirely dolomitized. The medial unit, the Aleman Formation is unique because it contains abundant chert (locally up to 70% by volume). The chert occurs as thin continuous beds of sponge spicules within calcisiltite or nodules within skeletal wackestone and packstone. Skeletal grainstone and muddy peritidal facies contain little chert. The abundance of chert and phosphate in the subtidal facies indicates the Montoya Group formed within a region of strong upwelling, possibly initiated by onset of glaciation during the Late Middle Ordovician.

INTRODUCTION

This paper describes the facies of the Late Ordovician Montoya Group of southern New Mexico and western Texas. These rocks were deposited during a transition from Early and Middle Ordovician global greenhouse conditions to Late Ordovician global glacial conditions (Fig. 1). This glaciation is enigmatic because it formed during a prolonged period of global greenhouse conditions with enhanced atmospheric pCO_2 concentrations up to 10-18 times greater than present (Berner, 1994). This glaciation was triggered by Gondwana migration across the South Pole (Crowley and Baum, 1995) possibly in conjunction with intense weathering of Taconic highlands that drove global temperatures down (Kump et al., 1999). One unresolved aspect of this glaciation is its tempo, one scenario suggests the glaciation began quickly during the Hirnantian stage and lasted a very short time, possibly less than 1 million years (Brenchley et al., 1994). Another scenario suggests glaciation began earlier during the mid-Caradoc and gradually built up to a global maximum during the Hirnantian (Frakes et al., 1992; Crowell, 1999; Barnes, 1999).

A 3-4‰ positive excursion in both $\delta^{13}C$ and $\delta^{18}O$ stable isotopes of carbonates from three continents during the Hirnantian is interpreted as evidence for a short-lived glaciation (Brenchley et al., 1994; Marshall et al., 1997). A longer glacial event in the Ordovician is indicated by Mid-Caradocian glaciogenic sedimentary rocks in Africa (Barnes, 1986; Theron, 1994; Crowell, 1999). A mid-Caradoc timing of these glaciogenic deposits corresponds closely with an abrupt faunal change in Laurentia (Patzkowsky and Holland, 1993). Similarly, high-frequency, moderate amplitude (20-30 m/20-100ky) sea level fluctuations in Late Middle Ordovician Lexington Limestone (Pope and Read, 1997a, b, 1998) and the influx of cool oceanic waters over much of equatorial Laurentia during the Late Middle and Late Ordovician (Brookfield, 1988; Holland and Patzkowsky, 1997; Pope and Read, 1998; Kolata et al., 2001) also are indirect proxy evidence for a prolonged Ordovician glaciation. This paper discusses new sedimentologic and stratigraphic data from the Late Ordovician Montoya Group in Texas and New Mexico and their equivalents that indicate the southern margin of Laurentia area was an upwelling zone produced by enhanced oceanographic circulation during a prolonged period of glaciation.

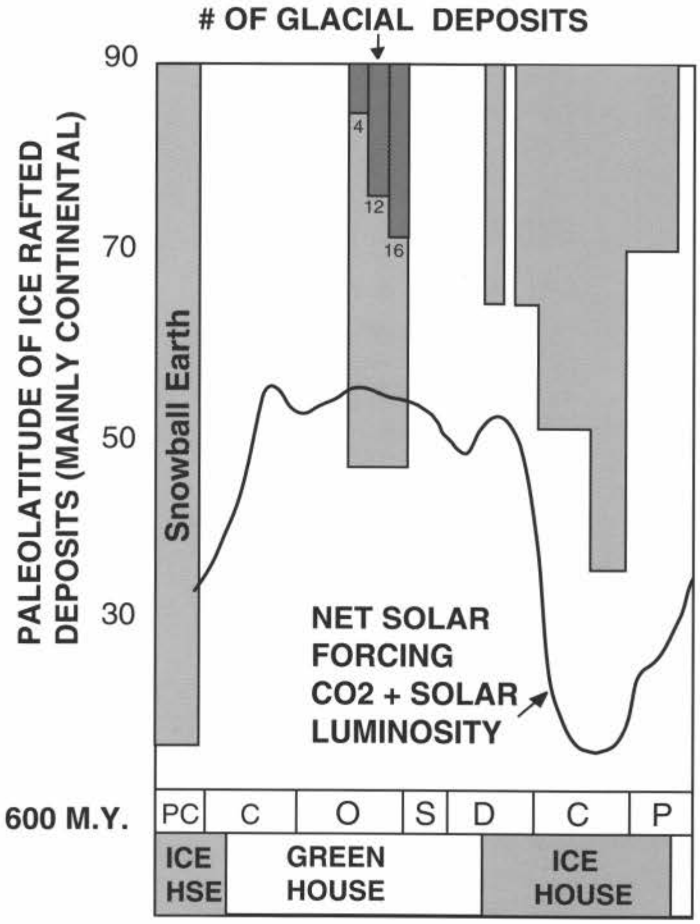

FIGURE 1. Diagram showing glacial deposits and their paleolatitudinal distribution from the late Proterozoic to end of the Permian (modified from Frakes et al., 1992). The dark bars with numbers during the Late Ordovician indicate the number of glaciogenic deposits.

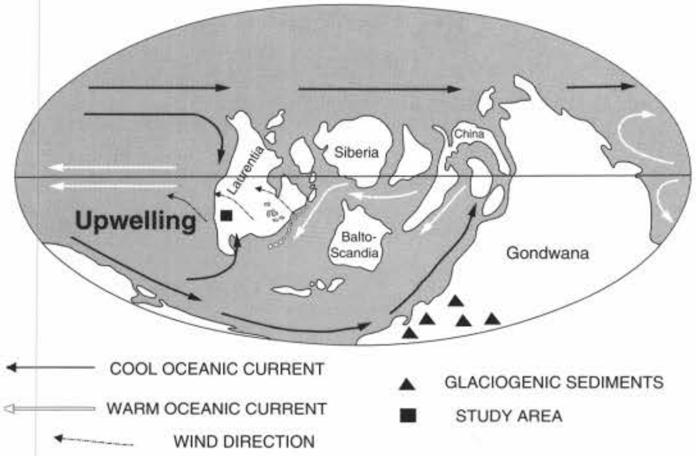

FIGURE 2. Map adapted from Scotese, 1997; Currents adapted from Wilde, 1991; Pope and Read, 1997.

REGIONAL STRATIGRAPHIC FRAMEWORK

Late Middle to Late Ordovician Montoya Group strata of southern New Mexico and western Texas are up to 180 m thick and formed a gently sloping ramp on this mature passive continental margin (Measures, 1985a,b; LeMone, 1988; Brimberry, 1991). Paleomagnetic reconstructions indicate this area (Fig. 2) was positioned between 5-20° south latitude, aligned approximately north-south and faced the Panthalassic Ocean (Scotese, 1997; Mac Niocaill et al., 1997).

The Montoya Group outcrops in mountain ranges throughout southern New Mexico and westernmost Texas that are surrounded by flat-floored valleys (Fig. 3). These mountains were produced by Cenozoic basin and range extension and the mountains commonly trend north-northwesterly. Forty-two full and partial sections were measured during this study (Fig. 3).

The biostratigraphic framework for the Montoya Group is provided by numerous workers utilizing a variety of fossil groups (Flower, 1958, 1961, 1964, 1969; Hill, 1959; Howe, 1959; Lemone, 1969; Sweet, 1979). These studies indicate the age of the Montoya Group is Franklinian (Late Middle Ordovician) to Cincinnatian (Late Ordovician) and that the Latest Ordovician (Hirnantian) is missing in this area (Figure 4). These studies and previous stratigraphic studies of the Montoya Group (Kelly and Silver, 1952; Pray, 1958; Howe, 1959; Pratt and Jones, 1961; Kottlowski, 1963) produced the gross regional lithostratigraphy (Fig. 4) that remains in use today.

The Montoya Group in southern New Mexico and westernmost Texas is subdivided into three distinct formations (Fig. 4) given in ascending order, Upham, Aleman and Cutter. All of these units are extensively dolomitized with limestone occurring locally only in the Upham and basal Aleman. The Upham Formation locally has a basal, thin (up to 16 m thick), calcareous-cemented sandstone (Cable Canyon Sandstone) that rests unconformably above the Early Ordovician El Paso Group. The Upham Formation typically is a light to dark colored, bioturbated wackestone to grainstone approximately 13-42 m thick. This unit has a gradational contact with the underlying sandstone or lies disconformably on the El Paso Group. The Aleman Formation (16-85 m thick) conformably overlies the Upham Formation and generally consists of a lower, intercalated dark brown-gray, thin-bedded carbonate and chert unit that grades up into nodular, cherty dolostone. The Cutter Formation (30-60 m thick), composed of light colored, fine-grained dolomite is the upper unit of the Montoya Group. A regional unconformity separates the Montoya Group from the overlying Silurian Fusselman Dolomite or younger units.

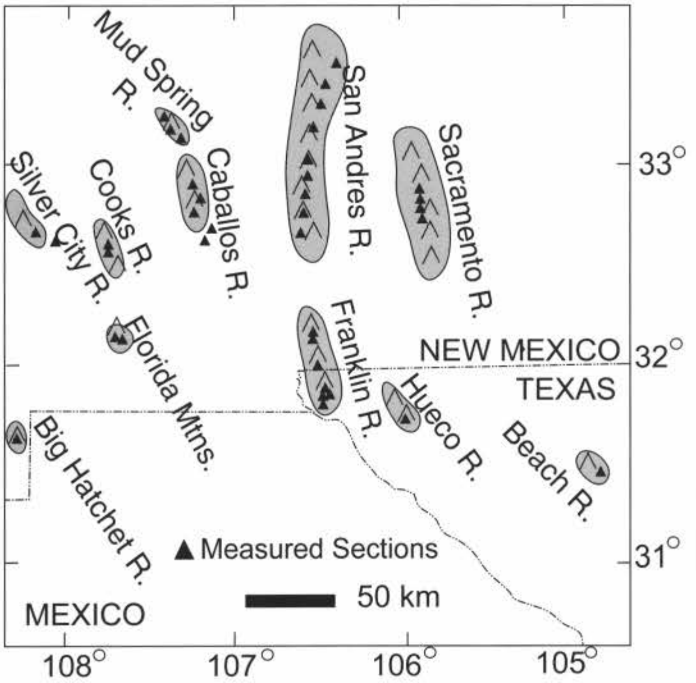

FIGURE 3. Location map showing mountain ranges (shaded gray) containing Montoya Group outcrops in southern New Mexico and western Texas.

FACIES ON THE MONTOYA RAMP

Cable Canyon Sandstone

This initial Montoya Group deposit occurs in the updip position as a carbonate-rich burrowed to cross-bedded coarse-grained sandstone or granule conglomerate. The thickness of the Cable Canyon Sandstone varies from > 15 m thick in the Cooks Range, thinning to less than 10 cm in the southern part of the field area. Burrows vary from complex, thick burrows to vertical *Skolithos* burrows up to 1.5 m deep and greater than 1.5 cm thick. These quartz sand-filled burrows obliterate much of the bedding in this unit. This unit contains abundant crinoid, gastropod, brachiopod and bryozoan fragments. The quartz sand is well-rounded and moderately to poorly sorted. Cross-bedded quartz sandstones have up to 2 m thick bedforms varying from large and small foresets to trough cross-beds that are oriented NW-SE (Bruno and Chafetz, 1988).

Interpretation: The Cable Canyon Sandstone was deposited as a sand-wave complex in an open-marine subtidal environment during the transgression over the Early Ordovician El Paso Group (Bruno and Chafetz, 1988). The well-rounded nature of the siliciclastics in this unit suggests these grains were previously deposited as sand dunes that were re-worked during the Montoya transgression. The source of the sand was likely exposed Precambrian basement and older Paleozoic siliciclastics to the north.

Upham Formation

Where the Cable Canyon Sandstone is thin or absent the basal unit of the Montoya Group is burrowed skeletal wackestone/packstone of the Upham Formation unconformably or disconformably overlying the Early Ordovician El Paso Group. The base of the Upham Formation commonly is rich in quartz sand, (up to 30%) but the sand commonly grades out within a few 10's of centimeters of the basal contact. The wackestone/packstone contains an abundant, diverse marine fauna including corals, crinoids, brachiopods, bryozoans, gastropods, especially *Maclurites*, receptaculitid algae and nautiloids (Howe, 1959, LeMone, 1988). Hardground surfaces commonly with less than 1 cm relief occur throughout this unit. The hardgrounds are locally coated with iron or phosphate and are not continuous making them difficult to trace more than a few 10's to 100's of meters laterally. Phosphate also occurs within the Upham Formation as a replacement of bryozoans and as small pellets. Occasional coarse-grained crinoidal grainstone beds occur within the Upham Formation. The uppermost unit of the Upham commonly is a crinoidal grainstone that generally is massive but does contain rare, preserved tangential cross-bedding.

Interpretation: The burrowed skeletal wackestone/packstone of the Upham Formation represents subtidal carbonate deposition on an open-marine carbonate ramp strongly influenced by warm waters. The crinoid grainstone in this unit represents formation of a high-energy crinoid shoals within a high-energy subtidal setting. Whether the shoals formed due to a lowering of sea level and progradation of the shoals or an increase in the effective depth of wave sweeping is currently unknown. The hardgrounds in this unit are marine cemented surfaces that formed subaqueously. The phosphate and iron coating these surfaces were deposited in anoxic conditions, likely during high-frequency sea level rises that formed during deposition of this unit. The phosphate was likely brought into this depositional setting by upwelling currents that transported phosphate-rich waters onto the shallow carbonate ramp.

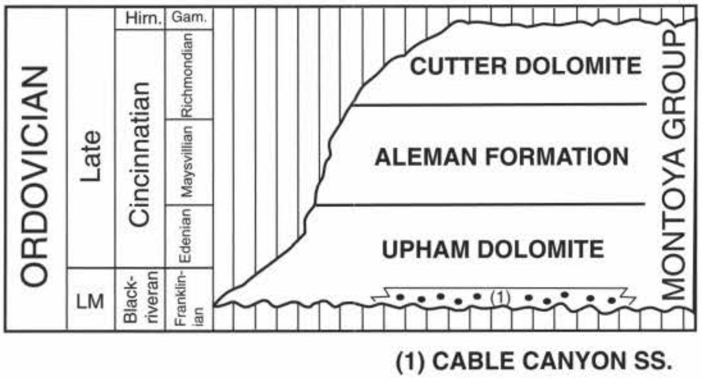

FIGURE 4. Biostratigraphic Chart for Montoya Group in southern New Mexico and western Texas. LM = Late Middle Ordovician; Hirn. =Hirnantian; Gam. = Gamachian.

Aleman Formation

The Aleman Formation is a complex subtidal carbonate unit containing abundant chert (up to 70% by volume). The chert abundance within the Aleman Formation is quite variable ranging from 0-70% with an average between 20-40%. The Aleman can commonly be subdivided into upper and lower cherty units that are separated by a widespread medial packstone/grainstone marker unit. The depositional environments represented by the Aleman Formation range from shallow, high-energy shoals to deep water settings, below storm wave base. The fossil assemblage in the Aleman is dominantly brachiopods, but gastropods and tentaculites also are common, and crinoids and bryozoans are rare.

Even-bedded laminated calcisiltite or mudstone and spiculitic chert

Even-bedded laminated calcisiltite and spiculitic chert is the basal unit of the Aleman Formation in the north-central part of the field area occurring primarily within an approximately E-W swath that includes the Cooks Range, Silver City, Nakaye Mountain, southern San Andres localities. The calcisiltite generally is horizontally laminated but locally shows small hummocky cross-lamination. The chert is composed almost entirely (>90%) of sponge spicules that were cemented by later silica, or less commonly carbonate. The spiculitic chert is interbedded with massive mudstone in the base of the lower part of the upper Aleman, above a regional, medial packstone/grainstone marker. The bedded chert commonly contains 1-5 % phosphate. Commonly the calcisilt interbedded with bedded chert contains up to 30% intermixed chert.

Interpretation: The even bedded calcisiltite or mudstone interbedded with spiculitic chert is interpreted to represent deposition in deep waters commonly below storm wave base. The calcisiltite and mudstone likely represent the background sedimentation on this ramp, whereas the spiculitic chert formed as the disarticulated sponge spicules moved downslope and accumulated. It is unclear what caused the alternation of carbonate and silica, it may be climatically or oceanographically induced. The abundance of spicules and lack of any other fauna suggests this facies formed in cool waters. The hummocky beds within this facies indicate that storm wave base did rarely impinge upon the seafloor during deposition of this facies.

Skeletal wackestone to packstone with irregular, discontinuous bedded to nodular chert

Skeletal wackestone to packstone containing irregular and discontinuously bedded chert up to a few meters wide and a few cm thick on outcrop grades laterally and vertically into skeletal wackestone/packstone with nodular bedded chert. This facies occurs within both the lower and upper Aleman. The abundance of chert in this facies varies from 5-60%. The chert nodules range from a few cm's to 10's of cm's in diameter. The chert margins vary from smooth to sharp and irregular. Some chert nodules contain carbonate within their centers giving them a "hollow" ball appearance. Primary laminations within the skeletal wackestone/packstone are rare but where they occur with the chert the laminations commonly are bent around the nodules. Phosphate occurs throughout this facies as pellets, coatings on hardgrounds and as a replacement of skeletal grains, most commonly bryozoans. Additionally there are many silicified burrows and fossils within the nodular cherty wackestone/packstone. Brachiopods are the main skeletal grains in this facies with lesser amounts of bryozoan and crinoid fragments. Analysis of the fossils in the Aleman Formation indicates it contains both life and death assemblages. The death assemblages occur in the wackestone/packstone interbedded with calcisiltite with broken fragments and fossil hash in graded beds. The life assemblages occur in the thicker beds of skeletal wackestone/ packstone and are marked by an abundance of articulated brachiopods.

Interpretation: These cherty carbonate facies formed on an open marine ramp in front of the grainstone shoal complex and above the interbedded calcisiltite or mudstone and spiculitic chert. The variety of chert abundance and morphologies reflects both original depositional features and subsequent early diagenetic silica enrichment. The abundance of brachiopods in this facies indicates the carbonates in this unit likely formed in cool waters. The lack of bedding and nodular appearance of chert suggests this facies was intensely bioturbated. Laminations surrounding chert nodules, preservation of burrows and unflattened skeletal fragments indicate much of the chert in this facies formed prior to burial and compaction.

Massive cherty breccia

Massive cherty breccia occurs rarely within the Aleman Formation. The massive cherty breccia varies from matrix- to clast-supported and is composed of angular to rounded fragments of chert, carbonate and cherty carbonate in a muddy matrix. These beds do not cross-cut bedding and appear to be lensoidal units 10's to 100's of meters wide and a few meters thick.

Interpretation: The massive cherty breccia formed early on the seafloor because it does not cross-cut bedding and it contains angular and rounded chert clasts. These breccias likely formed by gravitational instabilities such as downslope slumping, water escape or tectonic shaking.

Skeletal packstone/grainstone

Skeletal packstone/grainstone and colonial coral bafflestone including an open marine biota occurs basinward of burrowed mudstone or pertidal facies and as a widespread marker unit in the middle of the Aleman formation. Generally, this facies contains little chert, most commonly as a replacement of colonial corals. Crinoids, bryozoans, brachiopods and rugose corals are common within this facies. Low-angle tangential cross-bedding locally is common within this facies. Hardground surfaces are common within this facies and these commonly are encrusted by phosphate.

Interpretation: The skeletal packstone/grainstone and coral bafflestone is interpreted to represent a high-energy skeletal shoal or coral thicket. Widespread cross-bedding in this unit indicates high-energy currents during deposition of this unit. The abundance of corals in these facies indicates they were deposited in warm waters.

Cutter Formation

Skeletal packstone

The Cutter Formation contains occasional thin (< 5m thick), limy skeletal packstone beds. These packstone beds contain abundant bryozoans, brachiopods, and crinoids. Many of the packstone beds also contain interbedded carbonate mudstone.

Interpretation: Skeletal packstone beds within the Cutter Formation indicate an incursion of open marine conditions within this predominantly shallow subtidal or peritidal unit.

Burrowed mudstone

The majority of the Cutter Formation consists of brown, burrowed or massive mudstone. Gastropods and brachiopods are the only fauna in this facies. Rare thin beds of green-brown shale are locally interbedded with the burrowed mudstone in updip areas.

Interpretation: The burrowed mudstone is interpreted to represent shallow sudtidal deposition in a lagoon that formed landward of skeletal shoals. The bioturbation in this facies was produced by gastropods and brachiopods. Brown-green shale in this facies likely represents progradation of terrestrial siliciclastics during sea level falls.

Laminated mudstone and massive fenestral mudstone

Light-colored laminated mudstone and massive fenestral mudstone occur as thin units within the burrowed mudstone. The laminated mudstone contains abundant mudcracks, small burrows and rare intraclasts. Gastropods and ostracods are the only fauna in this facies. Massive fenestral mudstone occurs both interbedded with the laminated mudstone and as separate beds within the burrowed mudstone.

Interpretation: The laminations in this facies were likely produced by microbial mats and are referred to as cryptalgal laminites throughout the rest of this paper. The fenestrae in the mudstone formed as gas structures within shallow well oxygenated mudflats. The laminated mudstone formed on semi-arid tidal flats whereas the fenestral mudstone formed on more humid tidal flats (Grover and Read, 1977; Read and Grover, 1977). The tidal flats in the Cutter Formation suggest the climate fluctuated between warm and semi-arid to warm and humid during deposition of this unit.

SIGNIFICANCE OF CHERT IN MONTOYA GROUP

Petrographic analysis of over 300 Montoya Group thin sections reveals the variability of chert types in this unit. The contacts between chert and carbonate varies greatly from gradational to sharp. Much of the chert contains small euhedral dolomite crystals. The chert in the Montoya Group can be subdivided into 3 types: primary, early diagenetic and late diagenetic.

Primary Chert

Centimeter thick beds of chert interbedded with calcisiltite or mudstone and elongate discontinuous chert lenses in calcisiltite

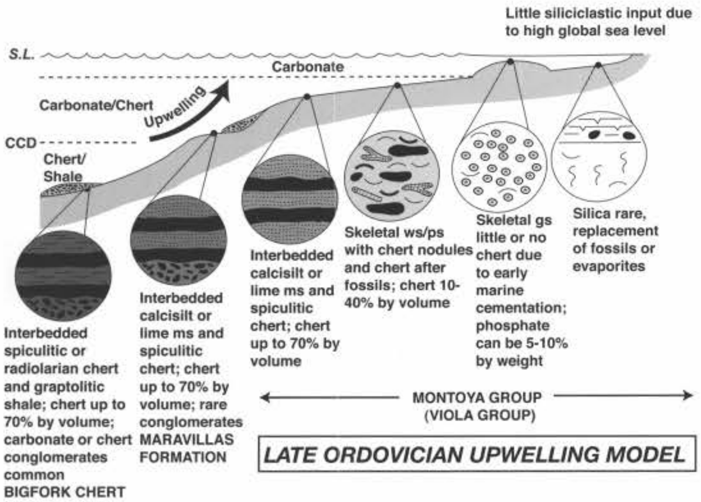

FIGURE 5. Proposed model for upwelling along the southern Laurentian margin during the Late Ordovician. As surface waters move away from the shoreline they are replaced from below by cooler, organic rich waters that allow abundant siliceous sponges to colonize the outer ramp. Upon death the sponges are disarticulated and their spicules accumulate to form the interbedded cherts and calcisiltite. Also, the silica in the sponges is readily available in solution during early diagenesis to precipitate as early-formed nodules. Farther up the ramp there is less silica available because there is less silica produced here and many of these rocks cement up early.

or mudstone are considered primary because petrography and etching of samples with hydrofluoric acid indicates they are composed almost entirely of sponge spicules. These chert beds formed from an accumulation of sponge spicules on the seafloor commonly below storm wave base. The abundance of sponge spicules and absence of any other fauna, save small brachiopods, indicates this facies formed in cool waters.

Early Diagenetic Chert

Almost all the nodular and irregular chert nodules in the Montoya Group are considered early diagenetic because laminations in the carbonate sediment bend around the chert. Also, the chert breccias contain rounded chert clasts, many articulated fossils and undeformed burrows are silicified suggesting the chert formed early on the sea floor prior to complete lithification.

Late Diagenetic Chert

Late diagenetic chert commonly occurs in three forms: 1) white to light gray nodules that cross-cut bedding and occur primarily in the tidal flat facies, these are interpreted to be a replacement of evaporite nodules; 2) gray to white nodules that cross-cut bedding including dark gray early diagenetic chert (e.g., Geeslin and Chafetz, 1982), these occur primarily updip and in the upper part of the Montoya Group and are also interpreted to be a replacement of evaporites; however, these evaporites likely formed much later following exposure of the Montoya carbonate platform; and 3) as elongate veins, or tabular beds that cross cut or are parallel to bedding.

The abundance of spiculitic chert, early diagenetic chert and phosphate (1-5% by weight) in the Montoya Group indicates it formed in an extensive upwelling zone (Fig. 5). The lack of a volcanic or continental source for the silica and phosphate suggests they were brought onto the shelf by upwelling of cool, deep oceanic waters. The presence of this upwelling zone hundreds of kms onto the continent over an 5-10 Ma period suggests that it likely formed in response to Late Ordovician glaciation. The development of this upwelling zone corresponds with a northward expansion of cool water trilobite faunas (Shaw, 1991) and a pronounced shift to cool water benthic faunas across eastern North America (Patzkowsky and Holland, 1993). Similarly, the abundance of silica-replaced fossils and bedded chert in the Late Ordovician (Kidder and Erwin, 2001) suggests there was a substantial paleoceanographic change to strong upwelling during this period.

Upwelling of cool oceanic waters onto eastern Laurentia occurred throughout the Late-Middle to Late Ordovician (Kolata et al., 2001; Pope and Read, 1998; Holland and Patzkowsky, 1997; Lavoie, 1997). The upwelling indicates vertical mixing in the upper few hundred meters over a very wide area (Parrish, 1982). This upwelling fits well with recent oceanographic computer modelling that indicates enhanced equatorial transfer of oceanic heat during the Ordovician glaciation (Poussart et al., 1999).

REGIONAL CORRELATIONS

The Montoya Group is regionally correlative with Late Middle to Late Ordovician cherty and phosphatic carbonates of the southern Midcontinent and Appalachian Basin (Fig. 6).

The Trenton Group (Late Middle Ordovician) and its equivalents (Galena Group, Lexington Limestone) in the Appalachian Basin and upper midcontinent are shallow-water carbonates that were deposited in cool phosphate-rich waters (Pope and Read,

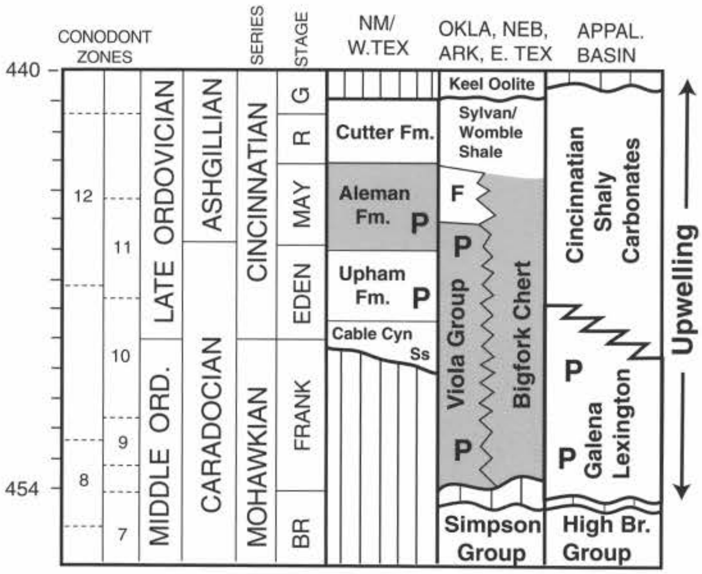

FIGURE 6. Stratigraphic chart showing the Montoya Group and its correlatives in the southern midcontinent and Appalachian Basin. The gray shading represents units with abundant chert. P represents a high abundance of phosphate in carbonate rocks. F= Fernvale Formation.

1997, 1998; Holland and Patzkowsky, 1997; Brookfield, 1988). These cool water carbonates are conformably overlain by Cincinnatian shaly carbonates (Holland, 1993; Pope and Read, 1997a, b; Holland and Patzkowsky, 1997).

The Late Middle to Late Ordovician Viola Group in eastern Texas, Oklahoma and Arkansas has two parts, a lower Trenton Group equivalent is overlain by a Cincinnatian part (O'Brien and Derby, 1997). The Viola Group consists of interbedded carbonate and chert deposited on a steep ramp that includes contourites and turbidites (Brown and Sentfle, 1997). The basal part of the Viola Group is particularly siliceous (up to 70% chert), including both biogenic (sponge spicules) and secondary silica (Galvin, 1983; Candelaria and Roux, 1997). Intra Viola Group karsting in Oklahoma formed prior to Richmondian (Sykes et al., 1997) and may be correlative to shallowing and progradation of a grainstone at the top of the Upham Formation or within the Aleman Formation. The top of Cincinnatian part of Viola Group is a crinoidal grainstone (equivalent to Fernvale or Welling formations) that is conformably overlain by Richmondian Sylvan Shale. Structural differentiation of basins and uplifts segmented the southern Oklahoma part of the Ouachita basin and produced distinctive lithologies in each area (Denison, 1997). The basins commonly are muddier and chert-rich, whereas the uplifts are grain rich, more dolomitized, and contain hardgrounds and karstic surfaces.

The Sylvan Shale overlies the top of the Viola Group and underlies the Latest Ordovician (Gamachian-Hirnantian) Keel Oolite. The Sylvan Shale records a single shallowing-upward trend of graptolitic black shale passing upward into unfossiliferous gray and green shale (Finney, 1988). The water depths of the Sylvan Shale are unknown, but this is not entirely a deepwater unit, rather it likely reflects muddying of the waters which poisoned the carbonate system shutting down the carbonate factory. This interpretation is compatible with a long term sea level drop that begins in the Cincinnatian and is marked by progradation of fine-grained siliciclastics to the west and south from the Appalachian Basin (Kolata et al., 2001).

The origination of these widespread and anomalously cherty and phosphatic carbonates in the Late Middle Ordovician indicates strong upwelling began during this period. The development of widespread upwelling zones commonly are indicative of glacially mixed oceans (Hay, 1988). Thus, the origination of this upwelling zone may reflect the initiation of Late Ordovician glaciation.

CONCLUSIONS

The Late Ordovician Montoya Group of southern New Mexico and western Texas formed a gently sloping carbonate ramp on a mature passive margin. This unit is dominated by subtidal facies whose abundant chert and phosphate content indicates these rocks formed in a long-lived upwelling zone. Regional correlation of this upwelling zone, its lateral extent and associated widespread change in biota suggests cool oceanic waters were bathing Laurentia throughout the Late Middle and Late Ordovician. The initiation of this widespread upwelling zone during the Late Middle Ordovician suggests glaciers had begun forming on Gondwana during this time.

ACKNOWLEDGMENTS

R.G. Myers, Range Geologist, U. S. Environmental Stewardship Division, is thanked for helping get the WSU group onto the White Sands Missile Range to measure sections. Dave LeMone provided some very helpful discussions concerning Montoya Group stratigraphy. Jessica Steffen has greatly helped the understanding of chert formation in the Aleman Formation. Dan Hunter, Bryn Clark, Steven Turpin and Luke LeMond are thanked for being very able field assistants. This paper was approved for public release by White Sands Missile Range; distribution unlimited. OPSEC review completed on August 19, 2002.

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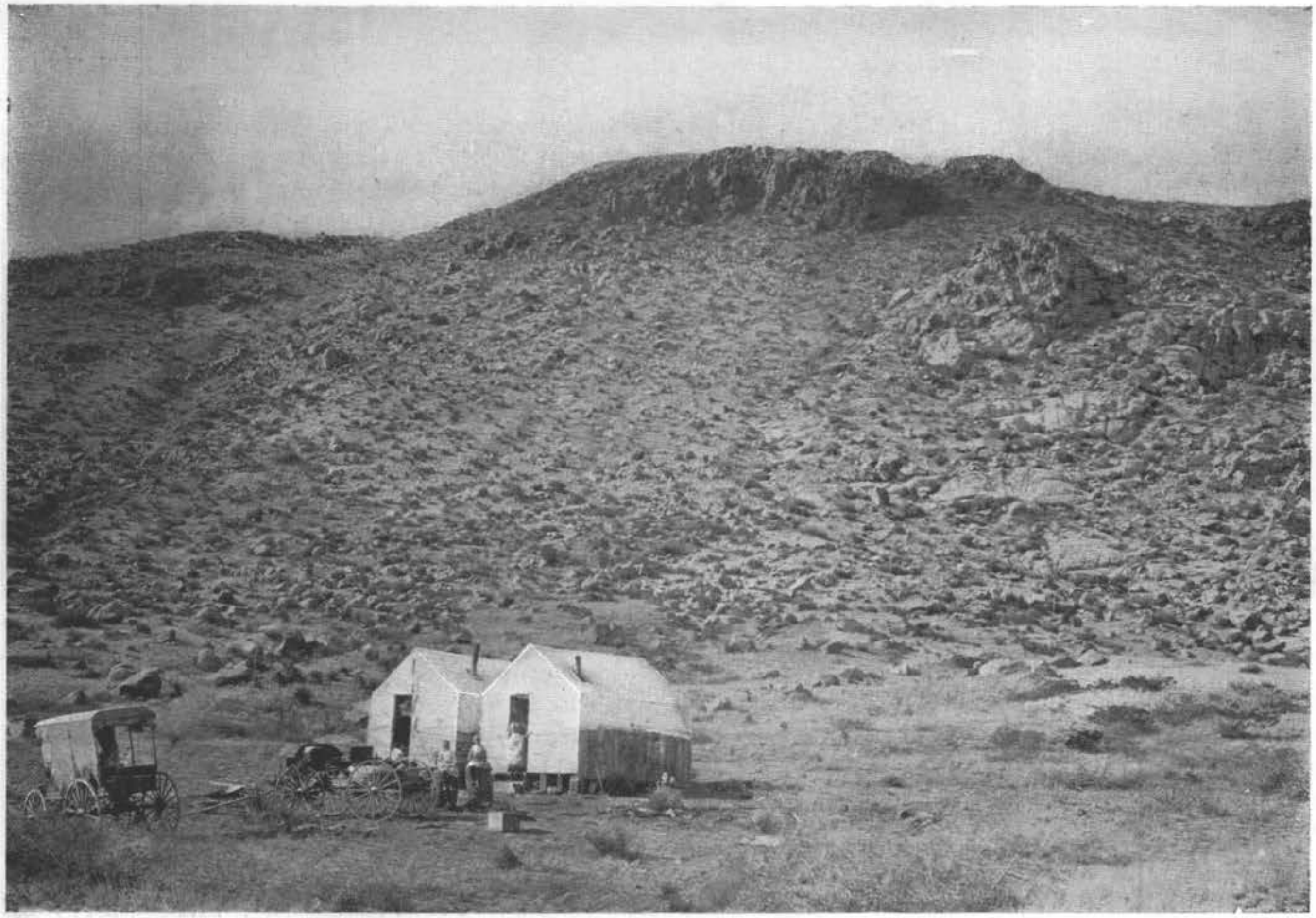

MINERS' CAMP NEAR "MOCKING BIRD" MINE

Miner's camp in Johnson Park, near the Mocking Bird Mine. Photo from the Dividend Mining & Milling prospectus (1905) – courtesy Robert W. Eveleth. The Mocking Bird Mine was advertised as one of the major copper ore producers for the Dividend Mining & Milling Company – so much for advertising!