Depositional environments and paleocurrents of Chinle Formation (Triassic), eastern San Juan Basin, New Mexico

Dennis D. Kurtz and John B. Anderson

New Mexico Geology, v. 2, n. 2 pp. 22-27, Print ISSN: 0196-948X, Online ISSN: 2837-6420.
https://doi.org/10.58799/NMG-v2n2.22

This page is intentionally left blank to maintain order of facing pages.

Hook, S. C., and Cobban, W. A., 1979, *Prionocyclus novimexicanus* (Marcou)—Common Upper Cretaceous guide fossil in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Annual Report 1977–78, p. 34–42, 5 figs.
———, 1980, Some guide fossils to the Upper Cretaceous Juana Lopez Member of the Mancos and Carlile Shales, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Annual Report 1978–79, p. 38–49, 7 figs.
Kauffman, E. G., 1977, Illustrated guide to biostratigraphically important Cretaceous macrofossils, Western Interior Basin, U.S.A.: The Mountain Geologist, v. 3 and 4, p. 225–274, 32 pls.
Kottlowski, F. E., 1965, Measuring stratigraphic sections: New York, Holt, Rinehart, and Winston, 253 p.
Lamb, G. M., 1968, Stratigraphy of the lower Mancos Shale in the San Juan Basin: Geological Society of America, Bull., v. 79, p. 827–854, 5 figs.
Lilly, O. J., 1952, The Doswell oil field, Rio Arriba County, New Mexico, *in* Geological Symposium of the Four Corners Region: Four Corners Geological Society, p. 99–103, 4 figs.
Molenaar, C. M., 1973, Sedimentary facies and correlation of the Gallup Sandstone and associated formations, northwestern New Mexico, *in* Cretaceous rocks of the southern Colorado Plateau, J. E. Fassett, ed.: Four Corners Geological Society, Mem., p. 85–110, 19 figs., 1 table
Newberry, J. S., 1861, Geological report, *in* Ives, J. C., Report upon the Colorado River of the west: U.S. 36th Congress, 1st session, Senate Executive Document and House Executive Document 90, pt. 3, 154 p.
———, 1876, Geological report, *in* Macomb, J. N., Report of the exploring expedition from Santa Fe, New Mexico, to the junction of the Grand and Green Rivers of the Great Colorado of the West in 1859: U.S. Army Engineer Department, p. 9–118, 11 pls.
Obradovich, J. D., and Cobban, W. A., 1975, A time-scale for the Late Cretaceous of the Western Interior of North America: Geological Association of Canada, Spec. Paper 13, p. 31–54, 3 figs.
Pearce, T. M., ed., 1965, New Mexico place names: Albuquerque, University of New Mexico Press, 187 p.
Rankin, C. H., 1944, Stratigraphy of the Colorado Group, Upper Cretaceous, in northern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 20, 27 p., 6 figs.
Thompson, G. G., 1972, Palynologic correlation and environmental analysis within the marine Mancos Shale of southwestern Colorado: Journal of Sedimentary Petrology, v. 42, p. 287–300 □

Depositional environments and paleocurrents of Chinle Formation (Triassic), eastern San Juan Basin, New Mexico

by Dennis D. Kurtz and John B. Anderson, Department of Geology, Rice University, Houston, TX

Strata of the Chinle Formation (Upper Triassic) crop out in the Nacimiento Mountains of Rio Arriba and Sandoval Counties on the eastern side of the San Juan Basin. The strata are exposed in the San Pedro–Nacimiento uplift, on the French Mesa–Archuleta arch, and in the Chama Basin (fig. 1). As elsewhere in the Southwest, the Chinle in north-central New Mexico was deposited under terrestrial conditions consisting of two cycles of fluvial-to-marshland or lacustrine sedimentation (Stewart and others, 1972). These cycles reflect the uplift and erosion of nearby highlands and can be used to decipher the effects of these uplifts on sedimentation.

Although the Chinle Formation has been mapped and studied principally to locate and assess sedimentary copper deposits near its base, relatively little work has been done concerning the details of its depositional history. In describing the lithostratigraphic sequence and the possible depositional history of the Chinle in north-central New Mexico, this report analyzes changes in sediment paleotransport directions between fluvial cycles and pebble lithologies to document changes in sediment source areas and dispersal patterns. These changes and concomitant changes in depositional energy form the basis for a discussion of the tectonic significance of the unit.

Methods

Paleocurrent measurements were taken from small (less than 4 cm), medium (4–15 cm), and large (more than 15 cm) crossbeds. Data were grouped according to the size of the crossbedding and were statistically analyzed using the von Mises distribution (Till, 1974). Though relatively few measurements were analyzed, each of these directions represents an average for a set of several tens of individual crossbeds. The mean vector directions are thus reasonable estimates of paleotransport direction and paleoslope.

Sediment texture was analyzed by settling tube. Thirty rock samples were disaggregated by dissolution of carbonate cement in hydrochloric acid or by pounding. This technique is suitable only for an approximation of mean grain size and particle-size distribution but is adequate for examining general textural trends within a given unit or gross changes between units. A sampling bias is present because only rocks with a calcareous cement were analyzed and because only the sand-sized fraction (0.0ϕ to 4.0ϕ) was used. This bias affects samples from the lowest unit, where only fine-grained beds have a calcareous cement, and from the uppermost member, where sandstone beds contain varying amounts of silt-sized material. Interpretations concerning the remainder of the formation, however, and those regarding overall textural trends are not significantly affected.

Unit descriptions

Wood and Northrop (1946) correlated Triassic strata in the Nacimiento Mountains with the Chinle Formation (Upper Triassic) in Arizona, named by Gregory (1917). The Chinle is the only representative of the Triassic in north-central New Mexico. Vertebrate remains (Reeside and others, 1957) and plant fossils (Daugherty, 1941) found in Chinle strata of the Nacimiento Mountains provide paleontologic evidence for Upper Triassic age.

The Chinle Formation in the eastern San Juan Basin has been divided into four lithostratigraphic units (Wood and Northrop, 1946), listed in ascending order: Agua Zarca Sandstone Member, Salitral Shale Tongue, Poleo Sandstone Lentil, and the upper shale member. In the present study the Poleo Sandstone Lentil is further divided into upper and lower portions.

The *Agua Zarca Sandstone Member,* first described by Wood and Northrop (1946), crops out in a northeast-southwest-trending belt, thickest (approximately 30 m) near San Miguel Canyon (fig. 2, section 1). Where present, it is a prominent ridge former. The Agua Zarca is thin or absent on the French Mesa–Archuleta arch and in the southeastern Chama Basin (fig. 3, sections 6, 7, 8). Erosional remnants of thick channels are present in the south-central Chama Basin.

The *Salitral Shale Tongue,* also first described by Wood and Northrop (1946), oc-

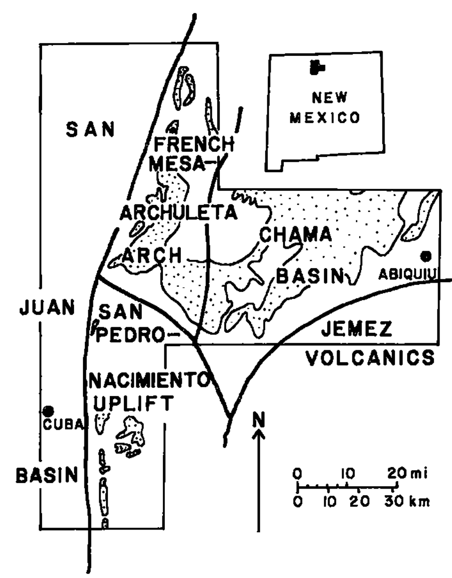


FIGURE 1—Location of eastern San Juan Basin–Chama Basin, showing major tectonic features. outcrops of Chinle Formation are delineated and stippled.

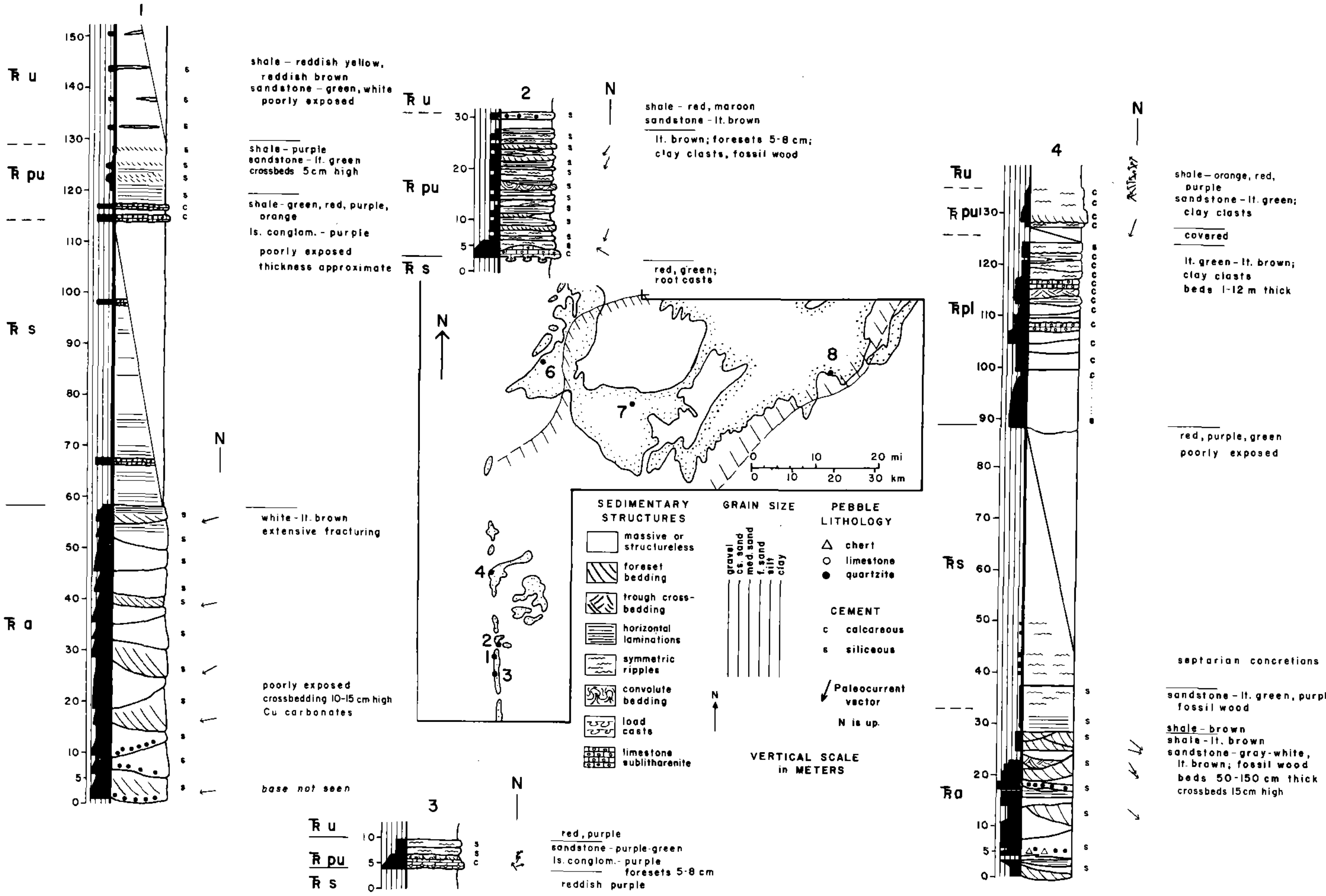


FIGURE 2—MEASURED STRATIGRAPHIC SECTIONS (1,2,3,4) AND SECTION LOCATIONS; hachured line on inset map indicates depositional boundaries of Salitral Shale Tongue.

curs throughout most of the Nacimiento Mountains but pinches out to the north and east along the lines shown in fig. 2. Southern and western depositional limits of this unit are unknown; maximum measured thickness is approximately 90 m.

Together, the Agua Zarca Sandstone Member and the Salitral Shale Tongue compose the lower fluvial-lacustrine sedimentary cycle. The Agua Zarca is in sharp erosional contact with the underlying Cutler Group (Permian). Locally, deep channels have been cut into these older rocks; on a regional scale, the contact is angular. The Agua Zarca directly overlies the Yeso Formation in the southern Nacimiento Mountains but rests on the older Abo Formation in the northern part of the range (Baars, 1962).

Typically, the Agua Zarca Sandstone consists of a discontinuous basal channel (0-5 m thick) overlain by a sequence of thinner (2-3 m) lenticular sandstone beds (fig. 2, section 1). Beds become less lensoid up section, where they are tabular and laterally extensive. Towards the top of the Agua Zarca, lenticular and tabular claystone units are interbedded with the sandstone (fig. 2, section 4). Claystones become more prominent upwards until, in the lower portion of the Salitral Shale Tongue, they become the dominant rock type, interbedded with discontinuous, very fine grained sandstones and siltstones. The remainder of the Salitral Shale consists of mottled red, maroon, and green bentonitic claystones and shales. The Agua Zarca–Salitral contact is thus transitional in most places; where the Agua Zarca is very thin, the contact is sharp, but it appears conformable in all sequences.

Coarse channel-fill conglomerates are present only in the lower portion of the Agua Zarca. These basal channel deposits crop out 25 km north of section 8 (fig. 3) and in the vicinity of sections 1 and 4 (fig. 2). The basal channel-fill unit probably extends between these two areas in a northeast-southwest-trending zone. Higher in the section gravelly zones occur at the base of some beds, but these too are most common in the lower part of the member. Individual beds are normally graded, and the unit as a whole fines upwards (fig. 2, section 1).

Sedimentary structures in the basal Agua Zarca include large-scale (greater than 50 cm) foresets and festoon bedding, convolute bedding, cut-and-fill structures, and flute casts. Horizontal bedding and 15-50 cm straight crossbeds in the tabular beds are more prevalent high in the section. Sandstones and siltstones of the Salitral Shale Tongue exhibit horizontal laminae and small-scale (2-3 cm) symmetric ripples. The remainder of the member contains no sedimentary structures, but plant-root casts are present, commonly preserved in place.

The *Poleo Sandstone,* first described by von Huene (1911), and redefined as a *lentil* by Wood and Northrop (1946), is recognized throughout the Nacimiento Mountains north of the Arroyo de los Piños (fig. 2, section 3). The unit is thickest (up to 90 m) on the French Mesa–Archuleta arch (fig. 3, section 6) and in the Chama Basin, where it is a prominent ridge former. The lower Poleo Sandstone extends north of Señorito Canyon (fig. 2, section 4); the upper Poleo Sandstone crops out north of Arroyo de los Piños. The Poleo Sandstone Lentil thins to the north (Lookingbill, 1953), but whether this change involves the upper or lower Poleo Sandstone or both is not known.

The *upper shale member,* defined as the uppermost member of the Chinle Formation in this area by Wood and Northrop (1946) and present throughout the field area, is by far the thickest member (up to 170 m). Because of the poor quality of exposures, the upper shale is also the most difficult to study. The present report is concerned principally with the lowermost portion of the upper shale member, near the Poleo–upper shale transition.

The upper and lower Poleo Sandstone and the upper shale member compose the upper sedimentary cycle. The basal contact of the

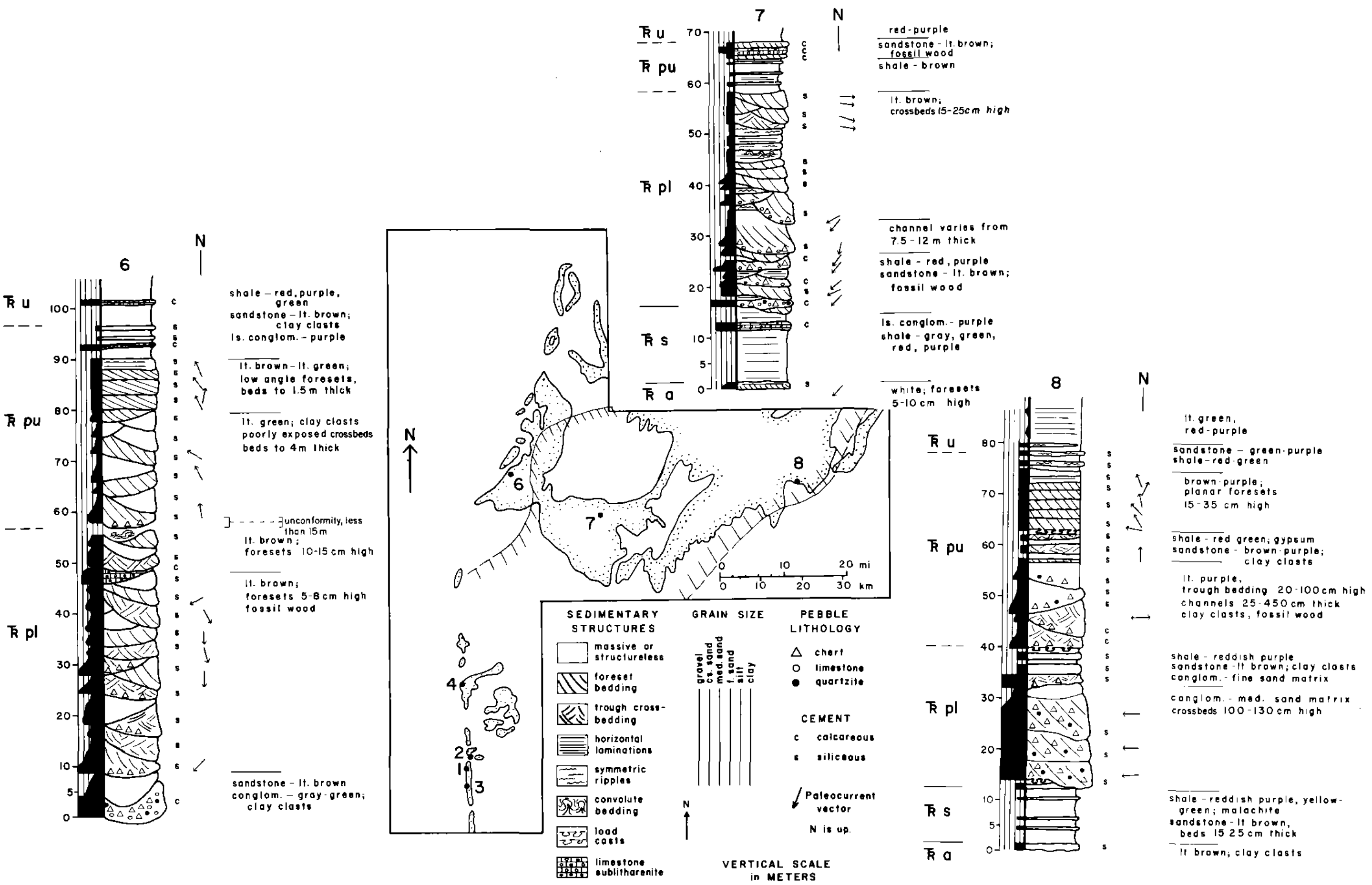


FIGURE 3—MEASURED STRATIGRAPHIC SECTIONS (6,7,8) AND SECTION LOCATIONS; hachured line on inset map indicates depositional boundaries of Salitral Shale Tongue.

Poleo Sandstone, whether with the Cutler Group (Permian) (fig. 3, section 6) or with the Salitral Shale Tongue (figs. 2 and 3, sections 1, 2, 3, 4, 7, 8), is typically sharp and erosional. In many localities the Salitral Shale Tongue contains a zone of light-green claystone at this contact. This claystone ranges in thickness from 2 to 40 cm and appears related to the erosional surface rather than to a particular depositional unit.

The lower Poleo Sandstone consists of a thick (up to 12 m), discontinuous conglomeratic channel sequence. The channel-fill conglomerates are coarsest and thickest in the Chama Basin (fig. 3, sections 7, 8). Finer grained basal channel-fill deposits crop out to the north and west at localities 4 and 6 (figs. 2 and 3). The basal channel is overlain by a 25-m to 30-m sequence of interbedded tabular or broadly lenticular sandstones (0.5–4.5 m thick) and red and purple claystone lenses (up to 30 m thick). A thin, laterally continuous claystone is present at the top of some lower Poleo Sandstone exposures (fig. 3, sections 7, 8). Load casts are present at the base of the overlying sandstones, and the contact between the upper and lower Poleo may be slightly unconformable. But the hiatus was not a lengthy one, and a transitional contact could exist between these units in some places.

The upper Poleo is characterized by interbedded tabular sandstones and siltstone or claystone beds and lenses. Sandstone beds range in thickness from 0.1 to 2.5 m. Lenticular channels are few or absent. Calcareous sublitharenite beds crop out near the top of the upper Poleo. These pellet limestones consist of coarse, sand-sized, limestone lithic fragments cemented by a muddy calcareous cement. The calcareous sublitharenites are interbedded with fine-grained sandstones, siltstones, and claystones. A transitional contact exists between the upper Poleo Sandstone and the upper shale member. The basal upper shale consists primarily of red, green, purple, and maroon claystones and shales, with interbedded very fine grained sandstones and siltstones.

Coarse conglomeratic sandstones occur only in the basal lower Poleo. Higher in the section pebbles occur in zones at the base of some beds, but even these basal gravelly layers are rare in the upper Poleo.

Many beds in the lower Poleo are massive, but contain planar foresets, horizontal bedding, cut-and-fill structures, and convolute bedding. Large channels contain festoon crossbedding. Individual beds may be normally graded; contacts between beds are sharp, and flute casts occur in places. Most sandstone beds in the upper Poleo exhibit 30–40 cm planar foresets or are massive. Thin, fine-grained beds may have small-scale (2–3 cm) ripple crossbedding. As a rule, individual beds are normally graded. Sedimentary structures are not preserved in the claystones and shales of the upper shale member, but small-scale (2–3 cm) ripple cross-lamination and horizontal laminae are preserved in the siltstones and sandstones.

Sandstone texture and pebble lithology

Sandstones in the Chinle Formation contain material ranging in size from pebbles to silt. Individual beds commonly exhibit grading from coarse sand to very fine sand-sized particles. Figs. 2, 3, and 4 summarize both field and laboratory sediment-size data. The Chinle as a whole fines upwards (fig. 4), with coarse pebble conglomerates to medium-grained sandstones characterizing the Agua Zarca Sandstone, medium to very fine sandstone typifying the Poleo Sandstones, and very fine grained sandstone and siltstone occurring in the basal upper shale member. Both the Agua Zarca and the upper and lower Poleo grade into overlying units, and sediment size decreases upwards in each of these units (figs. 2 and 3). Also, average sediment size decreases towards the southwest in the lower Poleo. The upper Poleo is finer grained than the lower sandstone. This is most evident in the sand-sized fraction (fig. 4). In addition, siltstone and claystone beds are more common and pebbly coarse-grained sandstones less common in the upper Poleo than in the lower Poleo (fig. 3, sections 7, 8).

Sand-sized material is subangular to subrounded. Resistant quartz or quartzite pebbles are well rounded, and less-resistant chert and limestone clasts are subrounded to angular. No lateral or vertical trends in particle roundness were found in either fraction.

Mineralogy of the sand-sized material is of little use in provenance studies because quartz and micas compose approximately 98 percent of this fraction. The remainder of the grains are orthoclase, feldspar, magnetite or ilmenite and assorted rock fragments. Pebble lithologies vary dramatically between the Agua Zarca and the lower Poleo (table 1). Quartz and quartzite are most abundant in the older member; chert is the most common pebble type in conglomerates of the lower Poleo. A few limestone clasts occur in this unit. Indurated pebbles are rare in the upper Poleo; most clasts are clay shards or other locally derived material.

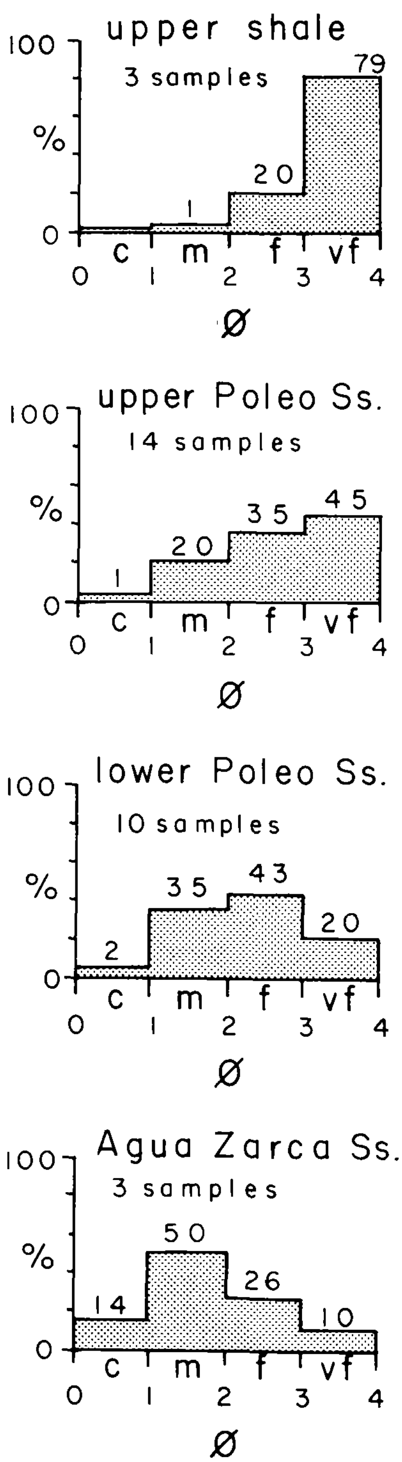


FIGURE 4—SUMMARY HISTOGRAMS OF 0.0ϕ TO 4.0ϕ FRACTION FOR EACH SANDY UNIT; number of samples analyzed per unit and precise percentages per one-phi interval are noted.

Paleotransport directions

Paleotransport indicators are numerous in both the Agua Zarca and Poleo Members. Sediment transport in the lower fluvial cycle was generally south-southwest (fig. 5); the mean vector direction for all Agua Zarca measurements is S. 41° W. with an angular standard deviation of ±33°. The variability shown in fig. 5 is probably caused by channel sinuousity because measurements from the same area exhibit little variability, whereas those from different locales may show different trends. Paleocurrent measurements near section 4, for instance, are consistently towards the southeast, while in most other localities they are to the southwest.

Sedimentary structures indicate that the upper fluvial cycle began with southwestward sediment transport in the lower Poleo Sandstone (fig. 5). The mean paleoslope direction for the unit is S. 22° W. ±45°. Paleotransport variability in the lower Poleo was caused by temporal fluctuations in channel orientation as well as in stream sinuousity. The paleoslope shifted gradually until it sloped to the northwest during upper Poleo deposition (fig. 5). The mean sediment paleotransport direction for the upper Poleo is N. 10° W. with an angular standard deviation of ±41°. Small-scale crossbeds in the upper shale member indicate westward transport, and this westward paleoslope may have persisted until the end of the Triassic.

TABLE 1—RELATIVE AMOUNTS OF QUARTZ, QUARTZITE, AND CHERT IN UPPER TRIASSIC CHINLE CONGLOMERATE. Percentages calculated from the number of unbroken clasts larger than 4 mm from disaggregated samples. Original samples had volumes of approximately 3,000 cu cm each.

Unit	Sample location	Percentage		
		Quartz	Quartzite	Chert
Agua Zarca Sandstone	Arroyo del Cobre	42.5	57	.5
Lower Poleo Sandstone	French Mesa	33	6	61
Lower Poleo Sandstone	Abiquiu Dam	20	7	73

Discussion

The Upper Triassic sandstones in north-central New Mexico represent the last clastic pulses associated with uplift in the southern ancestral Rocky Mountains. They not only document the episodes of uplift, but also record the decreasing magnitude of these uplifts and their waning influence on sedimentation patterns.

Southwestern paleocurrent directions in the Agua Zarca and the lower Poleo Sandstones indicate uplift to the northeast. Quartzite clasts in these members were probably derived from Ortega Quartzite (Precambrian) that crops out 90 km northeast in the Brazos uplift (Muehlberger, 1967). This uplift exposes rocks that were part of the late Paleozoic–early Mesozoic southern ancestral Rockies. Triassic sandstones pinch out in that region and all members of the Chinle Formation thin in that direction (Muehlberger and others, 1960).

Both paleotransport directions and source terranes changed prior to deposition of the upper Poleo Sandstone. The paleoslope shifted

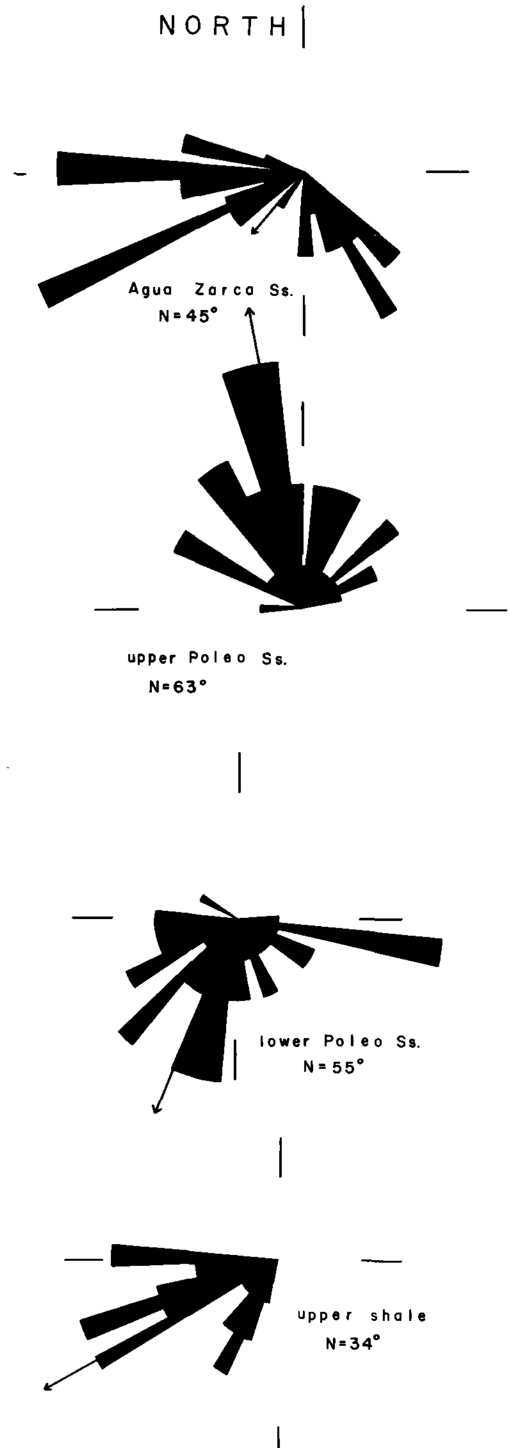


FIGURE 5—PALEOCURRENT ROSETTES AND TOTAL MEAN PALEOCURRENT VECTOR DIRECTIONS FOR FLUVIAL PORTION; arrows denote current vector direction.

to the northwest, and chert and limestone clasts were eroded from a sedimentary source area—probably from Paleozoic sediments exposed on the Pedernal high (Smith, 1961) or perhaps from as far as Texas. Calcareous sublitharenites were probably locally derived. The upland area being eroded was large, and the relief associated with the relatively localized southern ancestral Rockies did not have a major influence on sediment dispersal patterns. That clastic sediments of the Poleo Sandstone were deposited over a wider area than those of the Agua Zarca Sandstone also indicates a more widespread drainage basin for the younger units.

Tectonism caused initiation of the fluvial cycle. Erosive lower contacts, large basal channels, relatively coarse grain size, and medium- to large-scale sedimentary structures all attest to high-energy deposition on a steepening paleoslope. Paleoclimatic changes associated with the uplift exerted negligible influence upon sedimentation. Triassic uplifts were of lesser magnitude than their Permian predecessors, which shed coarse sediments over a wide area and formed thick clastic sequences. Triassic units are more localized and finer grained. Within the Upper Triassic sequence, the younger uplift, which initiated deposition of the lower Poleo Sandstone, was apparently less dramatic than the older uplift. Sediments in the Agua Zarca are coarse, and sedimentary structures are larger than those in the lower Poleo of the same area. Both units, however, were derived from the same region. Large channels and coarse-grained deposits occur in the lower Poleo only in the Chama Basin, 40 km nearer the uplift than similar deposits in the Agua Zarca. The regional angular unconformity beneath the Agua Zarca, when contrasted with the erosional, slightly discordant lower Poleo contact, also indicates greater uplift prior to deposition of the older unit.

Fining-upward trends in sandstone units and decreasing size of sedimentary structures upwards indicate that fluvial energy diminished on a decreasing paleoslope as highlands were eroded. Numerous large channels, cut-and-fill structures, and large-scale festoon bedding in the Agua Zarca suggest that deposition occurred via high-energy braided streams. With time, fluvial energy decreased somewhat, and thinner, more tabular beds were deposited. Channels and festoon bedding in the lower Poleo indicate that initially it too was deposited by high-energy braided streams. Much of the Poleo Lentil, however, consists of tabular beds with planar foresets. These and associated siltstones and claystones resemble deposits (described by Cant and Walker, 1978) from the low-energy, sandy, braided Southern Saskatchewan River.

A transgression of the Salitral Shale lake terminated deposition of the Agua Zarca Sandstone; but no analogous transgression took place during Poleo time, and the paleoslope diminished until a widespread marshland formed. The shales and fine-grained sandstones of the upper shale member were deposited in swamps and sluggish streams on this lowland.

Regional paleocurrent directions throughout the Southwest during the Upper Triassic were influenced primarily by the location and trend of the Ouachita–Marathon highland. Sediment dispersal was generally towards the northwest (Poole, 1961; Asquith and Cramer, 1975). Evidence for a continually decreasing paleoslope during Poleo deposition thus suggests that the shift in sediment-transport directions from southwest to northwest was a passive response to erosion of local highlands in the southern ancestral Rocky Mountains. Southwesterly paleotransport in north-central New Mexico was caused and maintained only by the presence of these nearby highlands. Were active local tectonism responsible for the shift in paleotransport directions, an influx of coarse clastics would be evident at the base of the upper Poleo Sandstone. No such influx occurred, and stream energy continued to decrease even while the paleoslope was shifting.

Coarse-grained fluvial sediments were deposited on the flanks of the uplift, but lateral facies relationships (fig. 6) for this area indicate that fine-grained sediments were deposited in lacustrine or paludal environments throughout the Upper Triassic. Low-energy deposition occurred in shallow sedimentary basins between uplifts. Isopach maps (Stewart and others, 1972) indicate that one such basin occupied a portion of the modern San Juan Basin. The presence of such basins probably reflects their intermontane position more than it does active basin development.

Deposition of the upper shale member was caused by formation of a broad, flat lowland as the highland was eroded. This unit is the final stage in the regional late Paleozoic–early Mesozoic cycles of uplift and erosion. Origin of the Salitral Shale Tongue, however, is problematical. Although its extent is unknown, a large Salitral lake could have existed for much of the Upper Triassic. The unit is 70 m thick in its westernmost outcrops, and a thick section of Upper Triassic shale has been drilled in the San Juan Basin (Stewart and others, 1972). The Salitral Shale Tongue represents a transgression of this lake, but why this transgression occurred is unclear. The event could reflect a paleoclimatic change that caused a widespread rise in base level. If so, regional correlations might be possible with contemporary units. Paleomagnetic stratigraphy could prove useful in this regard, especially with the scarcity of fossils in the area; but to date such studies have not been made.

ACKNOWLEDGMENTS—This paper is condensed from an M.S. thesis (Kurtz, 1978) that was supported by grants from the New Mexico Bureau of Mines and Mineral Resources and the American Association of Petroleum Geologists.

References

Asquith, G. B., and Cramer, S. L., 1975, Transverse braid bars in the Upper Triassic Trujillo Sandstone of the Texas Panhandle: Journal of Geology, v. 83, p. 657–661

Baars, D. L., 1962, Permian system of Colorado Plateau: American Association of Petroleum Geologists, Bull., v. 46, p. 149–218

Cant, D. J., and Walker, R. G., 1978, Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada: Sedimentology, v. 25, p. 625–648

Daugherty, L. H., 1941, The Upper Triassic flora of Arizona with a discussion of its geologic occurrence by H. R. Stagner: Carnegie Institute of Washington, Pub. 526, 108 p.

Gregory, H. E., 1917, Geology of the Navajo country: A reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geological Survey, Prof. Paper 93, 161 p.

Huene, F., von, 1911, Kurze Mitteilung uber Perm, Trias und Jura in New Mexico: Neues Jahrbuch fur Mineralogic, Geologic, Paleontology, Beilage-Band, 33 p.

Kurtz, D. D., 1978, Sedimentology and stratigraphy of the Triassic Chinle Formation, eastern San Juan Basin, New Mexico: M.S. thesis, Rice University, 177 p.

Lookingbill, J. C., 1953, Stratigraphy and structure of the Gallina uplift, Rio Arriba County, New Mexico: M.S. thesis, University of New Mexico, 118 p.

Muehlberger, W. R., 1967, Geology of Chama quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 89, 114 p.

Muehlberger, W. R., Adams, G. E., Longgood, T. E., Jr., and St. Johns, B. E., 1960, Stratigraphy of the Chama quadrangle—northern Rio Arriba County, New Mexico: New Mexico Geological Society, Guidebook 11th field conference, p. 93–102

Poole, F. G., 1961, Stream directions in Triassic rocks of the Colorado Plateau: U.S. Geological Survey, Prof. Paper 424-C, p. 139–141

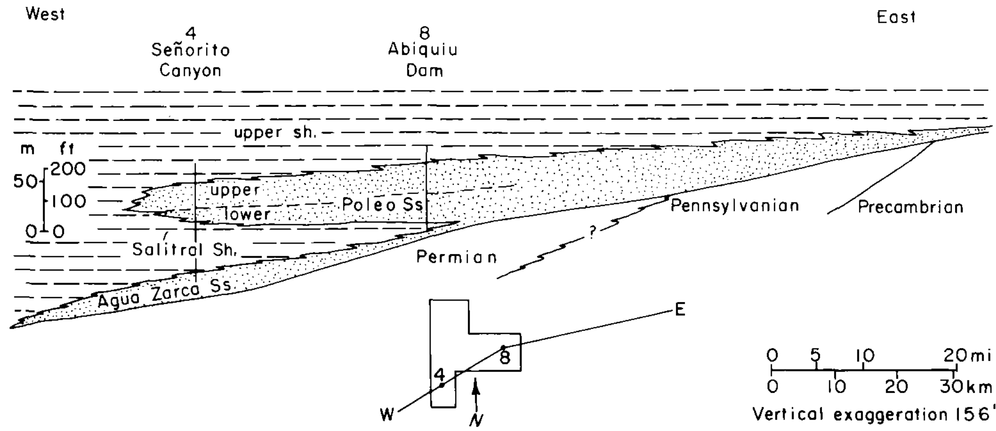


FIGURE 6—EAST-WEST CROSS SECTION THROUGH CHINLE illustrating relationships between fluvial sandstones and paludal-lacustrine shales. Sandstones are stippled, shales dashed.

Reeside, J. B., Jr., Applin, P.L., Colbert, E. H., Gregory, H. D., Haldey, H. D., Kummel, B., Lewis, P. J., Love J. D., Maldonado, M., Sanders, J., Silberling, N. J., and Waage, K., 1957, Correlation of the Triassic formations of North America exclusive of Canada: Geological Society of America, Bull., v. 68, p. 1451–1514

Smith, C. T., 1961, Triassic and Jurassic rocks of the Albuquerque area: New Mexico Geological Society, Guidebook 12th field conference, p. 121–128

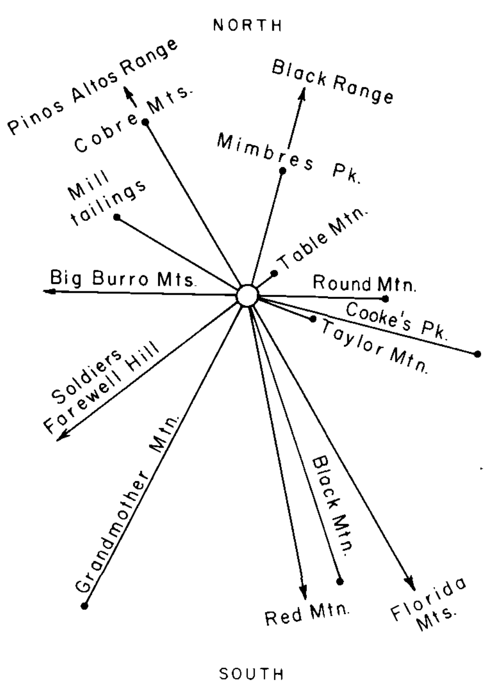
Stewart, J. H., Poole, F. G., and Wilson, R. F., 1972, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey, Prof. Paper 690, 336 p.

Till, R., 1974, Statistical methods for the earth scientist (An introduction): New York, John Wiley and Sons, 154 p.

Wood, G. H., and Northrop, S. A., 1946, Geology of the Nacimiento and San Pedro Mountains and adjacent plateaus in parts of Sandoval and Rio Arriba Counties, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Map, OM-57 □

Correction

In the February 1980 issue of *New Mexico Geology,* the panoramic diagram to accompany the City of Rocks article was omitted. That diagram is printed below.



Call for papers

The Rocky Mountain Section of the American Association of Petroleum Geologists will meet in Albuquerque April 12-15, 1981, at the Hilton Inn. Thomas E. Kelley of Geohydrology Associates, Inc., is General Chairman of the conference. Papers on Rocky Mountain regions are welcome; contact Lee Woodward, University of New Mexico, or Frank Kottlowski, New Mexico Bureau of Mines and Mineral Resources, Program Chairman, at your earliest convenience. □

Proterozoic tectonic setting in New Mexico

by Kent C. Condie, Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, NM

Geological features

Recent detailed mapping of Proterozoic terranes in New Mexico has enhanced our understanding of stratigraphy and tectonic setting. Chief areas of investigation (fig. 1) are Precambrian exposures in the south and south-central part of the state (Condie and Budding, 1979) and the Sangre de Cristo Mountains in the northern part of the state (Robertson and Moench, 1979; Barrett and Kirschner, 1979; Woodward and others, 1979; Nielsen and Scott, 1979; Condie, 1979).

Diagrammatic cross sections for the Proterozoic rocks in the Manzano and Ladron Mountains in central New Mexico are shown in fig. 2. The Manzano succession is characterized by a lower sequence of mixed arkose, quartzite, and subgraywacke, whose base is not exposed. This sequence is unconformably overlain by a thick succession of shales (now phyllites) with quartzite and arkose beds. The youngest rocks are bimodal volcanics whose felsic component dominates. The entire succession is folded into an overturned syncline and intruded with syntectonic to posttectonic granitic rocks. Unlike the Manzano succession, the Ladron succession is characterized by a lower bimodal volcanic sequence whose base is also concealed (Condie, 1976b). These volcanics are gently folded and intruded by the posttectonic Capirote granite. Unconformably overlying the granite is a succession of arkoses, quartzites, and conglomerates with minor shale and bimodal volcanics. This sequence is gently folded and cut by faults, and the entire Ladron succession (including the Capirote granite) is intruded by the posttectonic Ladron quartz monzonite.

Other supracrustal successions in New Mexico and southeastern Arizona show similar rock types and relationships to granites. All are characterized by bimodal volcanics with an absence or sparsity of volcanic or plutonic rocks of intermediate composition. Deformational features reflect chiefly vertical forces. Ophiolites, mélanges, blueschists, graywackes, and deep-sea sediments are absent.

Primary structures in the form of crossbedding, various sole markings, and ripple marks preserved in some of the clastic sediments are being investigated. Festoon crossbedding dominates in the arkoses and conglomerates; planar crossbedding dominates in the pure quartzites. Existing data seem to favor a nearshore, perhaps partly fluvial, environment of sedimentation for the coarse clastic sediments, with the shales being deposited in deeper, quiescent basins. Provenance studies (Condie and Budding, 1979) indicate source areas composed chiefly of high-K granites and reworked supracrustal rocks. No evidence exists for an older tonalitic source.

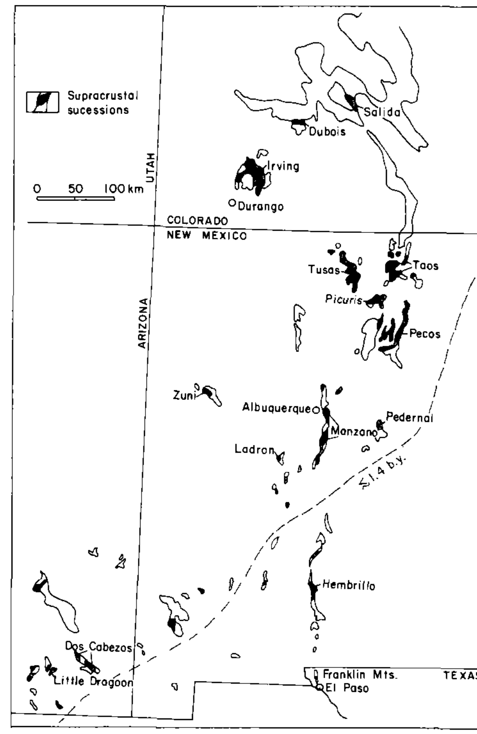


FIGURE 1—Distribution of Proterozoic rocks in New Mexico, southern Colorado, and southeastern Arizona.

Geochemical and Sr isotope studies

Geochemical studies of mafic and felsic volcanics and of granitic rocks have been important in determining magma origin and source composition (Condie, 1978a, b; Condie and Budding, 1979). Mafic volcanic rocks are tholeiites that range from depleted to undepleted in light REE (rare-earth elements). Geochemical model studies indicate that these rocks can be produced by 20–40 percent partial melting of a lherzolite source in the mantle followed by up to 30 percent olivine crystallization. REE distributions do not allow residual garnet, amphibole, or plagioclase in the source. Tholeiites depleted in REE occur only in the Pecos and Tijeras greenstones in central and northern New Mexico. Model studies indicate that these rocks were derived from depleted mantle sources similar to the sources of modern mid-ocean-ridge tholeiites. The absence of ophiolites in the supracrustal successions suggests that, although depleted mantle was tapped, oceanic crust was not formed.

Geochemical model studies of felsic volcanics and granitic rocks indicate an origin by partial melting of lower crustal rocks (granulite facies) for granodiorites and rhyodacites (Condie, 1978b). The high-K granites and rhyolites seem to have a similar origin fol-