

Revised basin geometry for the Bursum Formation (upper Virgilian-lower Wolfcampian), central New Mexico

Steven M. Cather

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New Mexico Bureau of Geology & Mineral Resources
New Mexico Institute of Mining & Technology
801 Leroy Place
Socorro, NM 87801-4796

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Figure 2. Interbedded fluvial sandstone and marine limestone in the lower part of the Bursum Formation. Hammer rests on arkosic pebbly fluvial sandstone, which is overlain by a transgressive succession of ~1.5 m of gray marine? siltstone and ~0.3 m of gray marine limestone (upper ledge). View is toward the east from 13S 0336949E, 3760462N, ~1.3 km north of the Cerro del Viboro measured section of Krainer and Lucas (2009), San Antonio quadrangle. All UTM data are NAD 1927.



Figure 3. Shallow paleovalley or paleochannel fills containing arkosic, pebbly sandstone in lower part of Bursum Formation. The channel deposit in the foreground (with hammer for scale) is about 0.5 m thick and 2 m wide. Larger valley-fill above and to the right (above gray bushes) is about 1.5 m thick and 10 m wide. Generally, paleovalley fills in the Bursum are thicker and wider than these, but are more difficult to photograph. View is toward the east (subparallel to the paleoflow direction) from near 13S 0337000E, 3760410N, ~1.3 km north of the Cerro del Viboro measured section of Krainer and Lucas (2009), San Antonio quadrangle.

Lucas and Krainer (2004) and Krainer and Lucas (2009, 2013) subdivided the Bursum laterally into four members (Oso Ridge, Bruton, Red Tanks and Laborcita members; note that the last three have at times been considered formation-rank terms). Not strictly lithostratigraphic in nature, these members are based on the ratio of marine to continental beds, overall thickness, and grain size. The range of lithologic characteristics for individual members has not been defined quantitatively, and member names have not been applied in a systematic fashion. For example, the Bursum strata of the Tinajas Arroyo measured section of Krainer and Lucas (2009) were classified as the Bruton Member (i.e., containing >50% marine strata; Lucas and Krainer, 2004, p. 44), despite only containing ~38% marine beds by their own estimation. The Bursum Formation is not subdivided in the present study.

The age of the Bursum Formation in central New Mexico, determined mostly from fossils within marine limestones, ranges from late Virgilian to early Wolfcampian (Krainer and Lucas, 2013). The Bursum Formation is regionally somewhat time-transgressive (Lucas and Krainer, 2004; Krainer and Lucas, 2009, 2013), and the contact between the Bursum and the overlying Abo Formation approximates the Pennsylvanian–Permian boundary as construed by Davydov et al. (1998; see summary in Lucas et al., 2016). Within the study area, age constraints are sparse. In the northern part of the study area near Cibola Spring, Allen et al. (2013) reported late Virgilian? fusulinids (*Triticites*) in the lower part of the Bursum and early Wolfcampian fusulinids (*Schwagerina* and *Triticites*) in its middle part. Also from the lower and middle Bursum near Cibola Spring, Kottlowski and Stewart (1970; their Palo Duro Canyon section in sec. 13, T1S, R2E, projected) reported *Schwagerina emaciata*, *S. jewetti*, *S. grandensis*, *S. cf. pinosensis*, *Stewartina* spp., *Triticites hugensis*, *T. ventricosus*, *T. n. sp.*, and *Oketaella?* The Wolfcampian fusulinid *Triticites creekensis* was collected by Maulsby (1981) in the central part of the study area. In a study spanning Bursum outcrops throughout the Quebradas area, Altares (1990) reported the Wolfcampian fusulinids *Schwagerina pinosensis*, *Triticites* aff. *T. creekensis*, *T. cf. Triticites directus*, and *Leptotriticites sp.* Except for *S. pinosensis*, all were collected within 10 m of the base of the Bursum Formation.

The Bursum Formation unconformably overlies the Virgilian Moya Member of the Atrasado Formation throughout most the study area (Krainer and Lucas, 2009). The associated lacuna appears to encompass part or all of late Virgilian time, representing perhaps a few million years or less. The late Virgilian was a time of eustatic sea-level fall (e.g., Montañez and Poulsen, 2013, their fig. 2g), which may partly account for the sub-Bursum unconformity. Eustatic effects, however, are difficult to prove, particularly given the clear evidence in New Mexico for tectonism at this time. For example, north of the study area along the western flank of Pennsylvanian Joyita Uplift, the Bursum laps across tilted and beveled rocks of Missourian, Desmoinesian, Atokan, and Proterozoic age (Kottlowski and Stewart, 1970). This angular unconformity must be, at least in part, tectonic in origin. To the south, the Bursum Formation in the study area is defined by the first occurrence of reddish continental deposits above the marine Moya Member of the Atrasado Formation. This contact is typically

sharp and unconformable. The unconformity at the base of the Bursum Formation represents perhaps the only substantial regional lacuna during Pennsylvanian–Permian sedimentation in the study area.

The nature of the upper contact of the Bursum Formation in the Quebradas region varies locally. I have seen evidence for both disconformable and conformable contacts with the overlying Abo Formation, as did Colpitts (1986) and Altares (1990). Other workers have interpreted the upper contact with the Abo to be gradational (Rejas, 1965; Kottlowski and Stewart, 1970; Arendt, 1971; Maulsby, 1981). In particular, there is no evidence within the six-quadrangle map area for significant soil development or deep ravinement beneath the Abo Formation, which suggests the Bursum–Abo contact represents at most a short lacuna.

In contrast, Krainer and Lucas (2009) interpreted the Bursum–Abo contact to be everywhere unconformable in the Quebradas region. This interpretation is based on their anomalously thick measured section at Gallina Well, which contains six unconformity-bounded depositional sequences. To explain the fewer sequences (three or less) present in their other, thinner measured sections, Krainer and Lucas (2009) invoked the effects of deep pre-Abo erosion. The Gallina Well section, however, may be fault-repeated (see below). Even if it is not, the increased number of depositional cycles in the Gallina Well section may simply reflect increased syndepositional subsidence relative to adjacent areas, rather than pre-Abo erosion. During my mapping of this region, I saw no evidence for more than a few meters of stratigraphic relief on the Bursum–Abo contact.

Ideally, the upper contact of the Bursum Formation is placed at the top of the stratigraphically highest marine limestone or mudstone beneath the Abo. In practice, however, the top of the Bursum is commonly placed within non-marine sandstones and mudstones, at a color change from greenish-gray and grayish- or purplish-red in the Bursum Formation to red and reddish-brown in the Abo. For example, in the Loma de las Cañas and Mesa del Yeso measured sections of Krainer and Lucas (2009), the top of the Bursum consists of non-marine beds, and their Joyita Hills B section is entirely non-marine. The uppermost parts of most Bursum Formation sections measured by Kottlowski and Stewart (1970) also consist of non-marine strata.

Paleocurrent analysis

Unlike the most of the underlying Pennsylvanian succession, the Bursum Formation is widely exposed in the study area and contains coarse clastic deposits that are amenable to paleocurrent analysis. A paleocurrent study was therefore undertaken to provide insight into the latest Carboniferous paleogeography and sediment dispersal systems. Most measurements are from bedload-dominated, probably braided, stream deposits. About 650 paleocurrent measurements from 12 localities were made in Bursum fluvial sandstones within and near the study area (Fig. 4). Nearly all were derived from the structurally restored (i.e., untilted) foreset dip-directions of tabular cross-bedding in sandstones (Fig. 5; this cross-bedding mostly reflects the downstream migration of subaqueous dunes within fluvial channels). The remainder (~7 %) is from trough cross-bedding and pebble imbrication.

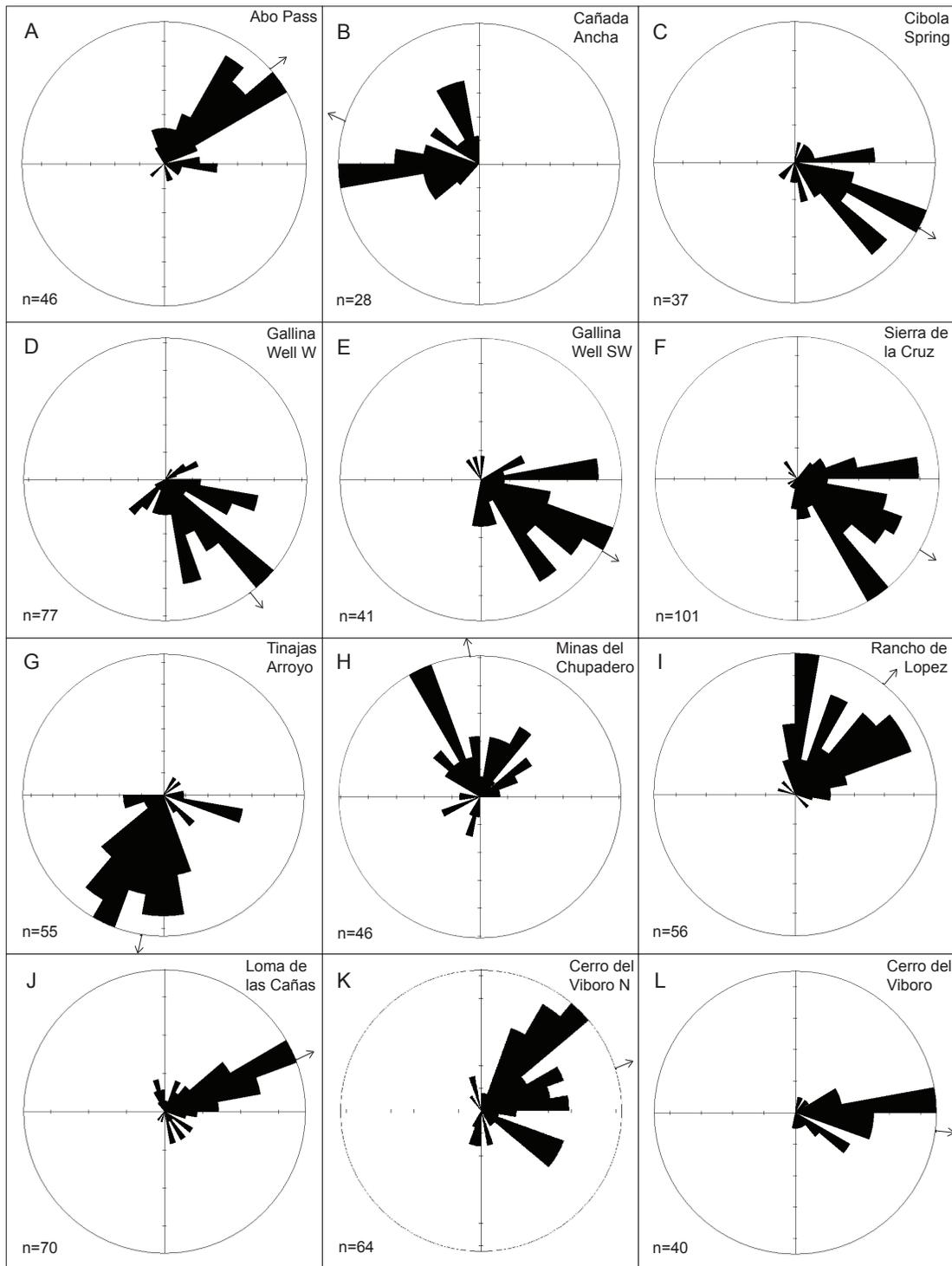


Figure 4. Paleocurrent data (north at top) and mean paleocurrent directions (arrows) for the Bursum Formation exposures in the study area and in surrounding areas. A—middle part of Bursum Formation near Abo Pass in roadcuts along US-60, measurements from 13S 0361994E, 3807769N and westward for ~300 m; B—upper part of Bursum Formation in the Los Cañoncitos area south of Cañada Ancha, near 13S 0333137E, 3796382N; C—lower and middle parts of Bursum Formation ~1 km southwest of Cibola Spring, measurements from 13S 0345147E, 3788062N and westward for ~1 km; D—lower part of Bursum Formation ~1.5 km west of Gallina Well, measurements from 13S 0341017E, 3779585 and north-northwestward for ~400 m; E—lower part of Bursum Formation ~2 km southwest of Gallina Well, measurements from 13S 0340740E, 3778278N and southward for ~400 m; F—middle and upper parts of Bursum Formation ~3.2 km south of Sierra de la Cruz, measurements from 13S 0343734E, 3780095N and southeastward for ~500 m; G—lower

and middle parts of Bursum Formation near Tinajas Arroyo section of Krainer and Lucas (2009), measurements from 13S 0340764E, 3775876N and southwestward for ~400 m; H—lower and middle parts of Bursum Formation near Minas del Chupadero, measurements from 13S 0332266E, 3775595N and eastward for ~300 m; I—lower, middle, and upper parts of Bursum Formation ~2.3 km south of Rancho de Lopez, measurements from 13S 0335787E, 3772676N and southward for ~1.7 km; J—lower and middle parts of Bursum Formation near the Loma de las Cañas section of Krainer and Lucas (2009), measurements from 13S 0338387E, 3771413N and north-northeastward for ~300 m; K—lower and middle parts of Bursum Formation ~1.3 km north of Cerro del Viboro section of Krainer and Lucas (2009), measurements from 13S 0337119E, 3760568N and southward for ~300 m; L—lower and middle parts of Bursum Formation near the Cerro del Viboro section of Krainer and Lucas (2009), measurements from the area around 13S 03337293E, 37592251N.



Figure 5. Crossbedding in the middle part of the Bursum Formation along Cañoncito de la Uva, near the Sierra de la Cruz measured section of Krainer and Lucas (2009). View to southwest from 13S 0343736E, 3780090N, Sierra de la Cruz quadrangle.

Not incorporated into the present study are paleocurrent measurements by Altares (1990), who collected relatively few measurements, some of which are based on features of dubious utility such as ripple cross laminations and the orientation of plant fragments.

In the present study, paleocurrents for individual localities typically display unimodal or closely-grouped polymodal distributions. The lack of polar bimodality suggests little or no tidal or estuarine influence during deposition of Bursum fluvial sandstones.

Two broad, semi-radial arrays of fluvial paleocurrent directions are present in the Bursum Formation within, and north of, the study area (Fig. 6). The southern array corresponds to notably arkosic Bursum exposures in the southern part of the study area in which pebbles consist mostly of Proterozoic lithologies (granite, gneissic granite, and vein quartz, with minor schist and greenstone; Fig. 7) with subsidiary, mostly intraformational carbonate clasts. The semi-radial easterly to northerly paleocurrents within this basement-derived petrofacies suggest Proterozoic exposures existed in what is now the southern part of the Socorro Basin of the Rio Grande rift. Herein, this source terrane is termed the San Antonio Uplift.

The northern semi-radial array of southeasterly to southerly paleocurrents corresponds to dominantly subarkosic to calcarenitic fluvial sandstones (e.g., point-count data in Colpitts, 1986) in which pebbles are mostly limestone and siltstone (Fig. 8); basement-derived pebbles are a minor constituent. Deposits of the northern semi-radial array are interpreted to represent a distributive fluvial system (e.g., Weissmann et al., 2010) in which sand and gravel were derived primarily from recycling of Pennsylvanian deposits, particularly the upper Madera Group. Reworking of upper Madera deposits may explain the differing composition of Bursum conglomerates and sandstones in the northern part of the study area—pebbles were derived mostly from indurated Madera limestones, but most sand was recycled from weakly indurated Madera subarkosic sandstones. The northern

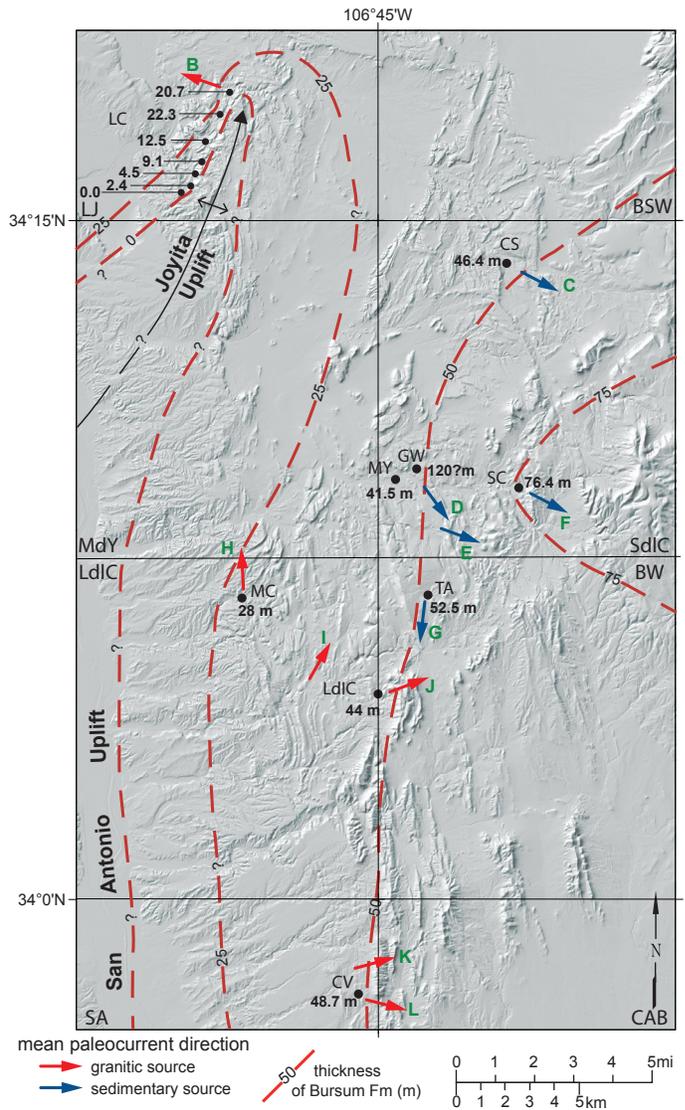


Figure 6. Digital elevation map showing modern topography and average paleocurrent directions (green letters are keyed to Fig. 4) and thickness for the Bursum Formation. Names of measured sections are modified from Krainer and Lucas (2009; note that several of their sections were incorrectly located on their maps and have been replotted here and on subsequent figures). LC—Los Cañoncitos; CS—Cibola Spring; MY—Mesa del Yeso; GW—Gallina Well; SC—Sierra de la Cruz; MC—Minas del Chupadero; TA—Tinajas Arroyo; LdIC—Loma de las Cañas; CV—Cerro del Viboro. Thicknesses are averaged for localities in which more than one section has been measured. These localities include Cibola Spring (average of 52.7 m measured by Altares, 1990, and 40 m by Allen et al., 2013), Mesa del Yeso (average of 57.9 m maximum thickness measured by Kottlowski and Stewart, 1970, and 25 m by Krainer and Lucas, 2009, their fig. 3), Sierra de la Cruz (average of 88.1 m measured by Altares, 1990, 78 m by Krainer and Lucas, 2009, and 63.2 m by Colpitts, 1986), Tinajas Arroyo (average of 51.9 m measured by Altares, 1990, and 53 m by Krainer and Lucas, 2009), Loma de las Cañas (average of 41.3 m measured by Altares, 1990, 54 m by Krainer and Lucas, 2009, and 36.7 m by Maulsby, 1981), and Cerro del Viboro (average of 41 m measured by Altares, 1990, 46 m by Krainer and Lucas, 2009, and 59 m by Fagrelus, 1982). Thicknesses at Los Cañoncitos are from Kottlowski and Stewart (1970) and those near Minas del Chupadero and Gallina Well are from Krainer and Lucas (2009, their fig. 5). The anomalous 120 m thickness near Gallina Well was not contoured (see text). Quadrangle abbreviations are Becker SW (BSW), Bustos Well (BW), Cañon Agua Buena (CAB), La Joya (LJ), Loma de las Cañas (LdIC), Mesa del Yeso (MdY), San Antonio (SA), and Sierra de la Cruz (SdIC).



Figure 7. Basement-derived clasts typical of pebble suites in Bursum outcrops in the southern part of the study area, consisting mostly of gneissic granite and quartzite. Note schist clast near pen tip. The angularity of the fragile schist clast suggests a proximal source. Outcrop photo from near the Cerro del Viboro section of Krainer and Lucas (2009), San Antonio quadrangle.



Figure 8. Typical fluvial pebble suite from the Bursum Formation in the northern part of the study area. Note dominance of clasts of Pennsylvanian limestone (gray) and siltstone (yellow-orange). The sandstone in the upper part of the photo is calcarenitic. Outcrop is in the lower part of the Bursum Formation near Cibola Spring (13S 0344943E, 3788457N), Sierra de la Cruz quadrangle.

array appears to have emanated from the Joyita Uplift. Northeast of the study area near Abo Pass, paleocurrent indicators in Bursum exposures along US-60 show paleoflow toward the northeast (Fig. 4A), similar to results of Krainer et al. (2009). The Abo Pass deposits also appear to have been derived from the Joyita Uplift, based on their sediment dispersal pattern.

In the Los Cañoncitos area on the western flank of the Joyita Uplift, Bursum fluvial deposits consist mostly of arkosic sandstone and conglomerate which contain Proterozoic clasts and, less commonly, Pennsylvanian limestone pebbles (Kottlowski and Stewart, 1970). Limited paleocurrent data from the upper part of the Bursum near section JH1 of Kottlowski and Stewart (1970) suggest paleoflow was toward the west-northwest (Fig. 4B).

Isopach trends

The thickness of the Bursum Formation, based on 15 measured sections by previous workers in the study area, ranges from about 25 to possibly 120 m. Figure 6 shows the contoured distribution of the averaged measured thicknesses of the Bursum Formation from previous studies. Because thicknesses measured within individual exposures vary among workers, the average measured thickness for each locality is presented in Figure 6. The reasons for the differences between measured thicknesses are unclear. Possibilities include actual thickness differences, differing placement of contacts, and a varying appreciation of structural complications between workers.

North of the study area, on the west flank of the Joyita Uplift, the Bursum ranges from 0 to 22 m thick in seven measured sections, thickening rapidly away from the uplift (Kottlowski and Stewart, 1970). Southeast of the uplift, the Bursum Formation thickens gradually and monotonically eastward. An exception is the anomalously thick (120 m) section measured by Krainer and Lucas (2009) near Gallina Well. In my opinion, this section likely represents a fault-repeated section (see citation of R. Colpitts, 2009, written communication, in Krainer and Lucas, 2009, p.168, for a similar opinion). The anomalous thickness of the Gallina Well section is illustrated by nearby, thinner measured sections in the Bursum Formation.

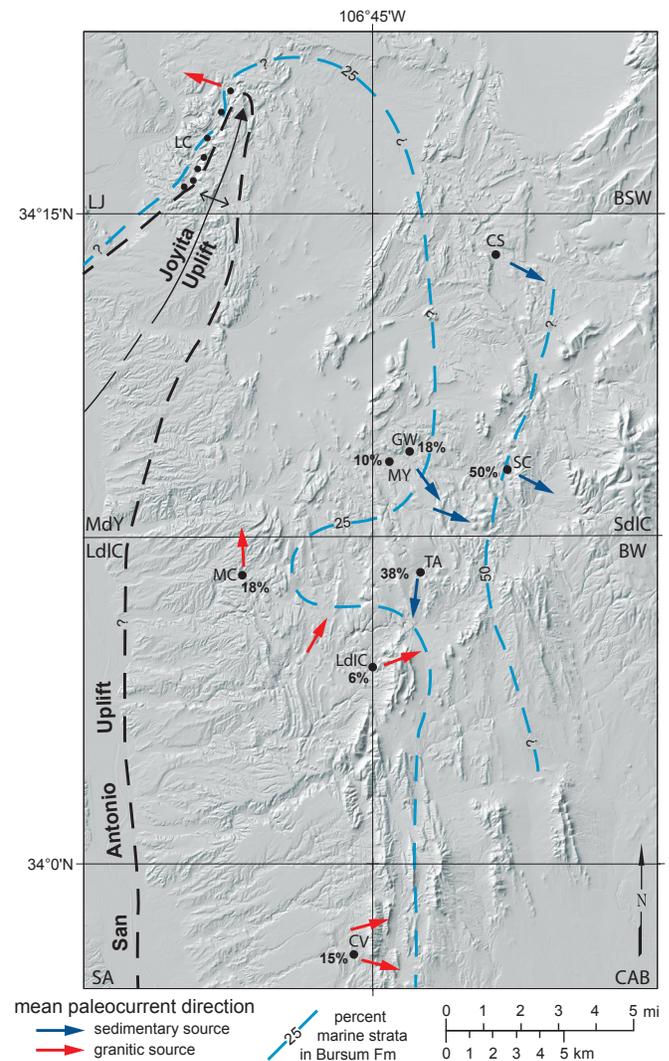


Figure 9. Digital elevation map showing average paleocurrent directions (from Fig. 4) and percentage of marine strata in Bursum Formation, compiled from the interpretations of Krainer and Lucas (2009, 2013). Percentage of marine strata in the Los Cañoncitos area west of Joyita Uplift is estimated from the lithologic descriptions of Kottlowski and Stewart (1970). Abbreviations are defined in Figure 6.

About 1.1 km west of the Gallina Well section, Krainer and Lucas (2009, their fig. 3) measured only 25 m of Bursum in their Mesa del Yeso section (note that the Gallina Well and Mesa del Yeso measured section locations are transposed on their fig. 1). Kottlowski and Stewart (1970, p. 23) measured no more than 57.9 m nearby to the west. Not contoured in Figure 6, the 120 m thickness of the Gallina Well section, if correct, would require a local, deeply subsided sub-basin within the study area.

Proportion of marine strata

Figure 9 shows the percentage of marine strata within ten measured sections of the Bursum Formation, based on the paleoenvironmental interpretations of Krainer and Lucas (2009). East of the Joyita and San Antonio uplifts, the abundance of marine rocks in the Bursum increases rather systematically eastward, as noted by Krainer and Lucas (2009). A westward embayment in the 25% marine contour approximately coincides with the area between the two semi-radial distributive fluvial systems defined above.

The increased percentage of marine strata in this area probably reflects a paleotopographic low area between two constructional lobes in which marine flooding was more frequent or persistent.

Maximum clast-size distribution

Maximum clast-size data, based on the average of the ten largest clasts observed at each locality, were collected from fluvial beds within the study area (Fig. 10). The measured clasts were mostly vein quartz in the south, and limestone in the north. These data define a fine-grained area between the two distributive fluvial systems, and suggest lower fluvial paleogradients existed in the intervening embayment. No systematic study of maximum clast size was attempted in the Los Cañoncitos area west of the Joyita Uplift. Kottlowski and Stewart (1970) reported clasts as large as cobbles in that area. No pebbles other than intraformational rip-up clasts were observed in the Abo Pass or Little San Pascual Mountain outcrops.

Regional structure and paleogeography

Paleocurrent data and the dominance of north-south contours of thickness, percent marine strata, and maximum clast size in the Bursum Formation (Figs. 6, 9, and 10) in the study area are not compatible with derivation solely from the Joyita Uplift, but instead suggest a Late Paleozoic uplift (the San Antonio Uplift) occupied much of the southern Socorro Basin. Although shown as being contiguous with the Joyita Uplift, available data also allow that the San Antonio Uplift was separated from the Joyita Uplift by a topographically low area north of the town of Socorro.

The Joyita Uplift has been depicted by most workers as a small positive feature with a paleogeographic extent similar to that of the present outcrops of Proterozoic rocks in the Joyita Hills, but its original Pennsylvanian geometry is partly obscured by subsequent Laramide and rift tectonism. The western flank of the Pennsylvanian uplift is well-preserved in the Los Cañoncitos area where Bursum and Abo beds lap onto the Proterozoic core of the uplift (Kottlowski and Stewart, 1970) and evidence of Late Paleozoic sinistral-oblique normal growth-faulting has been documented (Beck, 1993). The northern tip of the uplift was located near the present northern extent of Proterozoic outcrops where it plunges northward beneath antiformal beds of the Madera Group (Beck, 1993; de Moor et al., 2005). The locations of southern and eastern margins of the uplift, however, are poorly constrained. The eastern flank of the uplift was subsequently down-dropped by Laramide and Late Cenozoic slip on the East Joyita fault and buried (Beck and Chapin, 1994). The southern part of the Joyita Uplift lies concealed beneath the Neogene Santa Fe Group of the Socorro Basin.

The angular unconformity at the base of the Bursum Formation at Los Cañoncitos is indicative of a major pulse of late Pennsylvanian Ancestral Rocky Mountains (ARM) tectonism in the Joyita Uplift (Kottlowski and Stewart, 1970, Beck, 1993; Krainer and Lucas, 2009). Beneath the Bursum at Los Cañoncitos, Atokan through Missourian strata are anomalously thin, exhibit wedge shapes and local growth-fault relationships, and contain numerous unconformities (Kottlowski and Stewart,

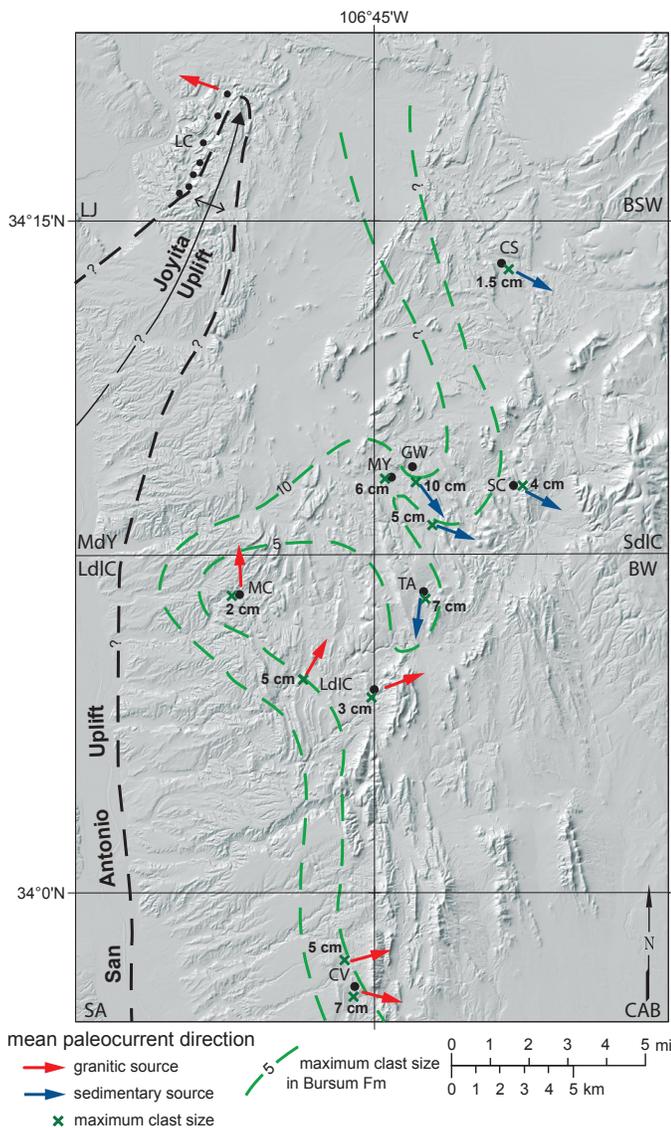


Figure 10. Digital elevation map of modern topography showing average paleocurrent directions (from Fig. 4) and maximum clast-size distribution for Bursum outcrops in the study area. Abbreviations are defined in Figure 6.

1970; Siemers, 1978, 1983; Beck and Chapin, 1994), all of which are suggestive of Pennsylvanian synsedimentary deformation on the western flank of the nascent uplift.

In the Los Cañoncitos area, pebbles in the Bursum Formation consist of mostly Proterozoic lithologies with subordinate clasts derived from the Madera Group. These pebble types are consistent with the rock types exposed along the west flank of the Joyita Uplift during onlap of the Bursum Formation. In contrast, pebble compositions in Bursum deposits derived from the east flank of the Joyita Uplift are dominated by Madera

Group limestone and siltstone. This suggests that extensive Madera exposures existed on the east flank of the uplift during Bursum deposition, but were obscured by east-down deformation along the East Joyita fault and subsequent burial.

On the Pedernal Uplift east of the study area, Proterozoic rocks are overlain by the Abo Formation (Broadhead and Jones, 2004). North of Carrizozo, between the Chupadera fault and the Pedernal Uplift (herein termed the Carrizozo Bench; Fig. 11), well data show the Bursum Formation is absent and the Abo Formation lies unconformably on

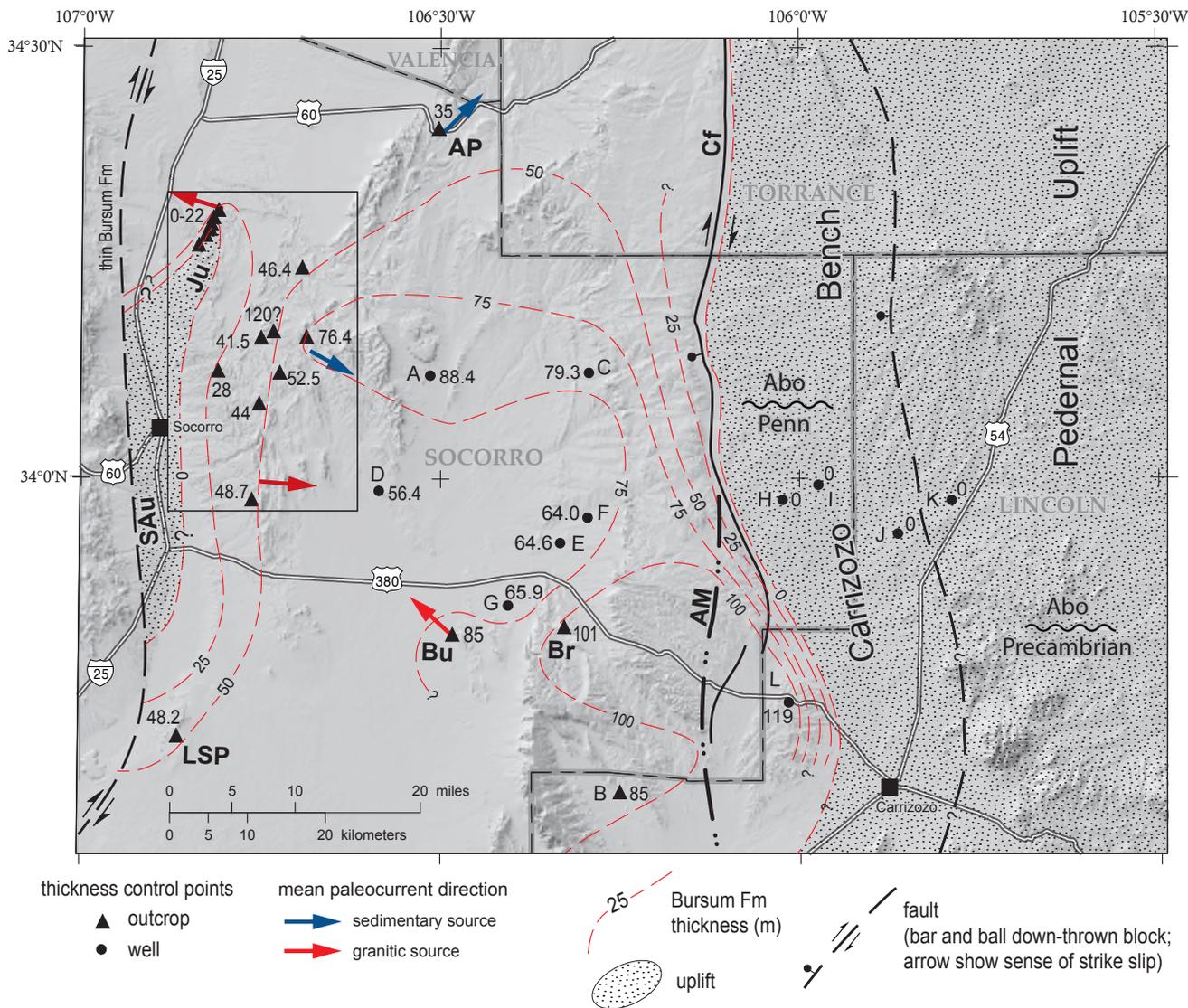


Figure 11. Digital elevation map showing modern topography of central New Mexico superimposed by latest Pennsylvanian paleogeography, major faults, mean paleocurrents, and regional Bursum thicknesses from outcrops and petroleum wells. The rectangle east of Socorro encloses area of Figures 6, 9, and 10. Paleocurrent directions within the rectangle are generalized; see Figures 4 and 6 for details. AM—aeromagnetic linear gradient which may represent lower-plate (sub-Yeso Formation) position of the Chupadera fault (Cather, 2009). AP—Abo Pass section (Bursum Formation thickness from Krainer et al., 2009; average paleocurrent direction is from Fig. 4A). B—measured section B of Bachman (1968). Bu—Bursum Formation type section (thickness and average paleocurrent direction from Lucas et al., 2002). Br—Bursum Formation thickness at the Bruton Formation type section (Bursum thickness from Lucas and Krainer, 2009). Cf—Chupadera fault. Ju—Joyita Uplift. LSP—Little San Pascual Mountain [Bursum thickness here is interpreted from the measured section of Pennsylvanian

unit 4 of Geddes (1963), south of Little San Pascual Mountain. The section is too fine-grained for paleocurrent analysis.]. Penn—denotes pre-Bursum Pennsylvanian strata unconformably overlain by the Abo Formation on the Carrizozo Bench. SAu—San Antonio Uplift. Bursum Formation thicknesses in wells are from Broadhead and Jones (2004; note that these thickness estimates are based of well cuttings and geophysical logs available from the New Mexico Library of Subsurface Data at the New Mexico Bureau of Geology and Mineral Resources, and exclude wells for which only scout cards or sample logs are available): A—Skelly Oil No. 1 Goddard; C—Yates Petroleum No. 1 McCaw Federal; D—Anderson No. 1 Wishbone; E—Lockhart No. 3 Lockhart; F—Virgle Landreth No. 1 Federal; G—Sun Oil No. 1 Bingham State; H—Manzano Oil No. 1 Cathead Mesa; I—Primero No. 1 Dulce Draw State; J—Primero No. 1 Jackson Ranch Federal; K—Manzano Oil No. 1 Spaid Buckle; L—Standard Oil Co. of Texas No. 1 J.F. Heard-Federal.

older Pennsylvanian strata (Broadhead and Jones, 2004). The lacuna associated with this unconformity is best constrained by the Manzano Oil No. 1 Cathead Mesa well, where an unpublished fusulinid study by Garner Wilde (cited by Broadhead and Jones, 2004) indicates the Abo Formation unconformably overlies lower Atokan strata. The Bursum Formation and the upper part of the Pennsylvanian section are thus missing in the well (Broadhead, 2009). The Carrizozo Bench represents a structural terrace along the western flank of the Pedernal Uplift that was moderately uplifted sometime before the Abo Formation was deposited. The Chupadera fault, a

southward continuation of the dextral Picuris–Pecos fault (Cather, 2009), thus experienced local east-up stratigraphic separation in the region north of Carrizozo during the Late Pennsylvanian and/or earliest Permian.

The nature and location of faults that controlled deformation during the Pennsylvanian in central New Mexico are poorly known, largely because of overprinting by the subsequent Laramide and rift deformations. The best documented Pennsylvanian faults lie along the west flank of the Joyita Uplift, where normal faults with west and northwest strikes are present. A particularly well-preserved fault there was active as a steep, north-striking,

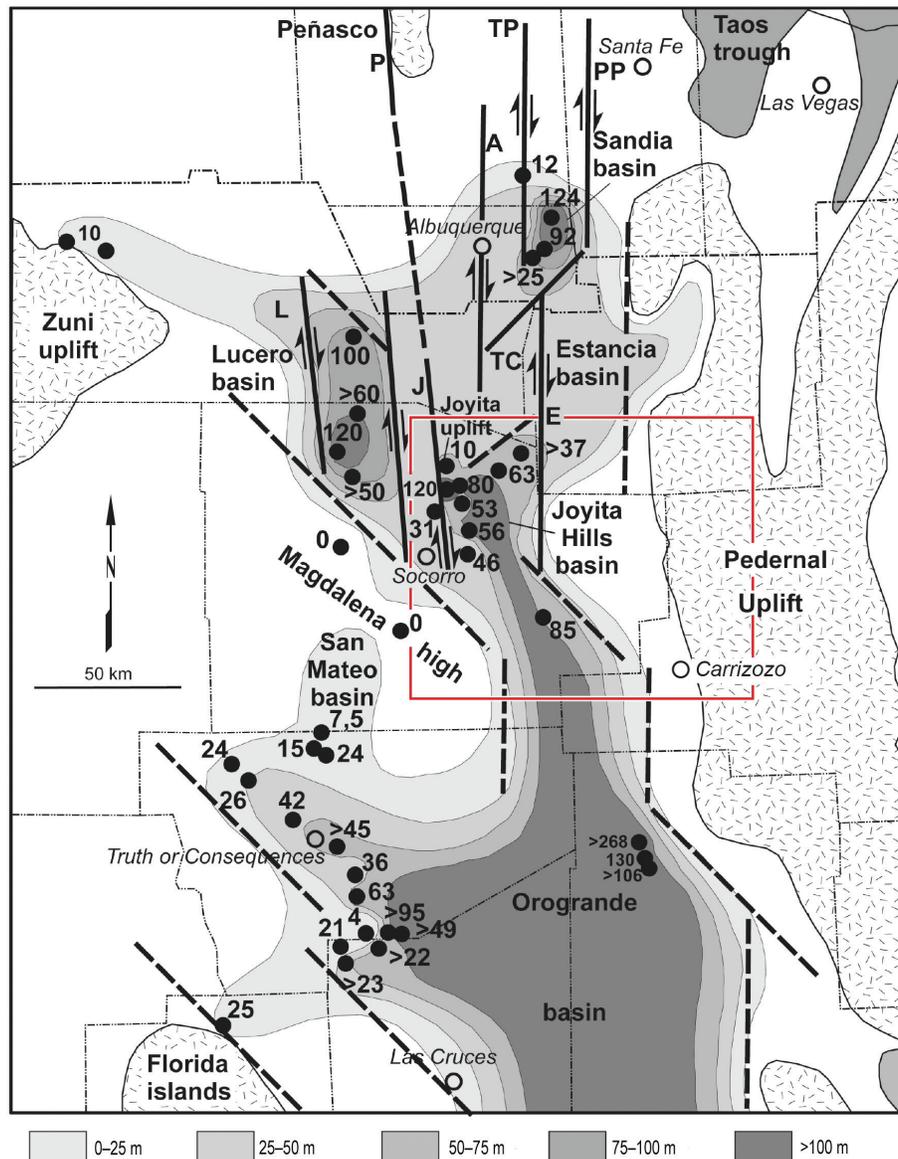


Figure 12. Isopach map of the Bursum Formation and equivalent units in central and northern New Mexico (Krainer and Lucas, 2009), showing paleogeographic features (including the “Joyita Hills Basin”), thickness control points (dots, with thicknesses in meters), and the area of Figure 11 (red rectangle). Note that this map does not consider the Bursum thicknesses documented in the subsurface by Broadhead (1997) and Broadhead and Jones (2004). Heavy lines are faults inferred by Krainer and Lucas (2009), several of which are incorrectly located or are hypothetical (i.e., they do not correspond to known faults or geophysical lineaments; see comments for individual faults in brackets). Faults are: P—Peñasco fault [This is the Nacimiento fault of most workers.]; A—Albuquerque fault [Does not correspond

to any known, single fault.]; TP—Tusas–Picuris fault [This fault is depicted ~40 km too far to the west. It actually passes north-south through Santa Fe (see Cather et al., 2006).]; PP—Picuris–Pecos fault [This fault is depicted ~30 km too far west. The actual fault lies ~15 km east of Santa Fe where it forms the western margin of the Taos Trough.]; L—Lucero fault [hypothetical]; J—Joyita fault [This presumably is the West Joyita fault, a rift fault with no known Paleozoic precursor. Its southward projection through the Bursum exposures in the Quebradas region is incorrect.]; TC—Tijeras–Cañoncito fault [Only the southwestern part of this fault is depicted.]; E—Estancia fault [Hypothetical, except in its northern part where it corresponds approximately to the Montosa fault.].

left-oblique normal fault during the latest Pennsylvanian (Beck and Chapin, 1991; Beck, 1993; Beck and Chapin, 1994). The Polvadera thrust fault in the Lemitar Mountains ~15 km northwest of Socorro records north-south shortening during Atokan time (Chamberlin, 1983; Chamberlin et al., 2001; Chamberlin, 2004). The Chupadera fault (termed the Monte Prieto–Liberty Hill structural zone by Broadhead and Jones, 2004) described above is the only other fault in the region for which Pennsylvanian slip can be reasonably inferred, although many other faults must have been active during that time. On Figure 11 a dextral fault, corresponding to the modern Socorro Canyon fault, is depicted along the west flank of the San Antonio Uplift. Pennsylvanian slip on this fault is speculative, and is shown only to suggest the possibility that the San Antonio Uplift might be analogous to the dextral transpressive Laramide Sierra Uplift (Cather, 2009) in the same location.

Two diametrically opposed models for regional faulting during the Pennsylvanian have been proposed. Beck (1993) and Beck and Chapin (1994) proposed a sinistral transtensional model for ARM deformation in New Mexico, and Krainer and Lucas (2009, their fig. 7, reproduced here as Fig. 12) presented a dextral transpressional model. Evidence is scant but probably favors the dextral model (see summary of ARM slip-sense indicators in Cather et al., 2006). It should be noted, however, that several of the ARM faults depicted in the dextral model of Krainer and Lucas (2009) are hypothetical (i.e., they correspond to no known fault or geophysical feature) or are incorrectly located (see caption of Fig. 12).

Krainer and Lucas (2009) interpreted the Bursum Formation southeast of the Joyita Uplift to have been deposited within a narrow (~35 km wide), symmetric, north-northwest-trending basin, which they termed the Joyita Hills Basin. Their isopach map (Fig. 12) depicts a narrow zone (~10 km wide) of thick (>100 m) Bursum Formation in east-central Socorro County that defines the axis of the basin. The only control point that supports such a thickness, however, is the questionable 120 m thickness measured by Krainer and Lucas (2009) in their Gallina Well section. Even if the 120 m thickness is correct, the Gallina Well section is surrounded by measured sections in which the Bursum Formation is relatively thin (Fig. 6). The extension of a zone of thick (>100 m) Bursum far to the south-southeast of Gallina Well by Krainer and Lucas (2009) is thus unlikely, if standard contouring protocols are observed.

The eastern side of the Joyita Hills Basin of Krainer and Lucas (2009) is demarcated by purported zero thickness of the Bursum Formation in east-central Socorro County. No evidence for missing Bursum in this area, however, was presented by them. Contrary to the interpretations of Krainer and Lucas (2009), significant Bursum thicknesses (56.4–119 m) have been documented in petroleum exploration wells of eastern Socorro County and western Lincoln County (Fig. 11) by Broadhead and Jones (2004).

There is no evidence for a narrow, elongate basin of Bursum age extending south-southeast from the Joyita Uplift, as was depicted by Krainer and Lucas (2009; their Joyita Hills Basin). Instead, a broad area (as much as 100 km wide) of gradually southeastward-thickening Bursum deposits existed between the Joyita Uplift and the vicinity of Carrizozo. I regard the area of Bursum deposition east of the Joyita and San Antonio uplifts as simply a weakly subsided saddle-shaped platform between the deeper Orogrande Basin and Estancia basins, the latter of which contains as much as 335 m of Bursum Formation within the deep Perro sub-basin (Broadhead, 1997). I suggest that the incorrectly characterized term “Joyita Hills Basin” be abandoned.

Summary

Because the Bursum Formation is widely distributed and relatively coarse-grained, it is perhaps the most suitable Upper Paleozoic unit in central New Mexico for paleocurrent analysis. Such analyses are the best source of paleoslope information, which in turn allows for a better determination of paleogeography. Paleocurrent data from the Bursum Formation in the Quebradas region east of Socorro indicate the presence of major Proterozoic exposures on a Late Pennsylvanian highland, herein termed the San Antonio Uplift, in what is now the southern part of the Socorro Basin. Isopach trends, isolith maps of percent marine strata, and maximum clast-size distribution in the Bursum all support such an interpretation.

The San Antonio Uplift and the long-known Joyita Uplift formed the western margin of a broad, weakly subsided shelf on which gradually southeast-thickening Bursum deposits accumulated. North of Carrizozo, the Chupadera fault marked the eastern limit of Bursum deposition. Between the Chupadera fault and the Pederal Uplift to the east, a terrace of moderate structural relief (the Carrizozo Bench) was the site of erosion sometime prior to deposition of the Abo Formation.

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