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Ramah Member of the Crevasse Canyon Formation—a new stratigraphic unit in the Zuni Basin, west-central New Mexico

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Abstract

Nonmarine deposition accompanying and following a regression of the Cretaceous Interior Seaway during late Turonian time left a sedimentary sequence consisting of fluvial channel sandstones, thin overbank sandstones, and paludal shales containing thin coal beds. This unit is herein designated the Ramah Member of the Crevasse Canyon Formation. The Ramah Member is locally well exposed in the Zuni Basin of west-central New Mexico where it rests on the Gallup Sandstone (marine) and is overlain by the distinctive, feldspathic Torrivio Member of the Crevasse Canyon Formation (formerly of the Gallup Sandstone). Near Ramah, New Mexico the sequence overlies the F member of the Gallup but northward it overlies progressively younger members. These younger members are discrete sandstone units associated with minor oscillations of relative sea level during a major regional-scale regression. North and east of Puerco Gap, near Gallup, New Mexico, the Ramah Member thins appreciably, and where unmappable it may be included with the Torrivio Member. Southward from Gallup in the Zuni Basin, the Ramah locally approaches 150 ft in thickness and contains minable coal beds. The interval was previously referred to as the coal-bearing member of the Gallup (Mapel and Yesberger, 1985) or the Ramah unit (Anderson and Stricker, 1984).

In the northern part of the Zuni Basin a problem may exist locally in determining the top of the Ramah Member. This is due to the presence of a fluvial sandstone with coarse-grained facies that looks much the same as the Torrivio Member, but underlies it. Two criteria may be employed to distinguish the lower sandstone from the Torrivio and properly place it in the stratigraphic succession: (1) the lower sandstone is generally not as feldspathic as the Torrivio nor do the coarse-grained facies contain pebble-size material; and (2) the lower sandstone is not nearly as widespread as the overlying Torrivio, which has a blanket geometry.

The type section of the Ramah Member is in the SE¼ NW¼ NW¼ sec. 16 T10N R16W approximately 4 mi southwest of the town of Ramah. The principal coal lies near the top of the member and was mined during the 1920s to supply coal for the Zuni Pueblo schools.

Introduction

This paper describes the stratigraphy, depositional environments, and coal resources of the nonmarine, late Turonian (Upper Cretaceous) rocks formerly included with the Gallup Sandstone, herein reassigned to the Crevasse Canyon Formation. The Crevasse Canyon Formation is an important coal-bearing unit that crops out throughout the Zuni Basin (Fig. 1) and is generally a slope-forming unit.

Changes and reassignments of stratigraphic nomenclature should in general be avoided except in those cases where the result is a more logical and meaningful subdivision of the local sedimentary succession. Using this criterion we have proceeded not only to recognize the coal-bearing, upper part of the Gallup Sandstone with a formal name—the Ramah Member—but also to reassign it to the essentially nonmarine Crevasse Canyon Formation. This change places a formation contact at the top of the light-colored, cliff-forming, persistent and evenly bedded, fossiliferous sandstones of unequivocal marine or marginal-marine origin. The overlying rocks are mudstone dominated, for the most part coal bearing, lacking in marine body fossils, with laterally discontinuous sandstone beds of fluvial origin. Thus, lithologies rather than genetic interpretations and subjective considerations constitute the primary basis for placement of the new Gallup–Crevasse Canyon formational contact, with the genetic contrast being a secondary factor. The significance of this lithogenetic break is that it marks the cessation of marine deposition in the Zuni Basin. With this downward revision of the Crevasse Canyon Formation basal contact, it is obvious that the Torrivio Member, as well as the Ramah, become part of the Crevasse Canyon Formation. No redefinition of the Torrivio per se is contained herein; it is merely the subject of a passive reassignment, consistent with its physical position—as much as 150 ft stratigraphically above the Gallup Sandstone.

Previous studies

Most of the geological studies in the Zuni Basin have focused on the coal resources in the Upper Cretaceous rocks. Shaler (1907) reported on the coal resources of this area following a reconnaissance survey of the Durango–Gallup coal field. He assigned all Cretaceous strata above the Mancos Shale to the Mesaverde Formation, extending that stratigraphic name southward from the type area near Cortez, Colorado. More stratigraphic detail and discussion of structural features was contained in a report by Sears (1925), in a work titled "Geology and coal resources of the Gallup–Zuni Basin, New Mexico." Sears formalized the member names of the

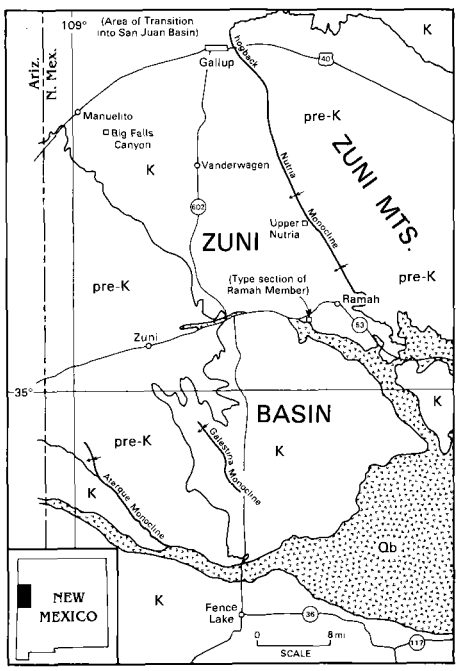


FIGURE 1—Index map of Zuni Basin showing major structure, type section of Ramah Member, and selected localities.

Mesaverde Formation; in ascending order they are the Gallup Sandstone, Dilco Coal Member, Bartlett Barren Member, and Gibson Coal Member. Sears recognized the Gallup as the only shore-marginal or littoral sand in the entire sequence. However, the upper part of Sears' Gallup Sandstone is unequivocally nonmarine, coal bearing, and is the subject of this paper.

Beaumont et al. (1956) elevated the Gallup to formation rank and included it as the basal unit of the newly defined Mesaverde Group. They also recognized and adopted Allen and Balk's (1954) Crevasse Canyon Formation as the dominantly nonmarine unit overlying the Gallup Sandstone. The names Dilco, Bartlett Barren, and Gibson were then utilized as member names within the Crevasse Canyon Formation (Fig. 2); this terminology has been widely accepted and is in general use.

Shomaker et al. (1971) reported in detail on the strippable, low-sulfur coal resources of the San Juan Basin and included a discussion of the coal resources and reserves of the Gallup–Zuni Basin. Of specific interest here is their discussion of the School mine coal zone in the central part of the basin.

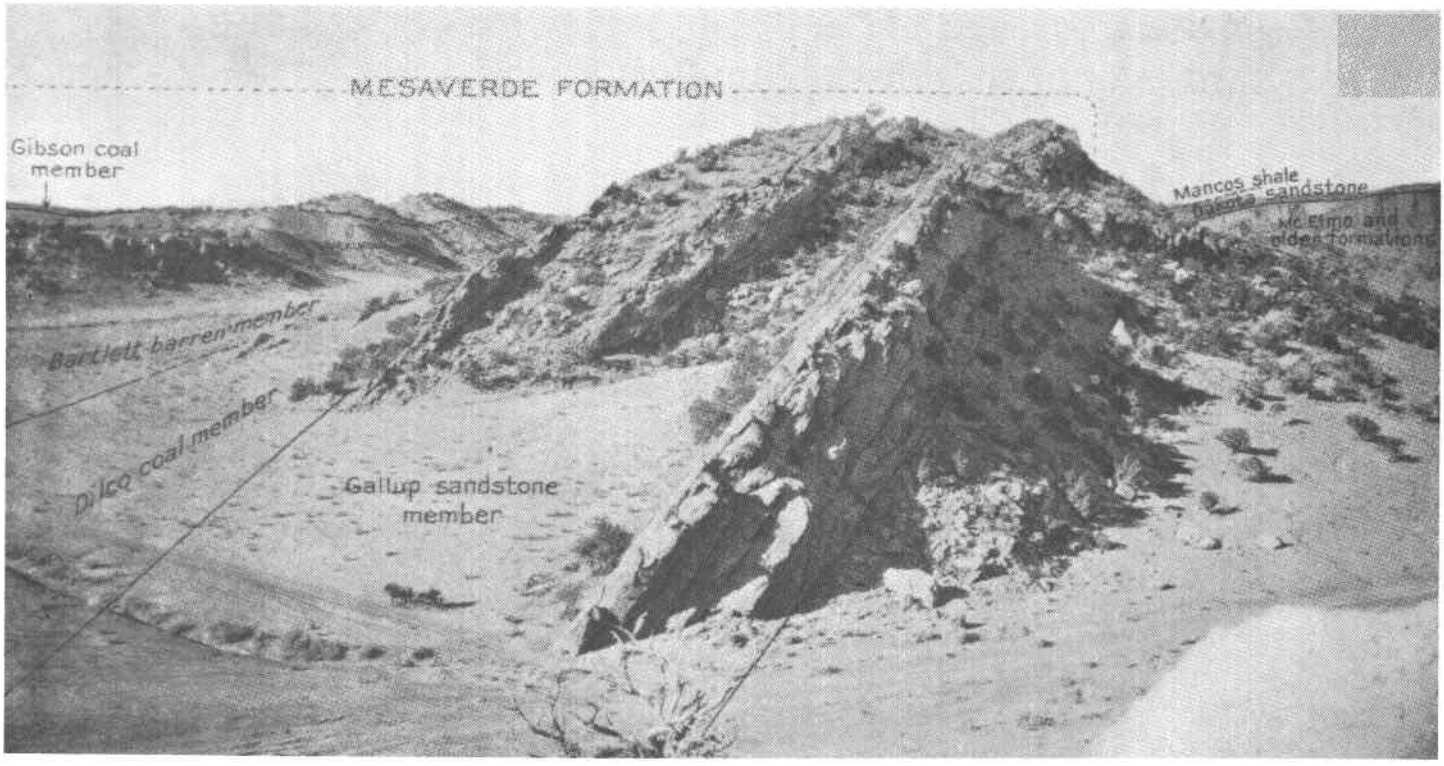


FIGURE 2—Photograph of westward-dipping Gallup Sandstone, from Sears (1925). The uppermost sandstone bed of the Gallup was later designated the Torrivio Member by Molenaar (1973). Crevasse Canyon Formation overlies the Torrivio. (Photograph by N. H. Darton)

An excellent description of the sedimentary facies of the Gallup Sandstone and associated formations was provided by Molenaar (1973). Molenaar also introduced the name Torrivio Member for the uppermost, coarse-grained unit of the Gallup Sandstone.

Hook et al. (1983) presented a redefinition of the Tres Hermanos Formation (middle to late Turonian) and established it as being a regressive-transgressive wedge of shoreface- and coastal plain-deposited rocks significantly older than the Gallup Sandstone and separated from it by the Pescado Tongue of the Mancos Shale. Previous to this, the Tres Hermanos sequence had been included as the lower part of the Gallup. The redefinition restricted the Gallup Sandstone to late Turonian and younger rocks.

Molenaar (1983) designated a principal reference section for the Gallup Sandstone, establishing it in the SE¼NE¼ sec. 13 T15N R18W, 2 mi east of Gallup, New Mexico. (Sears (1925) had not specified a type section for his "Gallup member.") Molenaar also presented numerous cross sections illustrating the stratigraphic relationships of the Gallup to adjacent units. These data have been widely used by subsequent workers in the Zuni Basin and Gallup areas. A nonmarine, coal-bearing unit in the upper part of the Gallup was recognized by Molenaar as being a tongue of the Crevasse Canyon Formation overlain by the Torrivio Member of the Gallup. He advised mappers that usage of the term Crevasse Canyon for that interval was appropriate. However, this inferred intertonguing of the Gallup with the Crevasse Canyon Formation was not based on a physical intertonguing of littoral sands with coastal plain deposits, but rather on an arbitrary definition of the Gallup Sandstone that included a fluvial sandstone (the Torrivio) as the uppermost member.

In a discussion of Cretaceous stratigraphy and coal resources of the Zuni Basin, Anderson and Stricker (1984) used the informal term Ramah unit for the coal-bearing upper part of the Gallup. This was consistent with Sears' stratigraphy of the Gallup Sandstone, except that the Ramah unit is considerably thicker than the equivalent unit at Sears' hogback locality; thus, Anderson and Stricker (1984) recognized the need for a separate stratigraphic unit but left its nomenclature informal at that time.

Following similar logic, Mapel and Yesberger (1985), in their detailed maps of the Ramah–Navajo Reservation, refrained from using "Tongue of the Crevasse Canyon Formation" for the upper, nonmarine part of the Gallup and referred to it informally as the coal-bearing part of the Gallup. Thus a proliferation of names was emerging, and no one seemed willing to accept an intertonguing relationship between the Gallup and Crevasse Canyon Formations in the Zuni Basin.

Anderson (1987, 1989, 1990), in detailed maps of the Atarque Lake area, Jones Ranch School quadrangle, and Vanderwagen quadrangle, respectively, used Ramah unit informally to refer to the coal-bearing strata in the upper Gallup. The top of the Gallup in those areas was defined as the top of the medium- to coarse-grained, slightly feldspathic, distinctive Torrivio Member, which is present throughout the Zuni Basin.

In a review of the usage of the term Gallup Sandstone, Kirk et al. (1978, p. 1) noted that the present usage of Gallup Sandstone "results in unnatural and awkward boundaries." They went on to state that this usage "has forced earlier and current workers alike to obscure and to misrepresent what we think are significant geologic relationships." We concur with Kirk's observations.

Millgate (1991) mapped the interval above the marine Gallup Sandstone as the Ramah unit but included it with the "lower part" of the Torrivio. His lower Torrivio represents a locally significant sandstone, medium to coarse grained, which underlies the more widespread upper Torrivio that features a blanket geometry.

When Sears (1925) named the Gallup Sandstone Member of the Mesa Verde Formation from exposures in the hogback just east of Gallup, New Mexico (Fig. 1), he included three discrete sandstone units (Fig. 2). The lower two, which tended to be "light gray" (although he noted that the basal one was locally "red to pink"), were fine grained, evenly bedded, persistent units separated by a 30–50-ft-thick shale unit. The uppermost sandstone was described as pink in most places with lens-

es of "very coarse material," and "in many places an arkose." He did not indicate a thickness for the shale unit that separated the middle sandstone from the uppermost sandstone, but he did note that it was coal bearing. The coal was referred to as the Myers coal bed, which was produced locally from the Richards and Myers mines as early as 1886.

Although Sears (1925) stated that the Gallup Sandstone represented a littoral deposit formed as the Cretaceous sea retreated eastward, he did not discuss depositional environments in detail. Curiously, he did not differentiate the upper coal-bearing (and obviously non-marine) from the lower littoral and marine sandstones. Had he recognized that the top of the littoral sandstone represented the final marine influence in the Gallup–Zuni Basin and accordingly placed the top of his "Gallup member" at that stratigraphic horizon, a much more natural subdivision of the local succession would have resulted. He did recognize the overlying Dilco coal member (and in turn, Bartlett and Gibson members) as being "laid down on floodplains of great rivers" and thus placed a member-rank contact at what he thought was the boundary between a littoral sequence and alluvial-floodplain deposits. He merely placed this boundary too high in the section. Thus, the present effort to invoke a more useful subdivision and lend more utility to the formation concept cannot be criticized for placing too much emphasis on lithogenesis, because the original stratigraphic nomenclature was based on genetic units; the original work simply had the important lithogenetic break placed incorrectly with respect to contemporary views and interpretations. The present work uses lithologies in conjunction with genetic interpretations to develop a subdivision that should be acceptable to the modern field geologist.

To Sears' credit, it must be noted that he had seen coal not only in the upper shale unit (above the littoral sands), but also in a lower shale unit separated by the littoral sandstones. While the present authors have not been able to find coal in this lower shale at Sears' described locality, elsewhere in the Gallup–Zuni Basin coal beds have been documented in a similar shale unit medial to littoral/shoreface Gallup sandstones. Anderson (1990) reported a 3-ft-thick coal bed in a similar stratigraphic position in the Vanderwagen area 16 mi south of Gallup. Sears clearly saw the Gallup as a marine sandstone unit interbedded with coal-bearing sequences right up through the coarse-grained sandstone at the top (later designated the Torrivio Member by Molenaar, 1973) and did not recognize the top of the "littoral deposits" as being significant to local stratigraphic interpretation. If there are coal beds present in the lower shale, they are relatively thin and probably in a lagoonal or bay-fill sequence, versus those of the upper shale which accumulated in a floodplain (paludal) environment.

Most later workers accepted Sears (1925) definition of the Gallup Sandstone, and numerous maps and coal resource work have been published using the original concept of the Gallup. These include Shomaker et al. (1971), Molenaar (1973), Hackman and Olson (1977), Molenaar (1983), Anderson (1987, 1989, 1990). However, following Molenaar's (1983) suggestion that the coal-bearing shale unit in the upper part of the Gallup (above the littoral sands of Sears) could be mapped as a tongue of the Crevasse Canyon Formation, Condon (1986), Kirk and Zech (1987a,b), and Zech (1989) mapped it as such in the extreme northern part of the Zuni Basin and adjacent San Juan Basin. That stratigraphy left the Torrivio Member isolated within the Crevasse Canyon Formation with no genetic, lithologic, or physical ties to its parent unit—the Gallup Sandstone—in the Zuni Basin, and pointed out the need for some stratigraphic simplification on behalf of the field geologist; hence our designation of the Ramah Member.

The Ramah Member of the Crevasse Canyon Formation

The Ramah Member of the Crevasse Canyon Formation consists of as much as 150 ft of shale and mudstone, sandstone, fine-grained sandstone and siltstone, carbonaceous shale, and minor coal. The sequence overlies a marine to dominantly marine Gallup Sandstone and represents deposition in paludal and fluvial environments. The member is named for the village of Ramah, New Mexico, an area where it is well exposed and shows good development. The type section is herein designated as being in the NE¼NW¼ sec. 16 T10N R16W where the unit is 130 ft thick (Fig. 3). A measured section at that locality (Fig. 4) illustrates the mudstone-dominated aspect, with only one sandstone bed thicker than 10 ft. Three coal zones are present if the very thin one at the base is included. The other two are considerably thicker at 3.3 ft and 2.0 ft, and lie 65 and 90 ft above the base, respectively.

Inasmuch as the Ramah Member is lithologically indistinguishable from the Crevasse Canyon Formation, it is at most coextensive with the overlying Torrivio Member. However, it is intended that the usage of the term Ramah Member be restricted to the Zuni Basin, even though as defined it does extend at greatly reduced thickness north and east into the San Juan Basin. In the more northeast localities the member thins in part because of progressive downcutting at the base of the overlying Torrivio Member in a seaward direction. In these areas, the thinned Ramah equivalent may be (1) mapped as a tongue of the Crevasse Canyon Formation (Dilco Coal Member) as Zech (1989) and others have done, or (2) included with the Torrivio Member of the Crevasse Canyon, especially appropriate where the member becomes difficult to map. A third alternative would be to map it as the Ramah equivalent in those areas considered to be transitional between the Zuni and San Juan Basins. As the cross section (Fig. 5) illustrates, the Ramah Member is correlative with the lower part of the Dilco Coal Member of Zech (1989), although the basal Ramah, having a more landward (SW) distribution, is slightly older than the basal Dilco.

Age constraints on the Ramah consist of faunal control on the underlying unit and some lithologic correlation of the overlying Torrivio. In the underlying Gallup Sandstone a Juana Lopez-age (early-late Turonian) fauna has been found. *Inoceramus dimidius* was reported by Anderson (1989) in an upper sandstone of the Gallup, near Vanderwagen in the central part of the Zuni Basin. Molenaar (1983) reported *I. dimidius* from the basal part of the Gallup in the Horsehead Canyon area farther to the south. The Torrivio Member, which overlies the Ramah at a scoured contact, is perhaps a "feeder system" for some of the younger, more seaward tongues of the Gallup, such as the C-tongue or member (Molenaar, personal communication). Nummedal et al. (1995) have addressed the relationship of the Torrivio to the younger tongues of the Gallup, but the area of their discussion lies outside the scope of this paper. These younger tongues of the Gallup are considered latest Turonian in age, and thus the Ramah Member is accordingly of late Turonian age. It is important to note that these relationships imply that the Torrivio Member was deposited as active channel fill during the regressive phase shortly after emergence of the coastal plain and not during a later (transgressive) cycle of backfilling the gently incised topography.

Thickness measurements taken along a northwest line more or less parallel to the depositional strike do not show any systematic thinning of the Ramah Member. Thicknesses at the southeast end of the basin vary from 100 to 130 ft, whereas in the north near Vanderwagen and Manuelito thickness measurements are in the 105- to 141-ft range. One measured section on top of the Torrivio anticline near the village of Manuelito revealed a thickness of only 95 ft; however, the section thickens to the west over a very short distance (5–6 mi) to more than 140 ft. A short distance (10 mi) in the other direction (seaward) from this locality, at the hogback east of Gallup (Fig. 1) where Sears named the Gallup, the Ramah Member has thinned to approximately 40

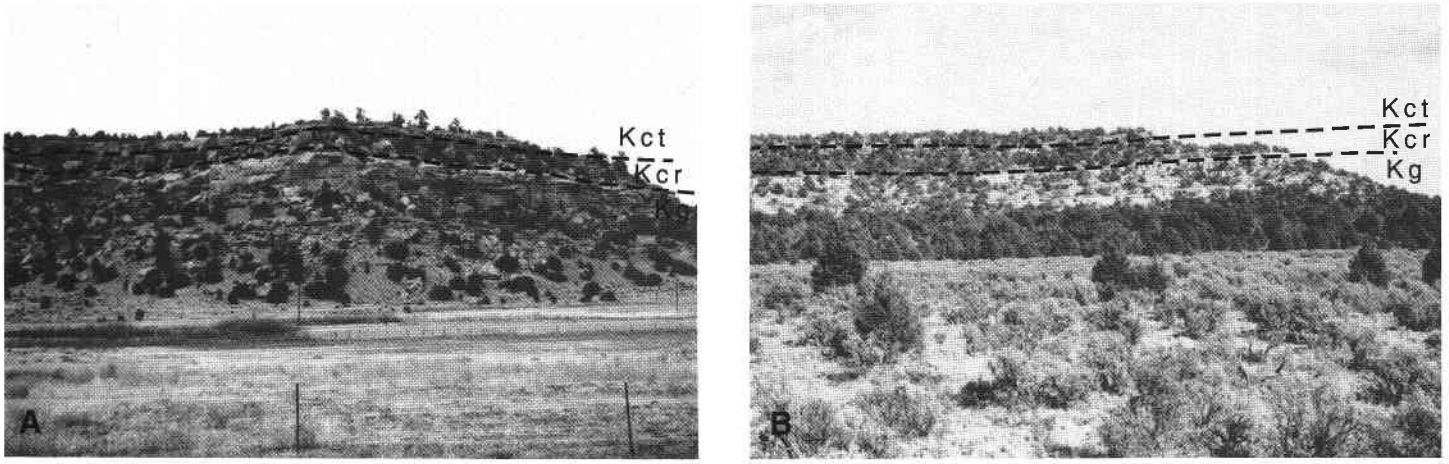
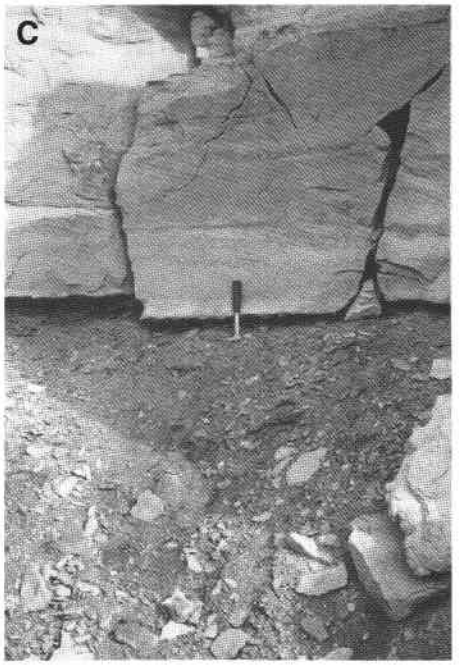


FIGURE 3—Photographs of Ramah Member of Crevasse Canyon Formation in Zuni Basin. **A**, Type locality of Ramah Member at Mower Hill, 4 mi southwest of Ramah, New Mexico; **B**, same area as in A, showing prominent medial sandstone in the Ramah Member; and **C**, carbonaceous shales of the upper of the Ramah Member overlain by thick-bedded sandstones of the Torrivio Member at hammer. **Kg,** Gallup Sandstone; **Kcr,** Ramah Member of Crevasse Canyon Formation; **Kct,** Torrivio Member of Crevasse Canyon Formation.



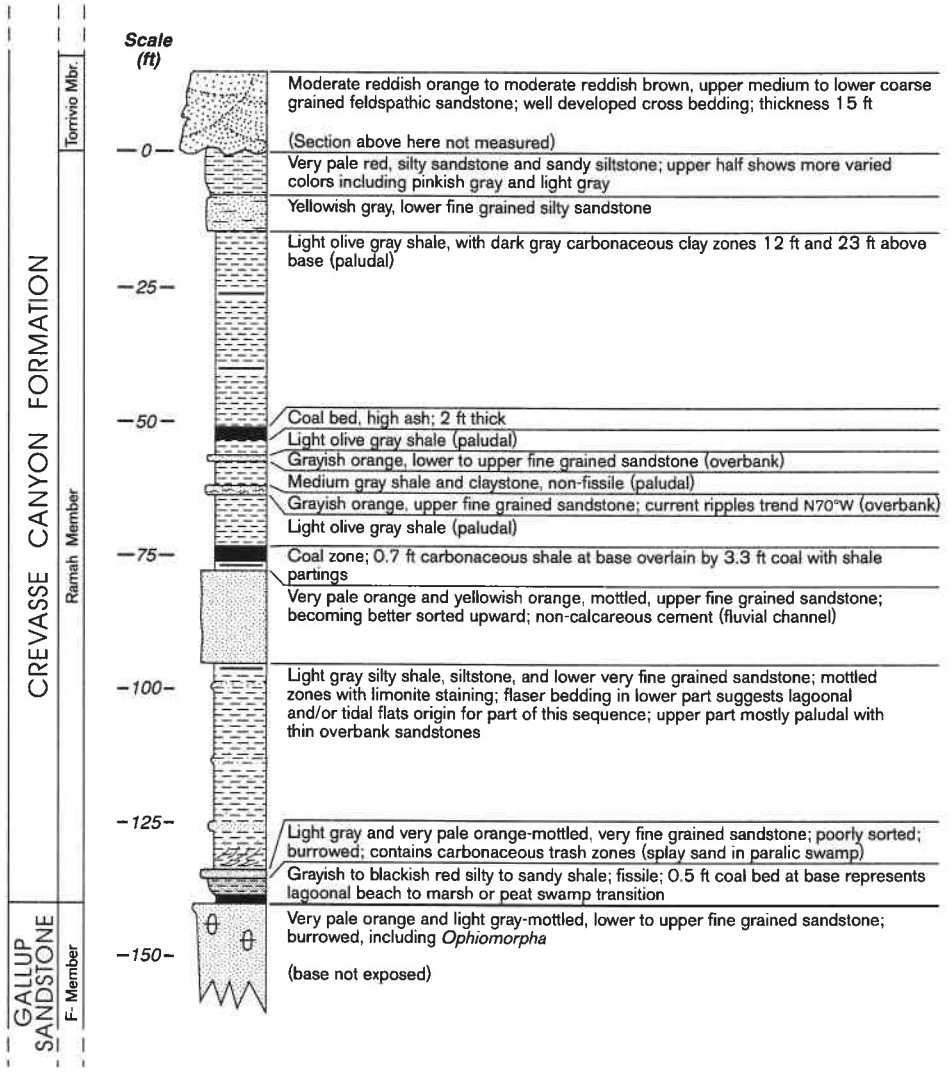


FIGURE 4—Measured section at type locality of Ramah Member of Crevasse Canyon Formation.

ft. The rate of seaward thinning of the unit in the northern part of the Zuni Basin is thus about 6.7 ft/mi.

Three measured sections of the Ramah Member were taken throughout the central portion of the Zuni Basin (Fig. 6) during a joint U.S. Geological Survey–New Mexico Bureau of Mines and Mineral Resources investigation of coal resources on the Zuni Reservation. These data show no systematic thinning with the exception that the northeast-thinning trend is apparent from the thickness at upper Nutria along the Nutria monocline; the monocline is the same structure as the hogback east of Gallup 20 mi to the north (Fig. 1).

The base of the Ramah Member is generally a sharp contact between upper shoreface sandstones of the Gallup and the paludal shale and carbonaceous mudstones, with overbank deposits, of the Ramah Member. Locally, fine-grained lagoonal or restricted bay-fill sequences form the base, but these grade laterally

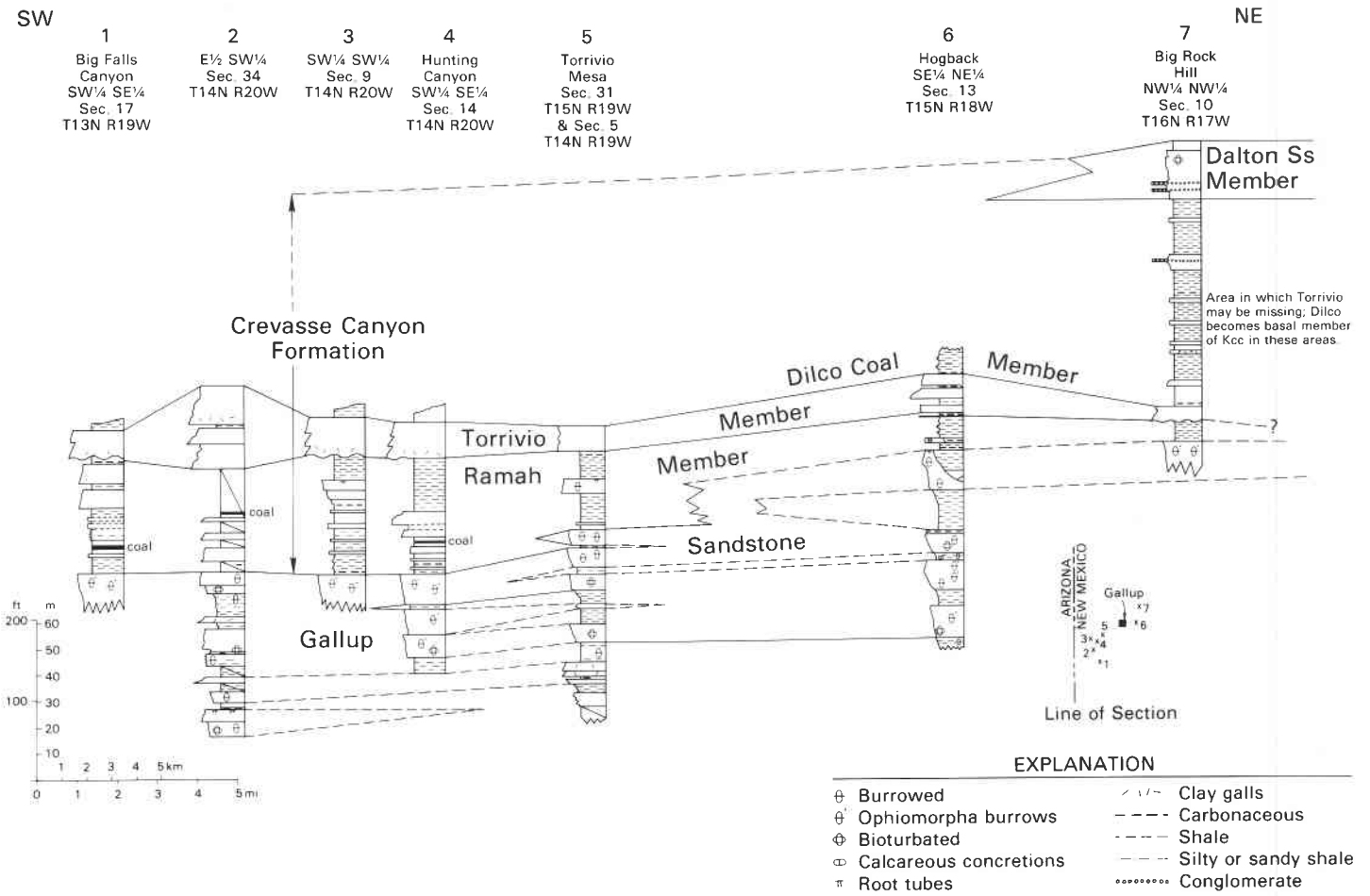


FIGURE 5—Regional stratigraphic cross section in northern part of Zuni Basin showing Ramah Member of Crevasse Canyon Formation, stratigraphically adjacent units, and lateral relationship to the lower part of the Dilco Coal Member.

over very short distances into paludal, coal-bearing sediments. The contrast in weathering characteristics produces a topographic break that is easy to trace; the Gallup is a cliff former, the Ramah is a slope former. The top of the Ramah can locally present a problem, however, such as on the Twin Buttes quadrangle where Millgate (1991) mapped a lower Torrivio with the Ramah Member and also at the boundary between the Vanderwagen and Jones Ranch School quadrangles near Big Falls Canyon (Fig. 1). At the latter locality the Ramah Member is uncharacteristically dominated by two stacked fluvial-channel systems, each about 50 ft thick. A 4-ft-thick shaly interval at the top of the two sandstones is here taken as the top of the Ramah Member. The Torrivio Member overlies with a scoured base of low relief and is readily identified by the presence of very coarse grained facies (generally lacking or very restricted in the lower sandstones) and its much greater lateral extent, giving it a blanket geometry. The Torrivio also has a somewhat more feldspathic aspect than the lower sands. Crossbed dip directions in the channel systems of the Ramah Member have not been studied in sufficient detail to permit a discussion here. Paleoflow directions in the overlying Torrivio member have been reported to be dominantly east and northeast (Anderson, 1989).

Coal resources

The Ramah Member is not a major coal-bearing unit. The coal beds tend to be thin and lenticular; however, there are localities where thickness and depth place the coals in the resource category, as defined by the U.S. Geological Survey (Wood et al., 1983).

In the northern part of the Zuni Basin in the Manuelito quadrangle, Anderson (1991) reported a coal bed as much as 3.5 ft thick near the middle of the Ramah Member. Outcrop data demonstrate the bed is highly lenticular and thins in all directions. Proximate analysis indicate the coal is high ash.

Immediately to the east on the Twin Buttes quadrangle, Millgate (1991) reported coal beds as much as 3.3 ft thick in the middle to upper part of the Ramah Member. Again lenticularity is suggested by the surrounding measurements, so coal resources are minimal and subeconomic. The coal zone, however, is thought to correlate with the coal zone in the middle of the member on the adjacent Manuelito quadrangle.

Sears (1925) reported coal production recorded as early as 1886 from the stratigraphic interval now defined as the Ramah Member. Production was from two beds, each of which was in the 2.5–3.0-ft thickness range and occur near the middle to upper part of the member. Sometimes referred to as the Myers, or Richards, coal beds from the Myers mine, production was from secs. 20 and 21 T15N R19W on the Gallup West quadrangle.

Farther south in the basin, Anderson (1990) noted coal at several stratigraphic levels in the Ramah Member on the Vanderwagen quadrangle 12 mi south of Gallup. The thickest coal beds are in the upper part of the member near the center of the quadrangle where one 5.4-ft-thick coal zone contains an aggregate of 4.3 ft of coal. In at least one locality it appears to have had very small production, perhaps for local use in space heating. Several other localities have coal beds in excess of 3 ft thick at the same stratigraphic level. Proximate analysis of these coals presented by Anderson (1990) indicate nearly all the coal beds have high ash (7.0–19.0%)

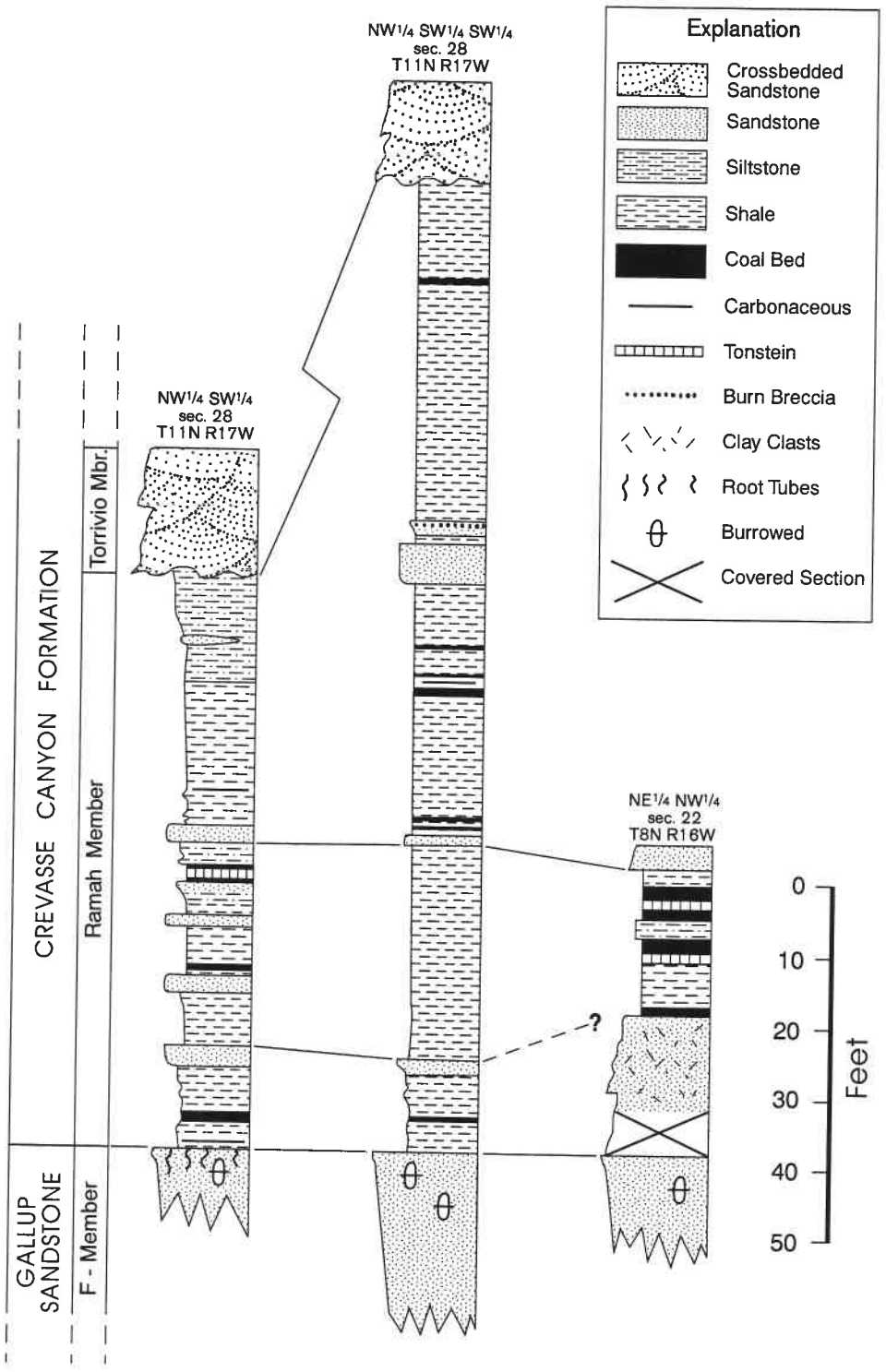


FIGURE 6—Coal-bearing sections in central part of Zuni Basin; datum is top of Gallup Sandstone.

and low sulfur (<0.7%) content with heating values in excess of 8,600 BTU/lb on an as-received sample. Resources are small, of the magnitude of 3.0 million tons/section, and subeconomic, essentially of local interest only.

Perhaps the best-known coal resources in the Ramah Member are those of the School mine coal zone on the Horsehead Canyon Northwest and the Horsehead Canyon quadrangles. Named from the small underground "School mines" (abandoned) in sec. 6 T11N R17W on the Horsehead Canyon Northwest quadrangle just north of Nutria Reservoir, the coal occurs in a 7-ft-thick zone with two or more partings of bone coal (argillaceous or high-ash coal) or tonsteins (altered volcanic-ash beds). Again, the coal is present in the upper part of the Ramah Member. It is overlain in general by a sandy shale or fine-grained, light yellowish-gray channel sandstone. Locally the Torrivio Member has cut down such that it rests on the coal zone.

Another locality that produced from the School mine coal zone is the Zuni mines (abandoned) in Coal Mine Canyon near the northeast corner of the Horsehead Canyon quadrangle just south of NM–53. These mines, which produced from two relatively thin beds during 1928–1951, saw total production of approximately 46,000 tons and became the most productive of any coal mines in the Ramah Member.

Coal-quality and resource data for the Zuni mines area were presented by Shomaker et al. (1971). They reported that the coal was moderate to high ash (16.4 to 18.6%) and low sulfur (<0.6%) with BTU values of 10,470 to 10,570. Resource estimates at the Zuni mines and for the eastward-adjacent Pescado quadrangle indicate that coal in excess of 7 million tons underlies the immediate 2 mi² area with maximum overburden of 110 ft. Unfavorable stripping conditions exist, however, because much of the overburden thickness is represented by the massive, well-indurated sandstones of the Torrivio Member.

Summary and conclusions

A more-natural and meaningful break in the late Turonian rocks of the Zuni Basin results when the top of the shoreface, lagoonal, and tidally influenced Gallup Sandstone is adopted as the upper contact of the unit and the base of the Crevasse Canyon Formation. This stratigraphic break is also significant in that it marks the end of marine influence in the sedimentary sequence of the modern Zuni Basin. The overlying strata, formerly included in the Gallup, herein designated as the Ramah Member of the Crevasse Canyon Formation, represent lower coastal plain and fluvial deposition following a retreat of the Western Interior Seaway during late-middle and late Turonian time. Age constraints consist of a Juana Lopez fauna (early-late Turonian) in the upper part of the marine Gallup Sandstone, which underlies the Ramah. The overlying Torrivio was part of a feeder system supplying sediment to the more-seaward tongues of the Gallup, which are of late Turonian age; thus, by inference the Torrivio is of late Turonian age. The Torrivio Member, formerly the uppermost unit of the Gallup Sandstone, is also affected by the downward revision of the Crevasse Canyon Formation contact. Although no redefinition of the Torrivio Member is undertaken or necessary, the unit is necessarily, by virtue of stratigraphic position, reassigned as a member of the Crevasse Canyon Formation.

Coal resources of the Ramah Member are contained in as many as three zones.

Although all are thin and discontinuous, in several areas individual beds attain a thickness of 3.5 ft; these areas are in the northern part of the basin on the Vanderwagen and Manuelito quadrangles. Production has been realized in at least three areas; the Myers or Richards mine in sec. 20 T15N R19W, the School mine in sec. 6 T11N R17W, and the Zuni mines in sec. 9 T10N R17W.

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