THE SALT THAT WASN'T THERE: MUDFLAT FACIES EQUIVALENTS TO HALITE OF THE PERMIAN RUSTLER FORMATION, SOUTHEASTERN NEW MEXICO

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ABSTRACT: **Four halite beds of the Permian Rustler Formation in southeastern New Mexico thin dramatically over short lateral distances to correlative clastic (mudstone) beds. The mudstones have long been considered residues after post-burial dissolution (subrosion) of halite, assumed to have been deposited continuously across the area. Hydraulic properties of the Culebra Dolomite Member have often been related to Rustler subrosion.**

In cores and three shafts at the Waste Isolation Pilot Plant (WIPP), however, these mudstones display flat bedding, graded bedding, cross-bedding, erosional contacts, and channels filled with intraformational conglomerates. Cutans indicate early stages of soil development during subaerial exposure. Smeared intraclasts developed locally as halite was removed syndepositionally during subaerial exposure. We interpret these beds as facies formed in salt-pan or hypersaline-lagoon, transitional, and mudflat environments. Halite is distributed approximately as it was deposited. Breccia in limited areas along one halite margin indicates post-burial dissolution, and these breccias are key to identifying areas of subrosion.

A depositional model accounts for observed sedimentary features of Rustler mudstones. Marked facies and thickness changes are consistent with influence by subsidence boundaries, as found in some modern continental evaporites. A subrosion model accounts for limited brecciated zones along (depositional) halite margins, but bedding observed in the mudstones would not survive 90% reduction in rock volume.

Depositional margins for these halite beds will be useful in reconstructing detailed subsidence history of the Late Permian in the northern Delaware Basin. It also no longer is tenable to attribute large variations in Culebra transmissivity to Rustler subrosion.

INTRODUCTION

Some see salt that was not there.
It was not there—not there, we swear.
It was not there again today;
we do not think it went away.
"Rustler halites—no dissolution."

(Apologies to H. Mearns; highly modified from J. Van Couvering, quoted in Schreiber 1978, p. 61.)

Beds in the Upper Permian Rustler Formation can be traced across tens to hundreds of kilometers, like other formations in large evaporite basins. Yet individual salt beds in the Rustler thin dramatically over short distances to equivalent siliciclastic (mudstone) units. These relationships in the Rustler have mainly been attributed to late-stage, or post-burial, subrosion (dissolution of halite) (e.g., Jones et al. 1973).

Facies changes in response to depositional environments provides an alternative explanation for dramatic thinning of these halite beds. Here we report on features, mainly from the mudstones, indicating changes in depositional environments expressed as mudflat facies adjacent to hypersaline lagoons or salt pans. We also show how subrosion at limited, specific locations along depositional margins of halite created breccia.

There is no dispute over the thickness and lithologic changes of several Rustler halite–mudstone beds across short lateral distances. *How* these relationships developed is controversial. Were Rustler halite beds deposited continuously across much larger areas and then removed by subrosion after burial, leaving the insoluble residue as mudstone equivalents? Or were these mudstones deposited on large tracts of mudflats adjacent to a hypersaline lagoon or salt pan, with facies transitions restricted by subsidence? The Rustler provides an opportunity to compare these hypotheses because the difference in thickness over short distances is not subtle, as might be the case with post-burial alteration of limited porosity.

Differences between these two explanations for the distribution of halite in the Rustler have broad implications. Hydraulic properties of the Culebra Dolomite Member vary by several orders of magnitude across the study area (e.g., Mercer 1983; Beauheim and Holt 1990) and have been related to post-burial subrosion of Rustler halite (e.g., Mercer 1983). If the halite beds are distributed as they were deposited, however, Culebra hydraulic properties are not related to post-burial subrosion of Rustler halite. A depositional margin for halite beds also helps define syndepositional tectonics and subsidence in this area.

Evaporite facies models for both marine and nonmarine halite have proliferated with detailed studies of modern environments as well as ancient deposits (e.g., reviews by Handford 1991; Kendall 1984; Smoot and Lowenstein 1991). Evaporites are also certainly susceptible to alteration (including dissolution) from the moment of crystallization. Hardie et al. (1985) separated alteration features into syndepositional and post-burial categories, and Rustler subrosion, as commonly interpreted, would clearly be post-burial. We focus on sedimentary features that are depositional and alteration that is syndepositional to very early diagenetic to interpret the Rustler halite distribution. Breccias in very local areas distinguish post-burial subrosion from depositional events.

The Rustler Formation has been studied intensively in southeastern New Mexico (Fig. 1) in support of the Waste Isolation Pilot Plant (WIPP), which is proposed for disposal of transuranic waste from U.S. defense programs (Weart et al. 1998). Scenarios describing hypothetical radionuclide releases from the site over the next 10,000 years generally involve fluid transport through the Culebra Dolomite Member. It can be shown that the variation in hydraulic properties of the Culebra is not related to the thickness of Rustler halite beds (Holt and Powers, unpublished work), and this should be a reasonable test (and rejection) of the hypothesis that subrosion of Rustler halite caused the variation. Nevertheless, the geologic grounds for invoking depositional processes to explain the distribution of Rustler halite can be independently established. Late Permian subsidence in southeastern New Mexico can also be reconstructed in much greater detail if depositional margins are established for Rustler halite.

Brief History of Recent Rustler Studies

When the U.S. Geological Survey began in 1972 to assess salt deposits in southeastern New Mexico for a radioactive waste repository, each of the Ochoan evaporite formations was considered partially dissolved (e.g., Jones et al. 1973; Bachman 1974). As WIPP drilling proceeded through the mid-1980s, several Rustler mudstones were routinely listed as "dissolution residues" (e.g., Ferrall and Gibbons 1980; Jones 1981), though these intervals were seldom cored and few textures or sedimentary features were recorded. Barrows et al. (1983) considered layering in the mudstone at drillhole WIPP 19 as evidence of post-burial, even geologically recent, karst rather than

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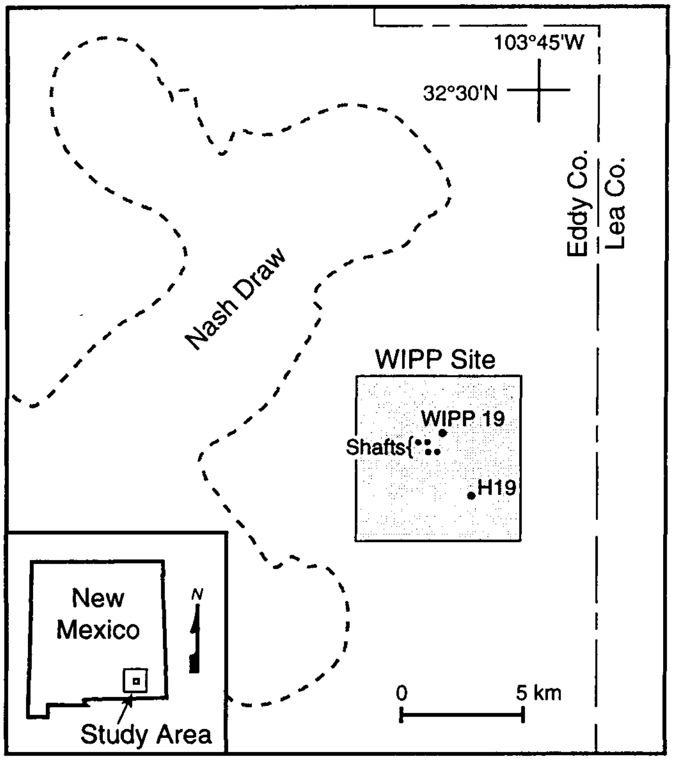

FIG. 1.—Map of WIPP, drillholes, and features in general study area of Rustler mudstone to halite beds.

as a depositional feature. Regional thickness variations within the Rustler were attributed mainly to subrosion (e.g., Powers et al. 1978). There were few observations of primary features and little sedimentological analysis of the Rustler. Eager (1983), an exception, provided some detail based on core studies in the southern part of the Delaware Basin. Ferrall and Gibbons (1980) catalogued some Rustler sedimentary features in several cores at the WIPP site.

We first mapped and described the Rustler during construction of the WIPP waste shaft (Holt and Powers 1984). Two additional large-diameter shafts were mapped (Holt and Powers 1986, 1990), and Rustler facies were identified and extended through cores and geophysical logs (Holt and Powers 1988).

On the basis of geophysical logs from five drillholes and core from a drillhole in Nash Draw, Snyder (1985) identified east-to-west changes from halite to mudstone, decreased thickness, and changes of underlying and overlying anhydrite to gypsum. Snyder (1985) concluded that Rustler halite had been dissolved, leaving the residues, and converting anhydrite to gypsum. Lowenstein (1987) described sedimentary structures and "late stage alteration" features from four WIPP Rustler cores. Lowenstein concluded that halite had been dissolved from these units, but he did not discuss sedimentary features that had already been reported in mudstones from two WIPP shafts that had been mapped and described by that time. West of the WIPP site, Bachman (1987) reported karst in Rustler sulfates at and near the surface, which is not in dispute; he also reported facies changes in lower Rustler clastics south of the WIPP area.

SEDIMENTARY STRUCTURES OF ALLEGED DISSOLUTION RESIDUES

Four Rustler intervals (Fig. 2) are most commonly described as dissolution residues: the basal Rustler mudstone, the mudstone–halite (M-2/H-2) underlying the Culebra, the Tamarisk mudstone–halite (M-3/H-3), and the Forty-niner mudstone–halite (M-4/H-4). We use "mudstone" more

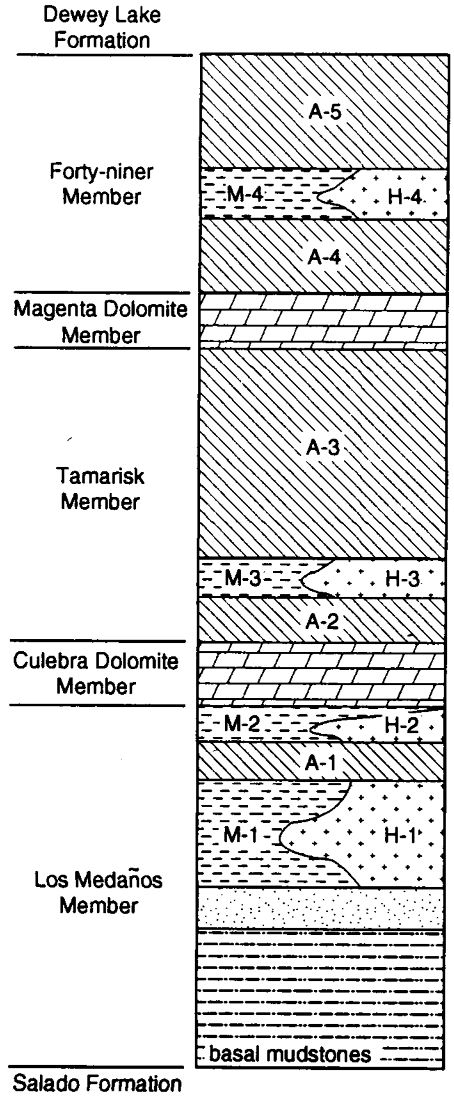

FIG. 2.—General Rustler Formation stratigraphy, lithology, and mudstone/halite lithofacies. Four intervals (basal Rustler, M-2/H-2, M-3/H-3, M-4/H-4) have been considered in the past to have had halite removed by solution in southeastern New Mexico. M-1/H-1 has not generally been specified as a solution residue; in some studies, thickness changes for the Los Medaños member are totaled. M = mudstone, H = halite, A = anhydrite. Los Medaños Member is proposed elsewhere as a new name to replace "unnamed member" (Powers and Holt in press). Modified from Holt and Powers (1988).

generally for these clastic units because silt and clay grain sizes predominate.

We limit references in our discussion to avoid repetition; data are based primarily on Holt and Powers (1984, 1986, 1988, 1990) because there are few other reports of such features.

Basal Rustler (Lowermost Los Medaños Member)

Salt of the upper Salado has been dissolved west of the WIPP site, creating a residue (Jones et al. 1960; Jones et al. 1973), and we agree with this interpretation of subrosion. At the WIPP site, the Rustler/Salado contact is easily defined in the shafts, in cores, and on geophysical logs. The upper Salado maintains a uniform thickness through this area, and no halite has been dissolved from the top of the Salado since the Rustler began to be deposited. Just above the contact, each WIPP shaft revealed erosional

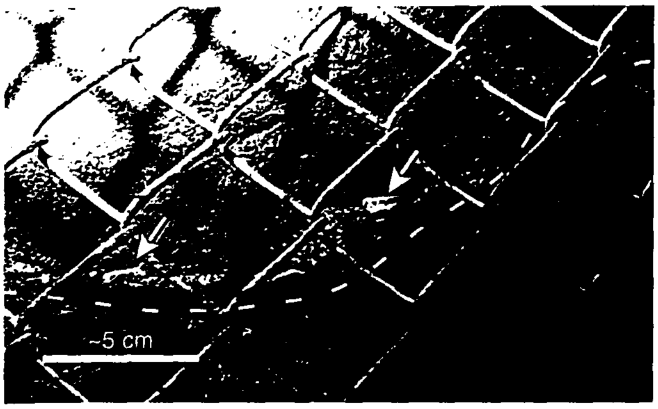

FIG. 3.—Undulatory contact (dashes) and clasts (arrows) in erosional channel of basal Rustler in photo from WIPP waste shaft. The retaining fence is against the shaft wall. Small fossil fragments are present, but they are not discernible in the photo.

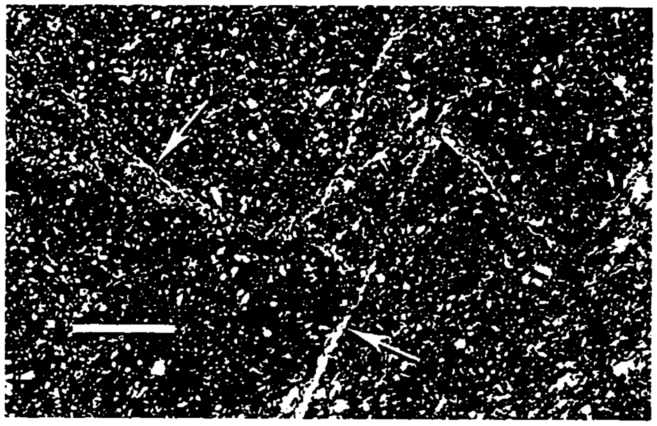

FIG. 4.—Oriented clay skin or cutan (see arrows) around mudstone particle formed during incipient soil formation in a mudflat environment. The modest cutan is consistent with limited soil development. The thin section was oriented vertically (perpendicular to bedding). Scale is 2 mm long.

surfaces with undulatory contacts or channeling (Fig. 3), pebble conglomerates with invertebrate fossil fragments, fining-upwards sequences, and varying bedding and cross-bedding. Cores include similar features, though channels and undulatory erosional contacts are not identifiable.

This interval records a transition from the Salado evaporites to Rustler clastics deposited in saline marine lagoonal environments (Powers and Holt 1990). Clasts with fossil fragments, continuous erosional contacts, and well-preserved channels (Fig. 3) near the base indicate a depositional origin rather than a dissolution residue.

M-2/H-2 (Top of Los Medaños Member)

Reddish brown to gray claystone to mudstone about 2 to 3 m thick underlies the Culebra and overlies a regionally persistent anhydrite (A-1) (Fig. 2).

The lower part of M-2 is reddish brown mudstone with bluish gray interlaminae and thin discontinuous laminae of gypsum. Oriented clay skins (cutans) around mudstone particles (Fig. 4) are diagnostic of soil-forming processes (e.g., FitzPatrick 1984). We also interpret smeared intraclast textures (see box) in M-2 as indicators of synsedimentary halite solution.

The upper part of M-2 is dark gray mudstone to claystone with siltstone interbeds. It is continuous across the region, of about the same thickness, and can be identified in geophysical logs by a strong natural gamma signal just below the Culebra. Thin laminae, wavy bedding, structureless intervals, fining-upwards zones, and contorted bedding have been identified.

The lower part of M-2 is a facies equivalent to halite in the Rustler depocenter east of the WIPP site. The halite is about 18 m thick 25 km southeast of the WIPP site, and the natural gamma signal is at background levels, indicating that clay is absent or very limited. Toward the WIPP site, natural gamma increases, manifesting lateral changes in the clay content corresponding to lateral changes in depositional environments.

M-2/H-2 facies were deposited in a salt pan to the east and as mudflats west of a transition zone. The mudflats were exposed subaerially, had halite removed syndepositionally (smeared intraclasts), and developed incipient soil features (cutans). On the basis of geophysical logs, halite in the depocenter is too pure to accumulate a mudstone residue as thick as M-2. Bedding would also have had to survive a 90–95% volume reduction if M-2 were a residue of a halite as pure as that present in the depocenter.

M-3/H-3 (Tamarisk Member)

M-3 is about 2–3 m thick at and near the WIPP shafts (Fig. 6). As in M-2, the lower part of the unit is reddish brown whereas the upper part is gray. Parallel bedding is observable throughout the unit. In the exhaust shaft, local stringers of fine-grained orange sandstone and thin laminae were observed. The air intake shaft reveals possible algal growth structures at the top of M-3, under thick Tamarisk sulfate. Smeared intraclasts, soft-sediment deformation, and probable flame structures were identified. Clasts of anhydrite become finer upward from near the base. The unit has abundant slickensides, gypsum-filled fractures, gypsum nodules, and broken, thin gypsum beds. The softer mudstone was deformed by ductile flow between thick, stiff anhydrites (A-2, ~6 m; A-3, ~18 m).

Channels at the exhaust and air intake shafts offer striking evidence of origin. At the air intake shaft, a channel about 0.8 m deep in the mudstone is filled with siltstone-pebble conglomerates (Fig. 7). In the exhaust shaft, a channel filled with mudstone eroded the underlying anhydrite, and anhydrite clasts grade upward to finer sizes. At drillhole WIPP 19, an erosional channel removed the lower Tamarisk anhydrite and was filled by a graded conglomerate of intraclasts (Fig. 8) and laminar siltstone.

H-3 thickens to about 50 m in the depocenter east and southeast of the WIPP site. Geophysical logs across the depocenter display very pure halite intervals, halite with either polyhalite or clay (indicated by increased gamma), and discrete beds of polyhalite and anhydrite (Fig. 6). Upper halite beds are more restricted than are lower units, demonstrating that the halite pan was shrinking with time.

Bedding, channels, graded conglomerates, and smeared intraclast textures indicate that M-3 accumulated on a mudflat environment adjacent to a deeper salt pan or hypersaline lagoon at the depositional center (e.g., Handford 1982). Runoff from surrounding areas flowed toward the depositional center, cutting channels and transporting intraclasts. Displacive and incorporative halite and gypsum grew in soft mud adjacent to the salt pan but were removed by rainfall and unsaturated runoff, producing smeared intraclast textures and nodules. Sulfate-rich water later flooded the basin, depositing the overlying thick anhydrite.

Salt in H-3 remains distributed approximately as originally deposited. Holt and Powers (1988) and Beauheim and Holt (1990) suggested that halite depositional margins are the most likely locations for postdepositional dissolution of halite. As an example, drillhole H 19 (Fig. 1), located at the margin of this halite (H-3), shows brecciation of the mudstone and overlying sulfate (Fig. 9), which we interpret as a consequence of dissolution of H-3.

M-4/H-4 (Forty-niner Member)

In the WIPP shafts, M-4 is mainly siltstone and is about 4–4.5 m thick. The M-4 siltstones displayed thin laminae to fissile beds, traces of cross-lamination and ripples, excellent thicker bedding, small lenses of siltstone

Smeared Intraclast Textures

In describing muddy halite to mudstone beds from the Rustler Formation, Holt and Powers (1988) repeatedly observed textures that they termed "smeared intraclasts" because of common features. Such features have not previously been described, though Smith (1971) saw the consequences of synsedimentary growth and dissolution of halite from soft sediments and called the process "haloturbation."

Characteristics:

1) they are discrete clasts, generally 2 to 5 cm in any dimension (Fig. 5A);
2) the lithology is the same (commonly mudstone or silty claystone) as the rest of the mudstone unit—the clasts are not transported in from far areas. For this reason, Holt and Powers (1988) termed them "intraclasts."
3) internal thin bedding or laminae are identifiable in many of the clasts, and the laminae were distorted or "smeared" while soft (Fig. 5B).

Origin

The origin of smeared intraclasts is based on *observations* of the sequence of features within Rustler cores. Interlaminated claystone and halite show the beginning. Halite growth textures and synsedimentary dissolution form clasts and smear bedding. Further removal of halite and subsequent deposition compacts intraclasts. Repeated episodes may stack smeared intraclasts. In mudflats proximal to the salt pan, successive layers may also be undisturbed until the water table falls. The geological *context* is consistent with development of such textures. Smeared intraclasts represent an important indicator of haloturbation on saline mudflats.

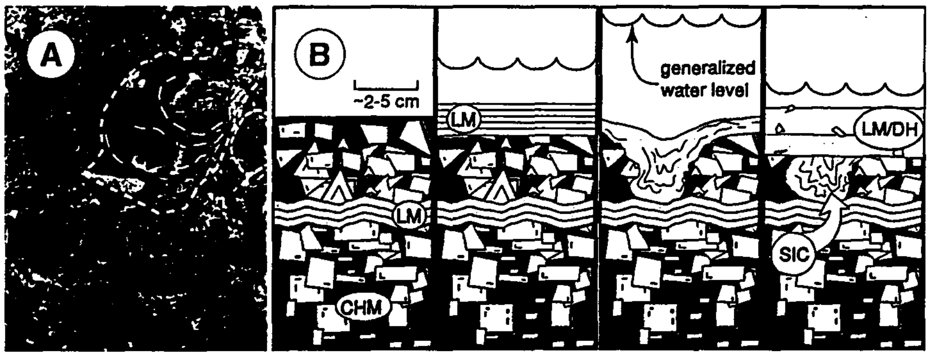

Fig. 5.—Smeared intraclast texture. **A)** Discrete clasts in halite are outlined by longer white dashes. Internal bedding is emphasized by thinner white dashes. The core is about 5 cm wide. **B)** Generalized diagram of stages of developing isolated smeared intraclasts, such as shown in A. CHM, chaotic halite and mudstone; LM, laminar mudstone; SM, smeared intraclast; DH, displacive halite.

and fine sandstone similar to flaser bedding, erosional contacts, sandstone pebbles, smeared intraclasts, local skeletal halite, soft-sediment deformation, and zones disrupted by gypsum growth and enterolithic gypsum. Small fractures in some beds were filled with gypsum. M-4 has reddish brown and gray interbedding.

Sharply defined bedding, crosscutting relationships, and sedimentary structures were formed by surface flow of water. The mudflat area may have had more sheet flow than in M-3, in keeping with the lack of deeper channeling. Erosional surfaces developed modest relief (centimeter scale) on a low-relief mudflat. Gypsum crystallized within soft sediments. Some features in this unit indicate limited haloturbation farther from the salt pan, whereas some halite within sediment closer to the salt pan survived.

In the depocenter, H-4 is about 9 m thick, and geophysical logs indicate that it is nearly pure halite. The halite pan was smaller for H-4 than for other Rustler halites. This 9-m-thick halite would not create a 4.5-m-thick residue (M-4), even if the sedimentary features of M-4 are disregarded.

DISCUSSION

Depositional Features

Within the mudstones previously interpreted as dissolution residues we have described different bedding and sedimentary structures that are syndepositional (Hardie et al. 1985), most of which are related to mudflats adjacent to saline pans or saline lagoons. Pedogenic features (cutans) found

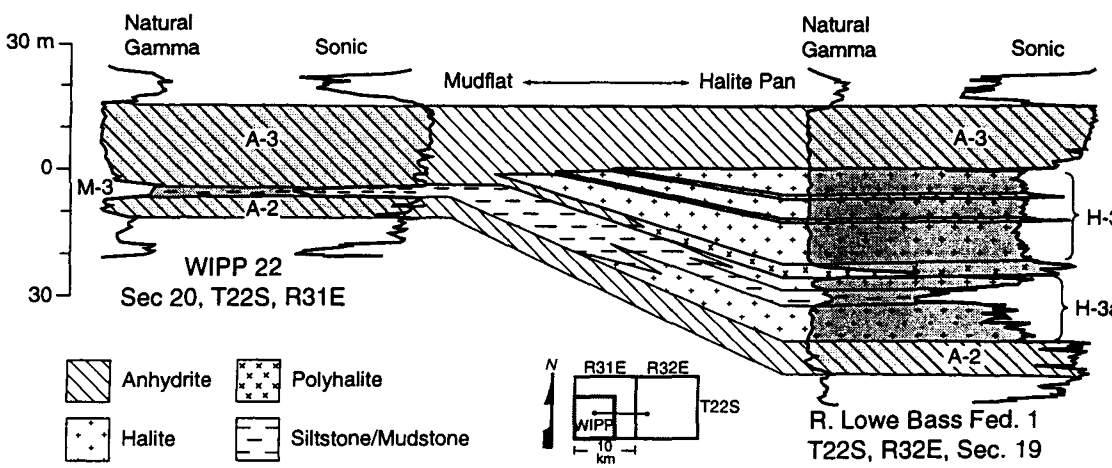

Fig. 6.—Geophysical logs and lithology, focusing on M-3/H-3 interval. Using base of A-3 as a level emphasizes thickness and changes in M-3/H-3. This cross section is across the northern edge of depocenter for M-3/H-3. WIPP 22 is 143 m north of WIPP 19 (Fig. 1).

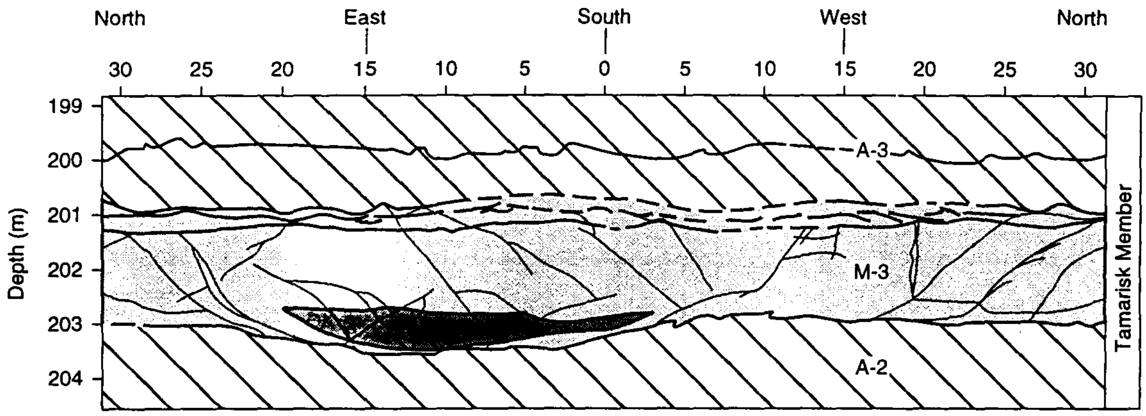

FIG. 7.—Mapped channel in M-3 from air intake shaft (after Holt and Powers 1990). The side of the channel was intersected only in the southeastern quadrant. A-2 and A-3 are anhydrite. M-3 is generally mudstone, whereas the channel is filled by siltstone pebble conglomerate. Irregular lines in M-3 show mapped fractures.

in one unit are diagnostic of subaerial exposure and infiltration of meteoric water. Cutans may be more common within mudflat facies that are exposed for longer periods of time, and should be looked for along with other pedogenic features in evaporites (see Smoot and Lowenstein 1991). Thin sections oriented perpendicular to the depositional surface best reveal them.

FIG. 8.—Core (from drillhole WIPP 19) of graded conglomerate of unit M-3 in the stratigraphic position of the underlying anhydrite (A-2). The conglomerate is interpreted to have been deposited in a channel, like those observed in WIPP shafts (Fig. 7), that completely eroded the anhydrite. The core is about 5 cm wide.

Smeared intraclasts are a texture that should help diagnose synsedimentary dissolution or haloturbation of bedded mudstones. Near smeared-intraclast textures, some cores show sharp truncation of halite by mudstone, indicating flooding of the salt pan with undersaturated water (Lowenstein and Hardie 1985). These preserved relationships indicate both that smeared intraclasts are syndepositional (not caused by post-burial subrosion) and that the setting was consistent with incursions of water capable of dissolving some of the halite. The deformed (smeared) laminae in some clasts may have begun as such truncating mudstones. In settings near the margin of the halite pan, the intraclasts have foundered into beds that include coarse halite crystals. We suspect that formation and destruction of efflorescent halite, such as found by Smoot and Castens-Seidell (1994), play a strong role in forming smeared intraclasts in more distal mudflats, where neither subaqueous halite nor phreatic halite crystallized.

Natural gamma logs show that the thickest part of halite units (depocenter) in the Rustler tend to have very little siliciclastic material. As a consequence, without some significant facies change, there would not be enough clastic material in these halites to form a "dissolution residue" as thick as the mudstones.

Post-Burial Dissolution

Halite has been dissolved from different formations with different results. Schreiber and Schreiber (1977) found that millimeter-scale halite beds disrupted epitaxial gypsum growth in Messinian evaporites; laterally the disruption occurred without the intervening halite, suggesting that halite had been removed by dissolution. Gustavson et al. (1980) reported salt sequences in Permian rocks of Texas that thin or are absent over distances of a few kilometers associated with consolidated to unconsolidated red-brown mud overlying salt beds, breccia beds, sinkholes, and collapse chimneys. Parker (1967) showed that salt dissolution in evaporites in the Williston Basin (North Dakota) resulted in rubble or breccia at the dissolution horizon and thicker units deposited after dissolution. Anderson et al. (1972) correlated breccias to salt beds in the Permian Castile Formation in the Delaware Basin and concluded that post-burial salt dissolution had created the breccias. Many other studies have concluded that post-burial dissolution of halite or other evaporite rocks at depth formed brecciated beds.

El Tabakh et al. (1998) proposed a novel origin for the Basal Anhydrite of the Cretaceous Maha Sarakham Formation as a solution residue by dissolving halite from underneath. Although anhydrite is altered at the microscopic level, no brecciation is evident. This process seems an unlikely explanation, however, for our observations of mudstones within the Rustler.

Cores of the Rustler and upper Salado Formation near Nash Draw, west of the WIPP site, are highly brecciated. In that area, the upper Salado is still being actively dissolved at depth (Jones et al. 1973) and the Rustler

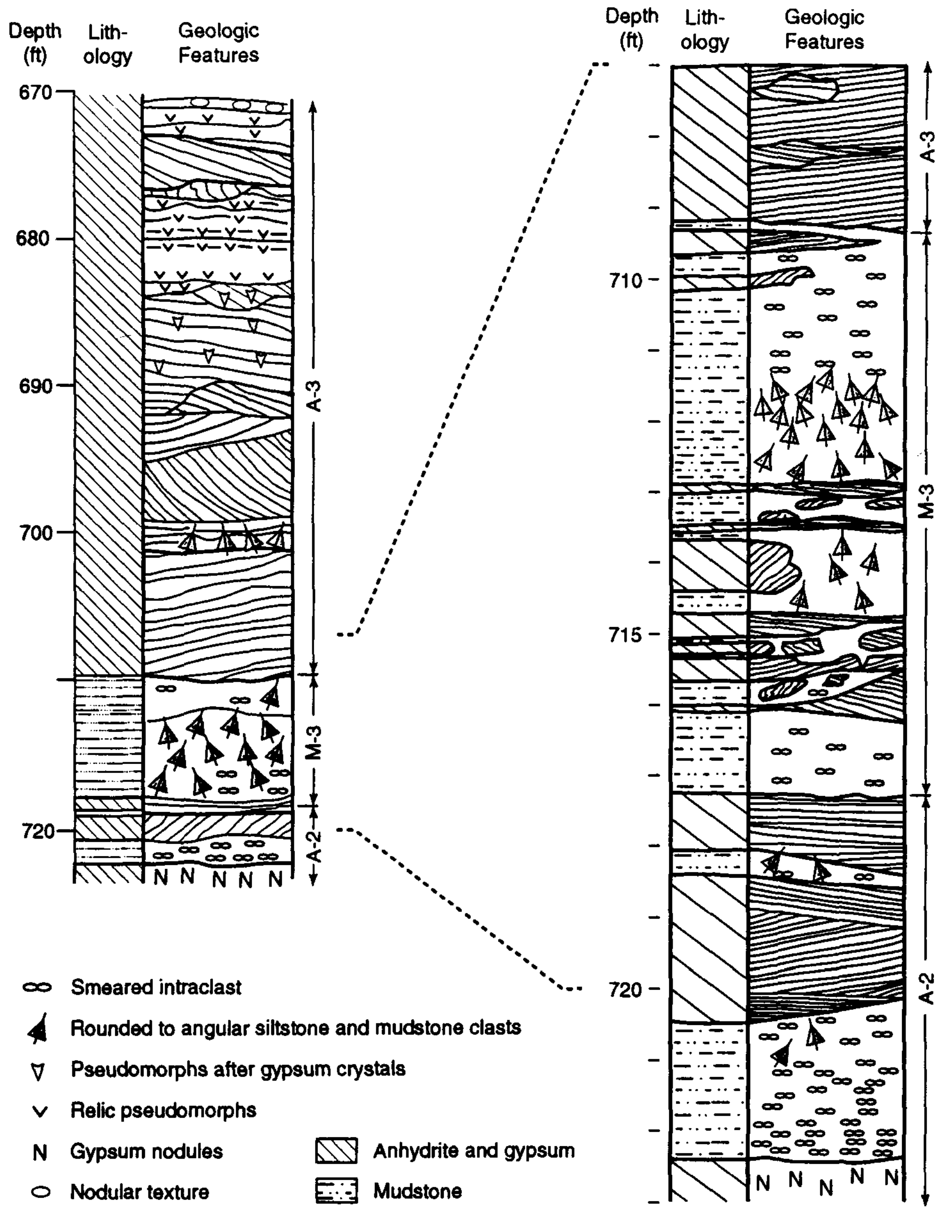

FIG. 9.—Brecciated intervals from drillhole H 19 where post-burial subrosion removed H-3 halite, as hypothesized by Holt and Powers (1988) and Beauheim and Holt (1990) prior to drilling. Modified from Mercer et al. (1998).

sulfate beds are being attacked by karst (Bachman 1974). Holt and Powers (1988) found that 1–2 m of the overlying Rustler was disrupted for every 1 m of Salado salt removed from the upper part of the Salado.

From study of WIPP cores and shafts, Holt and Powers (1988) and Beauheim and Holt (1990) hypothesized that halite in narrow zones along the halite margin in the Rustler might have been dissolved in the southeastern part of the WIPP site. Several closely spaced cores obtained since then at the H 19 drillhole location reveal that the mudstone (M-3) and overlying anhydrite (A-3) are brecciated. This is consistent with the proposal that halite is distributed in the Rustler principally in response to depositional environments and that this depositional margin develops brecciation if subrosion occurs.

An unwritten argument about depositional features we described from Rustler mudstones is that dissolution was very slow and therefore preserved them. We reject this argument for four reasons. More than 90% of the thickness would have had to be removed for some units while still preserving bedding features. Halite facies have insufficient insolubles for the thickness of equivalent mudstones or to protect bedding features. Breccias form in these rocks in areas when significant salt is dissolved. And the depositional features provide a simpler answer as a facies change. Lowenstein (1987) and Holt and Powers (1988) reported various post-burial alteration features not discussed here, and we believe that halite cements, in small volumes, could have been removed from some of the mudstones long after deposition without disrupting these features. Order-of-magnitude reduction in thickness in the Tamarisk Member, however, is quite a different matter.

Continuity

The two carbonate members and several major anhydrites in the Rustler are continuous well beyond the halite margins. It is implicit in the notion of post-burial subrosion of the Rustler that the halite beds were also deposited uniformly across much larger areas, and Lowenstein (1987) explicitly stated this expectation. Studies of the underlying Salado Formation have often emphasized just such continuity (e.g., Jones et al. 1960; Lowenstein 1988) across this area of the northern Delaware Basin, and the

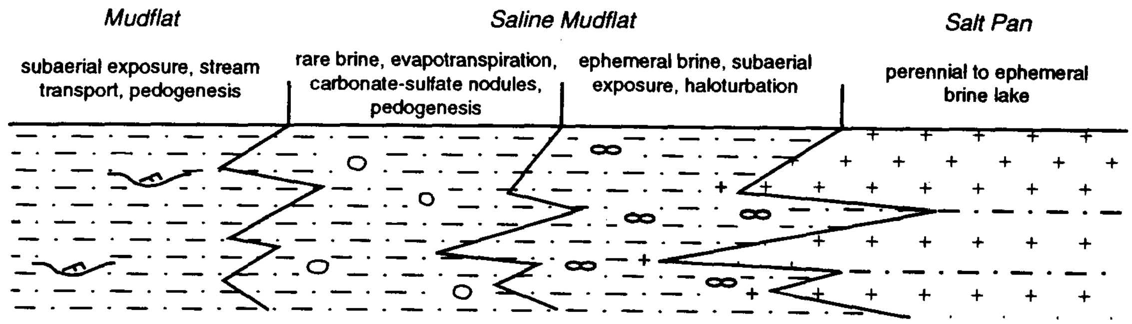

FIG. 10.—Generalized mudflat to salt-pan facies indicated by Rustler mudstones and halite.

Rustler might be expected to be similar. If such continuity is assumed, subrosion or some other postdepositional process must be invoked to produce the lateral changes observed in Rustler mudstone–halite units.

Though assumed continuity of beds is a reasonable initial hypothesis, it fails here for two reasons. As mentioned before, geophysical logs of the thick halite beds show little evidence of insoluble silicates; if these beds had continued across the facies tract now occupied by mudstone, subrosion would have left virtually no residue. Bedding and bedding relationships could not have survived such a high proportion of volume removal and be intact. The far simpler explanation is that we see continuity of beds, but in the form of facies expressing lateral changes in original depositional environment across the study area.

Model Contrasts

A general depositional model of salt pan or saline lagoon to distal mudflats (Fig. 10) is consistent with the features and lateral relationships observed in the mudstone–halite beds of the Rustler. This model is similar to, though differing in scale from and less detailed than, a variety of facies relationships commonly observed in modern evaporite environments (e.g., Handford 1982). Because of the continuity of the underlying evaporites in the study area, however, the sharp lateral changes were unexpected, and early investigators did not consider the possibility that the depositional environments did not extend across this area. Nevertheless, studies of modern continental evaporites show facies changes over short distances when influenced by the tectonic setting (e.g., Smoot and Lowenstein 1991). Evidence of facies changes based on sedimentological features leads us to consider tectonic influence for the Rustler halite distribution.

A model of subrosion of thick halite beds is also consistent with Rustler features in limited areas. Mudstone and overlying anhydrite has been brecciated along the margin of M-3/H-3 where cored at drillhole H 19. This is expectable where thick units have been dissolved under competent beds, and many other areas reveal the same phenomenon. West of WIPP, the Rustler has also been brecciated where the underlying Salado has been removed by subrosion.

Implications

The Rustler is a rare example of an ancient evaporite unit with sufficient sampling by shafts and cores to reveal features of mudflat deposition and a transition over a short distance to the salt pan or salt lake. Bedding, channels, conglomerates, soil features, and smeared intraclasts denote a mudflat origin. Breccias appear to be the key indicator of significant post-burial subrosion.

Depositional margins for halite in the Rustler leads to inferences about the tectonic setting and subsidence concurrent with deposition. The late Permian tectonic history of this part of the Permian Basin is more complicated than previously thought. Such a hypothesis (depositional margins of halite) is also consistent with the finding that hydraulic properties of the Culebra Dolomite Member are not related to thickness of Rustler salt, as would be expected if hydraulic properties developed as a consequence of subrosion.

Without evidence that the Culebra hydraulic properties developed in response to subrosion, especially subrosion over the last 10,000 years, there is no basis for concluding that Culebra properties will change in similar ways over the next 10,000 years, the period for evaluating isolation of transuranic waste at the WIPP. Understanding how halite in the Rustler was originally distributed is significant in predicting geohydrologic behavior for an important project.

SUMMARY AND SIGNIFICANCE

Though not explicitly stated, it is clear that prior to 1984 Rustler halite beds were assumed to have been deposited uniformly across the study area. Thin Rustler mudstones at and west of WIPP were considered to be residues left after subrosion of the much thicker halite beds. Sedimentological evidence shows instead that mudstone and equivalent halite facies were deposited in laterally varying depositional environments. Important features in the mudstones indicating, or consistent with, mudflat environments include halite growth textures, haloturbation, smeared intraclasts, enterolithic gypsum, bedding, channels, conglomerates, and soil textures (cutans). Rustler halite facies are still distributed mainly as deposited. The rocks have been brecciated where halite dissolved locally along the depositional margin of halite. Breccias are expectable where significant thickness of halite has been dissolved after burial.

Our model of deposition accounts for the observed Rustler mudstone–halite distribution. Significant post-burial subrosion is inconsistent with the sedimentological features of these mudstones. Until the WIPP shafts were available for mapping, however, there was no obvious geological basis for considering facies variability as an alternative to subrosion of Rustler halites.

During early WIPP work, it was also considered obvious that Culebra hydraulic properties were altered by collapse after Rustler subrosion, even though the largest change in thickness of Rustler halite occurs above the Culebra. The idea that Culebra hydraulic properties developed mainly as a consequence of dissolution of Rustler halite is no longer tenable. Neither is there justification for predicting large, additional changes in Rustler hydraulic parameters across the WIPP site over the next 10,000 years based on past Rustler halite dissolution.

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