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# DIAGENESIS OF THE SAN ANDRES FORMATION: UNIT 4 CARBONATE, G. FRIEMEL AND DETTEN WELLS

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## ABSTRACT

Petrographic examination of 71 thin sections from the San Andres unit 4 carbonate reveals a complex diagenetic history. Diagenetic events include precipitation of calcite cement, neomorphic replacement of micrite by sparry calcite, development of moldic porosity, dolomitization, precipitation of halite and anhydrite, minor precipitation of celestite, and replacement of halite by calcite, dolomite, and anhydrite. Porous intervals are recognized within the San Andres unit 4 carbonate, corresponding to partly or completely dolomitized intervals. These diagenetic phases reflect an active history of changes in water composition, suggesting potential for further studies of rock-water relationships.

## INTRODUCTION

This progress report presents data and preliminary interpretations of ongoing core analysis of the San Andres Formation. Previous reports have described the depositional environments and facies relationships in the San Andres Formation (Fracasso and Hovorka, 1984) and the facies and detailed stratigraphy of the thick halite of units 4 and 5 of the San Andres Formation (Hovorka and others, 1985). Data presented here are supplemental to those reports, and the reader is referred to them for background information.

Nine cores have been drilled by the U.S. Department of Energy (DOE) through the entire San Andres Formation (figs. 1 and 2). The core has been logged in detail and sampled for a wide variety of analyses. This paper discusses the petrography of the San Andres unit 4 carbonate in the Stone and Webster Engineering Corporation (SWEC) Detten No. 1 and SWEC G. Friemel No. 1 cores. This is the initial phase of a study of diagenesis of the carbonate, anhydrite, halite, and clastics in the entire San Andres Formation. Additional information acquired upon completion of petrographic study of the San Andres

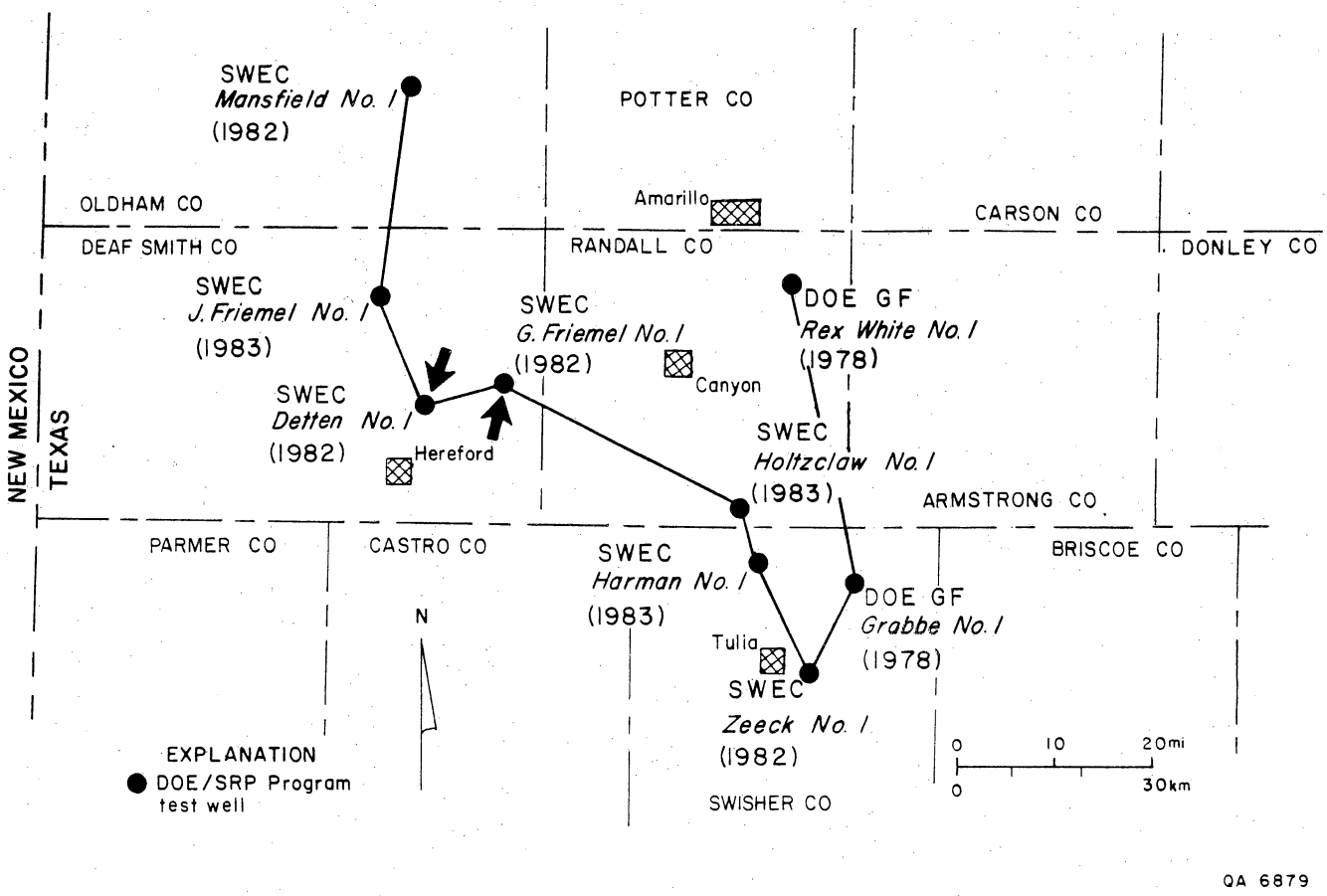


Figure 1. Location of wells cored by DOE in the Palo Duro Basin. Cores from the SWEC G. Friemel No. 1 and the SWEC Detten No. 1 wells examined in this study are indicated with arrows. Line of section indicates location of cross section (fig. 2).

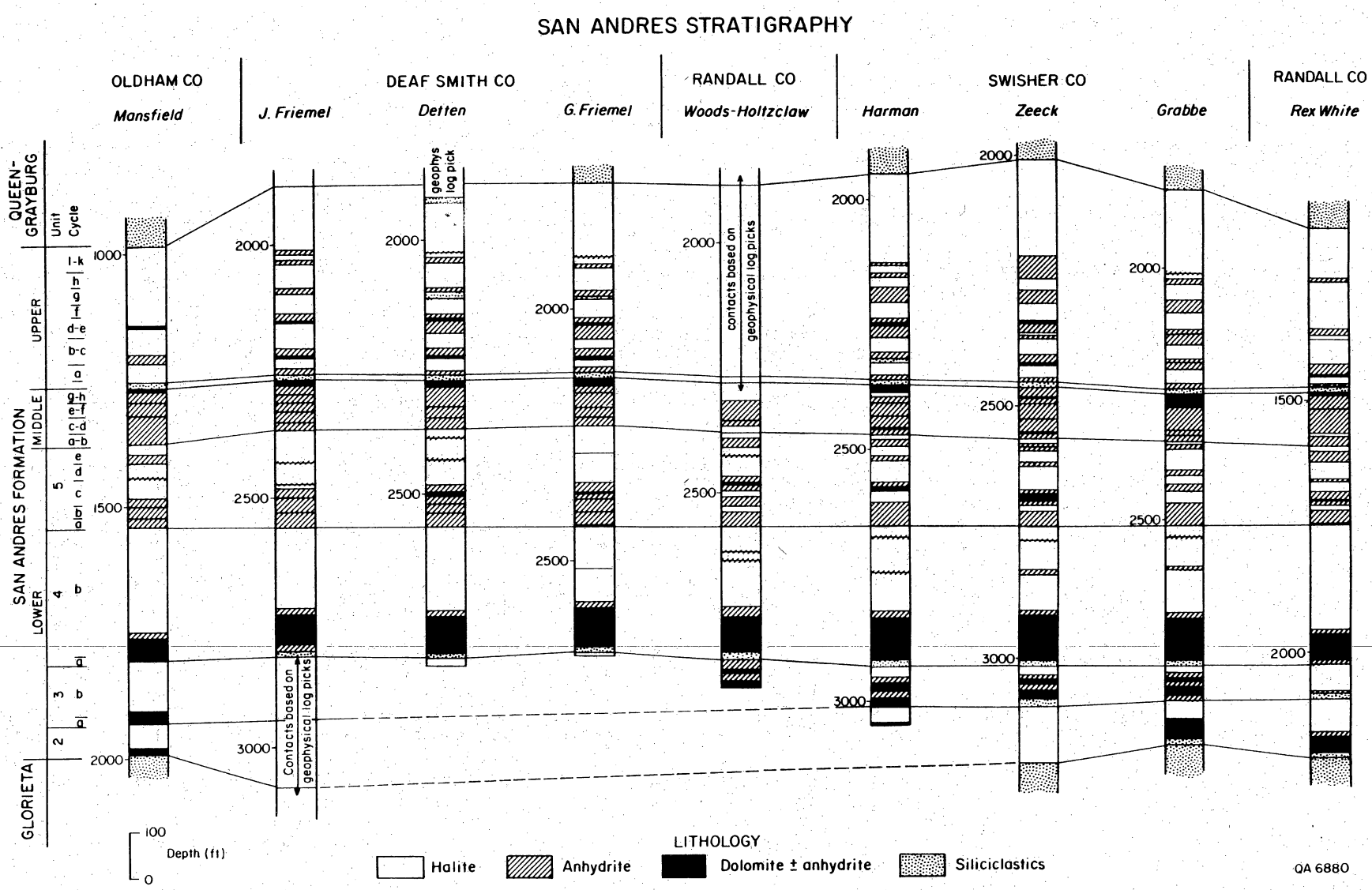


Figure 2. Stratigraphy of the San Andres Formation as shown in cores from DOE wells. The San Andres unit 4 carbonate in the SWEC G. Friemel No. 1 and the SWEC Detten No. 1 wells is the unit examined in this study. Line of section shown in figure 1.

unit 4 carbonate and the overlying and underlying units is expected to require modification of the interpretations presented here.

## PURPOSE AND METHODS OF STUDY

Petrologic examination of the carbonates of the San Andres Formation was undertaken in order to interpret the diagenetic history of these sediments. The unit 4 carbonate of the SWEC Detten No. 1 and SWEC G. Friemel No. 1 cores was examined for a limited pilot study to determine the kinds of diagenetic problems and the degree of complexity to be encountered in a study encompassing all of the DOE wells.

Slabbed core of the San Andres unit 4 carbonate from DOE wells was routinely examined and logged (app. A). Thin sections were selected from the San Andres unit 4 carbonate, the overlying thin anhydrite, and the underlying thin, dark mudstone (app. B). Samples were selected of (1) representative lithologies and (2) significant features requiring petrographic study. Thin sections were prepared in oil to preserve halite cements, and selected samples were impregnated with blue epoxy to reveal pores. After halite cement/pore relationships were examined, halite was dissolved from thin sections in preparation for staining. Alizarin red stain was used to identify calcite. Standard petrographic techniques were used to examine thin sections. The percentage of mineralogic constituents was determined by visual estimation. Allochems and sedimentary structures, which serve as indicators of depositional environment, were identified. Cement relationships were examined to identify the sequence of diagenetic events.

Petrography has been completed on 26 thin sections from the SWEC Detten No. 1 core and on 45 thin sections from the SWEC G. Friemel No. 1 core. Thin section descriptions are presented in appendix C and summarized in tables 1 and 2.

Table 1. Petrography of unit 4 carbonates -- SWEC G. Friemel No. 1 well.

| Sample # | Calc. (%) | Dolo. (%) | Silt (%) | Anh. (%) | Halite (%) | Pore (%) | Quartz | $SrSo_4$ | Pyrite | Other | Carbonate name | Allochems | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F 2589.0 | | 32 | | 45 | 20 | | | 1 | 1 | Magnesite ? | Intraclastic conglomerate | | Diagenetic skeletal halite |
| F 2594.5 | | 15 | | 85 | | | | ? | | | Laminated dol. anhydrite | | Deformed gyp. pseudomorphs |
| F 2599.0 | | | 5* | 90 | | | | | X | 5%* clay | Lam. muddy anhydrite | | "Mini teepees" |
| F 2601.3 | | 75 | 10 | 15 | | | Tr | | | | Lam. pelmicrite | Peloids, brach., foram. | Anh.→dol.; chalcedony→anh. |
| F 2604.0 | | 90-35 | | 10-65 | | | | | | | Lam. pelsparite, anh. cemt. | Bryozoan, echinoid | Sparite rims, anh.→grains, anh. cement |
| F 2604.6 | | 90 | | 9 | 1 | | Tr | ? | | | Pelmicrite with anh. lam. | Rimmed peloids | Microspar. rims, chalc.→anh.; hal. frac. |
| F 2607.5 | | 73 | | 25 | | 2? | | | | Hematite | Mud cracked? pelmicrite | Pel. molds & whole | Anh. nodules, cement |
| F 2610.4 | | 78 | | 5 | 15 | 2 | | Tr | Tr | | Rippled pelmicrite | Pel. molds & whole | Celestite, anh.→skeletal halite |
| F 2613.0 | | 92 | | 3 | | 5? | | | | | Burrowed pelmicrite | Pel. molds & whole | |
| F 2615.0 | | 85 | <1 | 5 | 8 | 3 | 1 | | | Organic | Rippled pelmicrosparite | Peloids | Anh. and halite cement in molds |
| F 2617.4 | 25 | 71 | <1 | 2 | 1 | <1 | | <1 | | | Rippled pel-foram micrite | Peloids, forams | Dol., anh., hal. cemt →calc. →celes.→anh. |
| F 2618.3 | 10 | 85 | 1 | <1 | 2 | 1 | | | Tr | 1% organic | Rippled pelmicrite | Peloids, forams? | Variable porosity, calcite cement |
| F 2621.2 | 10 | 77 | <1 | 1 | 10 | 1 | | | | | Pelsparite-pelmicrite | Peloids | Dol., anh., compact, calcite cemt. |
| F 2621.5 | 50 | 44 | 1 | Tr | 5 | | | | Tr | | Pelsparite | Peloids | Dolomitization, calcite cement |
| F 2624.1 | 64 | 30 | | 1 | 5 | - | | Tr | | Tr phosphate | Burrowed biomicrite | Brac., bryoz., algal, mollusks | Partial dolomitization, calcite→anh. |
| F 2624.4 | 99 | <1 | | | Tr | - | | Tr | | | Gastro-oncolite biosparudite | Oncolites, diverse | Calcite spar., tr. dolomite in micrite |
| F 2624.9 | 60 | 40 | <1 | | Tr | | | | | Tr organics | Oncolite biosparite | Onco., foram, mollusk | Microstylolites |
| F 2626.6 | 40 | 40 | Tr | <1 | 20 | | | | | Tr phosphate | Biomicrite | Skeletal frag. molds | Calcite spar. is post-dolomitization |
| F 2632.0 | 75 | 15 | | Tr | 10 | | | | | Tr organics | Burrowed oosparite | Ooids, peloids, brach. | Ooid radial structure preserved |
| F 2636.5 | 45 | 45 | | Tr | 10 | | | Tr | | Tr phosphate | Oncolite-mollusk sparrudite | Mollusk, oncolite | Neomorphic spar.→algae, halite cemt. |
| F 2639.0 | 98 | 2 | | Tr | Tr | | | | Tr | | Ooid-brachiopod sparite | Ooids, brach., pelecypods | Sparry nodules which destroy fabric |
| F 2642.2 | 30 | 65 | | 5 | | | | | | | Burrowed, packed pelmicrite | Peloids, bivalves, echinoids | Anh. and hal. inclusions in calcite spar. |
| F 2643.3 | 98 | 2 | | | Tr | Tr | | | | Phosphate? | Burrowed, packed pelmicrite | Bivalves, echinoids, bryozoans | Burrows-micrite, dol., open molds |
| F 2644.2 | | 95 | | 1 | 2 | 2 | | | | Organic wisps | Dolomicrosparite | None | Intercrystalline micro-pores; anh. |
| F 2646.2 | | 99 | | Tr | | ? | | | | | Dolomicrosparite | None | |
| F 2650.5 | 10 | 75 | | Tr | 15 | | | | | | Burrowed, packed biomicrite | Echinoid, foram, brach. | Burrow-coarse dol., halite, calcite |

Table 1 (cont.)

| Sample # | Calc. (%) | Dolo. (%) | Silt (%) | Anh. (%) | Halite (%) | Pore (%) | Quartz | $SrSo_4$ | Pyrite | Other | Carbonate name | Allochems | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F 2651.0 | 65 | 10 | | 5 | 20 | | | | | | Nodular biomicrite | Poor preservation | Halite→grains matrix: cal.→hal. in fractures |
| F 2652.0 | 97 | | | | 3 | | | ? | | | Algal-mollusk-foram biomicr. | Algae, foram, brach. | Calcite cement, neomorphic spar. |
| F 2652.8 | 99 | | | Tr | Tr | | | | | Tr organics | Biosparite-biomicrite | Algae, diverse skel. | Septarian cracks, skeletal halite |
| F 2653.8 | 96? | ? | | | 3 | - | | | | Tr organics | Packed biomicrite | Skeletal fauna | Early calc. cement, neomorphic spar. |
| F 2655.9 | 15-80 | 20-85 | | Tr | 2 | | | | | Tr organics | Sparse biomicrospar | Forams, small brach. | Calc. nodules, microstyl. dol. matrix |
| F 2656.9 | 5-60 | 30-80 | | Tr | | | | Tr | | Tr organics | Sparse echinoid biomicrite | Diverse, fine skel. | Calc. nodules, microstyl. dol. matrix |
| F 2659.6 | 84? | ? | | | 15 | - | | 1% | | | Burrowed pel-biomicrite | Pellets, mollusk, ech. | Halite and calcite spar. in burrows |
| F 2661.6 | 95 | | | | 5 | | | | | Phosphate grain | Packed foram biomicrite | Forams, peloids, mollusks | Compacted, microstylolitized |
| F 2662.6 | 95 | | | | 5 | - | | | | | Biomicrite-biosparite | Peloids, diverse fauna | Algal molds, halite, calcite cement |
| F 2666.1 | 50 | 45 | | | 5 | | | | | | Sparse biomicrite | Thin bivalves, spheres | Calcite skel., halite-replaced burrows |
| F 2666.5 | 50 | 50 | Tr | | Tr | | | | | Organic stain | Biomicrite | Spheres, peloids | Calcite cement around dolomite |
| F 2667.6 | 5 | 94 | | | | <1 | | | | Bone frag., wisps | Lam., burrowed biomicrite | Forams, spheres, ? | Intercrystalline calcite cement |
| F 2669.0 | <1 | 80 | | 20 | Tr | Tr | | | Tr | | Pelmicrite-anhd. dolomicrite | Peloids, fenestra | Macropores, calcite and anh. cemt. |
| F 2676.0 | | 95 | | ? | 4 | ? | | 1? | | Organic wisps | Wispy dolomicrite | Forams | Fracture fill: halite, celestite, anh. |
| F 2677.0 | | 65 | | 35 | | | | | Tr | Organic grains | Wispy dolomicrite | Forams | Anhydrite nodules |
| F 2679.2 | | 78 | 10 | | | | | | 2 | 10% clay | Muddy dolomicrite | Forams | Fissile |
| F 2679.6 | | 55 | 10 | 30 | | | | | 5 | 20% clay | Fissile, muddy dolomicrite | -- | |
| F 2681.8 | | Tr | 40 | 9 | Tr | | | | 1 | 50% mudstone | Laminated, dark mudstone | -- | Displacive halite rimmed by dol. |
| F 2684.4 | | Tr | 15 | 50 | Tr | | | | | 35% mudstone | Lam., anhd. mudstone | -- | Fining upward lam., molds of halite |

Percent determined by visual estimation.
Tr indicates trace.
* Mudstone arbitrarily divided into silt and clay components.
→ Replaces.

Table 2. Petrography of unit 4 carbonates -- SWEC Detten No. 1 well.

| Sample # | Calc. (%) | Dolo. (%) | Silt (%) | Anh. (%) | Halite (%) | Pore (%) | Quartz | $SrSo_4$ | Pyrite | Other | Carbonate name | Allochems | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| De 2744.3 | | X | X | X | | | | | + | Clay | Muddy anhydrite | -- | Coarse dol., mm lam., gyp. pseudo. |
| De 2746.1 | | X | | + | + | 10% | | ? | | | Pelmicrite | Peloids | Intercrystalline pores, halite cement |
| De 2746.3 | | X | | + | + | X | | ? | | | Biopelmicrite | Peloids, foram, bivalves | Fenestra, mudcracks, anh.→halite |
| De 2747.0 | | | | X | X | | | | + | Mud | Anhydritic halite | -- | Displacive, skeletal halite |
| De 2751.1 | | X | | + | + | | + | | | Tooth plate | Burrowed biomicrite | Bivalve molds | Large phylodont fish tooth plate |
| De 2752.0 | | 80 | | Tr | 20 | | | | | Organic grains | Rippled biomicrite | Bivalves, peloids | Anh. nodules, halite-filled fractures |
| De 2758.1 | | X | | + | + | 25 | | | Tr | | Mollusk biomicrite | Bivalve mold | Bivalve molds are anhydrite-filled |
| De 2762.6 | | X | | + | | | | | | | Mollusk pelmicrite | Peloids, forams | Early dolomicrospar, later anhydrite |
| De 2765.8 | X | X | | | + | | | | | | Biosparite | Bryozoan, forams | Cements: dolomite, calcite, halite |
| De 2773.5 | X | X | | X | + | ? | | | | Phosphate grains | Biosparrudite | Pelecypods, forams | Cements: dolomite, calcite, halite |
| De 2784.2 | + | X | <1 | | | | | | | Organic grains | Biomicrite | Skeletal sand-molds | Halite, anhydrite, calcite, cements |
| De 2789.4 | 65 | 25 | 5 | | | | | | Tr | 5% organics | Lam. micrite | Bivalves, bryozoans | Micrite and microspar, calcite allochem |
| De 2790.0 | + | X | | + | | | | | | Organic stain | Sparse biomicrite | Pelecypod | Calc. grains, matrix part dolomite |
| De 2791.3 | X | | | | | | | | | Bone fragment | Biosparrudite | Diverse, oncolites | |
| De 2800.0 | 30 | 70 | | | | | | | | Wispy laminae | Echinoid biomicrite | Echinoids, bryozoans | Matrix mixed calcite and dolomite |
| De 2802.4 | X | X | | | | X | | | | Wispy laminae | Brachiopod biomicrite | Brach., echinoids | Moldic and intercrystalline pores |
| De 2803.2 | X | -- | | + | + | | | | | Organics | Biosparite | Oncolites, diverse | Sparry calcite cement, local anh., hal. |
| De 2805.4 | 75 | 25 | | | | | | | | Organic grains | Sparse biomicrite | Brach., echinoid | Rims of echinoids replaced by halite |
| De 2812.0 | ? | ? | | + | | | | | Tr | | Burrowed biomicrite | Ooids, diverse skel. | Anhydrite, dol. and halite cements |
| De 2813.2 | | 99 | <1 | | | ? | | | | Organic grains | Dolomicrosparite | Forams, echinoids | |
| De 2814.9 | | + | | X | | | | | | | Nodular anhydrite | -- | Coarse anhydrite |
| De 2816.0 | | 14 | | 86 | | | | | | | Nodular anhydrite | -- | Pseud. after gyp.; anh. replaces dol. |
| De 2825.6 | | X | X | + | X | | ? | ? | X | Organics | Silty biomicrite | Skeletal hash | Halite fills fractures and molds |

Table 2 (cont.)

| Sample # | Calc. (%) | Dolo. (%) | Silt (%) | Anh. (%) | Halite (%) | Pore (%) | Quartz | $SrSo_4$ | Pyrite | Other | Carbonate name | Allochems | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| De 2826.1 | | X | + | X | X | | | | X | | Silty dolomicrite | Forams, peloids | Hal. in fractures, skel. crystals: anh.→hal. |
| De 2829.3 | | | X | X | | | | | X | Claystone | Mudstone, anhydrite | -- | Anh. cemt. and nodules |
| De 2831.5 | | | X | X | 5 | | | | | Clay | Mudstone-siltstone | -- | Dolomite cement in siltstone |

Percent based on visual estimation.

\+ Present.

X Abundant.

## SAN ANDRES DEPOSITIONAL ENVIRONMENTS

The San Andres Formation is divisible into 28 regionally traceable cycles (Fracasso and Hovorka, 1984). The lower cycles can be recognized in geophysical logs and have been numbered units 2, 3, and 4 (fig. 2). The upper cycles are better identified on the basis of core character and have been assigned letter designations (Fracasso and Hovorka, 1984) (fig. 2). Each of these cycles represents a transgression followed by a regression causing restriction and increasingly hypersaline conditions. Thin beds of dark anhydritic mudstone overlain by carbonate were deposited during and immediately after the transgression and therefore define the base of the genetic cycle. Anhydrite, halite, and fine-grained clastics were deposited during the regressive stages of the cycle.

The San Andres unit 4 carbonate is the thickest and most complex carbonate unit in the San Andres. It is of particular interest because it serves as an aquifer within the evaporite section. The geochemistry of the brines in the aquifer has been studied by Dutton and Orr (1985). They concluded that the brines could have originated either as modified connate evaporite brines or by modification of meteoric water introduced into the evaporite section. Study of the mineralogy and diagenetic sequence of the unit 4 carbonate rocks will likely contribute to understanding the genesis of the brines.

The San Andres unit 4 is composed of a lower, dominantly carbonate part (about 30 m thick in Deaf Smith County) and an upper, dominantly halite part (46 to 52 m thick). Six lithologies are recognized in the lower part of unit 4, forming two incomplete genetic cycles. In the thin lower cycle the lithologies are (1) dark, anhydritic mudstone, (2) wispy, sparsely burrowed, peloid-foraminifer dolomicrite, and (3) nodular to bedded anhydrite. The upper cycle contains (1) burrowed, skeletal limestone and dolomitic limestone, (2) ripple-laminated, anhydritic peloid dolomicrite, (3) muddy, dolomitic anhydrite, and (4) the overlying halite (fig 3). The depositional environments in which these sediments were deposited have been described in previous reports (Fracasso and Hovorka, 1984;

Hovorka and others, 1985) but will be reviewed here because of the relationship between depositional environment and diagenetic history.

Dark, anhydritic mudstone at the base of the cycle is interpreted as a transgressive deposit. When marine waters flooded the halite flat formed at the end of the preceding cycle, halite was dissolved. The insoluble components from the halite, including mudstone and anhydrite interbeds and disseminated materials, accumulated as the basal deposit of the cycle. The facies and textural relationships that indicate that the mudstone formed as an insoluble residue are discussed by Hovorka and others (1985). The materials in the dark, anhydritic mudstone were originally deposited as interbeds in the halite environment but then were exposed to marine waters that dissolved the halite. The top of the dark mudstone is gradational with dolomite, suggesting that the uppermost mudstone was reworked. Ripple lamination of the carbonate-mudstone mixture is evidence of reworking of residual mudstone in the carbonate environment.

Wispy, sparsely burrowed, peloid-foraminifer dolomicrite probably formed under hypersaline conditions. Evidence for hypersalinity includes upward gradation into anhydrite, low faunal diversity, and small, sparse burrows. Sedimentary structures, including wispy lamination and fine ripple lamination, are present but are not particularly diagnostic of any depositional environment. Structures indicative of subaerial or intertidal exposure are absent. The contact of the wispy-laminated dolomicrite with the overlying anhydrite is gradational by inclusion of anhydrite nodules in the dolomicrite.

Nodular to bedded anhydrite, which forms the top of the lower incomplete cycle in the unit 4 carbonate, preserves little evidence of the environment in which it was deposited. Poorly preserved pseudomorphs of bottom-nucleated selenite gypsum in the SWEC Detten No. 1 core suggest that deposition took place in a brine pool environment. Brine pool environments were the most common setting for gypsum precipitation throughout the San Andres (Fracasso and Hovorka, 1984), and such an environment is a plausible origin for this anhydrite bed. Contact of anhydrite with the overlying carbonate

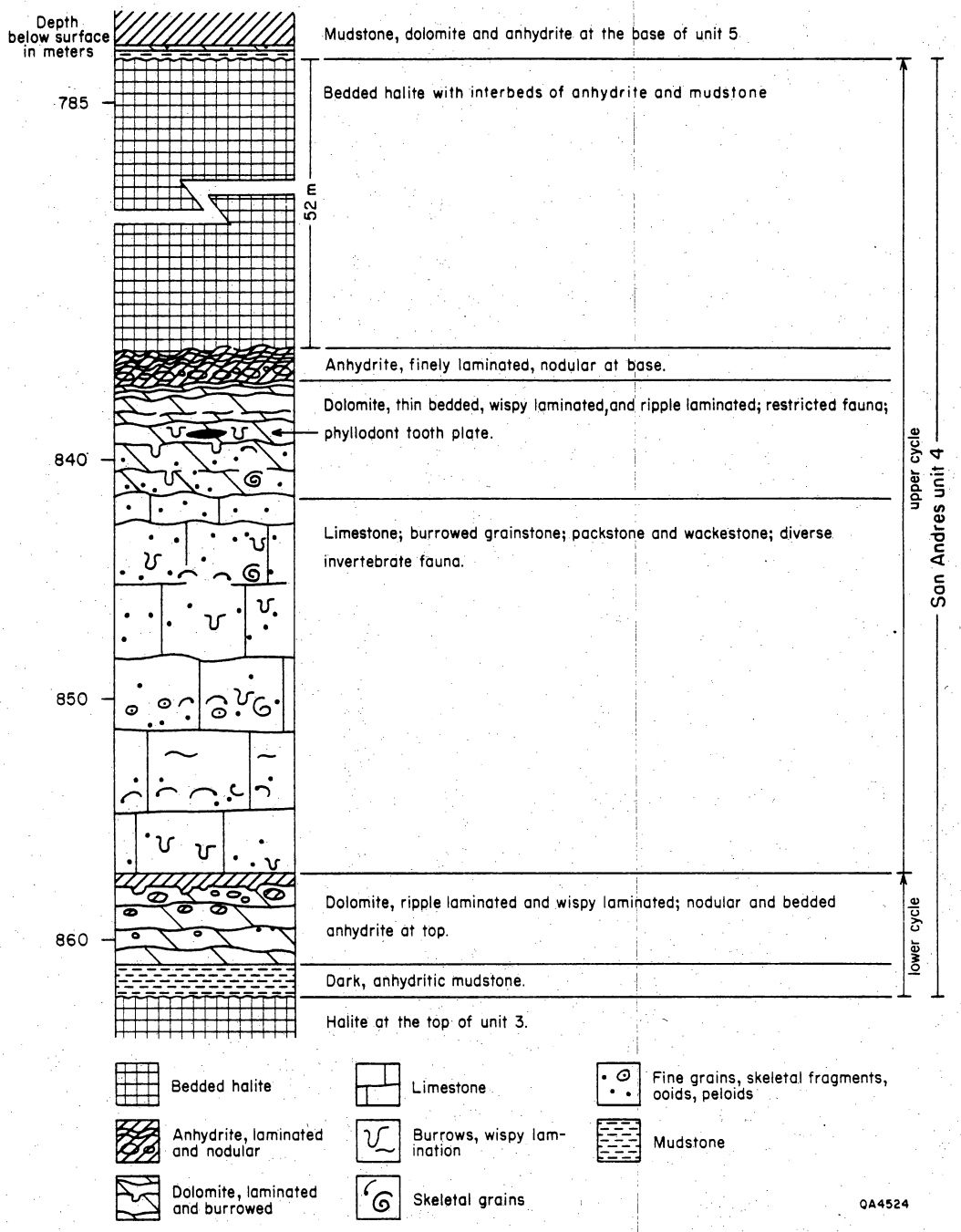


Figure 3. Generalized lithologic log of the San Andres unit 4 carbonate in the SWEC Detten No. 1 well, showing the distribution of lithologies.

is sharp. The carbonate immediately above the anhydrite is dolomite with fenestral pores and sparse skeletal material. The depositional environment of this dolomite may be transitional between the hypersaline environment of anhydrite and the depositional environment of the overlying normal-marine limestone.

Burrowed, skeletal limestone of the San Andres unit 4 carbonate is the most normal-marine carbonate in the Permian evaporite section of the Palo Duro Basin. A diverse skeletal fauna and intense bioturbation are the features indicating a normal-marine depositional environment. Skeletal grains include brachiopods, bryozoans, echinoid plates, foraminifers, and bivalves. Most grains are fragmented, but the presence of some large, intact productoid brachiopods with attached spines suggests that the diverse fauna was indigenous. Abundant oncolites, algal micrite coats on grains, and other algal grains indicate that the setting was fairly shallow water, in conformance with the overlying and underlying shallow-water evaporite facies. Burrowing has destroyed most bedding and admixed micrite and grains, but the abundance of grains and local preservation of grainstones attest to high-energy conditions, as might be expected in a shallow-water shelf setting. Various lithologies are present within this interval, including low-energy carbonate mudstones and skeletal wackestones and higher energy skeletal packstone and grainstones. Cross-laminated ooid grainstones represent shoal facies. These sediments are interpreted as being deposited within a middle shelf environment, as defined by Wilson and Jordan (1983). Fine-grained sucrosic dolomite beds and nodules within the limestone section contain the same fauna and structures as do the limestone and therefore appear to be part of the shelf depositional facies tract, dolomitized during later diagenesis. The burrowed, skeletal limestone grades upward into the overlying peloid dolomicrite with a decrease in faunal diversity and burrow density and size and an increase in the amount of dolomite.

Ripple-laminated, anhydritic peloid dolomicrite is the characteristic lithology of the upper part of the San Andres unit 4 carbonate. Low faunal diversity and thin bedding with

preserved ripple lamination, corresponding to sparse burrowing, characterize this interval. Anhydrite interbeds and nodules are abundant, and the sediment has been dolomitized. Bivalves, foraminifers, bryozoans, and an unusual phyllodont (fish) tooth plate occur, but the dominant grains are peloids with rims of dolomicrospar. Peloids are preserved as micrite or have been leached and are now cement-filled or open molds. Peloids are round or flattened and locally appear compacted against each other. Dark coloration due to organic material and pyrite in concentric rings are typical in larger grains, giving them an appearance of ooids. Microspar rims are of single crystal thickness and appear mostly unbroken, even in areas where the grains are compacted. Similar peloids are the dominant allochem in many other San Andres carbonates, where they may be up to several millimeters in diameter (Bein and Land, 1982; Hovorka, 1983). Other compressed or broken grains have been found in Precambrian carbonates from India (Sarkar, 1973), in the Cambro-Ordovician of Quebec (Beales, 1965), and in other Permian carbonates, especially the Wichita Group in the Palo Duro Basin. The origin of these grains and rims, however, remains problematic.

Facies position and decreased faunal diversity suggest that the depositional environment of the ripple-laminated, anhydritic peloid dolomicrite was hypersaline. Local possible desiccation cracks and fenestral textures suggest that some of these sediments were episodically exposed. A hypersaline shelf to carbonate tidal-flat depositional environment is interpreted for these sediments. Anhydritic dolomicrite grades upward into dolomitic anhydrite.

Muddy, dolomitic anhydrite is the uppermost lithology beneath the halite. This anhydrite differs from most anhydrite beds in the San Andres in that it is admixed with mudstone and has a highly altered appearance. Small, poorly preserved pseudomorphs after gypsum and some intervals of finely laminated anhydrite and mudstone are present in each core, suggesting subaqueous deposition in an evaporite brine pool. Other features, such as beds of intraclastic carbonate, small-scale teepee structures, and fenestral fabric in

dolomite interbeds, suggest intermittent subaerial exposure in a hypersaline shelf or lagoon to tidal-flat setting.

## DIAGENESIS OF THE SAN ANDRES UNIT 4 CARBONATE

### Introduction

In cyclic evaporite sequences, each sediment is exposed during early diagenesis to a series of brines of different compositions derived from evolution of the overlying brine pool. Each depositional cycle produced, in succession, (1) normal-marine water, (2) hypersaline, carbonate-precipitating waters, (3) marine-derived, gypsum-precipitating water, and (4) marine-derived, halite-precipitating water. The geochemical and facies arguments for the marine origin of the evaporite brines are presented by Fisher and Hovorka (1986) and Hovorka and others (1985). Marine origin of evaporite brines is significant because such brines contain concentrations of reactive phases, notably magnesium. The advanced (bittern) stage of evaporation was not reached within the Palo Duro Basin, but brines evaporated to halite saturation were available to react with sediment. Meteoric waters may have been contributed during episodes of subaerial exposure in the later parts of the cycle, but their geochemical signature has not yet been recognized in the San Andres.

Diagenetic processes recognized in this study include precipitation of sparry calcite cement, neomorphic recrystallization of aragonite, leaching of aragonite leaving moldic pores, dolomitization, microstylolitization, precipitation of anhydrite, precipitation of halite, and replacement of halite by calcite. The sequence of these processes is well constrained in some cases and poorly constrained in others. In addition, significant minor diagenetic phases are present.

## Early Calcite-Aragonite Diagenesis

Early calcite-aragonite diagenesis includes precipitation of sparry calcite cement, neomorphic recrystallization of aragonite to calcite, and leaching of aragonite, forming moldic pores. Sparry cement fills shelter porosity and moldic pores. A few examples of cement fabrics diagnostic of early marine cementation have been identified in the DOE-Gruy Federal Grabbe No. 1 core. Fracasso and Hovorka (1984, fig. 12) found possible fibrous cement and epitaxial overgrowths on echinoderms in the San Andres unit 4 carbonate. However, in the two wells examined in this study, calcite cement fabrics are all equant spar. The early formation of this calcite spar is evident in samples where calcite cement has occluded porosity in nodular areas and prevented formation of later diagenetic phases. Commonly, nodules of calcite-cemented skeletal packstone and grainstone occur within a matrix that has been dolomitized, microstylolitized, and cemented and replaced by halite.

Neomorphism of aragonite grains to calcite, especially algal and mollusk grains, was important in the formation of burrowed skeletal limestone. Neomorphism of micrite to microspar probably contributed to the reduction of porosity in nodules that were unaffected by late diagenetic events. In hypersaline facies, most or all skeletal grains were leached. Original aragonitic grains were most pervasively leached, but in some intervals calcitic skeletal grains such as foraminifers and brachiopods were removed. Many of these molds are filled with anhydrite and halite cements, indicating that mold formation predated halite cementation.

In carbonates from nonevaporite sections, neomorphism, solution of aragonite grains, and, commonly, formation of sparry calcite cement occur in the meteoric phreatic zone (Longman, 1980). Such an environment probably never influenced the San Andres unit 4 carbonate. Sparse supratidal facies in the San Andres are evaporite dominated, which would prevent development of a meteoric water system. Textural relationships between calcite cement, molds, and neomorphic spar clearly indicate that this early phase of calcite

diagenesis predated the introduction of halite cement. Timing of this halite cementation is probably related to the deposition of 50 m of bedded halite above the carbonate, as discussed in the section "Halite precipitation" (p. 19). Additional examination of the carbonate cements, including stable isotopic composition and cathodoluminescence, is needed to discriminate clearly between early and late calcite cements and to determine the geochemical setting in which cements precipitated. In an evaporite setting, these familiar carbonate cements do not seem to have the same significance as in a nonevaporite setting.

## Dolomitization

Dolomitization was the second major diagenetic event to affect the San Andres unit 4 carbonate. In the most hypersaline, muddy, dolomitic anhydrite facies, dolomite is aphanocrystalline and very dense. The hypersaline carbonate facies, wispy dolomicrite and ripple-laminated peloid dolomicrite, and the top of the the burrowed skeletal limestone have been pervasively dolomitized. Micrite matrix, micrite and skeletal grains, and cements are all dolomite. The dolomite consists of microspar (4 to 30 microns in diameter) anhedral loafish crystals. Early cement on most grains in the ripple-laminated peloid dolomicrite takes the form of fine (15 to 40 microns in diameter) euhedral dolomite spar rims. The original mineralogy of the spar rim cement is not known.

In the burrowed, normal-marine limestone, dolomitization is patchy. Commonly the limestone contains 10 to 40 percent dolomite. Some zones in the limestone have been completely dolomitized; others contain no dolomite. Most of the dolomite within the limestone is in fine to very fine (4 to 60 microns in diameter) rhombs and subhedra. Dolomitization has altered matrix and avoided allochems and areas of early calcite cement.

Extensive dolomitization of carbonates is expected in a marine evaporite section because of the high magnesium concentrations in evaporite brines. Geochemical evidence

in the evaporites indicates that magnesium-rich brines were available throughout the deposition of the 50-m-thick evaporite section in the upper part of the depositional cycle. Why, then, have the carbonates not been pervasively dolomitized? Until more is known about the hydrology of evaporite environments, particularly those deposited in broad, low-relief Paleozoic epicontinental settings, this question cannot be answered confidently. Of all the cycles within the Permian evaporite section, limestone is preserved in only the San Andres unit 3 and unit 4 carbonates. These carbonates differ from those of other cycles in three ways. (1) Their depositional environment was normal marine rather than mostly hypersaline; (2) they are the thickest carbonate units in the section; and (3) the anhydrite overlying the carbonate is usually thin and admixed with clastics. Further investigation is needed to identify the factors controlling dolomitization.

## Microstylolitization

Local dissolution of calcite is probably the third diagenetic event altering the unit 4 carbonate. Intercrystalline dissolution of calcite along microstylolite seams concentrated less soluble components, including silt, organics, pyrite, dolomite, and calcite allochems. These concentrations define irregular subhorizontal surfaces in limestone. In strata with nodular fabrics, the areas lacking early calcite cement have been compressed around nodules because of microstylolitization. Concentrations of dolomite in the microstylolitic areas indicate that the stylolites formed after or perhaps during dolomitization. The relation between microstylolitization and precipitation of anhydrite and halite cements is not clearly defined, but most microstylolites form early, before cementation.

## Anhydrite or Gypsum Precipitation

The fourth major diagenetic event is the precipitation of anhydrite. Anhydrite is present throughout the carbonate, but has different fabric relationships in different carbonate environments. In ripple-laminated, anhydritic peloid dolomicrite and nodular to

bedded anhydrite, gypsum was co-precipitated with the carbonate sediment. Here anhydrite forms beds and contains probable pseudomorphs after gypsum crystals. Relationships that identify the timing of dehydration of gypsum to anhydrite were not seen in these beds. On the basis of the pattern of preservation of other anhydrite beds, Hovorka and others (1985) argued that dehydration occurred within the first few meters of burial. Nodules of anhydrite are abundant in all the carbonate. Displacive nodular fabric, forming enterolithic fabrics and deformed bedding characteristic of sabkha deposits, has not been identified in the unit 4 carbonate. Most of the anhydrite appears, rather, to be replacive, occurring as blades that are aligned horizontally, parallel to nodule edges, or randomly oriented (felted).

Anhydrite occurs as nodules, euhedral crystals, and poikilotopic cement/replacement. Nodules are formed before compaction, as shown by slight deformation of bedding around them, and are abundant in hypersaline facies and sparse in other facies. Euhedral anhydrite crystals are dominantly blade-shaped; they replace both framework grains and matrix, forming after compaction. Inclusions of remnant carbonate in the euhedral anhydrite crystals document their replacement origin. Their crystal form indicates that they were precipitated as anhydrite rather than gypsum. Poikilotopic anhydrite cement/replacement also partly replaces dolomite allochems and matrix, leaving only ghosts of framework grains. Cement/replacement is very common in the Wichita Group of the Palo Duro Basin and occurs only locally in small masses in the San Andres unit 4 carbonate. Some anhydrite cement in hypersaline environments precipitated early, protecting grains from compaction. Anhydrite does not preserve fine textures well, so evidence of diagenetic gypsum in the carbonates is lacking.

The diagenetic sequence clearly indicates that anhydrite precipitation occurred several times during San Andres diagenesis, and some anhydrite was precipitated (probably as gypsum) in the depositional environment. Some sulfate-precipitating brines derived from this brine pool probably contributed sulfate to the underlying carbonate. Other

anhydrite has commonly replaced halite and rarely replaced late-formed celestite. The pre- and post-compaction character of anhydrite within a single area indicates that anhydrite precipitation took place several times. Geochemical sampling may assist in identifying the source of anhydrite-precipitating waters.

## Halite Precipitation

The fifth major diagenetic event in the unit 4 carbonate was precipitation of halite. Halite occurs as a cement, as displacive/replacive skeletal crystals, and as a replacement of carbonate. In most moldic pores, it is impossible to tell whether halite occurs as cement, filling the void left after dissolution of aragonite, or as replacement of aragonite without a stage of void formation. Halite of clearly replacement origin replaced the micrite in burrows and in the rims of echinoids and other skeletal grains. Characteristically, halite replacement contains no remnants of the original phase as inclusions. Other halite cement fills original pores within the sediment, such as fenestra and intergranular pores in grainstone.

Skeletal halite crystals occur abundantly in the muddy anhydrite directly beneath the bedded halite and less abundantly throughout the carbonate section, including the normal-marine facies. The skeletal character of the crystals results from more rapid growth of the crystal at its corners than at face centers. The host carbonate is not bedded enough to permit discrimination between a displacive and a replacive origin of these crystals.

All pores, regardless of origin, are filled with halite cement. In a few beds, micropores are not cemented, as discussed in the section on porosity (p. 22). Most of the halite cement was presumably introduced into the carbonate by brines derived from the deposition of the thick unit 4 halite, but geochemical studies have not been undertaken to document this relationship. Halite is isotropic and does not readily preserve fine detail, so a complex halite precipitation history involving multiple episodes could be masked by the apparent simplicity of halite.

## Replacement of Halite by Calcite

The sequence of diagenetic events just described could have resulted from the introduction of brines from an evolving brine pool. Each diagenetic product--calcite, dolomite, anhydrite, and halite--reflects the sequential contributions from an evolving, increasingly saline brine pool. However, the sixth diagenetic process, calcite replacement of halite, represents a shift away from this pattern. The origin of the brines that contributed this calcite needs further investigation.

Calcite occurs as a poikilotopic mosaic having coarse crystals up to 5 mm in diameter. The late origin of the calcite is apparent from textural relationships. Calcite poikilotopically cements dolomite, filling the intercrystalline pores; thus, 25 percent of the rocks are composed of late-formed calcite. Dolomite is preserved; dedolomitization (dolomite replaced by calcite) has not been observed. Calcite replaces skeletal halite crystals and contains abundant halite inclusions, indicating that it precipitated after halite and replaced it, rather than filling pores. Blocky, euhedral calcite rims many halite-filled voids. Calcite also replaces anhydrite around nodules. The distribution of late calcite is variable; halite is extensively replaced in some intervals. Occurrence of calcite replacement of halite is similar to the dolomite replacement of halite previously documented by Naimen and others (1983) and Hovorka and others (1985) in Palo Duro Basin evaporites.

## Other Diagenetic Phases

Minor diagenetic phases within the San Andres unit 4 carbonate include pyrite, celestite, and quartzine (length-slow chalcedony). These phases occur throughout the carbonate. Pyrite is abundant as scattered framboids and cubes where clastic materials are admixed with anhydrite in the dark anhydritic mudstone at the base of the cycle and in the muddy, dolomitic anhydrite at the top. This distribution probably reflects sources of

iron and sulfur. Iron could be contributed from the clastics, which are red where they are not reduced, and sulfur from the sulfates. Minor amounts of pyrite occur throughout the carbonate, mostly as fine specks within peloids. Organic material is fairly abundant within the carbonate and may serve as the reducing agent.

Celestite ($SrSO_4$) occurs in trace amounts throughout the carbonate as euhedral blades similar to anhydrite and as blocky crystals, replacing anhydrite and late calcite. Inclusions of anhydrite and late calcite within celestite indicate that celestite formed late, after precipitation of these minerals. Celestite also occurs as a cement or a replacement of halite in voids.

Locally, quartzine (length-slow chalcedony) has replaced anhydrite. Quartzine is a common replacement of sulfates, but it is rare in the San Andres within the Palo Duro Basin.

Fractures

Fractures are sparse in the San Andres unit 4 carbonate, but they may have been potential pathways for diagenetic fluids. Most of the fractures in the carbonate are vertical and only a few tenths of a millimeter wide. All are filled with halite, and a few contain isolated crystals of anhydrite. Short fractures with a septarian pattern occur in early calcite-cemented nodules and within oncolites. These fractures are filled with halite and pinch out into the host carbonate. Larger fractures are typical of the dark, base-of-cycle, anhydritic mudstone. In the dark mudstone at the base of unit 4, vertical fractures are filled with red-stained halite, minor anhydrite, dolomite rims, and possible trace celestite or polyhalite or both. These minerals are difficult to identify in thick section. No open fractures were identified. The questions of origin and timing of fracture raised by Collins and Luneau (1985) were not resolved in this study.

Porosity

Visual examination of the core failed to identify any pores in the San Andres unit 4 carbonate, but hydrologic tests indicate that the carbonate was water-bearing and permeable (Dutton and Orr, 1985). In the course of this petrographic study, pores impregnated with blue epoxy were first identified. Most of the pores are intercrystalline or small molds. The small size of the pores makes good visual estimation of the pore space difficult because of the thickness of the thin section and the difficulties of getting good epoxy impregnation. Porosity-permeability plugs would aid the understanding of porosity distribution. The distribution of impregnatable pores is patchy. Some molds and micropores are filled, and others are open within a single slide. Micropores were identified in ripple-laminated peloid dolomicrite in both cores and in different dolomitized intervals of the burrowed skeletal limestone in each core. The dolomite at the transition from nodular anhydrite to skeletal limestone contains open fenestral pores in the SWEC G. Friemel No. 1 core and micropores in the SWEC Detten No. 1 core. These porous intervals are possibly continuous between wells. Regional study is needed to confirm the correlation. In the rest of the unit 4 carbonate, early and late calcite, anhydrite, and halite occluded pores; no impregnatable pores were seen.

## CONCLUSIONS

Two significant new findings are emphasized as a result of petrographic study of the San Andres unit 4 carbonate in the SWEC Detten No. 1 and SWEC G. Friemel No. 1 cores.

(1) Open pores in the San Andres Formation are present in a variety of stratigraphic positions, especially in the dolomite of the upper cycle. It is unclear from examination of these two cores whether the porous zones are connected between wells. The open pores preferentially occur in microscopic intercrystalline spaces and small molds. Most large spaces, fractures, and large molds are filled with halite cement. Additional studies of porosity and permeability using plugs should be useful.

(2) The unit 4 carbonate has had a fairly complex diagenetic history, including early calcite cementation, early anhydrite cementation and replacement, dolomitization, halite cementation, replacement of halite by dolomite, anhydrite, and calcite, precipitation of celestite, and replacement of anhydrite by chalcedony. The precipitation of a variety of different diagenetic minerals indicates an evolution of the chemistry of the brines within the rock. Future studies may be able to relate the present brine composition to the diagenetic phases present in the rock and more rigorously define the history of brine evolution in the San Andres.

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Nan Minchow-Newman and Marty Thompson drafted the plates for this report, and Mark Bentley, Chris H. Dodson, and Don W. Thompson drafted the figures. Word processing was by Rosanne M. Wilson under the supervision of Lucille C. Harrell. Duran Dodson edited this report. Jules R. DuBar was technical editor.

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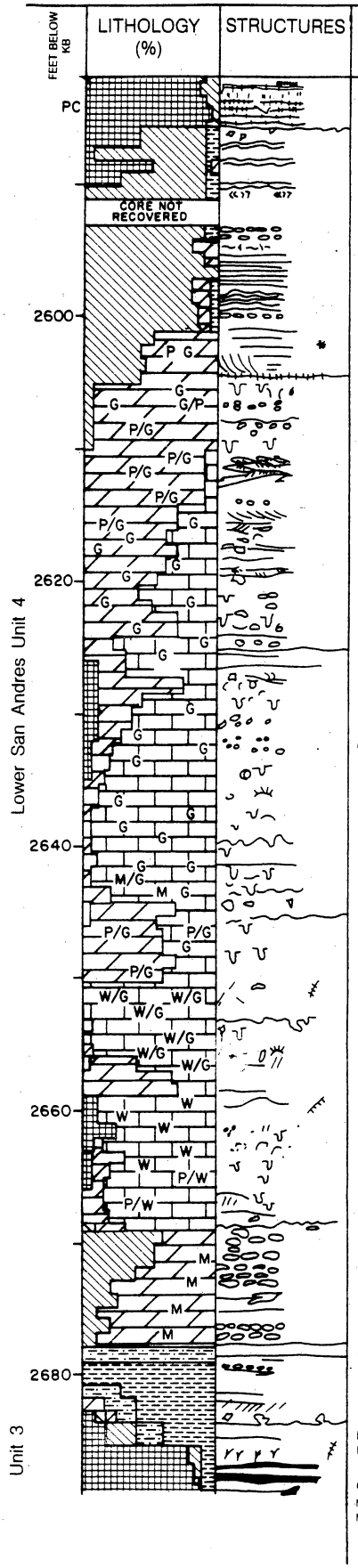
APPENDIX A. Detailed lithologic logs of the San Andres unit 4 carbonate in the SWEC G. Friemel No. 1 and the SWEC Detten No. 1 wells.

WELL: SWEC G. Friemel No. 1 COUNTY: Deaf Smith DATE: 7/82

INTERVAL: 2583-2693 ft Lower San Andres Unit 3 and Unit 4 LOGGED BY: DN; BL



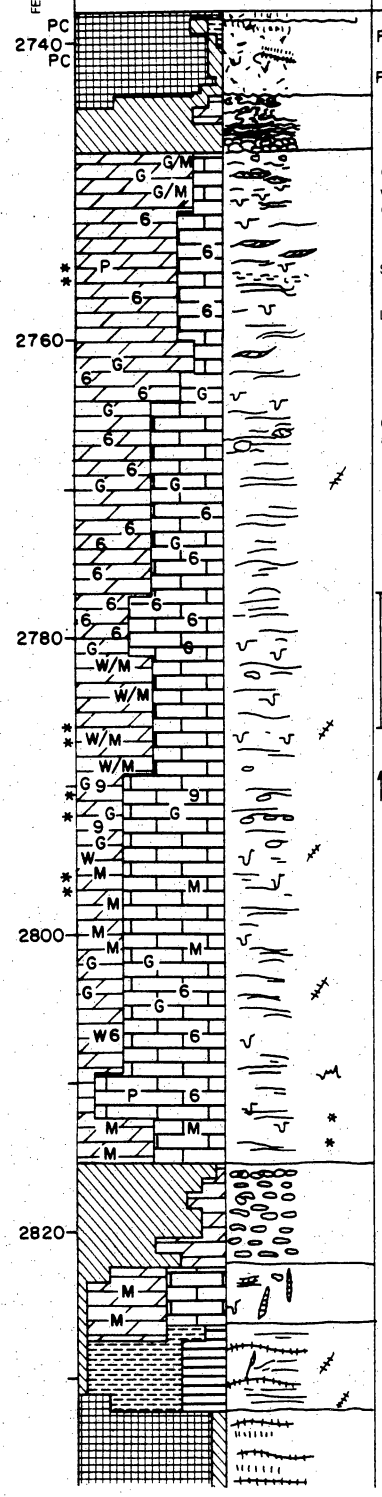

| CONTACTS | LITHOLOGIC DESCRIPTION |
|---|---|
| 1.2 | Clear to gray hal w/ small crystals & rare bedding. Disseminated anh throughout. |
| 1 S | Clear to cloudy, 50- to 70-mm beds hal w/ 0- to 2-mm gray anh drapes. |
| 2.5 | Gray wavy parallel to cloudy anh w/ clear brown hal, cubic w/tattered edges along horizontal banding. Upper boundary is extremely irregular. |
| S 2 | Gray anh highly disturbed w/patchy cubic hal, becoming laminar up section. Anh contains angular dol clasts less than 5 mm. |
| G 1 | Gray anh; massive horizontal to wavy parallel beds w/ minor black mdstn (less than .2 mm) between laminae. Horizontal clusters of white-rimmed hal replace small amounts of anh. |
| | Massive to mosaic gray anh, almost horizontal w/ minor black mdstn. |
| 3 | Very dark gray dolmtc anh; fresh, medium hard, very fine crystalline, vuggy (some irregular patches of dol), argillaceous anh (2595.2). |
| 4 | Dark-gray wavy parallel to discontinuous wavy anh w/ internal dol & less than 1-mm-thick partings of mdstn. Very thin laminations between 2598.5 & 2600 becoming massive up section. |
| G 3.2 | Brown & gray crossbedded algal pkstn/gnstn becoming extremely thinly laminated (less than 1 mm) w/ anh replacement of gnstn & displacive intralaminations anh. Distorted layers appear teepeelike(?); crystallotopic anh. |
| S 5.5 | Medium-brown anh- & hal-cemented algal gnstn/pkstn, mostly moderate to heavy bioturbation w/ rare, undisturbed foresets. Irregular anh nodules are elongate horizontally along stylolites & brecciated(?) horizons. Algae are ringlike plates less than .5 mm similar to 2 units below. Bioturbation increases up section. |
| G 11.5 S | Medium- to dark-brown interlaminated (crossbedded) algal gnstn & pkstn. Crossbeds are well formed to wavy & indistinct; lighter beds are more calcareous in lower part & contain more possible algal fragments (less than .3 mm). Grades into massive (burrowed?) strata. Nodules up to 10 mm. |
| 3.3 S | Gray-brown algal gnstn becoming peloidal & dolmtc w/ discontinuous wispy organics up section. Algae are chainlike, less than .5 mm, & encrust brachiopods, gastropods, & other broken fragments (1- to 5-mm rinds). |
| 1.2 | Gray skeletal gnstn to 30 cm thick w/ minor wispy, organic-rich partings. Gnstn is massive & has hal-filled molds & vugs (burrows?). |
| 15 | Olive-green oolitic gnstn; highly bioturbated; widely spaced, wispy laminated, & scattered anh nodules (.5-2.5 cm); entire section brachiopod-rich; lower 3.5 ft of oolites about .1 mm; next 3 ft of oolites .25-.5 mm; then grains become indiscernible. Hal replacement of fossils & anh; no bedding; burrows more hal- & dol-rich. Burrows 1-2 cm, increasing in number up section. |
| 1.8 | Medium-brown peloidal(?) gnstn, lowest 1.5 ft totally bioturbated & anh-cemented, grading up section to wavy laminated, muddy pkstn. Allochems less than 1 mm, round. |
| 2.5 S | Medium-brown peloidal(?) mdstn/gnstn moderately disturbed by large vertical burrows (greater than 10 mm). Some horizontal bedding. Displacive anh (less than 10 mm) & anh/hal cements in disturbed areas. No fossils. |
| 4.5 G | Medium-brown mdstn grading up section from mdstn/pkstn below, wavy to indistinct laminations, subhorizontal & essentially nonburrowed & nonfossiliferous (except echinoid spines in lower 1 ft). |
| 2.8 | Medium-brown skeletal(?) pkstn/gnstn; highly bioturbated w/ anh cement & thin mollusks less than 15 mm, grades up section into nodular wkstn/pkstn (as below) in light-brown gnstn matrix. Mdstn/gnstn laminae at top. |
| S 6.4 | Medium gray-brown wkstn to gnstn, burrowed to wavy laminated, containing dark-brown wkstn nodules greater than 25 cm w/ irregular shape bounding surfaces. Pkstn/gnstn composed of unidentified oval grains (less than 1 mm) often fractured w/ anh/hal fill in vicinity of nodules. Burrows 2-8 mm wide. Echinoid(?) spines abundant locally. Brachiopods. |
| 2 | Dark-tan wkstn grades up section to blue-gray wkstn/pkstn; skeletal anh replacement. Large irregular horizons of limy, porous, etched hal replacement, dol nodules 2-10 cm. Wispy organic beds 3-4 cm thick. |
| S 11 S | Dark-gray-green gnstn; anh replacement and/or cement; large irregular horizons 5-7 cm of grainy hal pore fill. |
| 4.6 S | Olive-green mdstn; slightly dolomitic; extensive burrows increasing in size & number up section (2-5 mm); burrows grainy & porous grading into probable etched-out hal fill. |
| 1.4 S | Light- to dark-gray-brown skeletal pkstn/wkstn grading into mdstn w/ lumpy, discontinuous laminations, becoming less organic rich up section. Allochems are less than 1 mm & round with hal-filled moldic porosity. |
| 9 | Light- to medium-brown laminated dolomdstn w/ displacive anh. Laminations are mostly 1-10 mm thick & may be lenticular to wispy. Nodules range from a few mm to greater than 100 mm, but average 10-40 mm. Dol beds are only slightly distorted by the anh. |
| 1.4 | Dark-gray-black micaceous fine siltstone, dol, very fissile w/ 1-5mm wavy laminations (oscillation ripple?). Grades up section into dol unit. |
| G 5.5 | SWEC field log: "2678.2-2682.3. Black shale, thin bedded, medium hard, clay size, subparallel bedding. Anh blebs. 2682.3-2683.3. Dark-gray & brown shale, very thin wavy disturbed bedded, slight surface erosion, medium hard. 1-3% ls. 2683.3-2683.6. Dark-gray shale, very thin bedded, fresh, medium hard. 2683.6-2685. Dark-gray shaly brown salt, shale very thin bedded, fresh surface, medium hard. Salt fresh, medium hard, medium crystalline." |
| I S 3.2 | Red-brown silty mdstn, bedded (20-80 mm) to highly disturbed by displacive irregular clear hal. Bedded anh nodules (.2-3 mm) coalesce up section. Fractures filled w/ fibrous orange hal 10 mm wide. |
| 2 G | Dark displacive hal cubes or minor cloudy horizons. Red mdstn drapes 2-40 mm thick. Disseminated mdstn & anh in hal crystals. Fluid inclusions are minor. |
| | Alternating black cloudy bands of hal, horizontal w/ no solid drapes, numerous fluid & organic inclusions; 5-15% is clear vertical cavity fill. |

| | | | |
|---|---|---|---|
| logged by | DN 2690-2560 | date | 7/82 |
| | BL 2600-2560 | date | 6/83 |
| checked by | SH | date | 6/83 |
| transcribed by | PH | date | 10/83 |
| typeset by | LH | date | 11/86 |
| drafted by | NM | date | 2/87 |

QA 7027

WELL: SWEC Detten No. 1 COUNTY: Deaf Smith DATE: 2/83

INTERVAL: 2738-2837 ft Lower San Andres Unit 3 and Unit 4 LOGGED BY: EC; BL; DP; ST



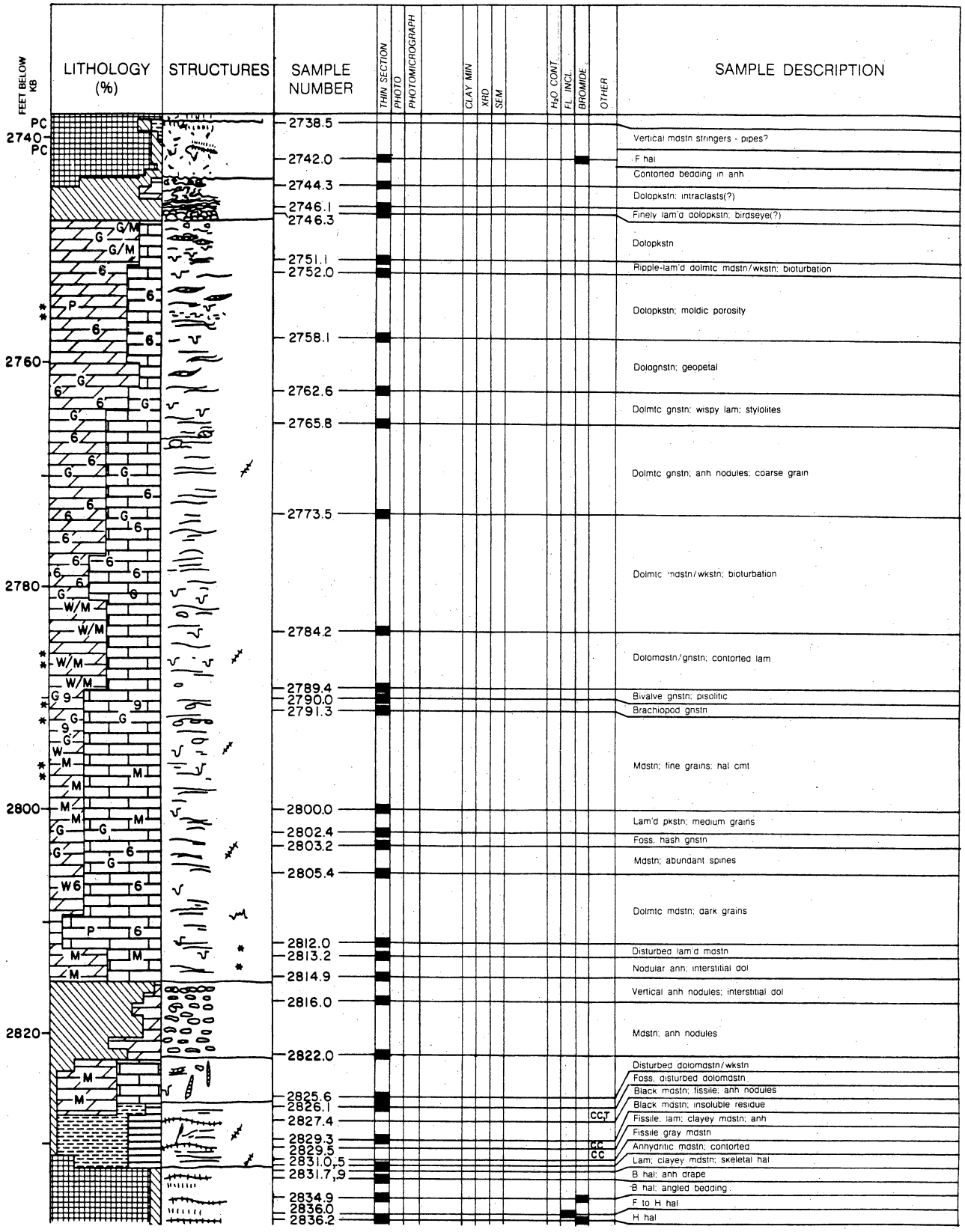

| COMMENTS | CONTACTS | LITHOLOGIC DESCRIPTION |
|---|---|---|
| F/B | 5.5 | F- to B-type, clear to olive-green & black common large hal crystals, cavity fill & pipes where disseminated interstitial anh is sparse; apparent cyclic variation of disseminated anh. Anh gray, black & tan, muddy in part; common euhedral hal possible; geopetal structures in anh cavity fills. |
| F | S | |
| | 3.2 | Gray distorted nodular, mosaic anh (1 ft) sharply overlain by contorted bedded anh w/ truncated folds; contains lenticular layers of salt & hoppers at top approaching contact w/ overlying hal. |
| | S | |
| | 1.7 | Yellow-gray dolopkstn, sand-sized allochems, wispy laminae becoming bedded up section. |
| | S | |
| | 3 | Blue & gray low-angle ripple-laminated dolopkstn w/ silt-sized allochems. |
| | S | |
| 6-cm-long by 1-cm-wide pore-filled w/ small (5 cm x 2 mm) arcs of anh & interstitial hal | 5 | Gray-blue dolopkstn, indistinct bedding, wispy laminae, bioturbated, sand-sized allochems. Moldic & intragranular porosity filled w/ hal. Orange laminations partly replaced by pyrite. |
| Skeletal hash - anh-filled molds | 3 | Gray-blue dolopkstn w/ silt-sized allochems, ripple laminated w/ bioturbated, disturbed zones. Contains a few .1- to .2-ft interbeds of pkstn w/ sand-sized allochems, bioturbated. |
| Large gastropods abundant | 1 | Yellow-gray dolopkstn w/ wispy organic-rich laminae, patchy cementation; wisps mark few areas of differential compaction; bedding otherwise indistinct; small hal hoppers. Hal-filled moldic & intragranular porosity. |
| | S | Yellow-gray dolopkstn w/ silt-sized grains, thinly bedded, ripple laminations. |
| Compaction features - wispy lam around carbonate-cemented clasts | 19.6 | Blue-gray partly dolognstn w/ patches of pkstn, fossils very fine, most unidentifiable; contains brachiopods, forams, coated grains. Bedding is thick to massive, marked by wispy organic-rich laminae, which mark differential compaction in areas of patchy cementation. Moldic & intragranular porosity is filled w/ hal. Contains scattered hal hoppers. |
| | S | |
| Very fine grains | 8.4 | Yellow-gray dolowkstn, very fine grained w/ unidentifiable fossils, burrowed, .2- to .4-ft-thick interbed w/ gray-blue dolomdstn, wispy laminated, bioturbated. 1-.4 ft thick. Contains anh nodules primarily in mdstn; also contains few hal hoppers. Contacts between wkstn & mdstn are usually burrowed or disturbed in some way. |
| | S | |
| Allochem fining upward | 6.1 | Gray-blue & yellow-white-gray gnstn, wkstn at base grading up to gnstn, wispy laminae, patchy cementation; contains a skeletal hal hopper. |
| Areas of early carbonate cement form nodules, abundant microstylolites, brachiopod spines | | |
| Abundant brachiopod spines, wispy lamination, organics | 5 | Gray-blue & wispy-laminated, fossiliferous mdstn w/ spine fragments thinly laminated, disturbed in places by burrows. |
| Y-shaped arm of dark-gray-blue organic-rich(?) laminae in calcareous mdstn w/ anh-replaced hoppers aligned along the y in the laminae | G | |
| | 4 | Yellow-blue & blue-gray gnstn, wkstn at base grading up section to gnstn, rich in spine fragments. Spines are flow aligned. Contains wispy organic laminations, patchy carbonate cementation. |
| | G | |
| | 4 | Gray-blue mdstn slightly dolomitic & fossiliferous in places. Wispy laminated w/ organic material, contains plant matter on parting planes, suggestion of bioturbation. Contains closed fractures. |
| | G | |
| | 2.8 | Yellow-blue to gray-blue pkstn w/ patchy carbonate cementation, wispy laminations, differential compaction; laminations are organic rich; parting planes contain plant fragments. |
| | S | |
| | 3 | Yellow-gray calcareous dolomdstn burrowed in the basal & upper portions; the middle portion of the interval contains highly disturbed gray laminations (protostylolitic?). |
| | S | |
| Odd texture in anh - possibly recrystallized, aligned gypsum swallowtails - now nodules | 7.2 | Gray nodules of anh arranged horizontally in beds w/ interstitial, mildly disturbed dolomdstn, parallel-laminated compaction deformed; anh becomes bedded nodular mosaic in uppermost foot. |
| | S | 1 ft blue-gray fossiliferous dolomdstn, forams & brachiopods(?), shell fragments; bedding is obliterated, contains hal-filled cavities & hoppers sharply overlain by yellow-gray dolomdstn w/ parallel beds about 1 cm & low-angle translatent strata, burrowed at base; contains flecks of black organic material along bedding & on parting planes; contains anh nodules following bedding planes. Anh increasing up section. |
| | 4.5 | |
| | S | |
| Several diagonal fractures; orange hal fracture fill | 5.5 | Dark-gray & gray-blue mdstn to clystn, finely laminated, bedding disturbed; contains ropy anh interbeds & nodules; also contains fractures filled w/ orange hal; mdstn becomes dolomitic up section. |
| | S | |
| Dissolution cavities | 5.2 | Bedded hal w/ both vertical-oriented crystals & recrystallized beds; zones are milky w/ inclusions, interbedded material is anh drapes. Bedded hal is truncated in 2 places by coarse, recrystallized hal w/ insoluble residue at the base. |
| Bedding tilted; some anh lam at angle to core | | |

| | | | |
|---|---|---|---|
| logged by | BL | date | 2/83 |
| checked by | SH | date | 2/83 |
| transcribed by | PH | date | 1/84 |
| typeset by | LH | date | 11/86 |
| drafted by | NM | date | 2/87 |

QA 7026

WELL: SWEC G. Friemel No. 1 COUNTY: Deaf Smith

INTERVAL: 2737-2837 ft Lower San Andres Unit 4




| | | | |
|---|---|---|---|
| logged by | PG | date | 8/85 |
| typeset by | LH | date | 11/86 |
| drafted by | NM | date | 2/87 |

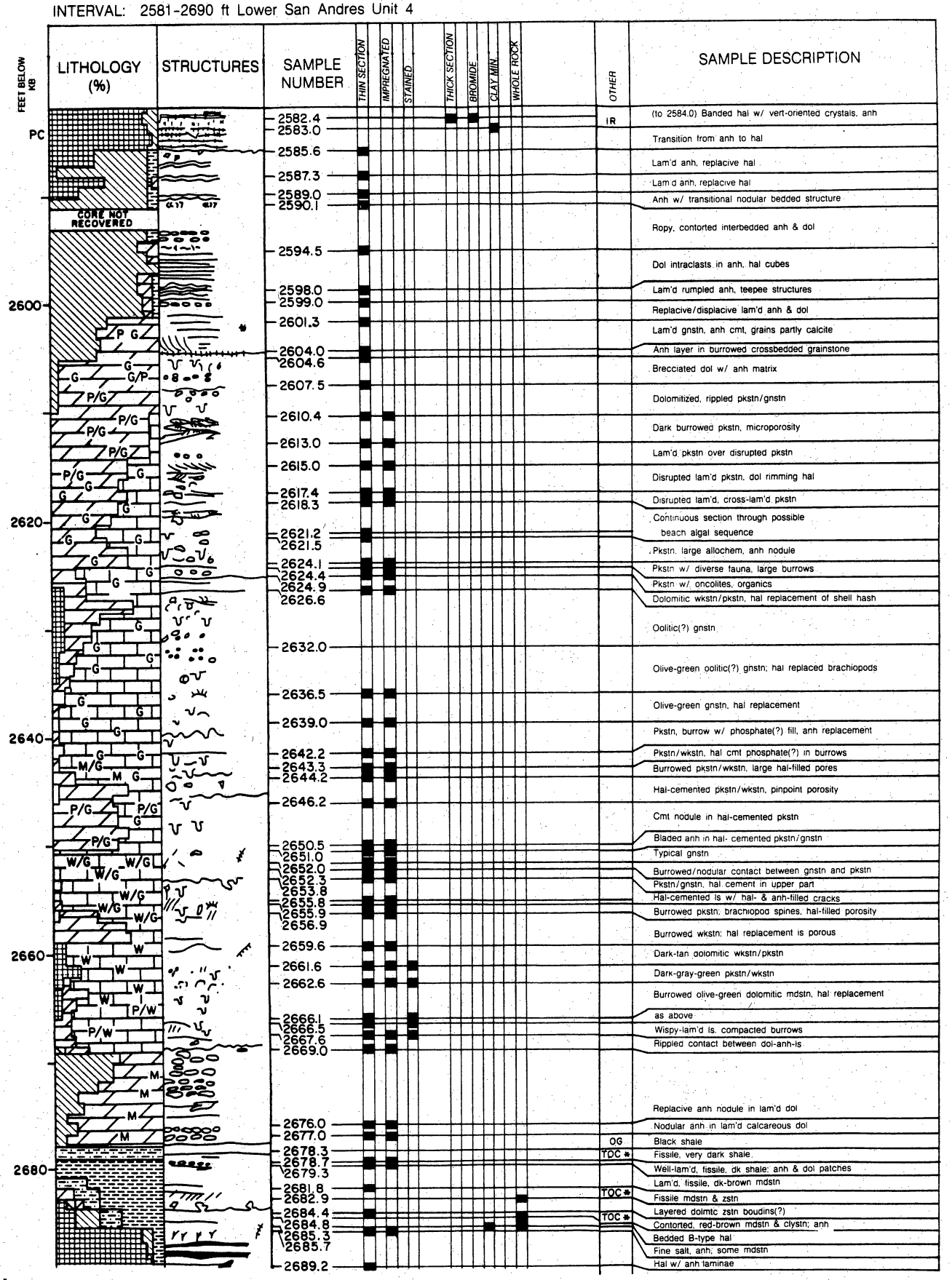
CC = complete clastic analysis
T = total organic carbon

QA 7029

APPENDIX B. Sample distribution in the San Andres unit 4 carbonate in the SWEC G. Friemel No. 1 and the SWEC Detten No. 1 wells.

WELL: SWEC G. Friemel No. 1 COUNTY: Deaf Smith

INTERVAL: 2581-2690 ft Lower San Andres Unit 4




logged by VDN date 8/84

typeset by LH date 11/86

drafted by NM date 2/87

IR = insoluble residue
OG = organic geochemistry
TOC = total organic carbon
* = grain size analysis
CC = complete clastic analysis

QA 7028

# APPENDIX C. PETROGRAPHIC DESCRIPTIONS OF THE SAN ANDRES UNIT 4 CARBONATE IN THE SWEC G. FRIEMEL NO. 1 AND THE SWEC DETTEN NO. 1 WELLS

SWEC G. Friemel No. 1

Sample # F 2589.0

Slab description: Dolomite-anhydrite intraclast conglomerate with abundant skeletal halite crystals

Stratigraphic interval: San Andres unit 4 anhydrite

Composition:

Dense carbonate--dolomite or possibly magnesite (32% est.): Clasts and matrix

Anhydrite (45%): Coarse to fine blades serve as matrix/cement for dolomite; coarser equant anhydrite +/- celestite

Celestite(??) (1%): Coarse crystals replacing anhydrite have anhydrite crystals within them.

Halite (20%): Skeletal displacive crystals, abundant inclusions of anhydrite and carbonate in them. Halite has partly replaced/cemented some carbonate.

Opaques (1%): Pyrite and leucoxene

Fabric: Intraclasts are mostly somewhat rounded, slightly size sorted. This is probably a detrital assemblage, although the extent to which large sulfate grains are clasts or replacement is unknown. Some areas are mostly ordinary anhydrite nodules with few or no intraclasts of dolomite.

Interpretation: Resedimented evaporites--channel fill(??); fabric later disturbed by growth of halite.

Photography: 3 slides

Comments: XRD to check for dolomite/magnesite, celestite/polyhalite, or all anhydrite. Any quartz?

Sample # F 2594.5

Slab description: Interbedded anhydrite and dolomite, some laminated fabric, some intraclastic fabric, possible pseudomorphs after gypsum
Stratigraphic interval: San Andres unit 4 anhydrite

Composition:
Anhydrite (85% est.)
Dolomite (15% est.): Anhedral aphanocrystalline isolated to mosaic crystals
Quartz (or celestite, trace): Replacing anhydrite with preserved anhydrite laths in it

Fabric: Complex fabric. Looks like probable large gypsum crystals were covered by dolomite-gypsum sediment. During diagenesis this fabric was modified, possibly by expansion similar to that of sample # F 2599.0, by nodule growth, or even by possible dissolution and collapse; may have contained some halite.

Interpretation: Subaqueous gypsum deposition, complex and atypical diagenesis; large amount of dolomite in gypsum environment is not typical in the San Andres either.

Photography: 1 slide

Comments: XRD to check for magnesite in fine, dense dolomite, celestite, and quartz. Is any clay present?

Sample # F 2599.0

Slab description: Laminated, periodically rumpled anhydrite and dark, silty terrigenous mudstone. The laminae have expanded and buckled up to form ridges with a tee-pee cross section and a polygonal pattern on the bedding surface.
Stratigraphic interval: San Andres unit 4 anhydrite

Composition:

Anhydrite (90%): Crystal size varies from laminae to laminae, from horizontal coarse blades to fine equant anhedral mosaic.

Mudstone (10% est.): Oriented sericite; quartz silt; dark brown color apparently from organics; abundant pyrite

Fabric: Finely laminated; laminae average 0.3 mm wide and are defined by changes in mud content and anhydrite orientation and crystal size. Slide was selected to examine the regularly spaced miniature tee-pee structures. The core of the tee-pee is formed by folded, bunched, or somewhat nodular anhydrite causing a thickening of one lamina. Overlying laminae have parallel folds, enlarging the structure. A few laminae have been thrust faulted at the crest of the anticline. Shear has occurred along the muddy layers. Tee-pees are confined to a few laminae and are not stacked.

Interpretation: Structures are the sort that might have formed by hydration of gypsum.

Photography: 3 slides

Sample # F 2601.3

Slab description: Laminated, slightly disrupted dolomite with anhydrite that is partly replacive, partly displacive or precompactional
Stratigraphic interval: San Andres unit 4 carbonate, top

Note: Not stained

Composition:

Dolomicrite (70% est.)

Siliciclastic silt (10% est.): Angular grains concentrated in layers and scattered throughout slide, quartz, twinned feldspar, and silt

Allochems (5%): Mostly peloids, some with rims, some squashed; fragments of brachiopods; forams are sparse.

Anhydrite (15%): Horizontally elongate nodules cut across bedding; anhydrite has replaced dolomite, as shown by abundant inclusions of dolomite in anhydrite; medium crystals, felted

Quartzine (trace): Length-slow chalcedony replaces anhydrite in a few spots.

Fabric: Closely spaced lamination (0.3 mm) defined by silt and organic stain, alternated with thicker, ripple-laminated laminae. Anhydrite nodules have only locally disturbed bedding in dolomite, indicating that replacement is dominant over displacement. The deformation present could reflect either compaction or minor displacive growth of anhydrite. Vertical hairline fractures are filled with trace amounts of halite and blades of anhydrite.

Interpretation: Lamination might be algal, might even be eolian.

Photography: 2 slides

Sample # F 2604.0

Slab description: Laminated grainstone with anhydrite cement
Stratigraphic interval: San Andres unit 4 carbonate, top

Note: Etched and stained for calcite with alizarin red

Composition:

Allochems:

Peloids (60 to 20% est.): 0.05-mm pellets, large 0.4-mm intraclasts, gradational between squashed and whole; many have microspar rims.

Encrusting bryozoans, echinoid plate, other skeletal grains (5%): Bryozoans are large plates.

Microspar (10 to 30%): Very finely crystalline anhedral isolated crystals to mosaic

Anhydrite (10 to 65%): Coarse, felted blades serve both as a cement and as a replacement of allochems and matrix. Amount of replacement cannot be determined because some areas may have had gypsum mud matrix or have been intensely replaced; minor amount of replacive anhedral anhydrite with inclusions of dolomite like sample # F 2604.6.

Fabric: Well laminated; lamination defined by strong horizontal orientation of grains and by amount of anhydrite cement. Laminae with less anhydrite cement is most compressed.

Interpretation: Bryozoan has a rim of dolomicrospar, which supports an early rim cement origin.

Photography: 3 slides

Comments: All carbonate is dolomite.

Sample # F 2604.6

Slab description: Anhydrite bed in burrowed cross-laminated grainstone
Stratigraphic interval: San Andres unit 4 carbonate

Note: Etched and stained for calcite with alizarin red

Composition:

Allochems:

Peloids, rimmed grains, tubes (40% est.): Most abundant grains are indistinct, almost indistinguishable from micrite matrix. Other grains are clearly defined by dolomicrospar rims and are round, flat, or paisley shaped, like squashed ooids, dolomicrite-centered or halite-cemented molds. Flat ones have much narrower cross sections than round ones, and so there are not two sections through the same grain. Some have complexly chambered or "wormy" internal fabric and double shells of microspar, but these are mostly molds--might be algal grains. Diameter 0.08 to .2 mm.

Echinoderm plates, ostracods (trace)

Dolomicrite (50% est.): Aphanocrystalline

Anhydrite (10% est.): Coarse (0.6 mm diameter) poikilotopic anhedral crystals have replaced dolomite allochems and matrix. Inclusions of dolomite are abundant, but ghosts of allochems are not well preserved within the replacive anhydrite. The replacement anhydrite may be nucleated on lesser amounts of void-filling anhydrite cement (intercrystalline and mold filling). Some is also associated with finely crystalline, felted anhydrite nodules.

Halite (1%): In molds and in hairline fractures extending out from the thick anhydrite bed

Length-slow chalcedony and macroquartz (trace) replacing anhydrite

Fabric: Crossbedding is not well defined in thin section because of burrowing. Vertical micrite and anhydrite feature, which may be a desiccation crack or a burrow, cuts the anhydrite bed.

Interpretation: Pelmicrite with interbeds of gypsum, possibly in an intertidal/supratidal environment; suggestion of two stages of anhydrite diagenesis: (1) cement and nodule and (2) replacive. The halite-filled hairline fractures might have formed after lithification of the thick anhydrite bed; they also contain euhedral anhydrite cement.

Photography: 7 slides

Sample #F 2607.5

Slab description: Real or pseudobrecciated dolomite, anhydrite between clasts
Stratigraphic interval: San Andres unit 4 carbonate, near top

Note: Etched and stained for calcite with alizarin red

Composition:

Peloids (35% est.): 0.05 mm diameter, round and well sorted; peloids have a variety of morphologies, including dense dolomicrite, dolomicrospar, grains with hematite(?) replacing the center, grains and molds with microspar rims, molds filled with poikilotopic anhydrite cement, empty molds.

Dolomicrite (38% est.): 0.015-mm subhedral dolomite

Anhydrite (25% est.): Medium crystalline (0.08 mm) subhedral felted mosaic of laths forms nodules and slighty coarser poikilotopic crystal cement.

Pores (2%?): Molds and intergranular pores; not impregnated, so it is difficult to be sure that these areas are pores and not etched-out halite cement; but stub does not taste of halite.

Fabric: Cross laminated; laminae cut by vertical features filled with dense micrite or anhydrite mosaic that may be desiccation cracks. Original fabric disturbed by growth of displacive/replacive anhydrite nodules. Some anhydrite appears to be beds cut by micrite-filled vertical cracks.

Interpretation: Pelmicrite, cross laminated, possibly desiccation cracked; anhydrite of primary (gypsum mud drape) as well as abundant diagenetic cement and nodule origin

Photography: 1 slide

Comments: No taste of halite on stub; all carbonate is dolomite.

Sample # F 2610.4

Slab description: Dolomitized, rippled packstone and grainstone. The largest ripples are 2 cm tall

Stratigraphic interval: San Andres unit 4 carbonate

Note: Impregnated; etched and stained for calcite with alizarin red

Composition:

Allochems (42% est.): All dolomite; (all tubes and round grains) 0.1 to 0.04 mm in diameter with radial 0.01-mm-thick dolomicrospar coats; some similarities to squashed ooids, in that the same kind of coats range from round to elongate; with some paisley-shaped intermediate forms. Micrite centers, dark-stained micrite centers with pyrite at the center, epoxy-filled molds, and halite(?)-filled molds all occur intermixed with the same kind of rim. Micrite-filled grains are most abundant in areas with micrite cement, halite-filled grains in areas with a matrix of coarse dolomite and intercrystalline halite. This is the same material that has been described as round grains and girvanella below, but here it appears to be one kind of grain. The proportion of round grains to elongate grains seems too high for all of the grains to be tube shaped.

Matrix (35% est.): 0.04-mm rhombic to anhedral dolomite, slightly finer and more loaf shaped where halite cement is minor

Halite cement (15% est.): Fills molds and intercrystalline voids; skeletal halite crystals in micritic areas

Anhydrite cement (5% est.): Laths fill molds and intercrystalline voids; flattened nodules along bedding planes

Celestite (trace): Associated with anhydrite

Pores (2% est.): In molds and intercrystalline voids

Fabric: Ripple lamination defined by variation in allochem preservation (percent of moldic grains) and by micrite matrix preservation. Some ripple tops highlighted by elongate nodules of felted anhydrite. Other ripple tops with micrite matrix contain molds in celestite, anhydrite, and halite of skeletal halite crystals. Celestite has replaced halite; euhedral anhydrite blades may have replaced celestite; peloid grainstone-packstone

Interpretation: Restricted fauna, intertidal/supratidal channel?

Comments: Check sulfate mineralogy.

Sample # F 2613.0

Slab description: Dark, burrowed packstone with microporosity
Stratigraphic interval: San Andres unit 4 carbonate

Note: Impregnated; etched and stained for calcite with alizarin red

Composition:

- Allochems:
  - Round moldic grains (5% est.)
  - Peloids (10%): Round 0.04- to 0.08-mm grains of dense microspar and slightly larger indistinct grains of less dense microspar
- Matrix:
  - Dolomicrospar (77% est.): Finely crystalline (0.04 mm) rhombs and anhedra
- Cements:
  - Anhydrite (3% est.): In nodules of finely felted crystals and as intercrystalline cement and filling molds, especially of organic grains
  - Halite: Difficult to identify because impregnation is uneven, but halite taste is very weak on the stub, might be minor.
- Porosity: Impregnation is uneven, but might be as much as 5%.

Fabric: Structureless in thin section

Comments: All carbonate is dolomite.

Sample # F 2615.0

Slab description: Ripple-laminated pellet-tube packstone overlies disrupted packstone.
Stratigraphic interval: San Andres unit 4 carbonate

Note: Etched and stained for calcite with alizarin red; poor impregnation

Composition:

- Allochems:
  - Peloids (5% est.)
  - Tube (5% est.)
  - Round moldic grains (10%): Might have been either girvanella, peloids, or possibly forams
  - Organic material (<1%): Large crushed grains, smeared stains
- Matrix:
  - Dolomicrospar (65% est.)
  - Siliciclastic silt (<1%): Scattered
- Cement:
  - Anhydrite (5% est.): In molds of round grains, intercrystalline cement
  - Halite (8% est.): Intercrystalline pores in dolomite, molds of round grains; exact amount is difficult to determine because of poor impregnation, but stub tastes of halite.
- Pores: Impregnation is poor, but light-colored areas of the slide (30%) may have 5% intercrystalline porosity.

Fabric: Ripple laminated at the top, slightly burrowed below; lamination defined by variation in abundance of dolomicrite matrix and preservation of micritic peloids.

Interpretation: Dolomitized, ripple-laminated girvanella-pelmicrite; restricted facies

Comments: All carbonate is dolomite.

Sample # F 2617.4

Slab description: High-angle, ripple-laminated girvanella-foram(?) packstone with large displacive skeletal halite crystals rimmed by calcite and minor celestite
Stratigraphic interval: San Andres unit 4 carbonate

Note: Impregnated; etched and stained with alizarin red for calcite

Composition:

Allochems:

Girvanella (30% ? est.) including abundant 0.06-mm-round grains composed of a radial, fine crystalline dolomite; most are moldic and are filled with calcite or halite; a few have micrite centers, suggesting that most of these grains might be coated grains.

Forams (1%): Possibly some or all of the round moldic grains are forams, but only a small number of the grains show the chambers typical of forams.

Dolomicrospar matrix (40% est.): 0.015-mm, loafish to euhedral crystals are the dominant matrix in areas without calcite.

Calcite cement (25%): Poikilotopic cement in some areas of the slide partly or completely replaces molds of halite crystals.

Anhydrite (2%): Small felted nodules have replaced carbonate; isolated laths occur in carbonate and in the outside rims of halite masses.

Celestite (<1%): Clearly replacing calcite at the rims of nodules

Siliciclastic silt (<1%)

Porosity (<1%): Moldic (in round grains) and intercrystalline (in areas of coarser dolomite) pores shown by impregnation

Fabric: Ripple lamination defined by amount of dolomite matrix, packing of allochems, and direction of elongation of allochems. Dolomitized girvanella-peloid-foram packstone, probably initially was a grainstone with pores lost to compaction and cementation by dolomite

This slide shows one of the clearest examples of a late diagenetic sequence. All of the original calcite has been dolomitized. The timing of dolomitization relative to other phases is not clear but might be precementation by halite because dolomite crystals appear to be floating in halite. Displacively grown skeletal halite crystals have deformed original ripple lamination and probably have cemented grainy areas and filled molds. Calcite replaced halite extensively, forming a mosaic of coarse anhedral to subhedral crystals. Abundant inclusions of halite in calcite and calcite clasts of skeletal halite crystals demonstrate replacement origin. Celestite replaced calcite at the edges of large nodules. The replacement origin is shown by inclusions of calcite along remnant calcite crystal boundaries in celestite. Blades of anhydrite have replaced celestite and calcite at margins of skeletal halite crystals. Replacement origin is shown by euhedral geometry of the crystals and by inclusion of calcite in anhydrite. Small finely crystalline anhydrite nodules and anhydrite cement in round allochems might have precipitated earlier or at the same time as the blades.

Interpretation: Well-sorted, restricted, algally dominated fauna and high-angle ripple lamination might represent a channel fill in an intertidal-supratidal setting.

Photography: 7 slides

Comments: Very clear diagenetic sequence; check celestite mineralogy on SEM.

Sample # F 2618.3

Slab description: Dolomitized, laminated, and ripple laminated peloid-girvanella(?) wackestone
Stratigraphic interval: San Andres unit 4 carbonate

Note: Impregnated; etched and stained with alizarin red for calcite

Composition:
- Allochems:
  - Peloids (5% est.): Indistinct micritic grains
  - Tubes(?) (5% +/-): Indistinct tubes and round grains; identity of round moldic grains questionable, might be forams
- Dolomicrite matrix (75% est.)
- Calcite spar cement (10% est.): In lower part of slide, poikilotopic coarse crystals
- Siliciclastic silt (1%): Scattered grains, mostly in the upper part of the slide
- Porosity (1%): Molds impregnated
- Halite cement (2%): Fills many round molds, intercrystalline areas
- Anhydrite nodules, anhydrite cement (<1%): Contain pyrite
- Organic stain and smeared organic grains (1%)

Fabric: Lamination and ripple lamination defined by organic material, concentrations of peloids, and orientation of elongated grains. The upper part is mostly dolomite with only sparse calcite cement; moldic and some possible intercrystalline porosity is abundant in this interval. The lower part of the slide has abundant calcite spar, which might be filling pores in an initially very porous rock or might be replacing micrite matrix or halite cement. This area is dark in the slab.

Interpretation: Silty, dolomitized peloid biomicrite; more late poikilotopic calcite cement of unclear origin

Comments: Stain shows that 10% of carbonate is calcite.

Sample # F 2621.2

Slab description: Two slides (F 2621.2 and F 2621.5) make up a crossbedded, laminated sequence interpreted as a berm and overlying algal mat sequence; ripple-laminated foram-girvanella-pellet grainstone
Stratigraphic interval: San Andres unit 4 carbonate

Note: Etched and stained, but stain didn't take; impregnated

Composition: Like sample # F 2621.5
Tubes, round molds (40%)
Dolomite matrix (37% est.)
Calcite spar (10%): Mostly in burrows
Halite cement (10% est.)
Pores (1%): Impregnated molds of round grains
Anhydrite nodules, pore-filling cement (1%)
Scattered siliciclastic silt (less than 1%)

Fabric: Slightly burrowed, crossbedded to laminated, dolomitized girvanella-pellet-biosparite and biomicrite; all exceptionally well sorted, fine-grained, with restricted fauna; berm origin plausible; calcite cement in burrow fills, some grainstone layers; dolomite is coarser in grainstone areas.

Interpretation: Interbedded grainstone and packstone; complex diagenesis involves dolomitization, compaction, calcite cementation, localized anhydrite cementation, and nodule growth.

Photography: 2 slides

Comments: 1% moldic porosity; stain does not show calcite, but acid shows that patches with poikilotopic cement are calcite similar to the underlying sample.

Sample #F 2621.5

Slab description: Two slides (F 2621 and F 2621.5) are a crossbedded, laminated sequence interpreted as a berm and overlying algal mat sequence; ripple-laminated foram-girvanella-pellet(?) grainstone

Stratigraphic interval: San Andres unit 4 carbonate

Note: Etched and stained with alizarin red for calcite; impregnated with pale blue epoxy

Composition:

Allochems: (30% est.): Oval to round 0.05- to 0.1-mm grains outlined in dolomite; not enough structure left in most to determine original allochem with certainty; some are definitely forams, others may be girvanella tubes, ooids, pellet rims. Small thin-shelled bivalves, organic grains (sparse)
Pellets preserved at top and bottom of the slide in areas with dolomite rather than poikilotopic calcite matrix

Siliciclastic silt (1%)

Calcite spar (50%): 5-mm-diameter poikilotopic crystals, mosaic of embayed crystals

Dolomite matrix (14%): At top and bottom of slide; finely crystalline 0.015-mm loafish to rhombic crystals

Halite cement (5% est.): In molds of round grains, intercrystalline areas in dolomite

Small anhydrite nodule with pyrite crystals in it.

Fabric: Crossbedding defined by size and density of allochem molds best seen in whole slide; allochems better defined in overlying slide; "algal" layers described from core correspond to dense dolomite with preserved horizontal girvanella filaments, whereas ripped intervals have calcite cement and are less compressed.

Interpretation: (1) Allochems dolomitized; (2) poikilotopic calcite cement prevents compaction. Timing of halite cement unclear. Calcite may have cemented grainstones rather than packstones.

Photography: 2 slides

Comments: Stain shows that about 50% of the carbonate is dolomite; calcite occurs only as poikilotopic cement, as a few preserved calcite allochems, present only as a late cement, and as a few remnant allochems. No impregnated pores.

Sample # F 2624.1

Slab description: Oncolite mollusk packstone; anhydrite nodule replaced at rim by calcite
Stratigraphic interval: San Andres unit 4 carbonate

Note: Impregnated, etched, and stained with alizarin red

Composition:

Allochems:

Mollusks (5% est.)
Oncolites (5% est.)
Forams and algal fragments (19% est.)
Ostracod fragments, phosphatic grains, brachiopod and bryozoan fragments (trace)

Matrix:

Calcite: Spar (5%) in allochem molds, intergranular cement; in tubes in oncolites and algal grains. Microspar (20%) matrix associated with dolomite in areas outside of burrows; micrite (10%) matrix in burrows, filling within and around many forams
Dolomite (average 30% est.): Fine crystalline (0.03 mm) loafish crystals in areas of microspar, not in burrow fills

Anhydrite (1%): 1-cm nodule composed of aligned medium crystals of anhydrite, extensively replaced by calcite spar

Halite replacing allochems (5%), especially outside of burrow fills; forams and molds are crushed and filled with halite.

Celestite (trace): Filling foram molds, replacing(?) micrite; may be being replaced by calcite; mixed with anhydrite and hard to identify

Fabric: Nodules defined by (1) areas of dolomite and microspar replacing some closely packed forams and (2) micrite matrix of the internodular areas. Sparry dolomitic nodules look bleached compared with darker, more organic(?) allochems of the oncolites and with internodular areas. Internodular areas are more compacted.
Coarse anhedral crystals of calcite have partly replaced anhydrite. Calcite crystals contain remnant anhydrite. Coarser, felted anhydrite masses around the edges of the nodule may represent renewed anhydrite precipitation; organic compacted parting at base

Interpretation: Micrite-rich equivalent of sample # F 2624.4; may also be a grainstone with compaction of micritic grains

Photography: 4 slides

Comments: Stain shows that 30% of carbonate is dolomite. No porosity was shown by impregnation.

Sample # F 2624.4

Slab description: Oncolite grainstone, diverse fauna, large burrows
Stratigraphic interval: San Andres unit 4 carbonate

Note: Etched and stained with alizarin red for calcite, impregnated

Composition:

Allochems:

Oncolites (15% est.): Dense micrite, foram fragments, tubes; well-formed concentric coats indicate formation in agitated water.

Mollusk fragments (15% est.): Spar-filled molds; gastropods may be dominant, evidenced by large and small intact shells. Many sparry grains in spar cement defined by thin micrite coats.

Forams (20% est.): Brown stain, filled and cemented by micrite

Pellets and intraclasts of pellet sparite (5%)

Algal fragments (trace)

Brachiopod fragments with oncolite coats (trace)

Halite-replaced grains (trace)

Echinoid plates (trace)

Calcite spar cement (45% est.)

Dolomite (<1%): Very fine loafish crystals (0.015 mm) replacing micrite in a few spots

Celestite (trace) as intergranular cement

Fabric: Many of the grains in the grainstone have been filled and coated by micrite, suggesting that this assemblage has been reworked from muddier sediment; gastropod-oncolite biosparrudite

Interpretation: Moderately diverse faunal assemblage, although the abundance of gastropods and oncolites suggests a slightly stressful (shallow and agitated[?]) environment, perhaps marginal to a normal environment, which provided the fragmented diverse fauna.

Photography: 3 slides

Comments: Stain shows that more than 99% of the carbonate is calcite; no impregnatable porosity because of sparry calcite cement

Sample # F 2624.9

Slab description: Dolomitic packstone with oncolites, concentration of organics at top, possible microporosity in oncolites?
Stratigraphic interval: San Andres unit 4 carbonate

Note: Etched and stained with alizarin red for calcite, impregnated

Composition:

Allochems:

Oncolites (2%): Dense micrite with a brown stain; did not stain well, so might be dolomitic. Small and large tubes preserved in oncolite; most are nucleated on skeletal material.

Bivalves (5%): Large shells with preserved sparry structure, may be mollusks; some brachiopod spine sections; thin oncolite coatings

Forams (8%): Intact and compressed chambered spheres and tubes with strong brown stain; some are encrusting brachiopod spines (some of this material might be spores or algae?).

Matrix:

Calcite (40%)
Dolomite (40%)
Coarse siliciclastic silt (<1%)

Calcite spar (5%) fills allochem molds

Halite(?) fills trace porosity, as indicated by presence of impregnation only at the edges of the slide.

Fabric: Silt, dolomite, calcitic allochems, and organic material is concentrated at the top of the slide with a wispy, microstylolitic appearance. Oncolites are concentrically cracked, and cracks are filled with halite.

Interpretation: Faunal diversity is low, although identification of bivalves would be useful because brachiopods and forams would suggest normal marine conditions. Dissolution of calcite to produce wispy lamination at top of slide occurred after dolomitization?

Comments: Staining shows that about half the carbonate is dolomite. Impregnatable porosity exists only at the edges of the slide.

Sample # F 2626.6

Slab description: Dolomitized packstone/wackestone, wispy laminae, halite replacement of allochems

Stratigraphic interval: San Andres unit 4 carbonate

Note: Etched and stained for calcite with alizarin red

Composition:

Dolomicrite matrix (40% est.)

Calcite spar (40% est.): Coarse, poikilotopic subhedral grains, fills pores or rims halite

Halite (20% est.): Filling centers of allochem molds

Phospate (>1%): Conodonts(?)

Anhydrite-filling pores (<1%): Euhedral blades

Siliciclastic silt (trace)

Fabric: Burrowed and wispy-laminated, dolomitized skeletal fragment packstone/wackestone

Interpretation: Calcite has a similar occurrence but is not as euhedral as dolomite where it rims halite. Calcite is postdolomitization, probably posthalite.

Photography: 3 slides

Comments: Stain shows that 50% of carbonate is dolomite.

Sample # F 2632.0

Slab description: Dolomitized oolitic(?) grainstone
Stratigraphic interval: upper part of San Andres unit 4 carbonate

Note: Etched and stained for calcite with alizarin red; stain only took well in lower right corner.

Composition:

Allochems:

Ooids (10%): Radial structure preserved, several shells; typically shells are buckled and spalled apart; dominant at the base of the slide

Coated grains (10%): Single shell with radial structure rims allochems; mostly algal grains

Compressed organic grains (30%): Some concentic lamination reminiscent of ooids, but compressed, embayed, and cracked by septarianlike cracks

Microspar intraclasts

Blue-green algal fragments, preserved as halite-filled molds

Ostracods, bryozoan fragments, brachiopods, forams (>1%): Dolomitized

Molds (10%): Filled with halite, poikilotopic dolomite and anhydrite

Calcite matrix (10%): anhedral calcite spar matrix embayed by micrite

Dolomite matrix: 0.05-mm dolomite rhombs (15%); micrite (15%); may show original spar/micrite relationships modified by dolomitization; micrite fills burrows, preserved in pockets

Fabric: Wispy-laminated seam at the top is composed of tightly compressed organic material in micrite matrix. Most of the slide below this is composed of organic calcitic(?) material; large micrite and spar-filled burrows

Interpretation: Ooids unusual because radial structure is preserved; dolomitized, poorly washed ooid-algal(?) sparite

Photography: 3 slides

Comments: 15% of carbonate is dolomite; staining is ambiguous in organic grains. Epoxy has stained pink. Porosity/halite relationships are indeterminable after staining, but halite taste is weak on slab.

Sample # F 2636.5

Slab description: Oncolite-mollusk packstone
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated

Composition:

- Allochems (mostly calcite)
  - Mollusk fragments (5% est.)
  - Large oncolite (15% est.): Dense micrite, mottled, algal structure, compressed appearance, many have been extensively replaced by neomorphic spars.
  - Phosphatic grain
- Matrix (70% est.): Pelleted micrite clots in and partly replaced by 0.04-mm rhombic dolomite (45%) and void-filling calcite spars (25%).
- Halite cement (10%): Filling intercrystalline areas in the matrix, centers of large vugs of indeterminate origin.
- Anhydrite and celestite(?) (trace): Filling large vugs

Fabric: Poorly washed oncolite-mollusk sparite, abundant dolomite, some sparry calcite, possible intermediate halite replacement; impregnated only where halite cement has been dissolved at the edges of the slide

Photography: 3 slides

Comments: Stain shows that about half of the carbonate is dolomite, half is calcite.

Sample # F 2639.0

Slab description: Olive-green ooid-brachiopod grainstone
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated, etched, and stained for calcite with alizarin red

Composition:

- Allochems (all calcite):
  - Ooids/coated grains (60% est.): Well-sorted, round grains with thick, complete oolitic coatings; brown color and minute fluid inclusions define radial structure; centers are dense micrite, some possibly algal; grains are tightly packed; locally, grains are squashed, in places even coalescing to wispy micrite.
  - Brachiopods (5% est.): Large whole, thin-walled punctate brachiopods, may be all the same species; abundant spines; preserved shells
  - Pelecypod fragments (5% est.): Spar-filled molds; some spar areas may be tubes or blades of green algae.
  - Forams, echinoids
- Spar (15% est.): Medium to fine crystals in intergranular area, filling pelecypod and algal(?) molds, rimming halite crystals
- Nodules (15% est.): Fabric highly destroyed in large areas; destroyed areas are characterized by coarse calcite mosaic with cubic forms defined by micritic and organic remnants of allochems. Possibly halite has replaced original fabrics? The areas of destroyed fabric have a sharp boundary with areas of well-preserved fabric.
- Dolomite (2%): 0.04-mm rhombs have replaced micrite and micrite and intraclasts in local patches
- Halite (trace): Filling large void at the edge of nodules
- Anhydrite (trace): In foram molds; replacing grains, cement, and micrite; associated with halite
- Pyrite (trace) in centers of ooids

Fabric: Ooid-brachiopod sparite, nodules with recrystallized textures; shelter porosity; all pores filled with calcite spar, minor halite, anhydrite in macropores.

Photography: 6 slides

Comments: Stain shows 2% dolomite in scattered patches.

Sample # F 2642.2

Slab description: Packstone, large anhydrite nodule; anhydrite and dolomite have replaced large allochems.
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated, etched, and calcite stained with alizarin red

Composition:

Allochems (20% est.):

Peloids

Bivalves, calcite- and dolomite-filled molds, some preserved shell structure

Echinoid plates: Some still calcite, some dolomitized, but skeletal structures preserved

Dolomicrospar matrix (60% est.): 0.04-mm rhombs of dusty to limpid dolomite

Dolomicrite burrow fills (5% est.)

Calcite spar (10% est.): Fills pores (replaces halite[?]; medium (0.1 to 0.2 mm) spar, includes anhedral halite and euhedral dolomite within poikilotopic calcite crystals

Anhydrite nodule (5%): Replaced by medium calcite anhedra around edges

Fabric: Burrowed, packed peloid micrite; allochems are halite filled; many of them have been partly or wholly replaced by poikilotopic calcite(?) spar. Dolomite rhombs float in spar. Coarse calcite(?) is also replacing margins of anhydrite nodule.

Interpretation: Calcite precipitated during late diagenesis is replacing halite and anhydrite. Rhombs formed before this late stage.

Photography: 4 slides

Comments: Stain shows that latest cement is calcite.

Sample # F 2643.3

Slab description: Halite-cemented wackestone
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated, stained for calcite with alizarin red

Composition:

Allochems (25% est.):

Bivalves: Mostly molds filled with anhydrite or halite (1%)

Echinoid plates (1%): Calcite replaced at edges by dolomite

Bryozoan: Now dolomite partly replaced by halite

Peloid, molds, and micritic grains (23%): Mostly well sorted, poorly preserved, all dolomite

Microspar matrix: Loosely packed 0.016-mm rhombs in halite cement

Calcite microspar (<1%): Isolated grains, some within areas of halite cement, a few rhombs rimmed with dolomite, possible dedolomite(?), possible remnant calcite

Dolomicrite (12% est.): In burrow fills

Epoxy-filled pores (trace): Allochem molds in burrow fills

Fabric: Burrowed, packed peloid micrite, diagenetic alteration in the form of dolomitization, replacement of allochems; dolomicrospar rims some open molds. Phosphatic grains in core description do not appear in slide.

Interpretation: Distribution of halite cement seems to respond to subtle influences--it fills peloid molds in packstone but leaves them open in denser, more finely crystalline burrow fills.

Photography: 3 slides

Comments: Stain shows 98% calcite.

Sample # F 2644.2

Slab description: Burrowed packstone/wackestone, large pores are filled with halite and anhydrite. Pinpoint porosity
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated, stained for calcite with alizarin red

Composition:
- Dolomicrospar (95% est.): Similar to sample # F 2646.2; finely crystalline rhombs (0.016 mm), some anhedra; no allochems identified in thin section; check of mineralogy shows all dolomite
- Halite (2%): In all macro- and some micropores in microspar; patchy distribution; also fills fractures; identified by taste test
- Anhydrite (1%): Small nodules, replacing halite in macropores
- Porosity filled with blue epoxy, intercrystalline (2% est.)
- Organic wisps

Fabric: No lamination; petrographic name for this rock is microsparite. Vertical hairline fractures are halite filled and connected to small halite crystals and anhydrite nodules.

Interpretation: Pores are in intercrystalline micropores; macropores and some micropores are filled with halite cement.

Photography: 2 slides

Sample # F 2646.2

Slab description: Halite-cemented wackestone(?), pinpoint porosity
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated, stained for calcite with alizarin red

Composition:

Dolomicrospar (99% est.): 0.016-mm-diameter mosaic of rhombs; all dolomite
Allochems(?) (1%): Mostly poorly preserved molds of skeletal grains, filled with anhydrite, organic wisps

Fabric: Impregnation only on the edges of the slide, but no taste of halite even in the center. Abundant isotropic matrix for dolomite suggests that halite cement or pores should be present. Some pinpoint porosity is anhydrite.

Comments: Stain shows all dolomite, possible permeability plug.

Sample # F 2650.5

Slab description: Micrite nodule in halite-cemented/replaced packstone matrix; matrix compacted around nodule
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: No evidence of impregnation; etched and stained for calcite with alizarin red

Composition:

Nodule: Microspar 0.016-mm in diameter, sparse allochems, 40% fine crystals of rhombic dolomite

Nodule rim: Packed biomicrite, best preservation of allochems, including large echinoid plates, forams, mollusks, ostracods, brachiopod fragments; in microspar/pseudospar matrix, 40% fine crystals of rhombic dolomite

Halite-replaced area: Allochems similar to those in rim, but sparser; matrix is 75% fine (0.04 mm) rhombs of dolomite with only 10% calcite, 15% halite matrix; trace of anhydrite in halite. Allochems are mostly calcite.

Fabric: Thin section is zoned. Possibly microspar is host micrite, and matrix is burrow fill. The center of the burrow fill is replaced by halite, but the margin has undergone normal carbonate diagenesis.

Interpretation: Burrowed normal marine limestone; diagenesis: the halite zone is characterized by coarse rhombs, indicating that unlike samples # F 2651.0 and # F 2652.0, carbonate diagenesis was different in the area of halite replacement. Is dolomitization partly responsible for creation of porosity later filled with halite? Anhydrite again is associated with areas of halite--is anhydrite replacing the halite or preceding it along the same porosity trends?

Photography: 2 slides

Comments: Stain shows dolomite throughout the slide, but most intense dolomitization corresponds to the halite-cemented burrow.

Sample # F 2651.0

Slab description: Calcite- and halite-cemented packstone, fractures, lowest large blades of anhydrite
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated; plucking is a problem in areas with halite cement; etched and stained for calcite with alizarin red

Composition (est.):

| | Right side | Left side |
|---|---|---|
| Allochems: Similar to those in sample # F 2652.0, poorer preservation | (20%) | (30%) |
| Micrite matrix: Includes some dolomite on right | (20%) | (50%) |
| Calcite spar | (15%) | (15%) |
| Halite replacement | (40%) | (5%) |
| Anhydrite replacement | (5%) | none |

Fabric: Right half of slide has been replaced by halite, had about the same texture as the left side, which is ordinary calcite-cemented packed biomicrite. Halite replaces micrite allochems and micrite. Anhydrite occurs as large blades within halite area, clearly replacive because of included micrite. Halite is too thin and slide too poor to see any crystal structure; no impregnated porosity. Large fracture, lined with (1) calcite and (2) halite, cuts both parts of slide with sharp margins.

Interpretation: Halite replacement followed calcite cementation and selectively replaced finer crystals (see arguments presented in sample # F 2652.0). Dolomite is present only on the right side of the slide. The amount of dolomitization is obscured by poor stain.

Comments: Stain shows that most allochems are calcite; some unstained micrite matrix on the right may be dolomite.

Sample # F 2652.0

Slab description: Typical grainstone
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated, stained for calcite with alizarin red

Composition:

- Allochems (67% est.):
  - Blue-green algal grains (15%)
  - Phylloid(?) algal grains (5%)
  - Miscellaneous peloids, intraclasts, algal grains (30% est.)
  - Mollusks (7%), including large crushed gastropod
  - Forams (10%)
  - Echinoid plates, brachiopod fragments, ostracods (1%)
- Spar cement (20% est.)
- Micrite (10% est.): Local packed biomicrite, possibly in burrows, protected areas between large allochems
- Sulfate (<1% est.): Gray; birefringence; celestite or gypsum(?) in allochem molds, replacing micrite allochems
- Halite (3% est.)

Fabric: Bioturbated, algal-mollusk-foram biosparite; diagenesis: calcite spar fills porosity; phylloid(?) algae neomorphosed(?) to fine yellow spar. Halite replaces allochems, especially forams and micrite matrix in patches, leaving spar; halite in center of some voids rimmed with calcite(?); unclear if halite is first cement, replaced by calcite, or final void-filling cement. Epoxy-filled pores occur only where halite dissolved at edges of slide during slabbing.

Interpretation: Ordinary diagenesis, except for halite replacement; replacement occurred after calcite cement because calcite cement remains in areas of replacement, and no calcite replaces halite. Therefore, the gastropod void was (1) cemented with calcite and (2) cemented with halite. Timing of celestite(?) is undefined

Photography: 6 slides

Comments: Stain, check sulfate mineralogy; stain shows all carbonate is calcite.

Sample # F 2652.8

Slab description: Burrowed/nodular contact between grainstone (above) and wackestone (below)
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated with pale blue epoxy; etched and stained for calcite with alizarin red.

Composition:

Grainstone (35% of slide, est.)

Allochems:

Algae (65% est.): A whole garden: blue green phylloid(?), some grains with good structures, all abraded; blue green has clean spar around micrite structures; phylloid(?) is fragments, now yellow (neomorphic[?]) spar. Blue-green and structureless coats on everything (5%).

Bryozoans, with micrite fills/coats

Mollusks (5%)

Echinoids (5%)

Forams (5%)

Round grains with fibrous brown rims similar to ostracods but too irregular; neomorphic centers (5% est.)

Calcite spar (25% est.): Medium crystalline, single generation

Packstone (60% of slide)

Allochems:

Sparry ghosts of phylloid algae (possibly mollusks) (30% est.)

Forams, echinoderms, bryozoans (5%)

Organic wisps (trace)

Microspar (60% est.)

Calcite spar (5%) filling molds of skeletal halite

Altered spar and micrite (5%):

Spar similar to described above, but all allochems have been dissolved; molds are now filled with multifaceted calcite(?), poikilotopic anhydrite blades, and halite centers. Micrite is dark and fractured in a septarian nodule pattern by halite, and halite is mostly replaced by calcite.

Fabric: Grainstone is coarse, intraclastic, well sorted. Packstone is poorly sorted, burrow disturbed. Initial mixing of grainstone and packstone is due to burrowing. Halite replacement has modified the fabrics. There is no impregnated porosity.

Interpretation: Algally dominated but still has a diverse fauna, big burrows; algal sparrudite and packed algal micrite; carbonates have been replaced in spots (along burrow-induced permeability); grains and matrix were replaced in grainstone, and micrite was replaced in packstone. There are two styles in packstone: skeletal crystals and septarian cracks. Halite was replaced extensively by anhydrite and calcite.

Comments: Stain shows that all carbonate is calcite.

Sample # F 2653.8

Slab description: Packstone with halite cement in upper part, calcite in lower part
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated with light blue epoxy, etched and stained for calcite with alizarin red

Composition:

Allochems (20% est.):

Brachiopod spines and thin-walled shells
Recrystallized (yellow, neomorphic) mollusk fragments
Forams, large micritic
Encrusting bryozoans
Echinoid plates
Organic wisps
Green algal grains(?)

Microspar (60%): Matrix of nodule

Micrite (16%): Matrix material did not stain but is suspected of being mostly calcite, perhaps with some clay or dolomite.

Halite (3% est.): In subhedral crystals in matrix outside of nodule, some cement

Coarse, multifaceted calcite (1% est.): Rimming halite crystals in matrix of nodule; calcite has about the same morphology as the coarse, multifaceted dolomite that typically replaces halite.

Fabric: Matrix and nodule both laminated; laminations show the extent of contortion during compaction; laminations defined by organic wisps; carbonate-filled hairline cracks; no porosity impregnated; packed biomicrite

Interpretation: Diverse fauna; nodule with calcite cement has neomorphic spar in mollusks, and matrix shows early diagenesis. Fabric indicates some precementation compaction in nodule. Matrix and nodule appear to be same material with different diagenetic histories. Compaction and microstylolitization precede halite replacement, but all avoid early cemented areas. Early cement has a sharp boundary, and outside of it both matrix and grains have been reduced by microstylolitization.

Photography: 3 slides

Comments: Stain of matrix is ambiguous.

Sample # F 2655.9

Slab description: Halite- and anhydrite-filled cracks in calcite-cemented nodule in soft, sediment-deformed, halite-cemented matrix
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Broken slide, light-blue impregnating epoxy, etched and stained for calcite with alizarin red

Composition:

Dolomicrospar (20% in nodules to 85% in matrix est.)
Calcite (80% in nodules to 15% in matrix)
Allochems (trace):
- Forams
- Echinoids
- Thin-walled brachiopods, small spines(?)
- Organic wisps

Halite (2% est.): In fractures
Anhydrite (trace): Acicular crystals in fractures; crystals are unusual because they are parallel to the fracture elongation.
Calcite spar (trace): Partly fills one fracture; the other phase in this fracture is halite; elongation perpendicular to fracture, gradation into microspar; might be multifaceted but is cloudier than is typical

Fabric: Wisps define laminations. Lamination is parallel but rotated in some nodules. In matrix, wisps are concentrated, yielding a darker color, and show deformation around nodules. Matrix is mostly dolomite with remnant calcite; nodules are mosly calcite. Fractures are en echelon, vertical, deviations depending on nodule fabric; some express skeletal halite crystal shape. No impregnated porosity is visible.

Interpretation: Nodules appear to be an early cementation/compaction phenomenon. Rotation of some nodules indicates significant dissolution may have occurred. Origin of cracks is not clear. Timing of introduction of halite and dolomite is synfracture growth; anhydrite is postfracture growth. Dolomitization here affects porous areas; local calcite cement is early.

Photography: 3 slides

Comments: Stain shows that the nodules are dominantly calcite with a dominantly dolomite matrix.

Sample # F 2656.9

Slab description: Burrowed echinoid wackestone; halite cement in upper part of slide, calcite in lower part of slide.
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Poor bonding in halite part of slide obscures halite distribution; slide supposed to be impregnated, but no evidence of it; etched and stained for calcite with alizarin red

Composition:

Allochems (14% est.) (mostly calcite):
- Echinoid plates
- Mollusks, preserved fabric
- Ostracods
- Forams
- Organic grains

Dolomite (30 to 80% est.): Very finely crystalline subhedral mosaic
Calcite (60 to 5% est.): Anhedral spar and microspar cement for dolomite
Halite (1% est.): In allochem molds, intercrystalline cement in upper part of slide; no halite in calcite nodule
Sulfate (trace): Anhydrite and celestite(?)

Fabric: Sparse echinoid biomicrite; upper halite-cemented part of the slide appears compacted/microstylolitized and has only remnant calcite allochems and cement in dolomite matrix. The nodule in the lower part of the slide has abundant original(?) calcite cement around calcite allochems and less dolomite.

Comments: Stain shows subequal amounts of dolomite and calcite; more intense dolomitization and more compaction occurs in the area outside of the calcite-cemented nodules.

Sample # F 2659.6

Slab description: Burrowed packstone. Abundant halite cement and replacement of carbonate by halite: check porosity
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated, etched and stained for calcite with alizarin red

Composition:
- Allochems (65% est.):
  - Peloids (50% est.): All molds
  - Mollusk molds (10% est.): Some preserved structure in some layers
  - Echinoid plates (5% est.)
  - Forams
- Micrite (35%): Matrix for allochems, especially abundant in burrows
- Calcite spar (20% est.): Filling moldic porosity, local intergranular spar
- Halite cement (15% est.): Filling moldic porosity, mostly in burrows
- Celestite (1% est.): Long blades in halite-filled molds

Fabric: Burrowed; grains compacted at the expense of matrix by microstylolitization, marked by organic wisps; burrowed peloid/mollusk/echinoid packstone; no impregnated pores except where halite has been dissolved at the edge of the slide

Interpretation: Normal marine fauna, large abundant burrows; might have been a grainstone, mixed by burrowing
Diagenesis: Halite cement in burrows: is halite in micritic (low-permeability) areas while calcite is in grainstone? Burrows lacking halite cement--filled peloids have yellow (neomorphic[?]) finely crystalline subhedral calcite spar similar to that in sample # F 2661. 6, but are only in the lower half of the slide.

Photography: 2 slides

Comments: Stain for calcite that shows all carbonate is probably calcite, although some areas of uneven stain indicate the possibility of some local dolomite.

Sample # F 2661.6

Slab description: Dark-tan, slightly dolomitic foram packstone
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Stained for calcite with alizarin red

Composition:
- Allochems (30% est.) (many unidentifiable grains):
  - Forams (diverse, including miliolids[?])
  - Phosphate grain (structureless)
  - Mollusk molds, large and small
  - Peloids, possible green algal structure
- Micrite (45% est.), including possible diffuse intraclasts
- Calcite cement (20% est.): Mostly cement in forams and mollusk molds
- Halite (5% est.): Intergranular cement and foram shell replacement

Fabric: Well laminated, compressed, and microstylolitized; evidence of compaction in broken spar-filled mollusk mold, close packing of grains; foram biomicrite

Interpretation: Normal marine to possible hypersaline fauna

Photography: 4 slides

Comments: Stain shows that all carbonate is calcite.

Sample # F 2662.6

Slab description: Dark-gray-green grainstone/packstone
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated; etched and stained for calcite with alizarin red

Composition:

Allochems (60% est.):

Mollusk molds (10% est.): All spar; some have some preserved textures.

Round grains: Have structure where replaced by yellow neomorphic calcite spar (25% est.); others are molds filled with calcite spar (25% est.). Some are green algal intraclasts, mostly micritic peloids with micrite (algal?) coats.

Ostracods (sparse)

Forams (sparse)

Micrite (30% est.): Aphanocrystalline to very finely crystalline, filling shelter porosity, possibly moved by burrowing; coexists with spar

Spar: Medium crystalline, poorly developed enfacial junctions, mostly intercrystalline (20%), some intracrystalline (10% est.)

Halite (5% est.): Filling molds of peloids

Fabric: Variable grain preservation causes mottling; no impregnated porosity

Interpretation: Restricted to normal marine assemblage

Diagenesis: Some algal grains leached and filled with calcite(?) spar or halite cement, others replaced by neomorphic spar. Timing of leaching/replacement is unclear; either event could have been first. Calcite(?) spar has euhedral terminations against halite in molds that have both phases, but relationship is unclear. Check mineralogy. All mollusks are filled with clear spar, but some of this is also neomorphic.

Photography: 4 slides

Comments: Stain for calcite shows that all carbonate is calcite; point count.

Sample #F 2666.1

Slab description: Burrowed, olive-green, dolomitic micrite
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Etched and stained for calcite with alizarin red

Composition:
- Similar to F 2666.5
- Dolomite (45% est.) euhedral crystals
- Calcite (50% est.) anhedral microspar matrix for dolomite
- Allochems: Thin-walled bivalves; more spheres appear to be section of tubes with radial extinction in walls; possible brachiopod spines, ostracods; allochems are calcite.
- Halite (5%) cement

Fabric: Halite cement has replaced some elongate, flattened burrow fills; these areas lack calcite cement.

Interpretation: Dolomitic micrite. Dolomite/calcite/halite relationships are somewhat obscure. Original calcite is preserved at least in allochems. Dolomitization is equally intense throughout, without regard to porosity differences. Halite cement precipitated preferentially in burrows. Time relationships between formation of these phases are not clear.

Photography: 3 slides

Comments: Stain shows subequal amounts of calcite and dolomite.

Sample # F 2666.5

Slab description: Burrowed, olive-green dolomicrite
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Poor bonding; etched and stained for calcite with alizarin red

Composition:

Dolomicrospar (50% est.): Fine to very finely crystalline (0.06 to 0.006 mm) rhombs
Calcite (50%): Anhedral calcite spar cement around dolomite
Siliciclastic silt (trace): Scattered
Allochems: Micrite masses associated with organic stain; spheres with radial extinction
No trace of clay to give color
Halite (trace): Filling intergranular and moldic(?) pores

Fabric: Slight variations in micrite density define lamination.

Interpretation: Dolomicrite; distinguishing between remnant calcite and later calcite cement is not possible.

Comments: Stain shows 50% calcite.

Sample # F 2667.6

Slab description: Typical wispy-laminated dolostone, compacted burrows, minor organic wisps

Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated; slide slightly thick; poor bonding; etched and stained for calcite with alizarin red

Composition:

Micrite/microspar (94% est.): Intimately admixed aphanocrystalline to very finely crystalline anhedral dolomite

Calcite (5%): Intercrystalline calcite cement

Allochems (trace): Thin-walled, flat skeletal grain; forams; spheres; dolomitized; a few are preserved as calcite.

Organic wisps, bone(?) fragments

Porosity (<1%): Intercrystalline pores

Fabric: Good lamination defined by variation in crystal size, oriented wisps; probable burrows; trace of impregnated intercrystalline microporosity; taste test shows no halite cement.

Comments: Stain shows that 95% of carbonate is dolomite.

Sample # F 2669.0

Slab description: Rippled contact between dolomite with anhydrite nodules and limestone-coated grain packstone at the contact between the lower dolomite-anhydrite cycle of unit 4 and the upper limestone cycle

Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated; etched and stained for calcite with alizarin red

Composition:

Upper third of slide: Dolomitized micritic coated grains, ooids, and molds of other round grains in a micrite matrix; dolomicrite is very finely crystalline, "dusty" anhedra; adjacent to molds, it coarsens to fine rhombs. Grains (30% of layer est.) are dense micrite, ooids, and complex rounded shapes with ill-defined internal (algal) structure. Pyrite dust rims some grains. Molds are (1) impregnated, (2) filled with halite, or (3) filled and partly destroyed by anhydrite. Grains are compressed together; matrix is dissolved by microstylolitization beneath anhydrite nodule. Anhydrite fills horizontal "fenestral" fractures. All dolomite except <1% of pores are filled with calcite spar.

Middle band: 5-mm-wide ripple form; coarser dolomite with abundant voids (fenestra) of indeterminate origin; some are impregnated, others are halite filled(?).

Lower half: Dolomicrite (60% est. of the interval) and anhydrite nodules (40%); similar to sample # F 2676.0

Fabric: Well laminated; unclear why anhydrite forms nodule in lower part but cement to replacement along fractures in the upper part; origin of spotty distribution of porosity is unclear.

Interpretation: The depositional environment is undergoing a major shift in facies from a dolomite to a normal marine sequence. Porosity may be localized at this horizon because of the depositional facies (fenestra) or because diagenetic processes are localized where the lithology changes. Impregnated macroporosity is unusual. Calcite spar fills moldic pores and appears to be late.

Comments: Stain shows that all but a minor amount of carbonate is dolomite; possible porosity plug.

Sample # F 2676.0

Slab description: Laminated dolomicrite; anhydrite nodule not in thin section; fault has a 2-mm displacement.
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated; stained with alizarin red for calcite

Composition:
Dolomicrite (>95%): Finely crystalline rhombs and anhedra
Organic wisps, sparse forams
Fracture fill: Halite, blocky anhydrite, and large rimming crystals of celestite(?) or oriented anhydrite
No impregnated porosity, but no taste of halite cement

Fabric: Lamination is defined by orientation and density of organic wisps; there are slight changes in dolomite size and packing.

Interpretation: Fracture fill sequence--halite-celestite(?)-anhydrite; halite is present as an inclusion in the other minerals; anhydrite rims celestite(?).

Photography: 2 slides

Comments: Stain; check sulfate mineralogy. All carbonate is dolomite.

Sample # F 2677.0

Slab description: Nodular anhydrite in laminated, calcitic dolomicrite; laminae do not bend around anhydrite nodules; therefore, anhydrite is replacive; stain and look for occurrence of calcite.
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated; etched and stained for calcite with alizarin red

Composition:
Dolomicrite (65% est.): Finely/very finely crystalline (0.016 mm diameter) anhedral crystals; even distribution; no ghosts or clotting
Allochems (<1%): Small micritic forams; scattered
Organic grains (trace)
Anhydrite (35% est.): Coarsely crystalline felted anhydrite blades; in nodules
Pyrite (trace): Fine crystals at rims of anhydrite nodules

Fabric: Micrite is wispy laminated because of orientation and concentration of organic grains; impregnated; no porosity

Interpretation: Anhydrite nodules might be replacive, but no remnant dolomite is left in them.

Photography: 2 slides

Comments: Stain for calcite shows that all carbonate is dolomite.

Sample # F 2679.2

Slab description: Fissile, dark muddy/silty dolomicrite
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Slightly thick slide, fragmented during thin section preparation, in blue epoxy matrix

Composition:

Dolomicrite (78% est.): Very finely crystalline anhedral crystals
Allochems (trace): Two foram tests in dolomicrite
Clay (10%[?] est.): Essentially invisible in this thick slide but identification based on brown color of dolomite and similarity of slide to the thin slide of sample # F 2679.6.
Siliciclastic silt (10% est.): Poorly sorted, angular
Pyrite (2% est.): In framboids, clustered in masses

Fabric: Similar to sample # F 2679.6; components intimately intermixed; no compositional variations to give fissility

Photography: 1 slide

Sample # F 2679.6

Slab description: Dark, fissile muddy dolomicrite at transition from mudstone to carbonate; anhydrite nodules in lower part
Stratigraphic level: Lower San Andres unit 4 carbonate

Note: Thin slide; cracks are artifacts of drying of the core.

Composition:

Muddy dolomicrite (70% est.): Very finely crystalline (0.006-mm diameter) equant dolomicrite; subequal amount of dark, optically oriented birefringent and sericitic clay matrix; 10% (est.) siliciclastic silt; 5% (est.) pyrite in small cubes
Anhydrite (30% est.): Felted, medium-bladed crystals in nodules

Fabric: Fissility noted in core is not evident in thin section. Clay and sericite are evenly distributed but have a horizontal orientation. Anhydrite appears to occur both as nodules and as a matrix for muddy dolomite clasts.

Interpretation: Mudstone at base of cycle is gradational into dolomicrite. Anhydrite still has high mobility in the dolomite, as it has in the mudstone.

Comments: An insoluble residue of the carbonate to show the subequal amounts of carbonate and mudstone as well as clay mineralogy might be interesting.

Sample #F 2681.8

Slab description: Laminated, fissile, dark mudstone from the base of the well-laminated interval; some soft sediment deformation
Stratigraphic interval: Lower San Andres unit 4 base of cycle mudstone

Note: Cracks in muddy areas of thin section and plucking due to poor bonding

Composition:

Siliciclastic silt (40% est.): Medium to fine, moderately well sorted; anhydrite and possible quartz cement
Mudstone (50% est.): Oriented birefringent clay, siliciclastic silt, and anhydrite
Anhydrite (9% est.): Nodules/intraclasts in siltstone; cements and isolated crystals
Pyrite (1% est.): In framboids and cubes(?); smaller aggregate in mudstones; large ones in siltstone
Dolomite and halite (trace): Dolomite rimming halite mass, which has grown displacively in clay intraclasts in siltstone

Fabric: Ripple lamination; molds of halite crystals filled with salt and very fine sand; similar to sample # F 2684.4

Interpretation: Halite precipitated in environment where mud was ripple laminated, not in a carbonate environment.

Photography: 1 slide

Sample # F 2684.4

Slab description: Laminated, dark anhydritic siltstone and mudstone; local deformation, including hopper molds, fluid-escape structures, disturbed nodular fabric, and base-cycle mudstone

Stratigraphic interval: Lower San Andres unit 4 base cycle mudstone

Composition:

Siliciclastic silt (15%): Coarse silt; moderate sorting; abundant rock fragments; opaques; silt obscured by anhydrite cement in lower part of same laminae

Mudstone (35%): Fine siliciclastic silt; optically oriented birefringent clay; sericite

Anhydrite (50% est.): Cement in siltstone; anhydrite nodules to intraclasts

Coarse dolomite (trace): Associated with halite in fracture near top of slide

Halite (trace): All cement is anhydrite; one oblique fracture near the top of the slide is filled with halite.

Fabric: Laminated sequences alternate with disturbed intraclastic and soft-sediment-deformed intervals. Laminae fine upward from silt to mudstone. Lamination is disturbed by clasts of halite hopper crystals, which represent crystallization of cubes of halite on the sediment surface. These cubes were dissolved, and molds filled with silt during deposition of the next layer of sediment. The top of the laminated interval is scoured and overlain by silt with mudstone and anhydrite intraclasts. Deformation includes fluid-escape features, soft-sediment microfaults, and anhydrite intraclasts or nodules. Some faults cut across laminated intervals.

Interpretation: The origin of the disturbed intervals is unclear. If they originated as residues after halite, anhydrite has been mobilized and has obscured fabrics. Abundance of anhydrite cement suggests a different diagenetic history than that of most clastics.

Photography: 7 slides

SWEC Detten No. 1

Sample # De 2744.3

Slab description: Contorted bedding in anhydrite, middle of thin (1 m thick) anhydrite
Stratigraphic interval: Lower San Andres unit 4 anhydrite

Note: Normal thickness, broken slide

Composition:

Anhydrite: Medium crystalline, bladed, aligned mosaic
Siliciclastic mudstone: Quartz silt; brown clay
Pyrite: Abundant irregular masses
Dolomite: Coarse crystals; corroded boundaries; silt and anhydrite inclusions

Fabric: Millimeter laminations defined by compositional variation are contorted by compressional folding; orientation of anhydrite crystals corresponds to lamina character (folded in folded areas); therefore, anhydrite crystals preserved since the time of folding; possible gypsum pseudomorphs in mudstone layers

Sample # De 2746.1

Slab description: Dolomite packstone with intraclastic(?) texture, a possible supratidal facies

Stratigraphic interval: Lower San Andres unit 4 carbonate, top carbonate

Note: Normal thickness, impregnated

Composition: Complex fabric, difficult to describe

Allochems:

"Compressed intraclasts": Variably sized micritic intraclasts; shapes look pressed against each other; each has a microspar rim; similar to "compressed ooids," but no structure within grains; fabric is best developed in large elongate intraclasts with epoxy-filled void space.

Girvanella(?) tubes, forams

Micrite matrix; difficult to distinguish between matrix and grains

Cements: In fenestra, intragranular and intergranular pores

Halite and anhydrite: Halite has large cubic, negative crystals and fills dominantly large pores. Anhydrite laths replace halite and locally dolomite, filling some allochem molds. There are also some coarse, poikilotopic crystals with gray birefringence rims and some halite--are these anhydrite or possibly celestite?

Pores: Epoxy fills pores; dominantly intracrystalline porosity in micritic areas lacking large pores; fairly high (10% est.) porosity, although difficult to point count. Slide was taken 1 cm into core; porosity should not be an artifact.

Fabric: Irregular lamination formed by drapes of micritic, compressed intraclasts alternating with areas with large fenestral(?) voids; possible supratidal facies

Photography: 3 slides

Comments: Possible area for permeability plug; point count porosity.

Sample # De 2746.3

Slab description: Very finely laminated dolomite peloid packstone, possible birdseye texture, possible intertidal/supratidal facies in upper meter of carbonate.
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Slightly thick slide; impregnated; small bubbles in epoxy

Composition:

Allochems:

Abundant tubes (0.016 mm diameter): Possible girvanella
Forams
Peloids
Thin-walled bivalves
This is a restricted/transported assemblage, in keeping with its origin as an intertidal deposit. Preservation is poor; all grains are dolomitized; matrix and grains are all now microspar.

Dolomicrospar matrix: 0.004 mm (very finely crystalline) anhedral dolomite

Cement: Halite and anhydrite fill some intergranular and intragranular porosity. Some large fenestral(?) pores also contain a sulfate with gray birefringence--celestite or large areas of similarly oriented anhydrite? Many epoxy-filled micropores and macropores; slide was taken 1.5 cm away from the sawed core surface, so surficial leaching is minimized.

Fabric: Microlaminated fabric is most visible in the stub; millimeter-scale lamination is defined by variation in the density of the micrite matrix and other cements. Microlamination is disturbed and contorted by features which may be mudcracks and fenestral cavities. Some cavities are filled with brecciated host packstone; others are open, partly filled with anhydrite, celestite, and corroded remnant halite. The anhydrite is a felted mosaic of laths similar to that filling the halite-filled mold in sample # De 2751.1. Removal of the halite is suspected of being an artifact of coring or slabbing.

Photography: 8 slides

Comments: Check sulfate mineralogy--is any of the gray birefringent cement celestite? Is some really quartz? Consider for permeability plug.

Sample # De 2747.0

Slab description: Recrystallized anhydritic halite, 10 cm above top of anhydrite
Stratigraphic interval: Lower San Andres unit 4 halite

Note: Thick slide, poor bonding

Composition:

Halite: 1-cm-diameter, skeletal, subhedral crystals; few fluid inclusions; inclusions are mostly larger than 0.1 mm were breached during slide preparation.

Muddy(?) anhydrite: Not much detail visible in thick slide

Pyrite: Framboids and irregular masses in anhydrite

Fabric: Anhydrite is highly disturbed; soft sediment was faulted and churned before displacive growth of skeletal halite.

Photography: 1 slide

Sample # De 2751.1

Slab description: Dolomite packstone-wackestone; halite- and anhydrite-filled bivalve molds; sample was taken to identify fish fossil assemblage in middle of slide.
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness, impregnated

Composition:

Dolomicrite

Allochems:

Large phylodont fish tooth plate; 4-cm-wide assemblage of phosphatic teeth and bones, an oval fossil 4 cm long cut in half by the slabbed plane of the core; identified by M. A. Fracasso (see Johnson and Zidek, 1981, Journal of Paleontology); teeth have preserved structure and halite cement between them.

Bivalve molds: Abundant in lower part of the slide

Organic wisps

Cements: Halite, anhydrite, and length-slow chalcedony; some molds are completely filled with halite, others filled with anhydrite, some mixed. One bivalve mold contains botryoidal chalcedony(?) and macroquartz(?). Chalcedony has low birefringence. Check mineralogy--might be phosphate from fish?

Fabric: Burrowing has not disturbed bedding. Packstone on bottom, wackestone on top above fish

Photography: 4 slides

Comments: Check mineralogy of chalcedony(?) in bivalve mold.

Sample # De 2752.0

Slab description: Ripple-laminated, slightly burrowed dolomicrite
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness; poor bonding and plucking in center; etched and stained for calcite

Composition:

Dolomicrite: Finely crystalline anhedra; 20% (est.) halite-filled intercrystalline porosity; minor bladed anhydrite cement also

Allochems: Present in burrow fills and some layers; sparse, poorly preserved anhydrite- and halite-filled molds; many grains unidentifiable; bivalves; peloids; forams

Crystallotopic anhydrite in one layer is a concentration of small horizontally flattened nodules with diffuse borders.

Fabric: Lamination to ripple lamination defined by concentration and orientation of organic fragments and anhydrite and by variation in the packing of the crystals in the dolomicrite. Vertical halite-filled hairline fractures cut dolomite and small negative crystals.

Photographs: 3 slides

Comments: Stain shows that all carbonate is dolomite.

Sample # De 2758.1

Slab description: Dolomite packstone with anhydrite-filled moldic porosity
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness; slide has halite crystals on the surface, locally plucked, etched and stained for calcite.

Composition:

Dolomicrospar matrix: Finely crystalline anhedral crystals; areas of finer crystals and concentrations of impurities are ghosts of peloids. The dolomite is very porous (25% est.), partly filled with blocky to bladed anhydrite cement as well as halite cement(?).

Organic (dark) wisps, minor pyrite

Allochems: Molds of large mollusks are filled with acicular anhydrite mosaic; there is possible halite cement between anhydrite crystals. Smaller grains are abundant, but preservation is too poor to identify them.

Fabric: No bedding; may be burrowed?

Photography: 2 slides

Comments: Stain for calcite shows 100% dolomite.

Sample # De 2762.6

Slab description: Gray dolomite grainstone; large allochems (gastropod in core not in thin section)
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness, bad bonding on slide, flaking off; etched and stained for calcite

Composition:
- Allochems: All dolomitized or replaced by anhydrite
  - Micritic and moldic 0.1-mm-round grains: girvanella(?), peloids, and forams
  - Large mollusk molds: Whole and fragmented bivalves, whole gastropods
  - Echinoderm plates
- Cement:
  - Dolomite microspar: Early generation of cement; may also replace some original micrite; replacement of early halite is possible, but there is no evidence. Dolomite is dusty, subhedral against anhydrite.
  - Anhydrite mosaic: Fills allochem molds and intergranular pores; no halite

Anhydrite-cemented mollusk-girvanella(?) grainstone

Fabric: Nonbedded; probably burrowed

Photography: 2 slides

Comments: Fauna may be restricted mollusk/algal assemblage. Stain for calcite shows 100% dolomite.

Sample # De 2765.8

Slab description: Partly dolomitized grainstone, an area of early carbonate cement surrounded by microstylolitic/compactional features
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness, areas of poor bonding, etched and stained for calcite with alizarin red

Composition:
Allochems:
Forams
Ostracods
Mollusk fragments, molds filled with halite and coarse, skeletal dolomite, some gastropods
Echinoid plates
Bryozoans
Carbonate cement: Calcite spar cement surrounds micritic grains; some dolomite(?) spar replaces halite in allochem molds.
Dolo(?)microspar: Rhombic crystals with few allochems fill burrows.
Halite cement: In some areas of the slide, halite has replaced the allochems, leaving well-defined foram molds in cement similar to the rest of the slide.

Fabric: Burrowed grainstone. Mollusk molds have been replaced by halite, and the dolomite is coarse and skeletal, rimming the mold. This dolomite appears similar to dolomite-replacing halite.
Diagenesis is similar to that in sample # De 2773.5; early isopachous dolomite cement, pore-filling sparry calcite; micrite forams have been replaced by halite--why are they not replaced by calcite or dolomite? Possible diagentic sequence:
1) Isopachous dolomite cement
2) Sparry calcite cement; calcite replaces micrite in foram/algal grains
3) Halite replaces some remaining micrite in foram or algal grains
Halite fills fractures across calcite. Molds of algal grains collapsed, indicating a void phase collapsed postdolomitization, prehalite cement.

Photography: 1 slide

Sample # De 2773.5

Slab description: Anhydrite nodule in partly dolomitized medium to coarse grainstone
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated with blue epoxy; etched and stained for calcite with alizarin red.

Composition:

Allochems:

Large pelecypods, some preserved calcite shell structure
Large thin-walled bivalves
Forams, some dolomitized, others moldic
Ostracods
Phosphatic grains

Cements: Poikilotopic calcite is the main grainstone cement, filling allochem molds and surrounding allochems and medium crystals of anhedral dolomite cement. Anhydrite has the same poikilotopic style in scattered occurrences. Coarse calcite cement fills some foram molds, some large mollusk molds, and some shelter pores (after halite?).

Anhydrite: Large nodule, medium laths, aligned parallel to nodule walls; coarser anhydrite cements allochems next to nodule; abundant coarse, anhedral calcite crystals appear as septa in the nodule.

Pores: A few allochem molds (foram and part of a mollusk were impregnated in the upper part of the slide); it is unclear whether this is real porosity or an artifact of leaching of halite during coring.

Fabric: Coarse grainstone, abundant shelter porosity; some allochems are preserved as calcite; sparry calcite cements ion allochem molds. Allochem molds and pores are filled with a sequence of (1) dolomite, (2) calcite, and (3) halite. Is this order a result of precipitation or replacement? Calcite could be prehalite or posthalite. Dolomite could be precalcite or postcalcite. Calcite has a coarse, poikilotopic late(?) morphology.

Comments: Consider for permeability plug (low, cemented).

Sample # De 2784.2

Slab description: Tan dolomite wackestone overlain by darker gray dolomicrite, both burrowed. Top of a "bar" sequence and the base of the overlying "nonbar" sequence
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness; some bubbles flawing slide; etched and stained for calcite with alizarin red

Composition:

Dolomicrite: Fine (0.15 mm diameter) anhedral crystals; variation in crystal size defines lamination; intercrystalline space is abundant and apparently filled with halite, anhydrite, and calcite cements. Cements are poikilotopic, rimming allochem molds; difficult to distinguish between anhydrite and carbonate cements

Siliciclastic silt - very fine sandstone: <1% (est.), scattered

Compressed organic material

Allochems: Abundant (20% est.), poorly preserved, moldic, sand-sized skeletal fragments

Fabric: Burrows are marked by variation in dolomite density, distribution of allochems, and truncation of lamination.

Sample # De 2789.4

Slab description: Dark, organic-rich, laminated micrite; "nonbar" facies above grainstone facies

Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness; etched and stained for calcite with alizarin red

Composition:

Micrite, some scattered microspar: About 70% dolomite, 30% calcite, all anhedral

Compressed organic grains: Varied grains (red, yellow, and brown) and scattered, noncompressed phosphatic(?) grains make up 5% (est.) of the rock.

Siliciclastic silt: 5% (est.)

Allochems: Echinoid plates, bryozoans, ostracods, thin-walled mollusks, all small and sorted, mostly calcite

Trace of fine pyrite

Silty, organic-rich biomicrite

Fabric: Lamination defined by aligned grains and wisps of organics and by variation in the percentage of organics; probable small horizontal burrows in some layers

Photography: 2 slides

Comments: Good sample for analysis of TOC; silt-size insoluble residue

Sample # De 2790.0

Slab description: Bivalve grainstone, coated grains, partly dolomitized
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness, etched and stained for calcite with alizarin red

Composition:

- Allochems:
  - Calcite: similar to that of sample # De 2791.3
  - Dolomicrospar matrix: abundant
  - Calcite spar present in shelter cavities
- Small anhydrite nodule
- Pelecypod biomicrite

Fabric: Dark micrite coatings on grains are locally replaced by neomorphic spar. Lower part of slide is more micritic with more preserved calcite; its stain is browner, and it looks more compacted. The micrite matrix was dolomitized before the micrite in algal coats, which is preserved. In the lower part of the slide, some micrite matrix is still calcite.

Sample # De 2791.3

Slab description: Mollusk-foram-oncolite grainstone, coarse facies
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness

Composition:
- Allochems:
  - Large mollusks: Gastropods, large bivalves
  - Forams
  - Peloids
  - Pellets
  - Brachiopod fragments, shells, and spines
  - Echinoids
  - Bryozoan fragments
  - Oncolites
  - Large phosphatic bone fragment
- Sparry calcite cement
- Biosparrudite

Fabric: All grains have a thick micrite coat; many grains are brown in transmitted light, light yellow in reflected light.

Photography: 3 slides

Sample # De 2800.0

Slab description: Calcite-cemented micrite, sparse echinoid spines
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness, poor bonding, etched and stained for calcite with alizarin red

Composition:
- Matrix:
  - Calcite micrite to microspar (25%): Anhedral
  - Dolomite (70%): 0.016 mm euhedra
- Allochems (<5% est.) (all calcite):
  - Echinoid spines
  - Forams
  - Mollusks(?) with prismatic structure
  - Bryozoans

Fabric: Wispy-laminated, dolomitized echinoid biomicrite; echinoid spines replaced by halite at the edges; bedding defined by sparse wispy lamination

Comments: Stain for calcite shows that 25% of carbonate is calcite and 75% is dolomite.

Sample #De 2802.4

Slab description: Laminated, medium-grained packstone; "frosting" of efflorescent halite on core surface suggests that this may be a porous interval
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness, impregnated with blue epoxy, etched and stained for calcite with alizarin red

Composition:
Matrix: Calcite micrite and dolomite microspar in rhombic grains (15% est.)
Allochems (mostly calcite):
Brachiopod spines
Thin-walled brachiopods
Echinoderm plates
Mollusks with preserved prismatic structure
Large ostracods, some pyritic
Abundant wisps of brown organic matter
Pores (shown by impregnation): Within grains as molds and leached pores within grains; against allochems (possible shelter porosity) as well as abundant epoxy within areas of micrite/microspar

Fabric: Laminated, partly dolomitized biomicrite; horizontal bedding defined by preferred orientation of allochems; wispy lamination, defined by organic stringers wraps around nodules, is compressed between them; microstylolitization of matrix micrite possible but not demonstrable; some breakage of grains during compaction; in some patches all matrix is dolomitized and the only calcite occurs in allochems; in other areas micrite is still calcite with a small percentage of dolomite rhombs.

Photography: 6 slides

Comments: Point count, especially porosity; good sample for permeability plug

Sample # De 2803.2

Slab description: Fossil hash from coarse interval in grainstone
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness, etched and stained for calcite with alizarin red

Composition:

Allochems:

Large whole gastropods(?), some preserved fabric in spar
Pelecypods fragments
Coated grains/oncolites--up to 5-mm-long; rotated geopetal fills; abundant, including grains, mollusk fragments, and peloids
Ostracods
Echinoids
Brachiopod fragments
Forams
Tubes--possible girvanella and slices of forams
Peloids

Matrix: Micrite coats and fillings on all grains, but all pores are filled with sparry calcite cement

Cement: In addition to sparry calcite, there is local cementation of foram molds by anhydrite and some anhydrite replacement of grains and matrix; halite has locally cemented/replaced oncolites and gastropod molds.

Mollusk-foram-coated-grain biosparite

Fabric: Mostly structureless, possibly due to burrowing; in the lower part of the slide, thin discontinuous layers with more micrite matrix also have organic (brown) material, possibly algal mat.

Comments: Stain shows no dolomite; point count.

Sample # De 2805.4

Slab description: Carbonate mudstone; area of calcite cement; abundant spines
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness, etched and stained for calcite with alizarin red

Composition:
- Micrite mosaic: Calcite (70% est.)
- Dolomite microspar (25% est.): Anhedral and euhedral
- Sparse (<5%) allochems:
  - Echinoid spines
  - Thin-walled brachiopods
  - Compressed organic grains
  - Encrusting(?) bryozoans

Fabric: No bedding; dolomite and calcite intermixed; rims of echinoids partly replaced by halite; dolomitic echinoid biomicrite

Photography: 1 slide

Comments: Stain shows that 25% of the carbonate is dolomite.

Sample #De 2812.0

Slab description: Burrowed packstone
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness

Composition:

Micrite to microspar*

Allochems: All molds, variably filled with carbonate*, anhydrite, and halite; many molds are rimmed with pyrite dust.

Large 1-mm ooid or algal grain molds: Irregular, rounded geopetal fill

Tubes: Seen in longitudinal and transverse section

Gastropod mold

Ostracod fragments with preserved shell structure

Pelecypod fragments

Forams, micritic

Fabric: Burrowed; the sequence of cementation and control on cement phase are not easy to determine. Both anhydrite and dolomite are at least partly replacing early halite. Halite may have been dissolved from some pores, leaving geopetal dolomite. Anhydrite may be earlier than dolomite.

Comments: Stain*

Sample # De 2813.2

Slab description: Burrowed micrite
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Impregnated, poor bonding, etched and stained for calcite with alizarin red

Composition:
Dolomicrospar mosaic: 0.04 to 0.01 mm calcite, <1% siliciclastic silt, <1% micritic forams, echinoid plate fragments, compressed organic grains
Anhydrite cement (<1%): Ragged edges

Fabric: Probably small burrows, obscured by poor bonding

Comments: Carbonate is all dolomite, but epoxy and pores have been stained pink. No significant halite cement was tasted on stub. Slide didn't impregnate, but moderately rapid drying pattern suggests some permeability may be present.

Sample # De 2814.9

Slab description: Nodular anhydrite with interstitial dolomite, coarser anhydrite crystal size than below.
Stratigraphic interval: Lower San Andres unit 4 carbonate, top lower cycle

Note: Normal thickness

Composition: Similar to sample # De 2816.0 except that some millimeter-long anhydrite blades are present in anhydrite nodules

Fabric: Similar to sample # De 2816.0 except that nodules are smaller and vertical fabric is absent

Comments: Coarser crystals--might be later diagenetic waters

Sample #De 2816.0

Slab description: Nodular anhydrite; good vertical orientation interpreted as pseudomorphs after bottom-nucleated crystals
Stratigraphic interval: Lower San Andres unit 4 carbonate, top lower cycle

Note: Normal thickness

Composition:

Nodular anhydrite (85% est.): Aligned, medium crystalline mosaic; blades parallel nodule boundaries

Replacement anhydrite in dolomicrite partings (1% est.): Equant, medium crystalline mosaic; replacement origin clear because of distribution and inclusions of dolomite

Dolomicrite (14% est.): Even-sized, rounded, very finely crystalline dolomite; some preserved bedding within horizontal dolomicrite partings defined by organic(?) wisps

Fabric: A good example of replacement of vertical crystals of gypsum in a dolomicrite matrix replaced and enlarged(?) by anhydrite nodules

Sample # De 2825.6

Slab description: Silty wackestone, molds of large fossil fragments; upper part of slide is microstylolitic, dark terrigenous clastic/organic interbed
Stratigraphic interval: Lower San Andres unit 4 carbonate

Note: Normal thickness, some plucking of halite from molds

Composition (sample very inhomogeneous because of bedding):

Dolomicrite: Very fine crystalline, rhombic to anhedral mosaic; 5% (est.) very fine sand/coarse silt; 5% (est.) isolated anhydrite crystals, ragged edges; swirls and stringers of dark silty, clayey, organic-rich, pyritic material throughout dolomicrite--possibly burrow fills, microstylolite zones?

Allochems: All halite-filled molds; two populations: skeletal hash less than 1 mm and bivalve molds larger than several millimeters; some large whole, thin-shelled pelecypods, a few bivalves with articulated shells; this is not a totally transported assemblage.

Dark clastics at top: Gradational contact of clastics with dolomicrite; dark mudstone and pyrite and dark, opaque organics are fractured; skeletal halite crystals and horizontal cracks are filled with gypsum or length-slow chalcedony.

Halite fillings of fractures and allochems: Details not visible in thin slide; many euhedral pits dissolved in halite surface (while making thin section).

Fabric: Origin of contortion is unclear. Stub looks like it has been sheared along diagonal bedding surfaces. Large masses of halite that don't fill allochem molds are locally enlarged by plucking and are associated with clastic/organic material. They could be either microstylolite-bounded nodules or replacement of irregular grains, possibly oncolites. Mudstone bed does not appear to be a concentration due to microstylolitization but a real clastic interbed because of gradational contact with dolomicrite.

Comments: Check mineralogy of fibrous fracture fills in dark mudstone--chalcedony? gypsum? celestite?

Sample # De 2826.1

Slab description: Dolomicrite drapes over anhydrite nodules at the base of the carbonate
Stratigraphic interval: Lower San Andres unit 4 carbonate, base

Note: Normal thickness, etched and stained with alizarin red

Composition:

Anhydrite: Finely crystalline anhydrite nodule; nodule 3 cm in diameter; dolomite inclusions

Silty dolomicrite: Rounded, 0.01-mm crystals; compressed organic material; abundant pyrite as framboids and dust in dolomite; local masses of anhydrite mosaic and bladed mosaic. Allochems: Sparse forams, probable pellets

Halite: Masses within dolomite contain low index cubes--are these flaws in the thin section? Halite appears to be replacing the irregular areas of less dense halite in irregular to slightly skeletal areas. A few blades of anhydrite replace halite. Halite fills a few small fractures.

Fabric: Dolomite not bedded; mottled fabrics of obscure origin due to variation in density of dolomite and distribution of pyrite; collapse origin possible

Comments: Check mineralogy of low index cubes and brown fibrous areas--all artifacts in halite?

Sample # De 2829.3

Slab description: Dark mudstone overlies (1) anhydrite, (2) anhydrite-cemented, very fine sand, and (3) coarse silt.
Stratigraphic interval: Lower San Andres unit 4 residue

Note: Normal thickness

Composition (sample very inhomogeneous because of bedding):
Mudstone: Upper 3 mm of slide is laminated sericitic claystone (gray, has good optical orientation), mudstone, and anhydritic mudstone. All contain abundant pyrite framboids.
Anhydrite: 2 cm thick, muddy laminae in middle
Siltstone to very fine sandstone, anhydrite cement and nodules, disturbed texture and variable composition

Fabric: Anhydrite and dark mudstone are laminated, siltstone to very fine sandstone has disturbed-intraclastic texture.

Comments: Point count for provenance.

Sample # De 2831.5

Slab description: Anhydritic dark mudstone-siltstone, wavy lamination, insoluble residue suite of three continuous slides
Stratigraphic interval: Lower San Andres unit 4 residue

Note: Normal thickness

Composition (sample very inhomogeneous because of bedding):
Mudstone: Like sample # De 2831.7
Siltstone: Moderately well sorted, coarse siliciclastic siltstone, silt-sized dolomite grains/cement
Anhydrite: Mosaic of finely crystalline equant to bladed, crystals' wavy lamination defined by mudstone intraclasts and interbeds and stringers of coarse dolomite and anhydrite. Dolomite and anhydrite occur as anhedral skeletal crystals at edges of halite masses. Where halite is gone, coarse dolomite is a mosaic of large crystals with undulose extinction and triple junctions.
Halite: 5% (est.) of slide, remnant irregular masses

Fabric: Wavy laminated to intraclastic; discontinuity of some lithologies, especially siltstone; origin of discontinuity unclear--early? channel? mudcrack fill? later? deformed during collapse?

Photography: 2 slides

Comments: Point count, especially siltstone pocket for provenance.