AAPG HEDBERG CONFERENCE
"MICROBIAL CARBONATE RESERVOIR CHARACTERIZATION"
June 4-8, 2012 – Houston, Texas

The Microbial-Dominated Reef and Slope of the Capitan Margin

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The drill site for the Gulf PDB-04 research well, located along the Northwest Shelf of the Delaware Basin, in Eddy County, NM, 19 miles (30 km) east-northeast of Carlsbad, was selected so that the well would penetrate the thick shelf margin of the Capitan reef [1]. Continuous cores from 510 to 5335 ft (155-1626 m) and logs provide invaluable information to those interested in assessing the subsurface record of this high-relief, microbial-dominated margin (Fig. 1). Because of the highly prograding nature of the margin, the PDB-04 core captured a complete succession of shelf-to-basin facies similar to those found in outcrops to the west (e.g., Permian Reef Geology Trail (PRGT) at McKittrick Canyon).

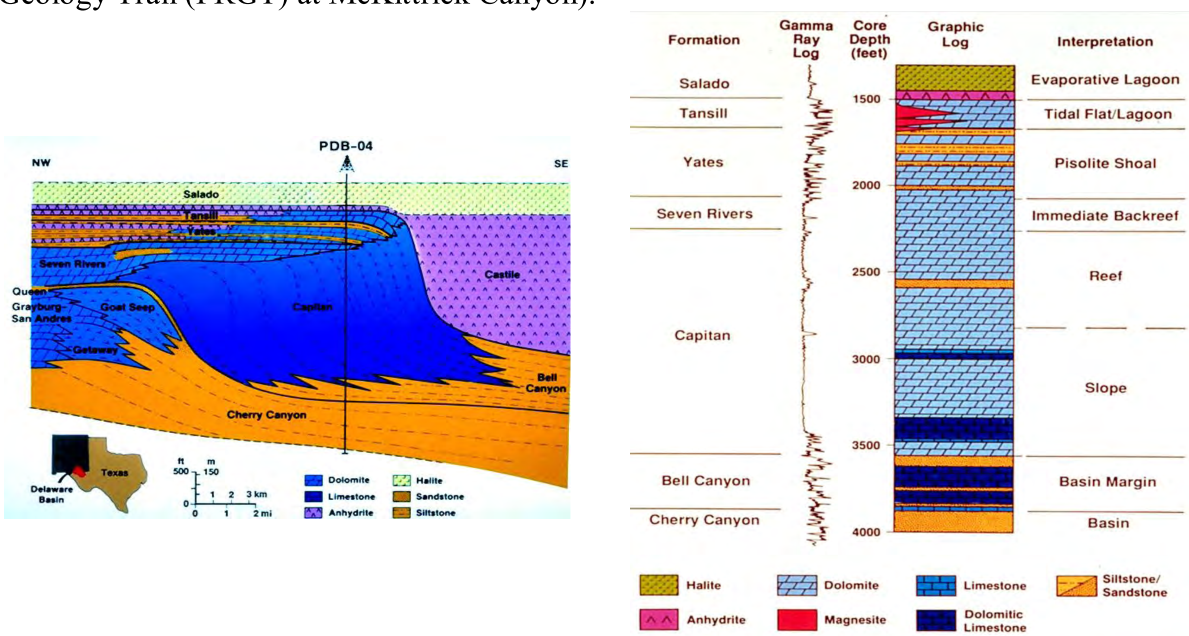

Figure 1. Subsurface cross section on left and summary of PDB-04 core description on right from Garber *et al.* (1989). Cross section shows PDB-04 stratigraphy, lithology, and location relative to the Capitan margin. Although schematic in appearance, the section is based on ten wells. Core description shows stratigraphy, GR log, lithology, and depositional environment interpretation.

The slope and reef facies of the Capitan Formation in the core reflect the varied carbonates that formed at the seaward edge of this shelf margin; debris primarily from the reef/upper slope accumulated on the slope as beds of skeletal dolowackestones to dolograinstones and as blocks of doloboundstone. The slope grades upward in the core into the reef, reflecting a change from allochthonous doloboundstone to *in situ* doloboundstone. As is typical for most reefs, the interval in the core is a complex admixture of boundstones, wackestones, packstones, and grainstones reflecting a reef framework of sponges and microbial carbonate, and the filling of growth framework and vuggy porosity by marine cement, internal reef-derived sediments, and locally siltstone.

Etched outcrops along the PRGT show that the Capitan reef and upper slope is locally a boundstone framework with bryozoans, calcareous sponges, and *Tubiphytes* in growth position. The framework was subsequently bound together by *Archaeolithoporella* (possible red alga), and displays large volumes of botryoidal aragonite and sediment-filled internal cavities (Babcock, 1977; Mazzullo and Cys, 1977; Garber *et al*., 1989). The association of cement and reef biota in the Capitan was described as microbial cement boundstone (Wood *et al*., 1996; Kirkland *et al*., 1998) based on the interpretation that the reef was bound and lithified by microbially precipitated micrite. In outcrop samples from the middle Capitan, micrite layers (about 1 cm thick) encrust the top, sides, and undersides of in situ organisms and also pile above organisms in thick (0.5 to >3 cm) accumulations, with high angles of repose (up to 90°). Primary encrustations commonly consist of thin, homogeneous, subparallel layers of *Archaeolithoporella*, whereas secondary encrustations (0.5–30 mm thick) contain peloids and fossil cyanophytes, and are usually bound by thin layers of micrite. Secondary encrustations of gravity-defying peloidal micrites are interpreted by Kirkland *et al,* 1998, as having precipitated within mucilaginous microbial aggregations, probably in dark cavities. The secondary microbial micrites were followed by cavity-filling, aragonitic botryoids, and thin (<1 mm) layers of clotted micrite were deposited on the first botryoids, probably by microbial biofilms.

Kenter *et al.* (2005) argued that the in situ production of microbial boundstone in depositional settings that are analogous to that of the Capitan can extend to great depths down a slope. Their examples show a highly productive microbial boundstone factory extending from the platform break down the slope to nearly 300 m (or more) depth and a lower slope dominated by (mega)breccias and grain-flow deposits derived from the margin and slope itself. The broad depth range of microbial boundstone increases the potential for production during both lowstands and high stands of sea level and thereby facilitates progradation independent from platform-top-derived sediment. Rapid in situ lithification of the boundstone provides stability to the steep slopes, but also leads to readjustment through shearing and avalanching.

Slope in the core – Based on stratigraphic data for the well, 735 ft (224 m) of slope is present (Fig. 1). The top of the slope facies was picked at 2820 ft (860 m) in the core where doloboundstones show a marked upward increase, and the lower boundary of the slope at 3555 ft (1084 m) is transitional into the more siliciclastic-rich basin margin facies. There is a general decrease in the extent of dolomitization downward in the slope facies. The slope consists of debris derived from the reef and upper slope (Fig. 2), which accumulated as beds of partially dolomitized skeletal wackestone to grainstone, and as beds of allochthonous doloboundstone. The wackestone to grainstone beds contain coarse skeletal debris and commonly exhibit inclined bedding. The allochthonous debris beds may be partially to completely dolomitized. Locally, secondary porosity is well developed in the slope and, together with other pore types, is commonly occluded by gypsum or anhydrite.

The doloboundstone is thought to be primarily reef talus blocks that rolled and slid down to their accumulation site on the slope, and appear as chaotically bedded mixtures of coarse skeletal material and lithoclasts. The boundstone fabric is a consequence of sediment binding by a microbial community, encrusting algae and bryozoans. The non-boundstone lithologies commonly exhibit inclined bedding and chaotic internal structures. Bedding angles of over 35° are visible in canyon exposures of the upper slope in the Guadalupe Mountains, such as along the Western Escarpment and in McKittrick Canyon (Garber *et al*., 1989; Tinker, 1998; Harris and Saller, 1999; Kerans and Tinker, 1999), but this clinoform style of bedding is not as obvious at the level of inspection offered by the core.

Reef in the core – The reef contains biota and depositional textures in core that are similar to those observed on outcrop (Newell and others, 1953; Babcock, 1974; Yurewicz, 1976; Wood *et al*., 1994, 1996; Senowbari-Daryan and Rigby, 1996; Noè, 1996; Wood, 1999; Weidlich and Fagerstrom, 1999; Kirkland *et al*., 1998, 1999). The reef occurs between 2230 and 2820 ft (680-860 m) in the core and is 590 ft (180 m) thick (Fig. 1). The contact with the overlying back-reef deposits is abrupt, and the contact with the underlying slope is transitional and, as mentioned above, was chosen where doloboundstones become interbedded with other textures of the slope.

The reef consists of *in situ* sponge-microbial doloboundstone (Fig. 2) that is admixed with dolowackestone, dolopackstone, and dolograinstone, reflecting the filling of growth-framework and vuggy porosity by internal sediments. The reefal interval is broken by a 56 ft (17 m) thick light gray siltstone/sandstone that is interpreted to be a gully or channel fill, based on wireline log correlations with nearby wells, perhaps shedding light on the pathways by which siliciclastic sands were transported across the shelf margin and into the basin.

Leaching and pervasive dolomitization have substantially altered the microtextures of the doloboundstone, to the extent that the boundstone matrix typically appears as a dolomudstone enveloping ghost structures of the original skeletal elements. Nevertheless, the macrotextures and biota of the boundstone are identifiable in most cases. Marine cements are locally present within the reef, but occlusion of pore spaces is dominantly by gypsum, anhydrite, and later dolomite cements.

Diagenetic overprint - Porosity in the core was formed during both dolomitization and leaching, whereas porosity occlusion was principally by marine cements and evaporites. Dolomitization is pervasive in all shelf and reef facies, but is variable in the slope. The dolomite typically preserves original depositional textures in shelf beds, including grains, matrix, pisoid laminae, and early-marine cements. In contrast, dolomitization of the reef has resulted in partial to complete destruction of original textures, but with resultant porosity and permeability as high as 16% and 80 mD, respectively. Dissolution was extensive in the upper portion of the reef and less common in the pisolite-shoal, immediate back-reef, and slope. Carbon and oxygen isotopic compositions determined for shelf, reef, and uppermost portions of the slope in the core do not discriminate different dolomite types. Comparing the carbon and oxygen isotopic composition of the dolomite with that of marine carbonates for the Late Permian (e.g., Lohmann, 1985, 1988) suggests that the dolomites had an early, near-surface origin, probably from waters originating in supratidal or sabkha settings.

AAPG Search and Discovery Article #90153©2012 AAPG Hedberg Conference Microbial Carbonate Reservoir Characterization, Houston, Texas, 3-8 June 2012.

Syndepositional marine cements reduced porosity substantially in the pisolite-shoal facies of the core and to a lesser amount in the tidal-flat/lagoon, immediate back-reef, and reef. Calcite, ferroan calcite, and baroque dolomite cements are minor diagenetic components in the core, whereas gypsum and anhydrite commonly plug porosity in all facies. Because the vuggy and fracture porosity in the core is principally filled by anhydrite or gypsum, and not by carbonate cements, a telogenetic origin for the dissolution cannot be ruled out.

Figure 2. Core photographs of the slope (left) and reef (right) facies from Garber *et al.*, 1989. The slope from 3512.3 to 3524 ft (1070.5 to 1074 m) contains mostly a possible large talus block from 3513.2 to 3522.2 ft (1070.8 to 1073.6 m) of brown doloboundstone with numerous sediment- and evaporite-filled cavities. Wackestone/packstone beds above and below show inclined bedding. The reef facies from 2308.6 to 2320 ft (703.7 to 707.2 m) is tan to mottled tan-gray doloboundstone with layers of skeletal dolowackestone/packstone and dolograinstone. Sponges, bryozoans, and microbial forms (*Archaeolithoporella*, encrustations, and rare stromatolitic forms) are the principal constituents forming the boundstone texture. Dissolution and precipitation of medium to coarsely crystalline dolomite have obscured, and locally destroyed, primary textures. Early-phase cements, having fibrous, bladed, and botryoidal textures, are present in some cavities (at 2312.7 ft (704.9 m), for example). Note the spectacular cavity-filling gypsum and anhydrite cements.

[1] Gulf Research and Development Company drilled the PDB-04 well in 1984, and descriptions were done at Chevron Oil Field Research Company during the mid-80's by Ray Garber, George Grover, Jim Borer, and myself. Chevron Energy Technology Company supported the preparation of this core workshop presentation and granted permission to publish.