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## High-Resolution Multibeam Bathymetry and Acoustic Backscatter of Selected Northwestern Gulf of Mexico Outer Shelf Banks

JAMES V. GARDNER AND JONATHAN BEAUDOIN

After the successful mapping of Stetson and the Flower Garden Banks, NW Gulf of Mexico, with a high-resolution multibeam echo sounder in the late 1990s, 14 additional banks located on the outer continental shelf and upper slope were mapped in 2001 using a similar system. Fourteen areas were chosen by benthic biologists to meet their needs for accurate base maps from which to conduct their various studies. The 14 banks display a wide variety of morphologies and associated surficial-sediment facies. The physiographies of some of the individual banks can be directly related to a salt dome that has either erupted through the seafloor or is in the near subsurface, whereas any association with salt tectonics at other banks is equivocal. Several of the banks clearly related to salt domes have basins that may represent dissolution features as has been previously documented on banks in other areas of the NW Gulf of Mexico. Simultaneously collected acoustic backscatter values suggest the sediment facies for each of the banks, which range from gravelly sand to mud. The spatial distributions of various features are often puzzling. Pockmarks are common around some banks but are absent from others. Pinnacles are abundant in the vicinity of some banks but are absent from others. However, west-to-east changes in some bank characteristics were found. Banks in the western sector of the mapped area have higher relief, have shallower tops, and are capped by coral reefs. Banks in the eastern sector are associated with abundant pinnacles, display a wide range of relief, and generally have smooth tops.

Bathymetric highs on the NW Gulf of Mexico outer continental shelf, often called “banks” or “reefs,” have been known since the pioneering work of Shepard (1937). The banks are generally related to underlying salt domes that have either erupted onto or are close to the seafloor (Shepard, 1937; Rezak et al., 1985; Roberts, 2001). These bathymetric highs became known for their biological diversity and are frequented by divers even though they are located more than 200 km from shore. The biological diversity of Stetson and the Flower Garden Banks led to their being declared the Flower Garden Banks National Marine Sanctuary in 1992. The physiographies of several of the banks have been discussed in several unpublished Mineral Management Service (MMS) reports as well as by Rezak et al. (1985), but only the general shape of a bank was deduced because they were interpreted from single-beam echo sounder profiles.

The advent of multibeam echo sounder (MBES) swath mapping in the 1980s and 1990s, together with the increased scientific activity on the banks, led to the need to generate high-quality, high-resolution, digital base maps of these areas for detailed studies.

Stetson, East Flower Garden, and West Flower Garden Banks were mapped with an MBES

in 1997 (Gardner et al., 1998). Fourteen additional banks east and northeast of the Flower Garden Banks National Marine Sanctuary were mapped in 2001 (Fig. 1) with an MBES to investigate their physiographic continuity and morphological similarities to the Flower Garden Banks. This report is a description of the new bathymetry, principally focusing on the physiographies of each bank but also with interpretations based on coregistered acoustic backscatter that was simultaneously collected during the mapping.

A Kongsberg Simrad EM1000 high-resolution MBES system was used to map the 14 banks. The EM1000 operates at 95 kHz and produces high-quality swath bathymetry with navigational accuracies of <0.5 m, a spatial resolution of 4 m at the water depths encountered, and a depth accuracy of better than 0.5% of the water depth (Beaudoin et al., 2002). The details of the EM1000 and ancillary systems used for the mapping, as well as the data processing, are given in Beaudoin et al. (2002) and are not repeated in this study. The EM1000 also collects coregistered calibrated acoustic backscatter that, when properly processed, provides a measure of the acoustic response of the seafloor to the 95-kHz sound pulse. Acoustic backscatter values

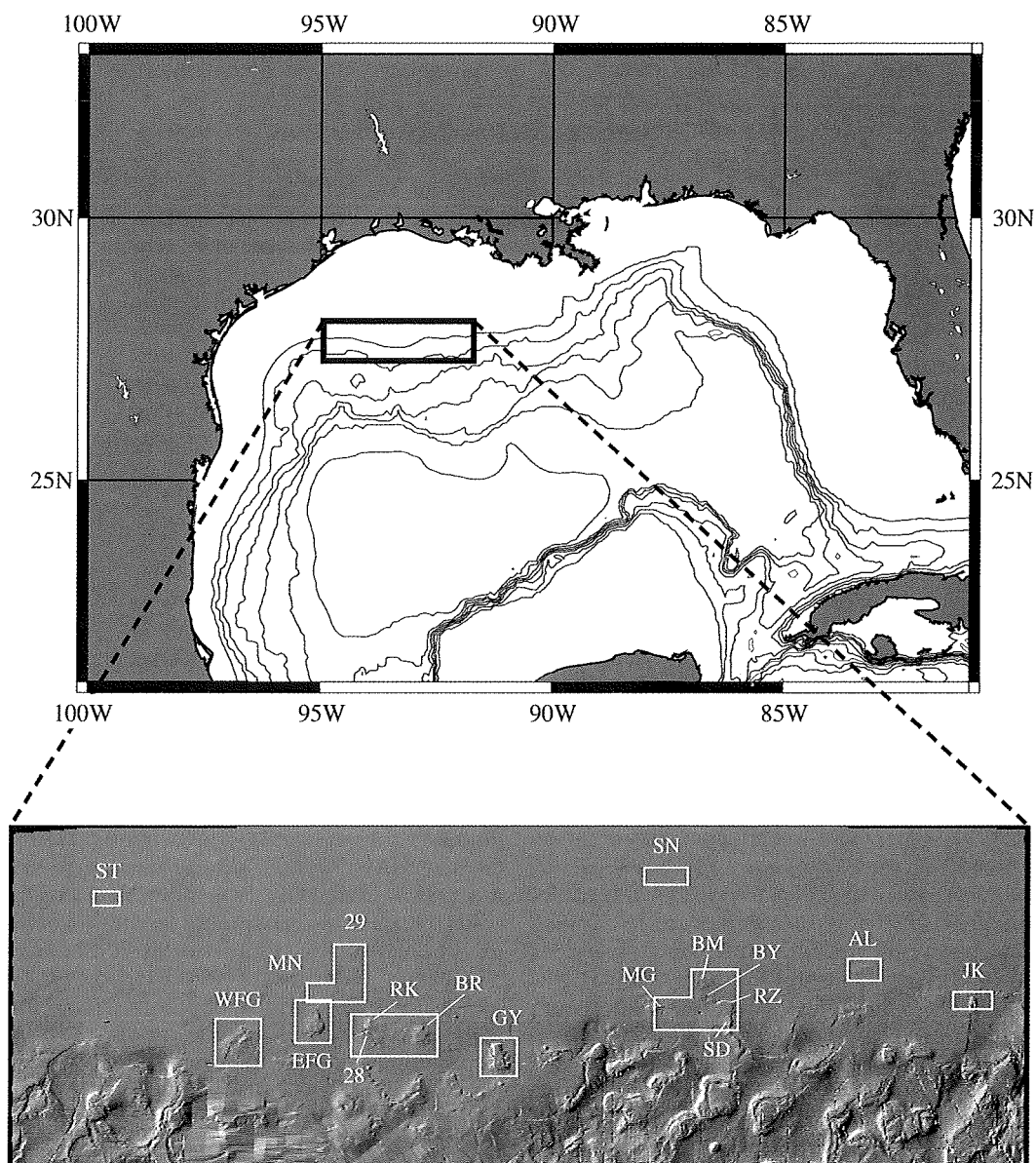


Fig. 1. Index map of the Gulf of Mexico with blow-up showing the locations of the banks discussed in text. The banks include Stetson Bank (ST), West Flower Garden Bank (WFG), East Flower Garden Bank (EFG), MacNeil Bank (MN), 29 Fathom Bank (29), Rankin Bank (RK), 28 Fathom Bank (28), Bright Bank (BR), Geyer Bank (GY), Sonnier Banks (SN), McGrail Bank (MG), Bouma Bank (BM), Bryant Bank (BY), Rezak Bank (RZ), Sidner Bank (SD), Alderdice Bank (AL), and Jakkula Bank (JK).

have been correlated to the results of Jackson (1994) but are given only as a suggestion of the surficial facies. Extensive ground truth is required to confidently map the sediment facies. The digital bathymetry and backscatter, as well as various images of the data are available to download at <http://walrus.wr.usgs.gov/pacmaps/wg-index.html>. It must be stressed that only the bathymetry and acoustic

backscatter have been used for the interpretations that follow because so little ground truth is publically available from these areas. Seismic-reflection data are available from many of these areas but have not been used because this study is focused on the bathymetry, not the subsurface. Hopefully, the following maps and data will be the foundation for extensive ground-truth sampling in the near

future so that reliable surficial facies maps eventually can be drawn for each area.

The banks that have been mapped with MBES are shown in Figure 1. The banks are located along the outer continental shelf and uppermost continental slope in regional water depths that range from ~60 to ~220 m water depth. Some of the tops of the banks rise to within a few decimeters or less of the surface. The discussion of each bank will proceed from west to east. East and West Flower Garden Banks and Stetson Bank will be only briefly described because they were the focus of Gardner et al. (1998).

#### STETSON BANK

Stetson Bank (ST in Fig. 1) rises on the continental shelf about 50 km north of the shelf break. The bank is an 800-m-long, 300-m-wide bathymetric high located within a low ring structure that strongly suggests the feature is related to an underlying salt dome (Shepard, 1937; Gardner et al., 1998). The bank abruptly rises 36 m above the 52 m water depths of the surrounding seafloor, with slopes steeper than 20°. The top of the bank is a relatively flat coral and sponge encrusted cap at about 16 m water depth with a local relief of about a meter. More details on the physiography of Stetson Bank can be found in Gardner et al. (1998).

#### WEST FLOWER GARDEN BANK

West Flower Garden Bank (WFG in Fig. 1) is located just beyond the edge of the continental shelf on a gentle slope in water depths of 100 to 120 m. The physiography of the bank is related to an emerged salt dome with a coral cap (Rezak et al., 1985; Gardner et al., 1998). The bank is roughly rectangular in plan view with dimensions of 6.5 by 8.9 km. The coral cap abruptly rises 20 m above a relatively smooth plateau at about 40 m water depth. The cap has slopes of 10–15° and shoals to within 16 m of the sea surface. Several other smooth plateaus occur in the immediate area but lack a rough coral cap. Other notable features of West Flower Garden Bank are the hundreds of pinnacles that rise as much as 10 m above the surrounding seafloor. More details on the physiography of West Flower Garden Bank are found in Gardner et al. (1998).

#### EAST FLOWER GARDEN BANK

East Flower Garden Bank (EFG in Fig. 1) is located at the edge of the continental shelf in

water depths of 100–120 m. The bank is pear shaped in plan view with a long north–south axis of 8.7 km and a short axis of 5.2 km. The main plateau is a gently dipping surface with slopes that range from 8° to more than 20° that rises ~60 m above the surrounding seafloor. A prominent coral cap rises 20–30 m above the main plateau to water depths as shallow as 20 m (Rezak et al., 1985; Gardner et al., 1998) and is adjacent to a dissolution basin and brine pool (Brooks et al., 1979; Bright et al., 1980a, 1980b; Rezak and Bright, 1981; Gardner et al., 1998). Unlike West Flower Garden Bank, the East Flower Garden Bank proper has only a few pinnacles, although there are numerous pinnacles to the north, west, and southwest of the bank. More details on the physiography of East Flower Garden Bank are found in Gardner et al. (1998).

#### MACNEIL BANK

MacNeil Bank (MN in Fig. 1) is located immediately N of East Flower Garden Bank on the outer continental shelf in ~80 m water depths. MacNeil Bank, together with 29 Fathom Bank (see below), are located on a large physiographic structure with a gently dipping terraced surface (Fig. 2A) inclined ~0.2° deeper toward the SSE. Water depths of the large structure increase at the 71-, 76-, and 89-m isobaths with pronounced semicircular-shaped drop-offs of 3–6 m and slopes of 2.5–3.0° (Fig. 2A). A large depression about 14 km across is a continuation of the eastern margin of the East Flower Garden structure and the western margin of the Rankin Bank (see below) (Fig. 2A). The prominent highs of East Flower Garden Bank, Rankin Bank, 28 Fathom Bank (see below), and MacNeil Bank rise on the semicircular rim of this depression.

MacNeil Bank (Fig. 2B) is a 6-km-long, 450-m-wide, elongated bathymetric high that is truncated along its western margin by the eastern side of a 250-m-wide linear NE–SW-trending trough and is bisected by a 230-m-wide E–W-trending trough. Both troughs have less than 3 m of relief. The northern portion of MacNeil Bank stands ~16 m above the seafloor to the east, with a relatively smooth but tilted top. The shallowest depths (64 m) of MacNeil Bank occur on a linear ridge located along the western edge of the feature. The southern, eastern, and northern margins of the northern portion of the bank have slopes that range from 10° to 14°, whereas the western margin has slopes as steep as 20°.

The southern portion of MacNeil Bank

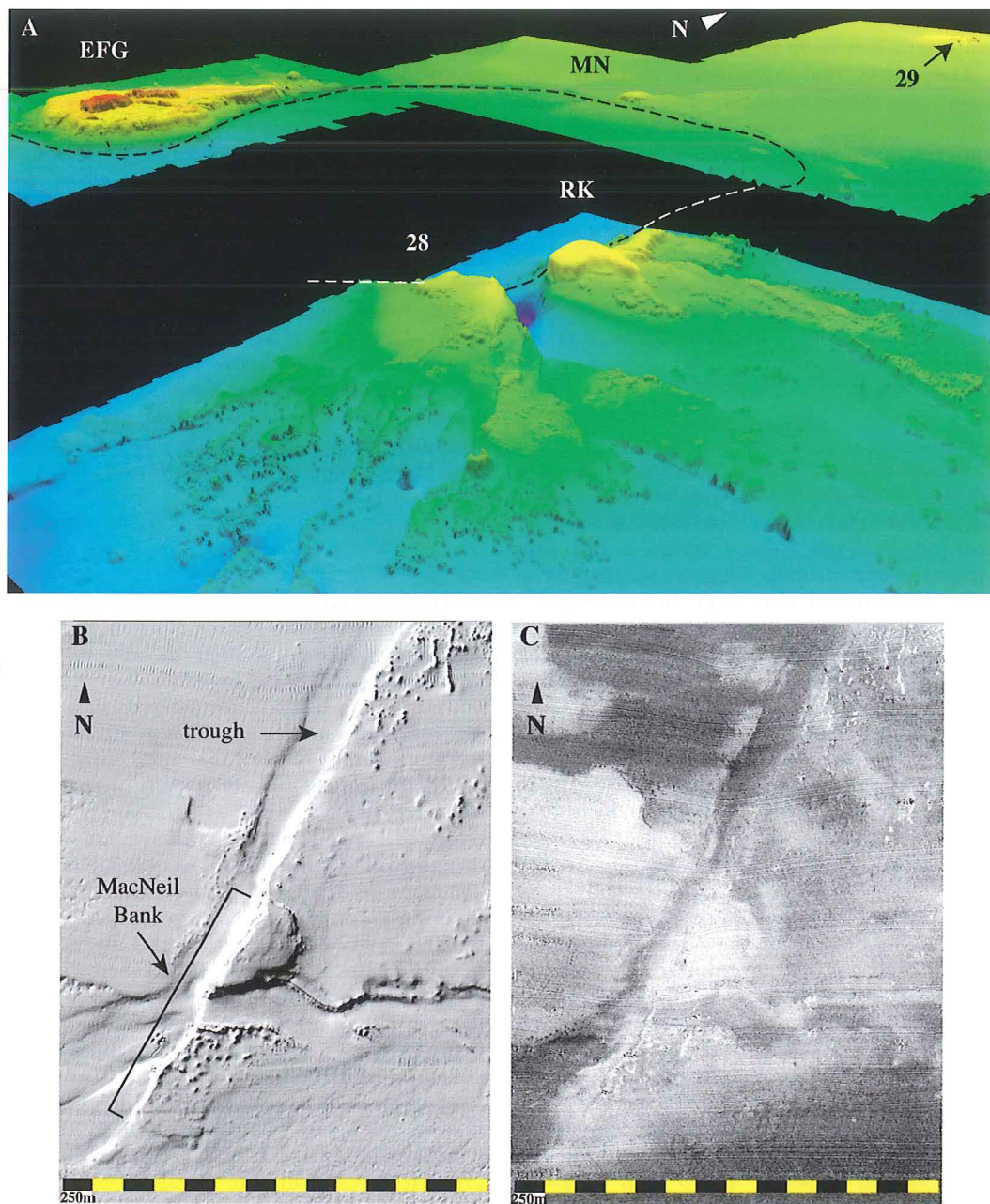


Fig. 2. (A) Perspective view of bathymetry of East Flower Garden Bank (EFG), MacNeil Bank (MN), 29 Fathom Bank (29), Rankin Bank (RK), and 28 Fathom Bank (28) (see Fig. 1 for locations). Vertical exaggeration  $\times 10$ , looking NW. Dashed line is perimeter of large circular feature discussed in text. (B) Shaded relief and (C) acoustic backscatter map view of MacNeil Bank.

stands less than 10 m above the surrounding seafloor compared with heights of more than 10 m for the northern portion. A field of isolated pinnacles in the southern portion rises from a surface that is tilted to the ESE by less than  $0.3^\circ$ .

The acoustic backscatter of MacNeil Bank (Fig. 2C) ranges from  $-22$  to  $-24$  dB, indicating a surficial facies of medium to fine sand. In contrast, the adjacent seafloor has backscatter values ( $-33$  dB) similar to the acoustic response of fine silt at the 95-kHz frequency.



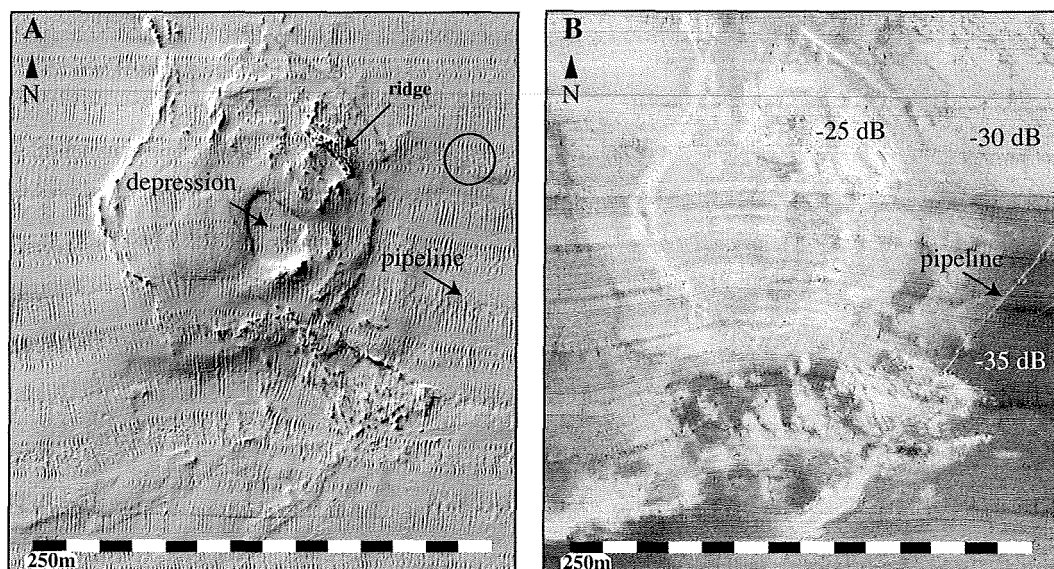


Fig. 3. (A) Shaded relief and (B) acoustic backscatter map view of 29 Fathom Bank. Note large bathymetric depression. Circled ripple-like texture in bathymetry is a heave artifact in the data and not actual seafloor relief. The ridge on the NE corner of the bank has the shallowest depths found on the feature.

#### TWENTY-NINE FATHOM BANK

Twenty-Nine Fathom Bank (informally named by Bright and Boland, 1985) is a 2-km-diameter circular dome that stands ~10 m above the main structure (Fig. 3). The surface of 29 Fathom Bank is a series of roughly concentric platforms and a prominent ridge. The platforms have irregular surfaces that are found in 54, 56, and 58 m water depths. The ridge is located on the northeastern rim of the bank, is 520 m long, and rises 8 m above the bank surface. The flanks of the ridge are asymmetrical, with a gentle slope of 3–4° facing the NE and a steeper slope of 10–18° facing the SW. The top of the ridge is smooth, similar in roughness to that of the main bank. The acoustic backscatter near the ridge is much higher (–25 dB) than the backscatter of the adjacent seafloor to the NE (–30 dB) (Fig. 3B), suggesting fine sand may have been shed from the ridge and buried the more silty basal sediments (–35 dB). A 500-m-long, 400-m-wide, and 5-m-deep oblong depression is located on the east-central part of the bank (Fig. 3A). The floor of the depression is featureless, is tilted to the SSE by ~0.5°, and has no backscatter expression.

#### RANKIN AND 28 FATHOM BANKS

Rankin Bank is located 15 km due east of East Flower Garden Bank on the outermost

continental shelf in water depths of 100–120 m. Rankin Bank (RK in Fig. 1) is actually two banks separated by a 1,000-m-wide trough (Fig. 4). The southern of the two Rankin Banks is often referred to as 28 Fathom Bank (E. Hickerson, pers. comm.) and that name will be used in this study. Twenty-Eight Fathom Bank is a southward-tilted (3.5°) bathymetric high that rises south of, and more than 100 m above, a pronounced trough. The top of the bank is at ~64 m water depth. The south flank of the bank gently merges with the tilted surface of a larger structure. The north-facing flanks are scarps with slopes that range from 22° to 32° that are interrupted by a terrace that varies in water depth from 110 m on the west to 93 m on the east. The outline of 28 Fathom Bank is somewhat arcuate shaped (Figs. 4, 5A) with an E–W length of 2.4 km and a width of ~0.8 km that encompasses an area of ~1.8 km<sup>2</sup>. The top of the bank is very smooth but gives way to small (<3-m-high) pinnacles and hardgrounds (a hard or indurated surface, regardless of origin or relief, as defined by Schroeder et al., 1988) that occur in water depths deeper than 77 m immediately to the south.

The acoustic backscatter of 28 Fathom Bank proper is high, with values of –21 to –22 dB (Fig. 4B) that suggest a surficial facies of sandy gravel to coarse sand. A zone of relatively high backscatter (approximately –26 dB) blankets

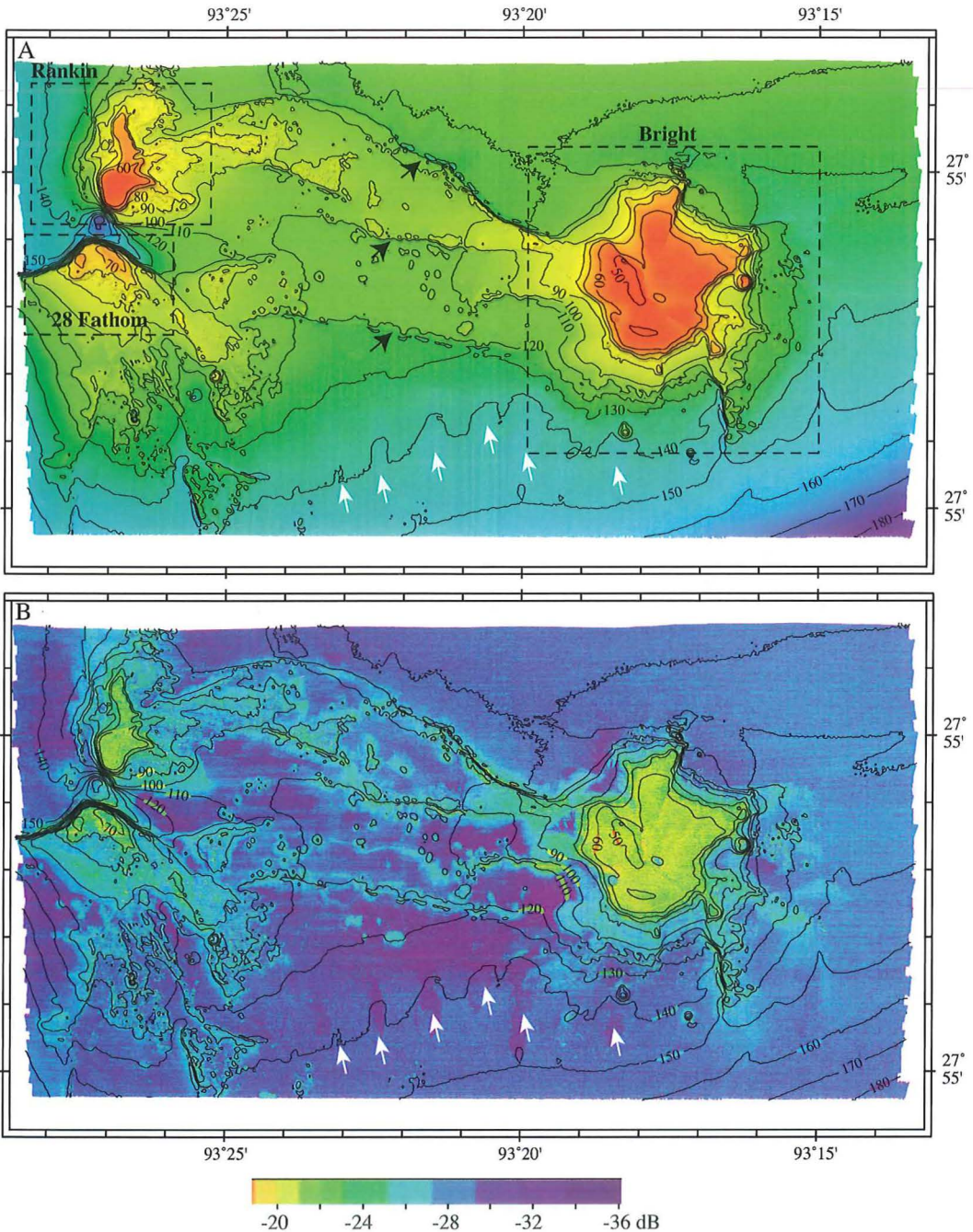


Fig. 4. (A) Color-shaded relief and (B) acoustic backscatter maps of Rankin, 28 Fathom, and Bright Banks (see Fig. 1 for location). White arrowheads point to bathymetric lows and black arrows point to ridges, both discussed in text.

the entire bathymetric feature to the south as well as the floor of the trough that separates Rankin Bank to the north from 28 Fathom Bank. The relatively high backscatter values suggest a surficial facies of medium to fine sand. The hardgrounds and pinnacles also

share these relatively high backscatter values. The seafloor beyond the bathymetric expression of 28 Fathom Bank has relatively low backscatter values of  $-30$  to  $-32$  dB, suggesting a surficial facies of coarse to fine silt.

The bank immediately north of the trough

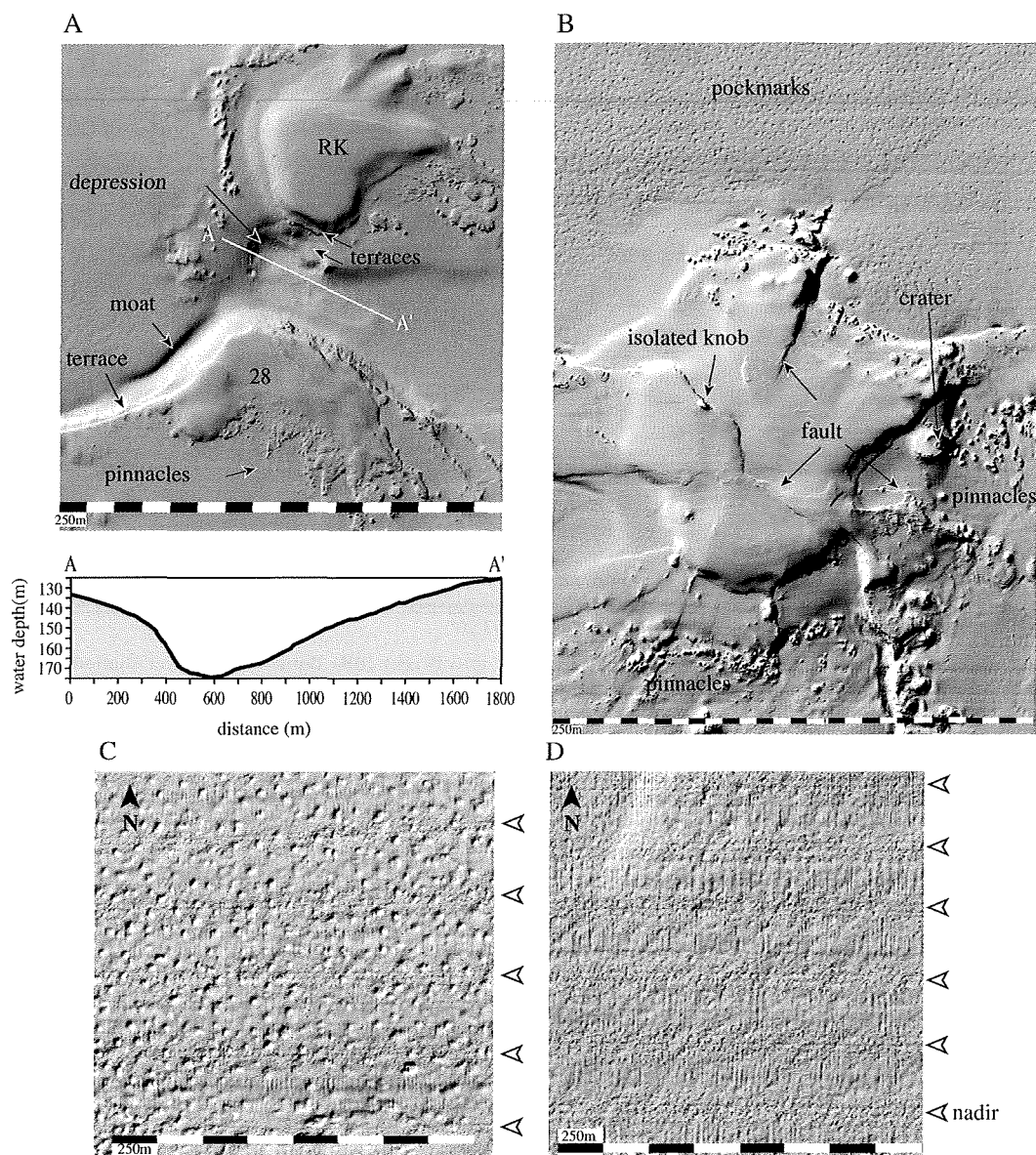


Fig. 5. (A) Shaded relief map view of Rankin (RK) and 28 Fathom (28) Banks. Cross section AA' shows asymmetric profile of the depression that separates the two banks. (B) Shaded relief map view of Bright Bank. (C) Shaded relief map view of typical pockmarks north of Bright Bank, (D) shaded relief map view of "mottled terrain" south of Bright Bank and southwest of 28 Fathom Bank. Open arrowheads in C and D point to subtle nadir artifact of MBES and vertical lines orthogonal to nadir are very minor heave artifacts. See Figure 6 for locations.

is sometimes referred to as Rankin Bank #2 (E. Hickerson, pers. comm.) but, because of a lack of consensus, will be called here simply Rankin Bank. Rankin Bank encompasses roughly the same area as does 28 Fathom Bank ( $\sim 1.2 \text{ km}^2$ ), is kidney shaped in outline, and rises to water depths of 50 m. The surface of the bank is very smooth with rounded edges, unlike the edges

of 28 Fathom Bank (Fig. 5A). Rankin Bank is located immediately north of the trough with south-facing slopes of  $18^\circ$  interrupted by one terrace at 88 m water depth and possibly another at  $\sim 140 \text{ m}$ . The other flanks are gentler, with a west-facing flank of  $13^\circ$ , a north-facing flank of  $8^\circ$ , and an east-facing flank of only  $2.5^\circ$ . Pinnacles occur around the western base



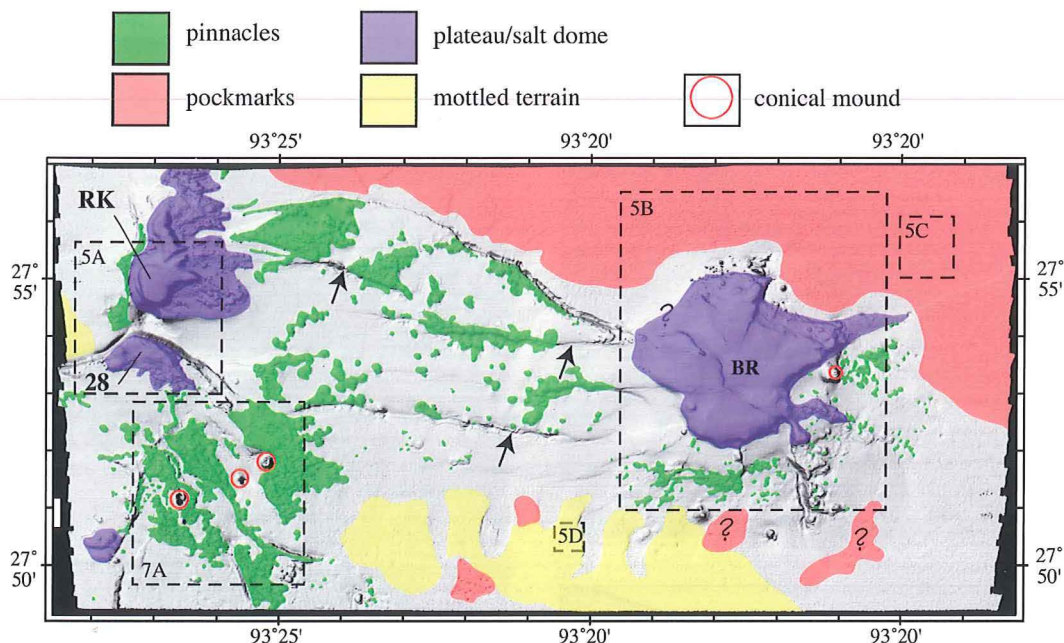


Fig. 6. Terrain map of Rankin (RK), 28 Fathom (28), and Bright (BR) Banks draped over shaded relief. The area is segmented into four classes based on bathymetric and acoustic backscatter texture. Black arrows point to ridges mentioned in text. Dashed rectangles are locations for Figures 5 and 7.

of the bank in water depths greater than 110 m, whereas hardgrounds occur just beyond the eastern and southeastern flank in water depths deeper than 80 m.

The acoustic backscatter of Rankin Bank is very similar to that of 28 Fathom Bank (Fig. 4B), with high backscatter values ( $-20$  to  $-22$  dB) on the tops, suggesting a facies of sandy gravel to coarse sand, and lower values, suggesting coarse to fine silt, beyond the banks.

The most striking feature in the Rankin and 28 Fathom Banks area is the large depression or trough that separates them (Figs. 4, 5A). The trough is  $\sim 500$ -m wide,  $1,850$ -m long, and  $\sim 30$  m deeper than the surrounding seafloor, with an asymmetric longitudinal profile (Fig. 5A). The steeper NW side of the trough has slopes of  $\sim 10^\circ$ , whereas the gentler SE side has slopes of  $\sim 3^\circ$ . Acoustic backscatter values within the depression, as well as immediately outside of it, range between  $-24$  and  $-27$  dB, suggesting the surficial sediments of these areas are sand.

#### BRIGHT BANK

Bright Bank (BR in Figs. 1, 5B) is located on the outer continental shelf 15 km east of Rankin and 28 Fathom Banks in water depths of 130–150 m. Bright and Rankin Banks are con-

nected by a series of linear to curvilinear ridges  $\sim 5$  m high that are defined by individual pinnacles (Figs. 4, 6). Bright Bank is a roughly circular bathymetric high that stands  $\sim 75$  m above the surrounding seafloor with a top at 48–50 m water depth. The relatively smooth top of the bank occupies  $\sim 21.2$  km<sup>2</sup> with a small isolated knob that stands 14 m above the bank top (Fig. 5B). The knob is elliptical ( $115 \times 200$  m) in plan with a smooth surface and rounded edges and is located along a truncated edge of one of several linear trends that may be faults. The most pronounced linear trend strikes N22E and has as much as 15 m of relief. A 25-m-deep, 800-m-wide trough strikes N40W across the bank top from the center. Fields of pinnacles are found just beyond the flanks of Bright Bank but not on its surface (Fig. 5B). The flanks of the bank have slopes of  $<15^\circ$  with the southern flank being the steepest ( $14^\circ$ ) and the north flank the gentlest ( $2^\circ$ ).

The acoustic backscatter from Bright and Rankin Banks can be segmented into four classes of backscatter; values of more than  $-22$  dB are found on the bank tops and on the pinnacles, values of  $-25$  to  $-22$  dB are found in the immediate areas surrounding bank tops and pinnacles, values of  $-28$  to  $-25$  are typical of the seafloor adjacent to the banks, and val-

ues less than  $-28$  dB are found in low-lying regions on the adjacent seafloor (Fig. 4B). If the correlations of Jackson (1994) are used to predict the surficial facies, then the bank tops are covered in medium sand, the immediate areas surrounding the bank tops are composed of fine sands that may represent debris shed off the bank tops, the regional seafloor is a blanket of coarse silt, and the low-lying areas of the seafloor are regions that have collected fine silt.

Bright and Rankin Banks appear to be related to one or more subsurface or surficial salt domes. The areas not directly on the banks are dominated by pinnacles and fields of pockmarks (Figs. 5C, 6). Individual pockmarks have diameters of  $<50$  m and depths of  $\sim 1$  m and occur with an average density of about 200/km<sup>2</sup>. However, in addition to the pockmarks, large areas have a surface texture that in some ways resembles pockmarks but, if they are pockmarks, then they have been modified into what, for lack of a better term, is called "mottled terrain." Mottled terrain has a rough texture but with relief of only a few tens of centimeters and no regular pattern or trend (Fig. 5D). Small fields of pockmarks are associated with the mottled terrain, and it may be that the mottled terrain is an old field of pockmarks that was reworked by bioturbation, bottom currents, or both.

A series of five shallow linear depressions, each  $<4$ -m deep,  $\sim 700$ -m wide, and 1,800–2,100-m long, trend directly N–S about midway between Rankin and Bright Banks (white arrows in Fig. 4A). The depressions have very low backscatter ( $-33$  to  $-35$  dB), suggesting the surficial sediments within the depressions are fine silt, whereas the backscatter values of the surrounding seafloor are typically  $-28$  to  $-29$  dB, indicative of coarse silt.

Five isolated conical mounds, ranging in size from 200 to 300 m in diameter at their base, each standing 10–30 m high, with pronounced summit craters as much as 25 m deep, are found just off the flanks of both Rankin and Bright Banks (Figs. 6, 7). The mounds are not associated with pockmark fields, but they do occur within areas of dense pinnacles. Although the mounds have characteristics similar to expulsion vents such as mud volcanoes (conical shape, meters to tens of meters of relief, central crater, etc.) (Hovland and Judd, 1988; Hovland et al., 2002; MacDonald et al., 2003), their precise origin in the Rankin Bank area is unknown.

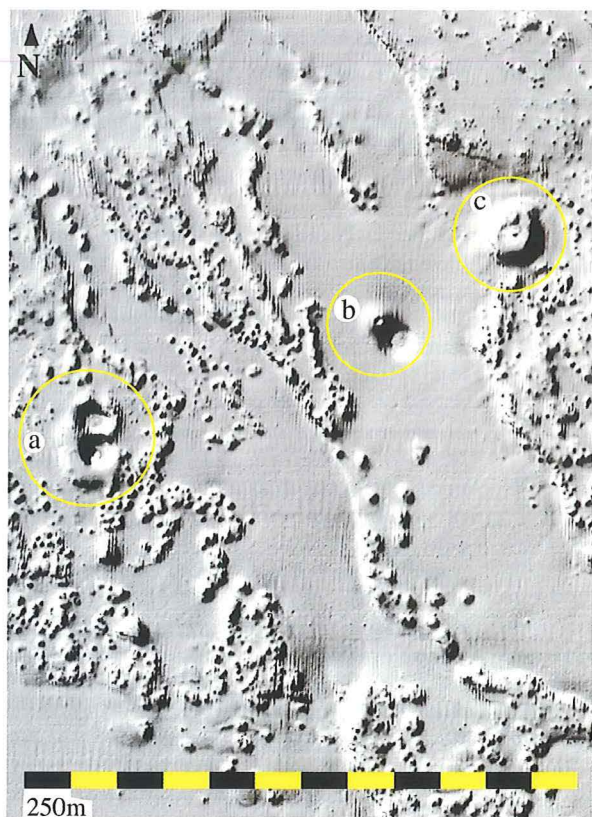
#### GEYER BANK

Geyer Bank is located 23 km ESE of Bright Bank on the upper continental slope, rising  $\sim 130$  m above the 200-m isobath (GY in Figs. 1, 8). The bank is pear shaped in outline and appears to be the surface expression of two coalesced salt domes. The composite feature has a 9.3-km N–S axis and a maximum of 5.4 km for an E–W axis. The flanks of Geyer Bank have slopes of  $6$ – $9^\circ$  on the south and east, whereas the slopes on the north and west are  $20^\circ$ . Rezak et al. (1985) interpreted the steep flanks of Geyer Bank as fault scarps. The broad top of the bank is relatively flat and lies between 60 and 100 m water depth. The surface of the northern dome is relative rough, with a series of concentric ridges with as much as 2 m of relief as well as a few pinnacles, the tallest of which rises almost 35–40 m water depth. The surface of the south dome is at 58–62 m water depth but with much less relief than occurs on the north dome. The south dome is dominated by a large ( $2.9 \times 1.9$  km), 20-m-deep depression that is bisected into two basins by a 2-m-high ridge that trends NE–SW. The floor of the northern basin is  $\sim 4$  m below the floor of the southern basin. Small-scale bedforms with wavelengths of 30–50 m, heights of  $<1$  m (at the limit of resolution of the MBES system), and trends of  $\sim N45W$  cover most of the depression floor. The surface of the southern dome that surrounds the depression is essentially featureless. Another depression is found at the junction of the two domes with  $\sim 5$  m of relief. Both of these large depressions are completely enclosed with no sign of an outlet.

Rezak et al. (1985) describe and have mapped slumps on the middle of Geyer Bank and on the SW side of the south dome. However, close inspection of the multibeam bathymetry and acoustic backscatter images does not reveal features that resemble slumps, even at the highest resolution allowed by the MBES data. The same can be said for pockmarks; Rezak et al. (1985) describe an area of gas seeps "... at a depth of 82 m." (Rezak et al., 1985, p. 178), but close inspection of the multibeam data around the 82-m isobath revealed no pockmarks.

The acoustic backscatter of Geyer Bank can be segmented into two zones. One zone has backscatter values that range between  $-17$  and  $-23$  dB and is found on the outside half of the surfaces of both the north and south domes, whereas another zone with values between  $-23$  and  $-26$  dB is found on the depressions and

A



B

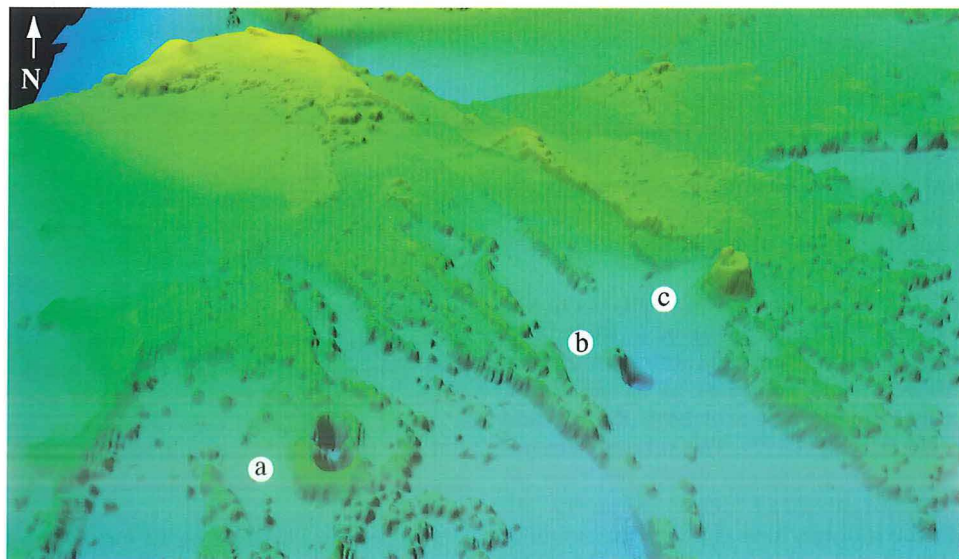


Fig. 7. (A) Map view and (B) perspective view of conical mounds found in the area south of 28 Fathom Bank. Mounds are circled in yellow and labeled a, b, and c. Other features surrounding mounds are pinacles. Perspective view has vertical exaggeration of  $\times 10$ . See Figure 6 for location.



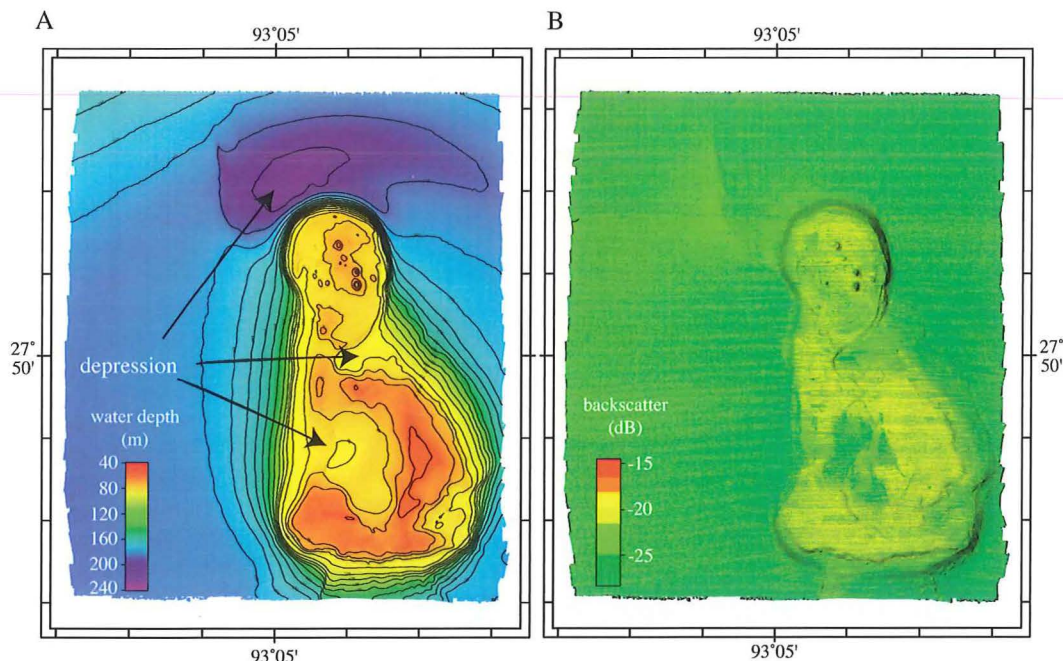


Fig. 8. (A) Color-shaded relief and (B) color acoustic backscatter maps of Geyer Bank. Depressions are discussed in text. See Figure 1 for location.

on the middle of the bank (Fig. 8B). The high backscatter zone sits above the main bank structures by as much as 20 m and has acoustical properties similar to cobbles to medium sand. The lower backscatter zone has acoustical properties similar to medium to fine sand. The backscatter of the local seafloor adjacent to Geyer Bank is similar to that of the depressions.

#### MCGRAIL, BOUMA, REZAK, SIDNER, AND BRYANT BANKS

McGrail, Bouma, Rezak, Sidner, and Bryant Banks were all mapped as one contiguous 440-km<sup>2</sup> area (MG, BM, RZ, SD, and BY in Figs. 1, 9). All these banks occur along upturned edges of a broad, smooth, NW–SE-elongated, dish-shaped structure with a mean water depth of ~115 m. Bouma, Rezak, Sidner, and Bryant Banks are located on the east side of the structure in water depths of ~60 m, whereas McGrail Bank occurs on the southwest side of the structure in water depths of ~45 m. The outline of the structure is very irregular with linear to curvilinear margins. The central half of the structure appears buried by sediment. A 10- to 20-m-deep moat is found immediately off the NE flank of Bouma Bank, S of Sidner Bank, and SW of McGrail Bank (Fig. 10G).

Shallower moats (<5 m deep) are also found E of Bryant Bank and NE and E of Rezak Bank. Although the margins of the structure are linear to curvilinear and do not suggest an underlying salt *dome* (as is the case for many of the banks in the NW Gulf of Mexico), there is no bathymetric evidence to exclude the association of salt tectonics with McGrail, Bouma, Rezak, Sidner, and Bryant Banks. Rezak et al. (1985, p. 190) state that Rezak and Sidner Banks are "...part of a rectangular block bounded by normal faults on three sides" but do not explicitly mention salt tectonics. However, Rezak et al. (1985) quote Trippitt and Berryhill (1982) as suggesting Rezak and Sidner Banks are part of a NW-trending series of banks that formed on a subsurface ridge of salt.

Acoustic backscatter is high (–23 to –21 dB) along the margins of the main structure and especially high on each of the banks (Fig. 9B). The seafloor surrounding the main structure has relatively low acoustic backscatter values (–34 to –30 dB) that suggest the area is blanketed by silt. Approximately 40% of the area is pockmarked with a pockmark density of ~200/km<sup>2</sup>. A large area of pockmarks between McGrail and Bouma Banks has a pockmark density of ~400/km<sup>2</sup>. The pockmarks vary from 15 to 50 m in diameter and from <0.5 to



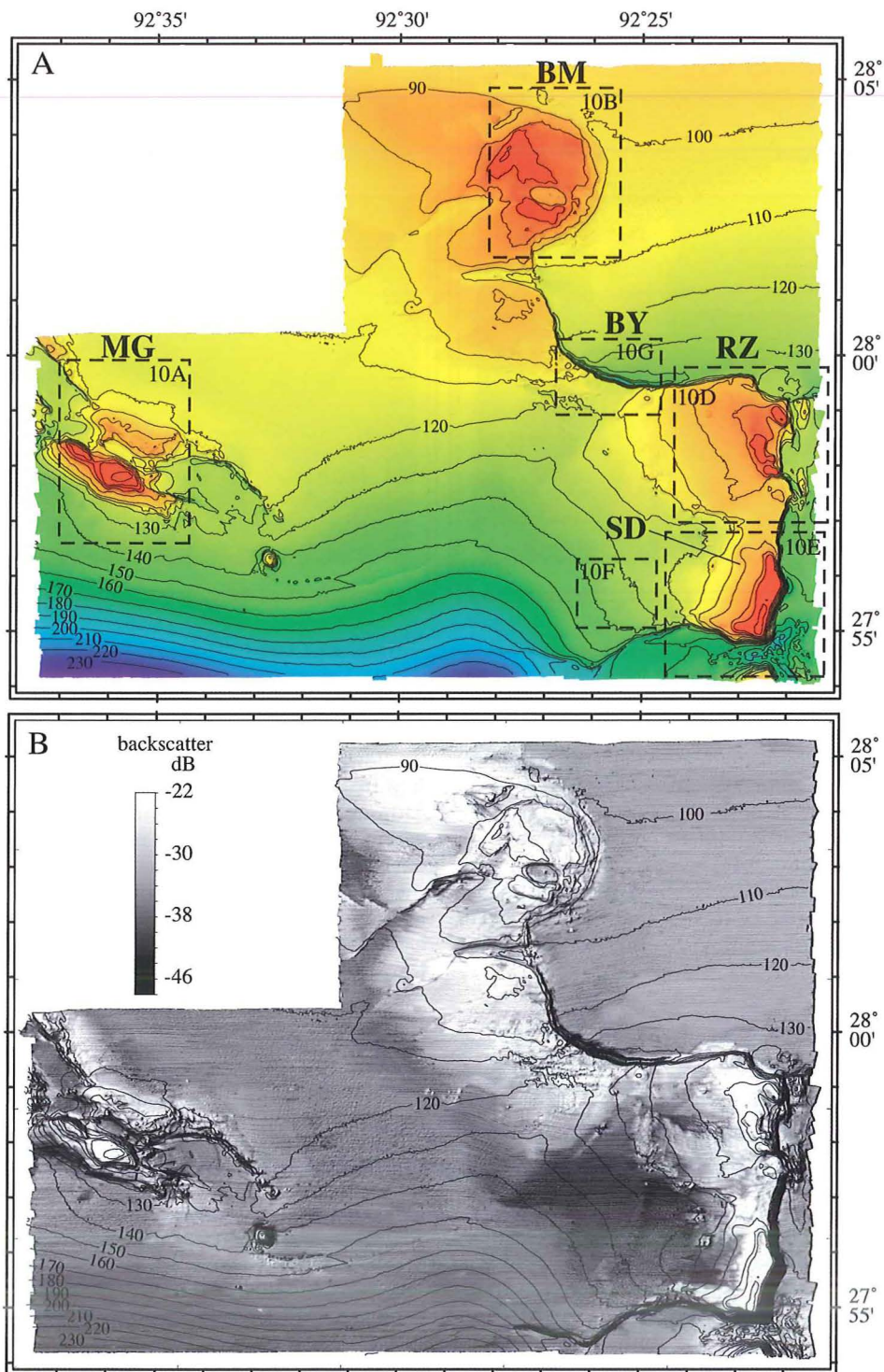


Fig. 9. (A) Color-shaded relief map and (B) acoustic backscatter map of area that includes McGrail (MG), Bouma (BM), Bryant (BY), Rezak (RZ), and Sidner (SD) Banks. Dashed rectangles are locations for Figure 10. See Figure 1 for location.

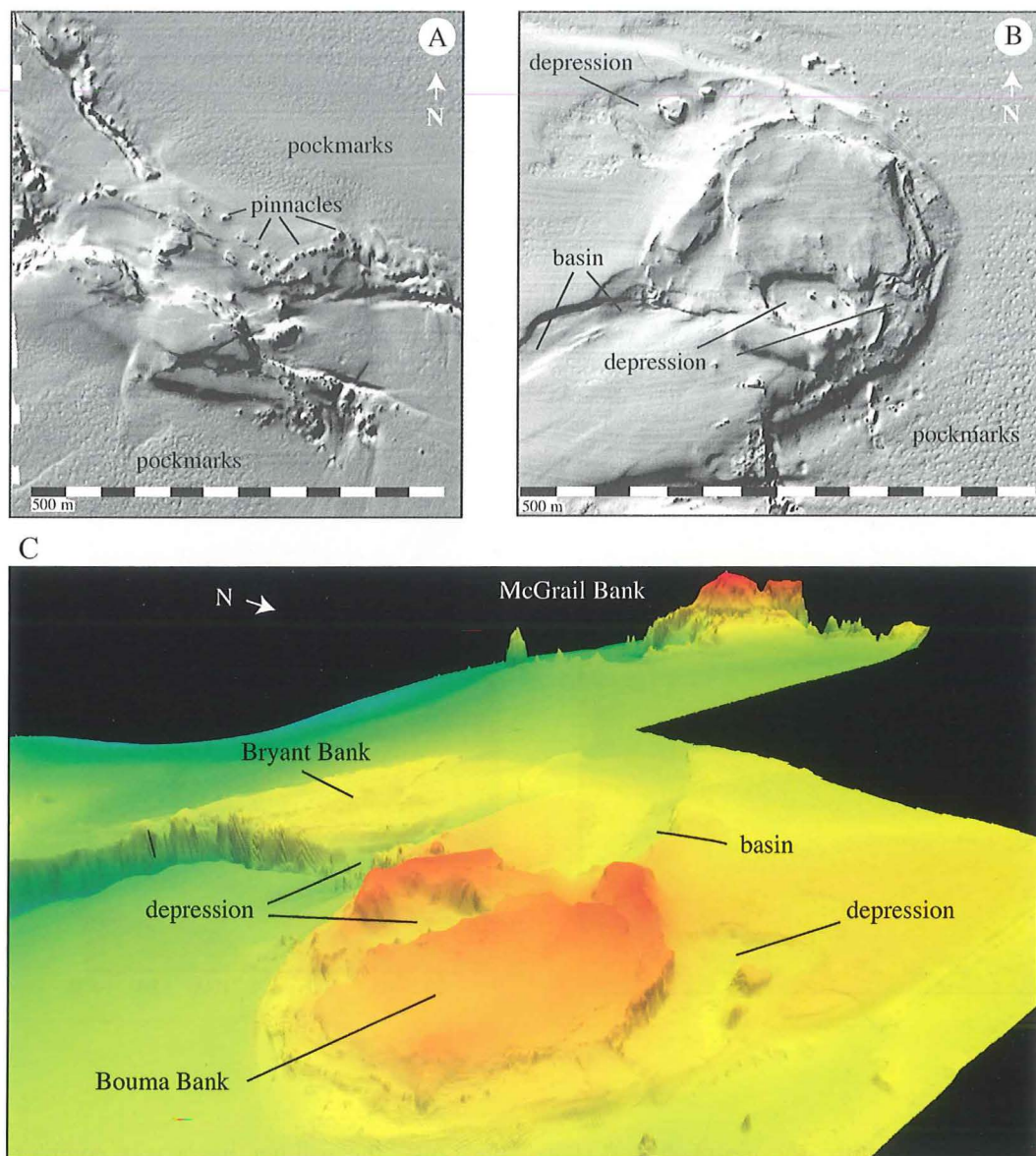


Fig. 10. (A) Shaded relief map view of McGrail Bank. (B) Shaded relief map view of Bouma Bank. Depressions and basin are discussed in text. (C) Perspective view of Bouma Bank with Bryant and McGrail Banks in background. Vertical exaggeration  $\times 25$ , looking SW. (D) Shaded relief map view of Rezak Bank. (E) Shaded relief map view of Sidner Bank. (F) Close-up map view of shaded relief of typical pockmarked bedform area at Sidner Bank. Black arrowheads along left edge of image point to subtle E-W ship-track artifacts, white circle shows individual pockmark and black dashed line shows trend of the bedform crests. (G) Shaded relief map view and cross section of moat located between Bouma and Rezak Banks. Note deep incision of moat. See Figure 1 for bank locations; see Figure 9 for location of figures.

$\sim 1$  m in depth with no apparent rims (Fig. 10A,B,G). Their geometries place the pockmarks somewhere between unit pockmarks and normal pockmarks in the nomenclature of Hovland et al. (2002).

A large area of seafloor in this area has a texture somewhat resembling the mottled tex-

ture described above for regions adjacent to Rankin and Bright Banks. However, the texture here resembles a complex of pockmarks and bedforms that covers  $\sim 8.5$  km<sup>2</sup> along the SE rim of the dish-shaped feature (Fig. 10E,F). This seafloor texture occurs only from the rim of the bank and down slope toward the axis of



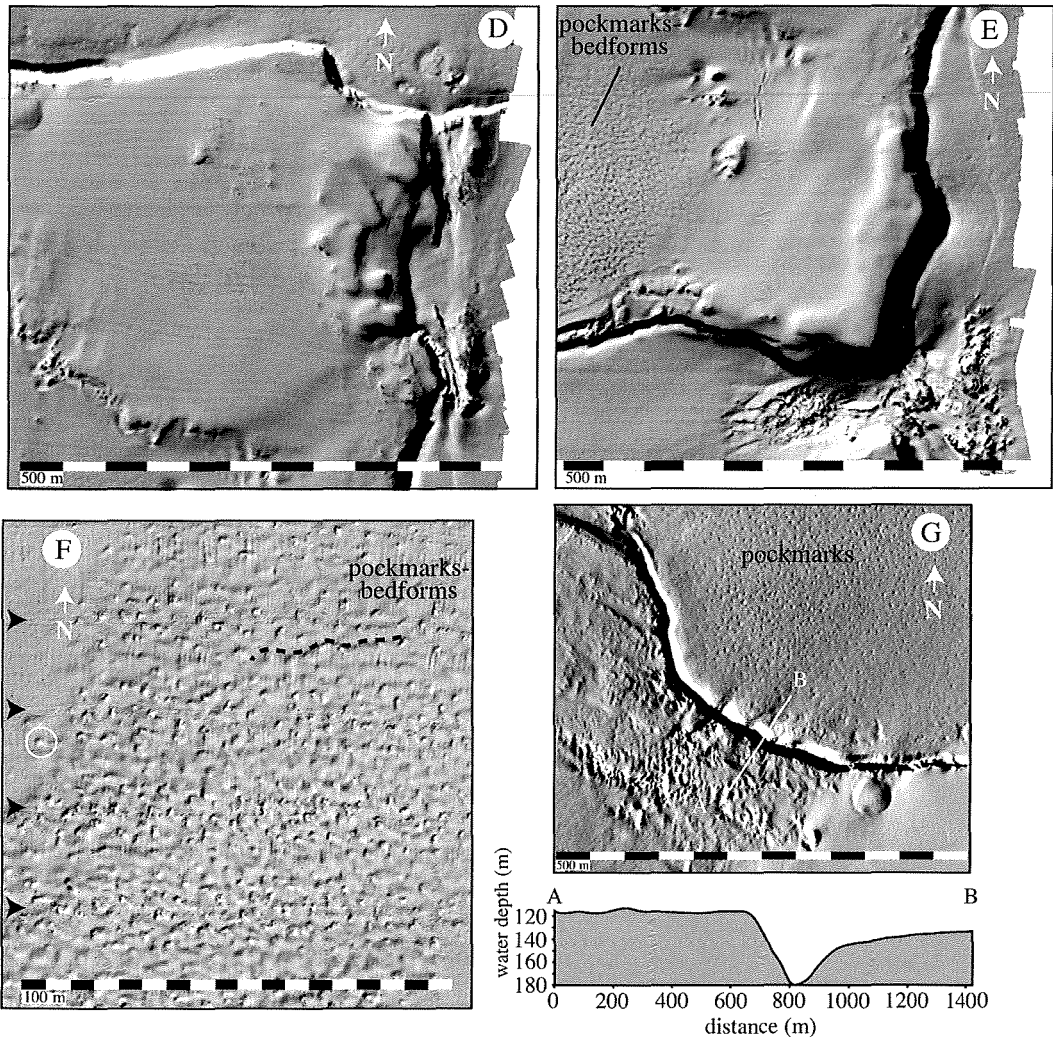


Fig. 10. Continued.

the main structure. The morphological characteristics of the pockmark-bedforms include distinct pockmarks with diameters of 10–50 m, depths of <1 m, and a density of ~400/km<sup>2</sup>. The pockmarks are superimposed on bedforms with narrow, arcuate, curvilinear crests <0.5-m high that trend roughly 45° to the maximum gradient. The narrower dimension of the bedform crests is less than two sonar footprints (8 m), making them difficult to resolve. The depressions of the pockmarks have higher acoustic backscatter than the bedform crests. This terrain texture may represent a zone of multiple gas expulsion events that occurred in a bedform field. Alternately, this texture may have been created by reworking a preexisting field of pockmarks into bedforms. Whatever

the cause, the seafloor has a very complex, confused, low-relief texture.

McGrail Bank

McGrail Bank is composed of two inline, elongate, smooth-topped rises that occur on and just beyond the SW rim of the main tilted dish-shaped structure (Figs. 9, 10A). The NW–SE axis of McGrail Bank is 4.4-km long and the width is ~3 km. The shallowest surface of McGrail Bank (44 m water depth) is located on a small knoll located in the SE part of the bank. Recent remotely operated surveys conducted by Schmahl and Hickerson (2005) have confirmed the presence of significant coral reef patches in this location. The bank area



and the conjugate rim on the main feature appear to be sitting on a broad, smooth, convex bathymetric high with a surface at about 90 m water depth. An intervening low between the bank and the main structure is ~15 m shallower than the surrounding seafloor and about 20 m deeper than the broad bathymetric high of the bank, giving the impression of a connection between McGrail Bank and the main structure. The slopes of McGrail Bank are as steep as 29° on the NE side but are only a maximum of 12° on the SW side. An isolated 550-m-diameter dome rises ~35 m above the seafloor 3.3 km ESE from the southeastern end of McGrail Bank. A 10-m-deep moat is located on the NE side of the bank.

Pinnacles are found in the immediate vicinity of McGrail Bank on the SW rim of the main feature, along E- and SE-trending scarps that lead away from the bank and in concentrated fields to the S and SE of the bank (Fig. 10A). The pinnacles vary in diameter at their base from 25 to ~120 m with heights as high as 7 m.

McGrail Bank has acoustic backscatter values that are consistently -22 to -21 dB, a response typical of coarse to medium sand at the 95-kHz frequency. This sharply contrasts with the low backscatter (less than -30 dB) of the surrounding seafloor that suggests the seafloor is covered with fine silt.

#### BOUMA BANK

Bouma Bank is located along the NE rim of the main tilted, dish-shaped structure (Figs. 9, 10B). The bank has a roughly circular outline with a flat to slightly dish-shaped, relatively smooth surface that measures 2.8 km NW-SE and 2.2 km SW-NE. A 1.2 × 0.7 km, flat-floored, enclosed depression with an average water depth of ~85 m occurs along the SE margin of the bank. The depression has slopes of up to 10° on all but the eastern side and is blocked on the eastern side by a shallow 6-m-high sill. The depression is similar to the dissolution depression on East Flower Garden Bank (Brooks et al., 1979; Bright et al., 1980a, 1980b; Rezak and Bright, 1981; Gardner et al., 1998) and Geyer Bank (Fig. 8).

Bouma Bank resembles a 10-m-thick plateau sitting on a broad, lower lying structure (Fig. 10B). The western rim of the plateau is a ridge that rises to 58 m water depth. A 50- to 1,500-m-wide, 2- to 15-m-deep basin leads away from the SW side of Bouma Bank, narrowing and losing relief toward the SW. The basin floor is inclined at <0.5° down toward the SW and is composed of two smaller basins separated by a

3-m-high sill. The SW end of the basin abruptly ends in a 2-m-high wall. Another large depression is located adjacent to the NW corner of Bouma Bank (Fig. 10B). This depression has dimensions of 2.3 × 1.3 km with a floor as much as 9 m lower than the surrounding seafloor. A ~1-m-high sill blocks the NE margin of the depression. A third depression is located on the E perimeter of the bank and breaches its eastern edge. This depression has a narrow outlet at 110 m water depth. The seafloor to the immediate east of Bouma Bank is covered by pockmarks with densities of ~100/km<sup>2</sup>.

The acoustic backscatter of Bouma Bank ranges from -24 to -23 dB, typical of the 95-kHz acoustic response of fine sand. The surrounding seafloor has backscatter values of approximately -33 dB that suggest the surficial material is fine silt.

#### BRYANT BANK

Bryant Bank is a low-relief feature located south of Bouma Bank in water depths of 90-105 m (Fig. 10C). Bryant Bank differs from the adjacent banks by not having a prominent shoal area on its surface. This bank is a triangular-shaped feature with sides ~2.5 km long. It has a flat surface at ~90 m water depth that descends gently (0.5°) to the SW to water depths of ~115 m where it merges with the center of the main structure. The surface of the bank is covered with a small-scale roughness that is just at the resolution of the MBES system. The NW surface of Bryant Bank is crossed by two facing, NE-SW-trending scarps <3 m high. The area between the scarps has a similar roughness to that of the main surface. The acoustic backscatter of Bryant Bank ranges from -26.5 to -24.5 dB, suggesting a surficial facies of medium to fine sand.

#### REZAK AND SIDNER BANKS

Rezak and Sidner Banks are located along the east-central and southeast edges, respectively, of the main structure in water depths of 100-160 m (Figs. 9, 10D,E). The two banks are thought by Rezak et al. (1985) to be related to one another but have been separately named by others. Both banks are constructed on a gently sloping tilted fault block related to salt intrusion (Rezak et al., 1985). The tilted surface of the block ranges in water depths from 95 m on the east to 105 m on the west with a slope of <1° for ~5 km. The surface is abruptly truncated on the north, east, and south with slopes as large as 30°. The western margin of

the surface is gradual with no distinct break west of Sidner Bank but abruptly drops as much as 10 m west of Rezak Bank.

Rezak Bank is a series of five elongate to circular mounds with plan dimensions of 200–1,000 m that rise 5–7 m above the surface described above. The mounds are smooth (at a resolution of 4 m/pixel) and generally have a steeper east-facing slope ( $5^\circ$ ) compared with the other slopes ( $<1^\circ$ ). The acoustic backscatter ( $-22$  to  $-21$  dB) of Rezak Bank has values similar to medium sand compared with the  $-33$  to  $-32$  dB backscatter values of the surrounding seafloor that suggest the surficial sediment is fine sand.

Sidner Bank is a 2.9-km-long bathymetric high that rises 15–20 m above the surrounding seafloor with a NW-dipping tilt of  $3$ – $4^\circ$ . Sidner and Rezak Banks are very similar to one another in profile with their steepest flank facing the edge of the large structure they are built upon. The acoustic backscatter of Sidner Bank is even higher ( $-19$  dB) than that of Rezak Bank, suggesting sandy gravel blankets its surface.

#### SONNIER BANKS

Sonnier Banks (SN in Fig. 1) are located on the mid shelf, outlined by the 60-m isobath on the north and east sides and is only  $\sim 0.5$  m deeper on its SW (Fig. 11). Although referred to in the literature in the plural, Sonnier Banks is actually a series of isolated clusters of pinnacles that rise mostly around the perimeter of a single roughly circular ring  $\sim 3.2$  km in diameter. A large ( $1.3 \times 1.5$  km), 3-m-deep depression occupies the southern half of the feature that is thought by Rezak et al. (1985) to be the result of the collapsed crest of an underlying salt diapir.

The pinnacles associated with Sonnier Banks are concentrated in the eastern half of the ring and shoal to as little as 19 m water depth, but most shoal only to water depths of  $>35$  m. Individual pinnacles are circular to elongate in plan view and abruptly rise from the seafloor with little or no basal apron. A large, somewhat flat-topped pinnacle is located on the south rim with a summit at 47 m water depth and is connected to a 1.5-m-high ridge that trends uninterrupted to the SE for more than 0.5 km (Fig. 12).

A subtle terrace, outlined by the 60-m isobath (Fig. 11), extends west from Sonnier Banks across the mapped area. The terrace represents a step up of  $\sim 0.5$  m in the bathymetry and connects with another somewhat cir-

cular high backscatter area  $\sim 2$  km to the west (Fig. 11B). The acoustic backscatter of the terrace between the two circular features is about 6 dB lower ( $-30$  vs  $-24$  dB) than that of the banks, suggesting this portion of the terrace is covered by silt, whereas the banks appear to be blanketed by fine sand. The high backscatter circular area to the west may represent another lobe of an underlying salt dome.

Linear streaks of high acoustic backscatter, mostly with no expression in the bathymetry, occur just outside Sonnier Banks (Fig. 11B). An ENE–WSW-trending streak  $\sim 400$  m wide roughly correlates with a pipeline clearly resolved in the bathymetry (Figs. 11B, 12). However, a persistent N22W trend of high acoustic backscatter with no bathymetric relief occurs from just W of Sonnier Banks across the mapped area (Fig. 11B). The acoustic backscatter of this streak has values of about  $-29$  dB compared with values of about  $-31$  dB for the surrounding seafloor. The backscatter values suggest that the high backscatter streak is composed of material that acoustically resembles coarse silt, whereas the surrounding seafloor resembles fine silt. A series of higher-backscatter streaks with a similar NNW–SSE trend is also found east of Sonnier Banks, but the high backscatter occurs both as distinct streaks and broad, diffuse zones. Those backscatter streaks not correlated with a bathymetric expression are clearly not artifacts of the multibeam system because they align across more than a dozen MBES swaths. The Minerals Management Service website (MMS in references) provides a geospatial database of locations of pipelines in the Gulf of Mexico. The area of Sonnier Banks was extracted from the database and three pipelines are seen to cross the area (Fig. 11B). However, MMS-located pipelines coincide with only two of the streaks, are offset from one streak, and are not correlated with several other streaks.

#### ALDERDICE BANK

Alderdice Bank (AL in Fig. 1) is located in the eastern part of the mapped area in about 100 m water depths. The oval-shaped bank is roughly outlined by the 90-m isobath (Fig. 13) with a 5.5-km-long axis that trends E–W, a 3-km-short axis that trends N–S, and a top at  $\sim 88$  m water depth. The main surface of the bank is composed of a series of concentric ridges only 0.5-m high as well as several fairly large areas that stand  $\sim 6$  m higher than the main surface (Fig. 14B). The bank proper stands  $\sim 15$  m above the adjacent seafloor and is sep-

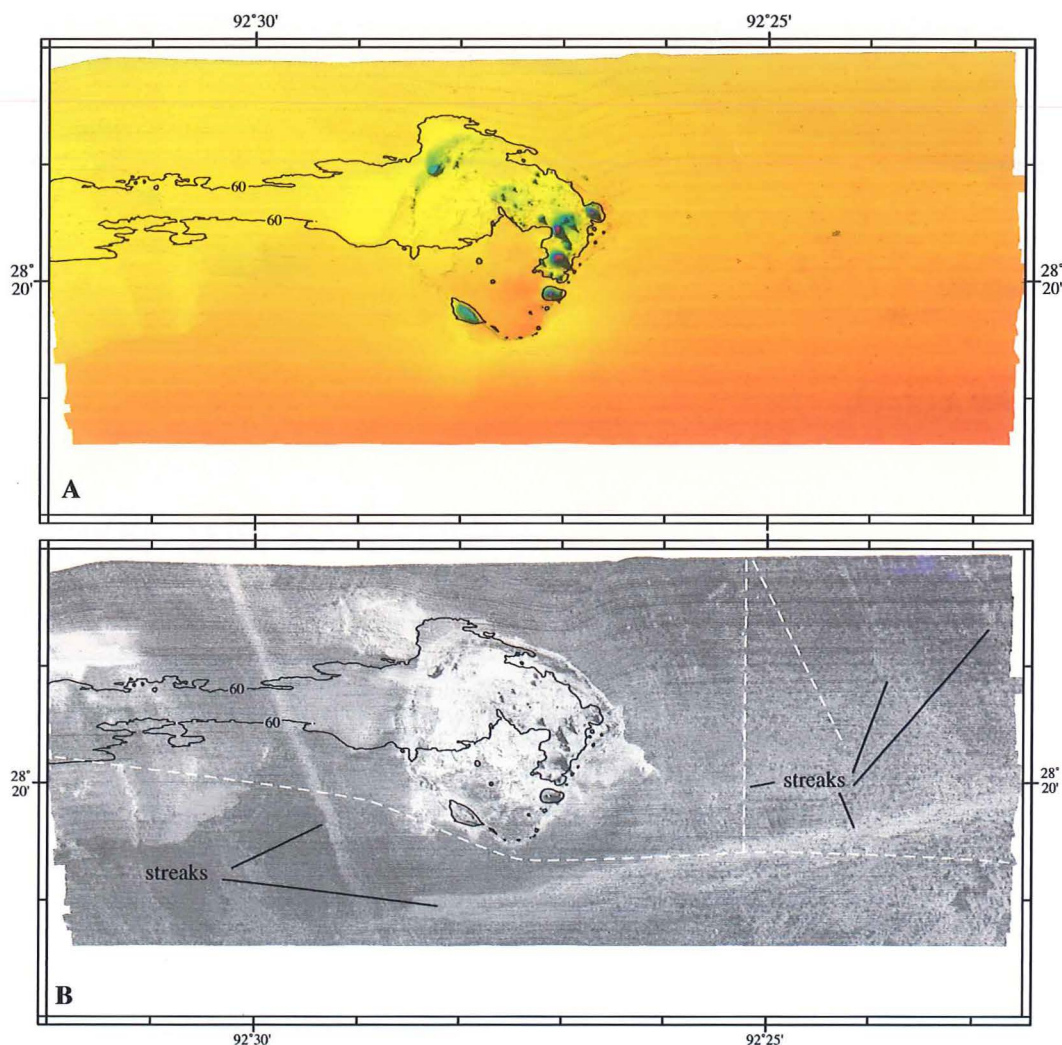


Fig. 11. (A) Color-shaded relief and (B) acoustic backscatter map views of Sonnier Banks. The 60-m isobath is shown to give indication of surface structure of the larger feature. White dashed lines on acoustic backscatter map shows MMS locations of pipelines. Note the additional high backscatter streaks that do not correspond to MMS-located pipelines. See text for discussion; see Figure 1 for location.

arated from it on the W and NW by a shallow (<0.5 m deep) moat-like depression. The eastern side of Alderdice Bank is marked by a 6- to 8-m-high ridge with 10–15° slopes facing W and a gently sloping (~1°) east-facing surface that gradually merges into the surrounding seafloor (Fig. 14B). Three prominent pinnacles rise 14–18 m above the main surface in the south-central part of the bank (Figs. 13, 14), the shallowest of which stands at 60.5 m water depth ("c" in Fig. 14A).

A series of relatively small and shallow basins are located on the periphery of Alderdice Bank (Fig. 13). The basins are 1–3-m deep and have dimensions of a few hundred meters. The

NW, SW, and SE basins have 0.5 m sills, but the outer edge of the south-central basin has no sill and empties directly down slope.

The main oval outline of Alderdice Bank is located just off the western side of an extensive, relatively featureless, broad, gently sloping area with water depths of 93–94 m. The southwestern margin of the broad area has a 600-m-wide terrace ~4 m deeper than the broad surface and the base of both the terrace and the broad surface have distinct 1-m-deep moats.

Rezak and Tieh (1984) and Rezak et al. (1985) present seismic-reflection profiles across Alderdice Bank that convincingly show the feature is related to a salt dome that has



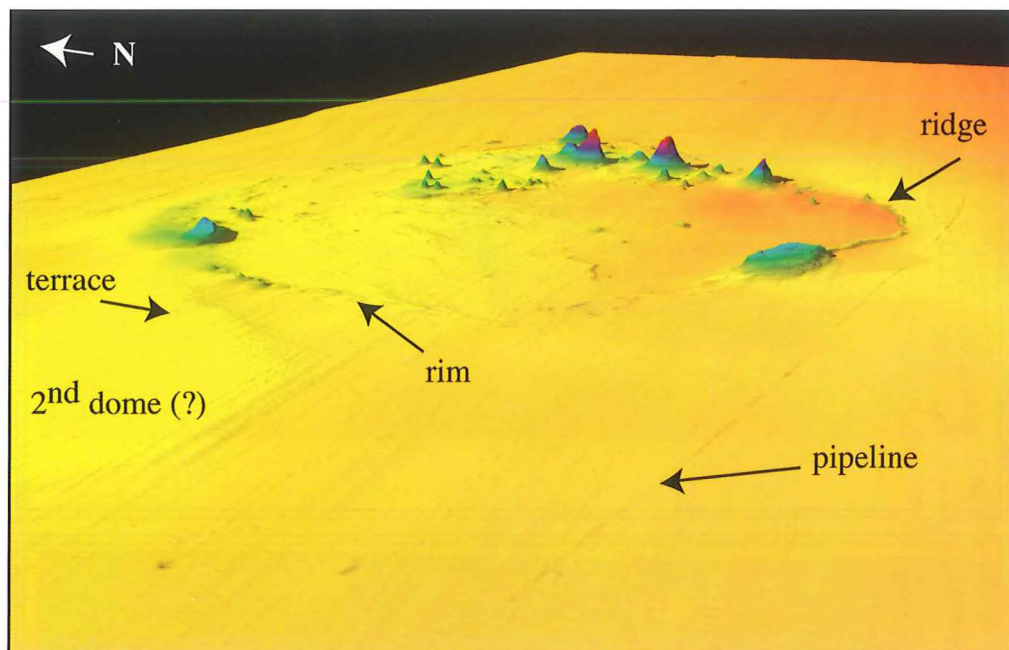


Fig. 12. Perspective view of Sonnier Banks. Note the individual pinnacles that rise along a rim. Also note the suggestion of a second salt dome only just affecting the surface bathymetry. Linear feature leading away from bottom of image is a pipeline. Vertical exaggeration  $\times 5$ , looking E.

breached the seafloor. They interpret the seismic data to show that the salt dome has been emerging for a long period of time and has undergone several periods of erosion and deposition. Although Rezak et al. (1985) mapped and discussed surficial faults related to the salt dome, no obvious faults are seen in the multibeam bathymetry.

One of the interesting aspects of Alderdice Bank is the recovery of alkalic basalt sampled on pinnacle "b" (Fig. 14A) (Rezak and Tieh, 1984; Rezak et al., 1985). The basalt, dated by Rezak and Tieh (1980, 1984) at 76.8 my, was interpreted by them as a "... dike or sill rafted to the surface by the salt diapir" (Rezak et al., 1985, p. 184). Video recordings from ROV and submersible dives on this pinnacle (E. Hickerson, pers. comm.) support the interpretation of Rezak et al. (1985) and show that blocks of basalt cover an extensive area around the base of the pinnacle.

Acoustic backscatter from Alderdice Bank varies between  $-20$  and  $-30$  dB (Fig. 13B). The three large pinnacles have high backscatter values of approximately  $-20$  dB, whereas the surface of the main bank has values that range between  $-26$  and  $-30$  dB. The latter range of backscatter values suggests the surface is covered with coarse silt to very fine sand, facies that are similar to those suggested by Re-

zak et al. (1985) based on submersible observations. The area of the seafloor immediately adjacent to the bank has a halo of relatively high backscatter, suggesting that coarse sediment has been swept off the bank on all sides and been deposited at the base of the bank margins.

#### JAKKULA BANK

Jakkula Bank (JK in Fig. 1) is located on the uppermost continental slope 35 km ESE of Alderdice Bank in regional water depths of 130–180 m (Fig. 15). The overall bank structure is composed of a basal platform with a roughly circular outline  $\sim 1.7$  km in diameter that rises  $\sim 20$  m above the adjacent seafloor (Figs. 15, 16). Water depths of this feature range from 95 to 112 m. The basal platform is topped with a smaller summit platform with a diameter of 1.3 km that rises 46 m above the smooth margins of the basal platform, with a shoal area at 62 m water depth. The flanks of the summit platform and the overall bank structure have slopes of  $10$ – $20^\circ$ . The top of the bank is a broad relatively smooth area at 66 m water depth with a concentric ridge that stands  $\sim 3$  m above the platform surface and  $\sim 150$  m inside the platform edge (Fig. 16A). The bank structure appears bisected by a N–S fracture

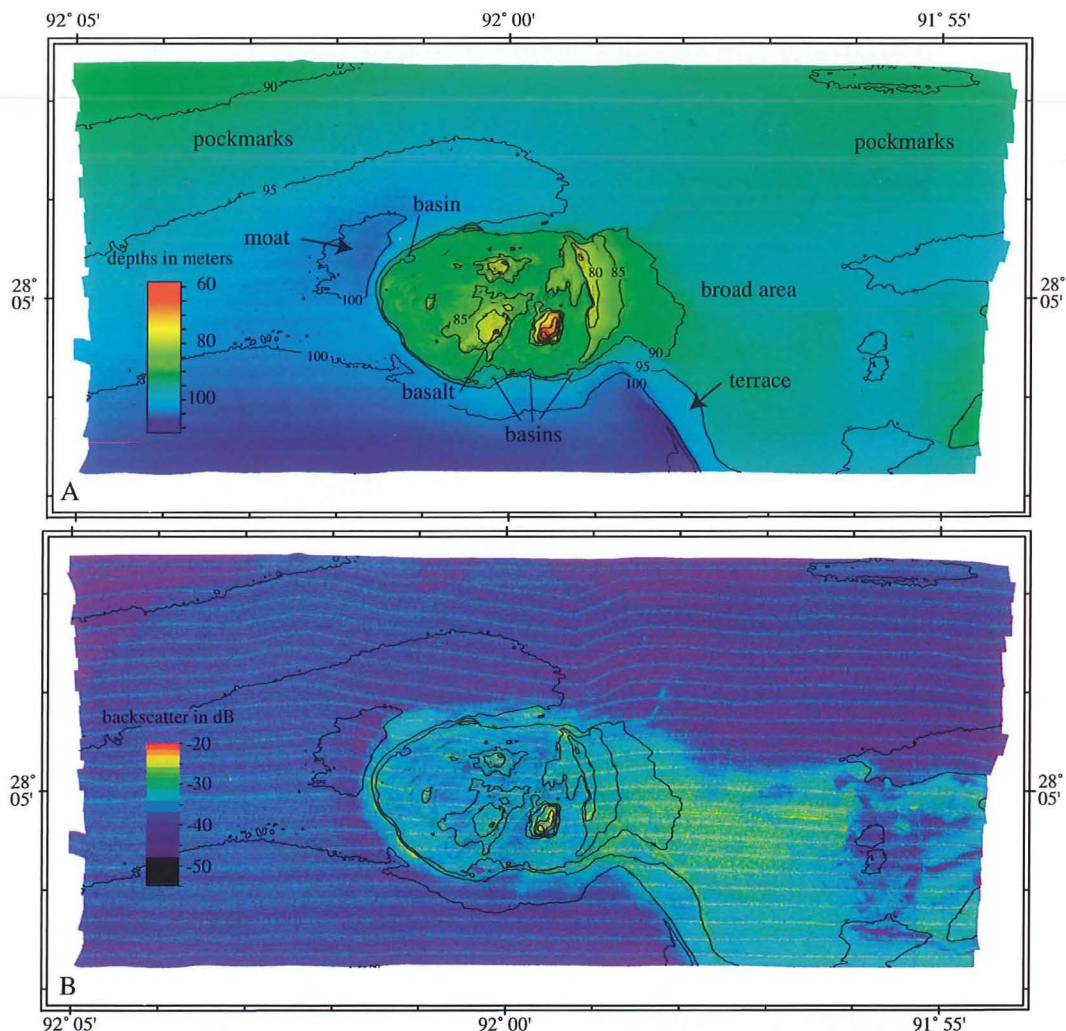


Fig. 13. (A) Color-shaded relief and (B) acoustic backscatter map views of Alderdice Bank. Prominent pinnacle labeled "basalt" is where Rezak and Tieh (1980) report Cretaceous basalt. Other labeled features discussed in text. See Figure 1 for location.

with as much of 50 m of relief (down to the E), although no vertical offset is seen on the summit area (Fig. 15A). The N-S fracture continues beyond the bank for more than 3 km in both directions.

The bank itself has no associated pinnacles, but numerous pinnacles occur just beyond the bank flanks. The pinnacles typically are about 1 m high, although the largest stands 14 m above the seafloor. Most of the larger pinnacles on the west side of the bank have associated moats, but no pinnacle moats are found on the east side of the bank.

A large, flat-topped mesa, informally called "west wing," extends northward from the north margin of Jakkula Bank for ~800 m and then abruptly changes trend to the west for

more than 6.4 km (the edge of the mapped area) (Figs. 15A, 16). Water depths along the smooth portion of the mesa range from 113 to 120 m. The top of west wing is covered with small (<4 m high) pinnacles and is rimmed by a ridge that stands ~5 m high. The western half of the northern margin of the mesa is smoother than the eastern half and is clearly separated from the seafloor to the north by a shallow (<4 m) moat. The seafloor N of the northern moat varies in depth, being ~2 m higher than the surface of west wing in the western area but ~4 m deeper in the area directly N of Jakkula Bank. The entire south flank of the mesa is a 20° slope that abruptly descends into a 15-m-deep, 110-m-wide moat that joins with a moat along the western base



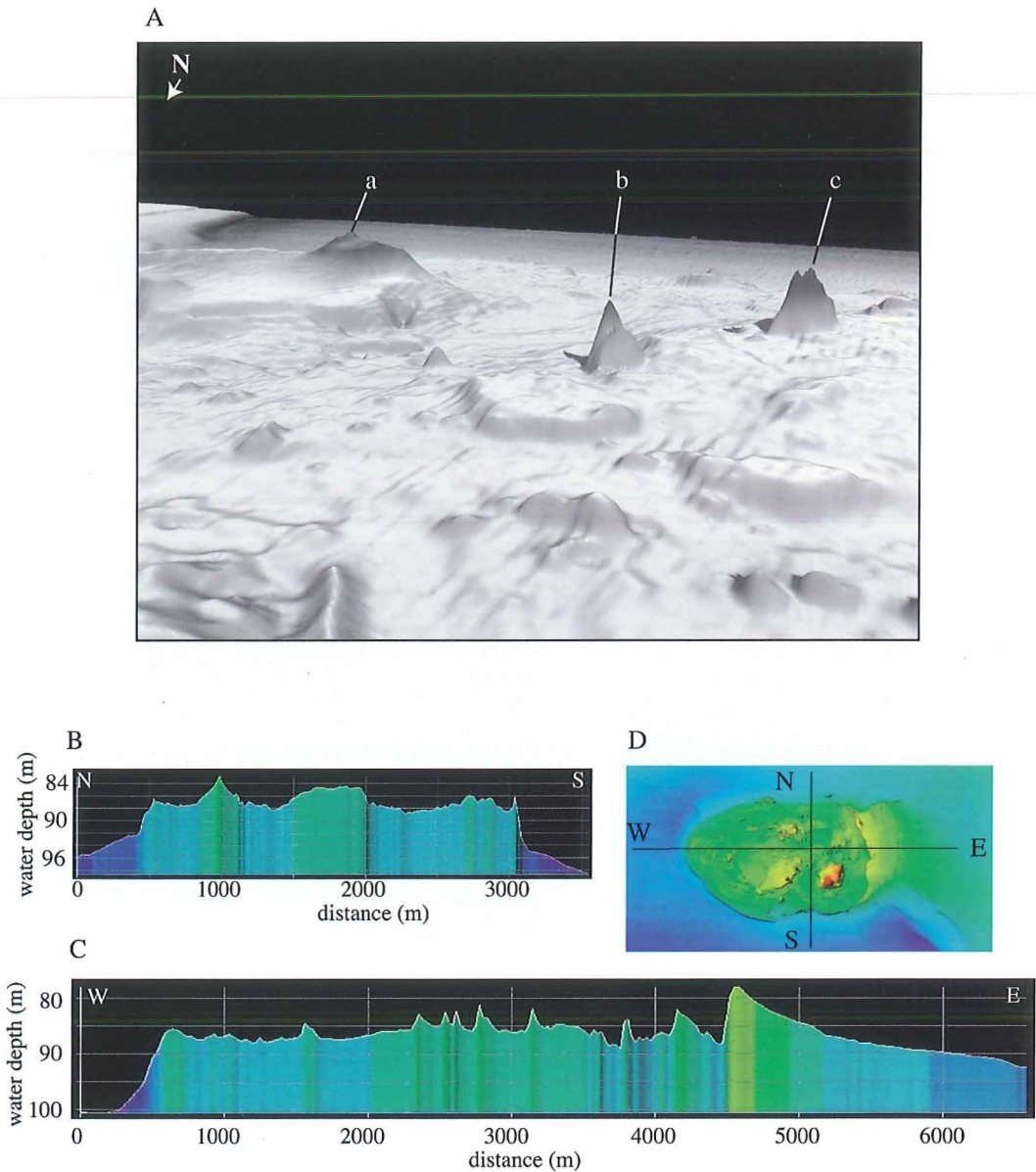


Fig. 14. (A) Perspective view of bathymetry of summit of Alderdice Bank, the three most prominent pinnacles are labeled a, b, and c. See text for discussion. Vertical exaggeration  $\times 10$ , looking SE. (B) North-south and (C) east-west cross sections of the summit of Alderdice Bank (see Figure 14D for location of cross sections).

of Jakkula Bank (Figs. 15A, 16). A small portion of what looks like a mesa similar to west wing branches to the east from the northern part of Jakkula Bank. However, not enough of this "east wing" was mapped to provide an adequate description, although a 10-m-deep moat was mapped along the southern flank of the east wing (Fig. 15A).

The acoustic backscatter of Jakkula Bank

and the rims of east and west wings (Fig. 15B) have high backscatter ( $-22$  to  $-20$  dB) giving an acoustic response similar to that of medium to fine sand. The surrounding seafloor and the surface of west wing has backscatter values that range from  $-27$  to  $-30$  dB that are typical responses of coarse to fine silt at 95 kHz frequency. The only exceptions are two regions in the SW portion of the mapped area (Fig. 17).



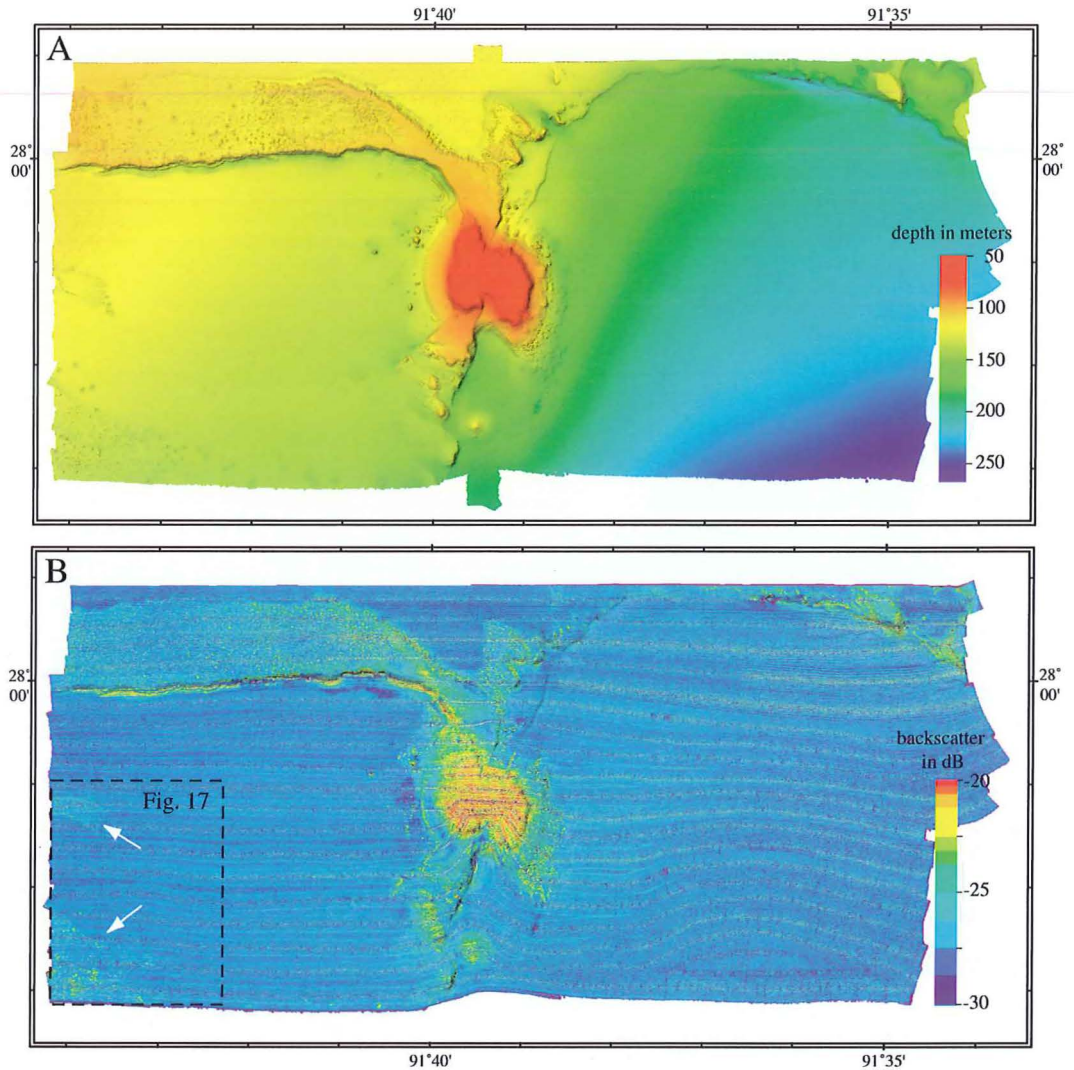


Fig. 15. (A) Color-shaded relief and (B) acoustic backscatter map views of Jakkula Bank. Note the “wings” to NW and NE that are raised regions with surrounding moats. White arrows point to low seafloor areas shown in Figure 17. See text for discussion; Figure 1 for location.

Both areas have a rough surface of pinnacles and pockmarks with as much as 10 m of relief and relatively high backscatter (–22 to –24 dB). In addition, both areas are ~2 m deeper than the immediate surrounding smooth seafloor. The bathymetry suggests a blanket of sediment has encroached toward the areas from the NE, partially burying the fields of pockmarks and pinnacles. However, there are large pockmarks, some as much as 6 m deep and 150 m in diameter, that have erupted through the smooth material (Fig. 17), suggesting expulsion processes continued after the area was buried.

#### CONCLUSIONS

Our major objective was to provide digital, high-quality bathymetric and acoustic backscatter maps of a series of outer shelf and upper slope banks that are of special interest to benthic biologists working in the NW Gulf of Mexico. The maps are intended to be base maps on which further studies, biological, geological, physical oceanographic, etc., can be conducted. This article is intended to provide quantitative descriptions and views of the banks, as well as the path to access the full digital datasets. However, as is clear from the

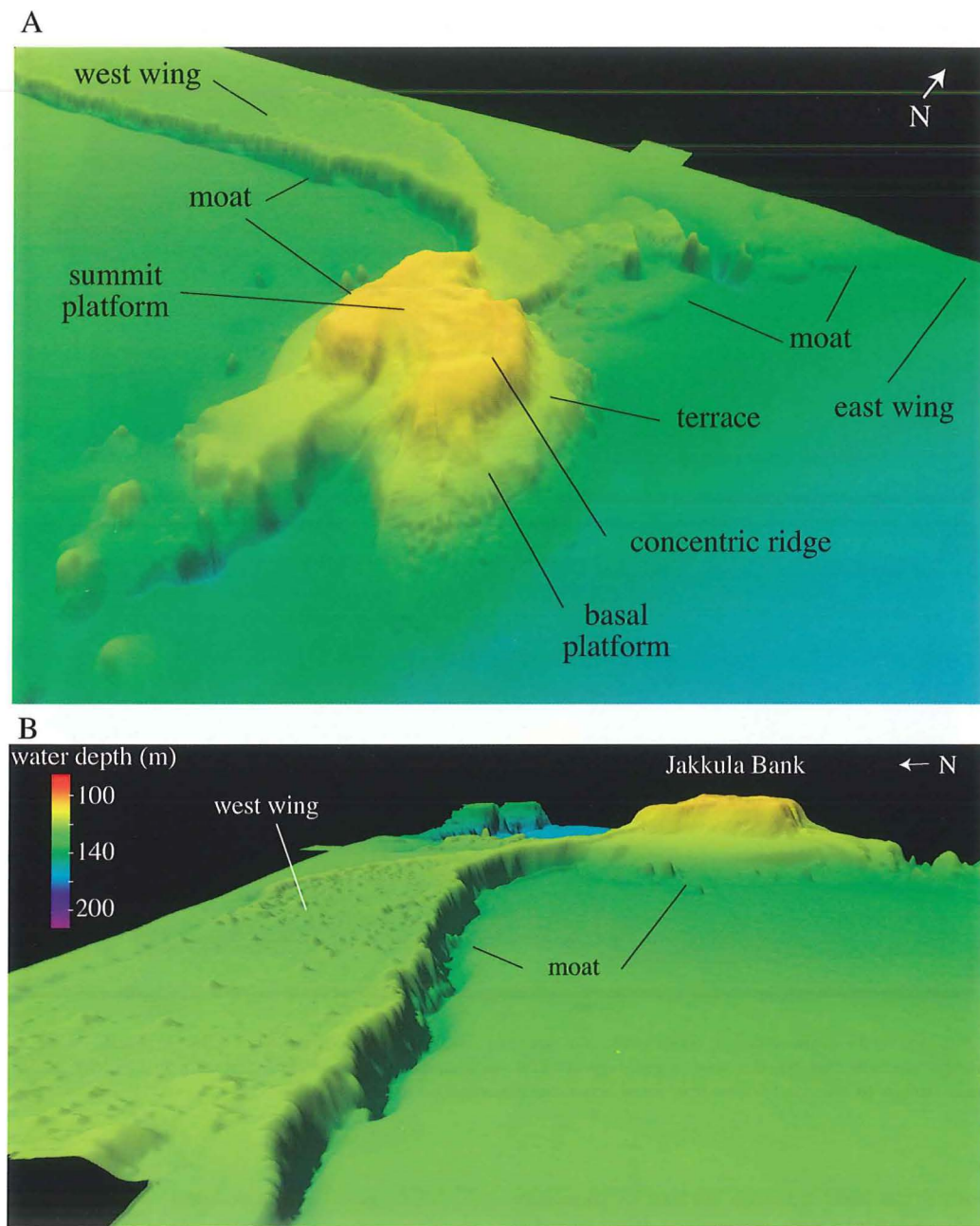


Fig. 16. (A) Perspective view of bathymetry of Jakkula Bank. Note pronounced terrace and moats along base of "wings." Vertical exaggeration  $\times 10$ , looking NW. (B) Perspective view of bathymetry of west wing of Jakkula Bank. Vertical exaggeration  $\times 10$ , looking E.

above discussion, it is difficult to withhold some general observations that these new data elicit.

There seems to be systematic differences of relief and the presence of reefs and pinnacles from west to east in the mapped region (Fig. 18; Table 1). The tops of Stetson, East and

West Flower Garden Banks, the westernmost areas mapped, are all less than 18 m water depth, whereas the tops of 29 Fathom, Rankin, and Geyer Banks range from 40- to 54-m deep and the summit of 28 Fathom Bank is at 64 m water depth. The summit of McGrail Bank is at 46 m water depth, whereas to the east the



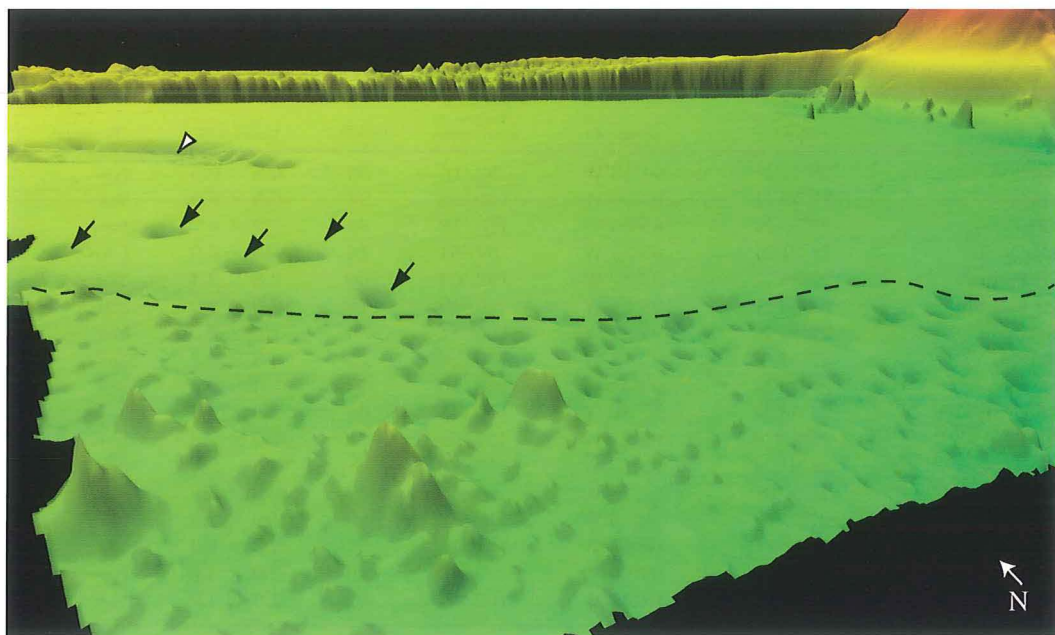


Fig. 17. Perspective view of SW corner of Jakkula Bank (see Fig. 15 for location). Black dashed line shows edge of sediment blanket discussed in text. Black arrows point to isolated pockmarks that have penetrated through the sediment blanket. White arrowhead in background shows another area with similar seafloor texture to the foreground.

summits of Bouma, Rezak, Sidner, Alderdice, and Jakkula Banks are all deeper than 50 m water depth. Sonnier Banks is an anomaly to this trend with a summit water depth of only 18 m, but it, like Stetson Bank, sits in shallower waters several tens of kilometers north of the shelf break.

The bank platforms also have distinct differ-

ences from west to east. All the bank platforms have smoothly rounded edges, but the platforms in the western and central sectors of the mapped area are high-standing features compared with those in the eastern sector. For example, West and East Flower Garden and Geyer Banks rise 40–60 m above the adjacent seafloor, whereas the platforms of Sonnier and Al-

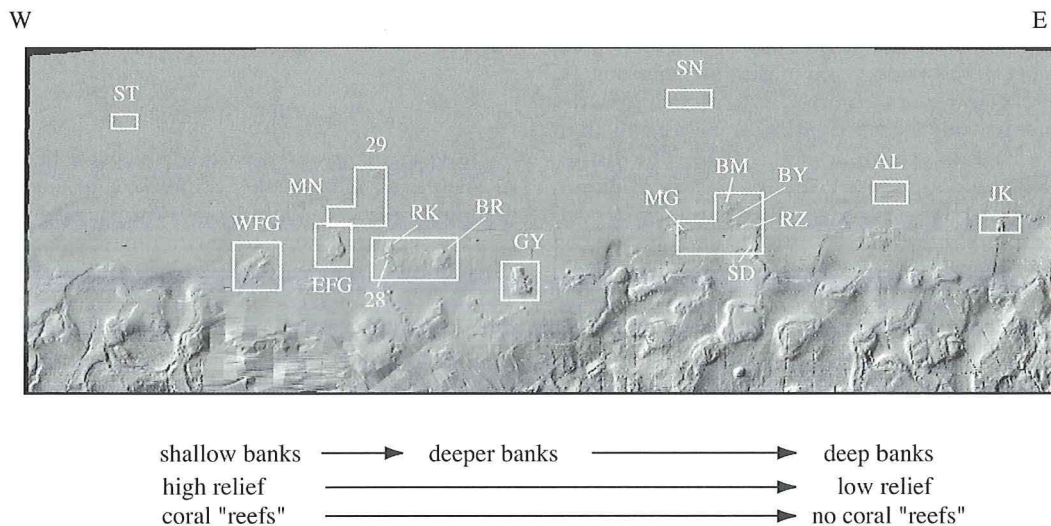


Fig. 18. Index map of mapped banks with W to E physiographic trends discussed in text.



TABLE 1. Comparisons of bank physiographies. Water depths and relief in meters, dimensions are in kilometers.

| Bank                   | Latitude <sup>a</sup> | Longitude | Regional/<br>shallowest<br>water depth | Relief <sup>b</sup> | Dimensions | Pinnacles |
|------------------------|-----------------------|-----------|----------------------------------------|---------------------|------------|-----------|
| Stetson                | 28°10'N               | 94°18'W   | 52/16                                  | 36                  | 0.8 × 0.3  | No        |
| WFG                    | 27°53'N               | 93°50'W   | 120/16                                 | 94                  | 6.5 × 8.9  | Yes       |
| EFG                    | 27°55'N               | 93°36'W   | 110/18                                 | 30                  | 5.2 × 8.7  | Few       |
| MacNeil                | 28°01'N               | 93°30'W   | 84/64                                  | 16                  | 0.45 × 6.0 | Close by  |
| 28 Fathom <sup>c</sup> | 27°53'N               | 93°27'W   | 142/64                                 | 100                 | 0.8 × 2.4  | Yes       |
| 29 Fathom <sup>c</sup> | 28°08'N               | 93°29'W   | 70/49                                  | 10                  | 2.0 × 2.0  | Rare      |
| Rankin                 | 27°55'N               | 93°27'W   | 105/51                                 | 50                  | 1.6 × 2.6  | Yes       |
| Bright                 | 27°53'N               | 93°18'W   | 130/33                                 | 75                  | 4.8 × 6.2  | Yes       |
| Geyer                  | 27°49'N               | 93°04'W   | 190/40                                 | 30                  | 5.4 × 9.3  | Yes       |
| McGrail                | 27°58'N               | 92°36'W   | 110/45                                 | 65                  | 3.0 × 4.4  | Yes       |
| Bouma                  | 28°03'N               | 92°27'W   | 101/59                                 | 18                  | 2.2 × 2.8  | No        |
| Bryant                 | 28°01'N               | 92°28'W   | 115/88                                 | 1                   | 3.0 × 3.0  | No        |
| Rezak                  | 27°57'N               | 92°22'W   | 90/61                                  | 7                   | 0.8 × 2.5  | No        |
| Sidner                 | 27°55'N               | 92°23'W   | 110/58                                 | 20                  | 1.6 × 2.9  | No        |
| Sonnier                | 28°20'N               | 92°27'W   | 61/18                                  | 37                  | 2.3 × 2.3  | Yes       |
| Alderdice              | 28°05'N               | 92°00'W   | 77/68                                  | 18                  | 3.0 × 4.6  | No        |
| Jakkula                | 27°59'N               | 91°39'W   | 160/64                                 | 92                  | 1.7 × 1.7  | Yes       |

<sup>a</sup> From Gulf of Mexico Gazetteer (Taylor et al., 2000).<sup>b</sup> Measured from adjacent seafloor to bank summit.<sup>c</sup> Not in Gulf of Mexico Gazetteer; determined from MBES data.

derdice Banks rise only 1–10 m. This difference might simply reflect the proximity of the main mass of the intruding salt to the seafloor causing the larger banks (i.e., West and East Flower Garden, Bright, Geyer, and Bouma Banks) to have higher platform relief than the smaller ones (Sonier, Alderdice, and Jakkula Banks). However, an alternate explanation might be burial of the features by sediments from the nearby Mississippi delta.

Coral reefs are present only on the banks of the western portion of the mapped area. Stetson, West Flower Garden, East Flower Garden, and McGrail Banks all have confirmed coral reefs developed on their shallow summits (E. Hickerson, pers. comm.). The reefs have a distinctive small-scale roughness evident in their bathymetry (Gardner et al., 1998). The distinctive reef roughness is absent on the shallower banks to the east, suggesting the lack of reefs on the eastern banks.

Curiously, the occurrence of pinnacles does not have a spatial pattern. Numerous pinnacles are found at West and East Flower Gardens, Bright, Rankin, MacNeil, 28 Fathom, Jakkula, and Sonier Banks, but pinnacles are rare at McGrail, Bouma, Bryant, Rezak, Sidner, Geyer, and Alderdice Banks. However, pinnacles are very abundant 400 km to the east along the outer shelf south of Alabama and Mississippi (Ludwick and Walton, 1957; Laswell et al., 1991; Gardner et al., 2001). Is the occurrence

of pinnacles also related to the proximity of the underlying salt to the seafloor? Detailed seismic-reflection profiling across fields of pinnacles might help answer this question.

The next stage in the study of the outer shelf banks should be geological ground truthing so that the surficial sediment facies can be determined from samples, not from an interpretation from the acoustic backscatter. The ground truth will also help to develop a database of northern Gulf of Mexico surficial facies versus acoustic backscatter so that interpretations from only MBES backscatter will become increasingly more reliable.

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