

BENTHIC STORMS, INTERNAL TIDES, AND COUNTERCURRENTS IN THE STRAITS OF FLORIDA

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KEY FINDINGS

- In the Straits of Florida, opposing undercurrents, internal tides, and benthic storms form a complicated bottom-current pattern underneath the Florida Current.
- These undercurrents produce coarse-grained contourite deposits that record the current direction, such as cross-bedding from the bidirectional internal tide and migrating sand waves from the unidirectional countercurrent.
- Cyclones from benthic storms move from south to north on the eastern side of the Florida Current; their path coincides with mud-free seafloor, indicating that the cyclones loft the fines from the seafloor into the overlying Florida Current, which transports them out of the system.

RATIONALE

The Straits of Florida is the gateway for the Florida Current, which moves an enormous water mass of 20 Sv (20 million cubic meters of water per second) northward. The Florida Current does not, however, fill the entire Straits and deep, opposing undercurrents and coastal countercurrents occur off Florida and the Bahamas. Observational and model data document that, in addition to the well-known perturbation of upper ocean currents by atmospheric cold front passages, the near-bottom current field in the Straits of Florida is also repeatedly perturbed by atmospheric cold fronts. Here we explore the effects of the near-bottom current pattern on the facies and sediment distribution within the Straits of Florida. We want to show how these near-bottom currents produce coarse-grained contourite deposits with sedimentary structures that reflect the bottom current but not the overlying Florida Current.

METHODS AND RESULTS

Current Measurements: Measurements of the near-bottom flow field by an Autonomous Underwater Vehicle (AUV), cruising 40 m above the seafloor at sites ranging from 14–48 km² in 590–875 m water depth in December 2005, record a complicated current pattern in space and time. Near-bottom currents are bidirectional, dominated by semi-diurnal tides, on the lower slopes of the Great Bahama Bank. Near-bottom currents flow north in the middle of the Straits but generally south along the Miami Terrace.

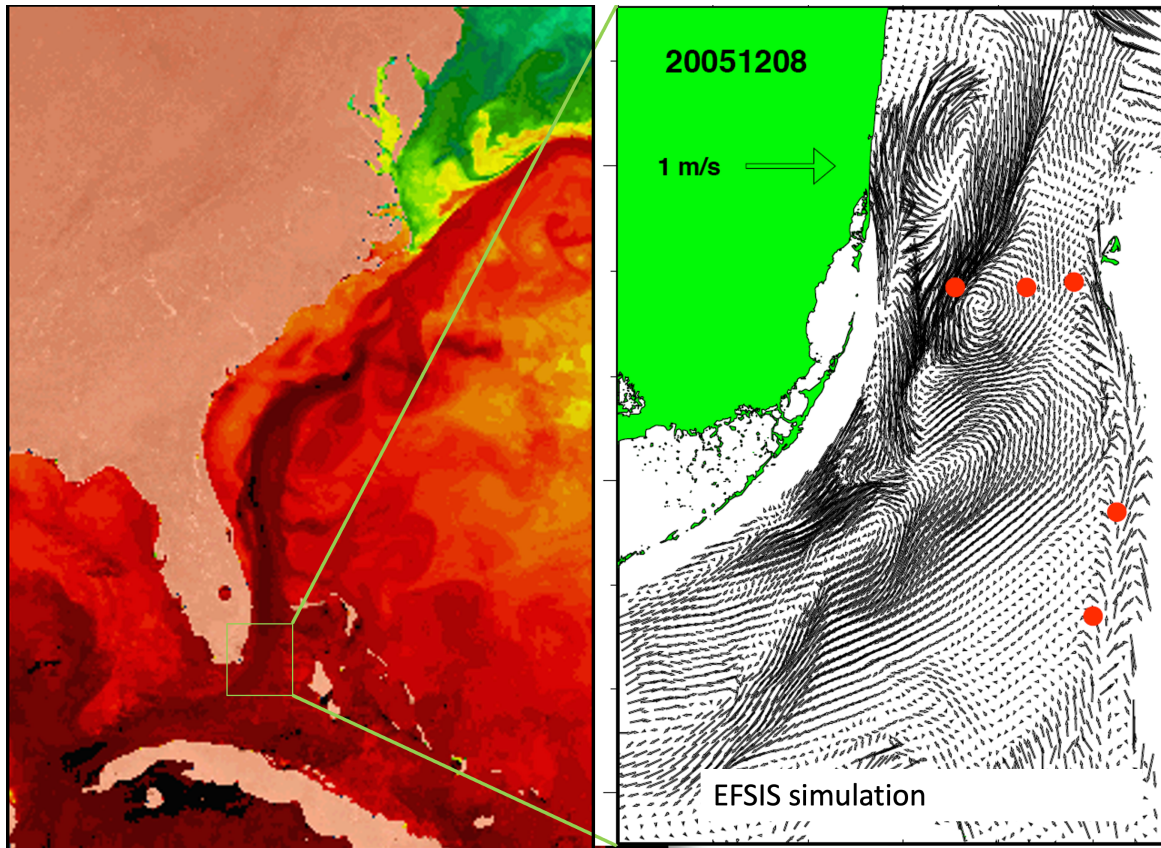


Figure 1: Left: False-color image of the Florida Current that flows between Florida and the Bahamas to the north as a warm surface current. Darker colors indicate higher temperatures. Right: Bottom current pattern underneath the Florida Current with opposing countercurrents and eddies produced by benthic storms. Red dots are locations of high-resolution bathymetry and current data collection.

Modeling Results: The 12 to 48 h AUV observational data at each site (red dots in Fig. 1) compare well with results of the quasi-operational 3D ocean circulation model EFSIS (East Florida Shelf Information System). The model enables the analysis of the bottom currents over extended periods and confirms that the near-bottom flow field in the Straits of Florida is highly variable on time scales ranging from 6 hours to several days, with magnitudes of ± 0.2 to 0.6 m/s, depending upon location.

During the observation period of December 2005, a recurring current variability is due to a sequence of deep cyclonic eddies that originate approximately every ten days near Cay Sal Bank and move northward on the eastern side of the Florida Current (Fig. 2). Offshore Bimini, where the Straits of Florida narrows and shoals, and the Florida Current accelerates, the near-bottom eddies intensify and start to move westward. When reaching the Miami Terrace the eddies occupy the entire water column. The timing of the eddies correlates remarkably well with the passage of atmospheric cold fronts. During cold-front passages, the Florida Current axis is displaced offshore the Florida Keys. A probable mechanism for the generation of the near-bottom cyclones is the interaction of Florida Current meanders with Cay Sal Bank.

The sedimentary record of the currents: The south-flowing countercurrent along the Miami Terrace is recorded in two ways. First, on the slope of the Miami Terrace a series of cold-water coral ridges are arranged perpendicular to the current (Correa et al., 2012). At the base of the terrace, a sand wave field consisting of coarse skeletal debris (pteropods, foraminifera) has southward migrating sand waves ornamented with ripples.

In the middle of the Straits where currents flow northward, muddy hills with cold-water corals up to 30 m high are arranged in a chevron-type pattern (Grasmueck et al., 2006).

The bidirectional current pattern of the internal tide along the lower slope of Great Bahama Bank produces large-scale cross-bedding in pteropod-rudstone-dominated cores, linking for the first time an internal tide to the sedimentary structures (Sianipar, 2013). It also leaves an imprint on the seafloor morphology by carving scours on both the north and south sides of blocks and mounds.

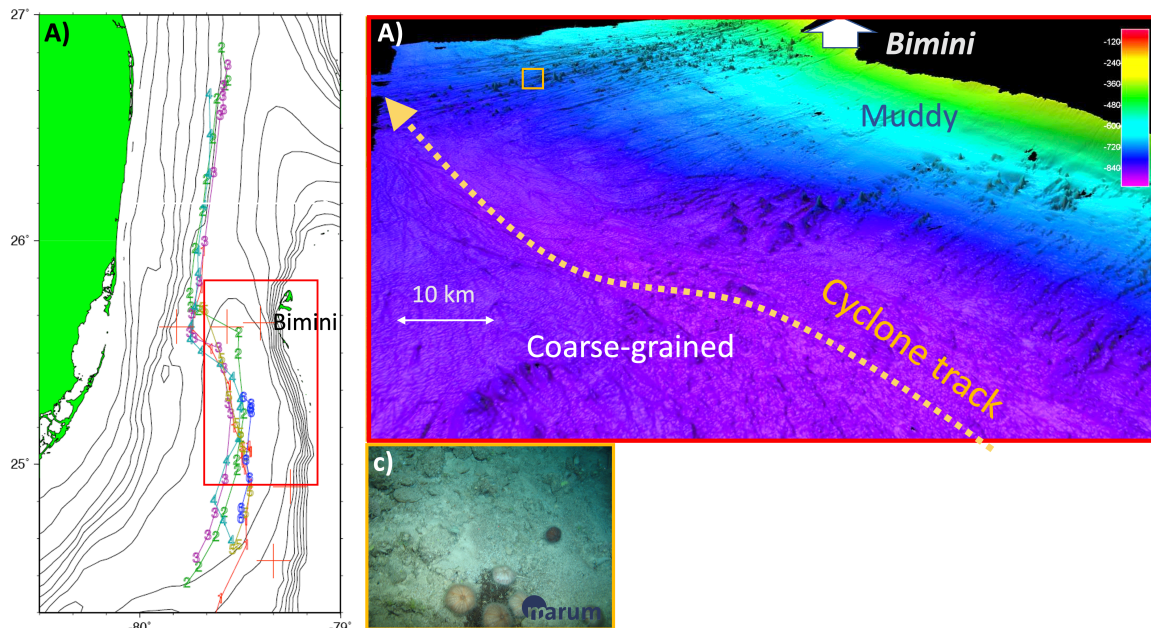


Figure 2: A) Bathymetry map of the part of the Straits of Florida with the tracks of north-moving benthic cyclones. B) Multibeam bathymetry of slope and bottom of the Straits of Florida depicting the rugged topography of the mud-free seafloor and the smooth upper slope with mud coverage. C) Photo from the mud-free seafloor (yellow box in B) displaying the coarse debris and a cluster of living sea urchins. Coarse-grained seafloor roughly coincides with the cyclone tracks, indicating that they loft fine-grained sediment that is then transported away by the Florida Current.

The eddies of the benthic storms do not leave a discernable sedimentary record. However, the path of eddies coincides with areas where there is no or only limited amounts of mud on the seafloor. The benthic storms are thought to stir up the fines on the seafloor and loft them into the water column, delivering it into the overlying Florida Current which transports the mud out of the system.

SIGNIFICANCE

The recognition that opposing countercurrents and internal tides exist below large ocean currents such as the Florida Current to produce coarse-grained contouritic deposits has implications for current reconstruction and facies distribution in contourite drift systems. In the Florida Straits contourite drift system, large, up to 800-m-thick, fine-grained drifts are deposited by the main currents. For example, the 24,000 km² Pourtales Drift is deposited by the Florida Current. It is so big that an ancient analogue in outcrop would probably not be recognized as a drift. In contrast, the much smaller and thinner coarse-grained contouritic deposits can be identified as current deposits. Yet their current direction might not reflect the flow of the main current, in this case the Florida Current.

Deep-water eddies have been postulated to occur in contourite drift systems, but it is generally assumed that they are connected to the surface eddies that extend into the deep. Our modeling results indicate that they can be generated near the seafloor and strengthen within the water column to potentially break to the surface. This upward increasing energy within the cyclonic eddies offers an explanation for the creation of mud-free areas on the seafloor. Like cyclones in the shallow water they will stir up fine sediment. The upward strengthening of the eddy can loft the fine sediment and deliver it to the main current. Thus, this mechanism will locally produce high-porosity, coarse-grained deposits with potentially good reservoir quality.

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