Submarine karst belt rimming the continental slope in the Straits of Florida

Received: 26 April 1999 / Revision accepted: 11 April 2000

Abstract  Nine submarine sinkholes have been surveyed and mapped with side-looking sonar and echo-sounder profiles in the Straits of Florida. These structures are irregularly distributed across the surface of the South Florida Margin, forming a discontinuous belt along the edge of the slope. The sinkholes occur in water depths too great to have ever been exposed above sea level, and some are several times larger than any known subaerial sinkholes in North America. Because most karst morphologies are the product of groundwater circulation, the distribution of submarine sinkholes in the Florida Straits may be directly related to the paleohydrology of the South Florida Platform.

Introduction

Sinkholes, or dolines, are circular depressions which typically range from 10 to 1000 m in diameter and which are about 2 to 100 m deep (Sweeting 1973). They commonly result from dissolution by meteoric groundwater in subaerially exposed carbonate strata (Esteban and Wilson 1993). For this reason sinkholes are often used as indices of subaerial exposure (e.g., Schlanger and Silva 1986; Lincoln and Schlanger 1987; Van Waasbergen and Winterer 1993). Thus, when Jordan (1954) first reported submarine sinkholes on the Pourtales Terrace south of the Florida Keys (Fig. 1), he assumed that they formed during a Tertiary sea-level lowstand. Burnett and Gomberg (1977) concluded from petrologic and geochemical evidence that Tertiary limestones of the Pourtales Terrace had been subjected to freshwater diagenesis, and that submarine karst features observed there must have been caused by Miocene subaerial exposure.

Although Malloy and Hurley (1970) proposed a marine origin for the South Florida submarine sinkholes, based on their interpretation of regional subsidence history, until recently most workers have accepted this subaerial interpretation. However, the origin of these features has been controversial since they were first discovered, because they are at the maximum possible depth for exposure to have occurred given any combination of tectonic subsidence and eustatic sea-level fall (Fig. 2; Malloy and Hurley 1970; Mullins and Neumann 1979).

Because the calcium carbonate saturation curve is non-linear, dissolution of carbonate rocks can occur when two fluids of different salinities combine even if both parent fluids are supersaturated with calcium carbonate (Runnells 1969; Plummer 1975; Hanshaw and Back 1979; Sanford and Konikow 1989a, b). Thus, submarine sinkholes may be the products of freshwater/saltwater mixing. Limestone corrosion resulting from the mixing of fresh and saline waters is well documented at groundwater discharge sites in shallow-water areas (e.g., Back et al. 1984; Smart et al. 1988). The lack of unequivocal evidence for active carbonate dissolution in deeper submarine environments is the principal reason for the controversy over the origins of karst-like features in the Florida Straits.

South Florida Slope

The continental slope off southeast Florida is interrupted by an intermediate-depth terrace, the surface of which coincides with a regional unconformity developed on Eocene–middle-Miocene strata. This erosional surface is exposed in the northern Straits of Florida as the Miami Terrace, and to the southwest as the Pourtales Terrace (Fig. 1). A post-Miocene sediment drape
Fig. 1 Bathymetry of the Straits of Florida and adjacent areas (contours in m at variable intervals). Horizontal and vertical lines Miami and Pourtales terraces, respectively. B-G Locations of sinkhole surveys in Fig. 4. B Key Biscayne Sinkhole, C Miami Sinkhole, D Jordan Sinkhole, E Jordan East Sinkhole, F Marathon Sinkholes, G NR-1 Sinkhole. Locations of other sinkholes are extracted from Jordan (1954), Jordan et al. (1964), and Malloy and Hurley (1970). Closed contours at the eastern end of the Pourtales Terrace indicate karst-like knolls (Jordan et al. 1964). Dashed line across Miami Terrace indicates location of Fig. 3.

separates the two terraces off Key Largo. Eocene/Oligocene strata beneath these terraces are offshore extensions of the Floridan Aquifer (Fig. 2), an important artesian aquifer in the southeastern United States which also hosts the sinkholes of the north central Florida karst terrane (Stringfield 1966; Meyer 1989).

The Miami Terrace occurs at 200–400 m water depths at the foot of a slope of post-Miocene sediment offshore Miami. The surface of the terrace consists of Oligocene–Miocene phosphatic limestone (Uchupi and Emery 1967), and is marked by a very irregular karst-like topography (Fig. 3; Malloy and Hurley 1970; Neumann and Ball 1970; Mullins and Neumann 1979). The Pourtales Terrace, in the southern Straits of Florida, is the drowned southern end of the Florida carbonate platform, located at 200–450 m water depths (Fig. 1; Jordan et al. 1964; Burnett and Gomberg 1977). Eocene limestones of the Floridan Aquifer system are presumed to crop out at the margin of the Pourtales Terrace, based on correlation with exploratory boreholes drilled at Marquesas and Big Pine Keys (Maher 1971; Puri and Winston 1974). Several submarine sinkholes occur along the southwest margin of the terrace (Jordan 1954; Jordan et al. 1964; Malloy and Hurley 1970).

In the 1960s through 1980s, Kohout and others published a series of papers (Kohout 1965, 1967; Kohout et al. 1977, 1988) documenting evidence for a type of open-cycle thermal convection occurring within artesian aquifers of south Florida, now commonly referred to as Kohout convection (Simms 1984). According to Kohout’s model, cool seawater in the Florida Straits invades highly permeable limestones of the Tertiary Floridan Aquifer at its submarine outcrop and flows inland. Geothermal heating increases the buoyancy of the encroaching seawater, causing it to migrate upwards where it becomes entrained with regional flow of fresh groundwater toward the coast. The mixture of fresh and saline waters ultimately discharges from submarine springs on the shelf and along the shelf edge. Kohout hypothesized that submarine karst phenomena in the northern Straits of Florida are the result of

Fig. 2 Idealized cross section of the Miami and Pourtales terraces, extracted from Malloy and Hurley (1970), and Miller (1986). A-D, G Depth (or elevation) of sinkholes in Figs. 1 and 4 (sinkhole A is not shown in Fig. 1). Because of the 50x vertical exaggeration (v.e.), relative depths only can be compared. The gentle slope of the escarpment is characteristic of the extreme western end of the Pourtales Terrace where the NR-1 sinkhole (G) occurs near the base of the escarpment in a Quaternary sediment drape.