Back to the Future

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INTRODUCTION

This short review is intended to establish how important fieldwork in Holocene carbonates was to our current understanding of sedimentary geology and to reinforce the recognition that further modern sampling and observational techniques undoubtedly will reveal many important discoveries yet remaining for us to uncover. We argue that now is the time for us to return to fieldwork in Holocene carbonates of the Arabian Gulf (Figure 1 a and b) and to use new perspectives of sampling and observational procedures now available to us in the geological sciences. We also believe that as these new field observations are integrated into the framework of modern sequence stratigraphy, we will gain in our understanding of gross sedimentary geometries and their diagenesis, and thereby again aid in basic geologic research, hydrocarbon exploration and exploitation, and aquifer management.

More than 50 years have passed since major scientific expeditions studying the modern carbonates of the Arabian Gulf were initiated. These forays in the mid-1960s were into what was then the geologic communities *terra incognito*, following the pioneering work of Emery (1956), Hubolt (1957), and Sugden (1963). The expeditions that followed led to many significant discoveries by the Imperial College group, led by Graham Evans and Doug Shearman, and the Royal Dutch Shell group led by Bruce Purser. Simultaneously, sediment and fauna on the Iranian side of the Gulf were examined by the Kiel University group led by E. Seibold (Dietrich et al., 1966; Hartmann et al., 1971; Purser and Seibold, 1973). Collectively, these studies and their discoveries served as catalysts for major advances in our comprehension of how the accumulation of modern and ancient carbonate facies occurred and what drove their diagenesis. This understanding greatly aided and influenced the search for, discovery, and extension of hydrocarbon reservoirs. Many of these discoveries were made while the development of the stratigraphic frameworks provided by sequence stratigraphy was still on our not-so-distant horizon. Our studies of the 1960s have since helped add flesh to bones of the layered stratigraphic models then yet to come.

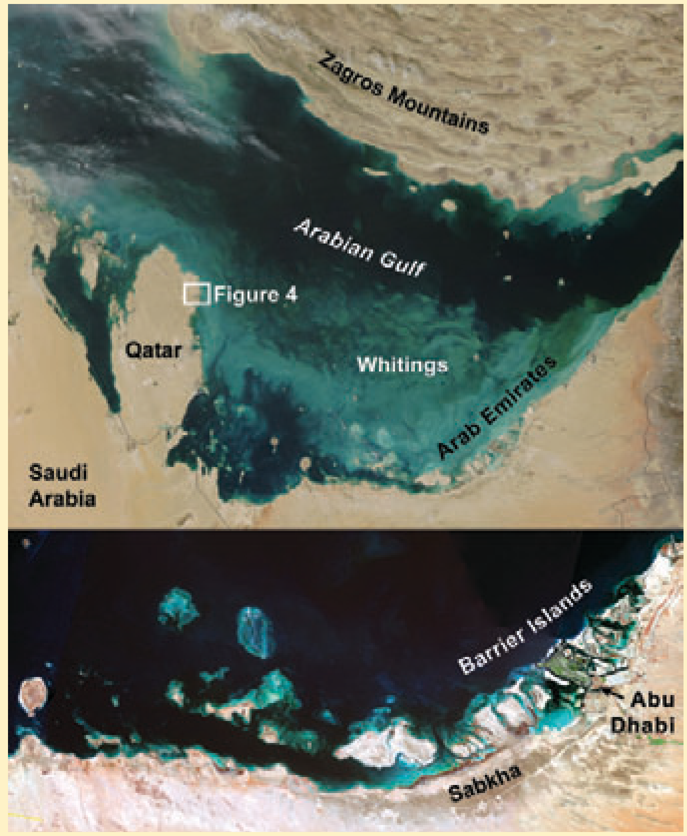

Figure 1. (a) Modern satellite image of the major 1960s study areas of the Arabian Gulf. Note that a nearly continuous whiting occupies the southern half of the gulf. (b) Detail of the Arab emirates (formerly the Trucial Coast)

PAST GLORIES

If we consider a short list of significant discoveries made as the result of fieldwork in the Arabian Gulf during the 1960s and 1970s, we see they helped trigger a golden age of research and scientific advance.

1. Modern anhydrite. This sulfate mineral (see figure 2) was previously thought to form only after dewatering during burial of gypsum (Curtis et al., 1963; Kinsman, 1964; Kinsman et al., 1964; Evans et al., 1964a; Evans et al., 1964b; Butler et al., 1965; Evans, 1966; Evans et al., 1969; Purser and Evans, 1973; Butler, 1969; Kendall and Skipwith, 1969).

2. Dolomite. Dolomite had been found forming in the Caribbean in rather small quantities (Shinn et al., 1965; Deffeyes et al., 1965; Shinn et al., 1969) and in the Australian Coorong Lagoon (von der Borch et al., 1964), but much more widespread examples were found associated with gypsum/anhydrite and cemented teepee structures (figure 2) on the Trucial Coast sabkha (now the United Arab Emirates) and Qatar (Curtis et al., 1963; Kinsman, 1964; Kinsman et al., 1964; Evans et al., 1964a; Evans et al., 1964b; Illing et al., 1965; Evans, 1966; Evans et al., 1969; Purser and Evans, 1973; Butler, 1969; Kendall and Skipwith, 1969).

3. Sabkhas. Large-scale accretionary (off-lap as shown in figure 3) arid tidal flats, known as sabkhas, and their sedimentary structures were described in detail, serving as modern analogues for hydrocarbon-producing areas throughout much of the geologic record (Curtis et al.,

Figure 2. Convoluted layer of anhydrite truncated by deflation of sabkha surface revealed in trench. White anhydrite below convoluted layer is known as chicken wire anhydrite. Both forms occur in the geological record. Location is near Abu Dhabi. Sediment below and mixed with the anhydrite is mainly fine-grained modern dolomite.

1963; Kinsman, 1964; Kinsman et al., 1964; Evans et al., 1964a; Evans et al., 1964b; Illing et al., 1965; Evans, 1966; Evans et al., 1969; Wood and Wolfe, 1969; Purser and Evans, 1973; Butler, 1969; Kendall and Skipwith, 1969; Shinn, 1973).

4. Carbonate barrier islands. Evans et al. (1964a and Purser and Evans (1973) described barrier islands composed of carbonate sands separated by ooid-sand-lined channels fronting accretionary sabkhas and lagoons along the Trucial Coast (figure 1 a and b). Similar processes in an area of longshore currents created narrow, laterally accreting barriers with hook-shaped spits (figure 4) along the Qatar coast (Shinn, 1973).

5. Marine cementation. Marine cementation (figures 5 and 6) in water depths ranging from the intertidal to 20 m or greater (covering approximately 70,000 km2) was a surprising new discovery (Kendall and Skipwith, 1969; De Groot, 1969; Shinn, 1969, 1971; Assereto and Kendall, 1977). Recent reevaluation has demonstrated how marine cemented and bored rock layers can be misinterpreted when applied under the rules of sequence stratigraphy (Shinn, 2011).

6. Cyanobacterial accumulations. Cyanobacteria incorporated in lime mud and as mats form significant accumulations in Holocene axis and tidal zones of the Arabian Gulf. Two major Holocene organic sources serve as probable models: whitings (figure 1a) that turn part of the Arabian Gulf milky white, and cyanobacteria forming mats on intertidal areas (figure 7). The mud and cyanobacteria are quickly sequestered into the sedimentary section in the axial trough of the Gulf as well as the extensive tidal flats that rim it (Hubolt, 1957; Wells and Illing, 1964; De Groot, 1965; Kendall, 1966; Kendall and Skipwith, 1968).

The six listed topics represent our most "eye-catching" discoveries but are among only a few of the major ones we believe remain to be discovered. Additional discoveries may have geological implications beyond our initial perceptions, especially when combined collectively to solve other geologic problems. Our retrospective memories of our time in the Arabian Gulf are all the more frustrating when we now realize how much we missed and how much more we could have found.

FUTURE GLORIES

Now, in hindsight, we argue it is time to ask what specifically we did not discover, or appreciate, and what remains to be investigated in this relatively unstudied carbonate nirvana. Here we list a few examples we prioritize as waiting for further study.

1. Whitings. Whitings (figure 1 a) are numerous and often widespread in the Arabian Gulf (Wells and Illing, 1964; De Groot, 1965), but details of their origin and their role as models for petroleum source rocks need investigation. Even their origins remain controversial, especially whitings on the Great Bahama Bank (Shinn et al., 1988; Robbins and Blackwelder, 1992; Robbins et al., 1996).

Figure 3. Sabkha off-lap sequence as revealed in trench near landward margin of sabkha near Abu Dhabi. View is toward the north and the open gulf. Note dark desiccated algal mat underlain by anhydrite-bearing dolomitic sediment overlain by mainly windblown sabkha carbonate. This trench was used in the 1983 AAPG film Arid Tidal Flats.

Figure 4. Longshore currents on northeast side of Qatar Peninsula created carbonate-sand barrier island with hooked spits (see location in fig. 1a) at Ras Um Said. Dates show previous locations of such spits determined by aerial photography. Two new spits have been created since the original study (Shinn 1973). Note how tidal channels have penetrated older spits. Sequential growth and beachrock formation (dark band on landward side of spits) is discussed in Shinn (2011).

Are they bottom muds stirred into suspension by fish, or are they precipitated directly from seawater? The Arabian Gulf has few aragonite-precipitating algae, and the bottom consists of rock and/or carbonate sand and coral reefs (Shinn, 1969; Kendall et al., 2007). Water depths in the open Gulf are more than double that on the Great Bahama Bank.

2. Leaching. Evidence of leaching is common in ancient limestone even when associated with what we would interpret as marine cement. How can that happen? During the halcyon days of discovery, researchers lacked access to sampling devices other than push cores, drop cores, vibracores, box cores, and grab samples. Divers were restricted to the use of rock hammers and pry bars. Hard impervious marine-cemented rock layers greatly impeded any investigation of sediments below and between those cemented layers. Today, we have at our disposal diver-operated diamond-studded core drills that allow sampling of more extensive areas, and especially the uncemented sediments known to lie below and between cemented layers (figures 5 and 6). Those sub bottom uncemented sediments were never investigated in detail. Preliminary unpublished work by Shinn and DeGroot revealed highly anoxic H_2S-rich water between impermeable layers of marine cemented rock. Those uncemented sediments in marine waters are likely sites for dissolution to occur, but further investigation is needed. Our concepts and understanding may in fact be heavily biased toward explaining dissolution as the result of meteoric water may not be wholly accurate.

3. Dolomite. The formation of dolomite for the most part remains a major chemical mystery, the solution to which would have tremendous implications for oil-and-gas exploration (McKenzie, 1991). The Arabian Gulf area provides numerous opportunities for the study of dolomite formation (figure 8 and 9) under actual field conditions (McKenzie and Vasconcelos, 2009). In addition, the areas where dolomite is forming are also contaminated with windblown detrital dolomite (Shinn, 1983). Pilkey (1966) first reported aeolian dolomite in the Arabian Gulf, but additional work is needed to distinguish diagenetic from detrital dolomite.

4. Source rocks. The abundance of cyanobacteria associated with algal mats (figure 7) and whiting formation (figure 1 a) should provide ample opportunities for further study of cyanobacteria as a source of carbon and as potential petroleum source rocks (Kendall et al., 2007).

Possibly the most important justification for returning to the Gulf after so many years is the potential for unanticipated discovery. Much of the former discoveries was the result of serendipity associated with various studies of modern carbonates. Certainly there are more discoveries waiting for the curious.

DISCUSSION

Beginning in the 1980s, sedimentology, and other sciences as well, became increasingly influenced by computers that gradually moved us away from secretarial help. We became one-person publication generators. The diversion of research funds as we ramped up for the digital future likely held us in offices typing and manipulating old data, leading to a reduction of new field observations. This statement is not intended to imply that the digital age precluded discovery and creativity, but certainly it diverted our funding, energies, and scientific orientation while promoting a constant rehashing and refinement of knowledge gained from earlier fieldwork. A comment often made by Bob Ginsburg states that in tribal life, "There are hunters and there are cooks." In other words, with the advent of evolving hardware and software, we stopped hunting and began cooking. Working in air-conditioned offices

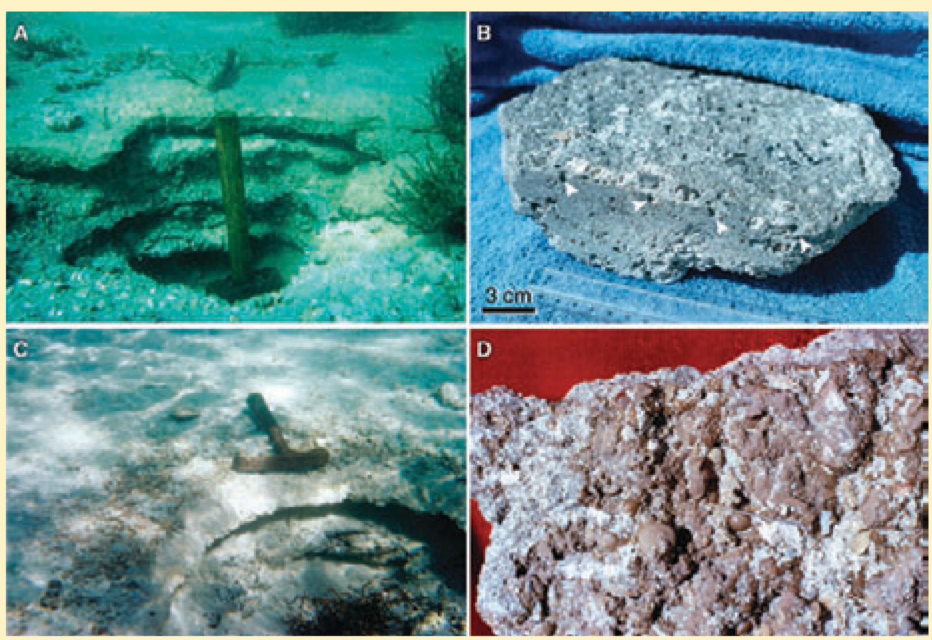

Figure 5. (a) Four marine cemented layers exposed in shallow pit on west side of Qatar Peninsula in approximately 1-m water depth. (b) Detail of top layer seen in (a) showing pholad borings (white arrows). (c) Underwater pit through two layers. Note precipitated aragonite (brown surface) near hammer. (d) Detail of aragonite-coated surface of layer shown in (c). Two-cm-long pin for scale.

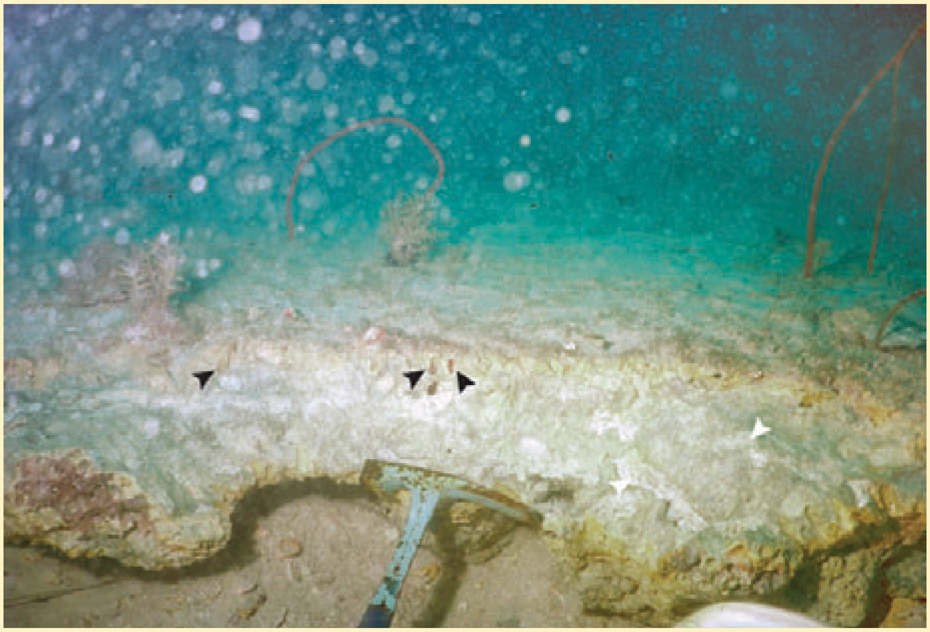

*Figure 6. Thick layer of marine cemented rock in 20 m of water on the Great Pearl Bank under whiting area in figure 1a east of the Qatar Peninsula. Black arrows show pholad borings; white arrows show filled and cemented sediment in burrows. Creation of this rock provides essential habitat for the pearl oysters (*Pectin *sp.), demonstrating diagenetic control of faunal distribution. See Shinn (1969) for details.*

and laboratories as opposed to oppressive heat/sweat and/or cold/frostbite out in the field certainly has its attractions. However, now that we are digitally saturated, this may be the ideal time to return to our geological roots/boots and get out in the field. This time, when we go back to the future we have many new tools at our disposal.

We can integrate our observations of modern depositional systems with the use of shallow-water acquisition of 3-D shallow seismic and borehole video (Cunningham et al., 2011). We can now make direct comparison with the ancient sections we see in outcrop and in down-hole images. Here the past is sometimes the key to the present and vice versa with shallow high-resolution seismic as a key that is still in development but appears an extremely powerful tool with resolution sufficient to identify individual beds. Similarly, satellite imagery accompanied with direct field observations is the key to mapping and characterizing Holocene carbonate depositional systems, guided by GPS, and is being used to delineate and quantify depositional facies patterns of carbonate reservoirs (Harris, 2010). We are able to combine and co-ordinate a variety of different high-end products using lidar images of ancient and modern exposures of rock from both the air and land-based equipment, ground-penetrating radar, portable seismic gear, portable rotary rock-coring devices, and of course digital cameras, especially when mounted on aerial drones or miniature helicopters, which allow almost unlimited inexpensive photographic documentation. The recent work of Strohmenger et al (2011), and Walkden and Williams (1998) show they have already begun to use more modern methods.

At the high end of the microscopic to submicroscopic end of the spectra of instrumentation, there are also many new devices that will supplement information gathered through fieldwork, and thereby extend derived observations and collections. Eclectic analytical tools include laser ablation for elemental analysis; GRAPE (Gamma Ray Attenuation and Porosity Evaluation); SHRIMP (Sensitive High-Resolution Ion Microprobe); new isotope systems Re\Os and the field of clumped isotopes; but there are more on the way. Hold on to gravity, the future is here.

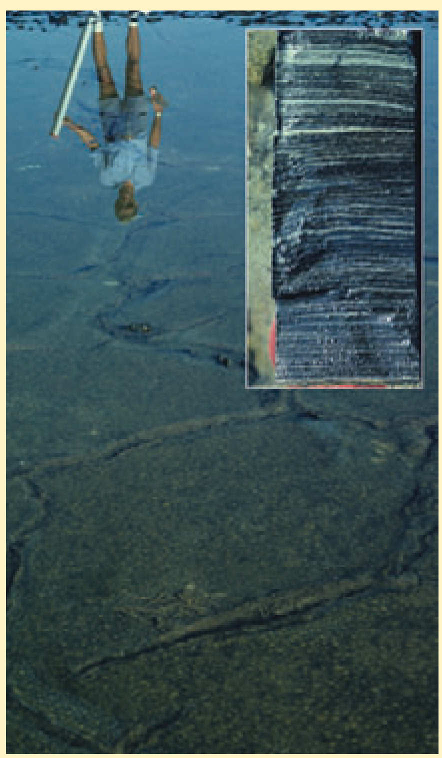

Figure 7. Dessicated algal mat under a few centimeters of water. Reflection of geologist with core tube provides scale. Inset shows 8-cm-wide core sample of the laminated, highly organic cyanobacterial algal mat.

Figure 8. The milky water at bottom of pit dug in coarse quartz sabkha sand contains well-formed dolomite crystals (see fig. 9). To the naked eye, the dolomite appears to precipitate instantaneously in the hypersaline water (Swart et al., 1987). Alternatively, the 2-micrometer dolomite crystals had precipitated in pore spaces and were flushed into the pit from between quartz sand grains as water flowed into the pit. Whichever is the case, the dolomite is a primary precipitate and did not form by replacement of carbonate. The phenomenon needs confirmational studies.

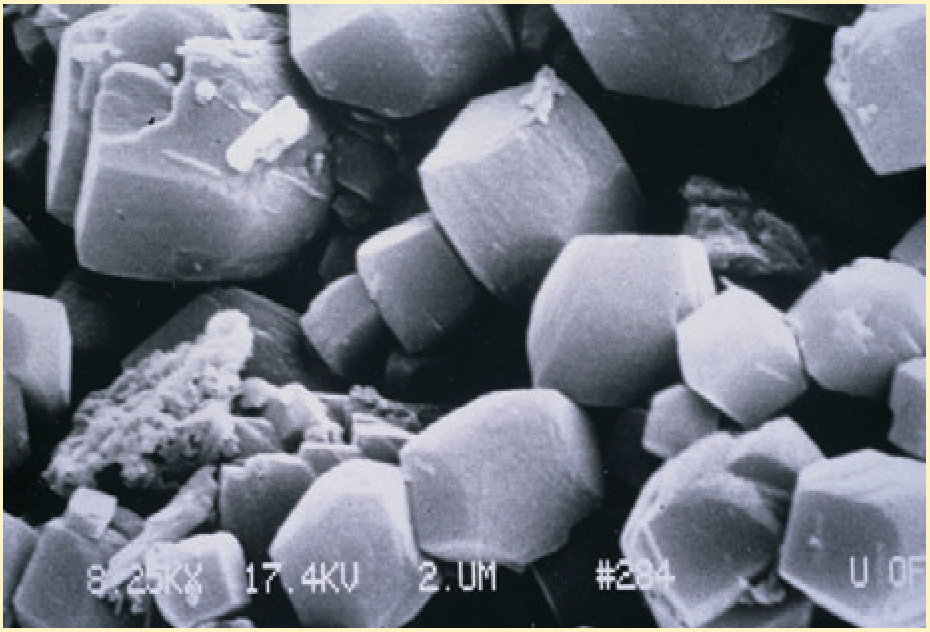

Figure 9. Scanning electron micrograph of well-formed 2-micrometer-long dolomite crystals from water shown in figure 8. Some cubes of NaCl are also present. C-14 analysis did not confirm instantaneous precipitation, possibly due to old carbon in the water. More study is needed.

SUMMARY

The future is here! Put your boots on and get back in the field where sedimentary geology began and grab those new toys that will enable you to make your data sing. The Arabian Gulf, with its variety of sediments and diagenetic processes is a good place to start while pristine areas remain. Timing is excellent for the present generation of new geologists to return to the field—before that inevitable shopping mall or mile-high hotel springs up on the pristine areas. Many sedimentary mysteries await to be unraveled, and your results may have the potential to further our knowledge and help push peak oil farther into the future.

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