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SPOTLIGHT

EVIDENCE FROM CARBONATE PLATFORMS BEARING ON CLIMATE, SALINITY, DASYCLADALEAN DIVERSITY, AND MARINE ANOXIC EVENTS DURING THE LATE JURASSIC–EARLY CRETACEOUS GREENHOUSE

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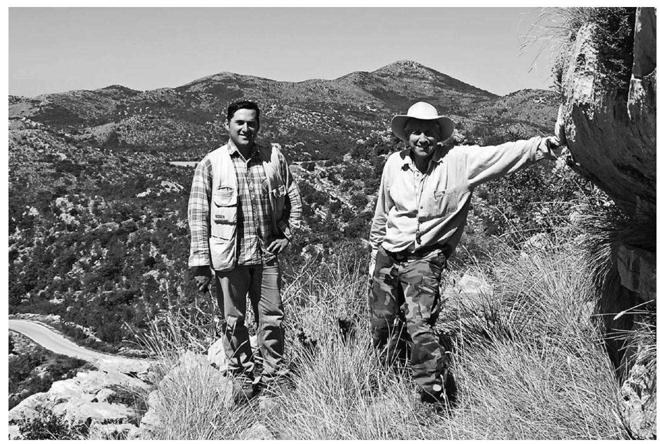
Carbonate platforms are sensitive recorders of environmental change through geologic time. Climatically induced changes in sea level or changes in subsidence are expressed through migration of sediment belts that are recorded in the accumulating sedimentary succession. Changes in nutrient levels are recorded in shifts in the biotic community and, if eutrophic levels are reached, platforms may drown due to breakdown in carbonate production (Föllmi et al., 1994). Our group has been focusing on the ~60 Ma Late Jurassic–Early Cretaceous period, which was originally considered to have had uniform greenhouse conditions (Fischer, 1982). Available climate proxy data, however, such as oxygen isotope data ($\delta^{18}O$) from deep sea cores, the paleontologic data (e.g., Frakes et al., 1992), and the $^{87}Sr/^{86}Sr$ and carbon isotope data of Jurassic and Cretaceous carbonates (Jenkyns and Wilson, 1999), indicate that there were major cooling and warming events that likely affected global ice volume, sea level, and the accumulating sedimentary and microfossil record of carbonate platforms.

Numerous carbonate platforms were developed within the tropical–subtropical belt of the circumequatorial Late Jurassic–Early Cretaceous Tethys Ocean. Many of these platforms have comparable shapes, sizes, facies, subsidence rates, and geologic structure to the present-day Bahamas Banks, a commonly used modern-day analogue (e.g., Bosellini, 2002, and references therein). In addition, the outcropping Tethyan platforms provide important clues to the poorly known subsurface Mesozoic carbonates that underpin the modern Bahamas platform. The Tethyan platforms were characterized by high rates of sedimentation (from <30 up to >100 m/myr; D'Argenio et al., 1999) and exhibit meter-scale shallowing-upward cycles or parasequences generated during high frequency, small sea-level fluctuations within the Milankovitch band (Strasser, 1991; Schulz and Schäfer-Neth, 1997; Lehmann et al., 1999; Strasser et al., 1999; Immenhauser et al., 2004; Husinec and Read, 2007). The Late Jurassic–Early Cretaceous platforms contain important information about changes in fauna, depositional facies, diagenesis, and climatic events, as well as the history of platform growth and demise (Simo et al., 1993).

As such platform tops lie near sea level, they are sensitive to such small changes in sea level as those driven by the earth's orbital forcing of global climate—Milankovitch forcing. There is abundant evidence of orbitally forced changes in climate and sea levels in Paleozoic and Mesozoic rocks from many carbonate platforms around the world (Read, 1995, and references therein). Namely, the cycles of precession (19–23 kyr, decreasing to slightly smaller values into the past), obliquity of the Earth's rotational axis (41–54 kyr), and eccentricity of the earth's orbit around the sun (98–123 kyr and 413 kyr) produce periodic variations in the insolation patterns (Berger, 1984; Berger and Loutre, 1994; Hinnov, 2000), which in turn cause variations in oceanic and atmospheric systems.



Antun Husinec (left) and Fred Read (right) studying the Upper Jurassic–Lower Cretaceous Adriatic platform, Croatia. Antun Husinec grew up in the small town of Krizevci in Croatia. He received a B.S., M.Sc., and Ph.D. in Geology from the University of Zagreb. His Fulbright postdoctoral research with J. Fred Read, Virginia Polytechnic Institute and State University, focused on the paleoclimatic context of Adriatic platform evolution. A central emphasis in Antun's research plan is directed at the use of microfossils and the sedimentary record, coupled with the integration of stratigraphic analysis, modeling, isotopic approaches, and spectral analysis to track the evolution of climates and oceans. Current research with Fred Read on the Adriatic platform of Croatia is funded by the U.S. National Science Foundation and the Croatian Ministry of Science. Recently, Antun "diverted" from the Mesozoic and began research on the Ordovician petroliferous subsurface Red River Formation, North Dakota, focusing on high-resolution sequence stratigraphy and facies evolution. This research is funded by the American Chemical Society's Petroleum Research Fund. When he is not teaching or doing research in Croatia or North Dakota, Antun enjoys taking his carbonate sedimentology students to study modern carbonate depositional environments of the Bahamas. He is currently an Assistant Professor of Geology at St. Lawrence University.

During greenhouse times, precessional cycles (roughly 20 kyr and decreasing slightly with geologic age) appear to be dominant when the Earth is relatively ice free (Fischer, 1982; Read, 1995). Carbonate platforms during greenhouse periods—as in the Late Jurassic–Early Cretaceous—developed under relatively small sea-level fluctuations (typically a few meters) with roughly 10–20 kyr periodicities on which are superimposed small, ~100 and 400 kyr sea-level fluctuations (Koerschner and Read, 1989; Bond et al., 1991; Goldhammer et al., 1993; Lehrmann and Goldhammer, 1999). These platforms are consequently composed of markedly layer-cake, meter-scale, low-energy peritidal and or subtidal cycles (e.g., Osleger, 1991; Montañez and Read, 1992; Elrick, 1995; Read, 1998).

During icehouse times when the Earth had major ice sheets, Milankovitch-driven sea-level changes were large (many tens of meters) and typically, obliquity (40 kyr) or eccentricity (100–400 kyr) domi-

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nated. Major ice sheets were absent in the Cretaceous; however, there is increasing evidence of cooling events and buildup of small ice sheets (Frakes, 1999). At these times, sea-level changes were likely to be larger (few tens of meters) than in greenhouse times, and were possibly driven by obliquity and eccentricity, rather than precession (Read, 1995). These conditions leave a very distinctive record on carbonate platforms (Smith and Read, 1999, 2001) and such cooling events should be evident on the Late Jurassic–Early Cretaceous Tethyan platforms, interspersed with the classic greenhouse cyclic succession.

The meter-scale carbonate cycles that make up the platform are the building blocks of depositional sequences—i.e., genetically related, unconformity-bounded successions of strata lacking apparent internal unconformities. The parasequences and parasequence sets are arranged in systems tracts (Mitchum and Van Wagoner, 1991). Depositional sequences (and parasequences) form as a result of changes in accommodation space (sea level plus subsidence; e.g., Sarg, 1988; Goldhammer et al., 1990; Van Wagoner et al., 1990; Osleger, 1991; Chen et al., 2001; Raspini, 2001). Many of the parasequences that developed during greenhouse worlds are typically shallowing-upward successions of genetically related strata capped by microbial laminites (Read, 1998); however, some parasequences lack regressive laminites and instead have burrowed and rooted upper parts, capped with green paleosols. We recently found that the presence or absence of regressive microbial laminites versus rooted-burrowed caps on the peritidal parasequences is controlled by salinity, and possibly by climate (Husinec and Read, 2011). The laminite-capped parasequences resulted from a salinity increase as the platform interior shallowed under (semi-arid) conditions. The rooted and burrowed parasequences capped by subaerial exposure surfaces likely formed during times of more humid climate favoring brackish to normal marine coastal waters and tidal flats colonized by macrophytes whose intense bioturbation inhibited development of microbial caps.

The interiors of Late Jurassic–Early Cretaceous greenhouse platforms commonly lack high-resolution taxa important for biostratigraphy; however, they typically contain abundant benthic foraminifera and dasycladalean calcareous algae, the latter likely being a major producer of aragonite mud today (Neumann and Land, 1975). Interestingly, Stanley and Hardie (1998) originally suggested that the abundance of dasycladaleans peaks during times with aragonite seas, with the only exception being the Late Jurassic–Early Cretaceous. Later studies have shown, however, that both calcite and aragonite episodes include periods of high and low dasycladalean diversity (Aguirre and Riding, 2005) and that peaks of dasycladalean diversity can be reached even when the Mg/Ca ratio plunges to a very low level (as in the Barremian; Husinec et al., 2009).

Another area of focus is the primary C-isotope record and its sedimentologic and paleontologic expression on shallow platforms, including their response to documented oceanic anoxic events (OAEs; e.g., Funk et al., 1993; Föllmi et al., 1994; Jones and Jenkyns, 2001; Jenkyns, 2003; Erba et al., 2004; Föllmi and Gainon, 2008). The carbon isotope signal from the bulk carbonate matrix of shallow-water platforms is not markedly altered, even in some sections with a meteoric diagenetic overprint (Grötsch et al., 1998). Consequently, carbon isotope excursions associated with carbon cycling and global oceanic anoxic events on Early Cretaceous Tethyan platforms can be used not only to improve the low-resolution biostratigraphy based on benthic foraminifera and calcareous algae, but also to study how shallow platform environments responded during OAEs in terms of biota, productivity, and parasequence stacking pattern. Our group has found evidence of short-lived, rapid Adriatic platform drowning at the Aptian OAE-1a ($\sim$120 Ma), accompanied by a major carbon-isotope excursion. Our studies also show carbon and oxygen isotope variations at the parasequence set scale, with C and O signatures becoming heavier toward parasequence set boundaries.

The Late Jurassic–Early Cretaceous greenhouse platforms also contain extensive dolomites with stable-isotope and trace-element geochemistry that indicate they formed from relatively normal marine waters—i.e., below evaporite precipitation field. Such dolomites are widespread in isolated platforms worldwide (Budd, 1997).

In summary, Tethyan Mesozoic carbonate platforms have provided and will continue to provide a fertile research area for sedimentologic, paleontologic, geochemical, paleoclimatic, and paleoceanographic studies.

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