city in hurricanes past, performed as designed and, unlike the Lake Ponchartrain levees, they were not breached.

The disastrous scenario as it played out was no surprise to emergency officials. In 2002, several media reports addressed the hurricane threat to New Orleans. The *Times-Picayune* in New Orleans ran a five-part series titled "Washing Away," which was eerily accurate in forecasting the consequences of the "Big One" (available online at http://www.nola.com/hurricane/?/washingaway/index.html).

In another story on the hurricane threat to New Orleans [*Zwerdling*, 2002], scientists noted that a hurricane-induced flood could submerge land up about 6 meters. Jefferson Parish Director of Emergency Management Walter Maestri described a fictional Category 5 hurricane scenario that included a track across south Florida, into the Gulf of Mexico, and then into New Orleans. Estimates of the number killed ranged as high as 40,000. The fictional scenario also was dubbed the tongue-in-cheek acronym "KYAGB."

Unfortunately, in the days of anarchy, human suffering, and infrastructure destruction that has taken place following Katrina, the "kiss your @#$ good-bye" scenario very nearly became reality.

Coastal hazard forecasts for the devastated cities in the region, including New Orleans, are not optimistic. Landfall data indicate that Louisiana experiences an average of approximately two hurricane landfalls in any five-year period. Recently published work [*Emanuel*, 2005] indicates that tropical cyclones are increasing in both intensity and days in existence.

Furthermore, locations in southern Louisiana face some of the greatest rates of coastal land loss in the United States. Current land submergence (~23.3 km^2/yr) is due partly to sea level rise, but the extraction of oil and gas from hydrocarbon fields in the area has dramatically worsened submergence rates. *Morton et al.* [2003] found land subsidence rates in the Mississippi deltaic region of Louisiana of ~22 mm/yr during the period 1969–1999, significantly higher than the geologic record from 400 to 4000 years B.P. (~2 mm/yr).

The deltaic plain south of New Orleans faces the bleak prospect of rising seas and subsiding wetlands, which, in combination with the shallow offshore continental shelf and flat topography of the region, will result in disastrous consequences from high storm surges. An unabated risk of relatively frequent hurricane landfalls, at increasing intensity levels, is possible in the near and distant future along the northern Gulf Coast of the United States.

References

Emanuel, K. (2005), Increasing destructiveness of tropical cyclones over the past 30 years, *Nature, 436*, 686–688.

Morton, R. A., G. Tiling, and N. F. Ferina (2003), Causes of hot-spot wetland loss in the Mississippi delta plain, *Environ. Geosci., 10*, 71–80.

Zwerdling, D. (2002), Nature's revenge: Louisiana's vanishing wetlands: Part IV—Hurricane risk for New Orleans, Am. Public Media. (Available at http://americanradioworks.publicradio.org/features/wetlands/hurricane1.html)

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MEETINGS

Seafloor Spreading, Sea Level, and Ocean Chemistry Changes

PAGE 335

High Cretaceous ocean crust production rates have been causally linked to high global sea level and global CO_2 due to increased outgassing. However, recent studies have questioned the empirical basis for high Cretaceous global seafloor spreading rates, high Cretaceous sea level (230–320 m above present), and the relationship between geochemical fluxes and spreading rates.

Although this topic has been discussed at several recent international meetings, there has been little opportunity for the protagonists in the debate of constant versus variable global seafloor spreading rates to interact. However, a group of tectonophysicists, stratigraphers, and geochemists recently met at Rutgers, The State University of New Jersey (Piscataway, N.J.) to discuss global seafloor spreading changes and their possible relationships to sea level and geochemical variations.

The conference refined the boundaries of what is known and showed that, like the fixity of hot spots, hypotheses linking seafloor spreading, sea level, and ocean chemistry changes over the past 100 Myr may not be true.

Sessions were held on seafloor spreading, long-term (10^7 years) sea level, and ocean chemistry changes. Steve Cande (Scripps Institution of Oceanography) took participants on a global tour of seafloor spreading rate changes through time and highlighted the influence of timescales. The duration of the Cretaceous long polarity quiet zone has progressively been lengthened from 84–108 Ma in earlier timescales to 84–125 Ma recent timescales, thus reducing estimates of Cretaceous global seafloor spreading rates.

David Rowley (University of Chicago) not only questioned high global Cretaceous seafloor spreading rates, but also argued that the record of oceanic crustal production is compatible with a model of a constant global rate over the past 180 Myr [*Rowley*, 2002]. He questioned relationships between spreading rates and sea level, because higher spreading rates might be balanced by dynamic topography caused by increased subduction rates.

Michelle Kominz (Western Michigan University) provided a different view. Her 1984 reconstruction of seafloor spreading and ridge lengths [*Kominz*, 1984] yielded an error analysis of ocean crust production and long-term sea level (range of 45–320 m). This 1984 study requires higher seafloor spreading rates in the Cretaceous, though the error bars are large because of subducted ocean crust and uncertainties in plate reconstructions based on data available in the early 1980s. Kominz provided new results from a reanalysis of ocean crust production that show Cretaceous rates were at least as high as in her previous estimates.

Rob Demicco (State University of New York at Binghamton) noted that Rowley's null hypothesis of no changes in the global average of seafloor spreading rates is only one of an infinite number of possibilities and that ocean chemistry changes implicitly require a decrease in seafloor spreading rates since the Cretaceous.

Maria Sdrolias (University of Sydney, Australia) provided an update of ocean floor age estimates with new data on marginal seas and accounting for the effects of lost ridges by mirroring remnant segments. Her animations show high mid-Cretaceous seafloor spreading rates.

Dennis Kent (Rutgers University) moderated a lively discussion of seafloor spreading rates, emphasizing problems in reconstructing ocean crust older than 52 Myr (i.e., 50% of crust older than this has been destroyed). Rowley noted that increased global spreading rates must be associated with increased subduction rates. Increased dynamic topographically induced subsidence associated with increased subduction rates could possibly counterbalance the sea level response to higher global seafloor spreading rates. This counterbalance would be maximized if increased subduction were concentrated in oceanic back-arc basins versus Andean-type margins.

There was no agreement among the participants as to whether global seafloor spreading rates have remained constant over the past 100 Myr. Bilal Haq (U.S. National Science Foundation) summarized the discussion well with a postmortem remark that these changes will remain largely unknown due to the "nature of the beast" (namely, reconstructing a world where more than half of the crust has been subducted).

In the session on long-term sea level changes, Chris Harrison (University of Miami) reviewed changes on all temporal scales, showing that long-term Cretaceous continental flooding estimates vary among continents with an average of 150 m, slightly less than Rowley's estimate of ~100 m based on paleogeographic reconstructions.

Mike Steckler (Lamont-Doherty Earth Observatory) described backstripping, a technique that provides sea level estimates by accounting for the effects of sediment compaction, crustal loading, and subsidence.

Dork Sahagian (Lehigh University) presented a 180–90 Myr global sea level estimate from backstripping Russian platform and Siberian sections.

Ken Miller summarized Phanerozoic sea level changes and included a new backstripped sea level synthesis of the past 100 Myr based on data from the New Jersey margin (K. Miller et al., The Phanerozoic record of global sea level change, submitted to *Science*, 2005). His estimate shows a Cretaceous peak of 50–70 m above present, although comparisons with other data sets suggest that the Cretaceous sea level increase was 100±50 m and not the 230–320 m previously assumed.

Garry Karner (Lamont-Doherty Earth Observatory) discussed errors inherent in estimating sea level on various scales; he showed backstripped estimates of a late middle Miocene sea level fall of 45–105 m that was refined to 56.5±11.5 m by integrating with stable isotopic data.

Nick Christie-Blick (Lamont-Doherty Earth Observatory) and Sahagian led a discussion of sea level changes, with general agreement that the Cretaceous sea level maximum rise was much lower (100±50 m) than previously thought. Haq stated that he had always suspected that the amplitudes in the Exxon Production Research (EPR) records [*Haq et al.*, 1987] were overestimates because they were scaled to a Cretaceous peak of 250–320 m based on early seafloor spreading estimates [*Hays and Pitman*, 1973]. Miller noted that the number and timing of the EPR sea level falls has proven to be valid in general, but the amplitudes of the EPR sea level changes are too high by more than a factor of two. Haq confirmed that the EPR curve was not backstripped.

In the final session on ocean chemistry, Bob Berner (Yale University) provided an overview of geochemical models showing that seafloor spreading rates do not greatly affect CO_2 estimates. He noted that the rise in oceanic magnesium (Mg) and fall in calcium (Ca) over the past 100 Myr could be attributed to decreasing seafloor spreading rates or to a decrease in the formation of dolomite.

Peter Rona (Rutgers University) showed a general increase in hydrothermal activity with spreading rate, although anomalies exist such as high plume occurrences on the ultraslow Gakkel Ridge, central Arctic Ocean. He suggested Eocene global plate reorganization might have contributed to sea level changes and the terrestrial contribution to ocean chemistry.

Dick Holland (Harvard University) reviewed Phanerozoic seawater geochemistry derived from brines trapped in halite, and he showed that the largest change in Mg and other elements occurred over the past 40 Myr when there were minimal changes in global average seafloor spreading rates. He emphasized the role of the formation of dolomite on ocean chemistry variations.

Miriam Katz (Rutgers University) reviewed changes in the carbon cycle over the past 200 Myr using a synthesis of organic carbon and bulk carbonate carbon isotopic data, and she attributed the radiation of eukaryotic phytoplankton that dominate the modern oceans to increases in ecological niches and nutrient availability associated with continental flooding. She concluded that increased storage of organic carbon on passive margins resulted in an increase in atmospheric oxygen.

Christian Bjerrum (University of Copenhagen) provided new geochemical models that illustrate that the magnitude of continental flooding, not necessarily global sea level position, is a critical variable in organic carbon sequestration and other geochemical variations.

The meeting showed that hypotheses linking high spreading rates to high sea level and atmospheric CO_2 remain unproven. Sea level was higher globally by at least 100 m in the Cretaceous, but it is not clear that this was due to high global seafloor spreading rates, because the combined effects of the absence of permanent ice sheets (~50 m effect), warm global temperature (~15 m effect), and other influences could explain most of this change. High sea level profoundly affected evolution, organic carbon burial, and atmospheric oxygen, but it is unclear if variations in Mg and Ca were due to changes in spreading rate or the formation of dolomite.

The old paradigm of changes in global seafloor spreading rates ruling sea level and ocean chemistry variations is tattered, but it is not clear that a viable new hypothesis will emerge. This uncertainty is the nature of the beast.

The conference on Relationships Among Seafloor Spreading, Long-Term Sea Level, and Ocean Chemistry Changes from the Late Cretaceous to Present was held on 21–22 June 2005 at Rutgers University, Piscataway, N.J. The authors of this meeting report were meeting conveners.

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References

Haq, B. U., J. Hardenbol, and P. R. Vail (1987), Chronology of fluctuating sea levels since the Triassic (250 million years ago to present), *Science, 235*, 1156–1167.
Hays, J. D., and W. C. Pitman, III (1973), Lithospheric plate motion, sea level changes, and climatic and ecological consequences, *Nature, 246*, 18–22.
Kominz, M. A. (1984), Oceanic ridge volumes and sea level change: An error analysis, in Interregional Unconformities and Hydrocarbon Accumulation, edited by J. Schlee, *AAPG Mem., 36*, 109–127.
Rowley, D. B. (2002), Rate of plate creation and destruction: 180 Ma to present, *Geol. Soc. Am. Bull., 114*, 927–933.

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