sinking velocity and geochemical techniques for constraining gross primary production, diapycnal mixing (the mixing across density surfaces that is a key factor in water mass transformations and the supply of nutrients to the surface ocean, and respiration using the isotopic composition of dissolved oxygen.

Of equal importance is the integration of such sensors onto autonomous platforms. Two different, complementary paths are being followed involving either low-power drifters, floats, and gliders or high-power moorings, autonomous underwater vehicles, and cable-based observatories.

Pilot studies are under way to add biogeochemical instrumentation to profiling floats similar to those used in the global Argo array, and to cabled systems that may be deployed as part of the NSF-sponsored Ocean Research Interactive Observatory Networks (ORION). Michael Bender (Princeton University) made compelling arguments for instrumenting Volunteer Observing Ships (e.g., commercial vessels, research ships, and Antarctic re-supply vessels), which provide excellent platforms for rapid and routine spatial surveys of the upper ocean biological and geochemical state.

An important message arising from the workshop is the crucial need to integrate information from different approaches and across multiple time and space scales. An example of this need is the controversy surrounding whether the upper water column in the open ocean is net autotrophic or heterotrophic. Results from some diurnal bottle incubation experiments showing net oxygen consumption are in conflict with geochemically derived, positive net community production estimates based on in situ surface oxygen supersaturation and atmospheric seasonal oxygen/nitrogen (O_2/N_2) cycles. Although methodological concerns of bottle incubations are always present, some of these differences may be real, reflecting the episodic character of production and respiration and its interaction with traditional shipboard sampling strategies.

The workshop on The Ocean Carbon System: Recent Advances and Future Opportunities was held 1-4 August 2005 at the Woods Hole Oceanographic Institution, Woods Hole, Mass.

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Tsunami Geology and its Role in Hazard Mitigation

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The timely topic of tsunami geology was addressed during a recent international workshop sponsored by the U.S. National Science Foundation (NSF). Participants from 15 nations compared criteria for identifying tsunamis by their geologic signatures; explored applications to plate tectonics, hazard assessment, and public education; and discussed recommendations for research priorities. A post-workshop trip occasioned heartfelt exchanges with Washington state coastal residents two days after a local tsunami scare.

Motives and Objectives

The workshop was prompted by the Indian Ocean tsunami of 26 December 2004, and began with several presentations about that tsunami and about the lessons being learned from it. Lacking documented precedent in its source region, the 2004 catastrophe provided a horrific reminder of a practical problem: Written and instrumental records rarely span enough time to warn of the full range of a region's tsunami hazards.

Geology has already begun to address this problem by extending tsunami history thousands of years into the past. Examples presented at the meeting included tsunami deposits from the North Sea (S. Bondevik), New England (M. Tuttle), Chile (M. Cisternas), Mexico (M. T. Ramirez), Cascadia (northern California to British Columbia) (H. Kelsey, A. Nelson, A. Moore, and I. Hutchinson), Alaska (J. Beget), Kamchatka (J. Bourgeois), and Japan (K. Hirakawa and F. Nanayama). Much of the workshop was accordingly focused on the opportunities and challenges of identifying and quantifying past tsunamis from their geologic signatures.

Identifying Ancient Tsunamis

Modern analogs provide geologic criteria for identifying ancient tsunamis. Several case histories of modern examples were presented at the meeting, including recent surveys from the Indian Ocean region. Compiling and synthesizing these observations into accessible data repositories were deemed important by discussants at the workshop.

Tsunami geology, which began with surveys of the 1946 Aleutian tsunami in Hawaii [*Shepard et al.*, 1950] and the 1960 Chile tsunami in Japan [*Kitamura et al.*, 1961], now encompasses a broad range of stratigraphic and geomorphic evidence, and it includes several published comparisons between tsunami and storm deposits.

Although no one criterion suffices as geologic proof of a tsunami, some participants at the workshop stated that several criteria together, in the right setting, can leave little room for doubt. For example, the 1700 Cascadia tsunami can be identified with confidence from a sheet of sand that tapers landward, contains marine fossils, extends kilometers inland from the limit of sand deposition by storm surges, and coincides stratigraphically with evidence for abrupt tectonic subsidence and seismic shaking [see bibliography in *Atwater et al.*, 2005].

Much debate at the workshop, therefore, focused on settings where tsunamis and storms may have similar geologic effects, for example, on the east coast of North America. Patricia Wiberg, Bruce Jaffe, Harry Yeh, and others presented evidence that tsunamis produce flows faster than those of storm surges. Workshop attendees agreed that quantifying such differences and linking them to the physics of sediment erosion, transport, and deposition are ultimate goals of tsunami sedimentology.

Applying Tsunami Geology

Several presenters described tsunami deposits as ground truth for numerical simulations on which tsunami evacuation maps are based. In Hokkaido, Japan; Washington state; and Oregon state, tsunami deposits have already contributed to such maps [e.g., *Priest et al.*, 1995]. The next step is to interpret the deposits in terms of flow depth and velocity, parameters of interest in the engineering design of tsunami-resistant buildings. This interpretation, a frontier of tsunami research spotlighted in presentations by Vasily Titov, Pat Lynett, and Costas Synolakis and in workshop discussions, requires collaboration with wave-tank experimentalists and hydrodynamic modelers.

Tsunami deposits provide tangible evidence of a community's tsunami risk. Though best appreciated in the field, these deposits can also be taken to classrooms and public meetings. At the workshop, deposits were displayed as peeled cross sections through tsunami deposits from Sumatra, Peru, Hawaii, Japan, the Philippines, and Cascadia.

Although many people may see tsunami geology as pertaining mainly to public safety, it also offers fundamental insights into Earth science. For instance, presenters showed cases where tsunami deposits help define active plate boundaries in northeastern Russia, help determine subduction-zone behavior in Chile, and help attest to asteroid impacts through geologic time.

Reaching Out to the Public

On the evening of 14 June 2005, in the middle of the workshop, the U.S. West Coast and Alaska Tsunami Warning Center issued a warning for much of the Pacific coast of North America (http://earthquake.usgs.gov/eqinthenews/2005/usziae/). The incident brought television cameras into the workshop and public attention to a post-workshop field trip.

On this trip, workshop participants from India, Indonesia, the Philippines, Sri Lanka, and Thailand visited the southern coast of Washington state, which draws more than 100,000 tourists on busy summer weekends. The group met first with police, fire, and public-works officials to evaluate the area's tsunami preparations in light of the 2004 tsunami's effects. The group then starred in a public meeting that began with the unveiling of tsunami evacuation maps—maps based, in part, on tsunami geology—and with a discussion of the county sheriff's decision not to order a full-scale evacuation during the tsunami warning.

At both meetings, the South and Southeast Asian visitors fielded questions such as: How did people and elephants respond to natural warnings of the 2004 tsunami? How widely were tsunami warning signs taught beforehand? What is the status of the relief efforts? Is more help needed?

Like the NSF workshop itself, these international exchanges were silver linings to a tsunami that had ignored the boundaries between nations.

Workshop Products

The workshop agenda, a list of conference participants, and other resources are posted at http://earthweb.ess.washington.edu/tsunami2/deposits/. A report to NSF is in preparation and will be posted on the Web site. The NSF Workshop on Tsunami Deposits and Their Role in Hazard Mitigation was held in Seattle, Washington, 12–15 June 2005.

Acknowledgments

The workshop was convened by Joanne Bourgeois (UW–University of Washington), Harry Yeh (Oregon State University), Brian Atwater (U.S. Geological Survey at UW), and Bretwood Higman (UW). NSF's support (EAR-0531497, shepherded by Paul Filmer and Rich Lane) was supplemented by the U.S. Geological Survey, the U.S. National Oceanographic and Atmospheric Administration, and the Department of Earth & Space Sciences at UW. Christie Leff handled logistics, with help from UW graduate students, and Jonathan Hughes led a workshop field trip. The post-workshop field trip was organized by Brian Atwater; the public meetings were organized by Stephanie Fritts.

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BOOK REVIEW

A Geologic Time Scale 2004

GRADSTEIN, JAMES OGG, AND ALAN SMITH, EDITORS

Cambridge University Press; ISBN 0-521-78673-8; xix + 589 pp.; 2005; softcover; $70.00.

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This may be the most straightforward book review imaginable to write. Just buy this book and use it! You will not regret it.

Verlyn Klinkenborg's 23 August 2005 editorial in the *New York Times* ("Grasping the depth of time as a first step in understanding evolution") serves as a most timely way begin a review of *A Geologic Time Scale 2004* (GTS2004). Klinkenborg writes, "One of the most powerful limits to the human imagination is our inability to grasp, in a truly intuitive way, the depths of terrestrial and cosmological time."

GTS2004 represents a celebration of decades of multifaceted efforts that help to minimize those limitations.

GTS2004 begins with an appropriate frontispiece: "With the acceptance of a reliable time scale, geology will have gained an invaluable key to further discovery. In every branch of science its mission will be to unify and correlate, and with its help a fresh light will be thrown on the more fascinating problems of the Earth and its Past" (Arthur Holmes, 1913, *The Age of the Earth*).

This contribution is the successor to *A Geologic Time Scale 1989* by W. Brian Harland et al. (1990) and *A Geologic Time Scale 1982*, also by Harland et al. (1982). The gargantuan effort to prepare GTS2004 took place under the auspices of the International Commission on Stratigraphy (ICS, http://www.stratigraphy.org/). The book represents not a culmination but a continuum of 90+ years of international study, since Holmes' first quantitative geologic time- scale, to better and better understand the approximately 3850 million years of Earth history.

As the authors of GTS2004 state, "no geologic time scale can be final." Since the preparation of GTS1989, several developments have resulted in considerable revisions to geologic timescales, including GTS2004. These are thoroughly explored in GTS2004 and include stratigraphic standardization by the ICS; improvements in several geochronologic methods resulting in higher-precision, more accurate age determinations; expanded use as calibration tools of global geochemical variations, Milankovitch cycles, and geomagnetic polarity records; and improved statistical methods of extrapolating age estimates and their uncertainties to specific stratigraphic events.

The book is organized into four parts, with a total of 23 chapters. Part I (an introduction as chapter 1 and chronostratigraphy as chapter 2), along with the preface, give the reader with virtually any level of background in the geological sciences a broad overview of the history of geologic timescales and an appreciation of the many approaches that have been taken in their construction. For educators, these chapters would make excellent reading for numerous classes.

Part II (Concepts and Methods) includes five chapters (3–8) that describe the many methods used to extract linear time from the rock record. These chapters focus on biostratigraphy (3), orbital parameters and cycle stratigraphy (4), geomagnetic polarity timescale (5), radiogenic isotope geochronology (6), strontium isotope stratigraphy (7), and statistical approaches (8).

Part III (Geologic Periods) consists of 14 chapters, two of which are devoted to the Archean and Proterozoic eons, nine to the Paleozoic and Mesozoic periods (Mississippian and Pennsylvanian combined as the Carboniferous), and the last three to the Paleogene and Neogene periods and the Pleistocene and Holocene epochs. Each chapter in parts II and III is authored by one or more additional contributors.

Part IV (Summary) involves a single, short chapter on the construction of the overall 2004 geologic timescale.

Three appendices are included. The first consists of a recommended color coding of timescale stages and includes a table comparing color sets (giving RGB, exact CMYK, and CMY color values) used by the Commission for the Geological Map of the World, (which are used in GTS2004), and by the U.S. Geological