The SEDIMENTARY Record

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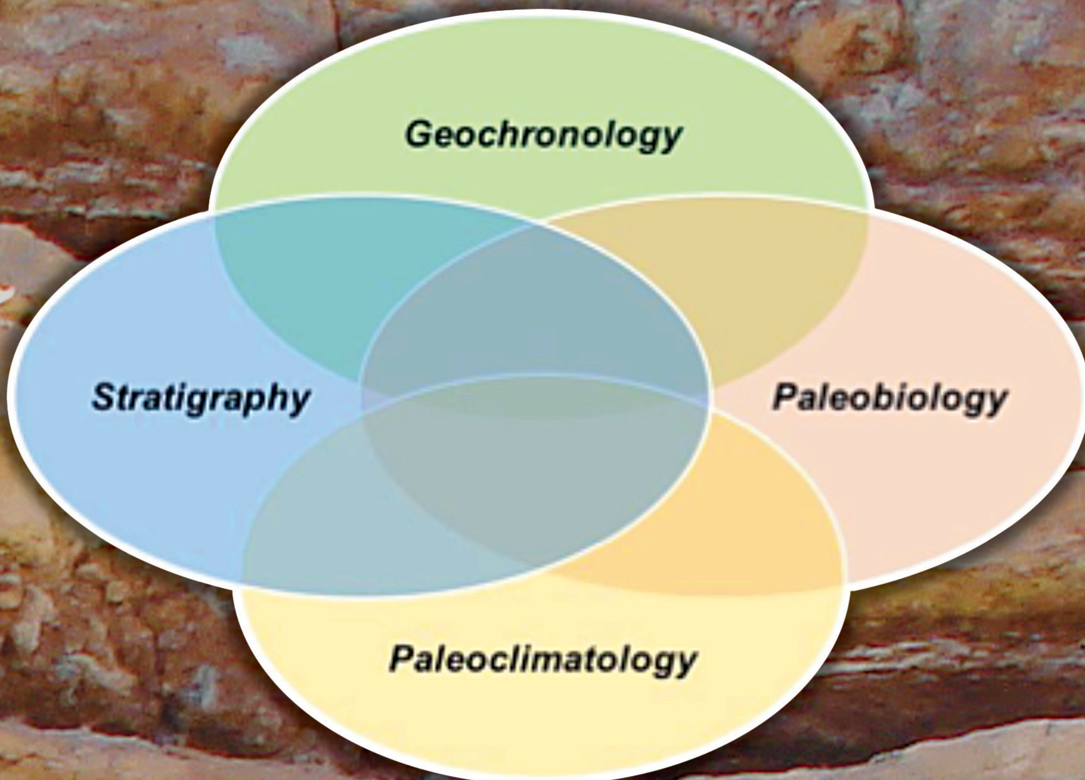

INSIDE: WHAT'S YOUR DELTA? EARTHRATES--A NEW NSF FUNDED RESEARCH COORDINATION NETWORK FOR LINKING SCALES ACROSS THE SEDIMENTARY CRUST

PLUS: PRESIDENT'S COMMENTS, UPCOMING CONFERENCES & MEETINGS

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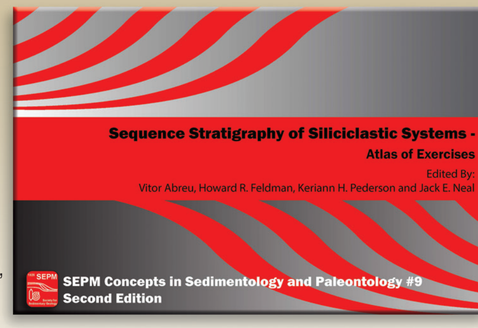
Concepts in Sedimentology and Paleontology 9 (2nd edition)

Sequence Stratigraphy of Siliciclastic Systems

Edited by: Vitor Abreu, Howard R. Feldman, Keriann H. Pederson, and Jack E. Neal



This publication is the result of more than 3 decades of sequence stratigraphy research and application. The objective is to emphasize the most important aspects of Sequence Stratigraphy—a method to guide geologic interpretation of stratigraphic data (seismic profiles, well-logs, cores and outcrops) across scales (from local to regional and global) and depositional environments (from continental to deep marine).The stratigraphic concept of a depositional sequence was introduced to the scientific literature by Peter Vail and his colleagues in the late 70s, building on the shoulders of giants like Chamberlain, Sloss and Wheeler. Since then, several papers compared and contrasted the original sequence-stratigraphic school published in the AAPG Memoir 26 in 1977 with other approaches to subdivide the geologic record, as well as, debating the model validity and impact on the community. At its core, the "model" is really a stratigraphic interpretation method, which was never explicitly documented in the literature. The objective of this book is to present the sequence stratigraphic method in its current form in an attempt to clarify its usage and application in diverse geologic data and depositional environments. This publication is the result of more than 3 decades of sequence stratigraphy research and application. The objective is to emphasize the most important aspects of Sequence Stratigraphy—a method to guide geologic interpretation of stratigraphic data (seismic profiles, well-logs, cores and outcrops) across scales (from local to regional and global) and depositional environments (from continental to deep marine). This book in an 11 x 17 format is designed to be easily used for teaching or self-learning experiences. In the second edition of the "Atlas", the book was divided in 2 separately bound volumes—Exercises and Solutions—to make it easier to use the publication as text book for sequence stratigraphy courses in universities. Also, a new exercise was added and several of the existing exercises went through major updating and editing.

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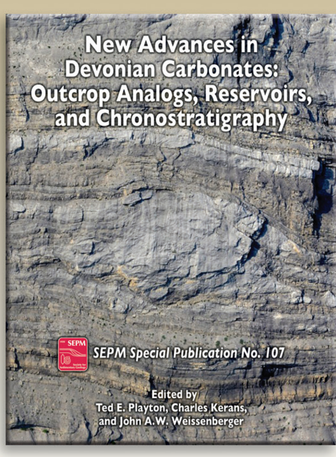

Special Publication #107

New Advances in Devonian Carbonates: Outcrop Analogs, Reservoirs, and Chronostratigraphy

Edited by: Ted E. Playton, Charles Kerans, and John A.W. Weissenberger

The Devonian stratigraphic record contains a wealth of information that highlights the response of carbonate platforms to both global and local phenomena that drive carbonate architecture and productivity. Signals embedded in the Middle-Upper Devonian carbonate record related to biotic crises and stressed oceanic conditions, long-term accommodation trends, and peak greenhouse to transitional climatic changes are observed in multiple localities around the world. Devonian datasets also show the importance of local and regional phenomena, such as bolide impacts, the effects of terrestrial input and paleogeography, syn-depositional tectonics, and high-frequency accommodation drivers. These add complexity to the carbonate stratigraphic record when superimposed on global trends. The unique occurrence of well-studied and pristinely preserved reefal carbonate outcrop and subsurface datasets, ranging across the globe from Australia to Canada, allows for a detailed examination of Devonian carbonate systems from a global perspective and the opportunity to develop well-constrained predictive relationships and conceptual models. Advances in the understanding of the Devonian carbonate system is advantageous considering, not only the classic conventional reservoirs such as the pinnacle reefs of the Alberta Basin, but also emerging conventional reservoirs in Eurasia, and many unconventional plays in North America. The papers in this volume provide updated stratigraphic frameworks for classic Devonian datasets using integrated correlation approaches; new or synthesized frameworks for less studied basins, reservoirs, or areas; and discussions on the complex interplay of extrinsic and intrinsic controls that drive carbonate architectures, productivity, and distribution. The 13 papers in this special publication include outcrop and subsurface studies of Middle to Upper Devonian carbonates of western Canada, the Lennard Shelf of the Canning Basin, Western Australia, and the western USA.

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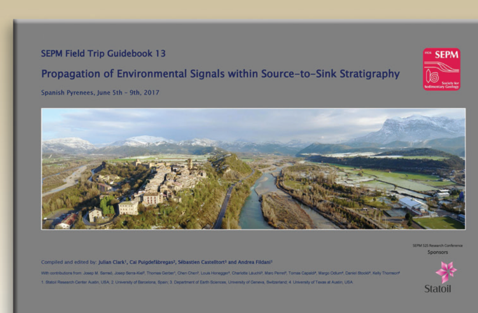
SEPM Field Trip Guidebook #13

Propagation of Environmental Signals within Source-to-Sink Stratigraphy

By: Julian Clark, Cai Puigdefàbregas, Sébastien Castelltort and Andrea Fildani



This guidebook was compiled for the field trip excursions of the SEPM Research Conference on the *Propagation of Environmental Signals within Source-to-Sink Stratigraphy*, (June 4th-10th, 2017). The world-class outcrop exposures and localities visited enabled the investigation of correlative stratigraphy from alluvial, fluvial, shallow marine, slope and deep marine environments with the direct observations of different segments of sediment routing systems. Decades of research in the region have contributed to our understanding of the basin-filling stratigraphic response to orogenic evolution and climatic events. These geologic insights and the well-preserved exposures have made the region a classic locality for both academic and industry-related geologic training, and a natural laboratory for continued research.

This SEPM Field Trip Guidebook presents key outcrops visited during the conference within a source-to-sink framework. The geologic map published herein is a cornerstone of this contribution, enabling and revising stratigraphic correlations required for this approach. An overview of source-to-sink concepts, methods and tools that can be applied to the stratigraphic record is provided, together with new data and analysis demonstrating environmental signals at different scales within the basin.

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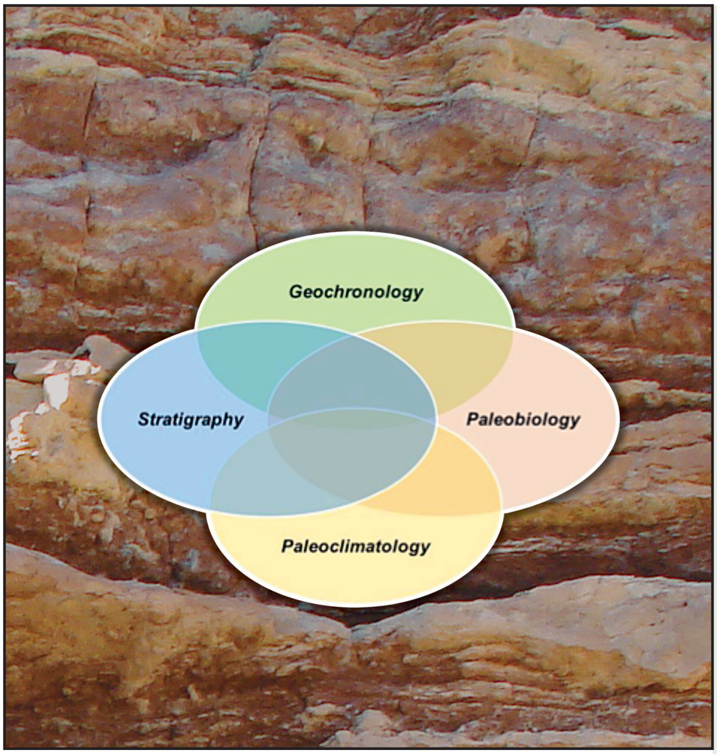

Cover image: The EarthRates community

CONTENTS

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What's Your Delta? EarthRates--A New NSF Funded Research Coordination Network for Linking Scales Across the Sedimentary Crust

Park Boush, Lisa, Center for Integrative Geosciences, University of Connecticut, 354 Mansfield Road, Storrs, CT 06269-1045

Lehnert, Kerstin, Lamont-Doherty Earth Observatory, Columbia University, 61 Route 9W, Palisades, NY 10964

Myrbo, Amy, LacCore, CSDCO, Department of Earth Sciences, University of Minnesota, 500 Pillsbury Dr. SE, Minneapolis, MN 55455

Noren, Anders, LacCore, CSDCO, Department of Earth Sciences, University of Minnesota, 500 Pillsbury Dr. SE, Minneapolis, MN 55455

Peters, Shanan, Department of Geology and Geophysics, University of Wisconsin, Madison, WI 53706

Singer, Bradley, Department of Geology and Geophysics, University of Wisconsin, Madison, WI 53706

Williams, Jack, Department of Geography, University of Wisconsin, Madison, 550 N Park St, Madison, WI 53706

WHAT IS EARTHRATES?

In the Anthropocene, which is characterized by rapidly accelerating rates of change and multiple interacting physical-social-biological feedback loops, understanding Earth as a system has never been more critical. Broad-based interdisciplinary research focusing on geological records of earth system dynamics is foundational to understanding Earth processes, governing feedback loops, location of tipping points and tipping elements, sensitivities of critical Earth system components, and the behavior of the earth system under forcings analogous to those expected in the near future (NRC, 2011). The need for multidisciplinary approaches to determine Earth boundary conditions and past and present states lies at the forefront of the major grand challenges outlined in numerous National Academy and community-driven reports (NSF 2009, NRC, 2011, NRC, 2012; Parrish et al., 2012). Building the capacity within the scientific community to address these challenges requires coordination and efforts to integrate a disparate community of researchers. The sedimentary crust community is large and diverse and includes sedimentologists, stratigraphers, geochemists, geochronologists, paleontologists, paleoecologists, modelers, and many others. Nearly one-third of Earth science faculty employed at U.S. universities work within one of these discipline areas (Wilson, 2013). National Academy and community-based reports have called for increased coordination and collaboration across these disciplines (Badgley et al., 2011; NRC, 2012; Parrish et al., 2012).

To address these needs and aims, we have established a National Science Foundation (NSF) funded Research Coordination Network (RCN) called **"EarthRates: Linking Scales Across the Sedimentary Crust."** This RCN will provide the framework and opportunity to engage critical communities and forge synergistic collaborations in order to foster transdisciplinary research in the sedimentary crust. EarthRates brings together community-led research science and outreach resources such as the Paleobiology Database, Neotoma, Macrostrat, EarthTime, EarthChem, IEDA, Earth-Life Transitions, Flyover Country, and the Continental Scientific Drilling Coordination Office to strategize, leverage and build partnerships, all to enable the community to address major grand challenges in Earth system science (Figure 1). These would include: 1) how have climate, the oceans, the Earth's sedimentary crust, carbon sinks and soils, and life itself evolved together, and what does this tell us about the future trajectory of the integrated Earth-life system? 2) what are the ranges of ecosystem response, modes of vulnerability, and resilience to rapid changes between Earth-system states? 3) how can we link together all geological observations into a common spatiotemporal framework, dynamically updated by the best available geochronologies? By bringing these groups together and building stronger partnerships and alliances, we will move towards the goal of **developing a fully integrated four-dimensional digital Earth to fully understand dynamic Earth system evolution**.

The EarthRates RCN builds on the recent activities of the former STEPPE Office (Smith and Iler, 2012) and facilitates efforts to grow and interlink the sedimentary crust community to 1) hold workshops, 2) develop working groups, 3) provide training opportunities, 4) launch data mobilization campaigns, 5) strengthen community ties, 6) discover new partners and opportunities and 7) promote with social media and strong web presence, with the ultimate aim to **build the capacity of the sedimentary crust community to further contribute to earth system science research**.

WHO IS EARTHRATES?

EarthRates was initiated and organized by the lead

PI, Lisa Park Boush (University of Connecticut) and the EarthRates Steering Committee, which currently is comprised of Kerstin Lehnert (Lamont-Doherty/Columbia University), Amy Myrbo (University of Minnesota), Anders Noren (University of Minnesota), Shanan Peters (University of Wisconsin), Bradley Singer (University of Wisconsin) and Jack Williams (University of Wisconsin). The Steering Committee will be expanded in the coming year to include additional members from across the community. With all of the workshop participants, working group members and others engaged with EarthRates, we consider everyone who studies the sedimentary crust to be a part of EarthRates!

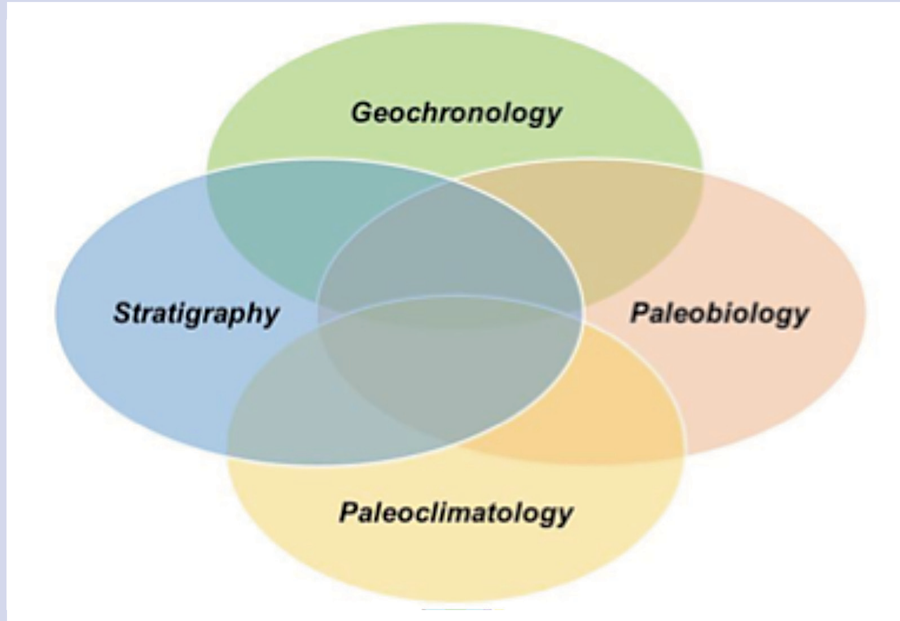

Figure 1: The EarthRates community

WHAT IS EARTHRATES GOAL AND MISSION?

EarthRates addresses the critical need to increase our understanding of surface Earth processes and rates of environmental change (NRC, 2011) by leveraging, coordinating and stimulating our diverse community of deep-time sedimentary crust researchers and informatics. We are building capacity by facilitating greater interaction between sedimentary crust scientists and creating new partnerships with other Earth and biological scientists to generate new tools and a community that are able to respond to the pressing research challenges of today and into the future, serving as a link among the many different ongoing activities.

EarthRates' vision is consistent with the vision of **EarthTime-EarthChem**, the **Paleobiology Database, Neotoma, Macrostrat, Flyover Country** and the **Continental Scientific Drilling Coordination Office** as well as the **Earth Life Transitions** PI community. Through EarthRates, these groups are being brought together to focus on the goal of building the framework for **a fully integrated four-dimensional Digital Earth to fully understand dynamic Earth system evolution as well as the research capacity to utilize a 4D Earth systems model and thus utilize this framework to understand rates of change in the geologic record (Figure 2).**

ON-GOING AND FUTURE ACTIVITIES

The focus of this RCN is to:

1. **Connect** established and emerging research communities
2. **Leverage** existing efforts in cyberinfrastructure to develop new capabilities
3. **Engage** new community members in collaboration and participation
4. **Build** overall capacity in sedimentary crust research
5. **Train** community members in using existing databases, their associated tools and services, and conduct data mobilization campaigns
6. **Create** a roadmap towards building a 4D Digital Earth

WORKSHOPS

One of the important functions of EarthRates is to bring scientists together. Thus far, we have supported two focused workshops—one for paleolimnologists interested in engaging with NEOTOMA, one on Conservation Paleobiology-- as well as one large, all hands workshop: **Setting Scientific Priorities for the Sedimentary Crust** (Figure 3). Based on proposals from an open call in September, 2017, we will sponsor 4 more small workshops in 2018 (Table 1). Our next call for small workshop proposals will be March 1, 2018. We anticipate the focus of these workshops to be on deep time.

For the **Setting Scientific Priorities** workshop, held November 9-11, 2017, EarthRates convened a large, all-hands meeting that included approximately 60 participants. This workshop brought together members of the EarthRates network to discuss updates to the major grand challenges (NRC, 2011) regarding **rates of change in the geological record** with respect to paleoclimate (e.g., tipping points and ecosystem thresholds), paleobiology (e.g., critical transitions of the past, extinction and evolution), crustal evolution and dynamics (e.g., modeling basin evolution, crustal tectonics and variability in sedimentary fill and paleoclimate indicators), and resources for humanity (e.g., the

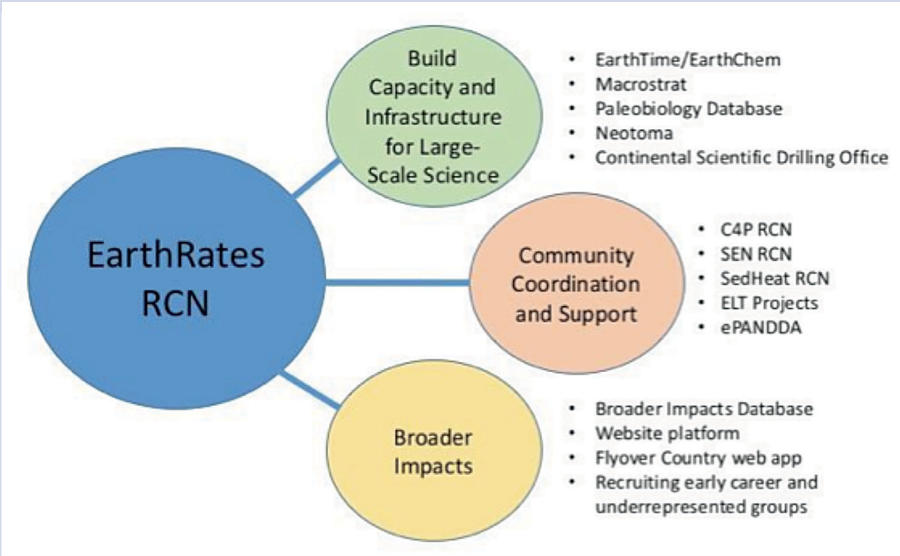

Figure 2: EarthRates-building a stronger community for the sedimentary crust.

coupling of key evolutionary events and environmental shifts, quantifying and managing energy stores for the future). During this workshop, participants began outlining a roadmap for broad-scale approaches to addressing these rates-based problems through vehicles--such as the 4D Digital Earth--as well as other transdisciplinary efforts. The outcomes of this workshop include 1) a series of 11 two-page documents that identify **key questions related to various topics and sub-disciplines and the major opportunities and approaches to addressing those questions**, 2) four responses to the NSF call for Mid Scale Infrastructure, and 3) the starting point for a community white paper that will focus on the **major science questions** of the sedimentary crust and develop a **strategic and action plan** for future activities to enable big-scale science. We anticipate the white paper will be available for community comment by late spring and presented to NSF in early Fall, 2018.

A **second large workshop** will be convened in 2019, which will include representatives of the working groups as well as community members identified in the EarthRates activities (e.g. webinars, demo camps, town halls, topical sessions, etc.). This workshop will be focused on dissemination of working group activities as well as further development of the strategic plan for building the 4D Digital Crust infrastructure. The outcomes of this workshop will rely heavily on those areas identified in the first workshop as priorities.

SMALL WORKSHOPS

Small, targeted workshops of ~10-20 people will be supported in the EarthRates RCN for the purpose of supporting RCN activities as well as the sedimentary crust community at large. Stand alone workshops will be supported at approximately $15,000 per workshop. In addition, we will explore the possibility of having multiple funding models, including the current levels of workshop support for stand-alone meetings and funding to support meetings that would occur in conjunction with larger professional society meetings or events. Calls for proposals will be approximately every 6 months (September, 2017; March, 2018; September 2018; March, 2019) and will be focused on various synergistic areas.

WORKING GROUPS

Working groups established through the large workshops or by other means will be supported by the EarthRates RCN via 1) hosting **virtual meetings**, 2) providing

Title	Location and Date
NEOTOMA/DIVA-GIS Database and Software Workshop	Santa Barbara, August, 2017
Conservation Paleobiology Workshop	Seattle, October, 2017
Speed Dating Pardee Session, Geological Society of America Annual Meeting	Seattle, October, 2017
All Hands Meeting-Setting Scientific Priorities for the Sedimentary Crust	Minneapolis, November, 2017
Developing a multi-proxy approach to reconstructing the climatic and environmental history of lakes in semi-arid India over the Common era	TBA
What forcing mechanisms sustained the large perennial North American Pliocene West	Minneapolis, January, 2018
Open and interoperable data standards in the paleogeosciences	TBA
Drilling Deeper for Connections Between Environmental Change and Evolution	TBA

Table 1: Workshops and Activities supported by EarthRates, Year 1.

Figure 3: EarthRates All Hands Meeting, November, 2017

online workspace and 3) **archiving of materials** generated by the groups. In addition, the RCN will help working groups apply for activities such as Goldschmidt and Penrose Conferences support and assist in convening topical or theme sessions at GSA or AGU meetings and will utilize GSA Divisions **(Sedimentary Geology, Limnogeology), as well as Society for Sedimentary Geology (SEPM), Paleontological Society, Society for Vertebrate Paleontology, the American Indian Science and Engineering Society (AISES), and Society for Advancing Hispanics/Chicanos and Native Americans in Science (SACNAS)** to contact and target members of the community to participate in these workshops and working groups. An example of this type of support was the Geological Society of America Annual Meeting Pardee session called **Speed Dating!** which was partially supported by EarthRates. This highly successful and innovative method to convene a Pardee session—posters with flash talks and 2 page take-aways on almost every major geochronometer—is the type of activity that EarthRates envisions supporting in the future.

TRAINING OPPORTUNITIES

DEEP-TIME DEMO CAMPS

Building on the successful models of iDigBio demo camps, the Community Surface Dynamics Modeling System (CSDMS) annual clinics, and the LacCore/CSDCO Drilling and Coring Summer Institute, the EarthRates RCN plans to provide targeted demo camps to help the community gain research and quantitative skills for using new tools and technology as well as big data to answer science questions. Deep-Time Demo Camps might include topics like: Applying ecological niche modeling to deep-time datasets; using geochronological and stratigraphic data to create basin sedimentation models; or generating models that incorporate disparate datatypes from both the geosciences and biosciences, learning analytical skills for collecting and analyzing geochronologic data. Demo camps will provide an opportunity for the community to learn new skills and will help identify needs for new tools development that can be the focus of future work (held in collaboration with ePANDDA, NEOTOMA, PBDB, etc.) and collaborative grants with partners to build new integration points with other large initiatives (e.g., Open Core Data, Flyover Country geoscience mobile app). All demo camps will have a webinar series, with speakers who are leaders in the field, followed by the Demo Camp. Webinars will be archived and available for later viewing/reviewing on the EarthRates website. Toolkits with software, code, etc. will be made easily accessible through this platform.

Figure 4: EarthRates affiliated organizations

DATA MOBILIZATION CAMPAIGNS

A number of data mobilization campaigns are planned for EarthRates. These would be in conjunction with the major databases and data platforms involved in the project: Paleobiology Database, Neotoma, Macrostrat, EarthChem, and IEDA. A particular focus will be on ways to expose radioisotopic age determinations and improve temporal resolution of earth history. These will be combined and coordinated with other efforts such as Deep-Time Demo Camps and workshops. The individual databases will be responsible for these efforts but the RCN will coordinate and support them.

DISCOVERING NEW PARTNERS AND INCREASING DIVERSITY

One of the major purposes of EarthRates is to develop the community and to recruit new partners and create new opportunities for collaborations. We will do this by targeting new PIs as well as underrepresented groups to invite to workshops, demo camps and other activities and ensure that we continue to strive to increase diversity in the geosciences.

EarthRates will also support projects such as ePANDDA, as well as the C4P, SedHeat, and SEN RCNs, and will work with these groups to build in a sustainable mechanism for the longer-term life of these projects that will allow them to continue even after NSF funding has ended. EarthRates will serve as the online repository of all associated documents (white papers/reports, papers, etc.) and provide continuing online virtual collaboration space for these groups when their project funding ends. EarthRates will act as an advocate for integrating and including these groups into ongoing activities and proactively provide support for their respective communities' development.

CONNECTING WITH EARTHRATES

EarthRates has an active website www.earthrates.org and Twitter feed @earthrates as well as a Facebook page. We also post information of interest on community listservs and in newsletters. You can contact EarthRates directly via email at earthrates@gmail.com (Figure 4).

SUMMARY

Never before has such a diverse community been poised to come together to begin building the capacity to do transdisciplinary research to address major science challenges. Because of individual efforts in databases like Neotoma, Paleobiology Database, Macrostrat, Flyover Country, IEDA and EarthChem and combined community building efforts like EarthTime, C4P, ePANDDA, SedHeat, the Continental Scientific Drilling Coordination Office (CSDCO) and the STEPPE Office, researchers interested in the grand challenges of understanding rates of processes within Earth's sedimentary crust will be able to come together in a series of workshops, working groups, and training opportunities to link and leverage their activities in order to build a 4D digital Earth. EarthRates will provide the means by which effective coordination and collaboration can take place to achieve that goal. We hope you join us in this effort!

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PRESIDENT'S COMMENTS

Dear colleagues, dear sedimentary friends,

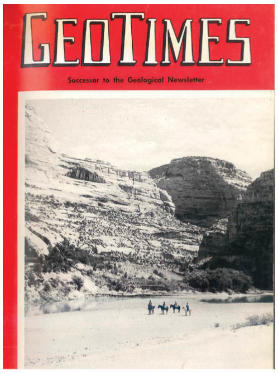
I am very pleased to announce that the location and dates for our first SEPM International Sedimentary Geologic Congress (ISGC) are set. The meeting will take place in Flagstaff (Arizona), April 26-29, 2020. The Congress location was selected in the heart of the North American West, close to magnificent sites such as Grand Canyon, Death Valley and the Mojave Desert. An extensive field trip program will offer unique opportunities to visit outstanding locations for outcrop discussions, training, and inspiration. The motivation behind the conference is to foster multidisciplinary and innovative approaches in sedimentary Geology, and offer opportunities for the cross-pollination of disciplines. Currently a joint SEPM/IAS Committee is planning our 2020 Congress. Stay tuned for news and requests for active involvement in the planning and program.

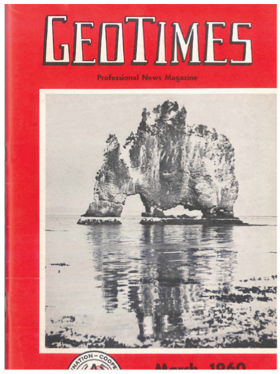
This Congress sets an important milestone in the relationship between SEPM and IAS, as both societies are committed to further their collaboration. The SEPM ISG Congresses will be organized by SEPM and co-sponsored by IAS and are planned to take place every four years, in rotation with the IAS International Meetings, which will be organized by IAS and co-sponsored by SEPM; meaning there will be an major international sedimentary geology meeting every two years. The SEPM and IAS global sedimentological community will enjoy a reliable platform to best share global advances in sedimentary geology, stratigraphy and paleontology. This acts as a phenomenal opportunity to nurture an active and global community of sedimentary geology, which we hope will more than ever attract new international members.

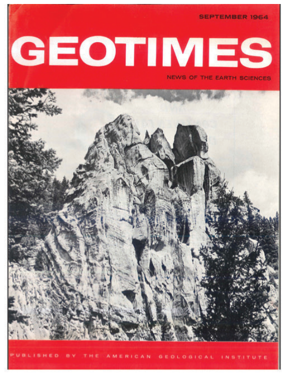
As part of the process of finding solutions for the future that can bring more benefits to our members, the SEPM Council has been busy planning a set of important initiatives, to ensure that the community keeps active and engaged. I would like to briefly mention three here. Council plans to expand on the involvement of international members by engaging specific regions into organizing classic Field Trips, which will be supported by SEPM. A call for proposals will be out soon. A second initiative will consist of Field Schools for Young professionals, co-taught by academics and industry. The first School is planned to take place in Summer 2019 in the Alps and will be organized by myself, Rick Sarg and Kristin Bergmann. Finally the first Bouma Conference on Deep-Water Geoscience is being overseen by a committee including: Donald Lowe; Zane Jobe; Giancalo Davoli; and Roberto Davila. Stay tuned for more information.

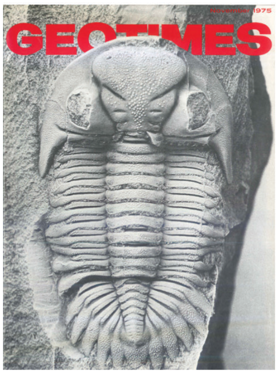
Let me conclude by wishing you all a healthy, successful and inspiring 2018.

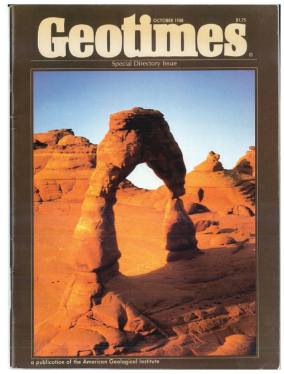
Maria Mutti, SEPM President

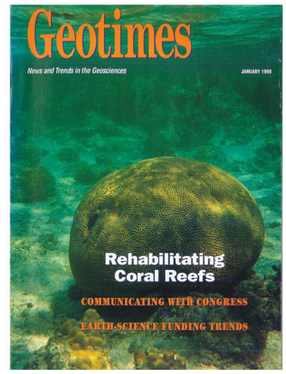


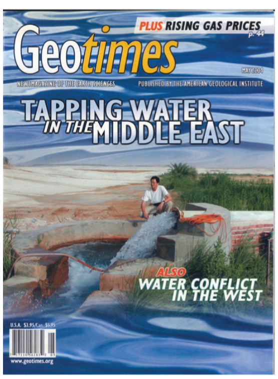










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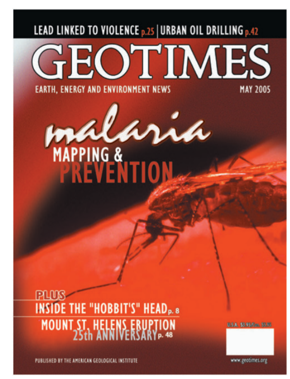
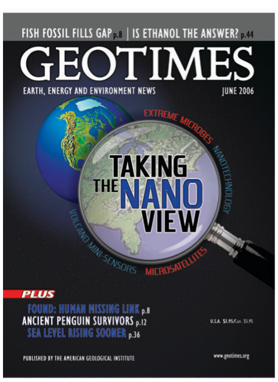
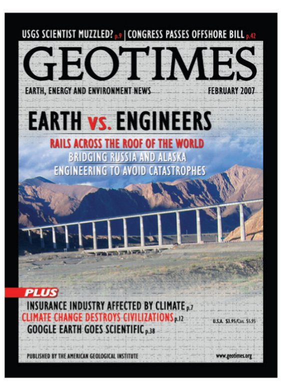
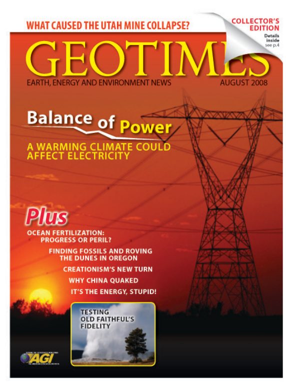
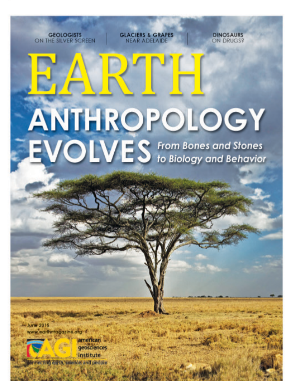
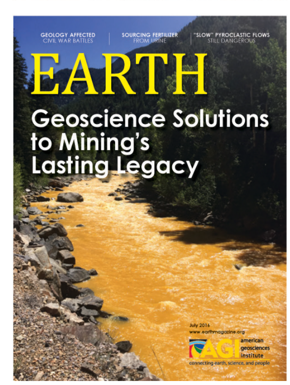












LANDMARK PAPERS IN PALEONTOLOGY AND BIOSTRATIGRAPHY

In anticipation of the 100th Anniversary of the American Association of Petroleum Geologists, it was decided to assemble lists of outstanding papers considered as landmarks in applied geology, more specifically within the petroleum industry. Subcommittees were formed for fifteen technical areas ranging from exploration concepts and salt tectonics, to unconventional resources and paleontology.

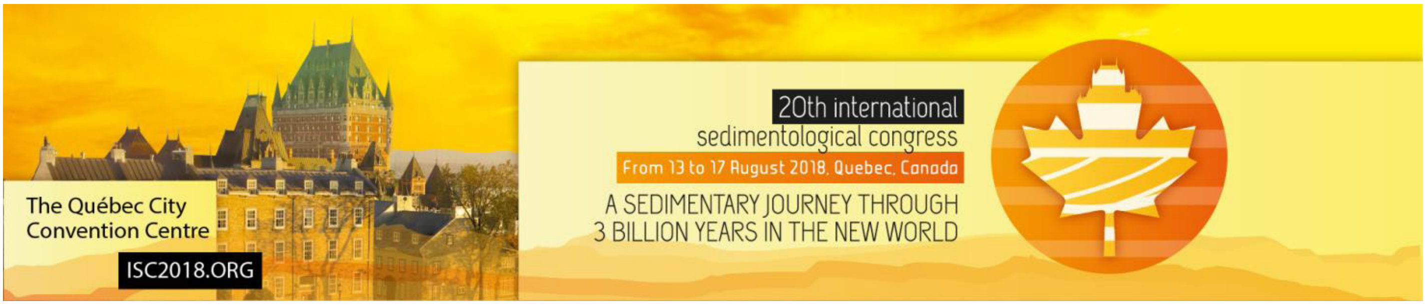
The AAPG Landmark Committee's Chair, Randi Martinsen, challenged each subcommittee to define a focusing theme and then to work toward a committee consensus selecting no more than ten landmark papers. For those papers selected, supporting text was to address why the paper made a significant contribution, whether or not it caused a paradigm shift, and if it had a lasting impact. The Landmark Papers on Paleontology are included as Appendices to this issue of *The Sedimentary Record*.

The Paleontology Subcommittee proposed that their work address both fundamental paleontological tools such as taxonomy and zonation, but also identify landmark publications in applied biostratigraphy. As our contribution in both areas demonstrates, limited to no more than 10 landmark papers each, resulted in compromises and citation of 100 additional significant papers. These results were achieved in an iterative process but without all contributor's being satisfied in the final list, a feeling many are likely to share. There is a wealth of additional papers and books that merit inclusion, especially in the global literature.

The AAPG Landmark Papers recognized eight contributions for "Paleontology Tools" and ten for "Applied Biostratigraphy" (Appendix A. AAPG Landmark Paper – Paleontology Tools and Appendix B. AAPG Landmark Paper – Applied Biostratigraphy). These AAPG Landmark Paper files have been released by AAPG for posting on the Websites of SEPM, The Cushman Foundation, The North American Micropaleontologic Society, and The Micropalaeontological Society.

These documents result from efforts of the following contributors:

John M. Armentrout, Mobil–retired, Damascus, Oregon; Ronald J. Echols, Mobil–retired, Naples, Florida; Nancy L. Engelhardt-Moore, ALS Oil & Gas – Reservoir Laboratories, Houston, Texas; Tony D'Agostino, Hess, Houston, Texas; Kenneth L. Finger, Univ. of California Museum of Paleontology, Berkeley, California; Maria A. Lorente, PDVSA-retired, currently ALS Oil & Gas, Houston, Texas; Ronald Martin, University of Delaware, Newark, Delaware; Michael J. Nault, Applied Biostratigraphix & ALS Oil & Gas, Houston, Texas; Edward Picou, Shell–retired, New Orleans, Louisiana; Mike Simmons, Halliburton, Great Britain; Art Waterman, Paleo-Data, New Orleans, Louisiana.



Abstract Submission now open!

The local organizing committee in collaboration with the scientific committee cordially invites you to the 20th International Sedimentological Congress (ISC) to be held from August 13 to 17, 2018 in Québec City. The five-day-long event will offer 6 parallel oral sessions along with short oral presentations and poster sessions. You can now submit your abstract through our website. 7 general scientific themes on fundamental to applied sedimentology have been identified. The sedimentological community enthusiastically responded to the call for sessions with 56 sessions being proposed, covering the following themes:

1. The carbonate depositional system
2. The clastic depositional system
3. Paleo-environments and Paleo-climates
4. Sedimentary Processes
5. Sources & Sinks
6. Applied sedimentology
7. Other topics

In addition, the Congress offers pre-, post- and mid-conference field trips, an exhibition, Early Career Scientists events as well as a variety of courses and workshops. It is possible for groups, institutions and companies to organize supplementary activities during the conference (meetings of working groups, etc.). Please, visit our website regularly as new details on field trips, workshops and short courses will be added shortly.

Call for papers is open – December 11, 2017

Registration begins – January 15, 2018

Abstract submission deadline – March 19, 2018

Paper acceptance notice – April 23, 2018

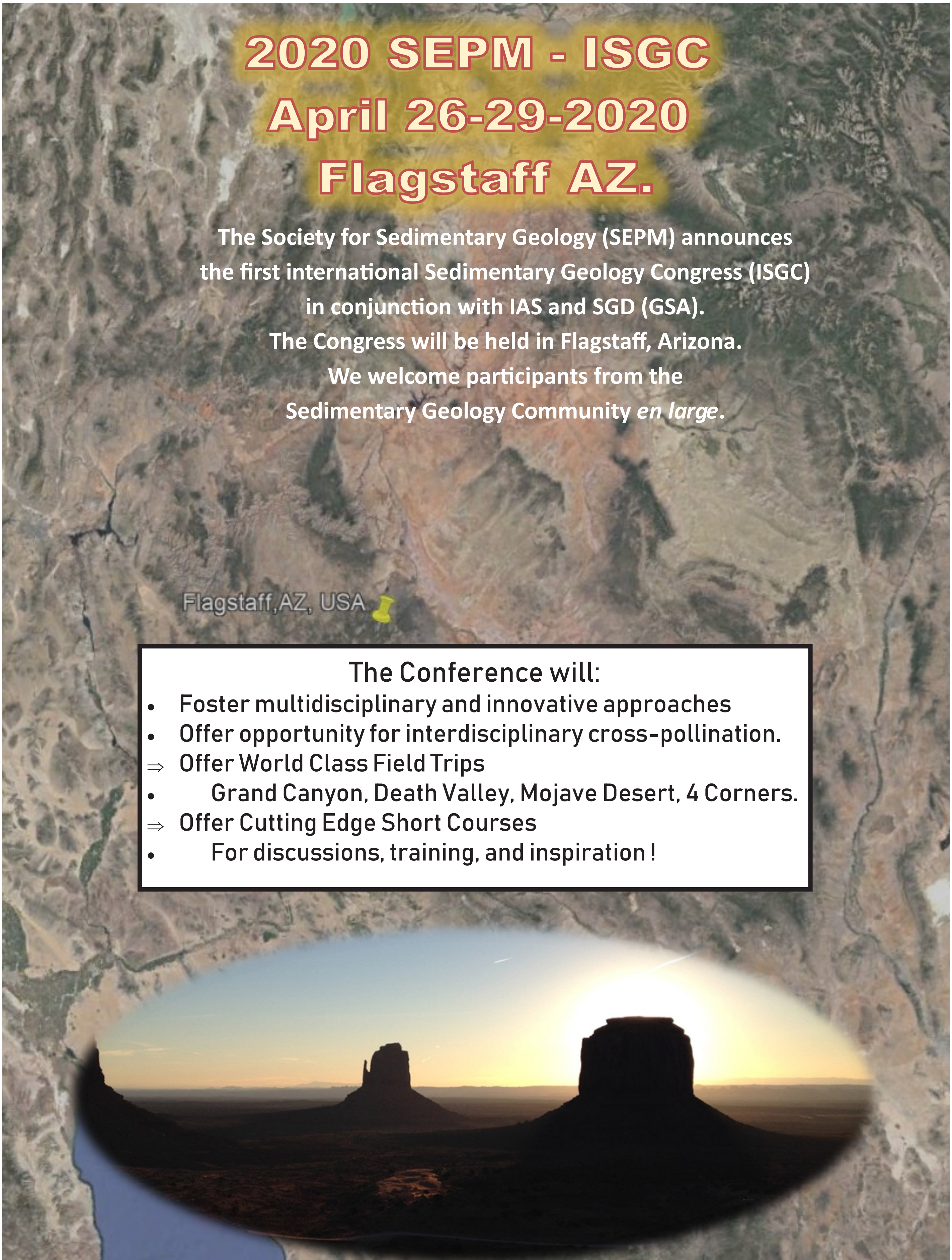
Early bird & presenting author registration deadline – May 14, 2018

ISC2018 is sponsored by the SEPM

Visit our website for more information & to submit your abstract

ISC2018.ORG

Follow us on Twitter **@ISC_2018**



2020 SEPM - ISGC
April 26-29-2020
Flagstaff AZ.

The Society for Sedimentary Geology (SEPM) announces the first international Sedimentary Geology Congress (ISGC) in conjunction with IAS and SGD (GSA).
The Congress will be held in Flagstaff, Arizona.
We welcome participants from the Sedimentary Geology Community *en large*.

The Conference will:

- Foster multidisciplinary and innovative approaches
- Offer opportunity for interdisciplinary cross-pollination.
- ⇒ Offer World Class Field Trips
- Grand Canyon, Death Valley, Mojave Desert, 4 Corners.
- ⇒ Offer Cutting Edge Short Courses
- For discussions, training, and inspiration !

UPCOMING SEDIMENTARY GEOLOGY MEETINGS

2018

- 2018 - Western Pacific Sedimentology Meeting, 2018WPSM, 19-20 March 2018, GwangJu, South Korea. https://2018wpsm.wixsite.com/home
- 2018 – Garrison Monterey Formation Research Conference (SEPM), May 8-10, 2018, Santa Cruz, CA, USA. www.sepm.org/pages.aspx?pageid=439
- 2018 - AAPG ACE/SEPM Annual Meeting, May 20-23, 2018, Salt Lake City, Utah, USA. http://ace.aapg.org/2018
- 2018 - International Conference Resources for Future Generations 2018, 16-21 June 2018, Vancouver, Canada. http://rfg2018.org/
- 2018 - International Paleolimnology Association and International Association of Limnology, June 18-21, 2018, Stockholm, Sweden. http://ipa-ial.geo.su.se/
- 2018 - Cyclostratigraphy Intercomparison Project Workshop, 30 July - 1 August 2018, Brussels, Belgium. http://we.vub.ac.be/en/cyclostratigraphy-intercomparison-project
- 2018 - 10th European Palaeobotony and Palynology Conference – 2018, August 12-19, 2018, Dublin, Ireland, http://eppc2018.ie/
- 2018- 20th International Sedimentology Congress (IAS). August 13-17, 2018, Quebec City, Quebec, Canada. http://isc2018.org/
- 2018 – 9th International Conference on Asian Marine Geology, October 10-12, Shanghai, China. http://icamg-9.tongji.edu.cn/
- 2018 – Asia Oceania Geosciences Society, June 3-8, 2018, Honolulu, Hawaii, USA. www.asiaoceania.org

AND

2020

- 2020 – 1st International Sedimentary Geology Congress (SEPM), April 26-29, 2020, Flagstaff, Arizona, USA. www.sepm.org

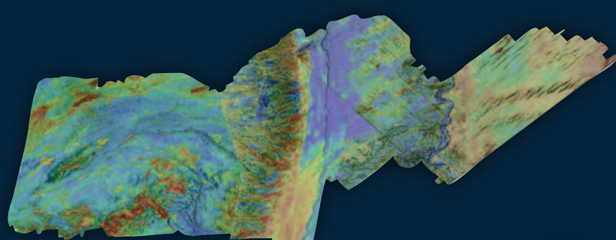
The Geological Society
serving science, profession & society

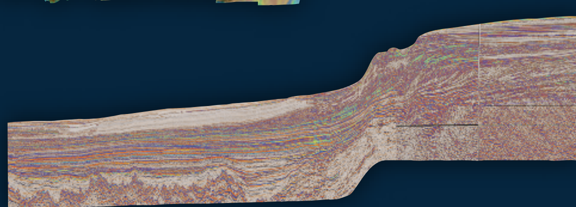
SEPM Society for Sedimentary Geology

BSRG Sedimentary Research

Seismic Characterisation of Carbonate Platforms and Reservoirs

10-11 October 2018 The Geological Society, Burlington House, London





Fundamental advances in the seismic imaging and characterization of carbonate platform strata, including reservoir rocks, have revolutionized understanding of carbonate geomorphology, stratigraphy and reservoir architecture. This meeting aims to synthesize these innovative developments and explore the variety of carbonate characteristics that can now be interpreted from modern and reprocessed seismic data. It will discuss and illustrate how the technology can be used in exploration, development and production evaluations, as well as for understanding long-term and large scale forcing of carbonate platform development. The focus will be on practical geoscience applications and the meeting will provide a forum for lively interaction between the upstream oil industry, seismic contractors, and carbonate sedimentology researchers.

Conference Themes

- Seismic evidence for controls on carbonate platform development over millennial time scales and kilometric length scales
- Seismic geomorphology and 3D internal architecture of carbonate platforms
- Carbonate sequence stratigraphy and palaeogeography from seismic data, and the discrimination of carbonate, clastic and volcanic features
- Carbonate seismic facies interpretation at reservoir scales and seismic characterisation of fractured carbonates
- Seismic attributes for porosity and lithology discrimination, identification of epikarst, hypogene karst and hydrothermal dolomitisation
- Using 3D and 4D seismic in carbonate reservoir modelling
- Carbonate rock physics and potential for AVO and EEI in carbonates
- Forward modelling carbonate geometries, seismic inversion and synthetic seismic models of carbonates
- Tailoring acquisition and processing for carbonate objectives

Convenors

Jim Hendry (Tullow Oil)
Pete Burgess (University of Liverpool)
Dave Hunt (Statoil)
Xavier Janson (University of Texas, Austin)
Valentina Zampetti (Shell)

Further information

For further information please contact:
Georgina Worrall, Conference Office,
The Geological Society, Burlington House,
Piccadilly, London W1J 0BG
T: (+44/0) 20 7434 9944
E: georgina.worrall@geosoc.org.uk
Web: www.geolsoc.org.uk/carbonates18

The Geological Society serving science & profession — 2018 YEAR OF RESOURCES

Call for Papers

Submission for oral or poster presentations are welcome. Registration and abstract submission forms are available via the conference web page, and the deadline for abstract submission is 2nd March 2018.

SEPM Call for Proposals

FIRST BOUMA CONFERENCE on DEEP-WATER GEOSCIENCE

Supported by a generous gift from the Arnold and Lieneke Bouma Endowment Fund.

The Kanaalkop Channel in the Tanqua-Karoo sequence, South Africa

Bouma Conferences are stand-alone research conferences to be held every 3 years designed to encourage communication, education, and study of deep-water systems.

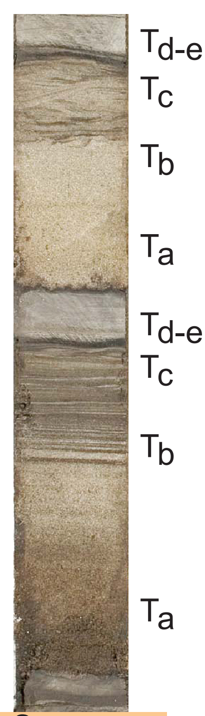
They may be 3-6 days in length, held anywhere is the world, and involve field trips to outstanding deep-water outcrops.

It is anticipated that the first Bouma Conference will be held in 2019 or 2020. Potential conveners should consult the guidelines for organizing research conferences on the SEPM Website. Proposals should include:

1. Conference title
2. Names of conveners and contact information,
3. Proposed dates — starting and ending points of the conference
4. Brief summary of the scope of the proposed conference and why it is timely (1 page)
5. Tentative program outline (oral, poster, discussion, field sessions)
6. Tentative list of key participants and the anticipated total number of participants
7. Minimum and maximum number of participants
8. A general budget estimate

SEPM will be the financial sponsor and will work with the conveners to construct the final budget and set registration fees. There should be partial funding from the Bouma Endowments to help students and early career professionals attend. Other budgeted items can include some travel costs for a few keynote speakers and registration fees for the actual conveners.

Proposals for the first Bouma Conference should be submitted to Howard Harper, Executive Director, SEPM, (hharper@sepm.org) by May 1, 2018.



The Bouma Sequence in turbidites

AAPG Landmark Papers

Paleontology Tools

Contributors

John M. Armentrout (retired from Mobil) – Coordinator
Ronald J. Echols (retired from Mobil)
Nancy L. Engelhardt-Moore, ALS Oil & Gas Reservoir Laboratories (retired, previously with Amoco, Devon, and Ellington & Assoc.) – Technical Editor
Tony D'Agostino, Hess Corp. (previously with ARCO)
Kenneth L. Finger, University of California Museum of Paleontology (previously with Chevron) – Technical Editor
Maria Antonieta Lorente, ALS Oil & Gas Reservoir Laboratories (previously with PDVSA)
Ronald Martin, University of Delaware (previously with Unocal)
Michael J. Nault, Applied Biostratigraphix and ALS Oil & Gas (previously with Tenneco, Chevron, BP)
Edward Picou (retired from Shell)
Mike Simmons, Halliburton/Neftex (previously with BP)
Mike Styzen (retired from Noble Energy and Shell)
Arthur S. Waterman, Paleo-Data (previously with Texaco)

INTRODUCTION

This compilation of landmark papers complements the Applied Biostratigraphy case histories. We have selected nine foundational publications that have enabled micropaleontologists and palynologists to assist in geologic interpretation. These works are historical contributions that have led to the modern interpretation and application of subsurface microfossil assemblages. They are sorted into three categories: 1) biozonation and chronostratigraphy, 2) biofacies models, and 3) application of graphic correlation.

Readers wishing to delve deeper into this subject are directed to the following publications containing excellent examples of value-added studies:

Berggren, W. A., D. V. Kent, M.-P. Aubry, and J. Hardenbol, eds., 1995, Geochronology, time scales and global stratigraphic correlation: Tulsa, Oklahoma, SEPM Special Publication, v. 54, 386 p.

Bolli, H. M., J. B. Saunders, and K. Perch-Nielsen, eds., 1985, Plankton stratigraphy: Cambridge, UK, Cambridge University Press, 1032 p.

Bowden, A. J., F. J. Gregory, and A. S. Henderson, eds., 2004, Landmarks in foraminiferal micropaleontology: history and development: London, UK, Geological Society, The Micropalaeontological Society, Special Publications, 360 p.

Bown, P. R., ed., 1998, Calcareous nannofossil biostratigraphy: London, UK, Chapman and Hall, British Micropalaeontological Society Publication Series, 315 p.

Gradstein, F. M., J. G. Ogg, M. D. Schmitz, and G. M. Ogg, eds., 2012, The geologic time scale 2012: New York, Elsevier, 1176 p.

Two quantitative works not included among our top 10 references are worthy of mention for their significance in biostratigraphic correlation:

Forgotson, J. M., Jr., and C. F. Iglehart, 1967, Current uses of computers by exploration geologists: AAPG Bulletin, v. 51, no. 7, p. 1202–1224.

Shaw, A. B., 1964, Time in stratigraphy: New York, McGraw-Hill, 365 p.

SELECTED FOUNDATIONAL PUBLICATIONS

1. Biozonation and Chronostratigraphy

Applin, E. R., A. E. Ellisor, and H. T. Kniker, 1925*, Subsurface stratigraphy of the coastal plain of Texas and Louisiana: AAPG Bulletin, v. 9, p. 79–122.*

In 1921, Ester Applin gave a presentation at a meeting in Amherst, Massachusetts, in which she proposed using microfossils in oil exploration, specifically for the dating of the rock formations in the Gulf of Mexico region. Although disputed by a professor from University of Texas at Austin, her contention was shared by Joseph Cushman, a native resident of Massachusetts whose name was about to become synonymous with foraminiferal research. A few years later, the landmark publication by Applin, Ellisor, and Kniker, as well as Cushman's successful application of foraminiferal biostratigraphy for an oil well in Mexico, established the utility of this new geologic tool, which was embraced by the American oil industry (Finger, 2013; Martin, 2013).

This paper was the first to document the application of foraminiferal biostratigraphy in subsurface geologic correlation and it represented the first step towards the extensive modern biozonation of the U.S. Gulf Coast. The authors used diagnostic taxa to define their “faunal” or assemblage zones, which they integrated with wireline log data to create a regional stratigraphic framework. It was a vast improvement over the prior method of geologic correlation, which relied solely on lithologies interpreted from well logs. This new approach was particularly beneficial in coastal areas, where reliable correlations were often elusive due to rapid facies changes and repetitive lithologies.

As Howe (1959, p. 511) stated in his review of the history of micropaleontology, “Credit for the resolution which took place in the use of foraminifera properly goes to three ladies, Esther Richards Applin [Rio Bravo Oil Company], Alva C. Ellisor [Humble Oil and Refining], and Hedwig T. Kniker [The Texas Company]. Their paper on the subsurface stratigraphy of the coastal plain of Texas and Louisiana (1925) had been presented before the Annual Meeting of the American Association of Petroleum Geologists in Shreveport, Louisiana and the discussion which followed opened the eyes of oil company executives.” Soon thereafter, micropaleontological biostratigraphy "bloomed" in both academia and industry.

Kleinpell, R. M., 1938*, Miocene stratigraphy of California: Tulsa, Oklahoma, AAPG, 450 p.*

Kleinpell's seminal publication was the first book documenting the biostratigraphic zonation for an entire region with multiple contemporaneous basins. It provided a major advancement in unraveling the complex stratigraphy of the hydrocarbon basins in California. His focus was benthic foraminiferal biostratigraphy. Being both abundant and relatively large, benthic foraminifera are the most conspicuous microfossils in California and their application as a correlation tool in the "oil patch" was still in its infancy when Kleinpell began working on his dissertation at Stanford University in 1931. He used these fossils to develop a biostratigraphic framework for the California Miocene that served as the major reference for most micropaleontologists working on the West Coast for many years. The Miocene section was of particular interest to the oil industry because it consisted predominantly of the Monterey Shale, a geographically extensive source-and-reservoir rock unit. Kleinpell's work was strongly influenced by fieldwork with his older brother William (an oil company geologist), his fellow Stanford student Hollis Hedberg, whose name later became synonymous with American stratigraphic principles, and biostratigraphic methods of the 19th Century German geologist Albert Oppel, who developed a Jurassic ammonite zonation for Europe. After completing his dissertation, Kleinpell applied the principles he had set forth to his consulting work in the oil industry with considerable success. He became widely recognized as the West Coast's leading expert on foraminifera and their biostratigraphy.

This book reflects the extensive taxonomic and biostratigraphic familiarity Kleinpell had with the benthic microfauna. He used this knowledge to formulate a zonation that emulated what Oppel had done with ammonites. Kleinpell divided the Miocene into six stages named for their respective type localities, which in turn were divided into 15 zones, each bearing the name of a prominent species and most being defined by the first appearance of a species at its base and the last appearance of a species at its top. Which and how many of the diagnostic species had to be present to identify a zone was a matter of subjectivity. In essence, each zone was a type of range zone, later termed "Oppel Zone", characterized by the occurrence of certain species within the interval, regardless of their associations in individual assemblages. This was the only viable means for interbasinal correlation of benthic faunas in the Miocene of California, and Kleinpell's application of it received worldwide recognition.

In 1946, Kleinpell joined the Department of Paleontology at the University of California in Berkeley where he supervised V. Standish Mallory's complementary dissertation on the California Paleogene, which in 1959 was also published in book form by the AAPG. This completed the benthic foraminiferal framework for the California Cenozoic as Natland (1952, 1957) had already named the Pliocene-Pleistocene stages in which he incorporated the zones that had been defined by Wissler (1943).

Imperfections of the California benthic foraminiferal composite scheme became increasingly evident as micropaleontologists often had difficulty applying both the taxonomic and zonal concepts of its authors. Each stage was described from its type locality in one depositional basin, so interbasinal correlations were often problematic.

Beginning in the early 1970s, more accurate planktic biostratigraphies, specifically those of calcareous nannoplankton and diatoms, revealed that Kleinpell's stages were plagued by time transgressions and overlaps. It also became evident that they could not be used to correlate two contrasting depositional environments, which supported Natland's long-held conviction that all of the benthic stages were based on paleoenvironmental changes that varied in time and space. Nevertheless, application of Kleinpell's benthic foraminiferal framework for California led to the recovery of billions of barrels of oil and its stage names are engraved in the regional geologic vernacular.

Martini, E., 1971, *Standard Tertiary and Quaternary calcareous nannoplankton zonation,* in *A. Farinacci, ed., Proceedings, 2nd International Conference Planktonic Microfossils Roma: Rome (Edizioni Technoscienza), v. 2, p. 739–785.*

Martini's publication was the first compilation of Tertiary and Quaternary nannofossil assemblages and stratigraphic ranges. His zonation was based primarily on his own research (i.e., Martini, 1970; Martini and Worsley, 1970) and that of others, including Bramlette and Wilcoxon (1967), Hay et al. (1967), and Gartner (1969). Martini's paper provides a comprehensive framework of zones bearing letter-number designations (NP 1–25 and NN 1–21) and defines the zonal boundaries. This zonation was widely adopted and is still considered the global "standard" for nannofossil zonation. Martini included useful range charts of the zone-defining species, charts comparing his zones to those for planktic foraminifera and silicoflagellates, and images of key taxa.

Although subsequent studies indicate that a few of the nannofossil taxa that Martini used to define zonal boundaries are not widely recognized or have diachronous datums, most have stood the test of time. Several amendments or additions have been proposed to improve the utility of his 1971 zonation. Some biostratigraphers now prefer the newer nannofossil zonation by Okada and Bukry (1980) that is based on low-latitude nannofloral assemblages. Martini's scheme, however, has been largely adopted by investigators in the DSDP, ODP and IODP research programs, which have expanded the application of calcareous nannofossils as a fundamental biostratigraphic tool in deep-marine deposits.

Hardenbol, J., and W. A. Berggren, 1978, *A new Paleogene numerical time scale: Tulsa, Oklahoma, AAPG Studies in Geology, v. 6, p. 213–234.*

Stratotypes represent the formal basis for relating time and rock units. Hardenbol and Berggren closely examined the relationship of the Paleogene stage stratotypes, all located in Europe, to a global chronostratigraphic framework in order to facilitate numeric basin modeling. Significantly, they correlated the Paleocene, Eocene, and Oligocene biozonations of planktic foraminifera and calcareous nannoplankton that were established in these stratotypes to magnetic polarity history and radiometric ages. The authors accomplished this by drawing on the global results of the Deep Sea Drilling Project. The result was a robust global chronostratigraphy for the middle and low latitudes.

This paper was published during the time that the development and application of "Exxon-style" sequence stratigraphy was shifting stratigraphic paradigms. Hardenbol and

Berggren were the first to take the multi-fossil group approach with microfossils instead of invertebrate macrofossils that were previously used to define biozonations of the European stratotype sections. Their high-resolution chronostratigraphy was of particular value to the newly emerging techniques of basin modeling and geohistory analysis that were applied to the Paleogene.

Similar methods incorporating additional types of data led to the more refined and chronologically extensive framework of Berggren et al. (1995), which stood as the standard chronostratigraphy until that of Gradstein et al. (2012).

2. Biofacies Models: Paleobiologic Maps of Depositional Environments

Natland, M. L., 1933, *The temperature and depth ranges of some Recent and fossil foraminifera in the southern California region: Scripps Institute of Oceanography, Bulletin, Technical Series, v. 3, no. 10, p. 225–230.*

Natland’s paper is fundamental to micropaleontology because it was the first to show that benthic foraminifera are sensitive environmental indicators and, conversely, that the environment exercises primary control on their stratigraphic distribution. Focusing on foraminiferal depth assemblages and using the present as key to the past, Natland designed a study that became a model for others of its kind. He and a colleague collected 153 bottom samples in the channel between Long Beach and Santa Catalina Island, recording the bottom depth and temperature at each station. He augmented that collection with a dozen samples from greater depths in the region giving him a sample set ranging from an ebb-tide depth of one foot in a brackish lagoon to more than 8,000 feet (2,438 m) offshore. He showed that the foraminiferal assemblages change in accordance with the decrease in temperature that accompanies increasing depth. Natland divided the faunal distribution into five "life-zones", each represented by characteristic species. These distinct groups are now referred to as biofacies. He then applied his modern foraminiferal data to interpret a Neogene sequence exposed in Hall Canyon near Ventura. His study indicated that the lowest beds were deposited in the coldest water, and there was a gradual warming from there to the top of the section. Natland was uncertain if the warming was entirely from shallowing, so, unlike those who followed in his footsteps, he refrained from correlating the interpreted water temperatures with depth.

Natland (1944) also recognized mixed assemblages of warmer (shallow) water forms with those characteristic of cooler (deep) water, leading him to explore the sedimentary dynamics off California, and he later recognized the major role played by turbidity currents (Natland and Kuenen, 1951; Natland, 1957). Those investigations have been vital to our modern understanding of gravity-flows and deep-water deposition, which is now of particular importance in the exploration for oil and gas in many parts of the world.

Natland’s work had a profound influence on foraminiferologist Orville Bandy at the University of Southern California. At a time when most foraminiferal research was taxonomic or biostratigraphic, Bandy and his students used Natland's work as a springboard from which they delved into ecological and paleoecological studies of foraminifera. Their publications include the first biofacies maps on stratigraphic horizons (e.g., Bandy and Arnal, 1960; 1969), several of the earliest studies that used biofacies to map polluted environments (Bandy et al., 1964a, 1964b, 1965a, 1965b), and the first thorough compilation of regional biofacies and their integration with the environmental factors that have shaped them throughout the Cenozoic (Ingle, 1980).

Phleger, F. B, and F. L. Parker, 1951*, Ecology of foraminifera, northwest Gulf of Mexico, parts I & II: Boulder, Colorado, Geological Society of America Memoir 46, Part I, p. 1–88 and Part II, p. 1–64.*

Phleger and Parker's two-volume publication was a major advancement in the study of living foraminifera that fundamentally set the ecology and environmental/bathymetric zonation standard for the Gulf of Mexico. This work also established a foundation for paleowater-depth biofacies currently used by biostratigraphers in the Gulf of Mexico and in other basins worldwide. Phleger and Parker's compendium was the "gold standard" for subsequent studies of a similar nature worldwide.

Having analyzed foraminifera from 550 bottom samples and 55 cores collected in the northwest Gulf of Mexico, Phleger and Parker delineated six bathymetric zones based on foraminiferal assemblages within middle neritic to abyssal depth interval of 263 feet (80 m) to more than 6,562 feet (>2,000 m). The authors presented the data and described the methodology used for their bathymetric zonation, and showed the value of using and refining ecologic/bathymetric zones for biofacies and sedimentary analysis. In addition, they used the planktic/benthic ratios of foraminiferal assemblages to help determine relative rates of sedimentation.

Phleger and Parker's work led to many additional studies on foraminifera in the Gulf of Mexico, most notably those of Albers et al. (1966), Pflum and Frerichs (1976), Poag (1981), Tjalsma and Lohmann (1983), Van Morkhoven et al. (1986), Poag (2015), and Denne and Sen Gupta (1993).

Bandy, O. L., and R. E. Arnal, 1960*, Concepts of foraminiferal paleoecology: AAPG Bulletin, v. 44, no. 12, p. 1921–1932.*

This classic paper pioneered the application of foraminiferal biofacies in basin analysis. Biofacies are now integrated with seismic stratigraphic systems tracts in order to interpret depositional environments with greater confidence.

Bandy and Arnal synthesized previously published studies on modern foraminiferal biofacies to develop and test multiple criteria in order to paleobathymetrically analyze ancient basins. They recognized seven criteria of greatest importance: (1) the general trends in species abundance and total benthic specimens relative to water depth and distance from shore; (2) the utility of porcelaneous foraminifera as indices of nearshore conditions; (3) the abundance of simple-walled agglutinated species in some brackish areas vs. the complexly structured tests of other agglutinated species in deep water; (4) the abundance of planktic foraminifera on the outer shelf and upper slope; (5) the validity of using fossil homeomorphs of modern species as paleoenvironmental indicators; (6) the recognition of displaced species; and (7) the utilization of upper-depth limits of the deepest-dwelling species in an assemblage to indicate the minimum depth of deposition.

Bandy and Arnal used the seven occurrence patterns as internal checks to validate their paleobathymetric maps of California's petroliferous San Joaquin Basin during the Luisian Stage (middle Miocene). They preview their much more extensive analysis (Bandy and Arnal, 1969) of this basin based on more than 5,000 core samples. Bandy and Arnal's maps appear to be the first basin-wide paleobathymetry maps based on subsurface biofacies data. Their 1960 paper also shows how paleobathymetric changes between two successive time-slices (beginning and end of the Luisian) can be used to quantify patterns of subsidence and uplift, which are key components for understanding relationships between oil fields and basin development.

This publication has been one of the most influential contributions to California micropaleontology. It laid the groundwork for their later studies (i.e., Bandy and Chierici, 1966; Bandy and Arnal, 1969; Arnal, 1976) and inspired others (e.g., Ingle, 1967, 1980; Lagoe and MacDougall, 1986; Finger et al., 1990; Olson, 1990) to adopt and further investigate the micropaleontologic criteria they recognized as useful tools in paleoenvironmental analysis.

3. Additional Selected Biozonations Used by Industry and Academia

***Ziegler, W., 1962**, Taxonomie und phylogenie Oberdevonischer conodonten und ihre stratigraphische Bedeutung (Taxonomy and phylogeny Upper Devonian conodonts and their stratigraphic significance): Abhandlungen des Hessischen Landesamtes für Bodenforschung, v. 38, 166 p.*

Conodonts are phosphatic teeth-like structures of pelagic 'eel-like' aquatic animals that are found in Paleozoic marine sedimentary rocks. Ziegler recognized that their abundance and rapid evolution gave them biostratigraphic utility. His landmark paper provides a case history of their Paleozoic biozonation, and his conodont zonation represents one of the earliest Paleozoic biochronologies useful in the subsurface. In this monograph, Ziegler established the standard for Devonian conodont biostratigraphy, which remained in force until updated by Ziegler and Sandberg (1990). Working principally on sections in Germany and Belgium, while considering stratigraphic distributions in North America and elsewhere, Ziegler established a series of zones based on evolutionary inceptions and he defined each zone by its characteristic conodont assemblage. The conodont biostratigraphy devised by Ziegler and updated by Ziegler and Sandberg includes 32 zones for the Late Devonian, each with a duration less than 500,000 years. This level of stratigraphic precision makes conodonts a valuable tool for both local and intercontinental correlations of Devonian sediments. As a result, the event stratigraphy and eustasy of the Devonian period is well understood (House and Ziegler, 1997). Devonian stages were amongst the first to be defined on the basis of their stratotypes (Becker et al., 2012).

Klemme and Ulmishek (1991) attributed approximately 25% of recoverable oil and gas reserves to three Paleozoic source rock intervals: Silurian, Upper Devonian, and Pennsylvanian–Lower Permian. These intervals are now being intensely investigated as resource plays in the United States (e.g. Bakken Shale) and elsewhere. In addition, there are key conventional hydrocarbon reservoir intervals of Paleozoic age. These include the giant gas fields of the Khuff Formation and its equivalents in the Middle East. There has been a critical need for biostratigraphic tools to provide correlation and age calibration of Paleozoic basin models. Conodonts, as well as acritarchs, chitinozoa, and fusulinids, are the microfossils that have been vital tools in calibrating the Paleozoic.

Germeraad, J. H., C. A. Hopping, and J. Muller, 1968*, Palynology of Tertiary sediments from tropical areas: Palaeobotany and Palynology Review, v. 6, p. 189–348.*

Biostratigraphic correlation is most often applied to marine strata, but many sedimentary basins have nonmarine successions that contain hydrocarbon resources. Winds widely distribute pollen and spores (palynomorphs), making them particularly useful in correlating sedimentary rocks deposited in nonmarine, transitional, and marine environments. This paper serves as a prime example of applied palynology.

In their paper, Germeraad et al. present the results of nearly 20 years of intensively studying Tertiary palynomorphs from wells and outcrops across the Tropics. They show how palynology is applied as a tool for age dating and correlation, and establish biostratigraphic zones based on the stratigraphic and geographic extent of 49 tropical pollen and spore species. Their zonation extends from Maastrichtian to Pleistocene and includes six pantropical zones recognized in the Caribbean and across tropical Africa, and Southeast Asia. Within the same framework are transatlantic and regional zonations for the Caribbean and Borneo. They also included palynological correlation panels across northern and western Venezuela, Trinidad, and Colombia, and species distribution charts for key sections in Venezuela, Trinidad, and Nigeria.

The Germeraad et al. zonation is so robust that, after almost 50 years, it is still used by palynologists working tropical terrestrial floras. While the biostratigraphic framework is the most obvious contribution of this paper, the authors extended the application of palynology as a stratigraphic tool by: 1) demonstrating the importance of quantitative and statistical analysis of pollen and spore assemblages for zonation recognition in the tropics, 2) discussing the transport and climate effects on the final characteristics of the assemblages, and 3) proposing botanical affinities for many of the key species to support their stratigraphic significance and geographic distribution. All of these attributes make this is a unique and timeless contribution on “terrestrial” palynology in biostratigraphy, which is of particular value to the oil and gas industry.

This paper built on the pioneering and historic papers of Kuyl et al. (1955), who demonstrated the application of palynology in oil exploration, and Muller (1959), which dealt with the distribution of palynomorphs in recent deltaic sediments. From the many papers that have been subsequently published that partially address in more detail the palynology of specific tropical areas, it is also relevant to mention Muller, Di Giacomo and Van Erve (1987).

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AAPG Landmark Papers

Applied Biostratigraphy

Contributors

John M. Armentrout (retired from Mobil) – Coordinator
Ronald J. Echols, Mobil (retired from Mobil)
Nancy L. Engelhardt-Moore, ALS Oil & Gas Reservoir Laboratories (retired, previously with Amoco, Devon, and Ellington & Assoc.) – Technical Editor
Tony D'Agostino, Hess Corp. (previously with ARCO)
Kenneth L. Finger, University of California Museum of Paleontology (previously with Chevron) – Technical Editor
Maria Antonieta Lorente, ALS Oil & Gas Reservoir Laboratories (previously with PDVSA)
Ronald Martin, University of Delaware (previously with Unocal)
Michael J. Nault, Applied Biostratigraphix and ALS Oil & Gas (previously with Tenneco, Chevron, BP)
Edward Picou (retired from Shell)
Mike Simmons, Halliburton/Neftex (previously with BP)
Mike Styzen (retired from Noble Energy and Shell)
Arthur S. Waterman, Paleo-Data (previously with Texaco)

INTRODUCTION

This compilation of landmark papers complements the companion selections on Paleontology Tools. Biostratigraphy has long been, and continues to be, applied within the petroleum industry as a primary means of correlation, age calibration, and paleoenvironmental interpretation. This in turn contributes to predictions of reservoir, source, and seal facies at exploration-to-reservoir scale and contributes to geohistory analysis in basin modeling. While developed within the petroleum industry, biostratigraphy has broad application in basin analysis and regional correlation in academic studies. As the Landmark Papers project was initiated by the AAPG, the papers selected here focus on applications of biostratigraphy in oil and gas exploration and production.

Biostratigraphy has saved millions of dollars in directional drilling by identifying key horizons in a timely manner, and by recognizing temporal changes in the depositional paleoenvironment indicated by fossil assemblages. Herein, we summarize 10 landmark papers that highlight "best practices" in applied biostratigraphy. These publications are placed into eight categories of value-added application, ranging from integration with sequence stratigraphy to wellsite and geohistory case studies in petroliferous regions, including the Gulf of Mexico, South America, the North Sea, and the Middle East. The categories are arranged in the following order:

1. Exploration scale integration of biostratigraphy with sequence stratigraphy: predicting the distribution of Petroleum System elements.
2. Biostratigraphic application in salt-related areas with poor seismic resolution.
3. Applications of graphic correlation, a tool for increasing stratigraphic resolution.
4. Biosteering: maximizing hydrocarbon recovery.
5. Regional Facies Mapping: biofacies calibration of depositional environments.
6. Fluvial to shallow marine facies correlations and subtle trap identification in a complex tectonic setting.
7. Geohistory analysis: predicting source rock maturity and charge.
8. Reservoir-scale facies mapping.

We also direct those interested in reading more about value-added biostratigraphy to these four excellent books:

Waterman, A. S., ed., 1987, Innovative biostratigraphic approaches to sequence analysis for new exploration opportunities: Houston, Texas, Eighth Annual Research Conference, Gulf Coast Section SEPM Foundation, 159 p.

Jones, R. W., and M. D. Simmons, eds., 1999, Biostratigraphy in production and development geology: Geological Society Special Publication 152, 318 p.

Gregory, F. J., P. Copestake, and J. M. Pearce, eds., 2007, Key issues in petroleum geology 3: stratigraphy: Geological Society Special Publication 386, 399 p.

Jones, R. W., 2011, Applications of palaeontology: techniques and case studies: Cambridge, UK, Natural History Museum, 420 p.

SELECTED CASE HISTORIES

1. Exploration Scale Integration of Biostratigraphy with Sequence Stratigraphy: Predicting the Distribution of Petroleum System Elements

Partington, M. A., P. Copestake, B. C. Mitchener, and J. R. Underhill, 1993a, *Biostratigraphic calibration of genetic stratigraphic sequences in the Jurassic–lowermost Cretaceous (Hettangian – Ryazanian) of the North Sea and adjacent areas,* in *J. R. Parker, ed., Petroleum geology of northwest Europe proceedings of the 4th conference: Geological Society of London, p. 371–386.*

Partington et al. present an excellent example of best practice in the application of biostratigraphy to sequence stratigraphy at a regional scale by providing a series of maps suitable for predicting Petroleum System elements. Their data set is from the hydrocarbon-bearing and -generating Jurassic sediments of the North Sea. Thirty-three regionally correlatable marine condensed sections containing maximum flooding surfaces were recognized using a combination of biostratigraphy, wireline logs (over 500 wells), and seismic data. The sections subdivided the North Sea's Jurassic succession into 32 genetic stratigraphic sequences. Each maximum flooding surface was biostratigraphically calibrated using microfossils (dinoflagellate cysts, radiolaria, ostracodes, and foraminifera). The relationship between the sequence scheme and dinoflagellate biozones and bioevents enabled correlation across the entire well set and calibration with the onshore ammonite-standard stratigraphy. These correlations provided the basis for a basin-wide stratigraphic framework for the Jurassic of the North Sea Basin, which reduced lithostratigraphic uncertainties and allowed for prediction of potential reservoir, source and seal facies. The developed sequence model still guides exploration and production thinking today.

This paper is an excellent demonstration of how to apply and document biostratigraphy in sequence definition. Following the suggestions of Loutit et al. (1988) and Emery and Myers (1996), Partington et al. focused their attention on maximum flooding surfaces, which show readily recognizable biostratigraphic (abundant and diverse fossil assemblages), well-log (high gamma ray excursions), and seismic signatures (laterally persistent high-amplitude horizons). Because these surfaces were recognized across the entire basin, they represent continuous deposition as opposed to a break in deposition (i.e., sequence boundaries) and they constitute a framework in which other sequence stratigraphic surfaces and systems tracts can be placed. Of particular value was the calibration of biostratigraphic horizons to standard chronostratigraphy. As a result, this approach has been followed in other parts of the world (e.g., Sharland et al., 2001).

Partington et al. (1993b) gave further details of the application of the biostratigraphically calibrated sequence scheme within the Late Jurassic. Presented in that publication are log correlations, chronostratigraphic charts, and maps of depositional environments, all of which help to elucidate the stratigraphic and geographic distribution of key Petroleum System elements including reservoirs, source and seal.

Armentrout, J. M., 1991*, Paleontologic constraints on depositional modelling: examples of integration of biostratigraphy and seismic stratigraphy, Pliocene-Pleistocene, Gulf of Mexico,* in *P. Weimer, and M. H. Link, eds., Seismic facies and sedimentary processes of submarine fans and turbidite systems: New York, Springer-Verlag, p. 137–170.*

Armentrout provides geoscientists with a workflow for integrated stratigraphic analysis of complex stratigraphy in shelf or slope environments. This paper is similar to the Partington et al. (1993b) paper above with the addition of discussions on biostratigraphic data quality and a depositional setting of dominantly progradation within a growth-faulted salt basin.

Armentrout's methodology employed three common data sets – biostratigraphy, well logs, and seismic reflection profiles. Using data from the Plio-Pleistocene of offshore Texas, he detailed the necessary steps to analyze quantitative foraminifera and calcareous nannofossil abundance and diversity, and bioevents (typically extinction datum's). He used his checklists of benthic foraminifera to define paleobathymetric zones and biofacies in order to interpret paleo-water depth environments across the shelf-slope profile. Well logs were combined with faunal/floral abundance and diversity plots to identify condensed sections, which are characterized by relatively high gamma-ray response and associated abundance and diversity peaks of microfossil taxa. Faunal discontinuities combined with well-log electofacies enabled the identification of candidates for third-order and fourth-order sequence boundaries. Armentrout combined Exxon's methodology (Vail, 1987), which focuses on unconformities and relatively low sea levels, with that of Galloway (1989), which emphasizes times of maximum inundation of the shelf (regionally extensive flooding surfaces) and condensed intervals.

Armentrout discusses potential pitfalls and the criteria for quality-checking biostratigraphic data, in particular between multiple workers. He resolved an apparent discrepancy between log-based and core-based interpretations of shoreline facies occurring ‘within’ bathyal biofacies. Mixed foraminifera assemblages of shallow deltaic intervals and the encasing outer neritic and upper bathyal mudstones often result in interpreting the entire interval as deep-water by assuming down-slope transport of the shallow biofacies assemblage. Consequently vigorous discussions arose between sedimentologists and paleontologists about ‘deep-water deltaic facies’ versus unreliable biofacies interpretations. Careful analysis of every cutting sample identifying *in situ* foraminiferal assemblages clarified that both interpretations were correct. The resulting interpretation identified a shelf-margin setting where sea level lowstand deltaic facies were deposited over preceding highstand deep-water mudstones, and then subsequently overlain by transgressive to highstand deep-water mudstones. In addition, he recognized that progressive and differential compaction of the shelf-to-slope clinoform mudstones often resulted in geometric water depth interpretations that are deeper than during original deposition. This observation helped resolved conflict between paleowater depth interpretations from recovered biofacies assemblages versus water depths interpreted from seismic geometry.

The third component of Armentrout's workflow was the use of seismic profiles. Following the methodology of Peter Vail and coworkers at Exxon, he defined six basic seismic facies and discussed their internal characteristics and lateral continuity. Armentrout explains how to use synthetic seismograms of well logs to correlate the stratigraphy interpreted from fossils and well logs to seismic geometries. He also detailed techniques for relating biofacies to seismic facies to produce map units for sand-prone and seal-prone facies on both the shelf and adjacent slope.

Integrated stratigraphic analysis, as documented in this paper, has become the standard technique employed by the petroleum industry in basins rich in biostratigraphic data, such as the Gulf of Mexico. Previous work tended to focus on seismic character (terminations, lapping relationships, geometries) to interpret sequence stratigraphy with only a passing regard to other data sets. By combining seismic and well-log interpretations with high-resolution biostratigraphy, and resolving discrepancies between biostratigraphic, sedimentologic and seismic stratigraphic interpretations, Armentrout provided the means for a truly integrated interpretation that is internally consistent between the three most common data sets available to petroleum explorationists and other stratigraphic analysts.

2. Biostratigraphic Application in Salt-related Areas with Poor Seismic Resolution

O'Neill, B. J., A. E. Duvernay, and R. A. George, 1999, *Applied palaeontology: a critical stratigraphic tool in Gulf of Mexico exploration and exploitation,* in *R. W. Jones, and M. D. Simmons, eds., Biostratigraphy in production and development geology: Geological Society Special Publication 152, p. 303–308.*

O'Neill et al. used foraminifera and calcareous nannoplankton to resolve issues of 'missing' reservoir facies in two Gulf of Mexico fields where seismic images have poor resolution along high-angle salt flanks and subsalt locations. Their examples include two deep-water sand fields: Shell's 'Bonnie', a salt dome field located on the shelf, and 'Mars', a mid-slope salt-rimmed mini-basin field.

At Bonnie, the play, based on 3D seismic, was to test a down-thrown fault block where seismic amplitude anomalies were projected up-dip along the flank of a salt-dome. The well failed to encounter the projected reservoir sands. The biostratigraphic analysis documented that the objective section had been penetrated, but the predicted sands were missing "most-probably" due to stratigraphic pinch-out. Recognition of this facies pattern resulted in a down-dip sidetrack that revealed significant hydrocarbon reserves in gravity-flow sands that pinched-out against a syndepositional structural/topographic high.

In the Mars case history, biostratigraphic correlation of the 1989 discovery well and subsequent delineation wells defined a deep-water gravity-flow depositional system within the mini-basin. The biostratigraphic data included foraminifera, calcareous nannoplankton, and palynomorphs. In 1991, an appraisal well was designed to test interpreted pay horizons beneath a salt-overhang. The well successfully penetrated the salt, and borehole biostratigraphy documented penetration of the objective section without encountering the predicted reservoir sands. Further analysis suggested lateral facies thinning of the gravity-flow sands with pinch-out down-dip to the well location rather than salt truncation. The integration of biostratigraphy and structural analysis enabled the Mars team to model the salt movement through time that controlled reservoir architecture, and thus constrained volume estimates. These data were critical to Shell's decision to proceed with the $1.2 billion field-development plan.

In both cases discussed by O'Neill et al., the integration of the high-resolution biostratigraphy with seismic structural and facies analyses led to a depositional model that resolved lateral pinch-out of reservoir sands, thickest within synclinal axes and thinning against salt-cored highs. Field development planning, based on the integrated depositional model, led to cost savings by placing wells only at optimal locations, which translated to drilling fewer wells, and the discovery of additional resources with side-tract wells drilling down-structural dip where thick deep-water reservoir sands occur.

3. Applications of Graphic Correlation, a Tool for Increasing Stratigraphic Resolution

Neal, J. E., 1996, *A summary of Palaeocene sequence stratigraphy in northwest Europe and the North Sea, in R. W. O'B. Knox, R. M. Cornfield, and R. E. Dunay, eds., Correlation of the Early Palaeogene in northwest Europe: Geological Society Special Publication 101, p. 15–42.*

Neal presented a high-resolution chronostratigraphic correlation framework for the Paleogene of northwest Europe, constructed by integrating subsurface and outcrop data using graphic correlation of cycles based on sequence stratigraphic principles. The graphic correlation technique, introduced by Shaw (1964), uses a composite standard database constructed by integrating fossil occurrence data from carefully correlated wells and stratigraphic sections. In this paper, the methodology facilitated the ordering of depositional cycles where the biostratigraphic record was equivocal due to low species diversity and the lack of regionally reliable index taxa.

Paleogene North Sea sediments record five major regressive-transgressive cycles. These major cycles overprint 19 higher-frequency cycles that control the distribution of depositional facies including potential reservoir and seal rocks. The cycles are best documented along basin margins in shallow-water settings. Once recognized, the cycles can be correlated into deep-water facies and tied to the geologic time scale facilitating basin modeling and geohistory analysis.

To establish the regional correlation framework, Neal integrated the microfossil data into a ‘composite standard’ showing the temporal succession of biostratigraphically useful fossils. This composite data, graphically displayed, facilitated correlation of depositional cycles and helped recognize depositional cycles that thinned toward basin depocenters where some had previously gone undetected.

Using the graphic correlation methodology, Neal correlated key bounding surfaces across northwest European Paleocene basins, resulting in recognition of 30 depositional sequences within five major transgressive-regressive cycles. This stratigraphic framework enhanced the mapping of depositional systems tracts useful in predicting Petroleum System lithofacies elements and timing of trap formation, and in modeling source rock maturation.

4. Biosteering: Maximizing Hydrocarbon Recovery

Holmes, N. A., 1999, *The Andrew Formation and “biosteering” – different reservoirs, different approaches, in R. W. Jones, and M. D. Simmons, eds., Biostratigraphy in production and development geology: Geological Society Special Publication 152, p. 155–166.*

Technological development of long-reach deviated and horizontal wells, and multi-lateral wells, has resulted in significant increases in borehole-to-reservoir connectivity. Keeping the well trajectory within the optimal interval of the reservoir is critical to maximize hydrocarbon recovery. This involves both monitoring the down-hole progress of the drill stem and utilizing wellsite biosteering to analyze biofacies in real-time.

Holmes described two examples of biosteering in deep-water sands of the late Paleocene Andrews Formation in the North Sea, United Kingdom sector. Definition of foraminiferal morphogroups and biofacies analysis provided high-resolution lithofacies characterization, useful in the pre-drill well-path planning and during drilling to provide real-time data for steering decisions.

The first example, from the Joanne Field, described biosteering through 10–15 foot thick turbidite sands. The reservoir was a succession of interbedded deep-water sand and limestone. Within the pay intervals, the occurrence of local dip variations, sub-seismic faults, and lateral thickness variations in the sand reservoirs were a challenge to well-bore steering. Both *in situ* and reworked microfossils were used to characterize up to 10 discrete field-wide lithobiostratigraphic units. Well site identification of these correlatable facies allowed for real-time correcting well-path deviation in order to avoid drilling non-reservoir facies.

The second example was from the Andrews Field. Here the discussion focuses on identifying the interbedded fossil-rich mudstone seals. High-resolution biofacies analysis was used to characterize potential sealing qualities and lateral continuity of adjacent silt and claystone intervals. Characterization of baffle vs. barrier qualities of the non-reservoir facies was used in planning the well path to optimize production through well placement and stand-off from oil-water and gas-oil contacts.

Holmes showed that the identification of high-resolution integrated biofacies and lithofacies routinely provide correlation data for biosteering in basins such as those of the North Sea and Gulf of Mexico. This methodology has wide application in multilateral and horizontal drilling in shale oil and gas plays where fracking is best constrained within uniform lithologies.

5. Regional Facies Mapping: Biofacies Calibration of Depositional Environments

Lowman, S. W., 1949, *Sedimentary facies in the Gulf Coast: AAPG Bulletin. v. 33, p. 1939–1997.*

Lowman provided a detailed analysis of methods developed for interpreting the complexities of the stratigraphy and structure in the Gulf Coast Basin, with particular emphasis on developing a paleo-water-depth model. He first reviewed the upper Tertiary stratigraphy of the region, where he stressed that stratigraphic variability existed. Then he presented his study along three transects in the northern Gulf of Mexico, which showed how the modern depth distribution of benthic foraminifera can be referenced against fossil assemblages in transgressive deposits.

Of particular note was Lowman's discussion concerning the determination of whether temporal changes among key species reflected extinctions or simply their morphologic variability in response to changes in water depth. He demonstrated that subsurface correlations are dependent on the microfossil fauna in the transgressive deposits above and below the non-fossiliferous regressive sands. Each couplet of coastal plain to shelf and slope sedimentation most often thickens toward the basin's depocenter, thereby outbuilding the continental margin. This then results in flexure and structural complexities, typically growth-fault systems, which enhance fault trapping of hydrocarbons. Lowman discussed how subsidence under depositional load enhanced the development of the Gulf Coast depocenters, which he compared to other sedimentary basins in the United States as well as several basins overseas.

This publication has stood for many years as the definitive work on the lithofacies and biofacies of the Gulf Coast Basin. It set the standard for geologic studies, both local and regional, in this incredibly petroliferous basin.

6. Fluvial to Shallow Marine Facies Correlations and Subtle Trap Identification in a Complex Tectonic Setting

Rull, V., 2002*, High-impact palynology in petroleum geology: applications from Venezuela (northern South America): AAPG Bulletin, v. 86, p. 279–300.*

Rull summarized traditional and new approaches to the application of palynology as a high-resolution and high-impact tool in oil and gas exploration in his study of fluvial to shallow-marine facies in Lake Maracaibo. Innovative concepts introduced include high-resolution ecostratigraphy at basin scale and the concept of ‘palynoblocks’ to estimate missing section in structurally complex areas. Rull’s paper was particularly noteworthy for demonstrating how quantitative palynostratigraphy integrated with wireline logs and seismic data could be used to identify subtle stratigraphic trap potential.

In the Maracaibo Basin, the ecostratigraphic approach of Poumot (1989) had been used to identify up to 21 palynocycles (equivalent to third-order eustatic cycles) in fluvial to coastal sections of Eocene, Oligocene, and Miocene age (Rull and Poumot, 1997; Rull and Lorente, 1999). Palynocycles had been also recognized in the Paleocene to middle Eocene of the Maracaibo Basin (Rull, 2000). In addition, the palynocycle methodology had been used successfully in both tectonic and high-resolution reservoir correlations (Lorente and Contreras, 1977). The application of high-resolution palynology helps to more precisely define the stratigraphic interval of interest and facilitate its identification in seismic profiles and electric logs.

In this paper, Rull provided an innovative definition of ‘palynoblocks’ as a tectonic element limited by faults and characterized by the occurrence of a single palynological zone at its top. Significantly, this paper introduced palynoblocks as a concept with tectonic, biostratigraphic, and chronostratigraphic attributes.

Seismic correlation and mapping of identified palynoblocks efficiently provide a detailed chronological picture of the surface below a major unconformity. This allowed for the interpretation of relative movement of the tectonic blocks in time, the quantification of erosion, and the location and magnitude of missing sections in structurally complex areas. Rull demonstrated that detailed history achieves a better understanding of the differences in the Petroleum Systems of neighboring blocks through a more precise reconstruction of their individual burial history. In turn, he showed that this provides more precise estimations of source-rock maturation and the timing of trap formation.

7. Geohistory Analysis: Predicting Source Rock Maturity and Charge:

Van Hinte, J. E., 1978, *Geohistory analysis – application of micropaleontology in exploration geology: AAPG Bulletin, v. 62, no. 2, p. 201–222.*

Van Hinte redefined what at the time was the 60 year-old technique of basin subsidence analysis, providing an enhanced methodology useful in Petroleum System modeling of what later became known as the 'Critical Moment' of hydrocarbon expulsion (Magoon and Dow, 1994; see Geochemical Landmark Papers herein). He demonstrates how high-resolution and high-precision biostratigraphic analysis of multiple fossil groups is crucial to unraveling the geologic history of a basin and specific exploration areas. The method capitalizes on relatively recent advances that had been made in the correlation of biozones to absolute linear time scales with precisions of ±1 Myr in the Cenozoic and ±2 Myr in the Mesozoic. By combining the new time scale with direct measurements of interval thickness and interpretive data (e.g., paleobathymetry and thermal gradients), it became possible to calculate precise rates of basin fill, subsidence, compaction, and uplift. It also improved estimating the amount of time missing at unconformities and the amount of missing sedimentary section. Having a high-confidence linear time scale made it possible to plot other time-related data such as heat flow, porosity change with burial, and petroleum maturation and migration, and to confidently extrapolate trend curves to fill gaps. This paper helped move biostratigraphers out of the shadows of a qualitative world into one where their data could be expressed in numerical forms that were more understandable and relatable for a broad range of geoscientists, engineers, and corporate management.

Van Hinte provided the equations, select nomograms, and workflow to execute a modern geohistory analysis of a well section or sections. The workflow could be applied to calculate a variety of sediment accumulation rates, as well as rates of subsidence and uplift. Quantification, even with broad error bars, could establish a trend line of estimated paleo-water depth that could be used to determine paleobathymetry at any particular time along the age-calibrated trajectory. This led to innovations in mapping facies distributions (tied to initial subsidence rate), timing structural events, and separating basement subsidence from the subsidence within the sedimentary section that is related to compaction, diapirism, or faulting. The high-precision age determinations also had a positive impact on petroleum system analysis. Fluid migration out of a basin could be predicted through construction of compaction rate maps. Mature hydrocarbons and other fluids move from areas of high compaction rates to areas of low compaction rates; thus, biostratigraphy enhances the predictive ability of this methodology. None of the step-change improvements in basin analysis, 3D and 4D fluid-flow modeling, structural analysis, or petroleum system analysis would have been possible without the concurrent advances in bio- and chronostratigraphy.

Hardenbol, J., P. R. Vail, J. Ferrer, L. Montadert, and R. Blanchet, 1981, *Interpreting paleoenvironments, subsidence history and sea-level changes of passive margins from seismic and biostratigraphy: Oceanologica Acta, Special Issue (0399-1784), p. 33–44.*

Hardenbol et al. analyzed basement subsidence, eustatic sea-level change, and sediment supply for the Cenomanian off northwest Africa to illustrate the procedure of geohistory analysis, which is a quantitative stratigraphic technique that places stratigraphic and paleobathymetric information in a time-depth framework. They followed the work of van Hinte (1978), which was based on U.S. Gulf Coast data, and demonstrated the applicability of the technique to the detailed structural evolution, basin analysis, and reservoir potential of petroleum systems of passive margins in general.

The northwest Africa section was chosen because of the amount and quality of seismic and paleontologic data. It is the same section Todd and Mitchum (1977) used to document Mesozoic sequences (see Sequence Stratigraphy Landmark Papers). Hardenbol et al. demonstrated how a stratigraphic framework integrated with seismic and biostratigraphic datums yields stratigraphic resolution far superior to either method alone. Repeating the procedure for networks of seismic lines defines sequences over a wide area of variable environments. In turn, this can be used to delineate relative sea-level changes, the relative magnitudes of which can be used to assign tentative ages to sequences by comparing successions to one in which the stratigraphy has been established. The authors noted that the technique of geohistory analysis in its modern quantified form became feasible with the introduction of high-precision time scale based on the integration of biostratigraphic zonations of multiple microfossil groups with magnetic chrons, seismic stratigraphy, and radiometric dates. In order to determine the paleo-water-depth of the seafloor, the technique also required detailed paleontology and biofacies records using methodologies first demonstrated by Natland (1933) and Bandy (1953) for California (see this issue's section on Paleontology ‘Tools’) and Lowman (1949) for the Gulf Coast (described above).

8. Reservoir-Scale Facies Mapping

***Hughes, G. W., 2000**, Bioecostratigraphy of the Shu’aiba Formation, Shaybah Field, Saudi Arabia: GeoArabia 5, p. 545–578.*

Biostratigraphic data has long been used to assist in determining paleoenvironments since the landmark paper of Natland (1933). This has provided key input into regional facies mapping within basins to help understand the distribution of reservoir and source rock units. Less common, but increasingly important, is the application of biostratigraphic data to provide detailed facies mapping at the reservoir scale within a single oil field.

The Shaybah Field lies within the modern gigantic dune fields of the Rub’al Khali desert. Surface static problems related to the dunes have prevented high-quality seismic imaging of the reservoir. To overcome this, Hughes examined vertical and coeval lateral variations in semi-quantitative biofacies data from more than 50 wells to define lagoon, back-bank, bank-crest, fore-bank and upper-ramp depositional environments. Facies patterns were mapped as discrete chronostratigraphic intervals using foraminifera, calcareous algae, and macrofossil biofacies distributions, as identified from thin-sections and core samples. The result was a series of high-resolution facies maps essential for planning production wells. As such, this publication is an excellent case study for field-scale biofacies application and demonstrates how carefully collected and evaluated paleontological data can be used to enhance hydrocarbon production from existing assets.

The Shu'aiba Formation and its various lithostratigraphic equivalents form major hydrocarbon reservoirs across the Arabian Plate. The platform margin includes bioherms and banks composed principally of rudist bivalves that constitute a key reservoir facies. These reservoir units are distributed within several transgressive-regressive cycles punctuated by exposure surfaces that cross the carbonate platform from the intrashelf basin and extend beyond the coeval shelf margin (e.g. Witt and Gokdag, 1994; van Buchem et al., 2010).

Hughes identified biofacies assemblages based on species of foraminifera, calcareous algae and rudist bivalves (often fragments) and established their likely paleoecological preferences by reference to sedimentological associations, modern analogues, and photosynthetic associations (e.g. Banner and Simmons, 1994). By placing the distribution of these paleoenvironmentally sensitive biofacies (integrated with other subsurface data) in a temporal framework defined by biostratigraphy, Hughes was able to produce maps interpolating depositional character for seven time slices within the Shu'aiba Formation across the entire field. These maps helped define reservoir architecture in 3D, which were used to define optimal well locations to capture facies-constrained resources.

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