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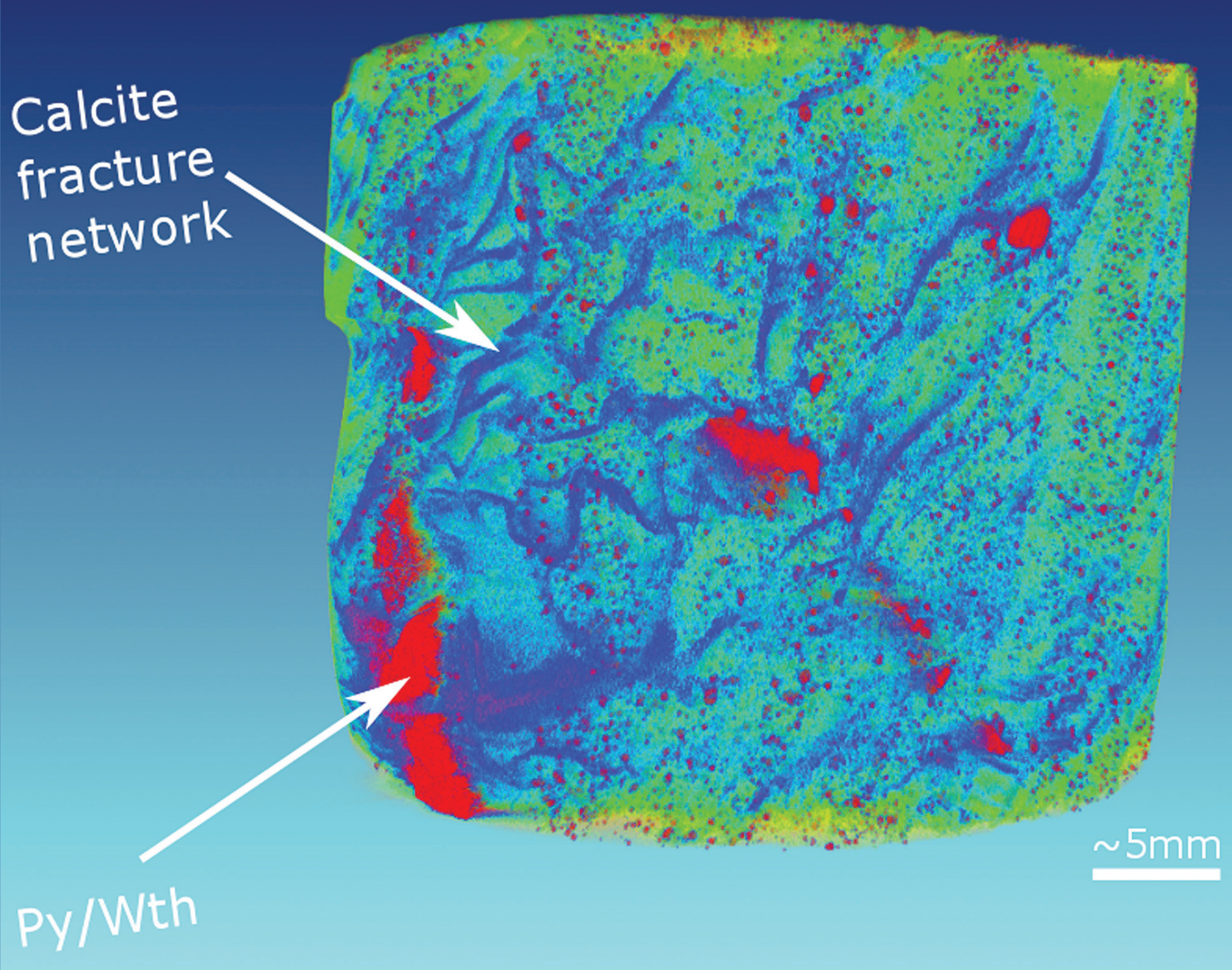

INSIDE: PARAGENESIS OF MINERALIZED FRACTURES AND DIAGENESIS OF PROMINENT NORTH AMERICAN SHALES

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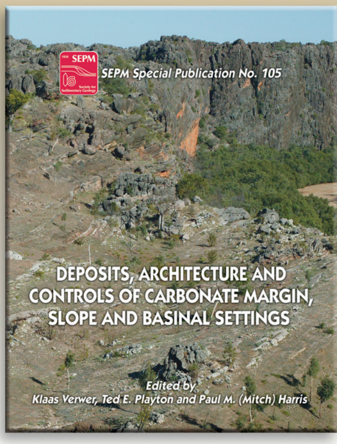

Special Publication #105

Deposits, Architecture, and Controls of Carbonate Margin, Slope, and Basinal Settings

Edited by: Klaas Verwer, Ted E. Playton, and Paul M. (Mitch) Harris

Carbonate margin, slope and basinal depositional environments, and their transitions, are highly dynamic and heterogeneous components of carbonate platform systems. Carbonate slopes are of particular interest because they form repositories for volumetrically significant amounts of sediment produced from nearly all carbonate environments, and form the links between shallow-water carbonate platform settings where prevailing in situ factories reside and their equivalent deeper-water settings dominated by resedimentation processes. Slope environments also provide an extensive stratigraphic record that, although is preserved differently than platform-top or basinal strata, can be utilized to unravel the growth evolution, sediment factories, and intrinsic to extrinsic parameters that control carbonate platform systems. In addition to many stimulating academic aspects of carbonate margin, slope, and basinal settings, they are increasingly recognized as significant conventional hydrocarbon reservoirs as well. The papers in this volume, which are drawn from the presentations made at the AAPG Annual Meeting in Long Beach, California (USA), in May 2012, as well as solicited submissions, provide insights into the spectrum of deposit types, stratal configurations, styles of growth, spatial architectures, controlling factors behind variations, and the hydrocarbon reservoir potential observed across the globe in these systems. The sixteen papers in this Special Publication include conceptual works, subsurface studies and outcrop studies, and are grouped into sections on conceptual works or syntheses, margin to basin development and controlling factors, architecture and controls on carbonate margins, and carbonate distal slope and basin floor development.

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Concepts in Sedimentology and Paleontology 12

Mudstone Primer: Lithofacies Variations, Diagnostic Criteria, and Sedimentologic–Stratigraphic Implications at Lamina to Bedset Scales

By: Remus Lazar, Kevin M. Bohacs, Juergen Schieber, Joe Macquaker, and Timothy Demko

More than two-thirds of the sedimentary record is composed of rocks dominated by grains smaller than 62.5 micrometers. These fine-grained sedimentary rocks serve as sources, reservoirs, and seals of hydrocarbons, influence the flow of groundwater, and can be rich in metals. These rocks have long been mined for clues into the past global carbon, oxygen, sulfur, and silica cycles, and associated climate and oceanography. These rocks are heterogeneous at many scales and formed via a range of depositional processes. Recent developments in drilling and completion technologies have unlocked significant hydrocarbon reserves in fine-grained sedimentary rocks and have triggered an explosion of interest in the sedimentology, stratigraphy, and diagenesis of these rocks. This Mudstone Primer covers this variability to better characterization and interpretation of mudstones. Definitions of key terms and a naming scheme for mudstones are provided followed with practical steps for studying mudstones in thin sections. Additional guidelines and a set of tools that facilitate consistent, repeatable, and efficient (time wise) description and capture of mudstone variability at thin section, core, and outcrop scale are included in seven appendices. This Mudstone Primer includes hundreds of Paleozoic to Tertiary examples of physical, biological, and chemical features that illustrate mudstone heterogeneity at lamina to bedset scales. The authors hope that individual workers will take the provided examples and interpretations and use them to enhance their own investigation strategies.

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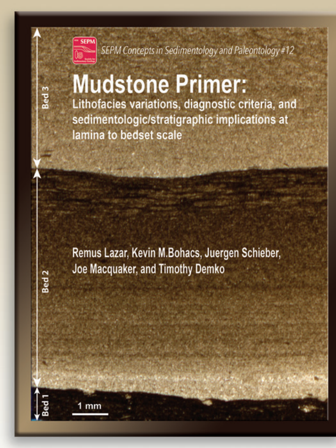

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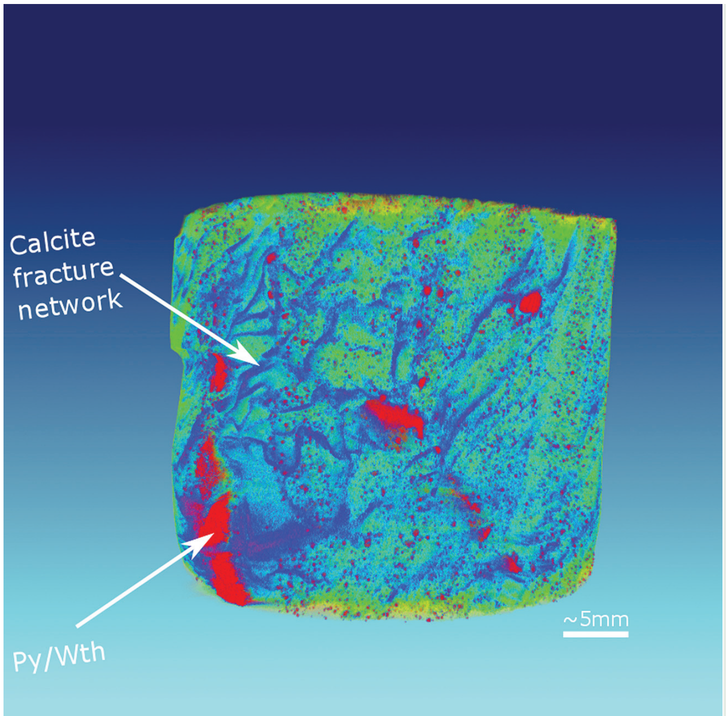

Cover image: X-ray computed tomography scan of a 1-inch Woodford plug. Red colors corresponds to high density minerals such as pyrite, barite and witherite. Blue colors denote calcite fracture network and green colors corresponds to a low density clay matrix. Image captured by Gerhard Heij.

CONTENTS

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Paragenesis of mineralized fractures and diagenesis of prominent North American shales

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ABSTRACT

Shale diagenesis is very complex and controlled by several variables operating across non-discrete spatial-temporal boundaries. While significant progress has been made in understanding shale diagenesis, fundamental issues such as whether or not shales behave as open or closed systems and how diagenesis controls migration pathways remain unresolved. In addition, we need to better connect scales of observation in shales. Addressing these issues is important if we are to better understand shale diagenesis and move beyond focusing just on the leaves and see the whole forest.

INTRODUCTION

The recent proliferation of unconventional oil and gas plays in North America has prompted an interest in the diagenesis of shale systems, and specifically the factors that control reservoir quality and its mechanical behavior. This interest has also raised fundamental issues such as developing a better understanding of whether or not shales behave as open or closed systems (e.g., Bjorlykke, K. and Jahren, J., 2012; Land et al., 1997) and how diagenesis controls migration pathways. Furthermore, connecting scales of observation from basin-scale to the micro/nano-scale is also a crucial issue. Shales are recognized as very heterogeneous because of depositional factors (e.g., Schieber, 2016) as well as their diagenesis (e.g., Milliken and Day-Stirrat, 2013; Manning and Elmore 2015; and others). This paper will focus on the diagenesis of shales with an emphasis on the paragenesis of mineralized fractures. Shale diagenesis can be highly complex due to a myriad of variables operating across non-discrete spatial-temporal boundaries within sedimentary basins (Fig. 1). The paragenesis of a given shale is a function of the contribution of each variable and many are interconnected. As a result, their paragenesis is complex and can be difficult to predict. This complexity can allow for diagenetic studies to focus on the details, which are clearly important, but can also result in not seeing the forest for the trees (or leaves).

Our approach has been to conduct integrated diagenetic studies of shale units. A key element is the construction of a paragenetic sequence through thin section petrography and the use of scanning electron microscopy (SEM). Fluid inclusion microthermometry is used to determine temperatures of formation and composition of fluids and geochemical data (e.g., $^{87}Sr/^{86}Sr$ values) can help determine the origin of the alteration, particularly in mineralized fractures. X-ray computed tomography (XRCT) is crucial to determine the 3-D microstructural features (e.g. fracture geometry). We also use anisotropy of magnetic susceptibility (AMS) to better understand burial and tectonic processes operating on sediments and paleomagnetism to determine absolute timing of events.

PARAGENESIS OF SHALES

We have investigated the origin and timing of diagenesis in several shale units including the Marcellus Shale (Devonian) in Pennsylvania and West Virginia (Steullet and Elmore, 2014; Manning and Elmore, 2015), Barnett Shale (Mississippian) in Texas (Dennie et al., 2012), Wolfcamp Shale (Permian) in West Texas (Wickard et al., 2016), and Haynesville Shale (Jurassic) in Louisiana and Texas (Benton and Elmore, 2013). We are currently continuing to study the Wolfcamp Shale as well as the Woodford Shale (Devonian-Mississippian) in Oklahoma and the Antrim Shale (Devonian) in Michigan. Our objective in these studies is to understand the paragenesis within the individual units but also to compare the paragenesis and timing of diagenetic events between the units (Fig. 2).

Our studies show some similarities in the paragenetic sequences between each unit (Fig. 2). Authigenic calcite, dolomite, quartz, barite, celestine, anhydrite, sphalerite, and albite are found in the matrix and/or in mineralized fractures in all five shale units. Despite the ubiquitous occurrence of these minerals within all five shale formations, the timing of the precipitation events are variable.

Common events during early diagenesis include precipitation of pyrite, concretions (phosphatic and calcitic), dolomite, and sphalerite. Dissolution of siliceous microorganisms and precipitation of quartz is very common during early diagenesis (e.g. Milliken and Day-Stirrat, 2013). Early precompactional fractures, usually filled

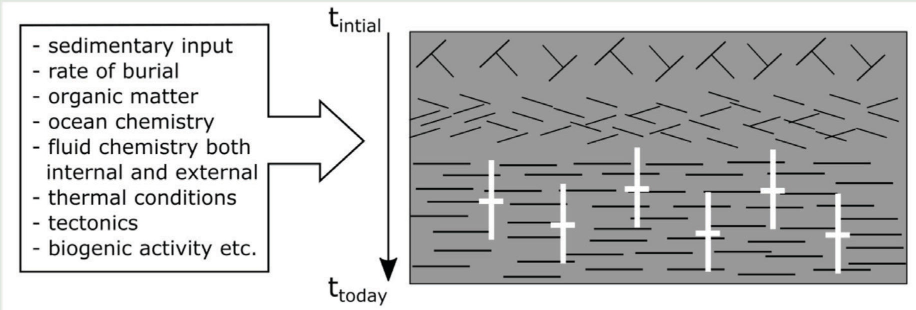

Figure 1: Schematic illustration of key variables involved in mudrock diagenesis. Model shows early (Tinitial) face-to-edge clay microstructures evolving to face-to-face contacts during progressive burial. Mineralized fractures shown by white symbols form during burial. The challenge of diagenetic studies is deciphering the diagenetic history (Ttoday) given the myriad of variables operating in shales.

with calcite, are common in some shales. Middle diagenesis is broadly characterized by clay diagenesis, specifically, the conversion of smectite to illite and in some cases chlorite precipitation. Middle and late diagenesis are commonly characterized by mineralization in fractures. The mineralized fractures show variable fracture habits and their mineral paragenesis can be complex. Fractures range from horizontal to vertical, can be anastomosing to relatively straight depending on the lithology they cut through (Fig. 3a). Some mineralized fractures are associated with breccias which can also have a very complex mineralogy. Common minerals filling fractures include calcite, ferroan calcite, dolomite, ferroan dolomite, barite (Fig. 3b), celestine (Fig. 3b), quartz, sphalerite (Fig. 3c), anhydrite, and pyrite. Other fractures are filled by witherite (Fig. 3d), magnesite, albite, and/or saddle dolomite which probably indicate alteration by low-temperature hydrothermal fluids. Hydrocarbons are also found in some fractures (Fig. 3e). Authigenic albite is not only present in fractures but also in the matrix (Fig. 3c) and is interpreted to form during late diagenesis (Fig. 2).

Fluid inclusions can also provide information on the origin of mineralized fractures. For example, in the Wolfcamp, entrapment temperatures of fluid inclusions in barite are approximately 100° C with salinities of ~ 25 Wt% $CaCl_2$ (Wickard et al., 2016). The high salinities suggest barite precipitated from saline hydrothermal fluids. Geochemical data, such as $^{87}Sr/^{86}Sr$ values, can be used with some restrictions as an alteration indicator for external evolved fluids. The $^{87}Sr/^{86}Sr$ values for samples of mineralized fractures from cores in the Barnett Shale proximal to the Ouachita thrust zone are elevated relative to distal, basinal samples. This is consistent with the interpretation that orogenic fluids from the Ouachita's altered the shale. Authigenic illite in the shale, however, formed from smectite with K derived from dissolved feldspars, which have relatively high ^{87}Sr values. Released ^{87}Sr probably contributed to the elevated $^{87}Sr/^{86}Sr$ values, and as a result, elevated Sr isotope values could be caused by internal or external fluids.

Horizontal and vertical calcite 'beef type' fractures (Fig. 3f) are common in several shales and are attributed to overpressuring (Cobbold et al., 2013). In the Haynesville, horizontal to subhorizontal 'cone-in-cone' fibrous dolomite mineralized fractures are common. The Barnett Shale contains complex mineralized fractures which include a vertical fracture filled with anhydrite, celestine, and barite that was refractured and filled by calcite and partially replaced by pyrite (Fig. 3b). Vertical fractures in several units contain a solid solution of celestine to barite (Figs. 3b, g) indicating evolving fluids. In the Wolfcamp authigenic chlorite is found in fractured barite/celestine next to a fracture (Fig. 3h). Hydrocarbons are also found between the clay sheets (Fig. 3h).

Some barite-celestine fractures in the Wolfcamp contain pores, some of which are occluded by ferroan dolomite rhombs (Fig. 3f). This suggests that these pore networks were open and continued to allow fluids to pass through them after the initial mineralization event. Additionally, there is ferroan dolomite alteration and calcite along the edge of fractures suggesting that fluids were also able to migrate along the matrix-fracture boundary. The presence of relic hydrocarbons also provides additional evidence for fluid migration through fracture networks in the Wolfcamp Shale (Figs 3e, f, and h).

XRCT provides nondestructive three-dimensional visualization and characterization through mapping the variation of X-ray attenuation, which relates to the density of minerals (e.g. Ketcham and Carlson, 2001). This analysis is particularly useful for visualizing microstructural features such as mineralized fractures and replacement textures in allochems. Critically, it also allows one to scale up from SEM and petrographic work. Figure 4a shows a vertical fracture containing pyrite and pyrite-replaced allochems dispersed in the matrix (colored red) from the Haynesville Shale. Lower density minerals are colored in green and blue and likely correspond to clays, quartz and calcite. Closer examination of replaced allochems shows a preferential replacement by pyrite along growth lines and margins of brachiopod shells (Fig. 4b). XRCT scans of the Woodford show complex fracture networks (Fig. 4c). The major fracture networks are shown in blue and are dominantly composed of calcite (confirmed petrographically). These fractures were likely displacive, considering that the measured rock fabric inferred from AMS shows a near vertical inclination. Additional segmentation of the data shows fishtail twinning that likely corresponds to authigenic gypsum/anhydrite. Complex suites of microfractures, largely comprised of

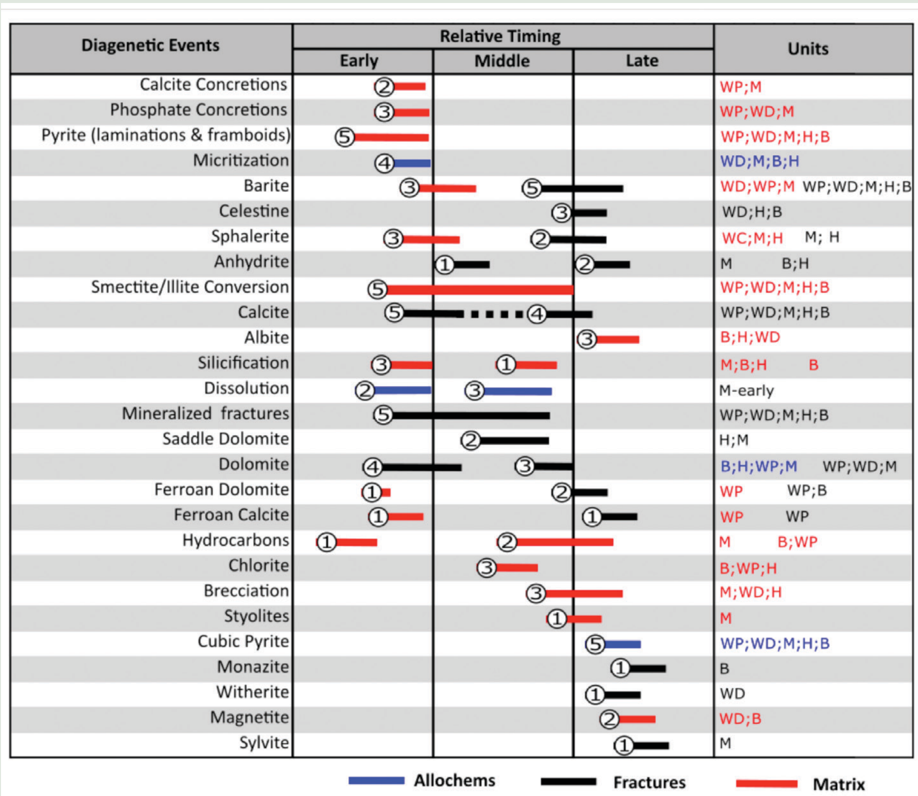

Figure 2: A combined paragenetic sequence from the Wolfcamp Shale - WP, Marcellus Shale – M (Steullet and Elmore, 2014), Woodford Shale –WD (Roberts and Elmore, 2014), Barnett Shale - B (Dennie et al., 2012), and the Haynesville Shale - H (Benton and Elmore, 2013). The number of formations that demonstrate the same diagenetic events are indicated by the number at the beginning of each line. The solid lines and dotted lines indicate the degree of certainty for the relative timing of diagenetic events.

barite and celestine, are found adjacent to larger fractures in the Wolfcamp Shale (Fig. 4e, f). This suggests that larger mm-scale fractures can trigger the formation of micro and perhaps nano-sized fractures. Closer examination of the large fracture shows a high degree of roughness along the fracture wall (Fig. 4g). These discontinuous surfaces can act as conduits for fluid migration and often serve as sites for the precipitation of later stage diagenetic minerals. XRCT analysis is a valuable tool to better characterize the complexity of diagenetic features that would otherwise be missed using conventional petrographic analysis.

In addition to porosity in fractures, other types of porosity occur in shales (e.g., Loucks et al., 2009; Slatt and O'Brien, 2011). For example, in the Wolfcamp Shale porosity occurs in organic matter, mineralized fractures, framboidal pyrite, intergranular, between clay sheets, associated with dolomite, and as intraparticle and moldic pores in allochems and carbonates.

A new frontier in diagenetic research has been the use of magnetic fabric and paleomagnetic analysis to measure the timing and nature of physiochemical processes operating in shales (e.g. Elmore et al., 2012, Heij et al., 2016). AMS quantifies the preferred orientation and intensity of magnetic grains in rocks, thereby defining its fabric. (see Tarling and Hrouda, 1993 for review). AMS is represented by a symmetric second rank tensor with three mutually perpendicular principal axes K^1 (long axis), K^2 (intermediate axis) and K^3 (short axis). In addition, the degree of anisotropy, a proxy for mineral shape anisotropy and shape factor with end-members ranging from oblate to prolate can be computed (see Jelinek, 1981). Our studies (e.g. Heij et al., 2016) suggest that clays control the AMS signal and compaction shapes their orientation with the K^3 (short axis) of grains oriented perpendicular to the bedding plane (oblate). Sub-vertical K^1 tensors with prolate shapes occur in horizons with elevated ferroan carbonate fractions and pervasive mineralized fracture networks (e.g. Fig. 4e). Punctuated degrees of magnetic anisotropy and shape factors occur across many of the cores (e.g. Wolfcamp and Haynesville) and could suggest the presence of compactional disequilibrium (Schwehr et al., 2006). Preliminary results suggest that these zones show differential fluid-flow behaviors and as a result, could impact reservoir properties (e.g. distribution of released hydrocarbons). Paleomagnetic analysis of shales provides evidence for remagnetizations that are inferred to be chemical remanent magnetizations (CRMs). These CRMs can be related to burial diagenetic events and/or fluid-flow events (e.g., Elmore et al., 2012) such as migration of hydrothermal fluids in the Woodford (Roberts and Elmore, 2014). Establishing the timing of these events can help refine paragenetic sequences for each basin.

DISCUSSION

The reasons for the similarities between the shale formations could be that many of the authigenic phases were sourced internally. Most of the elements in the authigenic minerals in the Wolfcamp Shale, for example, could have been derived from the mudstone and the minerals precipitated from internal fluids. Bacterial interactions during early burial may have facilitated decomposition of organic matter and precipitation of barite, sphalerite, and ferroan dolomite (González-Muñoz et al., 2003; Peltier et al., 2011; Selleck, 2014; Blättler et al., 2015). Barite is unstable in strongly reducing environments (Hanor, 2000; Arndt et al., 2006) and it could migrate into fractures along with celestine. Sulfate reduction may have developed framboidal pyrite and phosphate concretions. Biogenic silica micro-fossils dissolved during initial burial, providing silica for authigenic

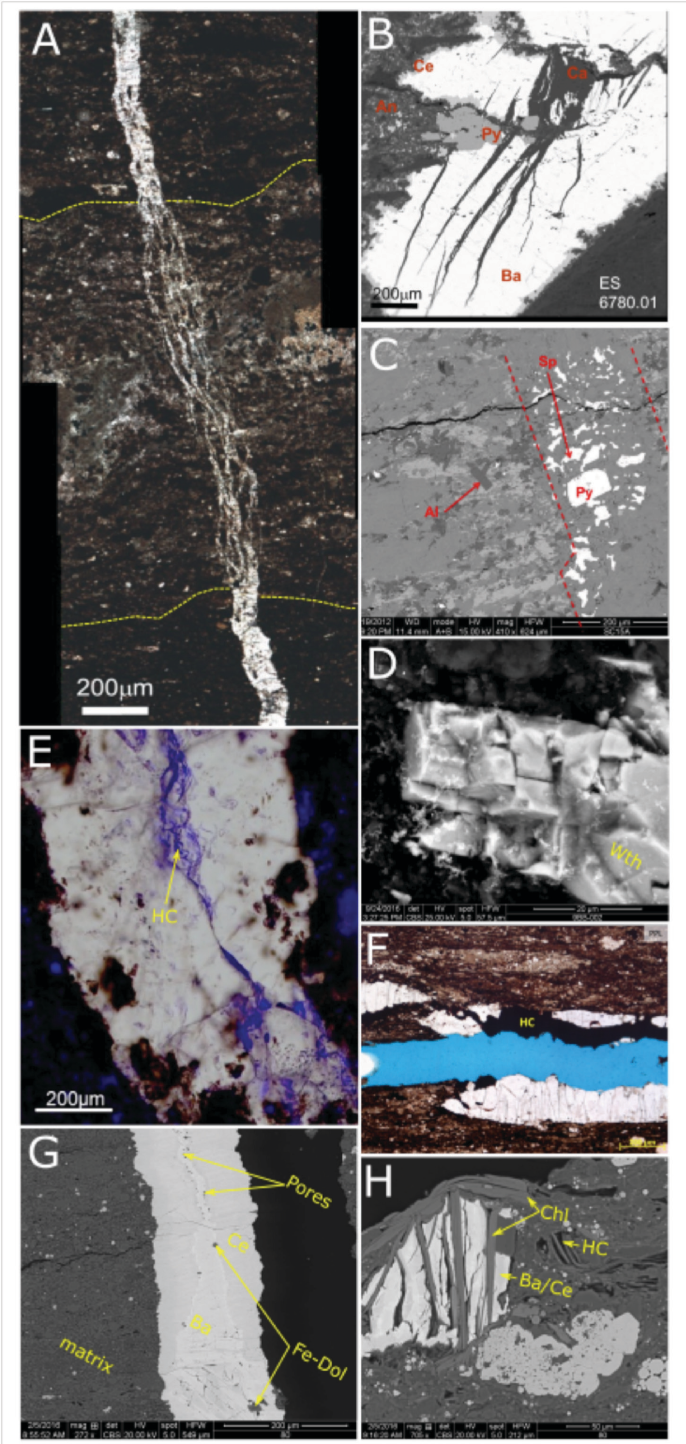

Figure 3: a) A fracture in the Barnett Shale. The lighter area with the anastomosing fracture pattern is carbonate rich while the dark shale with the straight fracture is clay rich., b) Backscatter image of fracture from the Barnett Shale. The fracture is filled with celestine (CE; outer rim) and barite (Ba) followed by anhydrite (An) and pyrite (Py) crosscut the fracture. The fracture was refractured and filled by a late calcite (Ca). (From Dennie et al., 2012). c) Backscatter image of a Marcellus mineralized fracture with sphalerite (SP) and pyrite in the fracture and albite in matrix (Al) d) SEM picture of witherite from a mineralized fracture in the Woodford Shale, e) A UV image of a vertical calcite fracture from the Wolfcamp Shale with hydrocarbons fluorescing, f) Photomicrograph of a horizontal 'beef' calcite (Cal) fracture with hydrocarbons at the top (HC) in a siliceous mudstone, g) Backscatter image of a Wolcamp fracture in siliceous mudstone which changes from celestine (Ce) along the edge to barite (Ba) in the center of the fracture. Along the margin between the celestine and barite, some small pores (Pore) are present and some are filled with ferroan dolomite, h) Iron-rich chlorite (Chl) in fractured barite from the Wolfcamp. Organic matter (HC) occurs between clay sheets.

quartz (Hesse and Schacht, 2011). Shale dewatering in the mudstones likely stimulated the migration of pore fluids that may have supplied magnesium, silica, and iron which could have been a source for ferroan carbonates and authigenic quartz (McHargue and Price, 1982; Coniglio and James, 1988). The smectite-to-illite conversion was likely a source for silica, iron, and magnesium (e.g., Coniglio and James, 1988), that formed chert and ferroan carbonates as well as for iron-rich chlorite during middle and late diagenesis. Authigenic albite is common in many sedimentary rocks and can from early to late diagenesis (Fishman et al., 1995). Authigenic albite formation can form isochemically from the constituents in the rock (Kastner, 1971). The Na could be derived from seawater or clay transformations and Si and Al from the smectite to illite transformation. Some workers have suggested that authigenic albite in carbonates can form from burial brines (Spötl et al., 1999).

Fracturing during burial probably allowed for migration of internal fluids in the mudstones (e.g. Millikan and Land, 1994). Strontium released from aragonite which formed in aragonite seas in the Permian (Hardie, 1996) is a likely source for the celestine in the fractures. Similarly, dissolution of allochems were probably a source for calcite in fractures.

Perhaps more intriguing than the similarities within shale formations are the differences. The variations between shale formations could be explained by differences in depositional environment, tectonic setting, and burial history. For example, the tectonic setting could trigger the migration of external hydrothermal fluids into the formation. Interestingly, each shale seems to have at least one major or minor authigenic mineral constituent which was not identified within the other shale units or one phase is found in much higher abundance than another. For example, the Woodford Shale (Roberts and Elmore, 2014) has significant variability within fracture networks when compared to other shales, containing hydrothermal minerals in fractures. Within the Barnett Shale monazite and stillwellite are identified above the Barnett/Viola unconformity, which may indicate some hydrothermal contribution (Dennie et al., 2012). The results from these units suggests the systems were at least partially open to external fluids.

Fractures can also influence the mechanical behavior of mudstones because they are pre-existing planes of weakness that can reactivate during hydraulic fracturing (e.g., Gale et al., 2014). The type of fracture fill is another variable because, minerals such as calcite, dolomite, barite, and quartz are brittle and promote fracturing (Dehandschutter et al., 2005). The role of micro fractures which may not be fully recognized without XRCT analysis should be addressed.

An important question in shale diagenesis is what were the pathways for fluid migration? Mineralized fractures are one obvious pathway, and the presence of porosity, refracturing, and replaced minerals in some fractures suggest they may have been a pathway for multiple fluid flow episodes after the initial mineralizing event. Thin horizontal intervals in mudstones with deformed prolate AMS fabrics (e.g., Heij and others, 2016) and thin carbonate intervals (Engle et al., 2016) are also hypothesized fluid conduits. In shale basins with high rates of subsidence, like the Midland Basin, differential overpressuring can aid pore fluid migration not just through fracture systems, but also by increasing permeability intervals within the mudstone matrix (e.g., Marshall, 1982).

The scale of the observations in shales is another issue that must be addressed. Many authors have discussed how nano scale porosity in organic matter is present in many shales (e.g. Loucks et al., 2009; Curtis et al., 2012) but other porosity types are also present. Few studies have devoted equal attention to each scale of observation. An important question is how to scale up from the nano scale

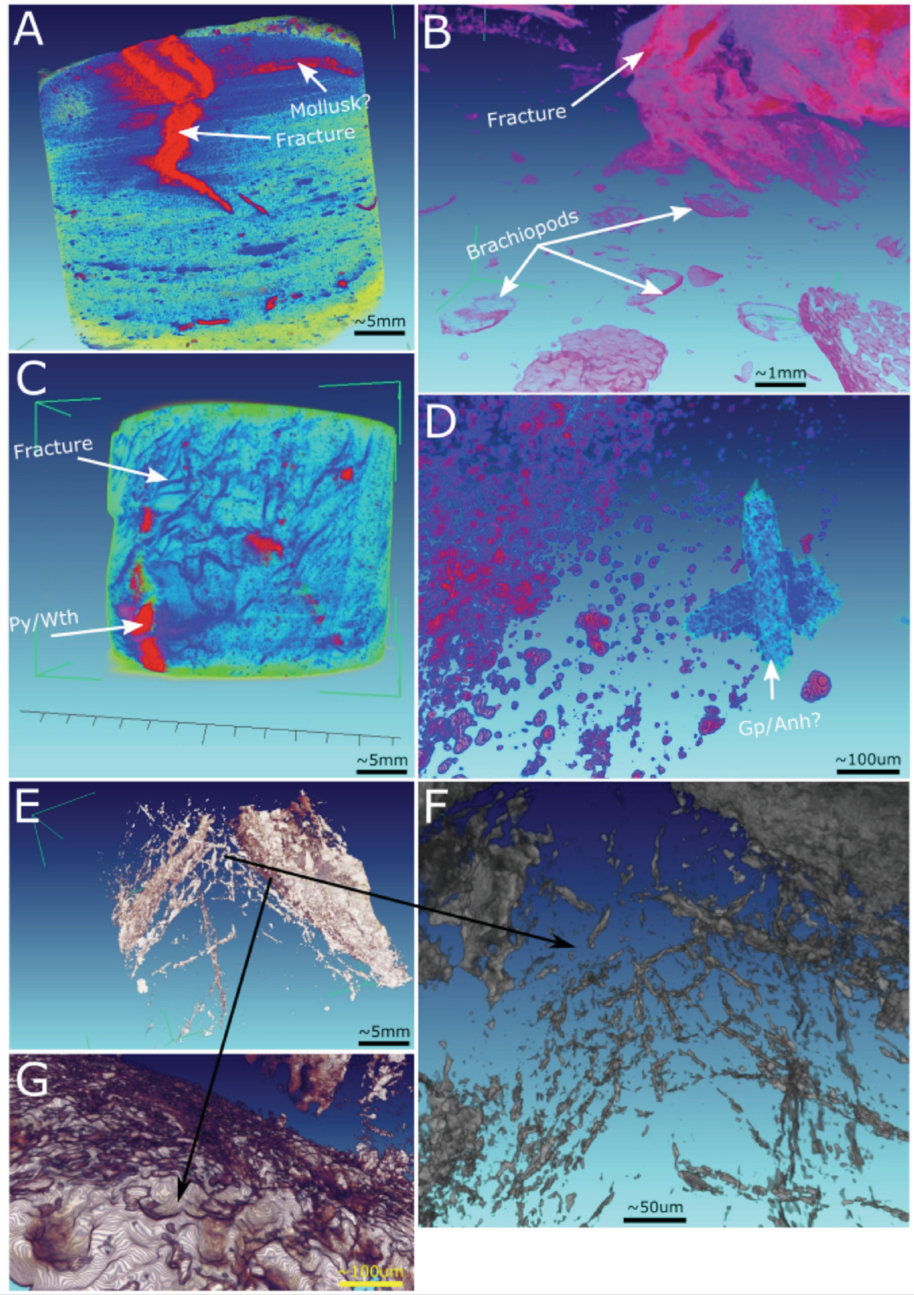

Figure 4: a) XRCT scan of 1-inch plug of the Haynesville. Red colors correspond to high-density minerals e.g. pyrite, blue and green correspond to medium and low density minerals respectively. b) Segmented image isolating high density mineral (pyrite). Note preferential replacement of pyrite along growth rims and margins of brachiopod shells. c) XRCT scan of 1-inch plug from the Woodford using same density profile as a). Note complex vertical fracture network possibly related to hydrothermal activity. High density minerals shown in red is likely some combination of pyrite and witherite confirmed using energy dispersive analysis. d) Segmentation of the Woodford plug shows medium to high density minerals. Note fish-tail twinning consistent with gypsum/anhydrite. e) Wolfcamp 1-inch plug segmented to show high density barite/celestine fracture network. f) Magnification of barite/celestine micro-fracture network. g) Contoured surface of large barite/celestine fracture shows high degree of fracture surface roughness.

to micron scale where porosity occurs in clays, fractures, pyrite, dolomitic intervals, and then upscaling further to larger features such as sedimentary structures and to basin-scale faults. One might assume that the different levels of porosity are interconnected but the nature of these connections is unclear and remains a fundamental question that should be addressed.

CONCLUSIONS

Mudstones can have a very complex diagenetic history that can show levels of intricacy equal to or greater than that of sandstones and carbonates. Shales can be either open or closed to external fluids, and it is possible that they evolve from closed to open during burial. In fact, shales are so complex that they may be open or closed at different times in their burial history. Many variables, which are not mutually exclusive, can influence their paragenesis. For example, thermal conditions can accelerate mineral transformations such as illitization and rapid burial rates can cause overpressuring. Tectonics can result in the introduction of external fluids which can precipitate hydrothermal minerals. Fluid chemistries also exert a control on the diagenesis such as the variability of authigenic minerals in fractures. The detrital input affects mineral stability and the presence of organic matter can influence mineral dissolution rates and the creation of porosity. Ocean chemistry can also influence mineral precipitation (e.g., higher strontium levels due to replaced aragonite). The interplay of these variables can add further complexity and obscure the diagenetic history.

Absolute timing of diagenetic events is a largely unresolved issue in many shales. Radiometric dating can provide dates for events like the smectite to illite transformation (e.g., Clauer et al., 2012) and paleomagnetism has also been successful in some shales (e.g., Dennie et al., 2012; Manning et al., 2015) to constrain the timing of fluid flow and burial diagenetic events but more work is clearly needed. AMS analysis may also prove useful in determining how some variables such as compaction and tectonism impact the spatial variability of rock fabrics (e.g. Pares, 1999; Heij et al., 2016).

Many hypotheses about the diagenesis of shales remain untested and should be investigated. For example, are mineralized fractures an important conduit for later flow? How complex are fracture systems and what is the role of micofractures? How does this complexity relate to the mechanical behavior of the shale? What is the nature of the contact between mineralized fractures and the matrix? Does roughness of the fracture wall effect fluid flow and the mechanical behavior? How do we connect scales of observations? Addressing these types of questions are important if we are to better understand shale diagenesis and move beyond concentrating on the leaves to focusing on the trees and see the whole forest.

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Accepted November 2016

2017 SEPM Shepard Medalist

Lynn Donelson (Don) Wright

352-283-6007, ldwright@bellsouth.net

2017 Medalists will be publically recognized at the SEPM President's Reception, Tuesday, April 4, 2017 at the Four Seasons Hotel, Houston, TX, USA

PRESIDENT'S COMMENTS

Dear colleagues,

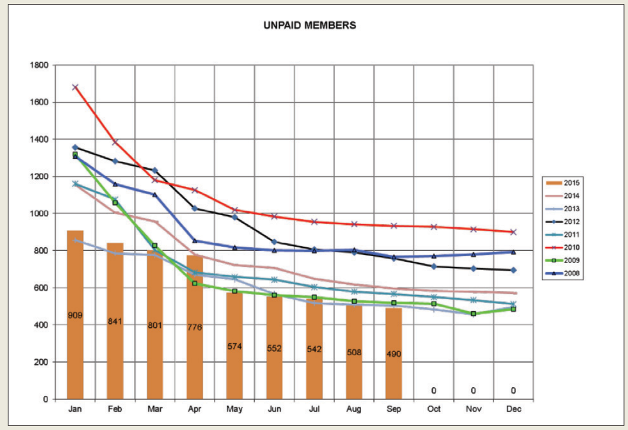
I would like to continue the discussion started in my last letter about how SEPM has been working to prepare for the future. As you are well aware, economy is still slow but may be showing some signs of stability and hopefully recovery. We have several initiatives focused on facing current adversities, some of which I have mentioned in the last edition of our magazine. Today I would like to share an update on the current status of our membership and also some recent good news.

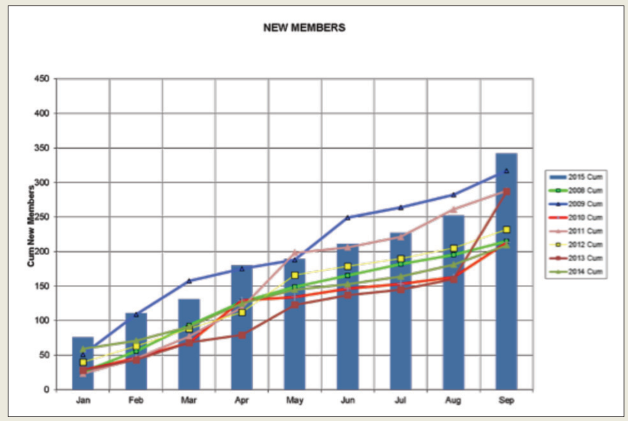
As we discussed last quarter, our membership numbers have been steadily decreasing since 2010, as many as 250 members in a year, from 3739 members in 2010 to 3084 at year end 2015. The first good news is that so far in 2016 our numbers are relatively flat to last year – maybe even slightly higher by the end of the year. Our staff has been very diligent in contacting our members for membership renewals and also offering promotions for renewal and new memberships. For example, a new membership for 2016 today will make your membership valid until December of 2017! A very positive consequence of the actions of our proactive staff is that we have now the lowest number of unpaid members since 2008, about 100 members less than at the same time last year. Please see graph at right.

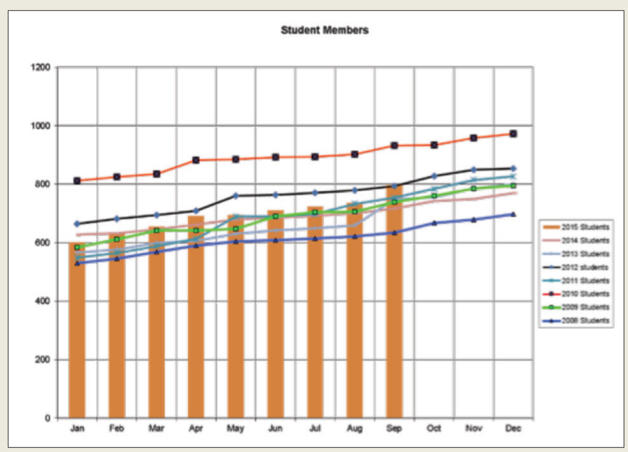
Another important impact on membership this year was our participation in AAPG and GSA meetings, with a booth to advertise our journals and books, as well as offering SEPM short courses and competing with our sister societies for new members. The result is that we have had a very good number of new applications at AAPG in Barcelona, Calgary and Cancun and at GSA in Denver. Kudos once again for our staff in making our booth in Denver the highlight for the students at the GSA meeting! The graph below shows the cumulative number of new members per month compared to previous years. The number of new members we have so far this year is already the highest number of new members in a year in our recent past!

Last but not least, our student membership numbers are very strong as well. One of our best years since 2010.

I was eager to share this with you. I truly believe this is not a "glitch" – I am positive this reflects the first evidence of a change in trend. Is this a reflection of a more stable market? I am not sure, but I interpret that we hit a firm low and we can now continue to build. I encourage you to continue talking to your colleagues and encouraging young professionals to join SEPM!







Finally, did I mention that if you pay your membership now it will be valid until December 2017??

Vitor Abreu,
SEPM President

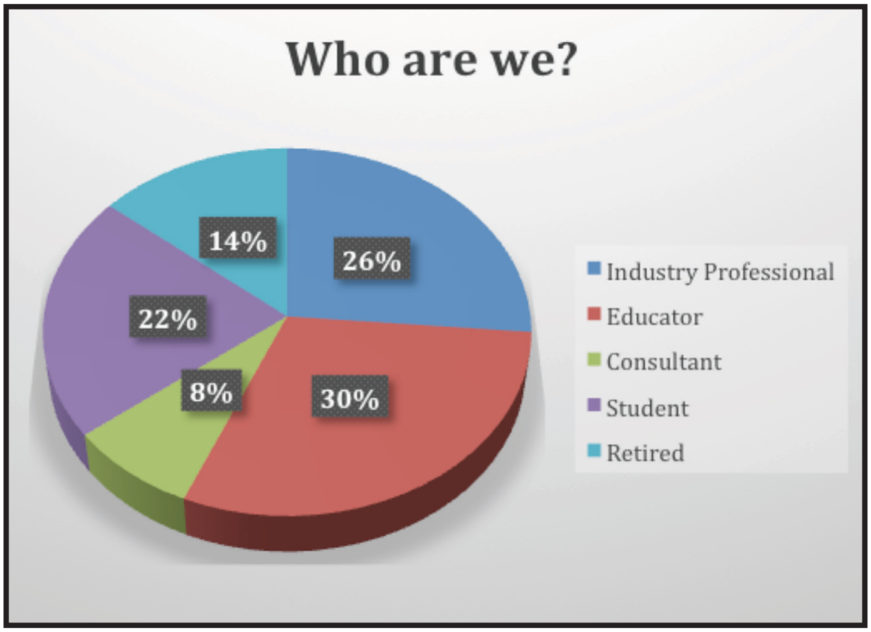
SEPM Society for Sedimentary Geology
"Bringing the Sedimentary Geology Community Together"
www.sepm.org

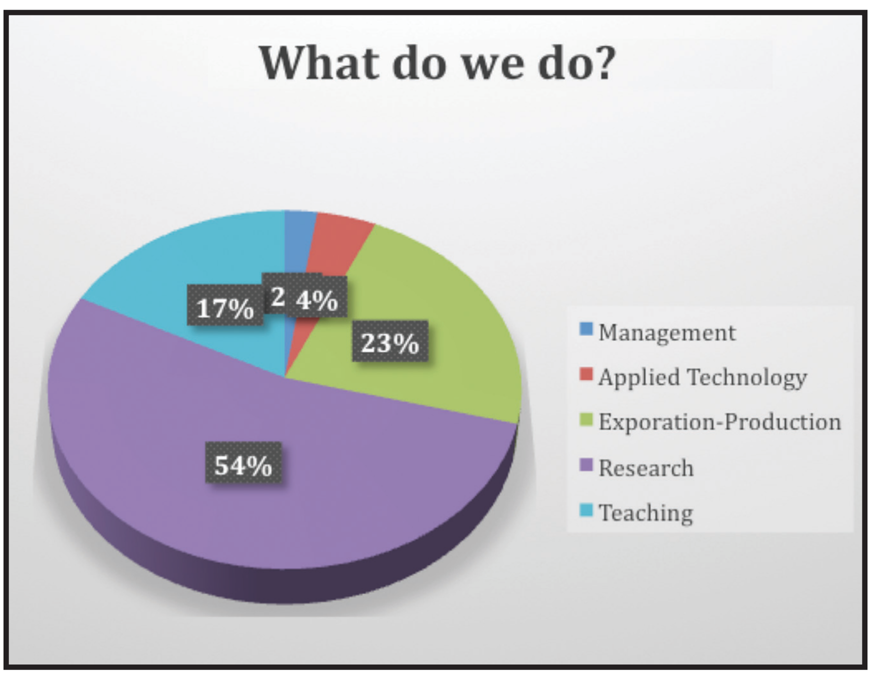
SEPM Member Survey Results

With about 25% of our members responding, so far, here are some interesting results of our new member survey. If you have not filled it out please go to https://www.surveymonkey.com/r/75WVQ6S to add your input.

There will be a drawing on December 31 for one lucky winner to receive an Amazon Firestick! Ten other members will also receive a 50% off coupon code to use in the SEPM Bookstore!

So far, SEPM appears to be a society well balanced between academic and industry researchers. What do you think?





SEPM Online First

Here is what's up at Online First – if you haven't gone there yet – take a look!
http://www.sepm.org/OnlineFirst.aspx

Special Publication #106 - Autogenic Dynamics and Self-Organization in Sedimentary Systems -

- Biological Self-Organization: Implications for Sedimentary Rocks with Examples from Shallow Marine Settings. Author: Thomas D. Olszewski
- Comparison of Avulsion Cycles from Subaerial and Subaqueous Fan Experiments with Supercritical Channels. Authors: Paul Hamilton, Kyle Strom, David Hoyal
- Measuring Scales of Autogenic Organization in Fluvial Stratigraphy: An Example from the Cretaceous Lower Williams Fork Formation, Colorado. Authors: Ellen P. Chamberlin, Elizabeth A. Hajek, Sheila A.M. Trampush
- Mud Begets Mud: Autogenesis of a Mud-Dominated Coastal Sequence. Author: James M. Rine
- A Mind of Their Own: Recent Advances in Autogenic Dynamics in Rivers and Deltas. Author: Chris Paola
- Lattice Models in Ecology, Paleontology, and Geology. Author: Roy E. Plotnick
- Trickle-Down and Trickle-Up Boundary Conditions in Eolian Dune-Field Pattern Formation. Authors: Gary Kocurek, Ryan C. Ewing
- River-Dominated Deltas: Upscaling Autogenic and Allogenic Processes Observed in Laboratory Experiments to Field Examples of Small Deltas in Southern Brazil. Authors: Maria Luiza, Correa da Camara Rosa, David Hoyal, Eduardo G. Barboza, Juan Fedele, Vitor Abreu
- Introduction to Autogenic Dynamics and Self-Organization in Sedimentary Systems. Authors: David A. Budd, Elizabeth A. Hajek, Sam J. Purkis
- Clustering of Elongate Muddy Delta Lobes within Fluvio-Lacustrine Systems, Jurassic Kayenta Formation, Utah. Authors: Galen Huling, John Holbrook
- Bedforms Created by Gravity Flows. Authors: Juan J. Fedele, David Hoyal, Zachary Barnaal, Joseph Tulenko, Shane Awalt
- Autogenic Modulation of Fluvial Channel Fills in Allogenically Formed Incised Valleys: Cretaceous Blackhawk Formation, USA. Authors: Hiranya Sahoo, M. Royhan Gani
- Self-Organized Pattern Formation in Sedimentary Geochemical Systems. Authors: Yifeng Wang, David A. Budd
- Spatial Self-Organization in Carbonate Depositional Environments. Authors: Sam J. Purkis, Johan van de Koppel, Peter M. Burgess

Special Publication #107 - New Advances in Devonian Carbonates: Outcrop Analogs, Reservoirs, and Chronostratigraphy -

- Devonian Reef Complexes of the Canning Basin, Western Australia: A Historical Review. Authors: Phillip E. Playford, Roger M. Hocking, Anthony E. Cockbain
- Paleotopography on the Intra-Swan Hills Formation Unconformity in an Isolated Platform, Carson Creek North Field (Upper Devonian, Frasnian), and Implications for Regional Stratigraphic Correlation. Author: Joel F. Collins
- Pattern and Timing of the Late Devonian Biotic Crisis in Western Canada: Insights from Carbon Isotopes and Astronomical Calibration of Magnetic Susceptibility Data. Authors: Michael T. Whalen, David De Vleeschouwer, Joshua H. Payne, James E. (Jed) Day, D. Jeffrey Over, Philippe Claeys

SEPM PRESENTATION AWARDS - 2016

2016 ACE Outstanding Presentation Awards

SEPM Outstanding Research Symposium Oral Presentation – Orals (tie)

- **Cari L. Johnson.** Recognizing Decoupled Controls on Accommodation and Sediment Supply, and the Importance of Axial Drainages in Foreland Basins: Adventures in Stratigraphic Correlation From the Cretaceous Straight Cliffs Formation of the Kaiparowits Plateau, Southern Utah
- **Julie Fosdick, T. M. Schwartz, B. Romans, R. Ali, J. S. Leonard, J. E. Bostelmann, R. UgaldePeralta, A. Bernhardt, S. A. Graham.** Cenozoic Evolution of the Magallanes-Austral Basin and Patagonian Fold-Thrust Belt: A Tale of Inheritance and Sediment Recycling

SEPM Outstanding SEPM Poster Award

1. Top Poster: **Clayton Schultz, M. Hofmann, M. Hendrix, B. Hart.** Diagenesis of the Sappington Formation in SW Montana: Implications for Reservoir Quality in the Time-Equivalent Bakken Formation
2. Honorable Mention: **Philip T. Staudigel, P. Swart, H. Elderfield.** A Diagenetic Origin for $\delta^{18}O$ Variability on the Margins of the Great Bahama Bank, Insights From Clumped Isotopes

SEPM Outstanding SEPM Oral Presentation Award

1. Top Oral presentation: **Robert W. Dalrymple, L. Padman.** Are Tides Controlled by Latitude?
2. Honorable Mention: **Rebecca L. Caldwell, D. Edmonds, J. L. Best, D. R. Parsons, R. L. Slingerland.** Morphodynamic Stratigraphy of River-Dominated Deltaic Bars

SEPM ACE Student Poster Awards – (top 3 - $500 each)

- **Wen Lin, J.P. Bhattacharya:** Estimation of Source-to-Sink Mass Balance and Depositional Systems Dominated Sediment Budgets by a Fulcrum Approach Assesment Using Channel Paleohydrologic Parameters: Cretaceous Dunvegan Formation
- **Matt Rine, S.E. Kaczmarek, W. Harrison, D. Barnes:** Development of a Static Reservoir Model for the Niagara-Lower Salina Reef Complex of the Guelph Formation, Michigan Basin
- **Maxwell E. Pommer:** Chemical Diagenesis in Stratigraphic Context: The Ervay Cycle of the Phosphoria Rock Complex (Permian), Wyoming and Montana

2016-GSA Annual Meeting Presentation Awards

SEPM-SGD Student Poster Awards (top 4 - $500 each)

- **Angela M. Norman:** Investigating the provenance of black sand in Iceland: Local vs. Distal Sources
- **Rachel Fliflet, J.M. Poirier, B.J. Mahoney and K.M. Syverson:** Diagenetic History of Cambrian Sandstone Units in Western Wisconsin
- **Cody J. Stopka, B.A. Hampton, and G.H. Mack:** U-PB Detrital Zircon geochronology, modal composition, and paleoflow trends from the Upper Cretaceious nonmarine strata in Southern New Mexico
- **Nicholas David Risedorg, and G.L. Gianniny:** Potential contraints on the timing of halokinetic megaflap deformantion; biostratigraphy and paleoecology of Permian/Pennsylvanian carbonates, Big Gypsum Salt Anticline, SW Colorado

SEPM Research Conference

Propagation of Environmental Signals within Source-to-Sink Stratigraphy

Dates: June 5th – 9th, 2017*

Tremp & Ainsa, Spanish Pyranees

(*Bus transportation to and from Barcelona on June 4th and June 10th)

Conveners:
Sébastien Castelltort *(University of Geneva)*
Julian Clark *(Statoil)*
Andrea Fildani *(Statoil)*
Cai Puigdefàbregas *(University of Barcelona)*

Confirmed Key Note Speakers:
Michael Blum *(University of Kansas)*, Douglas Burbank *(UC Santa Barbara)*, Ole Martinsen *(Statoil)*, Daniel Stockli *(UT Austin)* and Sean Willett *(ETH, Zürich)*

The focus of this research conference is on controls on clastic sedimentation at different geologic timescales and the propagation of sediment-flux signals in the stratigraphic record of correlative segments of source-to-sink sedimentary systems. The conference will aim to bring together scientists from Academia and Industry interested in the stratigraphic responses to tectonic, climatic and sea-level controls on sedimentation, and how these signals propagate or attenuate along the depositional profile.

Contributions will be solicited from earth scientists to cover the following:

- Studies from outcrop, subsurface and modern sedimentary systems showing long-range signal propagation along the sedimentary routing system
- Numerical and physical laboratory models of stratigraphic signal generation, propagation and attenuation
- Sediment flux vs accommodation and controlling effects on sediment partitioning
- Advances in tectonic geomorphology and application to understanding the stratigraphic record
- Thermochronometric methods applied to provenance controls
- Detection of climatic and tectonic signals and their timescales through use of multi-proxies

The 5-day meeting will be an integrated conference and field excursion, with approximately half the time spent in the field. The Pyrenean foreland basin offers a great opportunity to visit world-class exposures of outcrops that, through decades of geologic study, permit the investigation of cyclicity in correlative stratigraphy from alluvial, fluvial, shallow marine, slope and deep marine environments.

2017 MOUNTJOY CARBONATE RESEARCH CONFERENCE

The **2017 Mountjoy Conference**, sponsored by SEPM (Society for Sedimentary Geology) and CSPG (Canadian Society of Petroleum Geologists), will be held the week of June 26-30, 2017 in Austin, Texas, at the University of Texas Learning Commons and the Bureau of Economic Geology Core facility. With the theme ***"Characterization and Modeling of Carbonate Pore Systems,"*** the conference will showcase new approaches and results through oral and poster sessions as well as core workshops and fieldtrips.

The theme is broad, encompassing the:

- stratigraphic, facies and diagenetic influences on varied pore systems;
- petrographic, geochemical and visualization tools applied to enhanced characterization of pore systems, from nano- and micro-scale, to fractures and cavernous pores; and
- new approaches for modeling the origin and distribution of pore systems.

Integrated case studies from academia and industry are of particular interest.

One of the highlights of the 1st Mountjoy meeting in 2015 was the opportunity for individual discussion and interaction between the attendees and the presenters. The 2017 Mountjoy Conference will continue to stress the importance of dedicated time for discussion and one-on-one networking throughout the program.

1926 SEPM
Society for Sedimentary Geology

Canada's Energy Geoscientists
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