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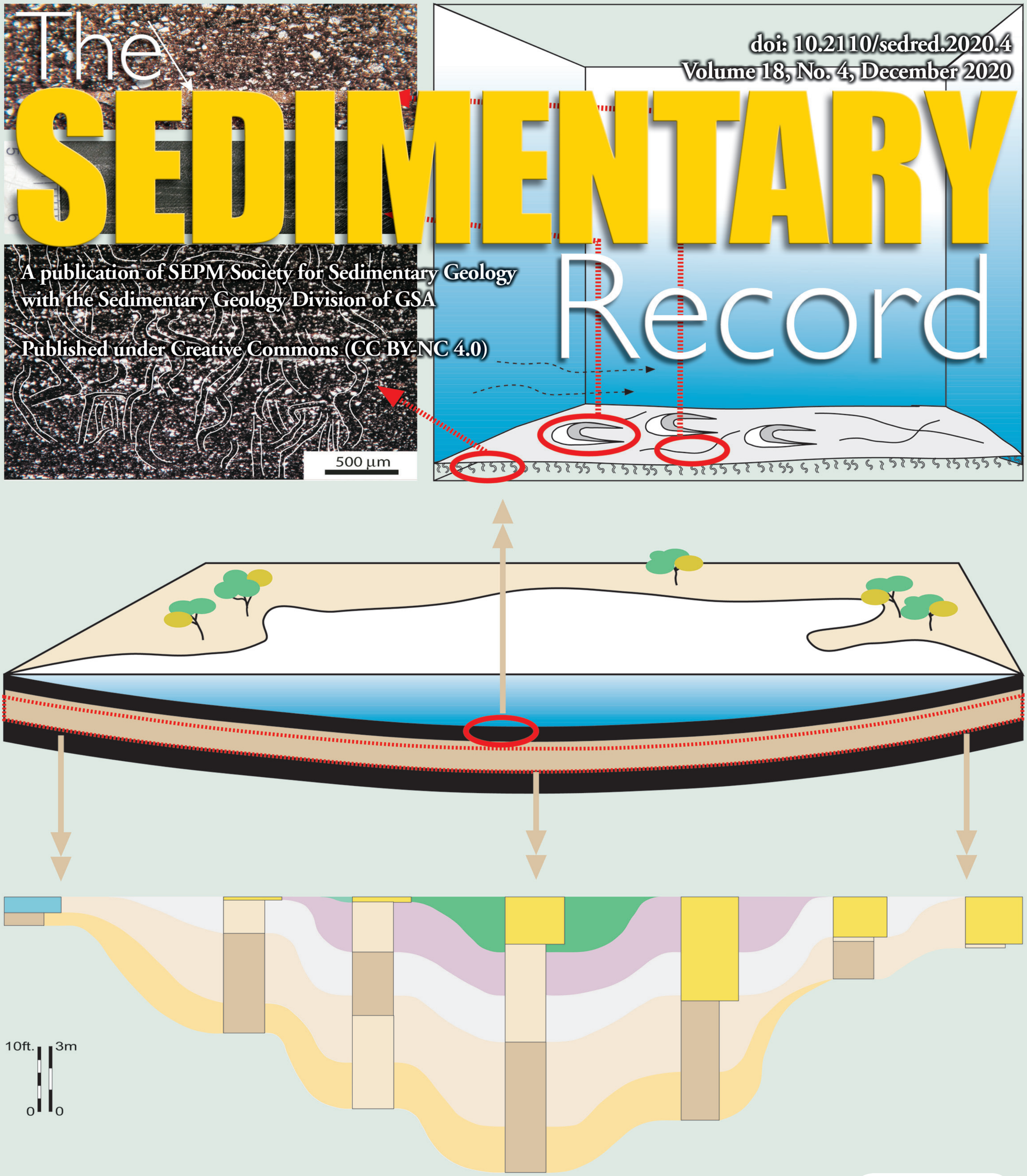

INSIDE: THE BAKKEN FORMATION – UNDERSTANDING THE SEQUENCE STRATIGRAPHIC RECORD OF LOW-GRADIENT SEDIMENTARY SYSTEMS, SHALE DEPOSITIONAL ENVIRONMENTS, AND SEA-LEVEL CHANGES IN AN ICEHOUSE WORLD

PLUS: PRESIDENT'S COMMENTS, WHO NEEDS STRATIGRAPHERS, SEDIMENTOLOGISTS & PALEONTOLOGISTS? EVOLVING ROLES THROUGH THE ENERGY TRANSITION

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Special Publication #112

Carbonate Pore Systems: New Developments and Case Studies

Edited by: Donald F. McNeil, Paul (Mitch) Harris, Eugene C. Rankey, and Jean C.C. Hsieh

SEPM (Society for Sedimentary Geology) and the CSPG (Canadian Society of Petroleum Geologists) convened the Mountjoy II Carbonate Research Conference in Austin, Texas, from June 25-29, 2017. The conference, honoring Eric Mountjoy and his numerous contributions as a geologist and graduate student supervisor, was attended by ~140 professors, students, and industry geologists and engineers from around the world. The theme for the conference and now SEPM Special Publication 112—Carbonate Pore Systems—follows the general concept to have topics that are relevant to the petroleum industry and therefore blend the best of cutting-edge geoscience research with industry needs by offering a major publication featuring studies with significant new results in the analysis of carbonate pore systems. This new SEPM–CSPG Special Publication is timely given the renewed interest in carbonate reservoirs, including those in carbonate mudrock deposits, as well as the many new technical advances and approaches that are being utilized in diagenetic studies.

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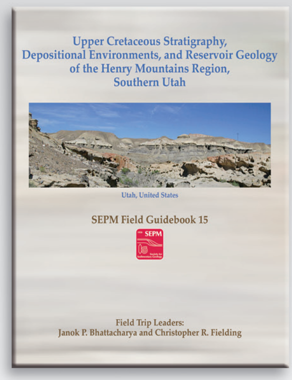

Field Trip Guidebook #15

Upper Cretaceous Stratigraphy, Depositional Environments, and Reservoir Geology of the Henry Mountains Region, Southern Utah

By: Janok P. Bhattarcharya and Christopher R. Fielding

This field guide describes a geological field excursion focusing on world-class exposures of the Upper Cretaceous succession in the Henry Mountains Syncline of southern Utah. The area is easily accessible via paved and some unpaved roads, and is a little over three hours' drive by road from Salt Lake City. It is adjacent to the world-renowned Capitol Reef National Park and other scenic attractions. There are numerous options for accommodation and eating out in Torrey, UT, which caters to the tourist trade. The stratigraphy comprises the Dakota Formation, Mancos Shale (Tununk Shale, Ferron Sandstone, Blue Gate Shale), Muley Canyon Sandstone, Masuk Formation, and Tarantula Mesa Sandstone, and collectively is equivalent to the well-known succession of the Book Cliffs, 100 km to the north. The succession is spectacularly exposed in three dimensions at scales ranging up to that of entire depositional systems, allowing investigation of stratal stacking patterns at all levels. The guide focuses primarily on the Turonian Ferron Sandstone, which has been extensively investigated by both trip leaders and their students over the past 12 years.

Among the geological features exposed in the Ferron Sandstone are incised valley fills, distributary channel deposits, and growth faulted delta front deposits. Stratal stacking patterns are exposed in both depositional dip-parallel and strike-parallel transects, and have been interpreted to record sediment accumulation under strong forcing from falling sea-level. The Dakota Formation preserves coastal fluvial, estuarine, and marine shoreface deposits. The Tununk and Blue Gate Shales are principally offshore shelf deposits with some mass flow deposits and shelf clinoforms. The Muley Canyon Sandstone comprises alternating coastal fluvial and shoreface deposits similar to the coeval Blackhawk Formation, while the Masuk Formation is a stack of coastal fluvial deposits with a transgressive coal zone near the base of the formation.

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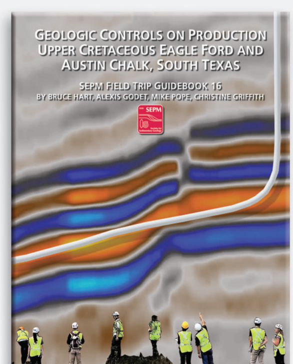
Field Trip Guidebook #16

Geologic Controls on Production: Upper Cretaceous Eagle Ford and Austin Chalk, South Texas

By: Bruce S. Hart, Alexis Godet, Michael C. Pope, and Christine Griffith



SEPM Field Trip Guidebook 16 is perhaps best thought of as an exercise in applied stratigraphy and structural geology. The technical goal is to make inter-disciplinary links, to demonstrate how stratigraphic and structural features affect exploration and development activities for unconventional hydrocarbon reservoirs.

The outcrops described in this guidebook should help to stimulate discussion on a series of interrelated topics such as: lithology, stratigraphic controls on hydrocarbons, horizontal drilling target, and geosteering challenges.

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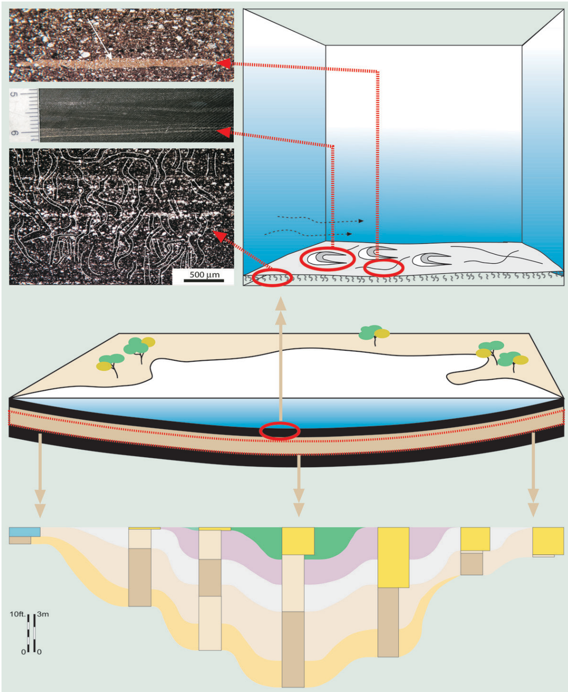

Cover image: Deposition of the Bakken Formation, Upper Devonian to Lower Mississippian, as envisioned from drill cores and thin sections. The middle figure is a sketch of the Williston basin with the two Bakken shales sandwiching the middle Bakken member. The top part of the figure shows characteristics of the Bakken shales – a Planolites *burrow, ripples, and siltstone laminae with abundant* Phycosiphon *isp. The bottom part of the figure displays a sketch of the diachronous nature of middle Bakken sedimentary packages, each of them interpreted to reflect time-equivalency and shown in a different color. Details in Egenhoff and Fishman (this volume).*

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The Bakken Formation – understanding the sequence stratigraphic record of low-gradient sedimentary systems, shale depositional environments, and sea-level changes in an icehouse world

Sven O. Egenhoff and Neil S. Fishman

ABSTRACT

The Bakken Formation is a major petroleum producer in the continental US. However, its deposition in an intracratonic, low-gradient setting has often been mistakenly described as "layer-cake". This contribution is designed to highlight the time-transgressive nature of its main petroleum-producer, the middle Bakken member. Correlation of individual parasequences reveal the subtle nature of otherwise invisible low-angle stratigraphic geometries. Sequence stratigraphically-relevant surfaces occur throughout the unit and subdivide the entire Bakken into 5 third-order sequences; one of them is a hidden sequence at the base of the petroleum-producing middle Bakken indicating both a lowstand and a subsequent transgression. The organic-rich shales above and below the middle Bakken were deposited in an oxygen-deficient environment and show several burrow/fecal string types and indications of active currents during deposition. The Bakken records high amplitude sea-level changes during sequences compared to relative low amplitude sea-level changes of parasequences. This, coupled with a likely mismatch in timing of Bakken deposition relative to world-wide ice-age-induced cyclicity makes it unlikely that the Bakken sea-level fluctuations were dominated by glaciation.

INTRODUCTION

The Upper Devonian-Lower Mississippian Bakken Formation is a focus of interest in parts of North Dakota and Montana because of its world-class source rocks and petroleum production (e.g., Gaswirth et al. 2013). Despite the keen interest in it, the internal stratigraphic geometries of the Bakken are so subtle that many consider the formation as a perfect example of layer-cake stratification (e.g. Meissner 1978; Sonnenberg and Pramudito 2009; Hart and Hofmann 2020). However, the sedimentary architecture of the Bakken, like other units deposited in intracratonic basins, is characterized by geometries that are at very low inclination—sub-parallel to the basin floor—making it difficult to recognize them in core or on well-logs. This contribution aims to clarify the subtlety of an intracratonic basin fill during sea-level fluctuations using the Bakken as an example. In this context, characterizing the sequence stratigraphy of the Bakken, as well as the depositional environment of all members of the formation, are of crucial importance. They allow us to reconstruct the dynamics of this sedimentary system and the relationship between the two organic-rich siliciclastic shales that overlie and underlie the middle member—a carbonate-siliciclastic unit. Ultimately, this understanding enables prediction of the characteristics of all these units. Lastly, the sea-level changes recorded in the Bakken are evaluated in the context of possible glacioeustasy related to an icehouse world.

GEOLOGICAL SETTING

The Williston Basin, an intracratonic trough formed in the Cambrian (Gerhard et al. 1990), occupies portions of present-day United States and Canada (e.g. Borcovsky et al. 2017; Fig. 1). The Bakken Formation component of the sedimentary succession is especially important because its two organic-rich shales were the source of petroleum in much of the Paleozoic section, including the overlying Mississippian Madison Group (Chen et al. 2009) and the underlying Three Forks Formation (e.g., Gaswirth et al. 2013). During Bakken deposition, the Williston Basin was subequatorial (Scotese 1994). The Bakken is up to 45 m thick (Meissner 1978), and is exclusively in the subsurface.

THE SEQUENCE STRATIGRAPHY OF LOW-ANGLE DEPOSITIONAL SYSTEMS – THE BAKKEN AS A PRIME EXAMPLE

The Bakken Formation is comprised of four informal members (LeFever et al. 2011; Fig. 1): the basal Sanish/ Pronghorn member (SP), which is aerially restricted, consists of sandstones and siltstones and locally a carbonate. Where present, it has a sharp contact with the underlying Three Forks Formation (Fig. 1; e.g. LeFever et al. 2011). The SP is overlain with a sharp contact by the lower Bakken shale (LBS), a black shale containing clay, organic

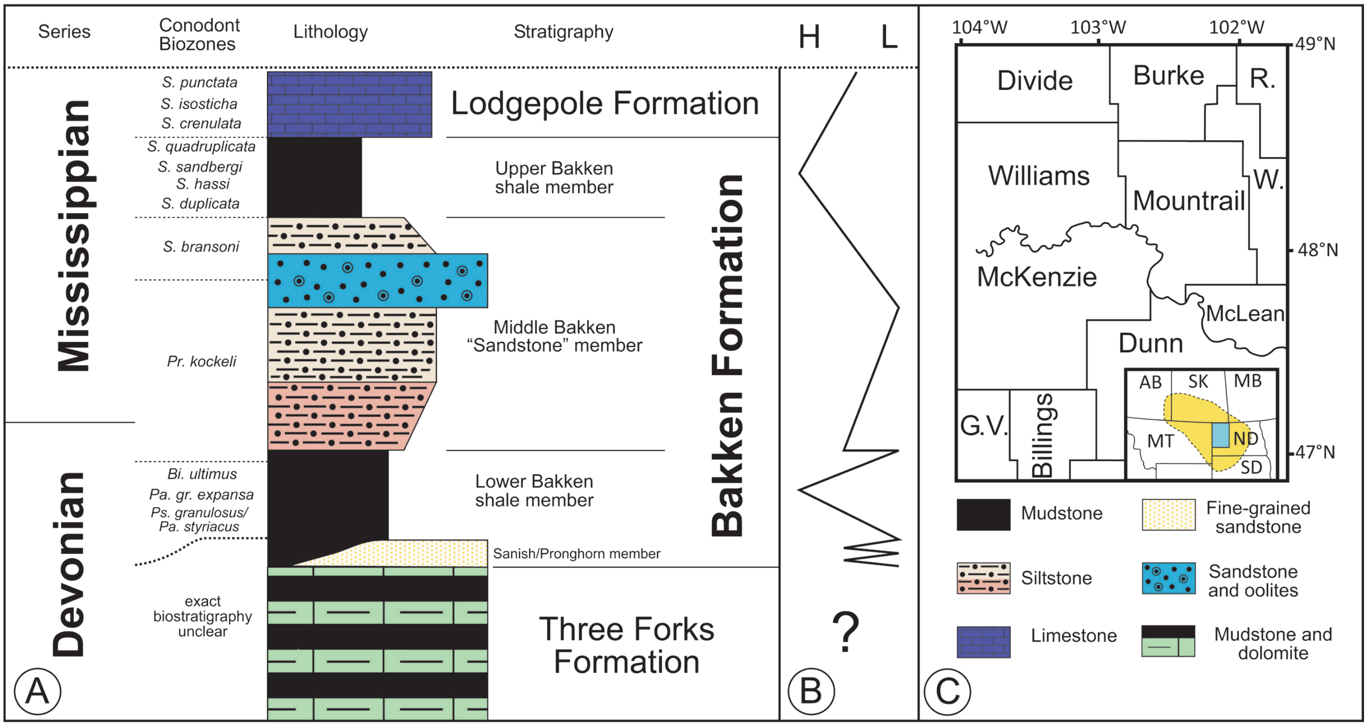

Figure 1: Stratigraphy of the Bakken Formation in North Dakota and Montana (A), a schematic reconstruction of sea-level evolution during Bakken times (B), and a location map of study area (blue, right side of figure) within the Williston Basin (yellow; C). Abbreviations of fossil names: Bi. **= Bispatodus;** ***Pa.*** **= Palmatolepsis;** ***Pr.*** **= Protognathus;** ***Ps.*** **= Pseudopolygnathus;** ***S.*** **= Siphonodella** ***(fossil identification after Hogancamp and Pocknall, 2018); H= high sea-level, L= low sea-level.***

matter, quartz silt, carbonate silt, and radiolarian microfossils. The LBS is organized into two sub-units; the lower half demonstrates an overall grain size decrease stratigraphically upwards, whereas the upper half contains more abundant siltstone beds as compared to the lower half (Albert 2014). The boundary between the LBS and the overlying middle Bakken (MB) is commonly sharp, with a centimeter-thick carbonate unit and clastic dikes tapering downward from the MB into the LBS (Egenhoff 2017). The MB consists dominantly of siliciclastics and subordinate carbonates, and is organized into two broad sub-units; the lower sub-unit (representing 1/2 to 3/4 of the succession) exhibits a generally coarsening-upward character, whereas the upper sub-unit broadly demonstrates a fining-upward character (Fig. 2; Novak and Egenhoff 2019). The lower sub-unit contains decimeter- to several meter-scale coarsening-upward packages that increase in number from the margin of the basin into the center (Egenhoff et al. 2011). The overlying upper Bakken shale (UBS) can be subdivided into 2 sub-units; the lower sub-unit contains abundant detrital clay, quartz, radiolaria, and organic-matter. In contrast, the upper sub-unit contains less quartz, fewer radiolaria, less organic matter but more clay than the lower sub-unit (Borcovsky et al. 2017).

Interpretation

The SP member is interpreted to have two regressive episodes — the siliciclastics – with an intervening transgressive episode – the carbonate. The sharp contact with the LBS shows a well-developed transgressive surface (Smith and Bustin 2000; Egenhoff et al. 2011) culminating in a highstand that corresponds to the top of the lower subunit of the LBS (Albert 2014). A regression separating the LBS from the MB is recorded by the upward coarsening in the upper subunit of the LBS along with the siliciclastic infill of the clastic dikes. This regression was followed by a transgression represented by the carbonates (Egenhoff 2017). The lower part of the MB contains 1-6 parasequences (in fig. 2 up to 5 are shown but 6 are present in well Ansbro Petroleum Loucks 44-30; Novak et al. submitted) interpreted as a forced regression and basinward progradation capped by a maximum regressive surface. The basinward progradation lead to successive exposure of the basin margins and resulted in a varying number but overall fewer parasequences at the margins versus the basin center. Following this regression <4 poorly organized parasequences record the subsequent transgression (Novak and Egenhoff 2019; Novak et al. submitted). Within the UBS, a lower transgressive section (the lower subunit) is overlain by an upper regressive section (Borcovsky et al. 2017).

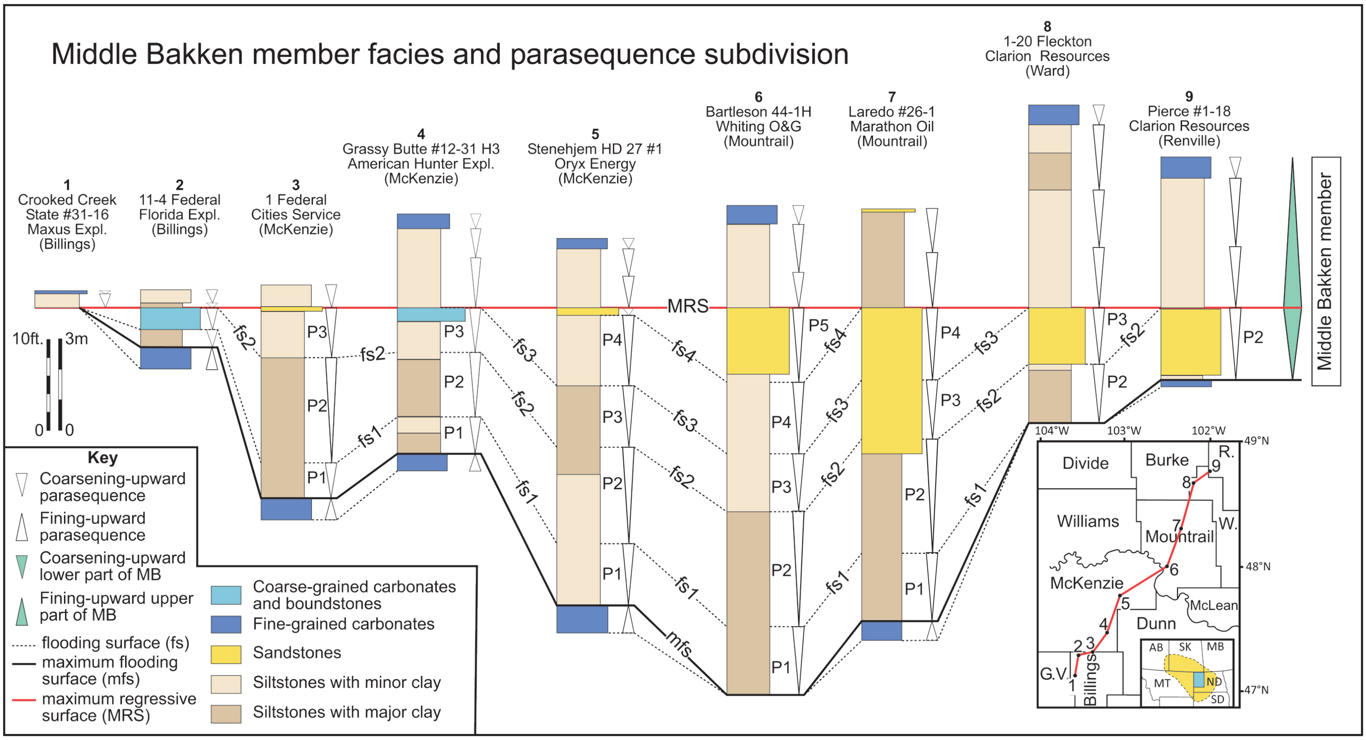

Figure 2: Stratigraphic cross-section through western ND from SW to NE simplified from Novak et al. submitted; note how the middle Bakken (MB) increases in thickness and shows more parasequences in the center of the basin (section 6) than towards the margins where it pinches out (section 1) or is reduced to a single parasequence (section 9). Lithological details are provided in Novak et al. submitted.

Therefore, the sequence stratigraphic framework of the Bakken Formation demonstrates at least 5 third-order sequences.

SUBTLE SEDIMENT GEOMETRIES INVOLVING THE UPPER BAKKEN SHALE

The UBS demonstrates a successively increasing number of parasequences from basin margin to center. Up to 22 decimeter to meter-scale coarsening- and fining-upward parasequences are observed in the basin center, whereas only 8-11 parasequences have been observed in cores close to the margin (Fig. 3; Borcovsky et al. 2017). The lower part of the UBS largely retains its thickness through the basin while the upper part thins from center to margin. Fecal strings and burrows are present throughout the UBS but decrease in abundance basinward from the margins. The same holds true for burrowing intensity, scours, and siltstone laminae (Borcovsky et al. 2017).

Interpretation

The overall basinward increase in the number of parasequences coupled with the decrease in thickness of the upper UBS is interpreted as reflecting an interfingering between the UBS and overlying carbonates of the Lodgepole Formation. Fecal strings and burrows in the UBS indicate at least oxygen-depleted conditions during deposition, and energy indicators such as ripple foresets and siltstone laminae show the influence of bed load on deposition (Fig. 3) particularly in more proximal reaches. The overall basinward decrease in these energy indicators implies currents, likely induced by storms (Egenhoff and Fishman 2013), which had a decreasing influence on bed load processes from the margin to the basin center.

SEA-LEVEL CHANGES IN AN ICEHOUSE WORLD

The Bakken Formation is broadly bounded by two well-documented, worldwide ice ages: the Late Devonian “Kellwasserkalk event” (Buggisch 1991) and the Carboniferous-Permian event best represented by Pennsylvanian cyclothems (Heckel 1986). Nevertheless, the later event likely started to leave a significant mark in the rock record in the Viséan (Early Carboniferous, e.g., Fielding and Frank 2015). Thus, neither of these recognized icehouse events are time equivalent to Bakken deposition (Fig. 4). Also, the Bakken shows distinct sea-level changes, prominently of two orders. Those that were longer, herein considered sequences, are likely about a million or more years in duration (e.g. Hogancamp and Pocknall 2018), whereas the shorter ones, equivalent to parasequences, were several tens to hundreds of thousands

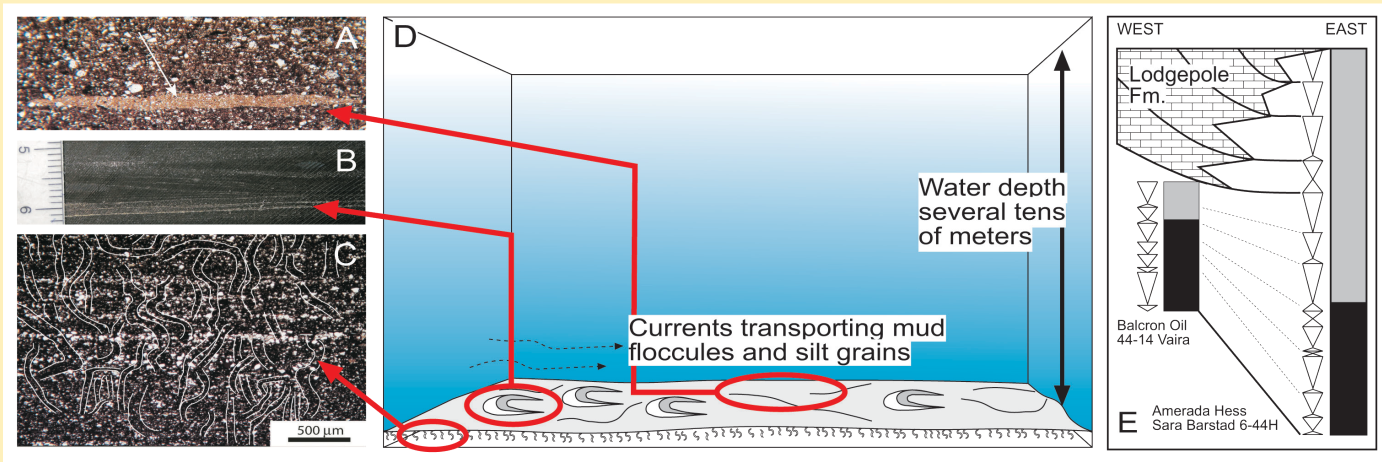

Figure 3: Depositional setting as envisioned for the LBS and UBS – (A) Planolites isp. (white arrow) is present in many of the thin sections, horizontal length is 700μm; (B) current ripples occur relatively frequently throughout the succession but are rarely well preserved, scale is in millimeters (modified from Egenhoff and Fishman 2013); (C) Phycosiphon incertum type B is observed in every thin section in great abundance (modified from Egenhoff and Fishman 2013); (D) envisioned conditions on the sea floor during deposition with migrating ripples, burrows, and fecal strings; (E) envisioned lateral transition between UBS in the Balcron Oil Vaira well close to the margin, and in the Amerada Hess Sara Barstad well representing the basin center; note the equivalency of the carbonates of the overlying Lodgepole Formation with the upper part of the UBS; upwards opening triangles – coarsening-upward, upward closing triangles – fining-upward; black represents lower portion of UBS, grey represents upper part of UBS, tiles represent Lodgepole carbonates; data from Borcovsky et al. (2017).

of years in duration (Novak et al. submitted). Importantly, the amplitude of the Bakken sequences is higher than the amplitude of the parasequences (see data in Egenhoff et al. 2011 and Novak et al. submitted). The relationship of sequences to parasequence in the Bakken would be atypical for sea-level fluctuations during a global ice-age where parasequences formed by Milankovitch-type cyclicity show very large amplitudes generally overshadowing everything else (e.g. Heckel 1986). As such, it seems unlikely that prominent ice-age derived sea-level fluctuations are recorded in the Bakken sequences or parasequences. Accordingly, we do not subscribe to the assignment of glacially-influenced cycles governing Bakken deposition as suggested by Hart and Hoffman (2020).

A similar picture emerges when data from the Bakken are compared to time-equivalent strata worldwide. The onset of ice-age type cyclicity is thought to have occurred in the upper Viséan according to successions in Scotland (Fielding and Frank 2015) which is post Bakken deposition; a similar age (Viséan to Serpukhovian) is reported from continental deposits sitting on striated bedrocks in the Paraná Basin of Brazil (Rosa et al. 2019). Glacial deposits in a fjord system in Argentina (Alonso-Muruaga et al. 2018) also point to a Viséan age for the onset of glacial deposition. Nevertheless, Lakin et al. (2016) were able to pinpoint three glaciation spikes in the latest Famennian, the mid-Tournaisian, and the Viséan in distinct regions of South America, Appalachia, and Africa before the onset of the main Carboniferous-Permian glaciation reported elsewhere. It therefore seems very probable that the Late Devonian glaciation is a direct precursor of the Carboniferous and Permian ice age; nevertheless, this ice age is not seen worldwide in cyclic sediments before the Viséan (see above).

DISCUSSION

A sequence stratigraphic interpretation of the Bakken Formation has been offered several times. Smith and Bustin (2000) presented an initial and controversial model; two of its shortcomings were that it largely equates the Bakken members with individual systems tracts, and its age correlations are not widely accepted. Another model (Hart and Hofmann 2020) relies heavily on glaciation as the driver of sea level change, although we argue there is a paucity of evidence of glaciation influencing Bakken deposition (see above). Instead, detailed sedimentological studies (e.g., Borcovsky et al. 2017; Egenhoff 2017) along with a comprehensive ichnological study (Angulo and Buatois 2012), as well as stratigraphic studies (LeFever et al. 2011) make clear that there is much more complexity in the entire Bakken succession than that proposed by Smith and Bustin (2000) or Hart and Hofmann (2020). Indeed, a properly developed sequence stratigraphic model for the Bakken succession requires inclusion of the entire package of rocks, from the SP through the UBS (Fig. 1).

Perhaps most important in interpreting the Bakken succession

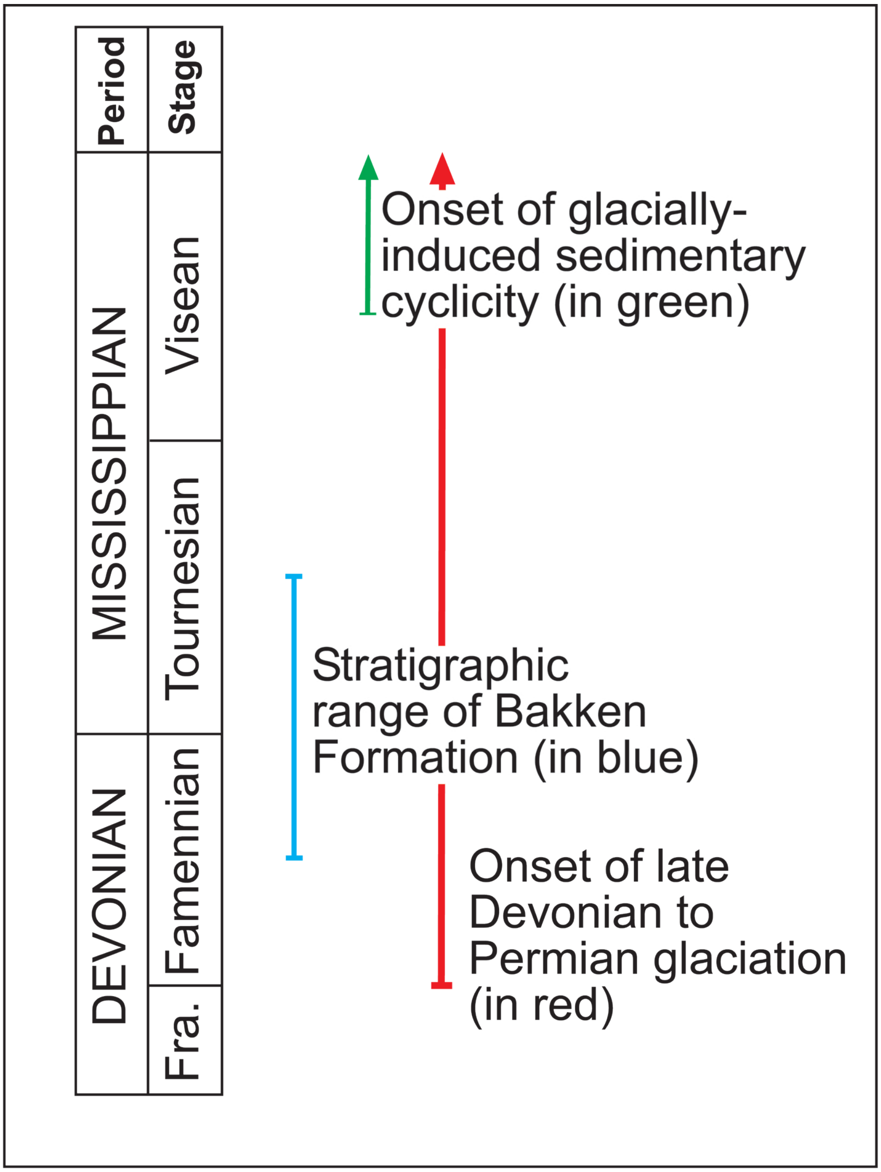

Figure 4: Schematic diagram of Bakken Formation age (blue) based on conodont data, the extent of the Devonian-Permian glaciation (red), and the onset of glacially-induced cyclicity (green). The diagram shows that Bakken deposition occurs before the onset of recognizable glacially-induced cyclicity in sediments worldwide. Fra. = Frasnian

properly is the recognition of several key parameters that can be gleaned by close examination of the rocks, both in core and in thin section. First, the SP points to initiation of Bakken deposition recording both regressions and transgressions (LeFever et al. 2011), and not the LBS as stated by Hart and Hofmann (2020). Secondly, the UBS demonstrates ample evidence of deposition from storms as well as significant bioturbation, despite their high TOC contents, which points to overturning the paradigm of deposition in waters well below storm wave base and under persistently anoxic conditions (e.g., Sonnenberg and Pramudito 2009), or even under euxinic conditions (e.g., Scott et al. 2017). Together, these parameters indicate that bottom currents were quite active and at least some degree of oxygenation persisted at the sediment/water interface during deposition of the LBS and the UBS (Albert 2014; Egenhoff and Fishman 2013; Borcovsky et al. 2017). Thirdly, the MB is characterized by abundant parasequences, each of them showing a flooding surface at both the base and the top which is likely driven by a series of transgressions and regressions throughout MB deposition (Egenhoff et al. 2011). Furthermore, some MB lithofacies, including ooid grainstones, were not deposited in a time-equivalent manner across the basin as evidenced by stacking patterns. Indeed, a depositional environment can establish itself in many different places in the basin based on sea-level changes and always produce a similar facies, but it is not sound to simply map similar facies and ascribe time equivalency to them (e.g., Hart and Hofmann 2020).

Sequence stratigraphic models must be constrained by a detailed sedimentological and bio- or chronostratigraphic framework (Catuneanu 2005). Below bio- or chronostratigraphic resolution, parasequence boundaries can be carefully traced through a basin and allow recognizing time-equivalency also for rocks of varying facies. Based on such models the Bakken shows (1) the lateral transition of shales into carbonates, and (2) a varying number of parasequences throughout the basin with more near the basin center and fewer towards the margins (Egenhoff et al. 2011; Borcovsky et al. 2017; Novak et al. submitted). This indicates that intracratonic basins adhere to sequence stratigraphic principles yet show geometries at incredibly low angles that are only visible when carefully correlating parasequences through a basin.

Although the Carboniferous-Permian glaciation is known to have commenced in the Late Devonian (e.g. Isaacson et al. 2008) the influence of glacially-induced sea-level changes on sedimentation seems to be only recorded in sediments from the upper Viséan on (Fielding and Frank 2015). A direct influence of the ice age on cyclicity in the Bakken, which was deposited near the paleoequator, therefore remains highly questionable.

CONCLUSIONS

The Bakken Formation consists of shallow-marine coarse-grained sediments to offshore organic-rich shales arranged in very gentle geometries equivalent to a nearly horizontal basin floor. The Bakken is organized into 5 sequences, which in turn consists of several parasequences. In regressive strata, their numbers increase from proximal to distal reflecting the successive exposure of the basin margin as sediment wedges step basinwards. Geometries in these strata are so gentle that they are only well recognizable in basin-wide transects. Nevertheless, regressive strata also show the black shales of the UBS transitioning into carbonates of the overlying Lodgepole Formation. The shales themselves exhibit evidence of burrowing and mudstone ripples and are interpreted to be deposited in an oxygen-deficient environment, subjected to common current activity. Finally, the high-amplitudes of sequences relative to the low-amplitude of parasequences make it unlikely that glacially-induced cyclicity governed sedimentation of the Bakken.

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PRESIDENT'S COMMENTS

I will keep this end-of-year Presidential Column brief and outline a few things that are ongoing in the society.

First, the International Sedimentary Geosciences Congress (now ISGC 2021) was to be held in April 2020 but was rescheduled for April 11-14, 2021. The current plan is to hold the meeting in person: as was the case for the original dates, SEPM has to schedule such an event far in advance, and financially commit to conference and hotel facilities. We are of course aware of the many issues related to holding a meeting in person, and are prepared to hold the meeting in hybrid or virtual or postpone to another time. But for now, I invite you to take a look at the current state of the conference program at https://www.sepm.org/ISGCSessionProgram. The topical sessions developed for the April 2020 meeting are still there, and a new topical session that will feature innovations in teaching the sedimentary geosciences has been added. The eventual success of this conference is a real boost to the future of SEPM, so I hope we can all participate in some way when the meeting takes place.

Second, the SEPM council has been rethinking *The Sedimentary Record* to increase the profile of its scientific content and comply with new open access guidelines. Open access represents a significant challenge to us all, from the individual researcher who needs access to published material, to libraries that must provide access to journals in a time of budget shortfalls, to funding agencies that encourage or require publication in open access journals, and to societies like SEPM that are financially tied to the success of their journals. A new editorial team comprised of Jenn Pickering (Shell), Jake Covault (UT-Austin), and Jeong-Hyun Lee (Chungnam National University) is planning a number of changes, including soliciting and publishing several short-format research articles, plus some articles on 'research advances' for each of the four annual issues. The team also plans to implement a new submission platform and apply for an impact factor this coming year, so as to provide further incentive for publication in this journal. *The Sedimentary Record* will then become SEPM's Full Open Access journal, which will limit impact of the open access process on the current status of *JSR* and *PALAIOS* and open up new opportunities for authors.

Third, the best part of being SEPM President, without question, is when you get to hear about, notify and then present awards to your colleagues. In past years, presentation of society awards has taken place at the SEPM President's Reception, held in the evening during the AAPG ACE/SEPM Annual Meeting. This year, AAPG ACE was postponed then held virtually in September. As many of you will know from having tuned in, the SEPM awards were presented virtually as well to an outstanding and deserving set of geoscientists that we can all be proud of as a society. At about the same time, we were finalizing SEPM's awardees for next year, which were then broadcast to the membership in October and early November. In case you have not seen the list of 2021 awardees, here it is:

- The William H. Twenhofel Medal for "Outstanding Contributions to Sedimentary Geology" will be awarded to Teresa (Terry) Jordan, Cornell University
- Honorary SEPM Membership acknowledges excellence in professional achievements and extraordinary service to the Society and is awarded to Kitty Milliken, Bureau of Economic Geology, Jackson School of Geosciences.
- The Raymond C. Moore Paleontology Medal recognizes "Excellence in Paleontology" and is awarded to Nigel Hughes, University of California – Riverside.
- The Francis P. Shepard Medal recognizes "Excellence in Marine Geology" and is awarded to Stanley Riggs, East Carolina University.
- The Francis J. Pettijohn Medal for Sedimentology recognizes "Excellence in Sedimentology" and is awarded to Isabel Montañez, University of California at Davis.
- The William R. Dickinson Medal recognizes a mid-career research geoscientist who is "Significantly influencing the sedimentary geology community with innovative work" and is awarded to Cari Johnson, University of Utah.
- The James Lee Wilson Award recognizes "Excellence in Sedimentary Geology by an Early Career Scientist" and is awarded to Emily Smith, Johns Hopkins University.

Last, if you have not already done so, please check out the relatively new SEPM blog, which covers timely updates and news-worthy announcements. Thanks to Rebekah Grmela, SEPM's Digital Marketing Manager, for her efforts on the web page as a whole, and the blog in particular.

As we witness the end of this tragic year, let us all hope for a better 2021 where we can reengage in person with our scientific community, extended families and friends, and others.

Happy holidays and stay safe and healthy.

Michael Blum, *SEPM President*

PEOPLE & SEPM

Newly Elected Council Members

Thanks to all of the eligible members* that voted in the recent Fall Ballot – 45% which is much higher than our regular 25%. The newly elected Council members will take office January 1, 2021.

- President-Elect: Elizabeth Hajek (Pennsylvania State University, USA)
- Early Career Councilor: Elisabeth Steel (Queen's University, Canada)
- International Councilor: Annette George (University of Western Australia, Australia)
- Special Publications Editor: Jean Hsieh (Consultant, Canada)
- SEPM Foundation President: Judith Totman Parrish (Emeritus, University of Idaho, USA)

And a thank you to Laura Zahm, Robert Mahon and Ernesto Schwarz for being candidates for the Council.

New Sedimentary Record Co-editors

- Jake Covault (Jackson School of Geosciences, USA)
- Jenn Pickering (Shell, USA)
- Jeong-Hyun Lee (Chungnam National University, South Korea)

And a great thank you to Lauren Birgenheier for all her work as the outgoing Editor of The Sedimentary Record.

Recently Passed Sedimentary Geologists in SEPM 'In Memory' - https://www.sepm.org/In-Memory

John R.L. Allen - 2020
Charlotte Schreiber - 2020
Paul E. Potter - 2020
Roger Slatt - 2020
Keith Crook - 2020
Stephen Ruppel - 2019
Harold Reading - 2019
Barbara Lidz - 2019
Philip W. Choquette - 2019
Lynn Watney - 2019
John L. Wray - 2019
Conrad Neumann - 2019

Who needs Stratigraphers, Sedimentologists & Paleontologists? Evolving roles through the Energy Transition

Andy Davies & Mike Simmons*, Halliburton, UK
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It seems that geoscience is facing something of an existential crisis. At the heart of the concerns are a drop in student numbers, with total 2019 undergraduate student enrolments down by 35% in UK universities from a high in 2014 (Boatright et al. 2019). There is evidence of similar trends in many other western countries, including the USA (Saucier 2020). Numbers for some vocational courses are down by even greater percentages.

The consequences could be dramatic. Fewer students equals reduced income, leading to university departments facing budget cuts and possibly even closure. In turn, this leads to a reduction in research activity and the development of the science. At the same time, employers could find themselves facing a talent shortage, especially if the brightest young people choose other subjects instead of geoscience.

Why are young people apparently less interested in studying geoscience? We desperately need hard data to get to the answer of this question, but there are a number of factors, probably acting in concert. Perhaps it's because the subject has yet to fully embrace societal diversity. Perhaps it's because the subject appears rather old-fashioned in an age of rapidly advancing technology. And perhaps it's because of negative environmental perceptions associated with the extractive industries that geology supports, and even that these industries are rapidly coming to the end of their days (i.e. even you wanted to work in industry, there aren't any jobs). We are in a time of energy transition, with renewable energy sources forming an increasing proportion of the energy mix. What does that mean for the employment of geologists, not least stratigraphers, sedimentologists and palaeontologists, very many of whom have historically found gainful employment in the oil and gas industry?

In order to begin this analysis, we need an assessment of society's appetite for energy and how this will be supplied. Access to affordable energy is essential for economic growth and social development (Lloyd 2017) and the meeting of UN sustainable development goals. Put simply, people with access to greater amounts of energy live longer and more prosperous lives (Figure 1). The current global population is 7.8 billion, with UN projections suggesting that this will most likely rise to 9.8 billion by 2050 and 11 billion by 2100 (United Nations 2019). Without very substantial changes in the efficiency of energy usage, a growing global population inevitably consumes more energy, especially as every nation seeks economic growth to ensure the prosperity and well-being of their citizens. As elegantly argued by Scott Tinker (e.g. Millam 2019), energy poverty is a very real issue. Currently, 940 million people (13% of the world population) do not have access to electricity. 3 billion (40% of the world population) have only intermittent access, at supply levels a fraction of that enjoyed in developed nations, and do not have access to clean fuels for cooking. This comes at a high health cost for indoor air pollution (https://ourworldindata.org/energy-access), leading to 3 million deaths per year. Therefore, because of population growth and economic growth, global annual energy demand is set to rise from current levels by around 50% by 2050 (www.eia.gov/ieo) (Figure 2).

How will this rising demand for energy be sourced if we are not otherwise simply to deny energy to large numbers of people, most likely those from developing nations? Doubtlessly renewable sources will form an increasing proportion of the energy mix, as electrification of heating and transportation promotes their greater use, especially as the price of their supply falls. The Energy Information Administration (EIA) project predicts that by 2050, renewables will be the single most important source of energy (Figure 3). However, because of rising energy demand, almost all energy sources see rises in demand, such that by 2050 global energy will be supplied by almost equal proportions of oil, gas and renewables, and a smaller proportion of coal, plus nuclear. The EIA projections can be compared with those of other organisations (e.g. BP Energy Outlook 2020; McKinsey 2019), but although there are differences in detail, none predict a significant collapse in the demand for gas and oil, with these forming part of a balanced energy supply alongside renewables.

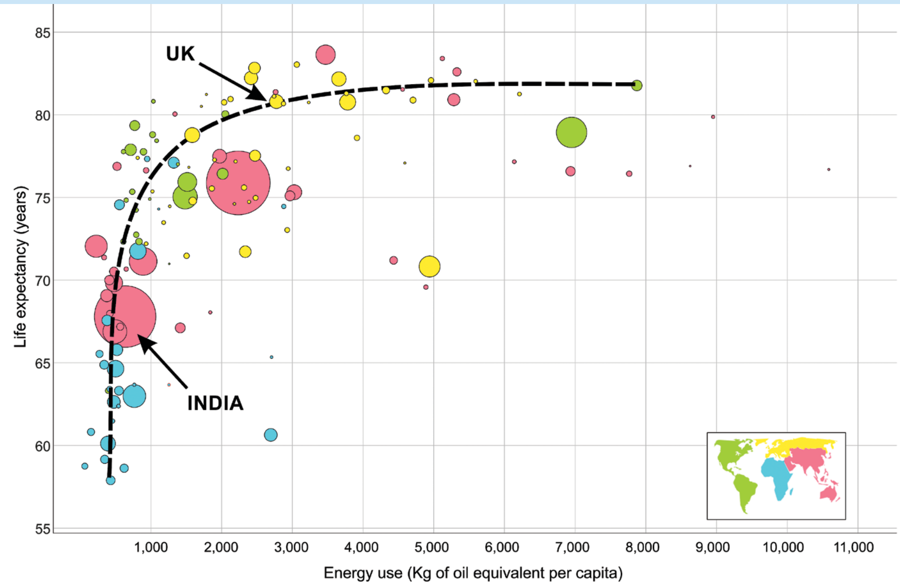

Figure 1: Graph displaying life expectancy vs. energy consumption (data for 2014). Each colored bubble represents a country, size proportionate to population. A clear trend indicates that greater energy consumption relates to greater life expectancy. Based on free material from www.gapminder.org

Even in scenarios which see a rapid transition towards renewables in order to meet the aims of the Paris Agreement on Climate Change, ~900 billion barrels of oil and ~4,700 Tcf of gas are required to meet demand between now and 2050 (Figure 4). To put that in context, that's almost two thirds of all the oil we have ever used and more than all the gas we have ever used. Some of that resource will come from existing discoveries, but a large part of it remains to be found.

Why does the energy mix continue to be diverse over coming decades? Discussion of all technological reasons why renewables cannot quickly and totally replace hydrocarbons as an energy source are beyond the scope of this brief note (see Mackay 2009 for a comprehensive discussion, and Smil 2020 for a condensed version). However, key issues relate to energy density (e.g. to power an aircraft engine, or industrial machinery), geopolitics, costs, intermittent supply and storage, supply uncertainties of raw materials for renewables, and the capital intensity of the energy system. Moreover, 85% of current global energy supply comes from hydrocarbons. With fossil fuels accounting for 11,865 mtoe of energy supply, it would take more than 1 mtoe a day, to bring hydrocarbon usage down to zero by 2050. 1 mtoe is equivalent to the energy supplied by a nuclear power station or 1500 wind turbines. The challenge is indeed enormous.

Therefore, and acknowledging that there will be those who will wish otherwise, oil and gas will be part of the energy mix for several decades to come. But this doesn't mean business as usual. The industry will focus on reserves with the lowest carbon intensity to find and produce – "advantaged hydrocarbons". Geoscientists, need to contribute to increasing the efficiency, and hence reduced carbon footprint, in obtaining these resources. In other words, getting the geology right and central to this are stratigraphy, sedimentology and palaeontology. Practitioners of these subjects have key roles to play in everything from regional geology studies high-grading areas for exploration, to building accurate reservoir models (Figure 5), through to rigsite work, and steering well trajectories so that production is optimized. Fewer dry wells and fewer poorly producing wells lead to a reduced carbon footprint.

Given the apparent inevitability of fossils fuels continuing to form a significant part of the energy mix in coming decades, carbon capture and

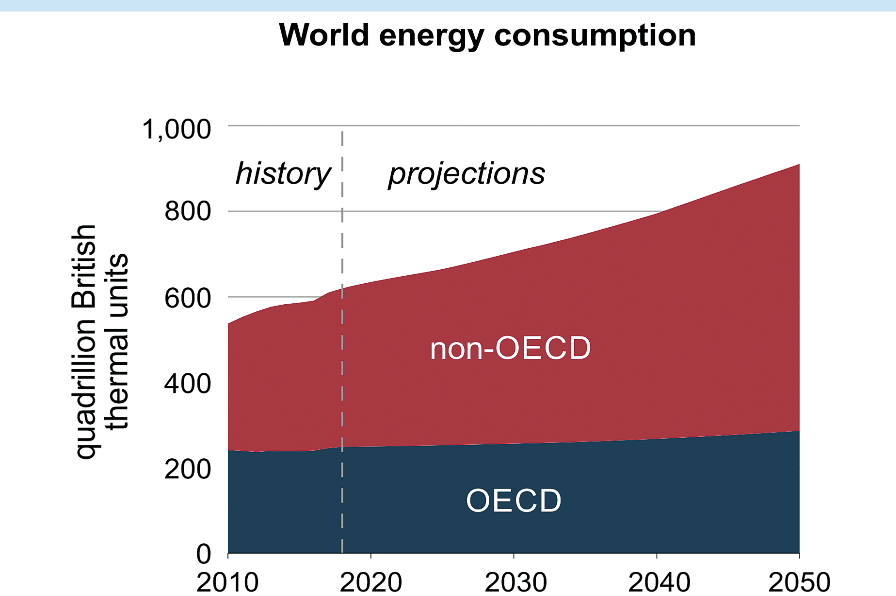

Figure 2: Projection of global energy consumption to 2050 (https://www.eia.gov/outlooks/ieo/). A rise of ~50% is predicted, mostly from developing nations.

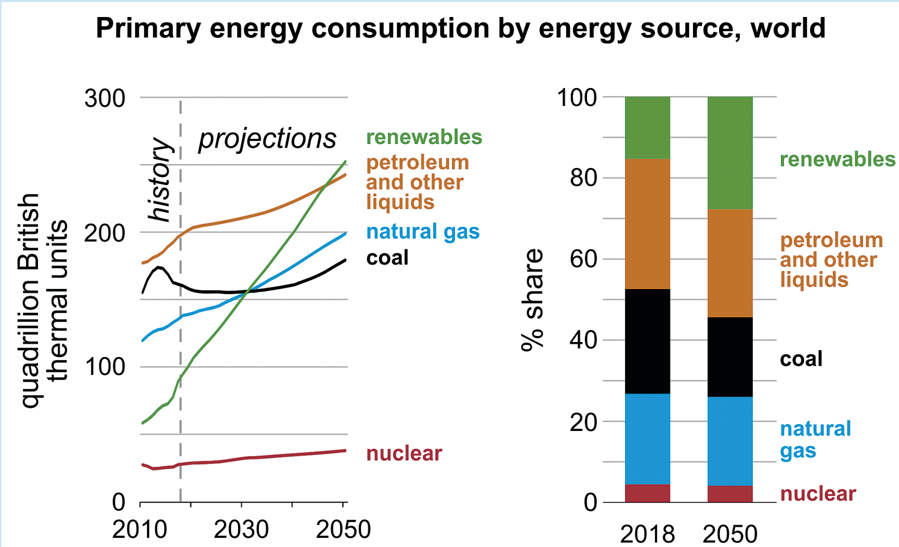

Figure 3: Projected primary supply source to 2050. By 2050, renewables will have become the most important energy source, but other energy sources remain an important and significant part of the energy mix (https://www.eia.gov/outlooks/ieo/)

sequestration (CCS) have become essential (Stephenson 2018; Ringrose 2020) – *"a necessity not an option"* to quote the UK Committee on Climate Change. Secure storage will require geoscientists who can locate and model suitable subsurface repositories for CO_2 and model the behaviour of CO_2 injected into those repositories. Once again, important work for stratigraphers, sedimentologists and palaeontologists. In addition, subsurface models will be needed for hydrogen storage (a key future energy source) and geothermal energy projects.

As oil and gas companies transition into energy companies, many will increase their investment in wind farm technology. Determining the appropriate location for wind farms requires an analysis of numerous factors, but the geotechnical suitability of their installation locations is a key concern. For example, in the North Sea, the considerable variability in the nature of sediments resulting from Quaternary glaciations is a key challenge. Technical challenges associated with a buried landscape of glacial and fluvial channels and thrusted moraine complexes (Cotterill et al. 2017) must be overcome. Detailed sedimentological and stratigraphic understanding support such geotechnical endeavours.

Geoscience is undergoing a paradigm shift. Although geoscience may be seen as rather old-fashioned, we are increasingly using digital technologies and techniques such as machine learning and AI to help make interpretations of outcrops, wireline logs, seismic data, and fossil assemblages. For this to be a success requires the in-depth domain expertise of stratigraphers, sedimentologists and palaeontologists. In turn, the reward is that geoscientists can dedicate more time to exploring different interpretation scenarios allowing more efficient, accurate, consistent, and insightful contributions to solving the challenges posed by the energy transition.

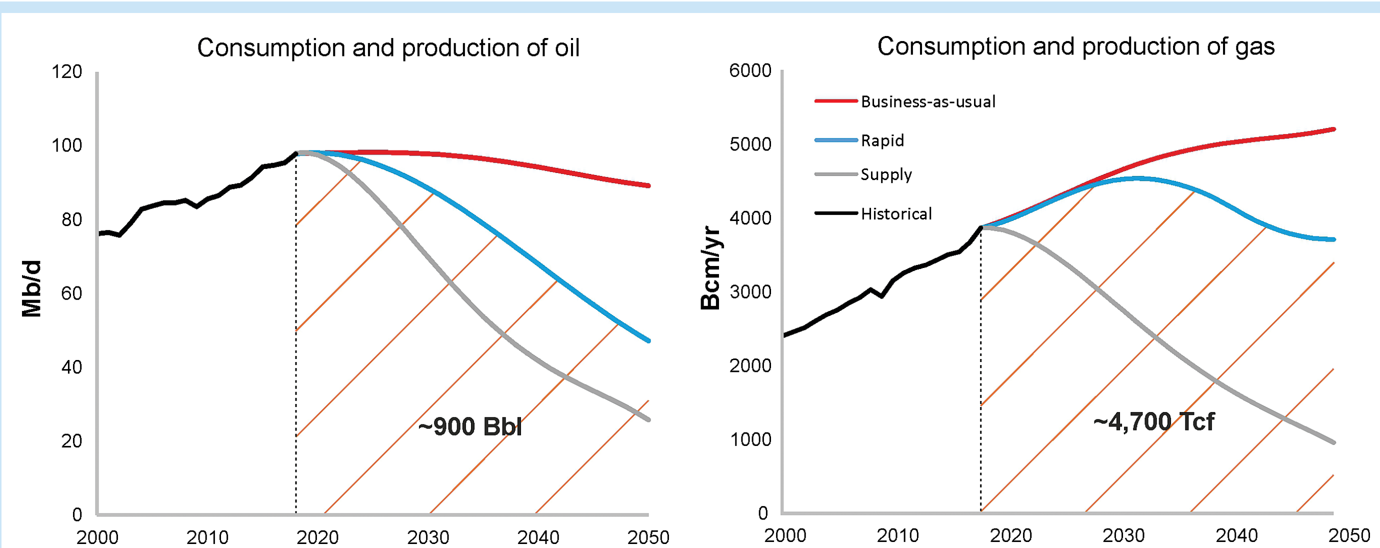

Figure 4: Future oil demand in a rapid energy transition and business as usual scenarios (BP 2020). Even in a rapid transition scenario, oil demand is forecast to be ~50 million barrels per day in 2050 with an annual gas demand of 3,700 Bcm. That translates to a demand for ~900 billion barrels of oil and ~4,700 Tcf of gas between now and 2050.

Figure 5: Outcrop of a key reservoir analogue in South Devon. Studying such helps build better reservoir models that in turn leads to efficiency in hydrocarbon extraction, reducing carbon intensity of operations. Or the models can be used in modelling carbon storage repositories and in green energy projects such as hydrogen storage and geothermal.

Outside of industry, if we are to meet the challenge set by one of the founders of geology, Georges Cuvier, who encouraged us to "burst the limits of time", meaning to envisage the history of the Earth and life upon it, and the mechanisms by which internal and surface Earth processes operate (Simmons 2018), the need for geoscience never ends. That challenge is now being taken to our neighbouring planets. This note has focused on the practical societal needs for stratigraphers, sedimentologists and palaeontologists, but of no less importance is the *wonder* of geoscience, simply (although actually far from simple!) to understand the Earth for its own sake. And this has practical value too, if we wish to model the future impact of humankind on the planet, we need to look to the geological past for analogues. Stratigraphers, sedimentologists and palaeontologists are amongst the custodians and curators of Earth history, perfectly placed to advise on the future of the planet and those who live on it.

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ISGC Updates: SEPM and the ISGC Program Committee are hoping to be able to have an in-person meeting in Flagstaff next April but including some hybrid options for recorded presentations, live streaming, etc. There is also a possibility that the in-person aspect of the meeting may have to be cancelled or reschedule (again) and a smaller virtual meeting may replace it. But as of now please bear with us in our all of our planning options and help support this meeting. The Program Committee should have the revised program set soon.

2021 SEPM Membership (renewal)

We hope that you are enjoying your current SEPM membership. To renew your membership for the 2021 Calendar year, please read the details below.

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Renew Your Membership

2021 SEPM Membership (new)

Join the largest organization dedicated to sedimentology. Exchange knowledge and research at our meetings and in our bespoke publications, receive *Geofacets* magazine, advance your career, network with peers, serve on committees and learn with our regional and topic-specific research and regional groups. To apply for membership for the 2021 Calendar year, please read the details below.

You can apply for either SEPM membership or SEPM Eastern or Gulf Coast Section memberships. If you are only joining Eastern or Gulf Coast Sections, then use separate application forms found below.

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