

Determining Initiation Conditions for Glass Ramps: Case Study at the Leading Edge of the Great Permian Spiculite Belt

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Abstract

Glass ramps are biosiliceous regimes that replaced coastal carbonate factories for multi-million year intervals throughout Earth history, but are unknown to most geologists because the resulting cherts are usually disregarded as coincidental diagenesis. Examining key biosiliceous deposits can reveal life's evolving role in global sedimentation and climate cycles, including formation modes of source, reservoir, and cap rocks vital to petroleum and mining industries. Despite increased study of modern sponges and ancient cherts, the biotic and environmental conditions that initiate, perpetuate, and terminate glass ramps are unknown. New field observations and microfacies analyses of rocks and fossils from the transitional edge of history's largest and most long-lived spiculite belt will test hypotheses to distinguish conditions of spiculite initiation and persistence. The key hypothesis is that siliceous sponges and their detrital bioclasts formed increasingly cohesive, exclusive fabrics, limiting carbonate bioclastic production and deposition to isolated patches. Alternately, transitions to glass ramps may coincide with regional environmental shifts, such as increased terrigenous flux or rapid accommodation space increase. Field observations of Permian cherts in Utah, combined with specialized microscopy, will allow detailed mapping of depositional conditions, benthic ecology, and sedimentation styles. The best-supported initiation interpretation will be tested on Mississippian spiculites in future work. Recognizing conditions that initiate glass ramps will influence the field of sedimentary paleoecology by: 1) distinguishing biosiliceous cherts as primary alternatives to carbonate or siliciclastic sedimentation; 2) constraining estimated Paleozoic silica concentrations, sinks, and weathering fluxes, and 3) determining biotic and environmental signatures of chert source and reservoir rocks.

Introduction: Known Glass Ramps

Carbonate and siliciclastic sedimentary regimes have fundamentally different formation modes, relationships to geochemistry and climate, resulting rock types, and sedimentological lexicons. Geologists address different questions and use different methods for carbonates than for siliciclastics. Biosiliceous cherts are a critical and under-recognized third regime type. Like carbonates, the formation of biosiliceous cherts is mediated by the physiology, abundance, morphology, and biogeography of marine life (Maldonado et al., 1999; Gutt et al., 2013). Like siliciclastics, biosiliceous sediments are subject to transport and can persist through a broad range of environments (Bell, 2008; Mazzullo et al., 2009). Biosiliceous cherts are important sinks for marine silica, a critical component of weathering and climate cycling (Treguer et al., 1995; Chu et al., 2011; Maldonado et al., 2012). Glass ramps are biosiliceous deposits on continental shelves which are critically important because they can form alternate ecosystem states that replace carbonate production (Gates et al., 2004; Norstrom et al., 2009; Ritterbush et al., 2015). Proposed work will test hypothesized roles of siliceous sponge ecology and biogeography in shaping glass ramps.

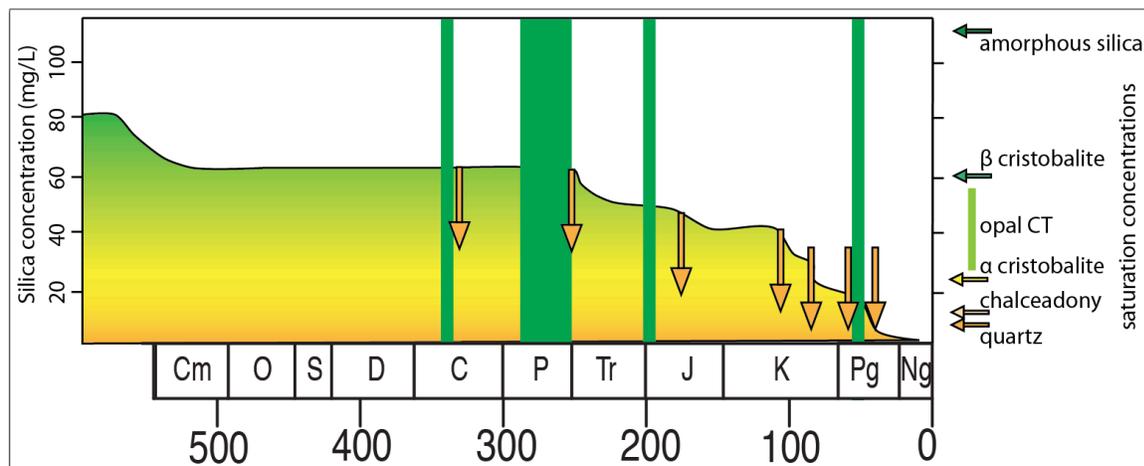


Figure 1. Timeline of estimated marine silica concentration (curve) juxtaposed against four intervals of known glass ramp establishment (green bars). Phanerozoic levels are interpreted to have been higher than modern, but it is unknown whether changes were step-wise (shaded gradient curve) or punctuated (arrows). Curve and arrows after Racki and Cordey (2000).

Glass ramps typically feature km-scale level-bottom geometry produced by “meadow” like colonies and detrital grain expanses of siliceous sponges (Gates et al., 2004; Blomeier et al., 2013). Figure 1 shows a timeline of known glass ramps from around the world. A Mississippian case in a tropical epeiric basin produced widespread shoals of spicules (microscopic sponge skeletal elements), which are now productive reservoir rocks in Kansas (Mazzulo et al., 2009). Massive spiculitic cherts of Permian age presently outcrop across the arctic from Svalbard to Canada, and as far south as Nevada, USA (e.g., Murchey, 2004; Gates et al., 2004; Beauchamp and Grasby, 2002; Blomier et al., 2013). Widespread spiculites appeared in both eastern Panthalassa (the proto-Pacific Ocean) and the Tethys following the Triassic/Jurassic mass extinction, and persisted for at least two million years, developing thick cherts now critical to gold and silver ore emplacement in Peru (Delecat et al., 2011; Wilmsen and Neuweiler, 2007; Ritterbush et al., 2014; Ritterbush et al., 2015). Finally, an estuary along a 1000 km section of southern Australia formed a prolific spiculitic ramp during the Eocene (Gammon et al., 2000; Gammon and James, 2003). The above examples exclude basinal sponge bioherms and laterally heterogeneous build-ups, focusing instead on widespread, laterally homogenous, millions-of-years duration state shifts from carbonate or siliciclastic regimes to glass ramps. The known examples do not constrain glass ramp formation to conditions of passive or active margins, cold or hot climates, volcanic activity or passivity, or known geochemical patterns. Consideration of modern sponge ecology allows speculation about what conditions glass ramps required, but, particularly compared to incredibly well-studied carbonate settings like coral reefs, the ecological requirements of glass ramps are virtually unknown.

Studies of modern sea sponges provide clues to the ecological requirements of glass ramps, but modern systems are inadequate analogues for ancient systems. Prolific siliceous

skeletons are produced both by hexactinellids and demosponges (Pisera, 2006). Hexactinellids tend to produce delicate, elaborately woven spicule frameworks (often termed, “glass sponges”), that flourish in settings protected from strong currents or inundation by coarse-grained sediment (Bell, 2008; Chu et al., 2011). Demosponges are more diverse in modern seas, and have produced a variety of morphologies including “stoney” lithistid sponges containing hypersiliceous claw-like interlocking spicules, and are more commonly found in shallow, high-energy settings (Maldonado et al., 1999). Water flow is important for most sponges to deliver food, including both plankton and dissolved inorganic carbon (Wulff, 2006; Gili and Coma, 1998; Pfannkuchen et al., 2009). Siliceous sponges live on a variety of substrates, including soft muds and their own spicule oozes (Bell, 2008, Gutt et al., 2013). On Antarctic slopes, sponges produce substrate inhospitable to recruitment by competing benthic colonizers, and sponge incumbency is mediated by colonization interrupted sporadically by removal from ice scour (Gutt, 2006; Gutt et al., 2013). Modern siliceous sponges are only prolific in deep, cold waters, but rather than an inability to withstand high energy or a preference for low temperatures, modern sponge distributions reflect severe limitation by inadequate silica saturations in warmer surface waters (Maldonado et al., 1999; Chu et al., 2011; Gutt et al., 2013).

Changes in silica concentration, residence time, sources, and sinks are poorly known across most of the Phanerozoic (Fig. 1). Modern seas are undersaturated with respect to amorphous silica (the hydrated mineral opal) by as much as two orders of magnitude, due largely to the abundance and rapacious uptake of diatoms (Maliva et al., 1989; Racki and Cordey, 2000). Pre-diatom seas of the Paleozoic and Mesozoic are interpreted to have had much higher concentrations of siliceous acid (Si(OH)_4^{-1}), based on evidence from radiolarites, jaspers, and chert nodules (Racki and Cordey, 2000; Grenne and Slack, 2003; Maliva and Siever, 1989).

Among sponges, living hexactinellids sequester the most silica (despite some dissolution), and desmid spicules apparently form only in high ambient concentrations (Chu et al., 2011; Maldonado et al., 1999). Biosiliceous chert sedimentation histories provide critical insight into the history of marine silica flux, a key component of Phanerozoic climate and weathering cycles (Kidder and Irwin, 2001).

The Great Permian Spiculite Belt

History's most extensive system of glass ramps surrounded boreal to temperate Pangea during the last 30 Myr of the Permian (Fig. 3; Murchey and Jones, 1992; Beauchamp and Baud, 2002; Gates et al., 2004; Murchey 2004; Blomeier et al., 2013). Artic deposits record over 400 m of chert from shallow shelves, for which sedimentological and paleontological models depict siliceous sponges dominated deposition along the inner- to mid-ramp (Gates et al., 2004; Blomeier et al., 2013). Along western Pangea, cherts that filled in the Havalla back-arc basin (between Pangea and the McCloud arc) were rich in hexactinellids and radiolarians, whereas cherts in the epeiric Eli and Phosphoria basins were dominated by demosponges (see paleogeographic maps in Figs. 3,4; Murchey, 2004). Carbonate sedimentation continued to rule tropical settings (Rigby and Bell, 2006), though Beauchamp and Baud (2002) interpret a switch to heterozoan communities in which calcareous sponges, foraminiferans, and bryozoans became more prominent at the expense of corals. Beauchamp and Baud (2002) explain the initiation and tenure of the Permian spiculite belt by the onset of glaciation and thermohaline circulation. Inundation by cold, nutrient-rich waters inhospitable to carbonate mineralization is supported also by Murchey (2004). Beauchamp and Grasby (2012) further proposed that carbonate bioclast production was limited by ocean acidification throughout the Permian, but this is controversial because ocean acidification events are thought to be restricted to shorter durations (Greene et al., 2012; Honisch et al., 2012). Nutrient loads in the Phosphoria Basin have been explained by

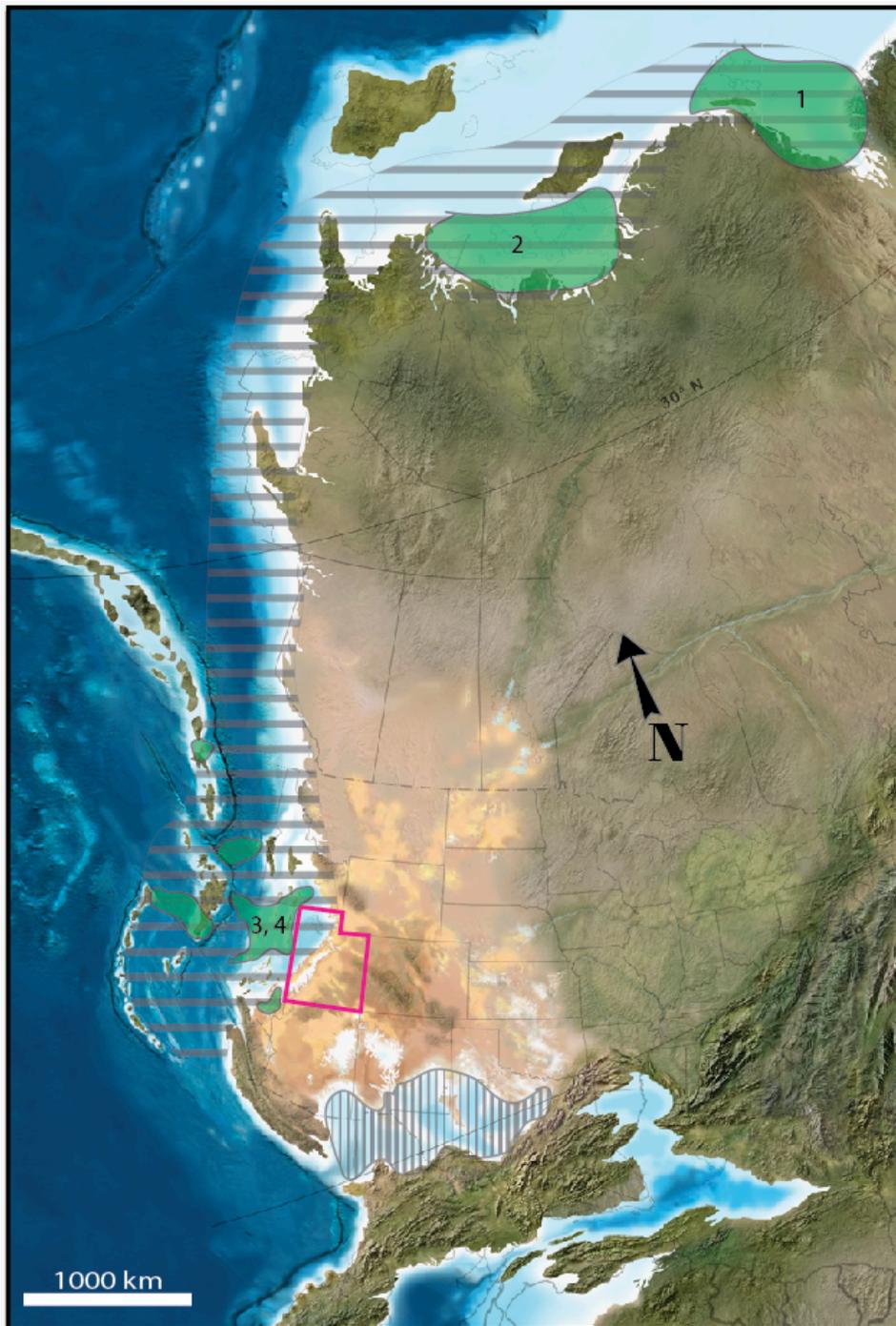


Figure 2. Map of the great Permian spiculite belt, which spanned from the boreal to tropical coast of Pangea. Shaded horizontal stripes indicate interpreted belt extent. Green patches indicate foci of microfacies and depositional model studies (1. Svalbard: Blomeier et al., 2013; 2. Canada: Gates et al., 2004; 3. USA: Murchey, 2004; 4. Nevada: Ketner 2009). Vertical stripes indicate contemporaneous carbonate bioclastic sedimentation in the Permian and Delaware Basins. The underexplored record of Utah (outlined) includes both the southernmost edge of the belt and the transition to tropical carbonate settings. Paleogeographic base map after Blakey (2013) and Garrity and Soller (2009).

upwelling (Murchev and Jones, 2002; Murchev 2004), but whether upwelling from the Havalla basin could have supplied the nutrients to a 600 km-wide shelf (Eli, Oquirrh, and Phosphoria Basins, Fig. 3) is debated (Ketner, 2009). Intensive sampling across Nevada has demonstrated that the Permian chert deposits are sponge rich and very high energy, supporting interpretations of a prolific biosiliceous shallow shelf fauna (Murchev, 2004; Ketner, 2009).

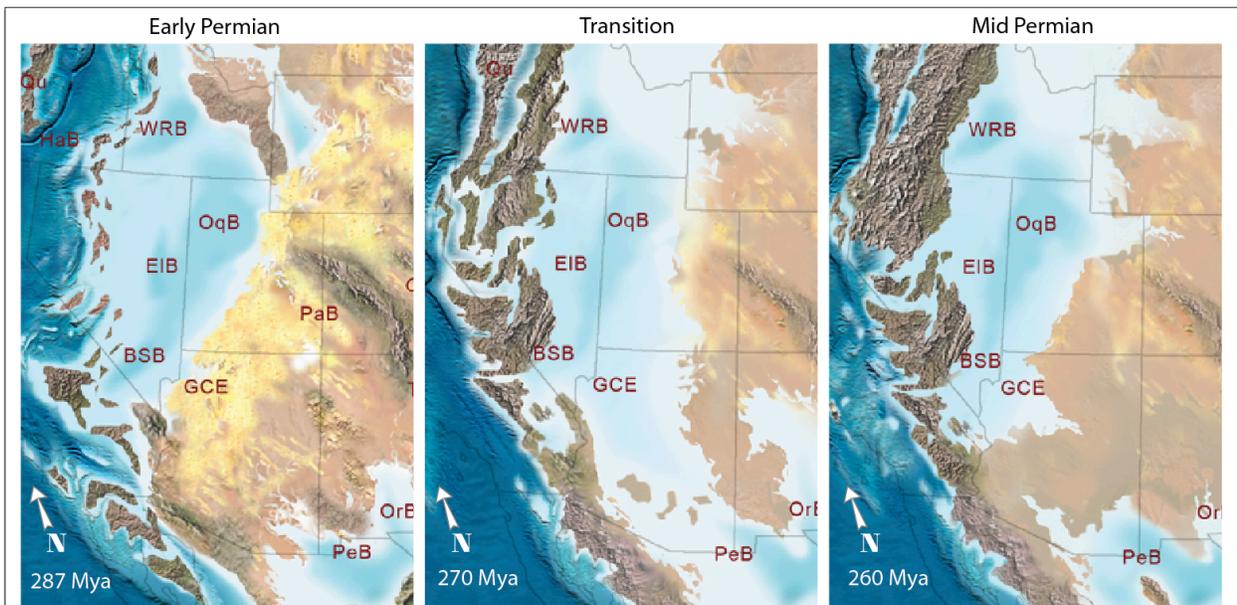


Figure 3. Paleogeographic maps of Utah during the Early and Mid Permian, after Blakey (2012). The Early Permian epeiric sea connected the Eli and Oquirrh Basins (EIB and OqB), while eolian sands covered the filled Pennsylvanian Paradox Basin (PaB) flanking the Uncompahgre Uplift (Hintze and Kowallis, 2008). In the latest Early Permian (Transition, center), the epeiric sea reached its widest extent and connected the Oquirrh and Permian Basins (PeB). The Epeiric sea persisted through the Mid Permian, above which Utah rocks typically record an unconformity overlain by Triassic strata.

Two critical aspects of glass ramp initiation and persistence can be better resolved by examining the extensive Permian chert record of Utah (Fig. 3-5). First, thick Permian sequences in Utah offer an opportunity to examine the onset of chert formation from the Early Permian through the Mid Permian (Fig. 4-5, compiled from stratigraphic section summaries in Hintze and Kowallis, 2008). Previous studies across the western states focused on determining the geographic extent of sponge deposition, and invoked rough correlation of Permian spiculitic cherts and phosphorites (Murchev and Jones, 1992; Murchev, 2004; Ketner, 2009). Deposits of Permian chert in northern Utah extend from hundreds to thousands of meters thickness, providing ample record of the interval of spiculite establishment (Fig. 5). Second, the Utah deposits record the transition between the temperate coast and the tropical basins farther south (Garrity and Soller, 2009; Blakey, 2012). The Utah deposits are the eastern-most extension of Permian marine cherts, and due to the paleogeographic orientation (north was approximately 45 degrees to the west of modern day north; Hintze and Kowallis, 2008) they also represent the southern-most deposits. The epeiric sea extended across most of tropical southern Utah during the latest Early Permian, forming a marine connection to the tropical Permian and Delaware Basins (recorded in Texas; Fig. 3). Cherts in southern Utah record marine sponge body fossils in shelly carbonate rocks (Griffin, 1966; Nielson, 1981; Whidden, 1990) and record the transition between the tropical and temperate biogeographic regimes (Fig. 5E). Proposed examinations of Permian cherts across Utah will evaluate environmental and biotic conditions during spiculite belt establishment and persistence.

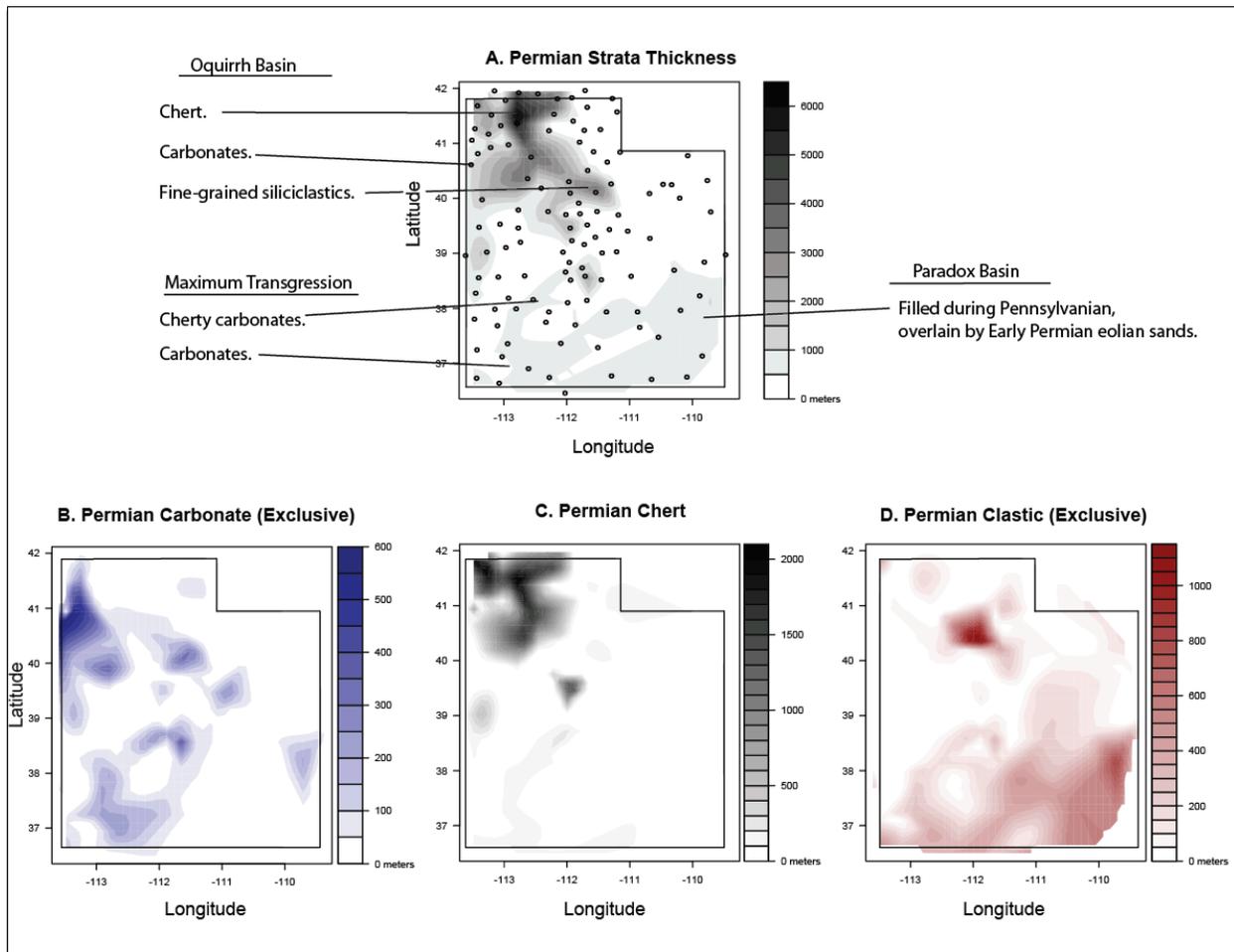


Figure 4. Isopachous maps of Permian strata preserved across Utah, compiled from Hintze and Kowallis (2008; see text). A. Thickness of all Permian strata represented in 116 distinct summary stratigraphic columns distributed across the state. B. Mean thickness of stratigraphic units designated as carbonate without noted chert or siliciclastic content. C. Mean thickness of stratigraphic units designated as chert or cherty, typically including carbonate or siliciclastic content. D. Mean thickness of stratigraphic units designated as siliciclastic without noted carbonate or chert content.

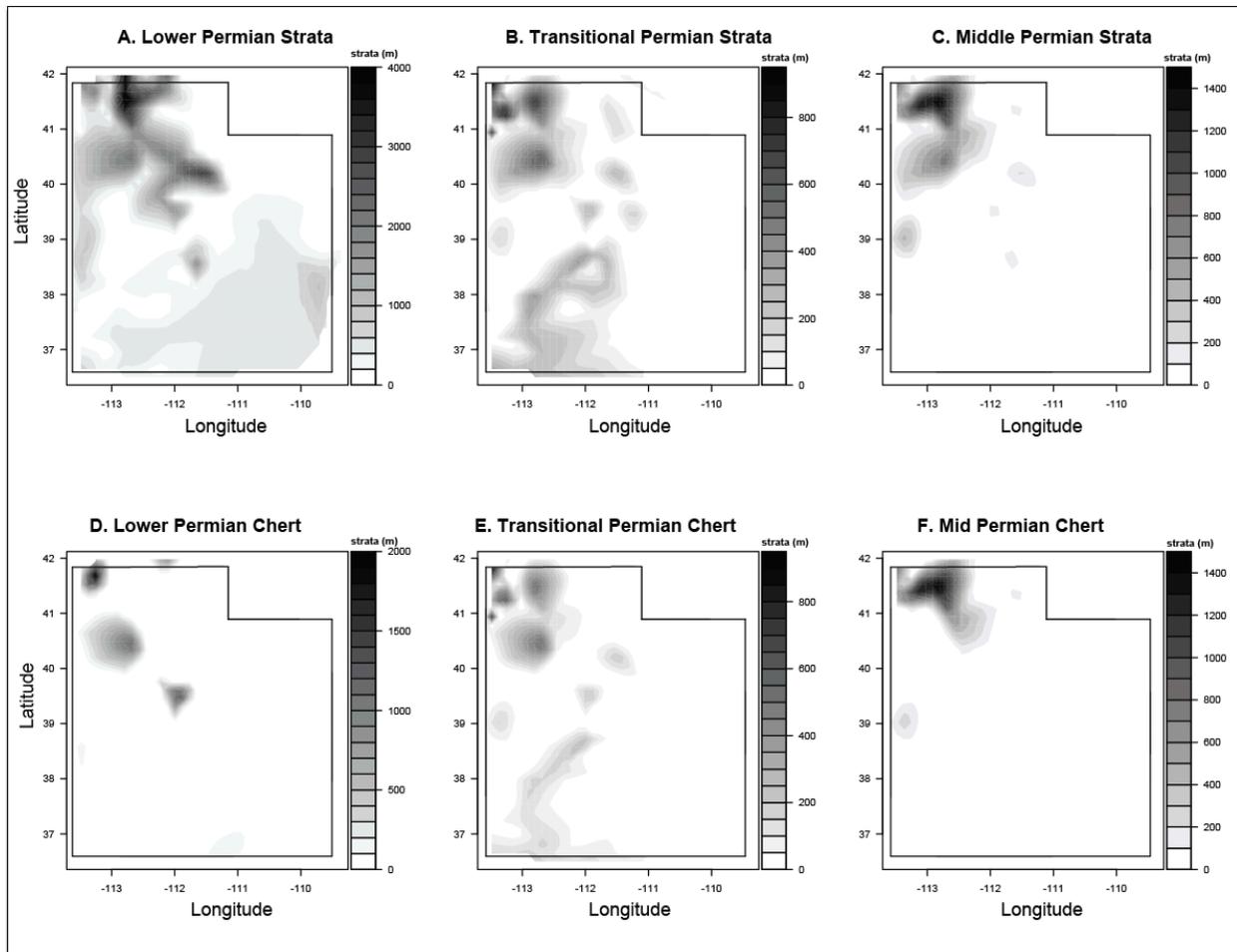


Figure 5. Isopachous maps of strata assigned to the Early and Mid Permian. A. Mean thickness of strata assigned to the Early Permian (Wolfcampian and Leonardian, excluding latest Leonardian; see Fig. 6). B. Mean thickness of strata assigned to the latest Leonardian interval of widest epeiric expansion (Fig. 3). C. Mean thickness of strata assigned to the Middle Permian. D. Mean thickness of cherty strata assigned to the Early Permian (excluding latest Leonardian), concentrated in the Oquirrh Basin. E. Mean thickness of cherty strata assigned to the latest Leonardian, during peak epeiric expansion. Note the southwestern tongue (Kaibab Formation). F. Mean thickness of cherty strata assigned to the Middle Permian, again concentrated in the Oquirrh Basin.

Hypotheses:

1. Chert content.
 - Utah cherts are spiculitic, specifically demosponges similar to those found by Murchey (2004) and Ketner (2009).
2. Chert succession.
 - The succession of cherts in the Oquirrh Basin demonstrate increasing cohesion, concentration, abundance, and exclusivity of siliceous sponges and detrital bioclasts, whereas carbonate biocalcifiers are increasingly restricted to laterally heterogeneous, patchy colonies extending less than a km.
3. Southern-most cherts.
 - The Kaibab Formation of southern Utah represents sponge colonization and spicule accumulation intermediate between that of the Oquirrh Basin and the Delaware Basin; specifically sponge body fossils are preserved but they do not reach critical abundance required to establish spicule mats, oozes, or shoals.

Plausible Alternative Results:

1. Chert content.
 - a. Utah cherts are richer in radiolarians and/or hexactinellids due to depth of the Oquirrh Basin.
 - b. Utah cherts represent true abiotic silica mineralization crusts, representing unprecedentedly high Si concentrations in the epeiric sea.
 - c. Utah cherts are dominantly diagenetic, representing fluid transport of silica from contemporaneous or overlying deposits.

2. Chert succession.
 - a. Siliceous sponge body fossils or spicules are even distributed throughout carbonate bioclastic deposits.
 - b. There is no systematic temporal change in the abundance, density, or cohesion of siliceous bioclasts.
3. Southern-most cherts
 - a. Sponge deposits in the Kaibab Formation closely resemble either the Oquirrh or Delaware Basin deposits, rather than an intermediate phase.
 - b. Sponge and chert deposits in the Kaibab Formation are very different from both the Oquirrh and Delaware Basin deposits.

Proposed Work

Establishment conditions and paleoecology of the Permian spiculite belt will be evaluated by field excursions and microscopy analyses based at the University of Utah's new paleoecology lab and lead by the Department of Geology and Geophysics' newest faculty member, K. Ritterbush. The work proposed below will be ideal training for two new graduate students, one seeking a PhD and another an MS.

Field observations of chert facies successions and associated fossils will provide framework for microfacies analysis and depositional modeling. Sixteen quadrangles with Mid Permian cherts between the NW Salt Lake Desert and Confusion range are presently under evaluation by Dr. Ritterbush for 4x4 accessibility, outcrop extent, stratigraphic coherence, and chert microstructure preservation. Five initial target field sites will be selected by spring 2016 for student training and research over the 2016/17 academic year. Tiered mentoring will advance the sedimentology and leadership skills of a paleontology PhD student (already bearing a MS), advance the paleontology skills of an MS student, and establish general field method skills of

undergraduate assistants. As their skills improve, students will design and lead trips to document successions of chert facies across northern Utah, and will generate specific hypotheses to explain bedding relationships, fabrics, and fossil-substrate relationships. Trips will use department field vehicles, and site proximities allow maximum student field time (flexibility for weather, academic obligations).

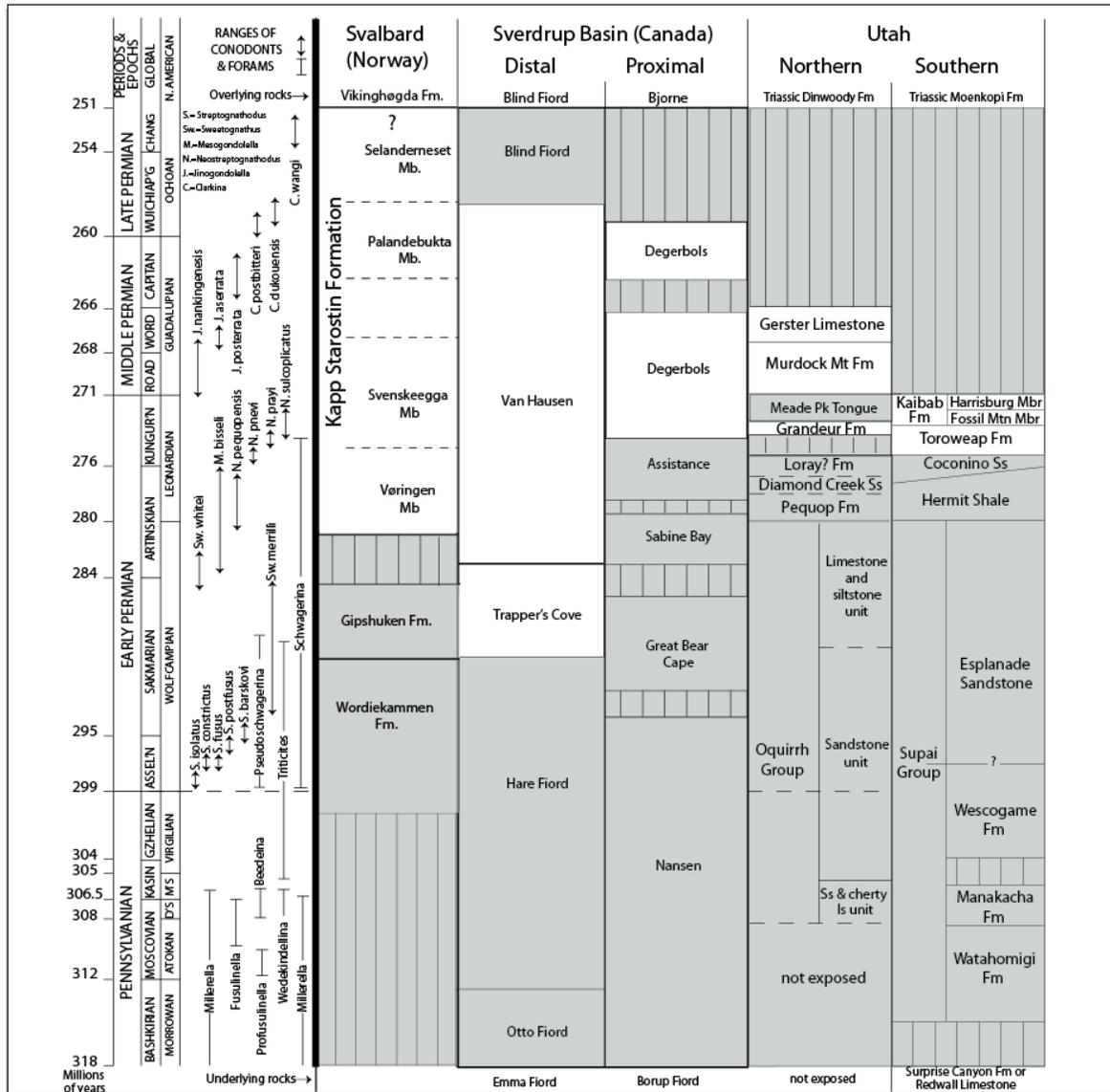


Figure 6. Correlation of Permian spiculite belt records, with cherty units in white. Stages and biostratigraphic ranges after Hintze and Kowallis (2008). Svalbard's Kapp Starostin Formation outcrops across > 80 km with thicknesses > 400 m, representing demosponge colonization of the inner to outer ramp (after Blomeier et al., 2013). Canada's Van Hausen and Degerbols Formations record distal to proximal spiculite accumulation for which the term Glass Ramp was coined (Gates et al., 2004; strata after Beauchamp and Baud, 2002). Utah strata are represented with columns from the Hogup Mountains and Grand Canyon (AZ), after Hintze and Kowallis (2008).

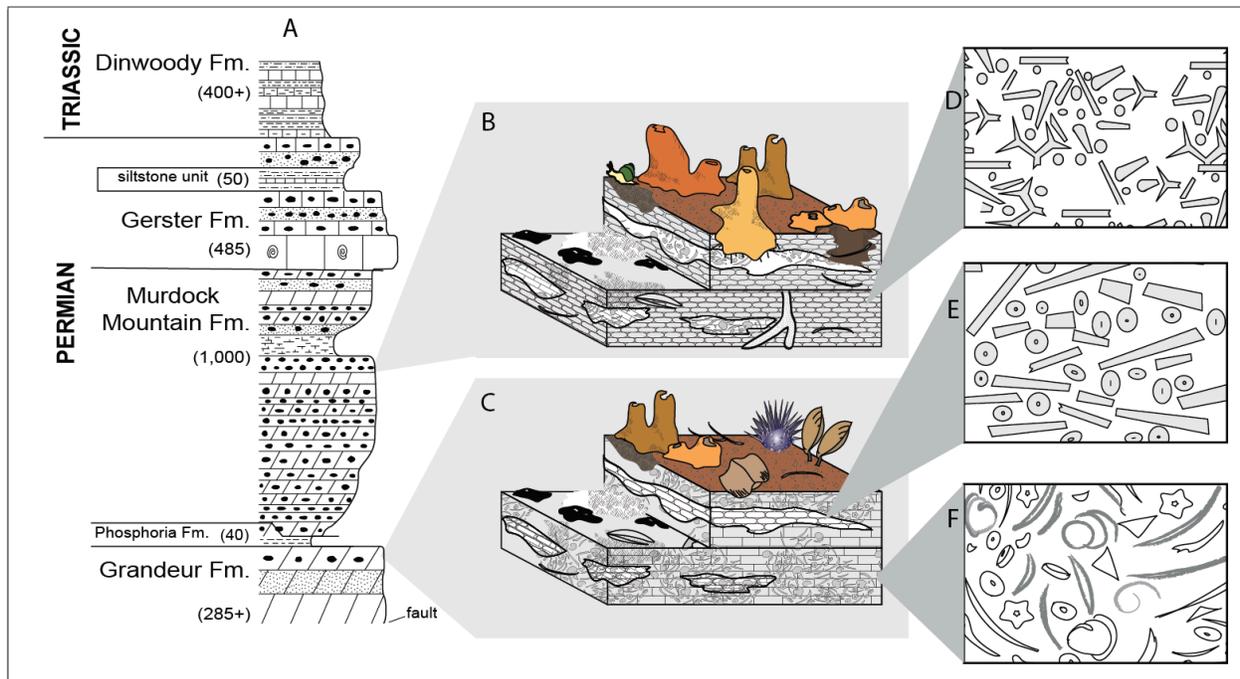


Figure 7. Schematic example of proposed work and Hypotheses 1 and 2. Outcrop scale field observations (A) are aided by microfacies analysis (D-F) to build models of deposition appropriate for the unique bedding features often presented by mixed chert and carbonate (B,C). A. Stratigraphic column for Late to Mid Permian strata at Terrace Mountain, in N Utah (after McCarthy and Miller, 2002). Black ovals indicate chert. B and C. Models for the paleoecology (upper surface, in color) and subsequent burial, diagenesis, and preservation of sedimentary frameworks. D to F. Schematic microfacies. The illustration hypothesizes demosponges (Hyp. 1) increase in abundance and exclusivity of bioclastic production (Hyp. 2) from the Early to Mid Permian. C. Late Early Permian demosponges distributed among shelly faunas, resulting in lenses of broken detrital transported spiculites (E) within bioclastic wackestone to packstone (F) carbonate. By the Mid Permian (B) demosponges dominate most areas of the mid ramp, producing beds of disarticulated and compacted spicules maintaining complex architecture (D).

Processes hypothesized to explain general and specific fossil-sediment relationships will be evaluated with advanced microfacies analysis. Cherts lack a simplified classification lexicon (as in Dunham and Folk's schemes for carbonates), but microfacies of biogenic and diagenetic cherts are well-researched (particularly with respect to petroleum source and reservoir rocks; Behl, 1999; Maliva and Siever, 1989; Mazzullo et al., 2009; Ritterbush et al., 2014, 2015, in press). Dr. Ritterbush will train students to focus on observation and interpretation of grains, cements, and diagenetic fabrics, culminating in the construction of paragenetic sequences to interpret the formation of microfacies samples. Key challenges include recognizing replacement

fabrics and distinguishing *in situ* vs. transported sponge microfossils. Students will incorporate paragenetic sequences of microfacies formation into bed-scale models of sedimentation. Students will then design additional field campaigns to further test if the sedimentation models fit observed outcrop-scale features. Iterating microfacies analysis and field work will allow students maximum opportunities to challenge and resolve more complex depositional models. Conceiving of spiculite sedimentation regimes as processes that span from initial marine ecology conditions to deposition, redistribution, preservation, and diagenetic processes is critical before any mature model of spiculites formation of petroleum reservoirs can be evaluated.

As summer approaches, Dr. Ritterbush will coach student production of overarching depositional models for the chert strata of northern Utah, and will plan a full field season to expand into southern Utah. At drive times of four to six hours, field work in southern Utah warrants longer camping trips. The Kaibab Formation is well researched, with particularly valuable unpublished stratigraphic sections from a dissertation (Nielson, 1981) and thesis (Whidden, 1990) recommending specific outcrops across over 65 km near St. George and Hurricane, Utah. When summer heats preclude field work, students can prepare fossil specimens (particularly dissolution of silicified fossils) and analyze microfacies on campus. Students will write and submit abstracts for GSA, AAPG and AGU meetings, and will evaluate ways to frame the results in research articles.

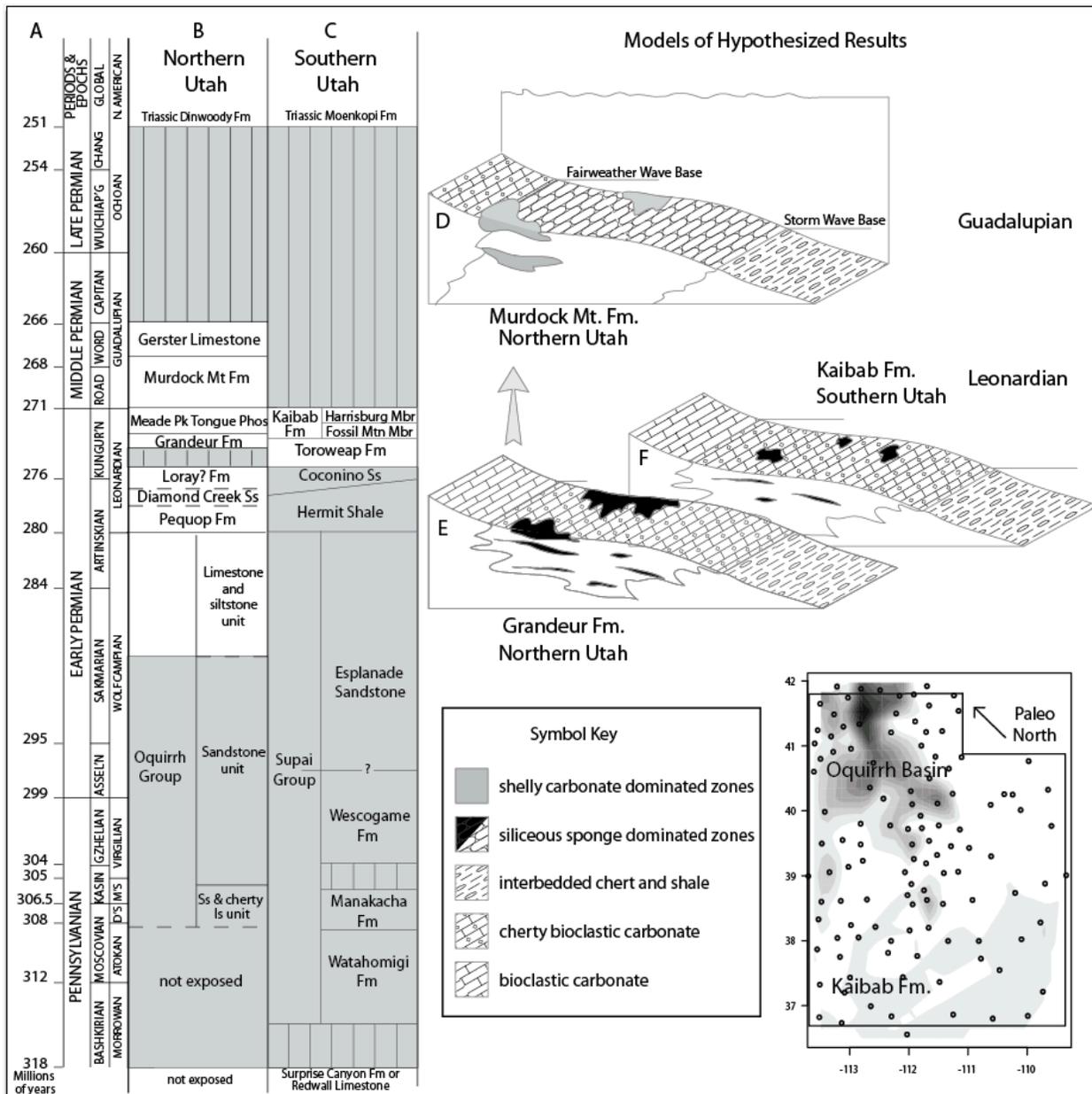


Figure 8. Schematic models for project results that would support Hypothesis 3. Timeline (A) and stratigraphy (B,C) after Hintze and Kowallis (2008) as in Fig. 6, but with white boxes for formations of interest (including pre-chert carbonate units; see text). Comparisons of paleoecological and sedimentological mode reconstructions (Fig. 7) across multiple stratigraphic sections support models of local shelf depositional modes (D-F). Following Hypothesis 1, strata from the Oquirrh Basin may indicate a change from patchy demosponge dominated zones (E) to prolific, exclusive demosponge accumulation on the mid ramp (D) by Mid Permian time. Following Hypothesis 2, the Kaibab Formation in southern Utah may represent more isolated demosponge colonies as a transitional condition between the temperate spiculite belt and carbonate bioclastic settings of the tropical Permian Basin (F).

Together with faculty, students will use the second year of the project to refine depositional models of the northern and southern Utah cherts and evaluate the project's key hypotheses. The research team will decide if demosponges demonstrated contribution to exclusive spiculitic sedimentation that enhanced incumbency and limited carbonate clast proliferation, or if results warrant other, perhaps more environmentally-driven mechanisms. The team will further determine if the southern Utah deposits represent an intermediate sponge colonization phase between the temperate belt and the tropical basins, or if results demonstrate a very different ecological state in the expanded epeiric sea. Students will reevaluate literature of past work and refine interpretation of glass ramp initiation and incumbency along the Early to Mid Permian coast of Pangea. Students will present research at national meetings and will meet personally with faculty and industry scientists from Canada, Peru, and possibly Norway to discuss research directions and challenges of spiculites. While preparing journal article submissions, students will consult with geochemistry faculty to evaluate the implications of documented chert paleoecology and marine silica cycling, and may generate hypotheses for future interdisciplinary research. Students will evaluate how the discovered aspects of spiculite formation facilitate petroleum reservoir properties, and generate hypotheses to refine and test more thorough formation interpretations.

The two-year interval will mark the full establishment of the new Paleoecology Lab at the University of Utah. In addition to recognition in paleoecological circles, the research group will be known as a contributor of relevant field and microscopy knowledge relevant to the broader academic and industry geology communities. Student success is a potent evaluation of all academic pursuits. The project MS student will be skilled and well prepared to pursue further steps along academic or industry paths. The PhD student will be well-prepared to propose and

execute the final years of field research (optionally international) to finish the degree. The lab will be in a position to welcome new masters and PhD students, and will forge stronger ties to intra- and inter-institutional faculty collaborations. Results from the project will provide a framework to propose work to the National Science Foundation, National Geographic Society, and National Aeronautics and Space Administration.

Detailed Timeline of Proposed Work

The following lists approaches to meet key known challenges in a flexible estimated timeline.

1. Sept. 2015 – Aug. 2016 (pre-grant; start-up funds)
 - a. Scout field sites and choose initial targets.
 - b. Establish microscopy lab (Zeiss AxioM2 & Stemi 508).
 - c. Acquire collection permits (BLM, Forest Service, UT, AZ states).
 - d. New PhD and Masters students (Jeff H. and TBD) arrive.
2. Sept. – Dec. 2016
 - a. Train students in field.
 - b. Measure initial target stratigraphic sections.
 - c. Observe sedimentary structures and identify problematic facies.
 - d. Sample & thin section production.
3. Jan – May, 2017
 - a. Analyze microfacies:
 - i. Train students on microscopes.
 - ii. Observe individual slides.
 - iii. Construct paragenetic sequences (including diagenesis).
 - iv. Compare microfacies of sites, strata, outcrop scale bedforms.

- b. Produce preliminary bedform/microfacies interpretations.
 - c. Produce preliminary shelf depositional models.
 - d. Evaluate hypotheses, alternatives, alternative approaches needed.
 - e. Evaluate previous and new target field sites.
4. Summer 2017
- a. Full field seasons in N and S Utah, following weather availability.
 - b. Sample extensively to test preliminary sedimentation interpretations.
 - c. Produce new thin sections and continue microfacies analysis.
 - d. Write abstracts for GSA, AAPG (Rocky Mountain), AGU.
 - e. Report 1st year outcomes to American Chemical Society.
5. Sept. – Dec. 2017
- a. Complete microfacies analysis.
 - b. Prepare fossils including dissolution of silicified materials.
 - c. Produce advanced models of paleoecology and deposition systems.
 - d. Select appropriate journal, write outlines and drafts of article(s).
 - e. Field excursions for any missing samples or photos.
 - f. Present results at GSA, AAPG (Rocky Mountain), AGU.
 - g. Students submit proposals for next projects (GSA, AAPG, NSF, etc.).
6. Jan – May, 2018
- a. Discuss feedback (GSA, AAPG, AGU), needed adjustments to project.
 - b. Masters student: begin thesis and plan final semester if needed.
 - c. Prepare publication figures:
 - i. Prepare and image fossils (Zeiss Stemi 508).

- ii. Automate thin section photomosaics (Zeiss AxioM2)
 - iii. Note outstanding or needed specimens, photos, etc.
 - iv. Train students with Adobe Illustrator, R (statistics).
 - d. Complete and submit article(s).
 - e. Determine summer field objectives and new opportunities.
7. Summer 2018
- a. Field season: expand work into Mississippian or refine Permian.
 - b. Handle article(s) feedback from editor, resubmissions, etc.
 - c. Masters student: complete thesis and/or prepare for final semester.
 - d. PhD student: prepare for qualifying exams.
 - e. Report project and student advancement outcomes to ACS.

Closing Comments on Logistics

The new Paleocology Lab at the University of Utah is uniquely poised to achieve the stated goals, and to advance integrated ecological biosedimentation research in the United States and abroad. Facilities at the University include a fleet of field vehicles, several wet labs for rock sample preparation, simple geochemistry (fume hoods for acid dissolutions, acetate peels, etc.), fossil preservation (including at the Natural History Museum of Utah), and a new microscopy laboratory. Two microscopes are currently in production, and undergraduate training will begin later this fall. The Zeiss AxioImagerM2 is a petrographic scope with fully automated x,y,z stage control and automated construction of microphotomosaics with interpolated microtopographic compensation. (It can rapidly produce an 8-foot-long poster of a 4-cm-wide thin section slide!) The Zeiss Stemi 508 is a binocular dissection-style microscope on a flexible arm to image hand samples and microfacies of uncut specimens. Faculty and research groups at the university include paleontologists, sedimentologists (including a petroleum career track MS program), and

geochemists to maximize student learning opportunities. Dr. Ritterbush' previous research projects focused on mass extinction paleoecology and on biogeography of survival statistics, but opportunities to explore microfacies led to larger fundamental questions about the biotic and environmental controls on biosedimentation regimes. The proposed work presents excellent challenges for students, allowing them to grow into mature scientists and join academic and/or industry careers. Execution of the project will incorporate the new Paleoecology Lab into the national and international geological sciences communities.

Proposal Narrative Word Count: 3,177

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