Bioclastic Reservoirs of the Distal Montney “Shale” Play*

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Search and Discovery Article #80548 (2016)**
Posted October 3, 2016

*Adapted from extended abstract prepared in relation to an oral presentation at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 16-22, 2016

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Abstract

Sedimentologic and stratigraphic analysis of 1500m of full-diameter core, integrated with petrographic description of cuttings from wells in the most basinward subsurface extent of the Lower Triassic Montney Formation, northeastern British Columbia, have identified two of the three most productive reservoir units as bioclastic in origin. Their excellent hydrocarbon deliverability within a leading North American resource play makes the origin, lateral variability, and heterogeneity of these reservoir units an issue of economic significance. Referred to for years as “the turbidite zone”, the lower of the two bioclastic units is a monospecific, life assemblage of *Claraia* sp. “flat clams,” interpreted as a biostrome, interbedded with highly bituminous, parallel-laminated siltstones deposited out of suspension near storm- weather wave base on a low-gradient, predominantly siliciclastic, ramp. The biostrome reservoir unit is bounded by a marine flooding surface below and maximum flooding surface above, and grades basinward into a dolosiltstone facies of hemipelagic origin and paleo-landward into lower shoreface coarse-grained siltstones to silty, very fine-grained sandstones. The younger of the two bioclastic units is interpreted as a mixed carbonate/clastic ramp facies association. Individual bioclastic beds are sharp-based, normally graded and comprised of an admixture of bivalves, brachiopods, and echinoderms, showing evidence of wave and/or storm transport, hence interpreted as tempestites. There are three parasequences within this reservoir interval, each of which grades basinward into bituminous siltstones and hemipelagic dolosiltstone. Paleo-landward (east) they become thinner through erosion by an overlying regional sequence boundary. The lateral distribution of bioclastic intervals form reservoir “sweet spots” within the Montney. Bioclastic beds are densely calcite-cemented with minimal measurable porosity (1-2%) and only rarely naturally fractured. However, the interbeds of siltstone in both successions are highly bituminous (TOC range 2-4%) and of relatively high total porosity averaging 5-7%. It is concluded that the hydrocarbon deliverability of the bioclastic reservoirs has less to do with primary or secondary reservoir quality and is more a function of geomechanical rock properties attributable to high-frequency interbedding of brittle-ductile facies resulting in significant permeability and geomechanical anisotropy leading to more effective reservoir stimulation through hydraulic fracturing.

Introduction

Sedimentologic and stratigraphic analysis of 1500m of full-diameter core, integrated with petrographic description of cuttings from wells drilled in the most basinward subsurface extent of the Montney Formation in northeastern British Columbia (Figure 1) have identified two of the three most productive reservoir units as being bioclastic in origin. Both occur within the lithostratigraphic Lower Montney and are interpreted, based on conodont biostratigraphy, as being Dienerian to late Smithian (Early Triassic) in age (Moslow et al., 2016). In light of their excellent hydrocarbon deliverability, the origin, lateral variability, and heterogeneity of these reservoir units has become an issue of economic significance within one of North America's leading resource plays.

Bioclastic Sedimentary Characteristics and Facies Associations

The lower of the two bioclastic units is an *in situ,* monospecific, life assemblage of bedded to laminated *Claraia* sp. "flat clams", interpreted as a biostrome, interbedded with highly bituminous, parallel-laminated siltstones deposited out of suspension near storm- weather wave base on a low gradient, predominantly siliciclastic ramp. Individual valves are observed both macroscopically and microscopically to be aligned parallel to bedding (Figures 2 and 3). Their somewhat remarkable preservation and encasement within a fine-grained matrix infers minimal mechanical transport. The inverse grading common to the majority of individual beds is consistent with a life assemblage accumulation at the sediment-water interface (McRoberts, 2010). Stratigraphically the biostrome reservoir unit is a parasequence bounded by a marine flooding surface below, and maximum flooding surface above (Figure 4). This reservoir interval has been colloquially referred to for years as "the turbidite zone" in industry but would be more appropriately termed as the "*Claraia* Biostrome," based on sedimentologic observations in core, as summarized above.

The *Claraia* sp. biostrome facies association thickens and becomes more bioclastic in a westerly (basinward) direction. In a paleo- landward (east) direction it grades laterally into lower shoreface facies of interbedded sandy siltstone to silty, very-fine grained sandstone. These changes are interpreted to reflect the lateral extent of the ecological niche in which the *Claraia* sp. biostrome facies accumulated at the time of deposition. Specifically, this is an environment of deposition at or near mean storm -weather wave base in the distal offshore- transition environment of deposition (Figure 5). As such, the *Claraia* sp. biostrome facies association is thickest and most laterally continuous along a NNW-SSE oriented fairway. The biostrome facies association grades laterally to the north into an interbedded dolosiltstone and bituminous siltstone. This suggests a northern limit to the biostrome facies possibly attributable to latitudinal (i.e., paleo- temperature) controls.

The younger of the two bioclastic units is interpreted as a mixed carbonate/clastic ramp facies association. Individual bioclastic beds are sharp-based, normally graded and comprised of an admixture of pelecypods and brachiopods showing evidence of wave and/or storm transport, hence interpreted as tempestites. There is an observed increase in the thickness and frequency of bioclastic beds within this facies in a paleo-landward (east) direction, reflective of a gradation from distal through proximal positioning on the mixed clastic-carbonate ramp depositional profile. Stratigraphically there are three parasequences within this reservoir interval (Figure 6), each of which grades basinward into bituminous siltstones and hemipelagic dolosiltstone. Paleo-landward (east) they become thinner through erosion by a overlying regional sequence boundary coincident with the Smithian –Spathian contact, as determined from conodont biostratigraphy (Moslow et al., 2016). Individual bioclastic beds are erosionally based, normally graded accumulations of a mixed assemblage of pelecypod and brachiopod valves and fragments interbedded with sandy coarse siltstone and very fine-grained sandstone (Figures 7 and 8). Individual bioclastic beds are the product of storm processes on a mixed carbonate –siliciclastic ramp.

Reservoir Quality

The lateral distribution of the bioclastic intervals forms reservoir “sweet spots” within the Montney Formation. MICP analysis and thin-section petrology reveal that the bioclastic beds are densely calcite-cemented with minimal measurable porosity (1-2%) and only rarely naturally fractured. However, the interbeds of siltstone in both successions are highly bituminous (TOC range 2-4%) and of relatively high total porosity averaging 5-7%. It is hypothesized that the hydrocarbon deliverability of the bioclastic reservoirs has less to do with primary or secondary reservoir quality and more a function of geomechanical rock properties attributable to the high frequency interbedding of brittle-ductile facies resulting in significant permeability and geomechanical anisotropy leading to more effective reservoir stimulation through hydraulic fracturing.

Summary and Conclusions

Within the “Lower” Montney of northeastern British Columbia there are two bioclastic facies associations with distinctly different origins and sedimentary characteristics, but similar reservoir properties. The Lower Montney L1 is comprised of three prograding mixed clastic-carbonate ramp parasequences. Each parasequence thickens in a paleo-landward (east) direction. There is observed a decreasing carbonate to clastic ratio from base to top, such that the lowermost of the three parasequences is the most bioclastic. Each parasequence is internally characterized by proximal through distal facies associations that display a lateral change to more siliciclastic facies to the east and more dolomitic facies to the west. Bioclastic beds are densely calcite cemented and have minimal porosity or reservoir quality and are interbedded at a high frequency with fine- to coarse-grained bituminous siltstone. It is believed that the alteration of highly brittle carbonate facies and more ductile clastic facies may be responsible for an enhancement of propant and frac fluid placement upon reservoir stimulation. If so, rock mechanics likely plays an important role in deliverability and productivity in this stratigraphic unit. Regardless of the specific reason, it is very likely that the best reservoir intervals are facies selective and that sedimentary facies variability and predictability play an important role in future successful development.

The “Turbidites” stratigraphic interval has not been observed to be of turbidite origin. It is instead a *Claraia* sp. biostrome characterized internally by a basinward (west) thickening facies association of interbedded in -situ assemblages of *Claraia* sp. valves and bituminous siltstone. The interval grades laterally to the north to interbedded dolosiltstone and bituminous siltstone and to the east (paleo- landward) into interbedded sandy siltstone and silty sandstone. The *Claraia* sp. biostrome facies are not obviously a product of higher or above average reservoir quality (porosity and/or permeability). It is likely that deliverability and productivity are a function of geomechanical rock properties associated with the contrast in brittle carbonate beds interfingering with ductile bituminous siltstones. If so, “sweet spots” or fairways should exist.

Acknowledgements

The authors would like to acknowledge the management of Progress Energy Canada Ltd., especially Wayne Hovdebo, Gerald Nyberg, and Peter Saltman, for their support in the compilation of this work and also for their permission to publish these findings. Audrey Whitlock provided invaluable assistance in the graphic presentation of this manuscript. Numerous geoscientists at Progress Energy provided constructive criticism and advice on the results presented herein. Beth Haverslew provided thin-section photomicrographs and petrologic descriptions. We thank Graham Davies for sharing his insights and experience that benefited this work.

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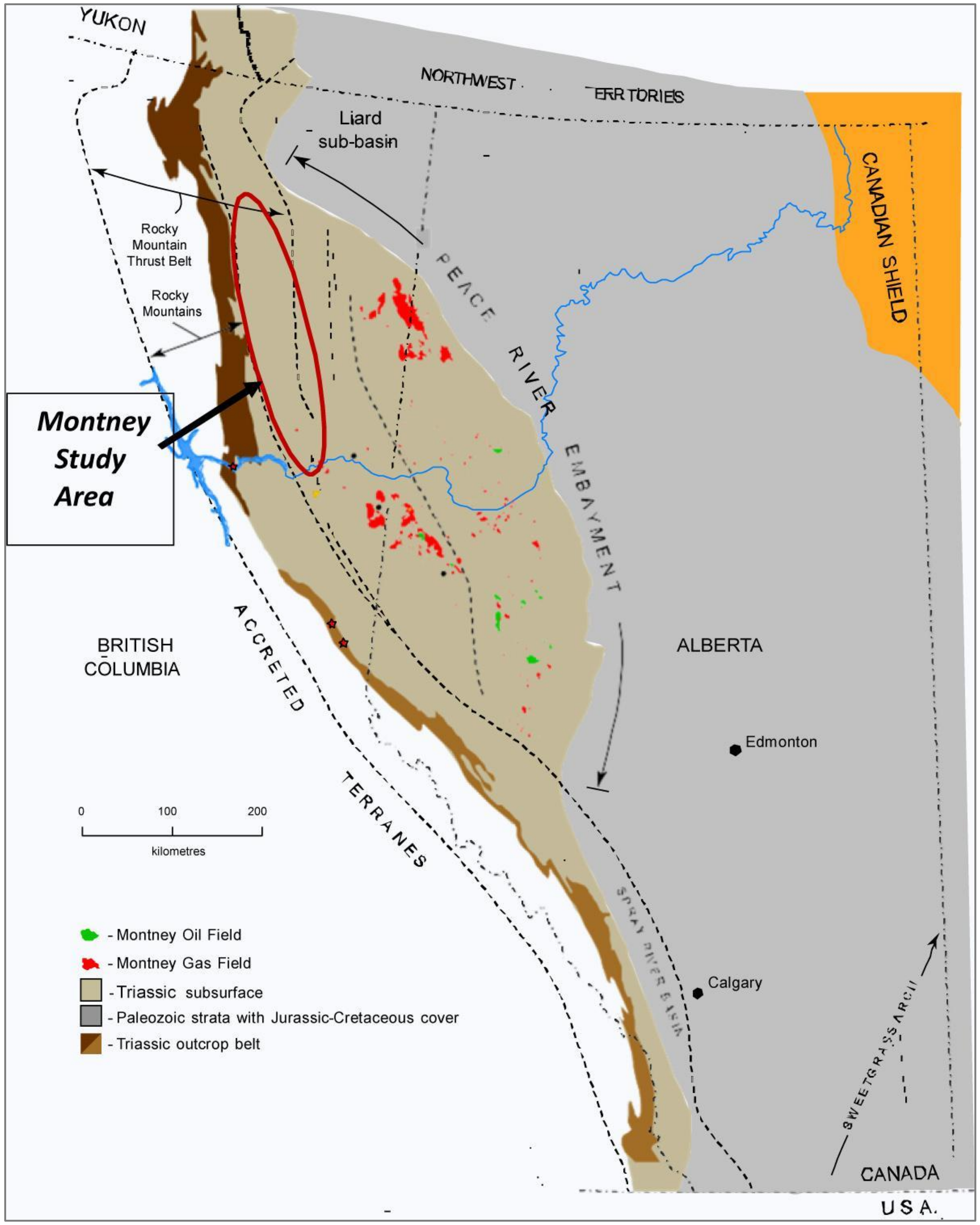

Figure 1. Map showing the outline of the Montney depositional basin within Alberta and northeastern British Columbia; red ellipse outlines the study area (from Zonneveld and Moslow, 2015).

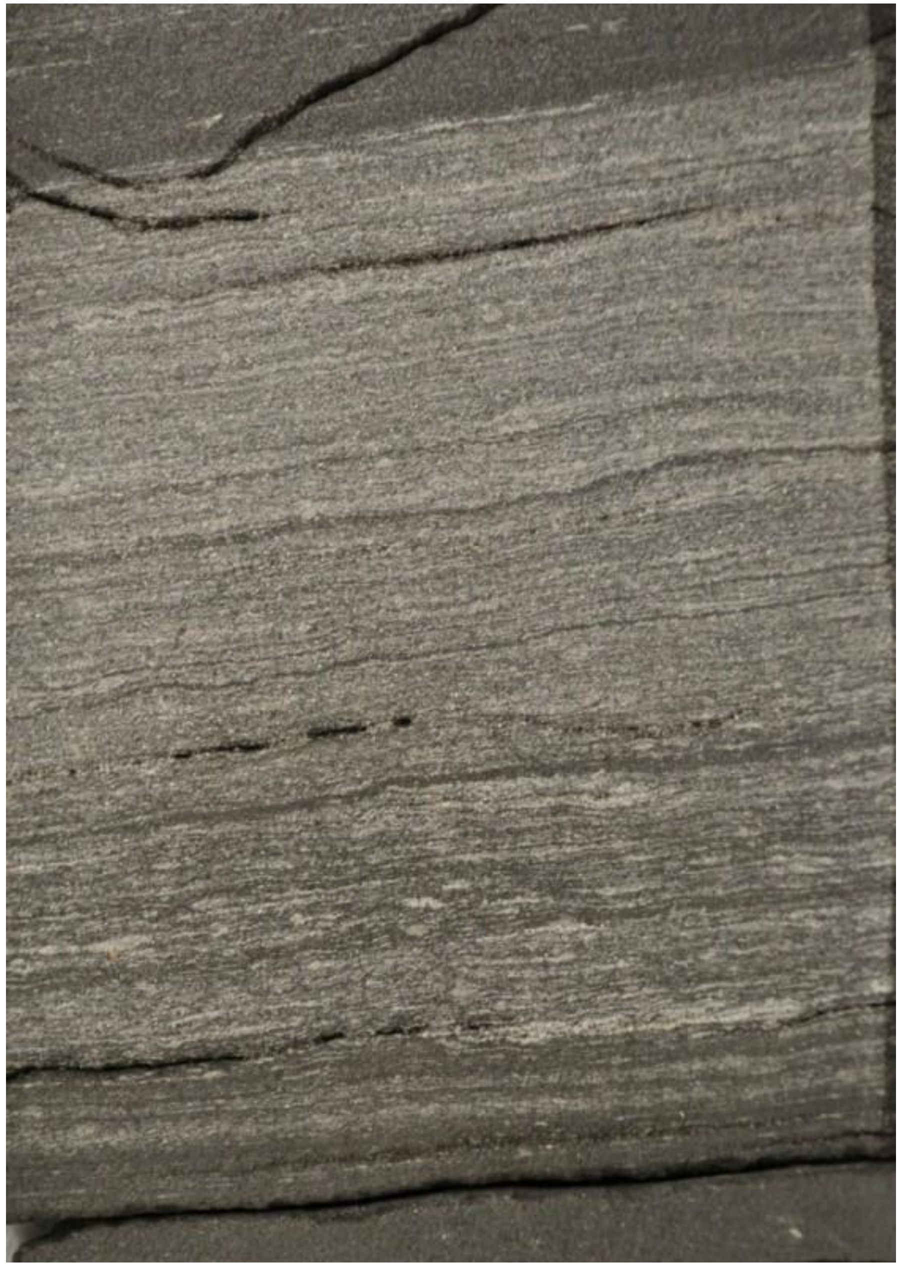

Figure 2. Relatively thick (11.5cm) inversely graded bioclastic bed comprised of a monospecific assemblage of *Claraia* sp. valves overlain and underlain by a bituminous fine-to coarse-grained siltstone within the *Claraia* Zone at 2068.7m in Pocketknife a-34-L /94-G-7. Core diameter is 9.0cm; well bore deviation is approximately 10 degrees.

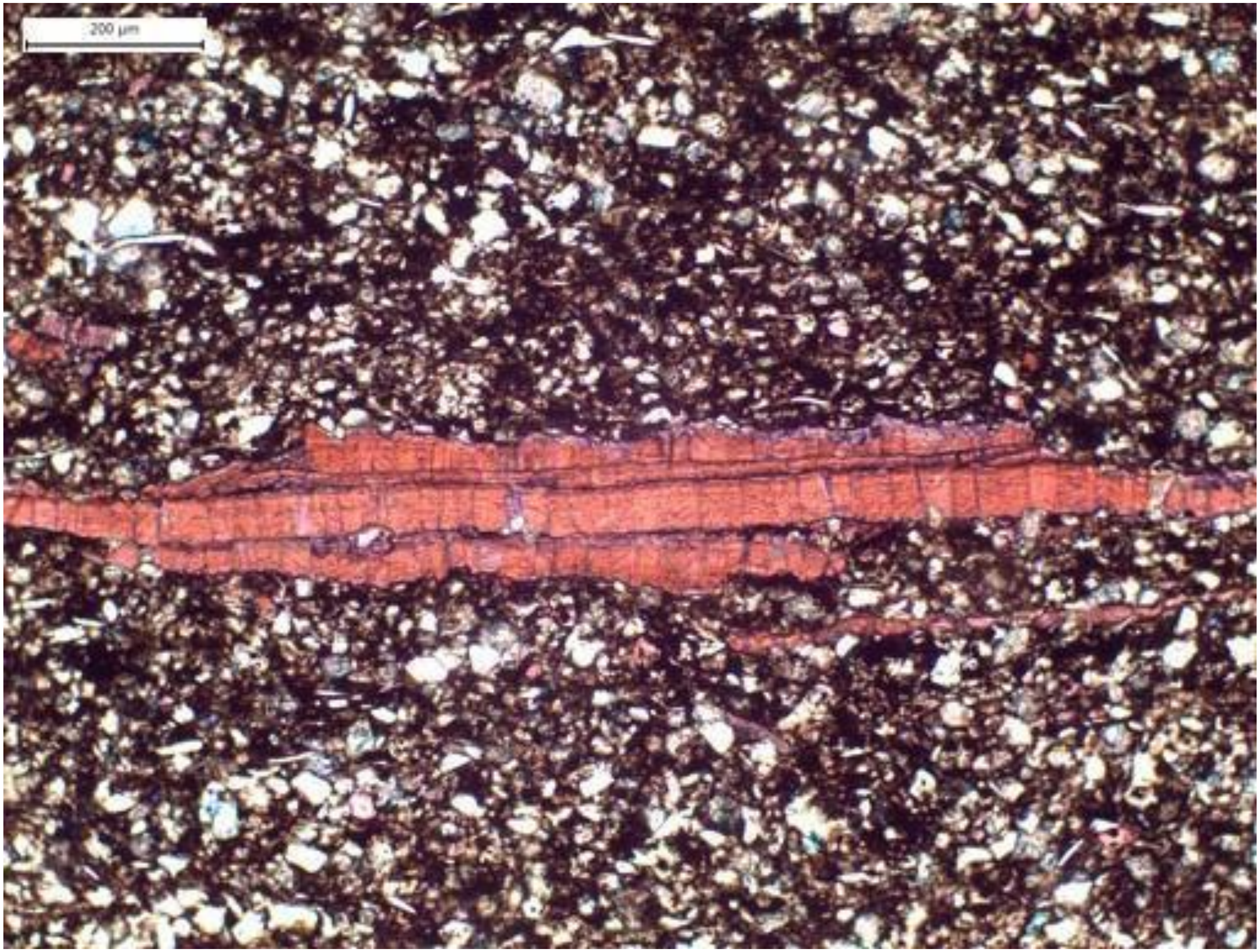

Figure 3. Thin- section photomicrograph of portions of bedding-plane-parallel *Claraia* values encased in bitminous fine- to coarse-grained siltstone matrix (c-4-F /94-G-8: 1981.5m).

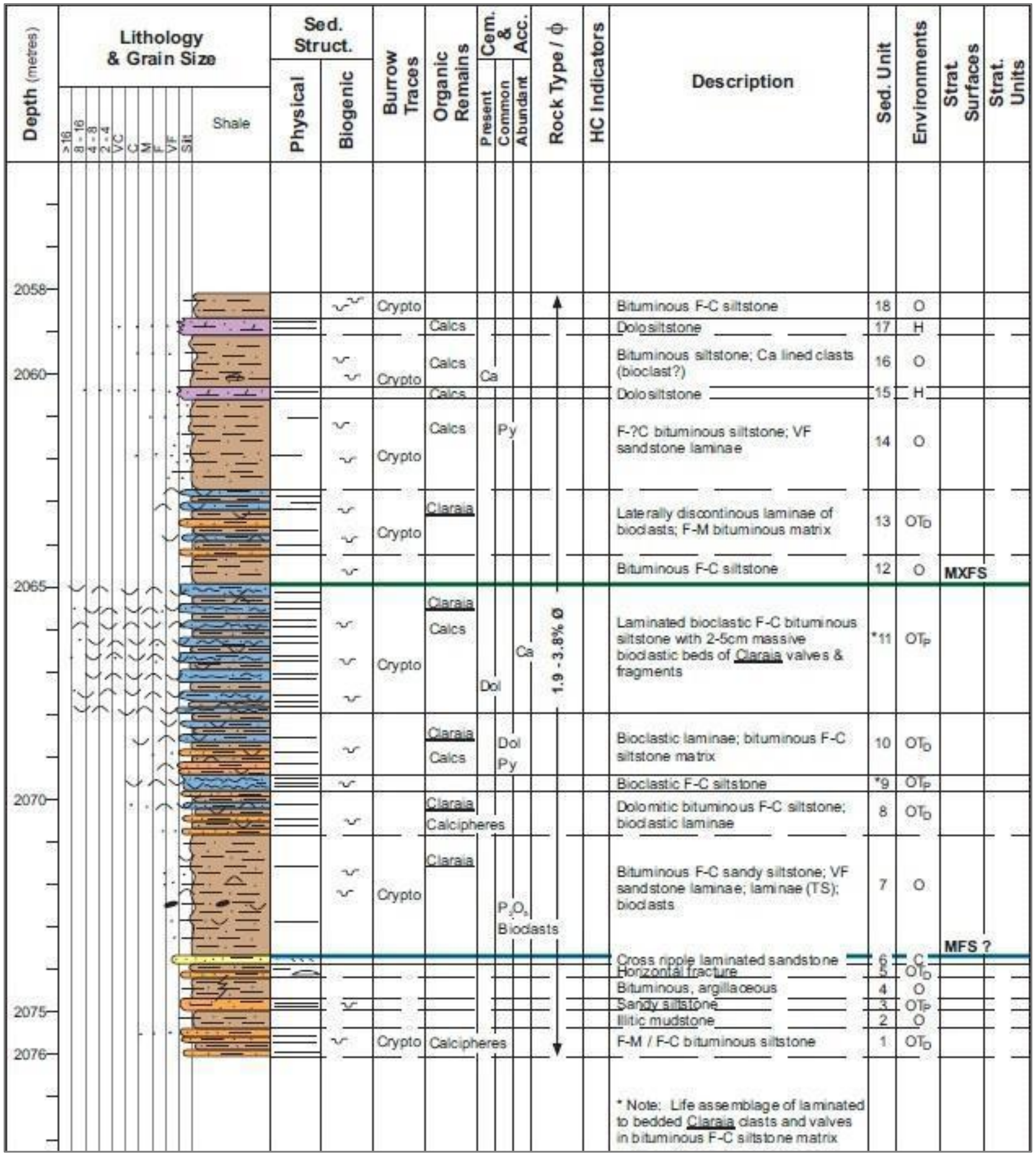

Figure 4. Sedimentologic description of *Claraia* Zone interval in the a -34-L/94-G-7. Individual beds are inversely graded in-situ accumulations of a monospecific assemblage of Claraia sp. valves and fragments interbedded with bituminous siltstone and interpreted as a biostrome.

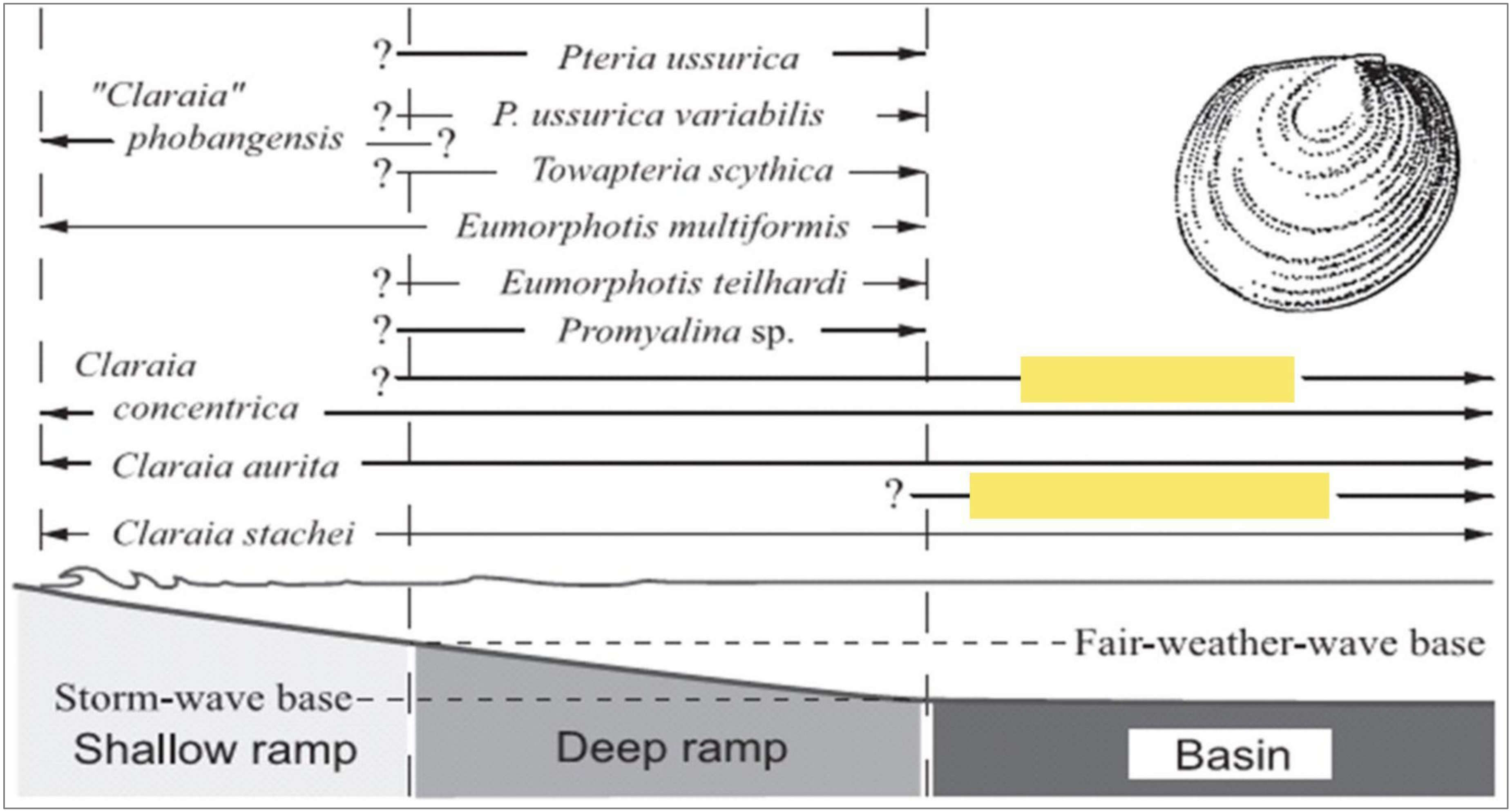

Figure 5. Schematic reconstruction of habitats for bivalves including *Claraia* sp. in the Lower Triassic. Note that varying species of *Claraia* have a far broader range of habitats than other contemporaneous pelecypods. *Claraia* sp. also has the ability to yield near monospecific assemblages in the distal part of the deep ramp and offshore (yellow), a setting below mean storm-weather wave base, where anoxic conditions prevail. This is interpreted to be the environment of deposition where the Montney "*Claraia* Zone" facies were deposited (from Komatsu et al., 2008).

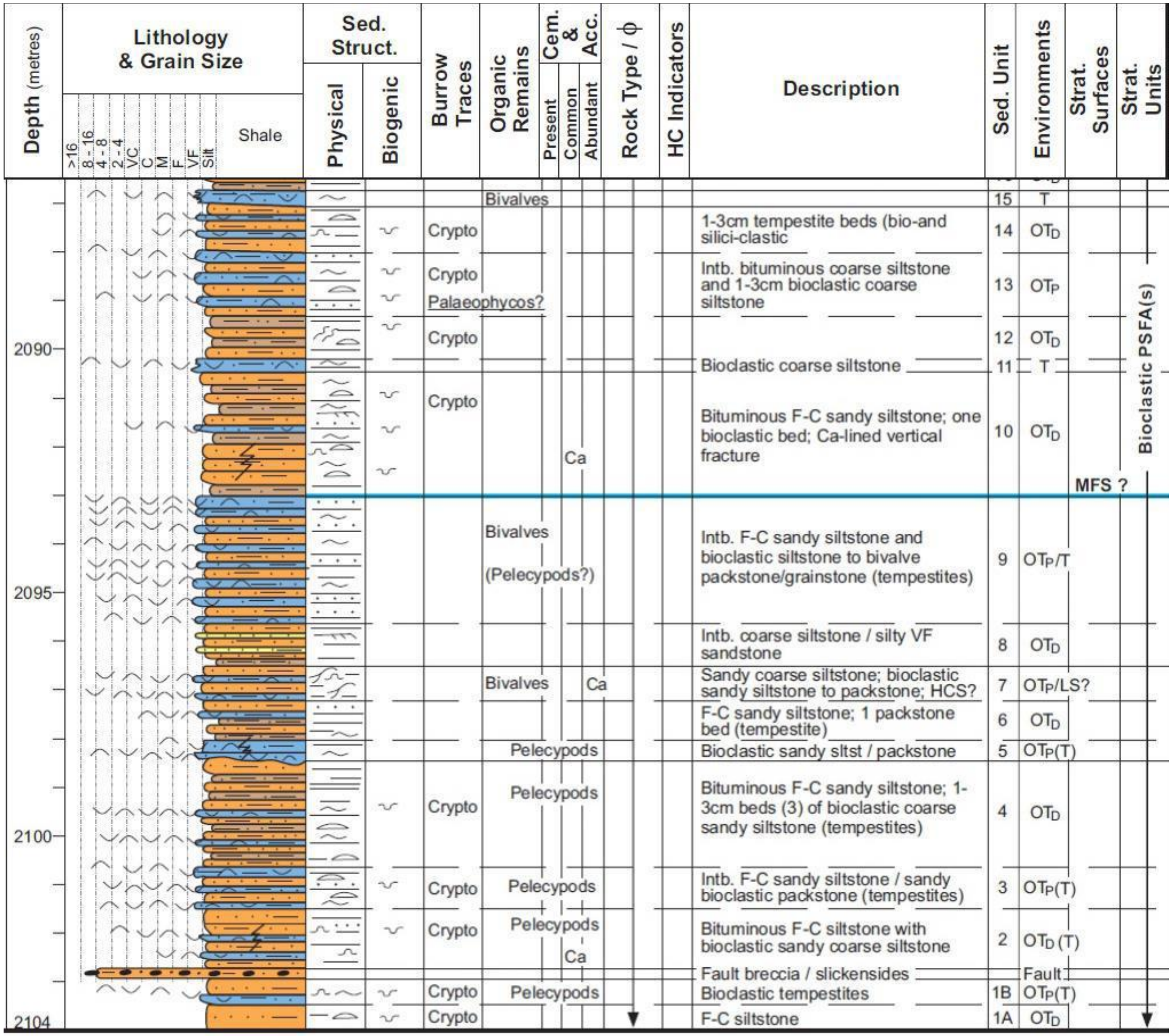

Figure 6. Sedimentologic description of the bioclastic tempestite interval in the d-40-H/94-G-7. Marine flooding surface (MFS) indicated by blue horizontal line at 2093.0m.

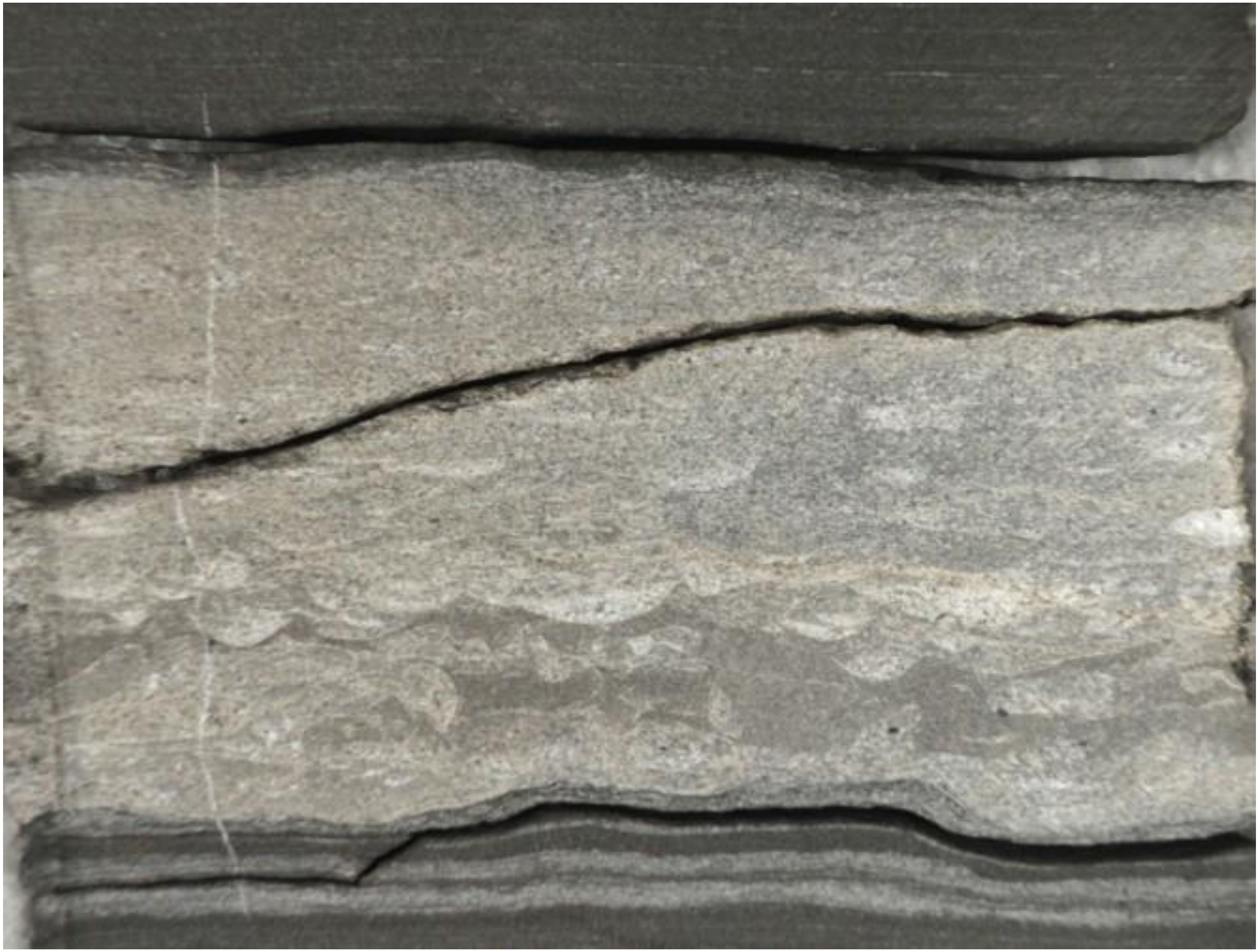

Figure 7. Close-up core photograph of a bioclastic tempestite bed. Note sharp erosional base and normal grading, with large calcite-replaced pelecypod valves concentrated in the lower half of the bed. Bed is 6cm in thickness. (d-55-A/94-G-7; 1787.6m).

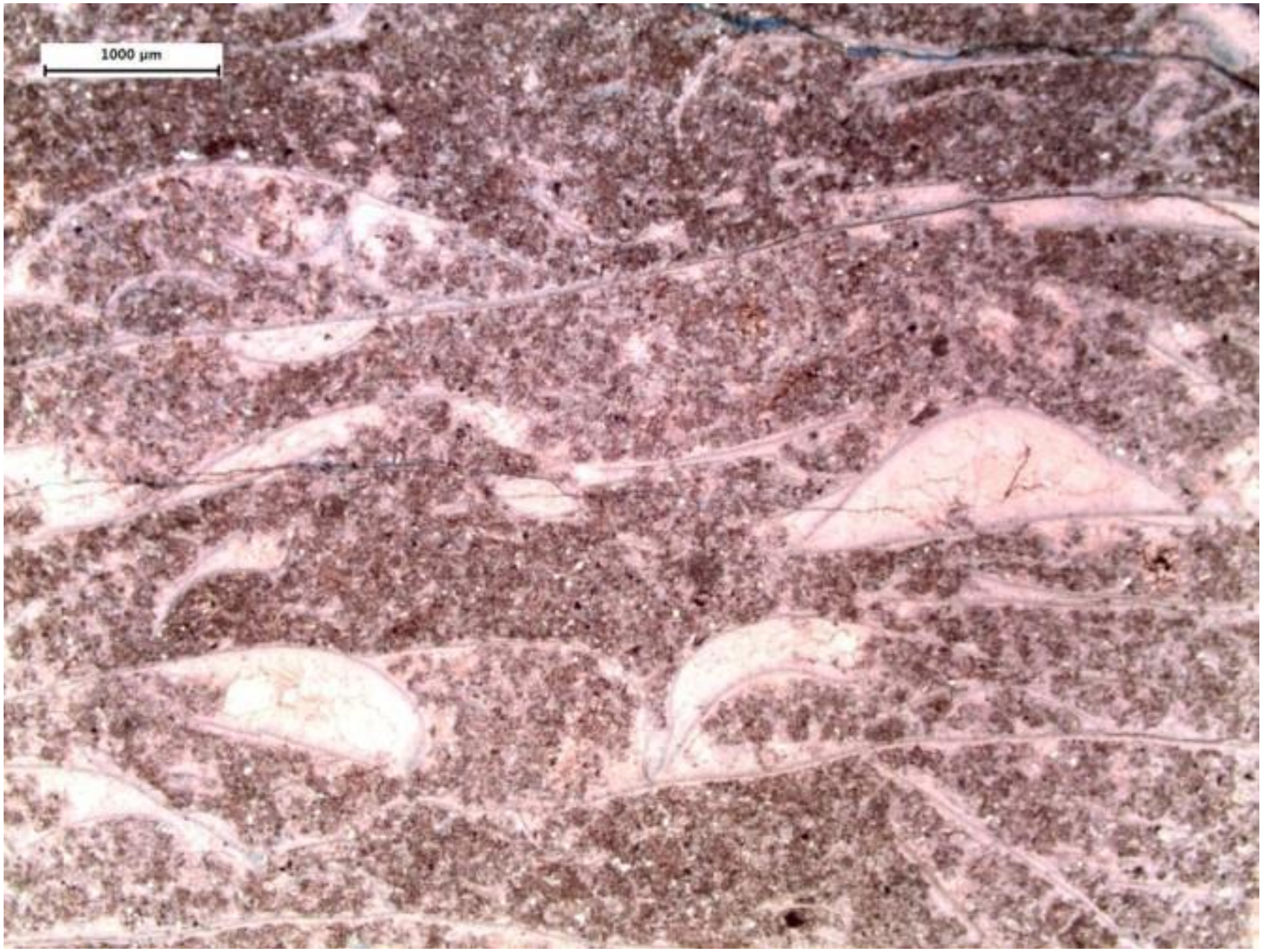

Figure 8. Bioclastic tempestite of distinctly curved, thin-walled bivalve fragments in a recrystallized and calcite-cemented, calcite mud matrix (d-97-C /94-G-7; 1841.5m).