# Event Deposition in Shales — Woodford Shale, Oklahoma, USA, and Bjørkåsholmen Formation, Sweden*

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## Abstract

Shales from two Paleozoic marine settings, the Devonian Woodford Shale of Oklahoma, USA, and siliciclastic mudstone intercalations into the Ordovician Bjørkåsholmen Formation carbonates of Sweden, exhibit distinct millimeter- to sub-millimeter laminae (present thickness) in thin section whereas in outcrop they both appear massive. The Devonian example shows a two-fold subdivision of laminae with a dark-colored lower and a light-colored upper part. The lower portion of the lamina contains abundant pyrite and, locally, silt-size detrital quartz and carbonate grains at its base. In the central to upper part of these laminae, pyrite is a minor constituent, significantly less than at the base. Planolites burrows cluster at the lamina top. Phycosiphon isp. fecal strings and Tasmanites algae are present throughout, but the fecal strings rarely penetrate the pyrite-rich lower part of these lamina. The siliciclastic mudstones in the Bjørkåsholmen Formation carbonates either contain abundant shell debris and phosphate clasts, or consist of intercalated light- and dark-colored bands of irregular geometries that are one to several millimeters thick. Phycosiphon isp. is present throughout. In the Woodford Shale, the laminated texture and the presence of Planolites burrows just at the lamina tops suggests lamina deposition in pulses, followed by non-deposition and limited bioturbation. The siliciclastic mud was carried as bed load indicated by local, basal silt-size lags, or as fluid mud. In either case, deposition was a result of an event, probably storms, from which was deposited one discrete millimeter-thick mudstone lamina. This mudstone lamina was subsequently colonized from the top downward in a dysoxic water column resulting in Planolites traces only at the top, and fecal strings diminishing in abundance downward. Only the basal portion of some of the thicker laminae remained largely undisturbed which is where the pyrite precipitated. The Bjørkåsholmen Formation mudstones also show lag deposits, both shell debris and phosphate clasts, which probably originated from currents that moved by bed-load transport. Similar to observations from the Recent Eel delta (USA), the Bjørkåsholmen Formation mudstones were most likely deposited by a series of storm events. This study therefore demonstrates the significance of event deposition (not suspension settling) in the accumulation of important source rocks and unconventional reservoirs, and under dysoxic-oxic conditions.

## References Cited


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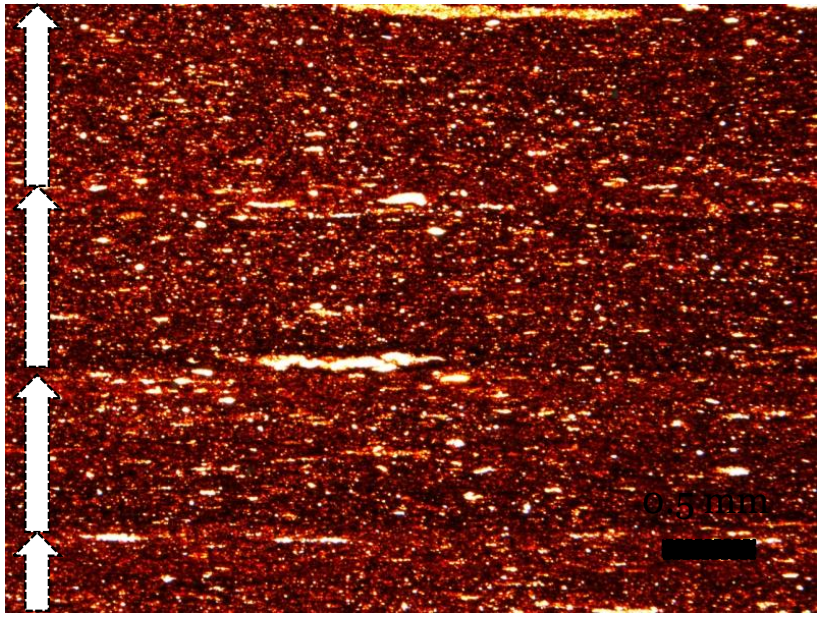
# Event deposition in shales:

## Woodford Shale, Oklahoma, USA, and Bjørkåsholmen Formation, Sweden



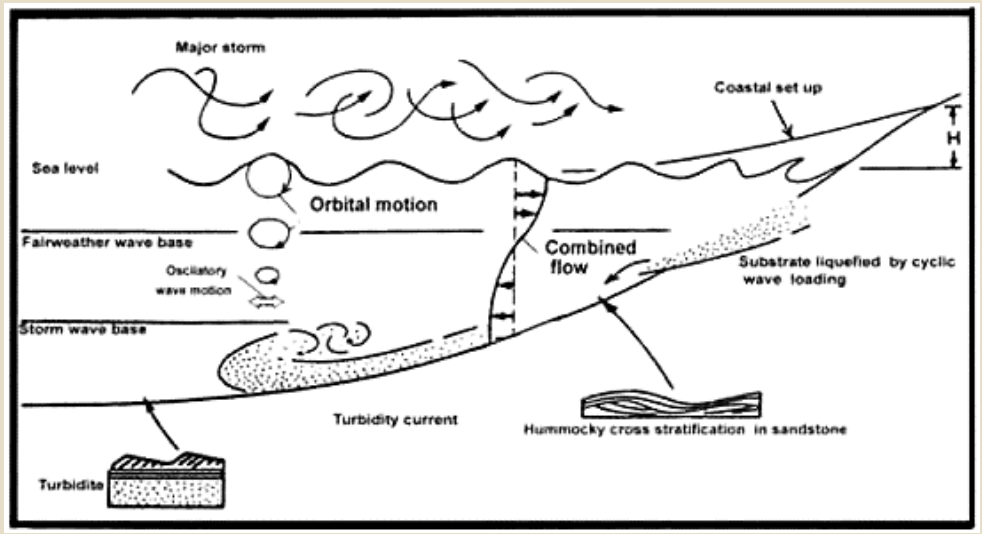

SVEN EGENHOFF, NEIL FISHMAN, PER AHLBERG, JÖRG MALETZ, AND STANLEY PAXTON

Tuesday, February 4, 2015

# Introduction and problem



- On shelf above storm wave base:

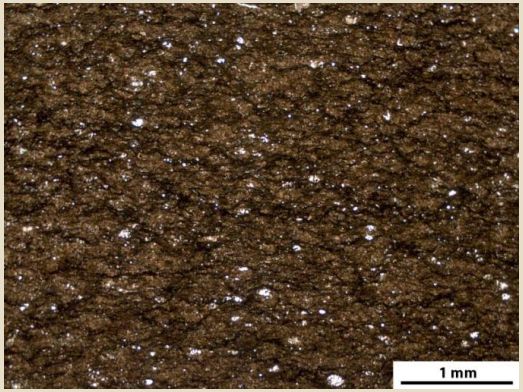


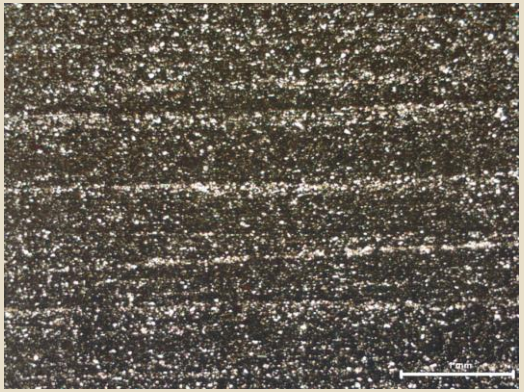

  - Fair weather – fine-grained sediments (suspension)
  - Storms – coarse sediment (bed load)
  - Typical storm-formed structures: HCS, gutter casts
  - Muds = fair weather deposition (suspension)

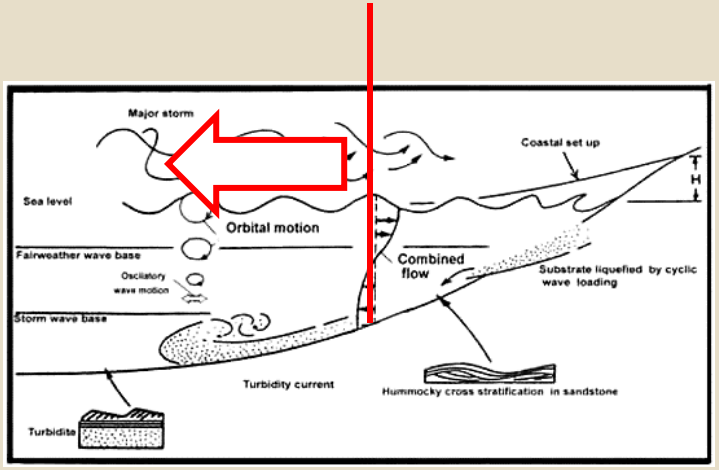
# Introduction and problem



- Focus up to now entirely on coarse-grained part
- Fine-grained part - completely neglected
- Let us go deeper – below SWB!
- If fair-weather deposits above SWB = suspension deposition → then everything below SWB = suspension deposition only, or?
- Deep shelf: What happens there?



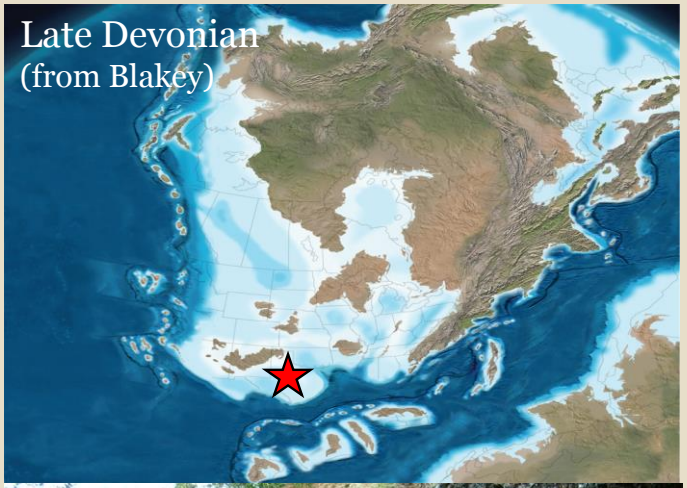


# Study Area 1: Woodford Shale, Devonian

## Arbuckle Mountains



- Woodford Shale, Arbuckle Mountains (star)
  - Located between Anadarko and Arkoma Basin
  - Study locality: Henry House Creek section
  - Unit 230 ft. thick at Henry House Creek



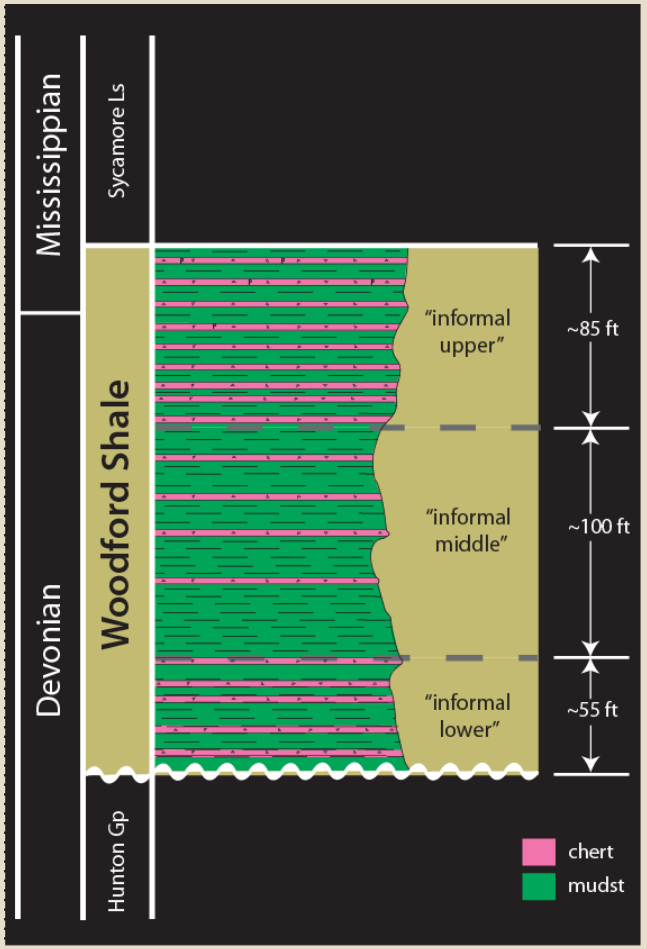

Fishman et al. 2013

# Study Area 1: Woodford Shale, Devonian

## Arbuckle Mountains



- Famous unconventional reservoir
- Subdivided into 3 members; main target middle and upper member
- Succession: intercalated mudstones and cherts (mudstones dominate)
- More cherts in lower and upper, more mudstones in middle




Fishman et al. 2013

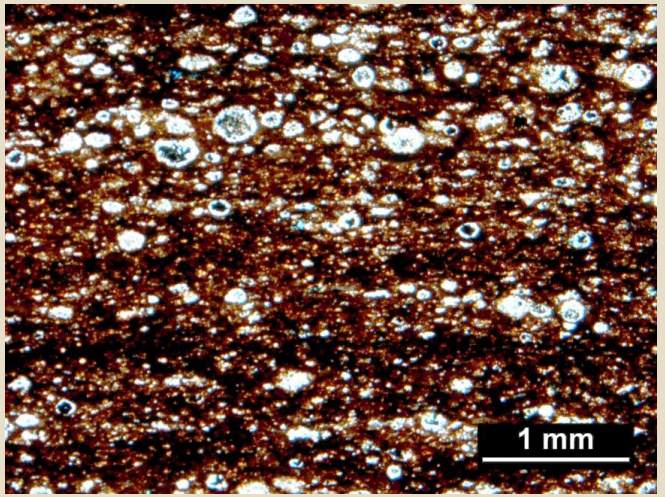
# Study Area 1: Woodford Shale, Devonian

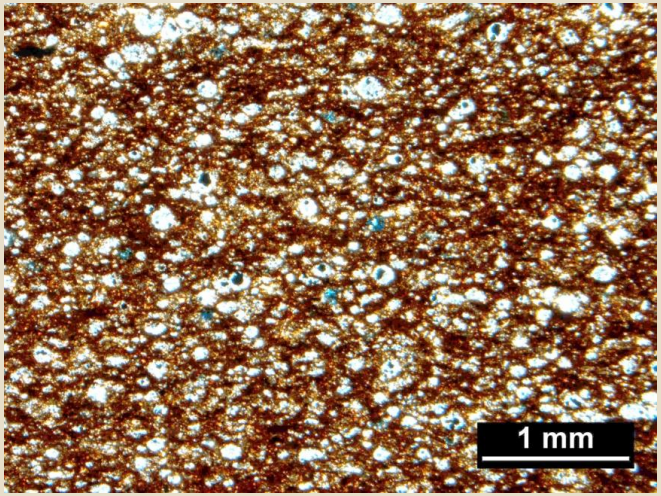
Arbuckle Mountains



**Cherts**

- Beds few cms to a maximum of 12 cm thick
- Massive radiolarites; many radiolarians compacted
- In places with intercalated sub-mm irregular mudstone laminae
- TOC mainly outside radiolarian tests
- Visible porosity often within tests
- Suspension deposition (blooms)
- Intercalated mudstones → current deposition (irregular geometry)



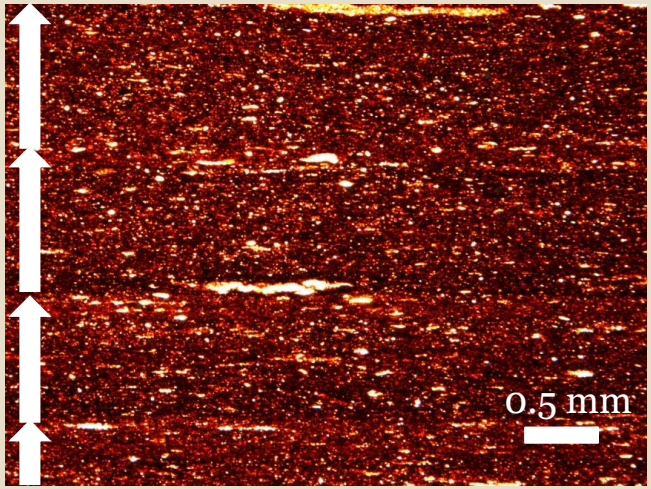
# Study Area 1: Woodford Shale, Devonian

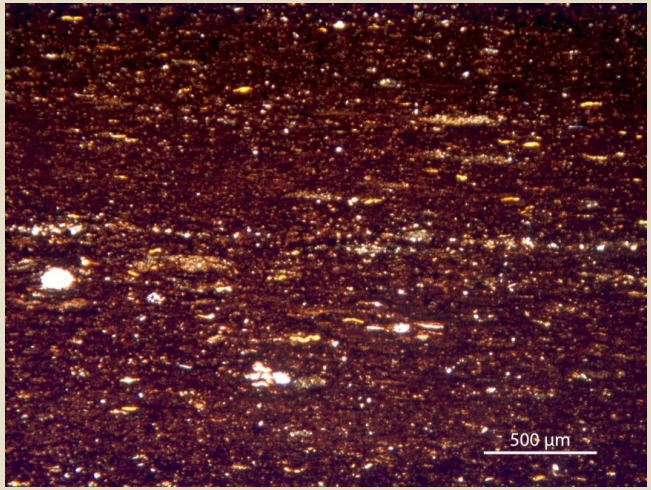
## Arbuckle Mountains



**Mudstones:**

- Beds up to 170 cm thick
- "massive"
- Heavily bioturbated (horizontal and multidirectional types)
- Contain minor siltstone laminae
- Generally organized into well organized mm-scale depositional units



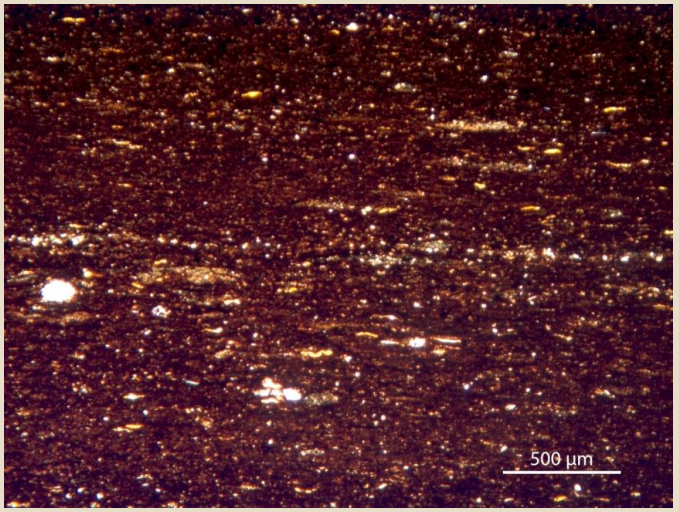
# Study Area 1: Woodford Shale, Devonian

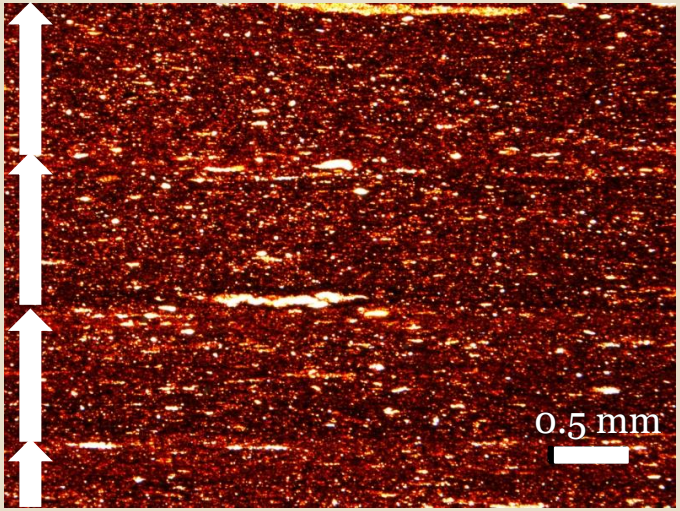
## Arbuckle Mountains

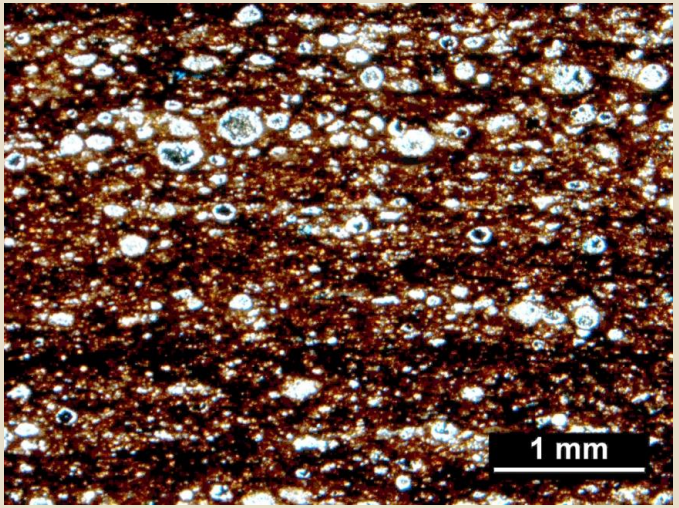


- Episodic Sedimentation
  - In mudstones – silt laminae; mm-scale units
  - In cherts – mudstone laminae
  - Processes

→ <u>In both cases event deposition</u>



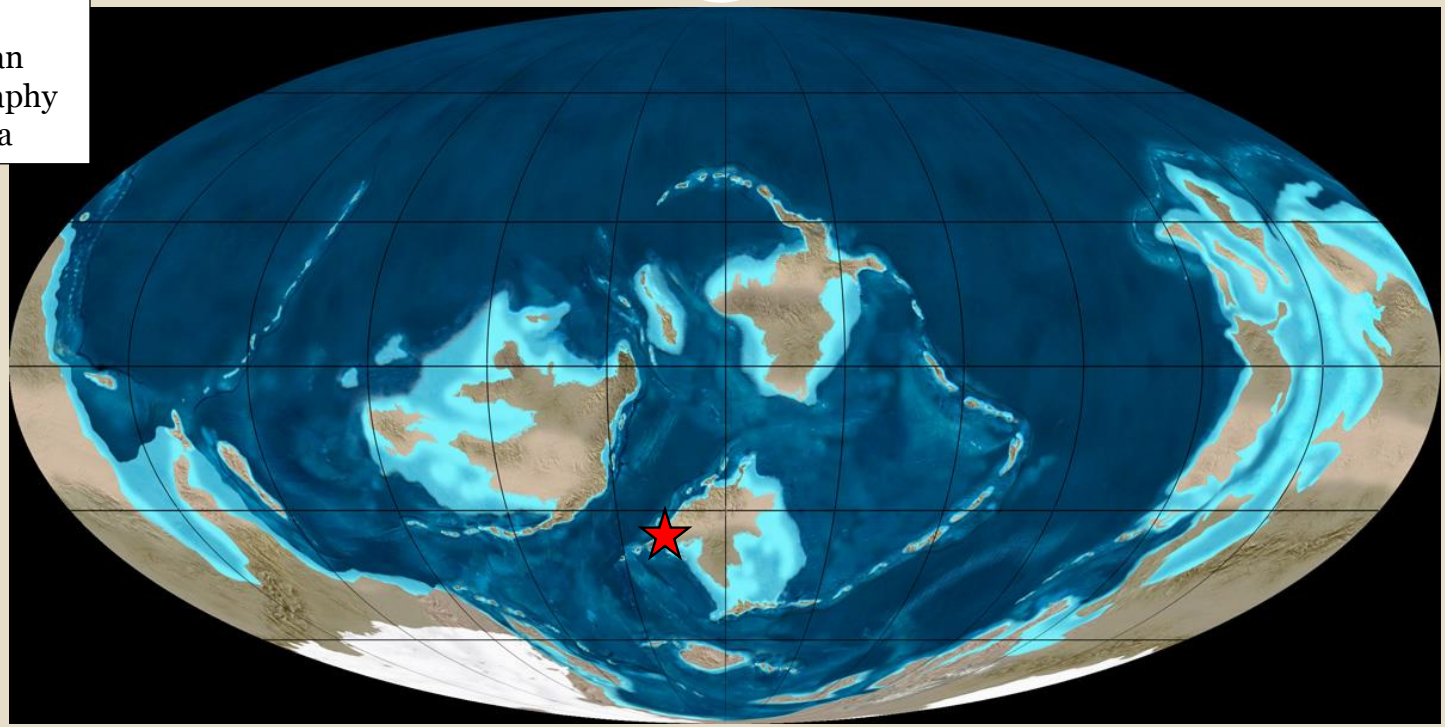



# Study Area 2

## Swedish Shelf (Ordovician)



Middle Ordovician paleogeography ~ 470 ma



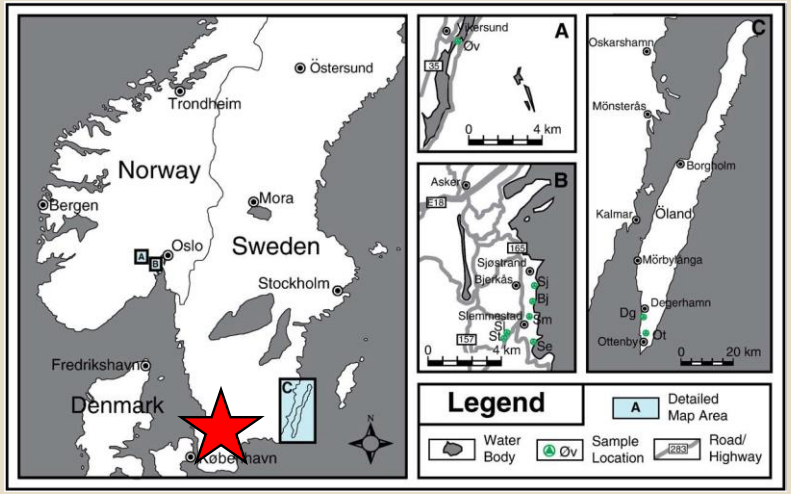
Blakey, (2014)

- Wide-spanned passive margin shelf of Baltica
- Baltica drifting N during Ordovician
- Unit = Bjørkåsholmen Formation, mostly carbonates

# General Stratigraphy - Bjørkåsholmen Formation

## Ordovician Baltica






| LOWER ORDOVICIAN | | Graptolites Maletz & Egenhoff 2001 | Conodonts Stouge, 2004 | Trilobites Nielsen, 1995, Pärnaste, 2006 | Lithology Oslo, Norway Owen et al., 1990 | Lithology Öland, Sweden Stouge, 2004 |
|---|---|---|---|---|---|---|
| | Floian | *Tetragraptus phyllograptoides* | *P. elegans* | *Megistaspis estonica* | Tøyen Shale Formation | Bruddesta Formation |
| | Tremadocian | *Hunnegraptus copiosus* | *Paroistodus proteus* | *Megistaspis planilimbata* | | |
| | | *Araneograptus murrayi* | | *Ekeraspis armata* | | Köpingsklint Formation |
| | | *Kiaerograptus supremus* | | | | |
| | | *A. victoriae* / *K. kiaeri* | *Paltodus deltifer* | *Apatokephalus serratus* | Bjørkasholmen Fm | Djupvik Formation |
| | | *Bryograptus ramosus* | *Cordylodus angulatus* | *Shumardia pusilla* (*Ceratocaris scanicus*) | Alum Shale Formation | Alum Shale Formation |
| | | *?Adelograptus tenellus* | | | | |
| | | *Rhabdinopora f. anglica* | | | | |
| | | *Anisograptus matanensis* | | | | |
| | | *Rhabdinopora f. parabola* | *C. lindstroemi* | (*Hysterolenus*) | | |
| | | *Rhabdinopora praeparabola* | *C. intermedius* | | | |

Egenhoff et al. 2010

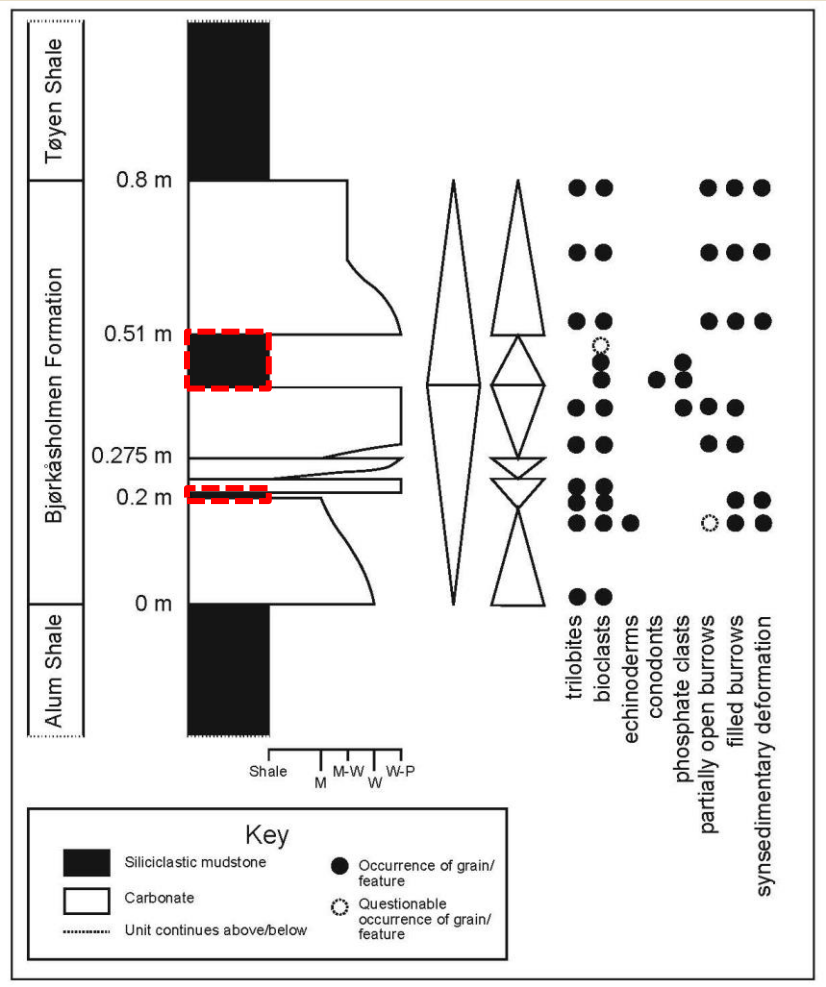
- Lower Ordovician
  - Locality: Flagabro (red star)
  - Comparable sections in Oslo (Norway) and on Öland, Sweden
  - Biostratigraphy – graptolites, conodonts, trilobites

# Bjørkåsholmen Formation

## Ordovician Baltica



- Bjørkåsholmen Formation at Flagabro locality
  - Unit less than 1 m thick, slight increase, subsequent decrease in grain size
  - White = carbonate, black = shale (mudstone)
- Important – shales intercalated into carbonates




Egenhoff & Maletz, submitted

# Bjørkåsholmen Formation

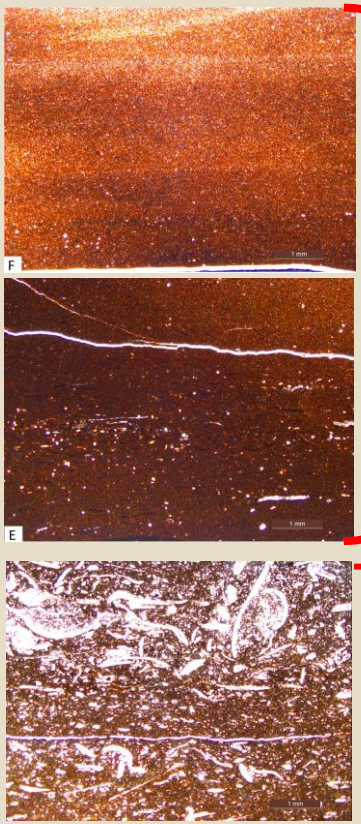
## Ordovician Baltica

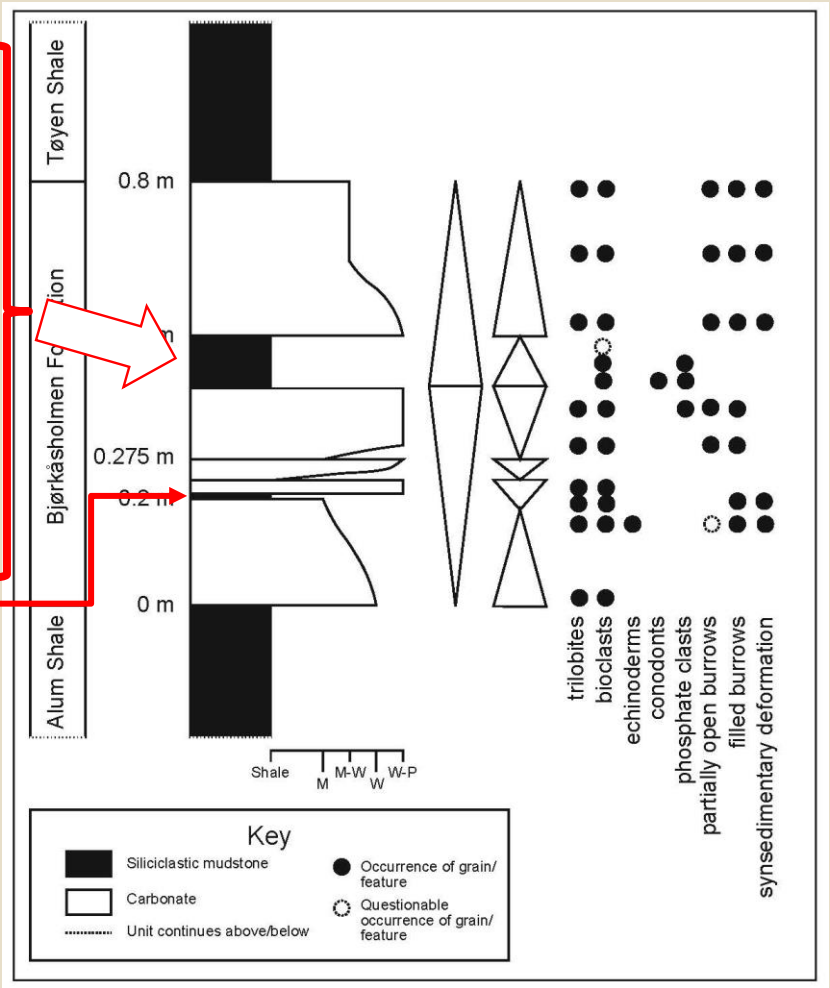


- Shales: 2 units
  - Lower unit – shells, accumulated in lags
  - Upper unit – shell lags, shales laminated; many graded

→ Turbulent waning flows

→Deposited during events (laminations!)





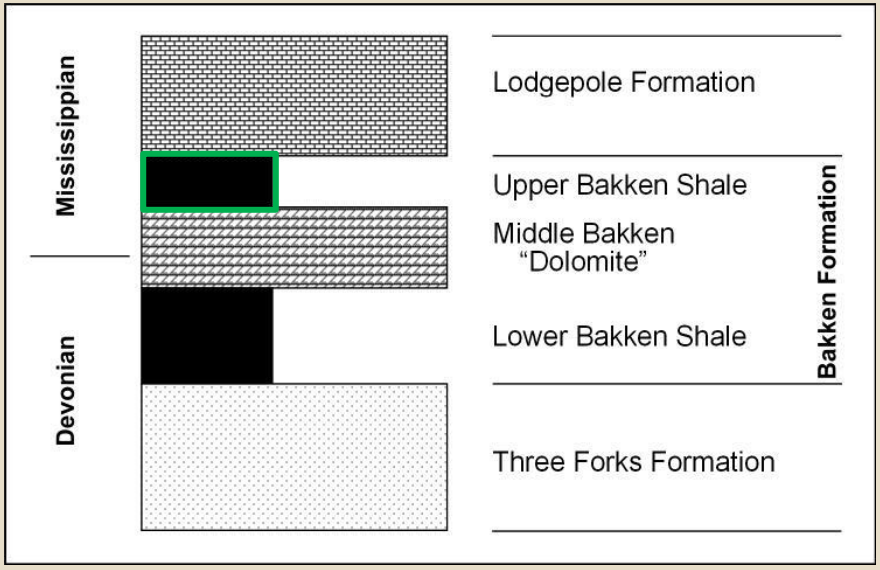

Egenhoff & Maletz, submitted

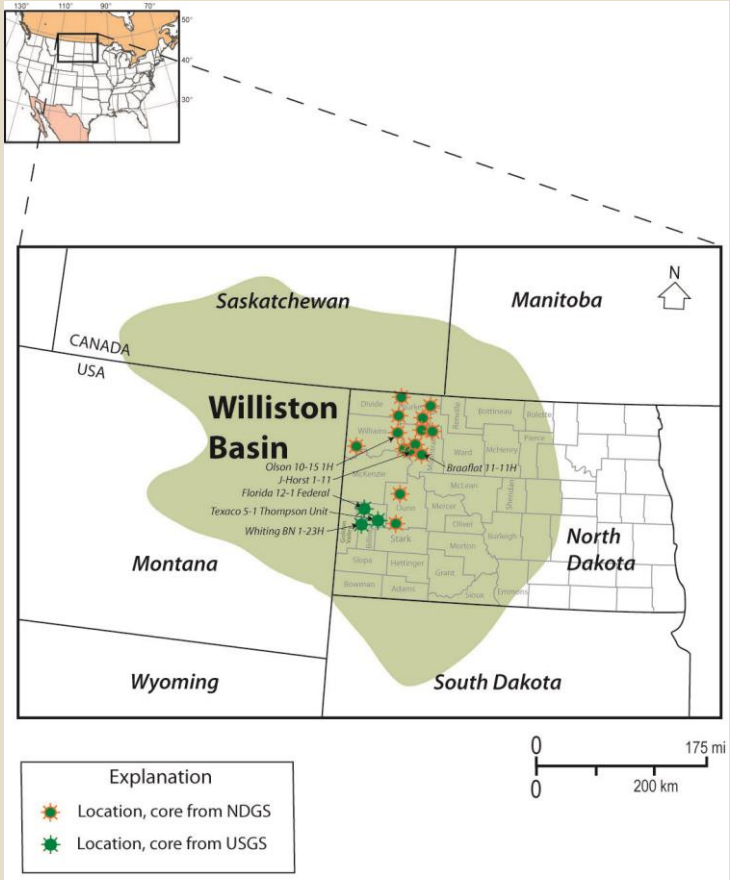
# Discussion

## Upper Bakken Formation, North Dakota, USA



- Shale deposition
  - In both examples, Ordovician and Mississippian – deposition of shales not from suspension, but events
  - Is that common in the rock record?



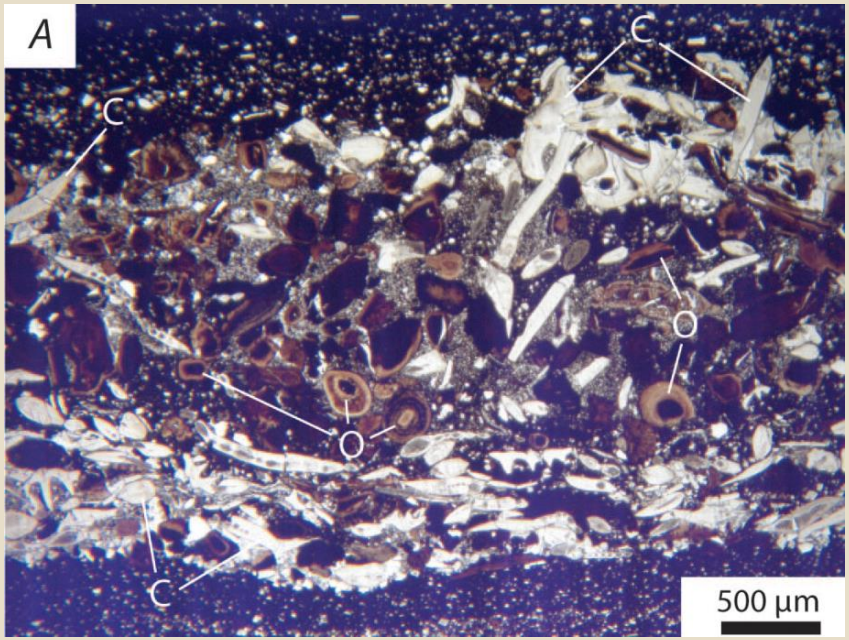

Egenhoff & Fishman 2013, JSR

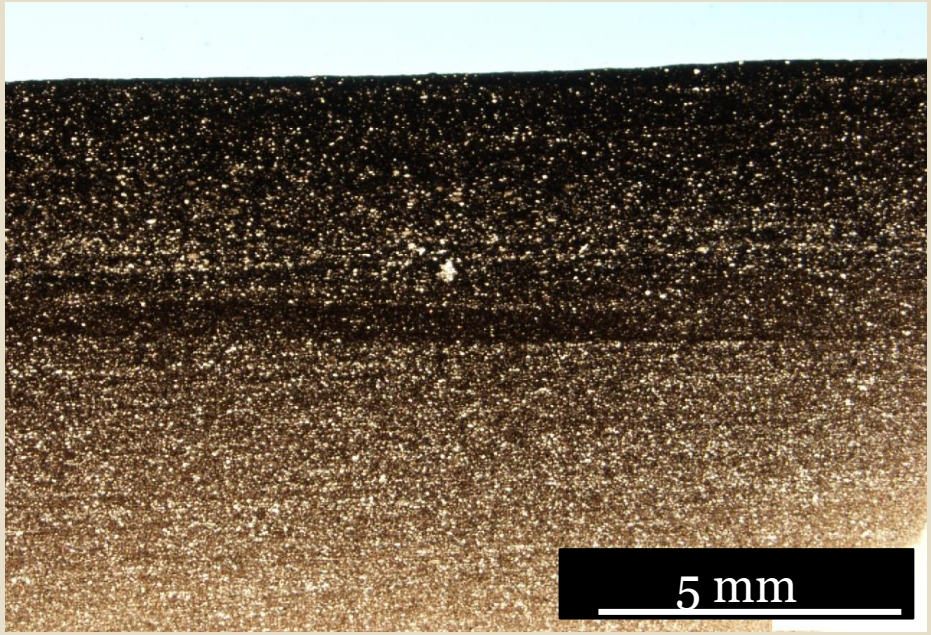
Figure 1

# Discussion

## Upper Bakken Formation, North Dakota, USA






Egenhoff & Fishman 2013, JSR

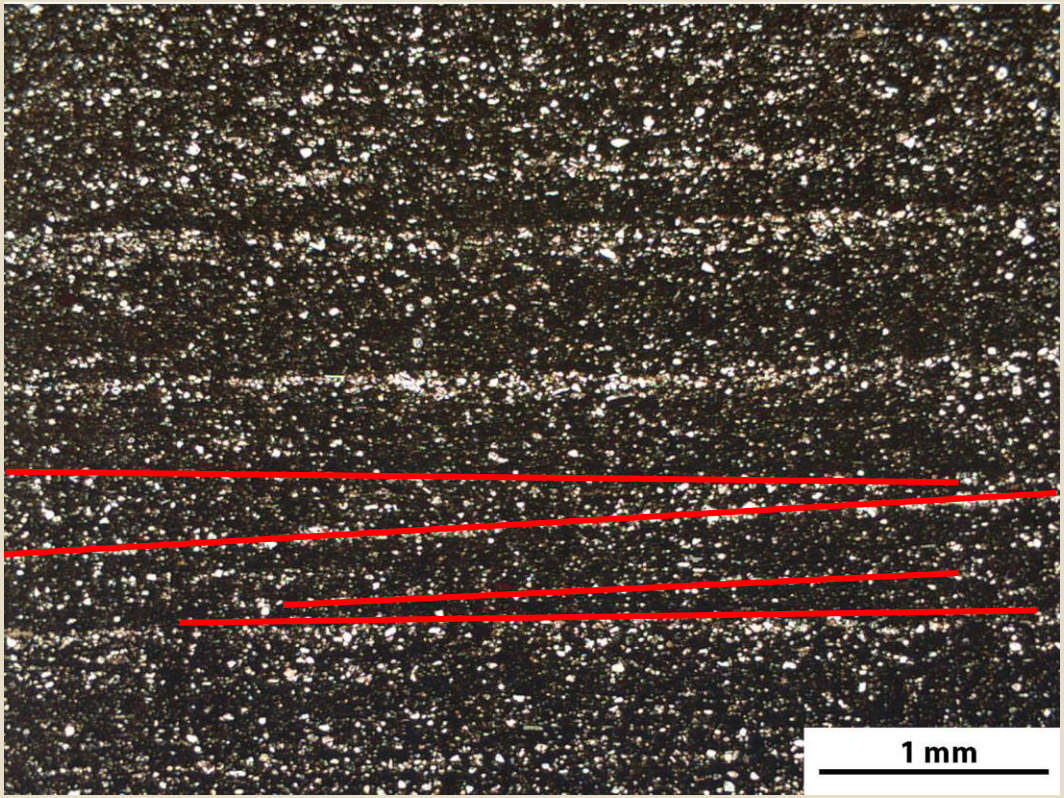
- Obvious event deposition – lags
- Obvious event deposition - ripples

# Discussion

## Upper Bakken Formation, North Dakota, USA



- Bulk of the rocks – described as structureless
- But despite bioturbation – look at geometries!




Egenhoff & Fishman 2013, JSR

# Conclusions



1. Woodford Shale and Bjørkåsholmen Formation → shales laminated; Woodford – cherts with mudstone laminae
2. Laminae → deposition of shales not from suspension but episodically during events
3. Other units (upper Bakken) also show laminations – also likely common event deposition