Preliminary report on the Oldenburg "butter shale" in the Upper Ordovician (Katian; Richmondian) Waynesville Formation, USA

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Abstract. The Cincinnatian Series (Upper Ordovician; upper Katian) of the Cincinnati Arch region, Ohio, Indiana and Kentucky) contains several bed packages informally referred to as "butter shales" or "trilobite shales". These packages are typically 1–2 m of relatively pure, homogeneous claystone with isolated, lenticular limestone beds. These claystones are most widely known for their excellent preservation of abundant trilobites, especially *Isotelus* and *Flexicalymene*, as well as diverse and commonly articulated bivalves, and nautiloids. A newly recognized butter shale interval in the Clarksville Member of the Waynesville Formation contains a typical butter-shale fossil assemblage, dominated by bivalves, orthoconic cephalopods and trilobites. To better study the fabric of this claystone, a large, epoxy-coated block of the claystone was dry-cut. Polished surfaces show a variety of otherwise cryptic features, including pervasive bioturbation and the presence of probable lingulid escape burrows (*Lingulichnus*), as well as abundant fodinichnia (*Chondrites*, *Planolites*, *Teichichnus*). Preservation of articulated trilobites and closed bivalves in approximate living position, as well as escape burrows, indicates deposition as a series of mud burial events or obrution deposits. We suggest that the butter shales resulted from net accumulation of multiple episodes of re-suspended mud deposition, which rapidly smothered organisms and resulted in exceptional preservation. Between events the seafloor was colonized by abundant deposit-feeding infaunal organisms, which destabilized the substrate and generated turbidity near the sediment–water interface, thus inhibiting sessile suspension feeders. Rapid net deposition was also interrupted by more prolonged periods (tens to hundreds of years) of low sedimentation that permitted colonization by epifaunal brachiopod-dominated communities. While most butter shale units are regionally extensive, the Oldenburg is confined to a few outcrops, apparently because it has been removed in most areas beneath a subtle but significant disconformity.

Key words: Cincinnatian, trilobites, *Teichichnus*, Lagerstätten, *Chondrites*, mudstone, claystone.

INTRODUCTION

In the outcrop area of the Upper Ordovician, Cincinnatian of Kentucky, Indiana and Ohio, the term "butter shale" is used to describe clay-rich shale Lagerstätten noted for excellent preservation of trilobite and molluscan body fossils. Fresh outcrops are blue-green in color and disaggregate when weathered to a pale yellowish-brown mud. Some of these butter shales, generally less than 2 m thick, have been traced for over 100 km laterally (Frey 1987b). There are over a dozen butter shale horizons in the Cincinnati Ordovician, and half of these occur in the Waynesville Formation (Richmondian), a 30 m succession of siliciclastic mudstones alternating with bundles of skeletal pack- and grainstone. We recognized a new unit, the Oldenburg shale submember from the middle portion of the Waynesville Formation near Oldenburg, Indiana (Fig. 1). The Oldenburg shale occupies the highest stratigraphic position in the Clarksville Member of the Waynesville Formation. In contrast to most other "butter shales", which are widely traceable, the Oldenburg appears to be restricted to an area of just a few tens of square kilometers in southeastern Indiana, probably owing to its removal in most other areas at a significant and previously unrecognized disconformity (Fig. 1) (Aucoin et al. 2014).

GEOLOGIC SETTING

At the time of deposition, the present-day Ohio, Kentucky and Indiana Tristate region of Laurentia was covered by a shallow epicontinental sea. The basin exhibited a shallowly dipping ramp, which deepened in a modern northerly direction. Paleogeographically, the

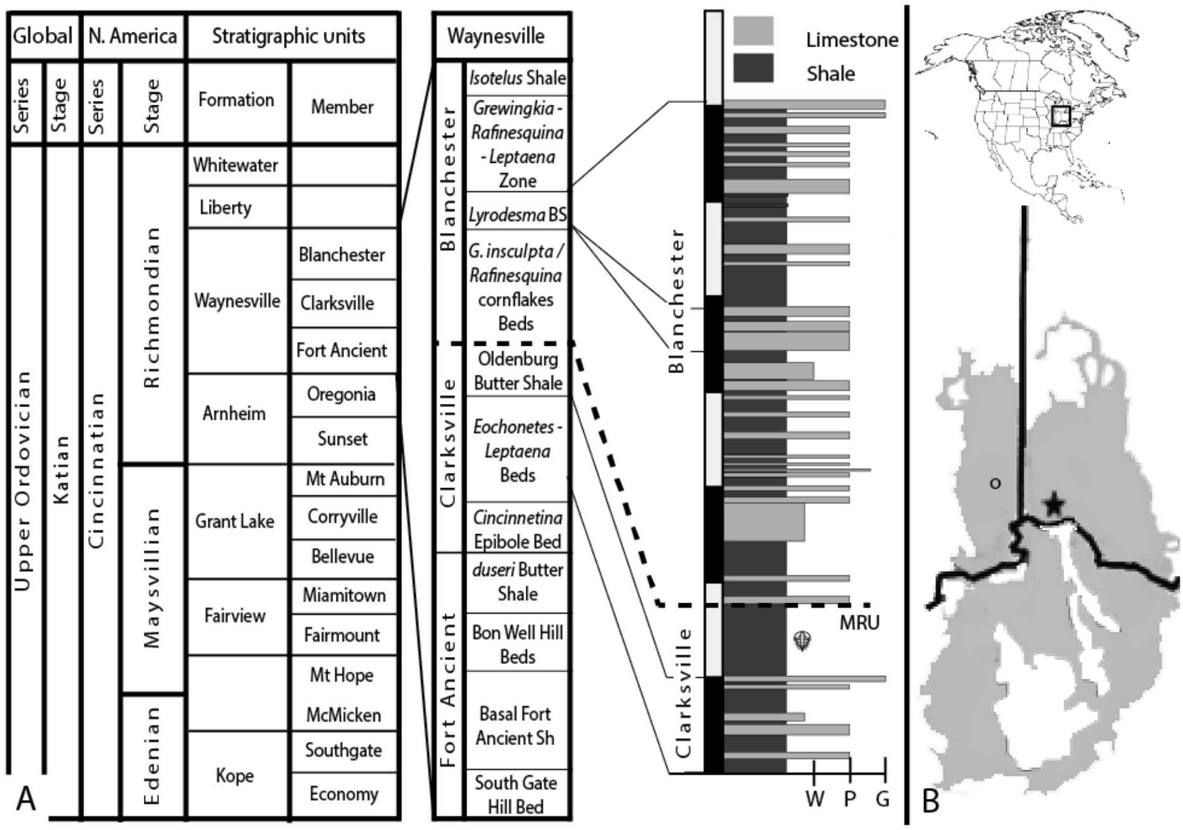

Fig. 1. A, generalized stratigraphic column of the Cincinnatian with a focus on the Waynesville Formation exposed near Oldenburg, Indiana. The dashed line indicates the location of the Mid-Richmondian Unconformity (MRU) in the section. The trilobite indicates the location of the Oldenburg butter shale (BS). The scale bar is in meters. **B**, map of the Ohio–Kentucky–Indiana tri-state with the Cincinnatian rocks marked in gray. The star represents Cincinnati and the "o" indicates the approximate location of Oldenburg, Indiana. W = wackestone, P = packstone, G = grainstone.

basin was located near 20° S paleolatitude and rotated clockwise about 45° from its current orientation (Holland 1993; Brett & Algeo 1999; Holland & Patzkowsky 2007; Jin et al. 2013). Sediments included terrigenous clays and silts, derived from the uplifted Taconic Orogen to the east-southeast, and autogenic skeletal carbonates, mostly bryozoan zoaria, brachiopod shells and crinoid ossicles.

METHODS

The Oldenburg butter shale was measured and sampled in natural exposures along the Harvey's Branch stream bed and in a shale pit situated on private property just north of Oldenburg, IN. About 5 m of the section is exposed in a small quarry excavated by D. Cooper and 2 m of beds below the floor of the pit are exposed in a nearby stream bank. The trilobite- and bivalve-bearing interval lies in the lowest 30 cm of the quarried section.

To study the micro-sedimentary features and fabric of this butter shale, a block of the fresh claystone measuring 25 cm × 25 cm × 30 cm was removed with a portable concrete saw. Each side of the block was allowed to dry and coated with EnviroTex Lite, High Gloss resin to fill the cracks and stabilize the block. Then an additional layer of fiberglass-reinforced resin was added all around for further support. The block was then sectioned without water, using a Hillquist 24 inch slab saw, into a series of vertical and horizontal slabs approximately 1.5 cm thick.

TEXTURES AND STRUCTURES

In outcrop, the shale appears to be homogeneous massive claystone; it breaks conchoidally and displays no obvious bedding. A vertically sliced and polished slab of the shale (Fig. 2) shows three major depositional units, each heavily bioturbated by *Chondrites* and

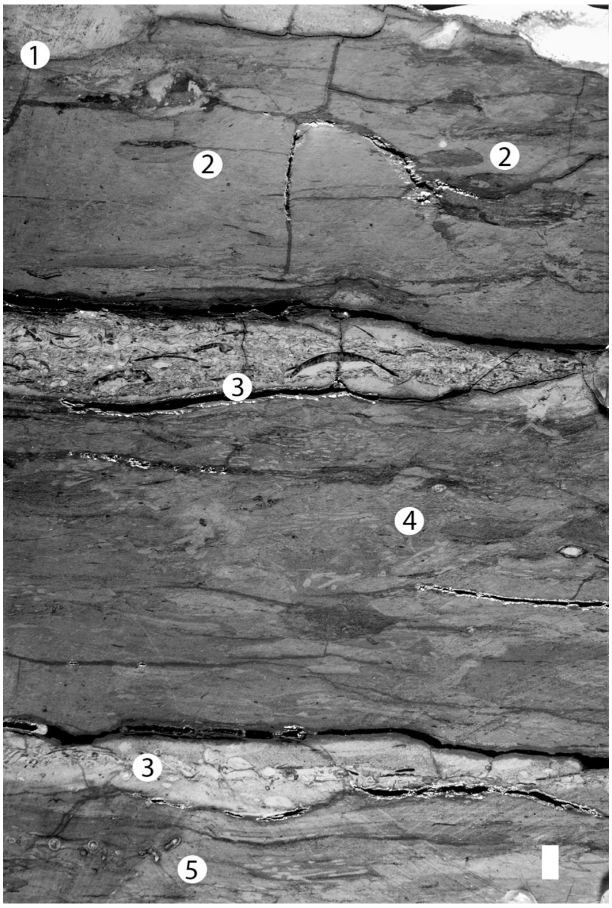

Fig. 2. Photograph of the sliced butter shale block. 1, Concretions; 2, *Teichichnus*; 3, limestone lenses; 4, *Chondrites* zone; 5, in situ bryozoan colony. The scale bar is 1 cm.

Teichichnus. *Chondrites* has been previously reported from other butter shales (Brandt Velbel 1984; Gaines et al. 1999; Hughes & Cooper 1999; Hunda et al. 2006).

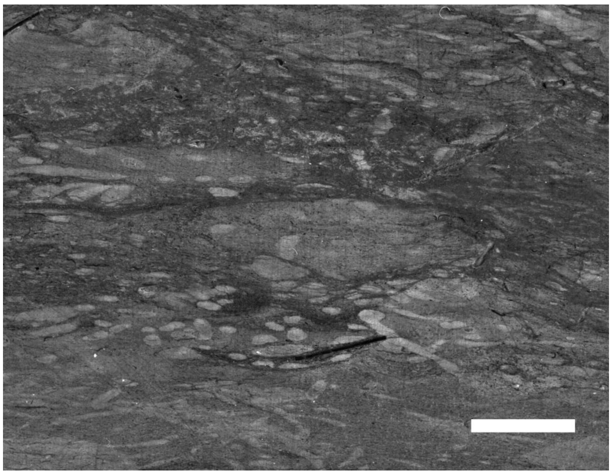

Fig. 3. Enlarged image from the middle of the shale showing a concentration of *Chondrites* traces. Note that some have been compacted vertically. The scale bar is 1 cm.

Many of the *Chondrites* traces show vertical compression indicating some compaction of the mud during lithification (Fig. 3). Preliminary height and width measurements of perpendicular cross sections through *Chondrites* tunnels provide an average compaction ratio of 2.3, which suggests a substrate water content of about 20–30% (Rhoads 1970; Crimes 1975; Lobza & Schieber 1999). The shale units are bounded by two laterally-discontinuous lenses of wackestone to grainstone, which reach a maximum thickness of 3 cm. These thin lenses contain abundant brachiopods, gastropods and bryozoans and are typically overlooked in outcrop because they are laterally discontinuous. Towards the top of the shale is a horizon of spherical to ovoid concretionary nodules that reach a maximum thickness of 3 cm. Siltstone fills of small gutters within the shale show hummocky stratification interrupted by *Lingulichnus* traces (Fig. 4).

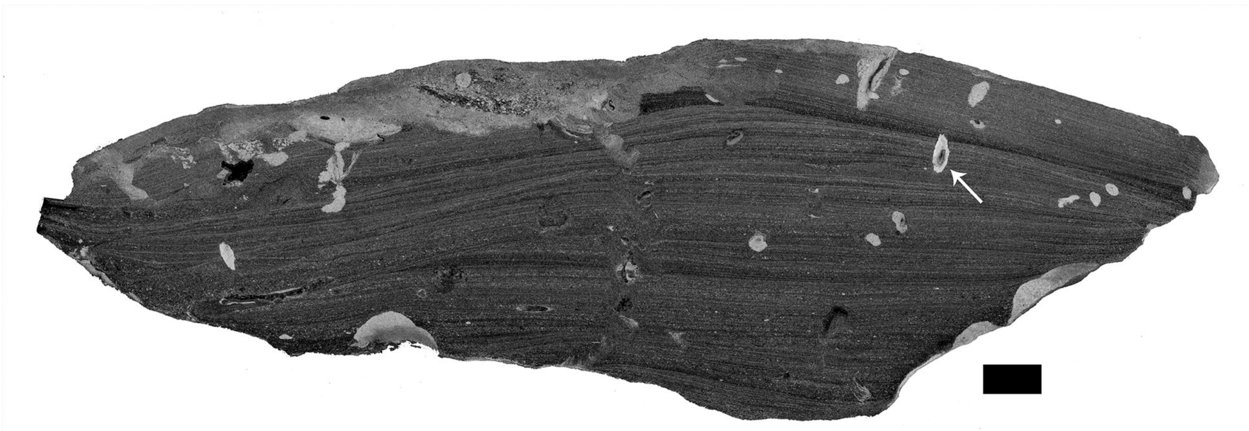

Fig. 4. Polished section of a gutter cast found within the trilobite-bearing shale unit. The image clearly shows the strong hummocky stratification. The white arrow indicates *Lingulichnus* escape traces. The scale bar is 1 cm.

PALEONTOLOGY

The Oldenburg butter shale contains a relatively low-diversity assemblage dominated by mollusks and trilobites. The most common, frequently articulated trilobites found in the butter shale are *Flexicalymene* and *Isotelus*, including many large specimens (5–30 cm) of *Isotelus*. Among more than 200 articulated *Flexicalymene*, approximately 20% are prone, 20% are fully enrolled and the rest are partially enrolled. The rare trilobite *Amphilichas* has also been collected. Among the bivalves, the semi-infaunal *Modiolopsis* (Pojeta 1971; Frey 1987a) dominates, while *Ambonychia* and *Caritodens* are also common. Bivalves are commonly articulated and typically preserved as composited external and internal molds (Pojeta 1971) coated by a black film, presumably the remains of periostracum. Calcitic brachiopods are relatively rare and represented mostly by *Zygospira* and *Platystrophia clarksvillensis*. Lingulid brachiopods are more common and usually preserved in approximate life position, vertical to bedding. The shale also contains bryozoans, orthoconic cephalopods, rare crinoids and conulariids.

DISCUSSION

A number of studies conducted on Cincinnatian butter shales have focused on trilobites and bivalves (Frey 1987a, 1987b; Schumacher & Shrake 1996; Hunda et al. 2006); however, only a few have addressed micro-stratigraphy and claystone fabrics (Brandt Velbel 1984; Hughes & Cooper 1999; Hunda et al. 2006) and none have addressed the Oldenburg shale.

Although other studies have reported *Chondrites* in the shales, traces have been typically regarded as rare (Brandt Velbel 1984; Schumacher & Shrake 1996; Hughes & Cooper 1999; Hunda et al. 2006). Study of polished slabs of additional intervals may reveal that ichnofossils are more abundant than previously reported in most or all butter shales. Given the articulated condition of many trilobites and the uniform, massive appearance of the mudstone, this seems counter intuitive. In fact, the pervasive bioturbation may not only help to give the butter shale its soft, seemingly homogeneous consistency, but also help to explain the unusual faunas of these beds as a result of trophic group amensalism, i.e. activities of bioturbating organisms rendering the seafloor environment less hospitable to many sedentary suspension feeders.

The fauna of the Oldenburg shale is similar to that seen in other butter shales and is deficient in brachiopods as compared to associated Cincinnatian limestones and more calcareous, shelly shales. The dominance of mobile scavengers and predators, as well as semi-infaunal bivalves and soft-bodied biota, together with a paucity of brachiopods, suggests unstable mud substrates and/or high turbidity near the sediment–water interface. The presence of well-preserved, articulated trilobites and bivalves, along with hummocky-bedded siltstones with gutter casts, supports the hypothesis that this butter shale, along with others like it, were deposited in a series of rapid burial events, which smothered the benthic fauna (Brandt Velbel 1984; Hunda et al. 2006). The chaotic orientations of trilobites in certain layers suggests that these organisms were entrained in sediment flows. Hence, the trilobite-rich layers probably represent Type II obrution deposits in the classification of Brett et al. (2012), i.e. a series of seafloor-following sediment flows, as opposed to rapid suspension settling. The presence of *Lingulichnus* escape traces indicates that some organisms did extricate themselves from mud burial layers. Hunda et al. (2006) reported seven silt–clay couplets in the Mt Orab butter shale, likely indicating at least seven burial events. Based on individual *Chondrites* horizons, the preserved upper 30 cm of the Oldenburg butter shale in the quarry can be split into approximately eight separate events.

Finally, the presence of abundant bivalves and *Chondrites* data suggests that much of the substrate was soft and plastic. This likely prohibited colonization by the typical Cincinnatian brachiopod fauna. In contrast, the discontinuous lenses of wackestones and grainstones may represent periods of non-deposition, during which localized storm winnowing reworked multiple generations of shelly benthos permitting a firm substrate that favored shelly benthos, including brachiopods and bryozoans.

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REFERENCES

Aucoin, C. D., Brett, C. E. & Dattilo, B. 2014. Evidence for a Mid-Richmondian unconformity in the Upper Ordovician (Katian) strata along the Cincinnati Arch, USA. In *4th Annual Meeting of IGCP 591, Estonia, 10–19 June 2014, Abstracts and Field Guide* (Bauert, H., Hints, O., Meidla, T. & Männik, P., eds), p. 13. University of Tartu, Tartu.

Brandt Velbel, D. 1984. Ichnologic, taphonomic, and sedimentologic clues to the deposition of Cincinnatian Shales (Upper Ordovician) Ohio, USA. In *Biogenic Structures: Their Use in Interpreting Depositional Environment* (Curran, H. A., ed.), pp. 299–307. Society of Economic Paleontologists and Mineralogists Special Publication.

Brett, C. E. & Algeo, T. 1999. Sequence, cycle, and event stratigraphy of Upper Ordovician and Silurian strata of the Cincinnati Arch region. In *Proceedings, Kentucky Geological Survey Guidebook and Road Log for the Great Lakes Section of the Society for Sedimentary Geology and the Kentucky Society of Professional Geologists*, p. 3.

Brett, C. E., Zambito, J. J., Hunda, B. & Schindler, E. 2012. Mid-Paleozoic trilobite Lagerstätten: models of diagenetically enhanced obrution deposits. *PALAIOS*, **27**, 326–345.

Crimes, T. P. 1975. The stratigraphical significance of trace fossils. In *The Study of Trace Fossils: a Synthesis of Principles, Problems, and Procedures in Ichnology* (Frey, R. W., ed.), pp. 109–130. Springer-Verlag, New York.

Frey, R. C. 1987a. The occurrence of pelecypods in Early Paleozoic epeiric-sea environments, Late Ordovician of the Cincinnati, Ohio area. *PALAIOS*, **2**, 3–23.

Frey, R. C. 1987b. The paleoecology of a Late Ordovician shale unit from southwest Ohio and southeastern Indiana. *Journal of Paleontology*, **61**, 242–267.

Gaines, R. R., Droser, M. L. & Hughes, N. C. 1999. The ichnological record in Ordovician mudstones: examples from the Cincinnatian strata of Ohio and Kentucky (USA). *Acta Universitatis Carolinae, Geologica*, 1/2, 163–166.

Holland, S. M. 1993. Sequence stratigraphy of a carbonate-clastic ramp: the Cincinnatian Series (Upper Ordovician) in its type area. *Geological Society of America Bulletin*, **3**, 306–322.

Holland, S. M. & Patzkowsky, M. E. 2007. Gradient ecology of a biotic invasion: biofacies of the type Cincinnatian Series (Upper Ordovician), Cincinnati, Ohio region, USA. *PALAIOS*, **22**, 391–407.

Hughes, N. C. & Cooper, D. L. 1999. Paleobiologic and taphonomic aspects of the "Granulosa" trilobite cluster, Kope Formation (Upper Ordovician, Cincinnati Region). *Journal of Paleontology*, **73**, 306–319.

Hunda, B. R., Hughes, N. C. & Flessa, K. W. 2006. Trilobite taphonomy and temporal resolution in the Mt Orab Shale bed (Upper Ordovician, Ohio, U.S.A.). *PALAIOS*, **21**, 26–45.

Jin, J., Harper, D. A. T., Cocks, L. R. M., McCausland, P. J. A. & Rasmussen, C. M. Ø. 2013. Precisely locating the Ordovician equator in Laurentia. *Geology*, **41**, 107–110.

Lobza, V. & Schieber, J. 1999. Biogenic sedimentary structures produced by worms in soupy, soft muds; observations from the Chattanooga Shale (Upper Devonian) and experiments. *Journal of Sedimentary Research*, **69**, 1041–1049.

Pojeta, J. 1971. Review of Ordovician pelecypods. *Geological Survey Professional Paper*, 695, 1–46, pls 1–20.

Rhoads, D. C. 1970. Mass properties, stability, and ecology of marine muds related to burrowing activity. In *Trace Fossils* (Crimes, T. P. & Harper, J. C., eds), pp. 391–406. Seel House Press, Liverpool.

Schumacher, G. A. & Shrake, D. L. 1996. Paleoecology and comparative taphonomy of an *Isotelus* (trilobite) fossil lagerstätten from the Waynesville formation (Upper Ordovician, Cincinnatian Series) of southwestern Ohio. In *Paleontological Events* (Brett, C. E. & Baird, G. C., eds), pp. 131–161. Columbia University Press, New York.