

A new Early Jurassic (ca. 183 Ma) fossil *Lagerstätte* from Ya Ha Tinda, Alberta, Canada

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ABSTRACT

Lagerstätten—deposits of exceptionally preserved fossils—offer vital insights into evolutionary history. To date, only three *Konservat-Lagerstätten* are known from Early Jurassic marine rocks (Osteno, Posidonia Shale, and Strawberry Bank), all located in Europe. We report a new assemblage of exceptionally preserved fossils from Alberta, Canada, the first marine *Konservat-Lagerstätte* described from the Jurassic of North America. The Ya Ha Tinda assemblage includes articulated vertebrates (fish, ichthyosaurs), crinoids, crustaceans, brachiopods, abundant mollusks (coleoids with soft tissues, ammonites, gastropods, bivalves), wood, and microfossils. Paired bio- and chemostratigraphies show that *Lagerstätte* deposition occurred during the late Pliensbachian through early Toarcian, capturing the carbon isotope excursion associated with the Toarcian Oceanic Anoxic Event. Therefore, the Panthalassan Ya Ha Tinda biota is coeval with Toarcian *Lagerstätten* from the Tethys Ocean (Posidonia Shale and Strawberry Bank). Comparisons among these deposits permit new insights into the diversity, ecology, and biogeography of Jurassic marine communities during a time of pronounced biological and environmental change (e.g., expanded subsurface anoxia, warming, and extinctions). They also highlight the possibility that Mesozoic Oceanic Anoxic Events are temporal foci of exceptional preservation.

INTRODUCTION

During the Early Jurassic there were several major environmental and ecological perturbations that influenced Mesozoic evolution, notably the Toarcian Oceanic Anoxic Event (T-OAE). The T-OAE is associated with benthic and pelagic extinctions including ammonites, fish, foraminifers, radiolarians, corals, bivalves, and brachiopods (e.g., Little and Benton, 1995; Lathuilière and Marchal, 2009; Caruthers et al., 2014; Caswell and Coe, 2014; Danise et al., 2015). Compelling as this record may be, it is biased; unbiomineralized organisms are rarely preserved, yet represent the majority of marine biodiversity (e.g., Schopf, 1978; Morris, 1986). While unusual environmental circumstances allow for preservation of soft tissues and provide a more complete perspective on evolutionary history in *Konservat-Lagerstätten* (Seilacher, 1970; Briggs, 2003), only two occur within the T-OAE: the Posidonia Shale (primarily) in Germany (e.g., Seilacher, 1990) and the British Strawberry Bank *Lagerstätte* (Williams et al., 2015).

Here we describe a new Early Jurassic (Pliensbachian–Toarcian) *Lagerstätte* from Alberta, Canada: the Ya Ha Tinda assemblage (Fig. 1). This deposit is significant as both the first marine *Konservat-Lagerstätte* described from the Jurassic of North America and the first described Pliensbachian–Toarcian *Lagerstätte* outside of Europe.

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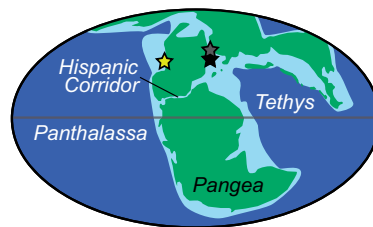


Figure 1. Global paleogeography during Toarcian and location of Ya Ha Tinda (Alberta, Canada; yellow star), Strawberry Bank (UK; gray star), and Posidonia Shale (Germany; black star) *Lagerstätten*. Green areas are landmasses, light-blue areas are shallow seas, and dark blue represents open oceans.

METHODS

Exposures of the Fernie Formation at the Ya Ha Tinda Ranch (southwest Alberta) were measured and described in centimeter-scale detail; exact localities cannot be disclosed. Intervals with exceptional preservation (e.g., Fig. 2) were quarried and specimens prepared for study (reposited at the Royal Tyrrell Museum of Palaeontology, Canada); see the GSA Data Repository¹ for extraction, preparation, and analytical techniques.

RESULTS

Ya Ha Tinda Biota

At Ya Ha Tinda, exceptionally preserved fossils can be found in both the Red Deer and Poker Chip Shale members of the Fernie Formation (Fig. 2). Platy calcareous shales interbedded with fine siltstones and black limestones compose the late Pliensbachian–early Toarcian Red Deer Member, whereas the Toarcian Poker Chip Shale is composed of poorly cemented, black calcareous shales and mudstones interbedded locally with bituminous limestones (Fig. 2; Them et al., 2017). Ages of these units are constrained by ammonite and coccolith biostratigraphy, carbon isotope chemostratigraphy, and U-Pb zircon dates from intercalated ash beds in outcrops at Ya Ha Tinda Ranch (Hall et al., 2004; Them et al., 2017). Well-preserved specimens have previously been collected, mostly from float (Hall, 1985, 1991; Feldmann and Copeland, 1988), but the full scope of preservation (i.e., soft tissue preservation at multiple horizons) and fossil abundance has only recently become apparent. The preservation of cuticle (arthropod carapaces) and soft tissue (coleoid ink sacs and mantle muscle tissue) (Fig. 3) marks this deposit as a *Konservat-Lagerstätte*.

Coleoid cephalopods, specifically Vampyropoda (eight-armed, gladius-bearing coleoids), exhibit the most exceptional preservation. Vampyropod specimens (Figs. 3D–3E) include isolated gladii (chitinous internal shell), gladii and ink sacs, and gladii with mantle muscle and ink sacs. Chitinous

¹GSA Data Repository item 2017066, sample excavation, preparation, and analytical methods, lithological description, and additional fossil images, is available online at www.geosociety.org/datarepository/2017 or on request from editing@geosociety.org.

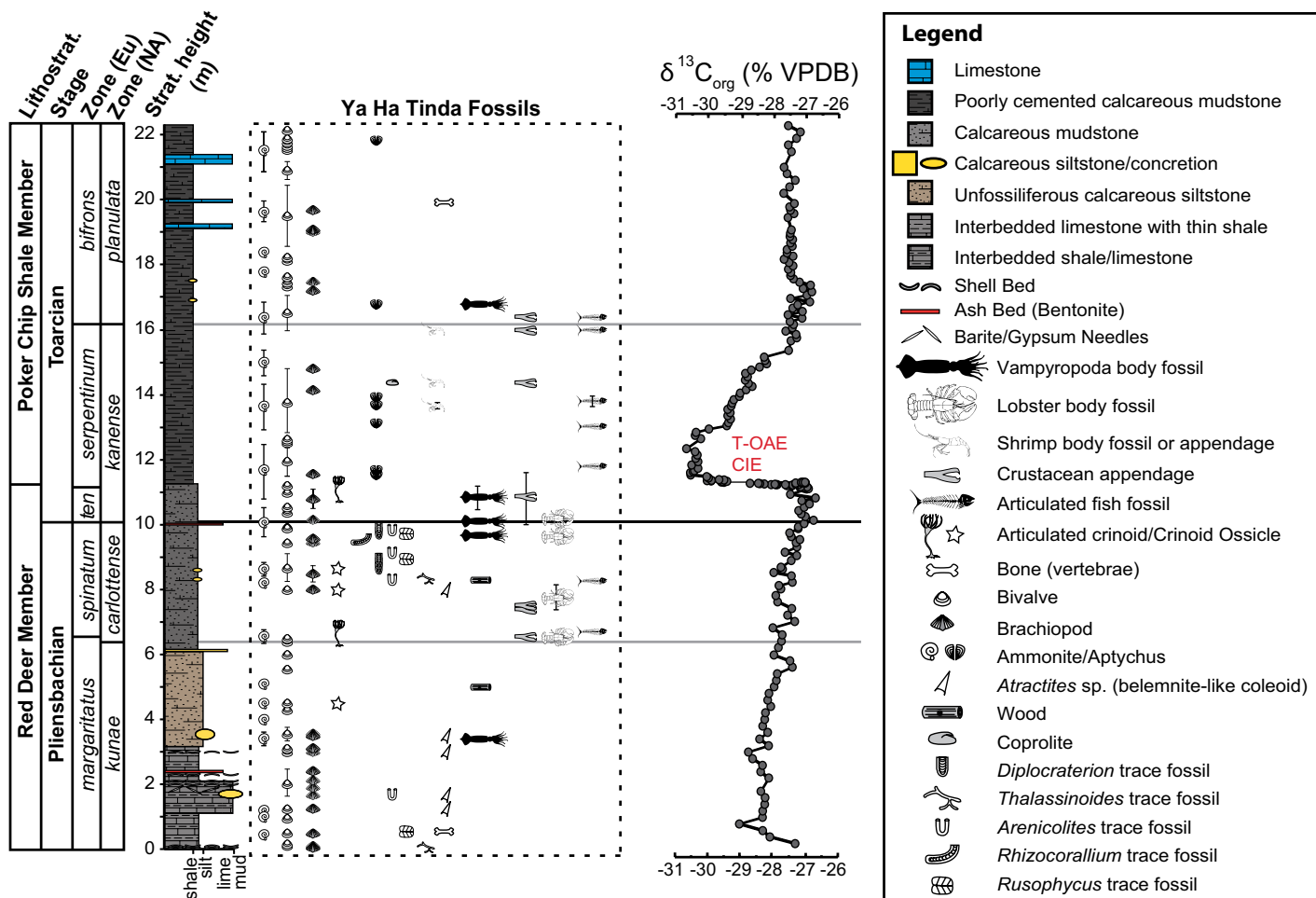


Figure 2. Stratigraphic column of East Tributary of Bighorn Creek section (Ferne Formation, Ya Ha Tinda, Alberta, Canada) with fossil occurrences (Royal Tyrrell Museum of Palaeontology locality L2428). Chemostratigraphic and biostratigraphic data are modified from Them et al. (2017). Lithostrat.—lithostratigraphy; Strat. height—stratigraphic height in section; Zone (Eu)—northwestern Europe ammonite zonation; Zone (NA)—western North America ammonite zonation; *ten.*—*tenuicostatum*; *org*—organic; VPDB—Vienna Pee Dee belemnite; T-OAE CIE—Toarcian Oceanic Anoxic Event carbon isotope excursion.

tissues typically preserve relatively well (Kear et al., 1995); ink sac preservation is less easily accounted for, but may relate to the abundance of decay-resistant melanin in this organ (Glass et al., 2012) and clay mineral authigenesis. Recent excavations have uncovered fifteen specimens of vampyropods (Figs. 2 and 3; mostly loligosepiids and prototeuthids), making this the largest known deposit of Jurassic vampyropods outside of Europe.

Crustacean preservation at Ya Ha Tinda is excellent. Specimens include compressions of appendages and fully or partially articulated carcasses (Figs. 3F–3H). Full lobster carapaces have only been found below the T-OAE carbon isotope excursion (CIE), whereas appendages occur throughout the studied interval. Ya Ha Tinda crustaceans include a shrimp (Fig. 3F) as well as lobsters such as *Uncina ollerenshawii* (Feldmann and Copeland, 1988; Schweigert et al., 2003), the first complete specimen of *Uncina pacifica* (appendages from this site described by Schweigert et al. [2003]; Fig. 3G), a new *Uncina* species, and an undetermined eryonid lobster with thin, scissor-like claws (Fig. 3H).

Other fossils include articulated vertebrates, the most abundant of which are leptolepiform and saurichthyiform fish (Fig. 3B). Ichthyosaurs and fish also occur as lone vertebrae, vertebral columns (Fig. 3A), and articulated skeletons with skulls (Hall et al., 1998). Important invertebrate finds include articulated crinoid stems up to 1.75 m long (*Seirocrinus* sp.) and a *Seirocrinus subangularis* calyx (Hall, 1991) (Fig. 3C), as well as numerous *Atractites* sp. (an aulacocerid coleoid), several preserved with soft tissues. Ammonites are abundant and occasionally occur with

ptychi. Additional fossils include a dinosaur bone, brachiopods, gastropods, bivalves, wood, and coccolithophores (Hall, 1991; Hall et al., 1998). Ya Ha Tinda bivalves are abundant and taxonomically similar to those from Europe (e.g., Röhl et al., 2001). Compressions of transported logs have been found, but no crinoids or bivalves have been attached to them.

Paleoenvironment and Preservation

Soft tissue preservation has been identified at three different Ya Ha Tinda Ranch outcrops, but the best in situ material occurs in beds exposed along a tributary of Bighorn Creek (herein called East Tributary). The *Lagerstätte* interval (Fig. 2) occurs from the North American *kunae* ammonite zone of the late Pliensbachian (Red Deer Member) to the *planulata* zone of the middle Toarcian (Poker Chip Shale Member) (Them et al., 2017). This interval corresponds to the *margaritatus* through *bifrons* European zones (Pálffy and Smith, 2000) and contains the T-OAE CIE (Them et al., 2017).

Previous studies on the Red Deer and Poker Chip Shale members have suggested that deposition occurred on a gently sloping shelf to basin and that the water column was recurrently to persistently dysoxic to anoxic (Stronach, 1984; Hall, 1985, 1991; Hall and Neuman, 1989; Ross and Bustin, 2006), which accounts for the high organic carbon content (0.3–7.6 wt%; total organic carbon [carbonate-free] is 2.0–35.5 wt% [Them et al., 2017]) and lack of skeletal disarticulation (scavenging) throughout the East Tributary section. Still, in Pliensbachian strata, the presence of macroscopic bioturbation, benthic fauna, and large bivalves and brachiopods

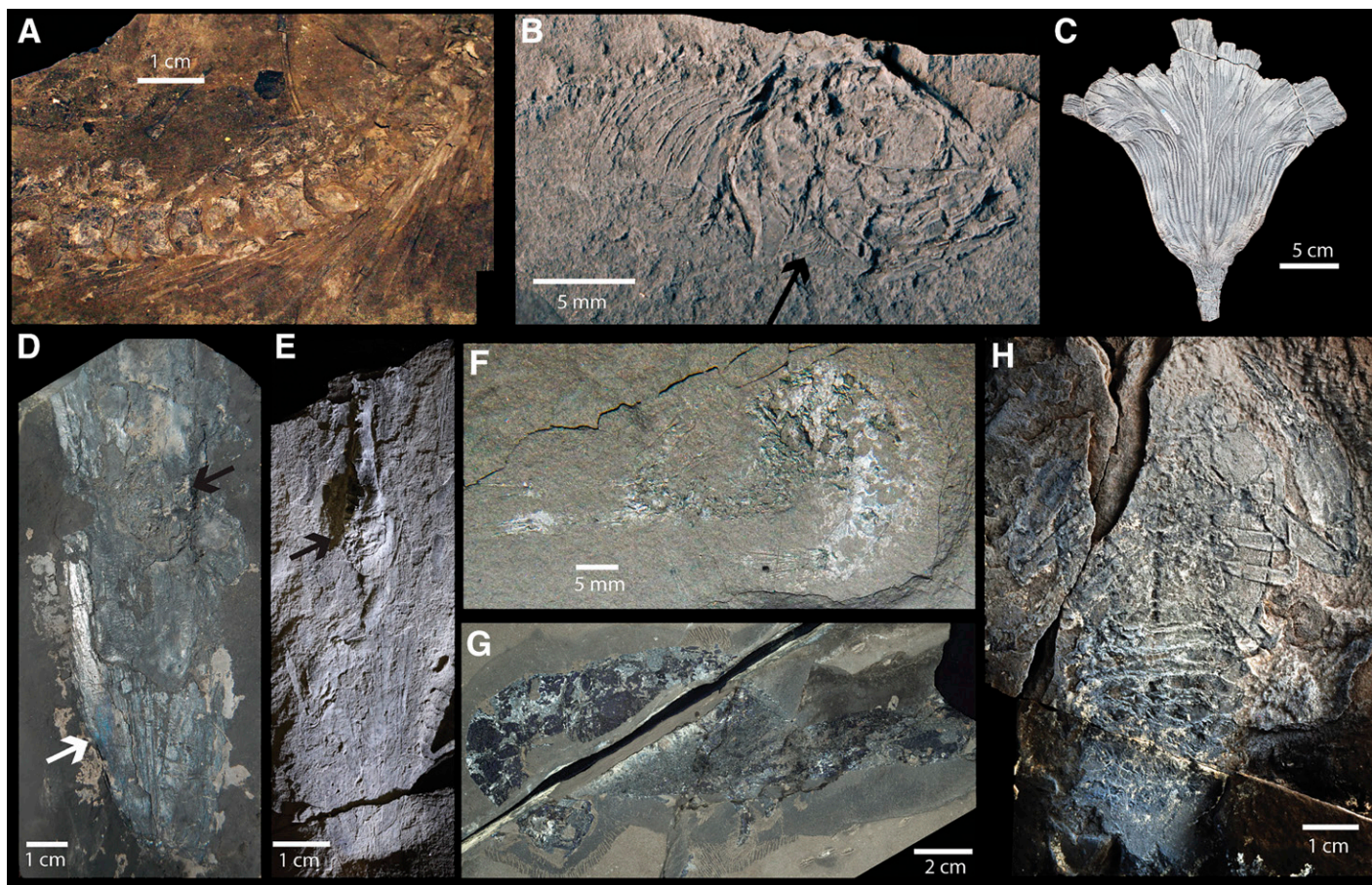


Figure 3. Exceptionally preserved fossils of Ya Ha Tinda Lagerstätte (Alberta, Canada; specimen numbers are provided in Data Repository [see footnote 1]). RDM—Red Deer Member; PCS—Poker Chip Shale Member. **A:** Articulated ichthysaur vertebrae and ribs (RDM, late Pliensbachian). **B:** Skull of small teleost fish (PCS, within Toarcian Oceanic Anoxic Event [T-OAE] carbon isotope excursion [CIE]); note preservation of gills (arrow). **C:** *Seirocrinus subangularis* (crinoid) calyx collected by Russell Hall (RDM, late Pliensbachian). **D:** Vampyropod gladius with mantle muscle (white arrow) and ink sac (black arrow) (RDM, early Toarcian). **E:** Loligosepiid vampyropod gladius with ink sac (arrow) (RDM, early Toarcian). **F:** Shrimp body fossil (PCS, within T-OAE CIE). **G:** Complete body fossil of *Uncina pacifica* lobster, proximodistally flattened (RDM, late Pliensbachian). **H:** Complete body fossil of erylionid lobster, dorsoventrally flattened, ventral view (RDM, late Pliensbachian).

suggests persistent, multi-annual episodes of oxygenation. At the onset of the T-OAE CIE, benthic fauna experienced a major turnover and diminution in size, bioturbation ceased, and benthic colonization events became ephemeral, while nektonic fauna persisted. These data collectively suggest a role for dysoxic or anoxic bottom waters during the T-OAE in controlling soft tissue preservation, faunal distribution, and diversity.

Exceptional preservation occurs in multiple horizons, but the best soft tissue preservation occurs just below the T-OAE CIE (Fig. 2). Fossilized tissues contain high levels of carbon, calcium, phosphorus, and sulfur when compared with surrounding matrix, suggesting preservation as carbonaceous compressions and mineral replacements (apatite and occasionally clay minerals). Rarely, bivalve shells exhibit pyritization, but typically remain calcified. All soft tissues (ink sacs being the exception) occur as two-dimensional compressions (Fig. 3); only calcified hard parts (e.g., proostracum, crinoid ossicles, bones) are preserved in three dimensions. These observations imply that mineralization occurred after tissue collapse (Briggs and Kear, 1993). Carbonization and phosphatization appear to have been the primary taphonomic pathways, and unlike in the Posidonia Shale, pyritization is rare.

DISCUSSION AND CONCLUSIONS

The Ya Ha Tinda Lagerstätte is contemporaneous with the Posidonia Shale and Strawberry Bank Lagerstätten; all three span the *tenuicostatum* and *bifrons* zones of the early Toarcian (Jenkyns, 1988; Etter and Tang,

2002; Williams et al., 2015; Them et al., 2017). Significantly more material has been discovered at European Lagerstätten, but Ya Ha Tinda is exceptionally productive and may in time rival these deposits. Additionally, at Ya Ha Tinda, soft tissue preservation occurs through a more expanded interval, which includes the late Pliensbachian. Importantly, these contemporaneous Lagerstätten collectively allow for direct comparisons of Early Jurassic biodiversity, environments, ecology, and fossilization between northeastern Panthalassa and the Tethys Ocean.

Despite the paleogeographic separation of the Toarcian Lagerstätten (Fig. 1), their faunas are similar. Each contains ichthyosaurs, ray-finned fishes, gladius-bearing coleoids, crustaceans, ammonites, bivalves, and crinoids. In many cases, families or genera are the same or sister taxa, but species vary by ocean basin. Lobsters exemplify this: Ya Ha Tinda uncinid lobsters, *U. pacifica*, *U. ollerenshawii*, and *Uncina* sp. 1, are unique to Panthalassa, whereas *Uncina posidoniae* and *Uncina alpina* only occur in Europe (Schweigert et al., 2003). This strong faunal link between deposits suggests similar ecosystems and connections between basins (e.g., the Hispanic corridor; Fig. 1). Furthermore, the T-OAE biotic turnover is present at Ya Ha Tinda, confirming the global nature of this crisis (e.g., Little and Benton, 1995; Caruthers et al., 2014).

In terms of depositional environment and taphonomic processes, Ya Ha Tinda and the Posidonia Shale appear to be the most similar. The host lithology of both is bituminous shales intercalated with limestones, and episodic bottom-water anoxia has been invoked for both to explain

exceptional preservation (Seilacher, 1982; Röhl et al., 2001; this study, and references therein). In both *Lagerstätten*, specimens are flattened and tissues preserved as carbonaceous compressions or through authigenic mineralization (apatite and clay minerals); pyritization and preservation in nodules are more common in the Posidonia Shale. In contrast, Strawberry Bank is interpreted to represent a nearshore, shallow marine environment due to the abundance of insect fossils; additionally, fossils are predominantly preserved as three-dimensional specimens in calcareous nodules or muddy limestones (Williams et al., 2015).

The three Toarcian *Lagerstätten* provide a unique opportunity to study contemporary taphonomic pathways in similar, but geographically separate, ecosystems. Furthermore, the abundance of coeval *Lagerstätten* implies that Mesozoic Oceanic Anoxic Events may be poorly appreciated sources of exceptional fossil deposits. Anoxia has long been known as a necessary environmental control on many preservational pathways, but it alone is insufficient to induce soft tissue preservation (summarized in Briggs, 2003).

The discovery of the Ya Ha Tinda *Lagerstätte* means that we can, for the first time, compare exceptionally preserved Early Jurassic marine faunas from the two major ocean basins (Fig. 1). This rare occurrence will allow for a much more nuanced understanding of global biogeography, taphonomic controls on preservation, and the relationships of Early Jurassic communities between different ocean basins. Importantly, Ya Ha Tinda fossils add to the documentation of a persistent nektonic and pelagic marine community during a time of increased biotic turnover, constraining interpretations of evolution during an interval of global environmental perturbation.

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