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# Jurassic vertebrate bromalites of the western United States in the context of the global record

Adrian P. HUNT[1], Spencer G. LUCAS[2]

**Key words:** bromalite, coprolite, consumulite, evisceralite, Jurassic, Morrison Formation, Sundance Formation, western USA.

**Abstract.** The bromalite record of the western United States is quite limited, especially in contrast to the Triassic and Cretaceous records of the same region. Indeed, there are only a handful of well documented vertebrate bromalites from the Jurassic strata of the western USA, including: (1) coprolites from the nonmarine Early Jurassic Glen Canyon Group; (2) consumulites and evisceralites from the Middle Jurassic Todilto and Sundance formations; and (3) consumulites, putative coprolites and pseudobromalites from the nonmarine Upper Jurassic Morrison Formation. Early Jurassic red beds are notably less fossiliferous than those of the Triassic (*e.g.*, contrast the fossil record of the Chinle and Glen Canyon groups). The Middle Jurassic of the region includes several eolianites and sabkha-like deposits representing environments that preserve few bromalites. The Upper Jurassic Morrison Formation contains abundant vertebrate body fossils and many tracks but very few bromalites in contrast to many broadly similar fluvial deposits of Triassic and Cretaceous age in the same region. The global bromalite record also appears to be depauperate in the Jurassic, with a few exceptions such as marine shales and lithographic limestones in Europe (*e.g.*, Lower Jurassic of England, Upper Jurassic Solnhofen Limestone of Bavaria). This relative lack of a global Jurassic bromalite record may in part be more a result of a lack of collection and study. However, the relative lack of nonmarine bromalites is clearly influenced by high sea levels in the Early Jurassic, a paucity of Middle Jurassic nonmarine vertebrate-bearing units and a lack, or lack of recognition of, bromalites in major Upper Jurassic nonmarine vertebrate faunas (*e.g.*, China, Tanzania, Portugal, *etc*.). In the Western United States there is clearly a need for more detailed examination of known specimens (*e.g.*, putative Morrison coprolites) and a focus on collecting more examples.

## INTRODUCTION

Vertebrate bromalites, notably coprolites, are common in the upper Paleozoic/Triassic and Cretaceous/Paleogene of the western United States (*e.g.*, Hunt, Lucas, 2007, 2013; Suazo *et al.*, 2012; Hunt *et al.*, 2013). However, there are relatively few reports from Jurassic strata. The purpose of this paper is to briefly review the Jurassic bromalites of western North America (Fig. 1) and to compare them with the global Jurassic bromalite record.

## JURASSIC BROMALITES IN THE WESTERN UNITED STATES

### EARLY JURASSIC

### Moenave Formation

**Whitmore Point, Arizona.** The type locality of the Upper Triassic–Lower Jurassic Whitmore Point Member (Rhaetian–Hettangian) of the Moenave Formation is, at Whitmore Point, a south-facing promontory of the Vermillion Cliffs in

[1] Flying Heritage Collection, 3407 109thSt SW, Everett, WA 98204; e-mail: adrianhu@flyingheritage.com
[2] New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104; e-mail: spencer.lucas@state.nm.us

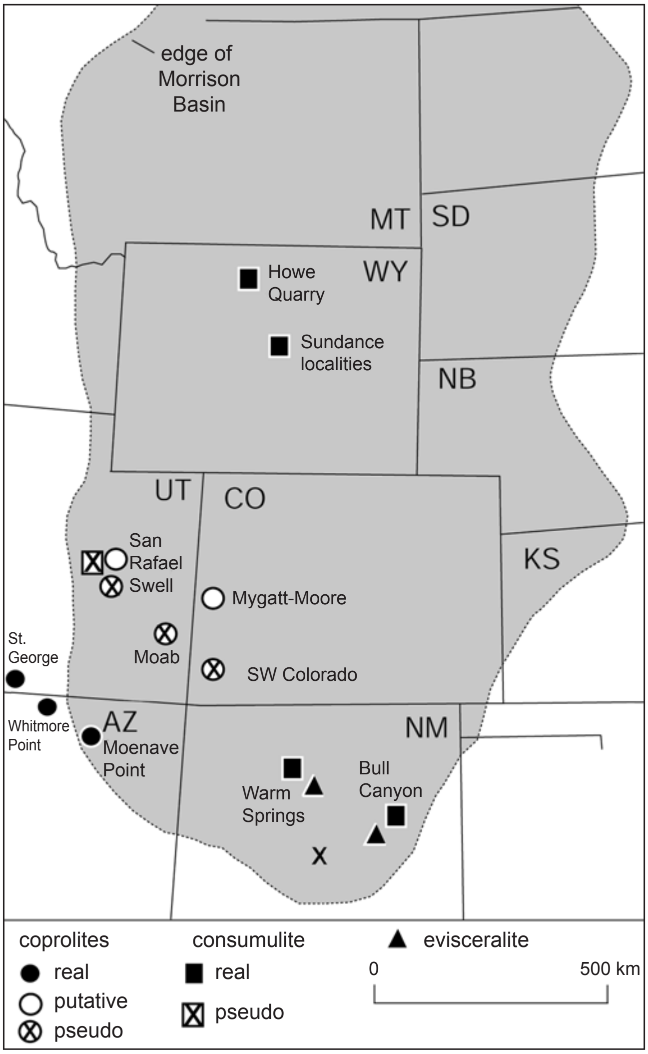


**Fig. 1. Location map for localities of bromalites (coprolites, consumulites, evisceralites) and pseudobromalites (pseudoconsumulites, pseudocoprolites) from the Jurassic of Western North America**

Mohave County, Arizona, where the unit comprises 22 m of fish- and coprolite-bearing shales, siltstones, sandstones, and minor limestones (Wilson, 1967; Tanner, Lucas, 2010; Lucas *et al.*, 2011). At nearby Potter Canyon the unit consists of shale, mudstone and siltstone beds that locally contain conchostracans, fish scales and coprolites (Lucas *et al.*, 2011).

**St. George, Utah.** In the Whitmore Point Member at St. George, Utah, coprolites occur with the rich fossil assemblage that is associated with extensive dinosaur trackways (*e.g.*, Milner, Lockley, 2006; Williams *et al.*, 2006). However, these are now known to occur within the Rhaetian portion of the Whitmore Point Member (Lucas *et al.*, 2011), so we regard them as of latest Triassic, not Jurassic age.

### Kayenta Formation

**Moenave Point, Arizona.** Clark and Fastovsky (1986) noted common coprolites and fish fossils at Moenave Point at a locality about 25 m above the base of the Kayenta Formation (Early Sinemurian), but no further documentation of these records is available.

## MIDDLE JURASSIC

### Todilto Formation

**Bull Canyon, New Mexico.** An extensive fossil fish assemblage occurs in the Luciano Mesa Member of the Todilto Formation (late Callovian) at Bull Canyon in Guadalupe County, New Mexico (Koerner, 1930; Schaeffer, Patterson, 1984; Lucas *et al.*, 1985). The vast majority of specimens represent two taxa of holostean fishes, of which *Hulettia americana* is much more common than *Todiltia schoewei* (Lucas *et al.*, 1985). Whereas only rare specimens of *Hulettia americana* contain consumulites (fossilized ingested food material preserved within the body cavity *sensu* Hunt, Lucas, 2012), approximately 70% of the specimens of *Todiltia schoewei* preserve them (Schaeffer, Patterson, 1984; Lucas *et al.*, 1985). Based on the interpretation of Schaeffer and Patterson (1984), these consumulites are cololites (infillings of the gastrointestinal tract posterior to the stomach, *sensu* Hunt and Lucas, 2012; Fig. 2). One specimen preserved exterior to a skeleton is probably an evisceralite, which is a cololite that is a preserved segment of infilled fossilized intestines preserved exterior to a carcass (Hunt, Lucas, 2012, 2014; Fig. 2).

**Warm Springs, New Mexico.** The Warm Springs locality in Sandoval County, New Mexico, yields fossils of insects and a few fish from the Luciano Mesa Member of the Todilto Formation (Bradbury, Kirkland, 1966; Polhemus, 2000; Lucas *et al.*, 2000). Three narrow, elongate objects in the assemblage are probably evisceralites (Hunt, Lucas, 2014).

## LATE JURASSIC

### Sundance Formation

**Central Wyoming.** The Redwater Shale Member of the Sundance Formation (Oxfordian) yields four taxa of marine reptiles (Massare *et al.*, 2013). Two thirds of the specimens represent the ichthyosaur *Ophthalmosaurus natans*, and the others can be assigned to two cryptocleidoid plesiosaurs (*Tatenectes laramiensis*, *Pantosaurus striatus*) and one pliosauromorph (*Megalneusaurus rex*) (Massare *et al.*, 2013).

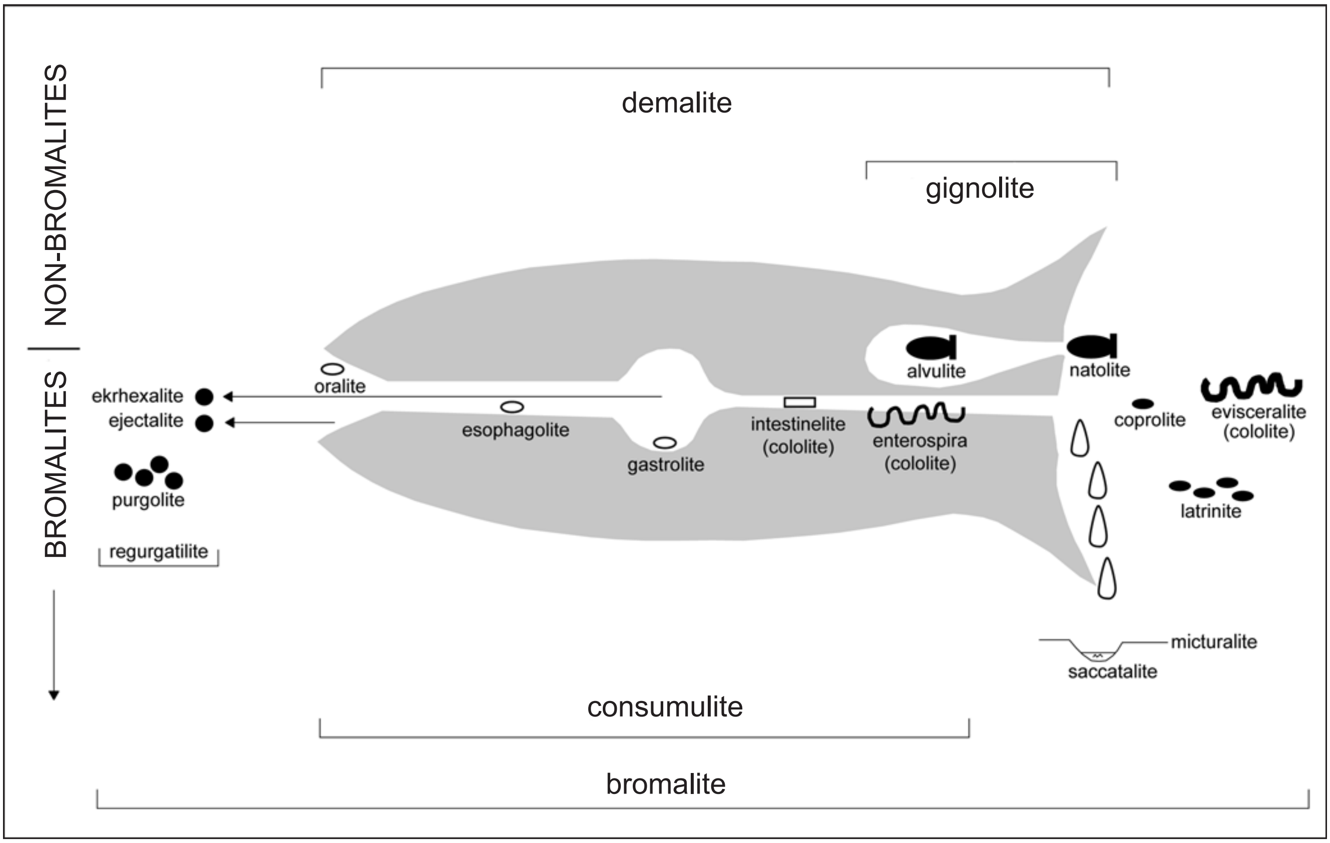


**Fig. 2. Selected classification terms for bromalites and associated trace and body fossils (from Hunt, Lucas, 2012)**

Comsumulties are known for each of these taxa (Massare *et al*., 2013). These consumulites consist primarily of belemnoids with coleoid hooklets, but they also include a cardiocerid ammonite jaw (cryptocliedoid plesiosaur), indeterminate fish bones (*Megalneusaurus*, *Pantosaurus*) and embryonic centra of *Ophthalmosaurus* (cryptocleidoid plesiosaur) (Massare, 1987; Massare, Young, 2005; Wahl *et al.*, 2007; O'Keefe *et al*., 2009; Wahl, 2012).

## Morrison Formation

**San Rafael Swell, Utah.** There are three reports of dinosaur bromalites from the Brushy Basin Member of the Morrison Formation in Emery County, Utah. Stokes (1964) collected a large ovoid specimen that he interpreted as a gastrolite (fossilized stomach contents) of a sauropod. This is a calcareous, matrix-supported conglomerate containing plant and bone specimens, which was subsequently demonstrated to be a part of a laterally continuous bed about 30 m in extent (Sander *et al.*, 2010, figs 14.5–14.6). Thus, Stoke's specimen is clearly part of a sedimentary lens and is not a bromalite (Ash, 1993; Sander *et al*., 2010, 2011).

Stone *et al*. (2000), in an abstract, presented a preliminary description of a 3-m-long object that is about 46 cm wide and 10 cm thick. The putative coprolite consists of a main mass that is tapered at both ends and a 1.52-m-long section of small isolated coprolites that are interpreted to represent defecation while walking. The specimen includes angular bone fragments that constitute about 50% of an apatitic matrix. The putative coprolite is attributed to *Allosaurus* based on its size and the inclusion of a tooth fragment attributed to this taxon. Stone *et al*. (2000) also mention a second putative coprolite and pieces of similar lithology from two other locations.

Chin and Bishop (2004, 2007) described isolated pieces of another putative theropod coprolite (Fig. 3) from a locality about 4 km from the area that yielded the specimens described by Stone *et al*. (2000). They interpreted these samples of bone-bearing conglomerate as representing theropod coprolites on the basis of: (1) lack of sorting and a paucity of sedimentary clasts argue against a hydrodynamic accumula-

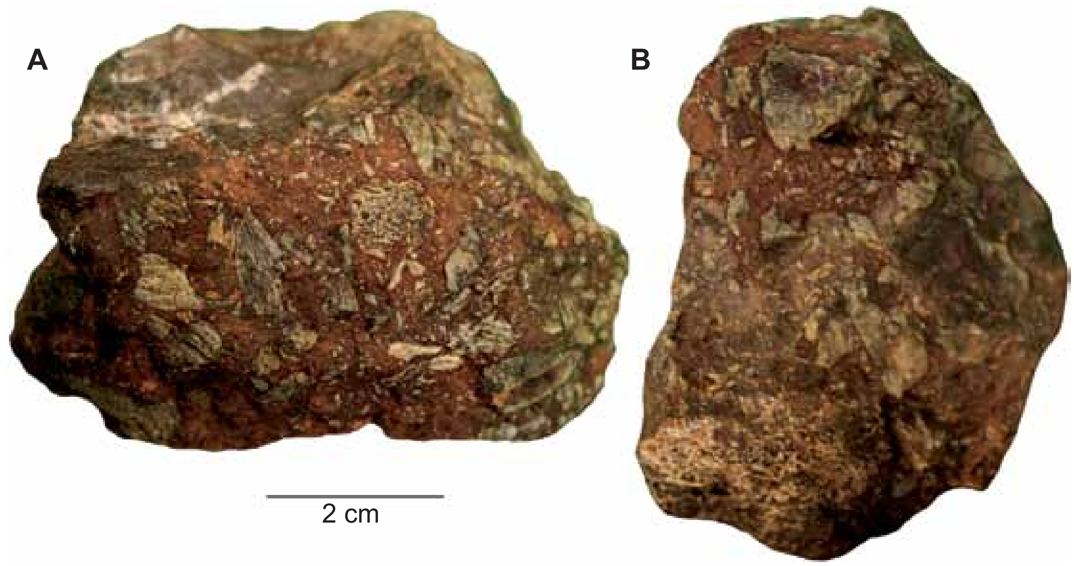


**Fig. 3. Two views of UCM (University of Colorado Museum) 98013, putative coprolite fragment from the Brushy Basin Member of the Morrison Formation, Emery County, Utah**

Note multiple angular fragments of bone. **A.** Lateral view. **B.** End view

tion or concentration due to feeding; and (2) the matrix contains phosphate, although not as much as in other theropod coprolites.

Although the material described by Stone *et al*. (2000) and Chin and Bishop (2007) could represent bromalites, we think there is need for further detailed description of complete *in situ* specimens. Several factors do not seem consistent with a bromalite origin, including: (1) large size of masses (meters in length); (2) high percentage of angular bone fragments; and (3) lower phosphate content in the matrix than in other coprolites. Based on the size it is possible that these specimens represent latrinites (accumulations of coprolites *sensu* Hunt and Lucas, 2012). If this is the case then size would not be such an issue and they could also represent another large carnivore such as a crocodilian.

**Eastern Utah.** A probable coprolite containing bone fragments and fish vertebrae was collected by a volunteer from the Museum of Western Colorado (J. Foster, pers. commun., 2014). This specimen, which may pertain to a crocodile, is probably from the Yellow Cat area but it is unclear if it derives from the Morrison Formation or the Lower Cretaceous Cedar Mountain Formation (J. Foster, pers. commun., 2014).

**Mygatt-Moore Quarry, Colorado.** Chin and Kirkland (1998) described plant-bearing nodules from the Brushy Basin Member as dinosaur coprolites. They studied six specimens with compositions varying from siliceous to calcareous. They all contain fragmented plant material, although the quantity and quality varies considerably (Chin, Kirkland, 1998). Indeed, plant material is disseminated throughout the matrix of the quarry, but it is particularly concentrated in the bone-bearing interval (B. Britt, J. Foster, pers. commun., 2014).

We think that it is most parsimonious to consider these putative coprolites as concretions that formed around concentrations of plant debris (Sander *et al.*, 2010; B. Britt, J. Foster, pers. commun., 2014) based on the following lines of evidence: (1) irregularity in shape from round to irregular (Chin, Kirkland, 1998); (2) variation in size from 5 to 15 cm in diameter (Chin, Kirkland, 1998); (3) preservation and taxonomy of the plant material in the putative coprolites does not differ from that in the quarry matrix (B. Britt, pers. commun., 2014); (4) some of the plant material in the putative coprolites is well preserved and unetched and it includes intact fern sporangia retaining spores and attached to fronds, cycad fronds and petioles and seeds with fleshy outer layers, none of which could reasonably be expected to survive passage through a digestive tract (Tidwell in Sander *et al*., 2010; B. Britt, pers. commun., 2014) ; and (5) the putative coprolites include volcanic ash, which would not be expected to be voluntarily ingested (Sander *et al*., 2010).

**Howe Quarry, Wyoming.** The Howe Quarry is located near Shell and yielded significant dinosaur skeletons for the American Museum of Natural History in the 1930s, and later in the 1990s, for other institutions. Several authors have reported plant material associated with sauropod skeletons that they interpreted to represent consumulites (Brown, 1935; Bird, 1985; Michelis, 2004).

**Pseudocoprolites, Utah and Colorado.** Many of the "coprolites" for sale in rock shops in the United States are not coprolites, but instead are agatized concretions from the Morrison Formation, principally from Utah and Colorado, notably southwest Colorado, the San Rafael Swell and Moab in southeastern Utah (*e.g.*, Speedlove, 1979; Dalrymple, 2014; Fig. 1). "There is an area of southern Utah where the canyons and valleys are so prolific with the coprolite that it used to be mined with a front end loader and hauled by dump truck to rock shops around the country" (Dalrymple, 2014, p. 176). However, these specimens are clearly inorganic concretions (*e.g.*, Dalrymple, 2014, p. 174, 178, 179), some of which may represent silicified calcrete nodules (Chin, Kirkland, 1998).

## GLOBAL RECORD OF JURASSIC BROMALITES

### COPROLITES

Buckland (1829) first mentioned coprolites from the Jurassic. He referred these specimens from the Lower Liassic (Hettangian–Lower Pliensbachian) of southwestern England to ichthyosaurs. Subsequently, Buckland described more specimens in detail, and several authors have published on related specimens during the last decade (Buckland, 1835, 1836; Hunt *et al*., 2007, 2012a; Duffin, 2010).

However, in general, Jurassic coprolites have not been well studied (Hunt *et al*., 2012). Other Early Jurassic units in Europe have yield relatively few coprolites, for example the Posidonienschiefer of Germany (*e.g*., Hauff, 1921). The Early Jurassic portion of the Newark Supergroup in eastern North America contains coprolites but they are little studied (*e.g*., Hitchcock, 1844; Dana, 1845; Gilfillian, Olsen, 2000).

The Oxford Clay of England contains abundant coprolites (Martill, 1985), and there are largely unstudied samples in various collections (*e.g*., Natural History Museum, London; Hunterian Museum, Glasgow) (Hunt *et al*., 2007, 2012b). The Natural History Museum also has a collection from the Purbeck Limestone Formation and Oxford Clay Formation of England, which are largely unstudied (Hunt *et al*., 2007, 2012b). Late Jurassic (and Cretaceous) lithographic limestones in Europe contain coprolites (*e.g*., Hunt *et al*., 2012a, b), but the only detailed study of them is by Schweigert and Dietl (2012).

### CONSUMULITES

Vertebrate consumulites are most commonly preserved in aquatic organisms, because taphonomic factors (*e.g*., water chemistry, deposition rates) in aqueous environments increase the likelihood of the preservation of complete carcasses relative to subaerial conditions (Hunt *et al*., 2012a). Some of the most impressive consumulites are found in skeletons of marine reptiles, for which the Jurassic is notable (*e.g*., Pollard, 1968; Hunt *et al*., 2012a). There are extensive samples of Jurassic ichthyosaur and plesiosaur skeletons, notably from Germany and the UK, which include consumulites that are in need of detailed study.

## DISCUSSION

The Jurassic bromalite record of the western United States is quite limited, especially in contrast to the Triassic and Cretaceous records of the same region (*e.g*., Suazo *et al*., 2012; Hunt *et al*., 2013). Some of the notable factors contributing to this limited record are:

- Early Jurassic red beds are notably less fossiliferous than those of the Triassic (*e.g*., contrast the fossil record of the Chinle and Glen Canyon groups).
- The Early and Middle Jurassic of the region includes several aeolianites and sabkha-like deposits representing environments that preserve few bromalites.
- The Upper Jurassic Morrison Formation contains abundant vertebrate body fossils and many tracks but very few bromalites, in contrast to the broadly similar fluvial Triassic and Cretaceous strata of the same area, maybe in part due to a lack of collection but principally probably due to adverse taphonomic conditions.

The global bromalite record also appears to be depauperate in the Jurassic, with a few exceptions such as marine shales and lithographic limestones in Europe (*e.g*., Lower Jurassic of England, Solnhofen). This relative lack of a Jurassic bromalite record may in part be more a result of a lack of collection and study than of any other factor. However, the relative lack of nonmarine bromalites is clearly influenced by:

- High sea levels in the Liassic.
- Paucity of Middle Jurassic nonmarine vertebrate-bearing units.
- Lack, or lack of recognition of, bromalites in major Upper Jurassic nonmarine vertebrate faunas (*e.g*., China, Tanzania, Portugal, etc.).

In the Western United States there is clearly a need for more detailed examination of known specimens (*e.g*., putative Morrison coprolites) and a focus on collecting more examples.

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