Ichnofabric analysis and benthic oxygenation in the Monte dei Corvi cliffs, Ancona, Italy

Bryan D. Stanley
Department of Geology, Williams College, Williamstown, MA 01267
Faculty Sponsor: William T. Fox, Williams College

INTRODUCTION

The study site at Monte dei Corvi is located along the Conera Riviera on the Adriatic Sea approximately 10 km south of Ancona, Italy. The Miocene limestone and shale cliffs of Monte dei Corvi are exposed continuously from the ground to 90m above sea level. The excellent exposure is due to the wave action of the Adriatic Sea . Approximately 80 m of vertical exposure can be traced laterally along the shore.

The Miocene outcrops extend from the upper part of the Langhian through the Servallian and Tortonian into the lower Messinian. The lithologies contain the Schlier Formation and the lower portion of the Euxinic Shale Formation (Montanari et al., 1995). The Servallian age rocks in the Schlier Formation comprise the majority of the outcrop. Exposure of the Servallian Schlier Formation is excellent since it has not been covered with landslides. Also this particular exposure offers a seemingly conformable and continuous sequence of deposition of limestones, marly limestones, marls, and shales. In addition the Servallian Schlier has thicker deposits than anywhere else in this region of Italy (Montanari et al. 1995).

The Schlier Formation has been interpreted to be hemipelagic to pelagic deposition concurrent with the Northern Apennine orogeny (Montanari et al. 1995). With the exception of occasional sandstone turbidites horizons, the rock-types represent a cyclic to pseudo-cyclic progression of limestones, marls, and shales containing minor sedimentary structures, high levels of bioturbated rock and excellent preservation of ichnofossil assemblages. The trace fossils are characterized by the occurrence of *Planolites, Thalassonoides, Zoophycos* , and *Chondrites* in an ichnofossil assemblage (Fig. 1). These four trace fossils are typically found to be preserved together at other locations (Sarvda and Bottjer, 1986). The cross-cutting relationship and tiering patterns of the four main trace fossils can be used to interpret the benthic oxygenation levels and behavioral patterns.

METHODS

The field work performed in the area during late June to early July 1995 consisted of measuring a four-meter stratigraphic section of the Servallian age Schlier Formation and recording lithology, extent of mottling at bed contact, presence of biogenic sedimentary structures, and location of iron nodules and replacement. Ichnologic work included identifying trace fossils, measuring burrow diameters, documenting behavioral patterns and deducing cross-cutting relationships. Samples were taken for research and for thin sections in the United States. The four-meter section was divided into 15 beds which were distinguished by lithology; however, often the contacts displayed mixing of sediments by bioturbation (Fig. 2). The bedding planes contacts were described as sharp with no intermixing of lithologic components, sharp-gradational with a 0-3 cm transition, and gradational a >3 cm transition. The relative abundance of iron nodules and iron-replaced burrows appeared to be related to the lithology and bioturbation. Trace fossils were rated on relative abundance of a particular species. Abundance was determined under the classification of sparse, sparse/frequent, frequent, frequent/abundant, and abundant. Cross-cutting relationships were based on the trace-fossil types and their interrelationships. These relationships included the color of the burrow fill from white to light gray, gray, dark gray, and red-brown. In addition, the cross-cut burrows were diagnosed as truly cross-cut, or merely secondarily burrowed.

TRACE FOSSILS

Planolites . The trace fossil *Planolites* ranged in diameter from 5 mm upwards to 15 mm and traveled parallel to sub-parallel to the bedding. In rare instances *Planolites* reached 20 mm in diameter. Relative abundance is based on a count in the field of view. *Planolites* were especially abundant in the shale units, beds 1, 8, 12, while sparse in the limestone, beds 3 and 5 (Fig. 2). Often *Planolites* burrows displayed a fill dependent on the position within the bed. *Planolites* found in the lower or upper portion of a bed is filled with the sediment from the nearest adjacent bed, while *Planolites* found in the middle of a bed rework the sediment to make the fill slightly darker than the sediment color. Typically *Planolites* were cross-cut by *Chondrites* and

Zoophycos . Sparse is 0-6 percent; sparse-frequent is 7-12 percent; frequent is 13-18 percent; frequent-abundant is 19-24; abundant is >25 percent.

***Thalassonoides*.** The trace fossil *Thalassonoides* normally displayed diameters on the order of 15 to 30 mm and traveled parallel to sub-parallel with bedding. Beds 3 and 5 contained exceptionally large *Thalassonoides* ranging from 50 to 55 mm in diameter. Thalassonoides are normally found in more abundance around the contacts of the marl and marly limestone beds. *Thalassonoides* often cross-cuts *Planolites* but was not usually cross cut by others. Typically, *Thalassonoides* was secondarily burrowed by *Chondrites* and in rare occasions cross-cut by *Zoophycos*. *Thalassonoides* fill was almost exclusively a light gray. An abundance rating for *Thalassonoides* of sparse is 0-4 percent; sparse-frequent is 5-8 percent; frequent is 9-12; frequent-abundant is 13-16; abundant is >16 (Fig. 2).

***Zoophycos*.** The ichnofossil *Zoophycos* diameters ranged in size from 5 mm to 10 mm with lengths reaching up to 1 m laterally. *Zoophycos* traveled vertically up to 0.5 m in the typical spiraling pattern.. The fill was usually derived from the bed above its trace. *Zoophycos* had no secondary burrow but would often be cross-cut by *Chondrites*, as well as, cross-cutting *Chondrites*. A relative abundance rating for *Zoophycos* of sparse is 0-4 percent; sparse-frequent is 5-8 percent; frequent is 9-12; frequent-abundant is 13-16; abundant is >16 (Fig. 2).

***Chondrites*.** The trace fossil *Chondrites* had the typically vertical to sub-vertical branching pattern with sizes that ranged from 1 mm up to 3 mm. Chondrites was filled with material piped down from the bed above its trace. *Chondrites* cross-cut every other major trace fossil and it was not cross-cut infrequently by *Zoophycos*. A relative abundance rating for *Chondrites* of sparse is 0-6 percent; sparse-frequent is 7-12 percent; frequent is 13-18 percent; frequent-abundant is 19-24; abundant is >25 percent (Fig. 2).

DISCUSSION

Oxygenation and the Lithologic components. The lithologic components of the bed types represent the fluctuating oxygen levels of the bed. Limestones represent oxygen-rich periods while the shales represent extended anoxic events. The rock-types of marly-limestone, and marl depict varying degrees of disoxic periods. The relationship of iron nodules and iron replaced burrows occur most frequently in the less oxygenated beds. The frequency of iron suggests that the lack of oxygen in the water and sediment allows for iron to be preserved before being oxidized and later altered after deposition as a diagenetic effect. The iron in the limestone bed is oxidized or dissolved long before possible preservation.

Also there is a relationship between the bed-type and the biogenic structures found. The limestones beds of 3 and 5 have the least bioturbation but the largest trace fossils (Fig. 2). Both marl and marly limestone tend to have a fair amount of overall reworking, but the shale units, beds 1, 8, and 12, all have the highest abundance of bioturbation and the best tiering patterns despite being the smallest beds.

Oxygenation and Ichnofabric Analysis. As anoxia sets in on the seafloor, the larger creatures, burrowing are unable to obtain enough oxygen and die out. *Planolites*, the pioneer species of these barren sediments, will then rework the sediments into the mottling seen at the base of shale units (Bromley and D'Alessandro, 1992). Upon return of oxygen to the benthic environment, *Zoophycos* and *Chondrites* return crosscutting *Planolites* in the organic rich shale layers. Planolites then fade in prevalence but do not ever really disappear from this section of outcrop. Then, *Zoophycos* disappears and finally *Chondrites*.

In oxygen-depleted environments, Sarvda and Bottjer (1986) report that the order of disappearance as *Planolites*, *Thalassonoides*, *Zoophycos* and finally, *Chondrites* (Fig. 1). This outcrop at Monte dei Corvi contains all four groups expected for oxygen-depleted environment but *Thalassonoides* does not follow the role as predicted. Rather, Thalassonoides is found primarily with the lowest 5 to 10 cm of non-shale beds. This apparent discrepancy indicates that burrow size is related to oxygen content of the environment. Since *Thalassonoides* are typically larger than *Planolites*, *Thalassonoides* should be expected to be primarily found in the more oxygenated environments. Also Denman (1996) points out that *Thalassonoides* is reworked early on before preservation is possible in the small shale beds. This is further supported by *Chondrites* and *Zoophycos* which are able to extend down further into the sediment from higher levels above as shown with the type of fill. As *Planolites* are unable to dig further down due to the decreasing amounts of oxygen in the pore waters, *Chondrites* and *Zoophycos* can still burrow deeper even as the sedimentation of higher beds continues. *Chondrites* eventually outlasts *Zoophycos* also showing how burrow size and oxygenation affects trace fossil presence.

CONCLUSIONS

The Servallian age portion of Schlier Formation at Monte dei Corvi represents a hemipelagic to pelagic setting. The outcrop shows a strong relationship between the lithologies of the exposure and the oxygen levels at the time of deposition. The ichnofossil assemblage consisting of *Planolites*, *Thalassonoides*, *Zoophycos*, and

Chondrites contains evidence which supports the reactions of benthic burrowing organisms to these variations in oxygen contents.

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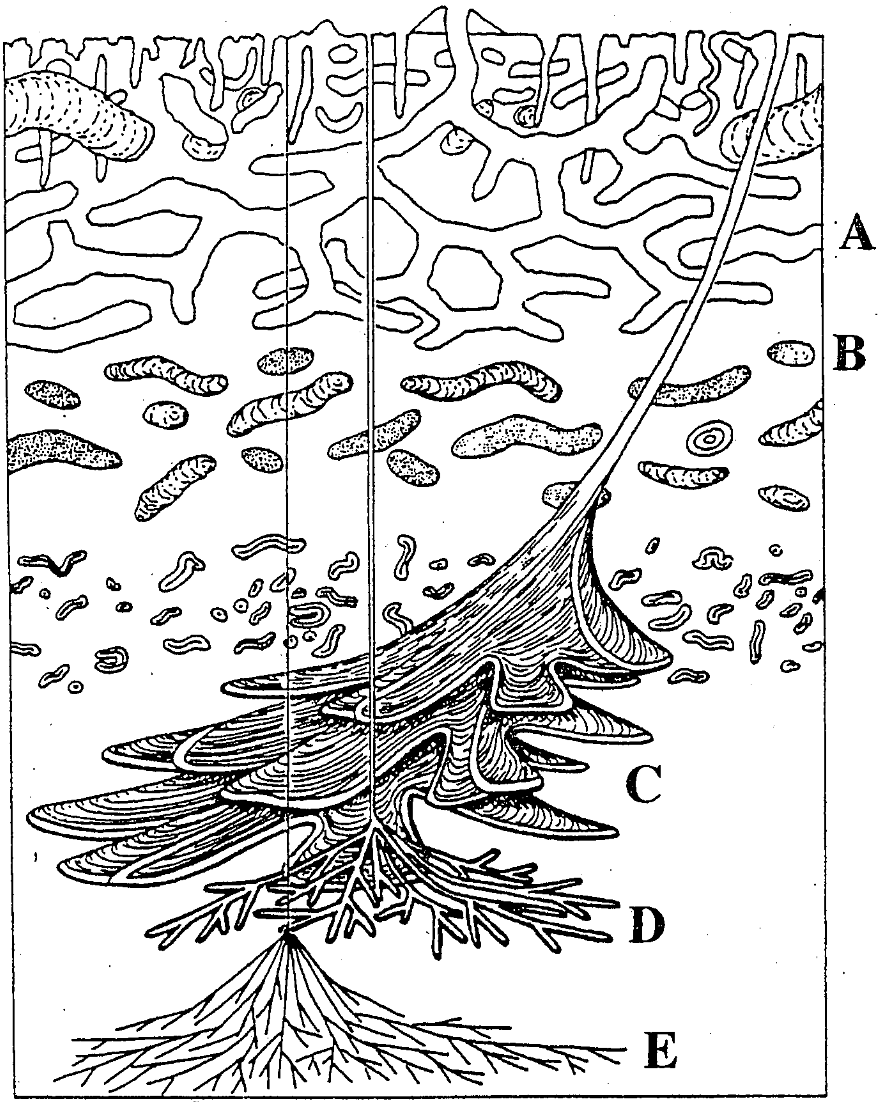

Figure 1. Generalized tiering structures seen in the Monte dei Corvi limestones and shales, Ancona, Italy. A, Thalassonoides ; B, Planolites; C, Zoophycos; D, Large Chondrites; E, Small Chondrites. (Adapted from Ekdale, 1992, Fig. 7).

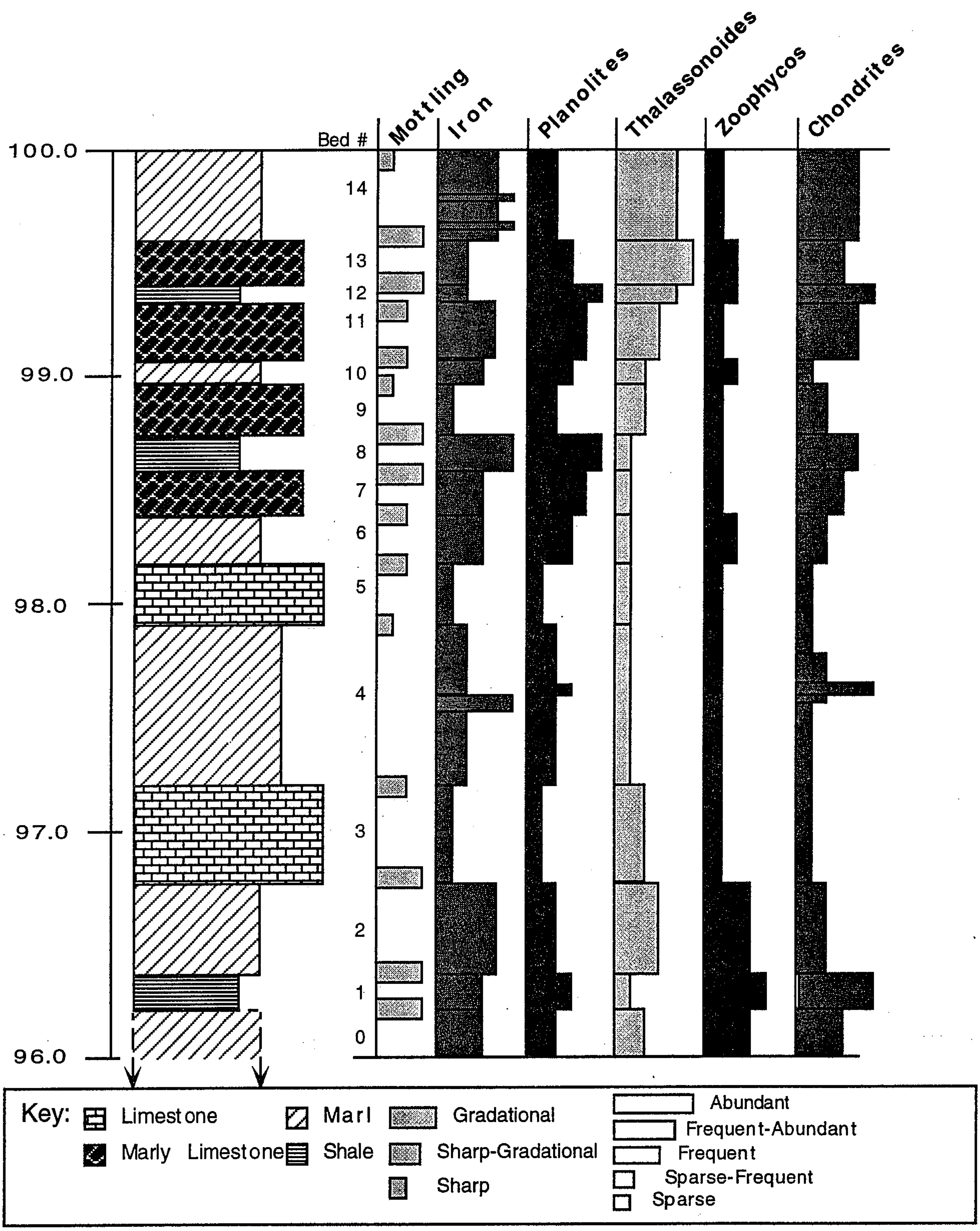

Figure 2. Stratigraphic column of the Monte dei Corvi outcrop Ancona, Italy.