Ichnology and Barium Chemistry as Indicators for Paleo-Benthic Oxygenation and Marine Productivity

John M. Denman

Department of Geology, Colorado College, 902 N. Cascade Ave., Colorado Springs, CO 80946

Faculty Sponsor: Dave Bice, Carleton College

INTRODUCTION

In the central Apennine region of Italy, the Tortonian stage of the Miocene is represented by a thick pelagic and hemipelagic succession. Tectonic sandstone turbidites, originating from the denudation of the emerging Alpine-Apennine orogenic front, interrupt thick carbonate units deposited in Tetheyan marine basins that were subsiding since the Jurassic. The north-eastward advancing orogenic thrust front began in western Italy (i.e., Tuscany) during the Eocene, depositing flysch and marl in NW-SE trending foreland pelagic basins. Flysch deposition in the Umbria-Marche region of Italy began in the Langhian forming the Marnoso-Arenacea Formation near Gubbio (Montanari et al., in press).

The Middle to Upper Miocene pelagic and hemipelagic carbonate units, forming the cliffs between the city of Ancona and a locality known as Il Trave (see Fig. 1), represent the youngest flysch to be involved in the orogenic deformation. The Langhian to Tortonian Schlier Formation, exposed at the base of Monte dei Corvi, contains cyclic carbonate and marl deposits from basinal environments which are the subject of this study. The schlier formation contains a number of cycles composed of limestone, marl, and shale beds, the latter of which record anoxic events in a marine environment. This study was undertaken to document ichnological characteristics of the cycles in order to determine the changes in bottom water redox conditions across and between anoxic events. Biological barium concentration used as a proxy for marine productivity indicates a possible relationship between the anoxic shale and marine productivity. The differences in lithology, degree of bioturbation, and concentration of organically derived barium contained in the sediment, permits the reconstruction the paleoenvironmental benthic conditions of oxygenation and paleoproductivity of the marine setting.

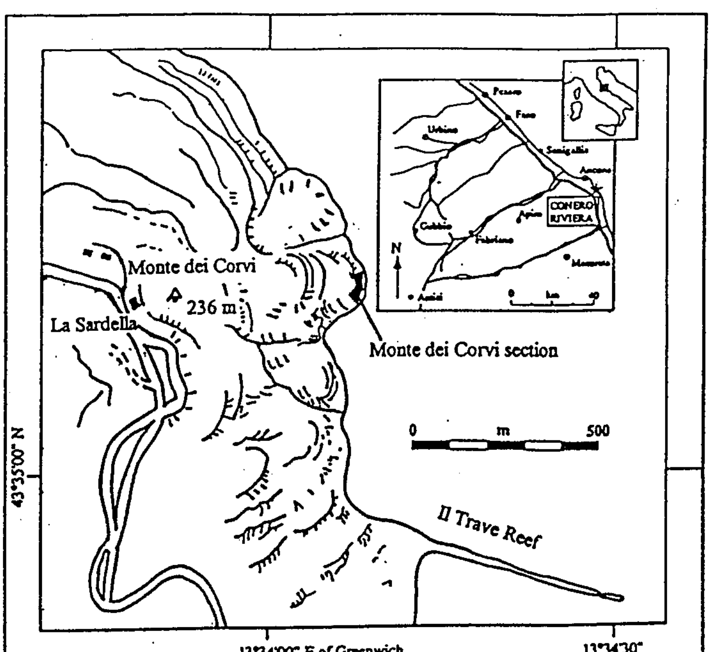

Figure 1. Location map for Monte dei Corvi section (modified from Montanari et al., in press).

METHODS

Field. Ichnofossil data was recorded with black and white photographs, color slides, sketches and diagrammed in a field stratigraphic column. Samples for organic barium analysis were collected at four centimeter intervals across a 1.0 meter measured section containing two shale-marl-limestone cycles.

Laboratory. Ichnofossil assemblages were identified and drafted in a detailed stratigraphic column (Fig. 2). Barium/aluminum ratios were determined by digesting powdered samples in hydrochloric and nitric acids and then analyzing them with an Inductively Coupled Argon Plasma Emission Spectrometer located at The Colorado College.

PREVIOUS WORK

Research on the stratigraphy, geophysical characteristics, paleomagnetism and geochemistry of the Monte Cònero section has been performed by Montanari et al. (in press) and provides an extensive overview of the entire Messinian section. R. Coccioni (in Montanari et al., in press) describes the biostratigraphical zonation of planktonic foraminifera and calcareous nanofossils found throughout the section and correlates them with the Early to Late Miocene Mediterranean faunal zones of Iaccarino et al. (1985).

M. A. Kruge et al. (1994) analyzed the Monte dei Corvi shale layers for signs of microflora and microbial regeneration across the anoxic events. Petrographic analysis, analytical pyrolisis gas-chromatography, and mass spectrometry study of organic material extracted from the shale shows several types of fossil algae dominating the organic matter and a regeneration of similar microflora/microbial assemblages took place during each anoxic event.

Savdra and Bottjer (1986) developed trace fossil tiering models for categorizing ichofossil assemblages into oxygen-related ichnocoenes in order to infer temporal changes benthic redox conditions. Ekdale and Mason (1988) describe oxygen related models that detail the transition of ichnocoenes across redox boundaries. In addition, Savdra and Bottjer (1987) discuss how a number of characteristics including sedimentary fabric, burrow diameter, depth of burrowing, and cross cutting relationships can be used to interpret relative oxygen levels.

Chow and Goldberg (1960) suggested that marine barium in sediments could be used to infer paleoproductivity of marine settings. Dehairs et al. (1980) note that although marine systems naturally recycle most of the nutrients in the water column, enough organically derived barium reaches the sea floor to use as a proxy for paleoproductivity. Dymond et al. (1992) describe factors that may alter the barium signal such as terrigenous sources of barium, diagenic alteration of the barium signal during and after deposition, and uncertainties surrounding the interplay between the sedimentation rate and rate of carbonate production.

DISCUSSION

Lithology. Stratigraphic changes in the lithologies at Monte dei Corvi define cyclic deposition within an epeiric basin. Packages of foraminifera-bearing marly limestone (~75% $CaCO_3$) are gradational with marls (~50% $CaCO_3$) and reflect a highly productive carbonate factory in a tropical marine environment (Montanari et al., in press). The lack of sediment transport fabrics and evaporites within the deposits is consistent with restricted marine facies of epeiric shelves that have little tidal or storm wave effects (Jones et al., 1992). Organic rich shale layers (~20- 40% $CaCO_3$) (Montanari et al., in press) record anoxic periods that interrupt the aerobic carbonate succession, but are followed by marls reflecting gradual reoxygenation of the benthic water.

Cyclicity in this section was either allocyclical and driven by external factors that varied siliclastic sediment supply, or autocyclical and driven by carbonate production. The most obvious allocyclical mechanism for cyclicity are Milankovich-driven climatic cycles that result in alternating periods of wet and dry phases which differentially effect terrestrial runoff, benthic oxygen levels, carbonate production, and biotic productivity (Kauffman et al., 1987).

Ichnology. Mild to catastrophic fluctuations in the bottom water and benthic oxygen concentrations created habitation stresses for benthic dwelling organisms. Their trace fossils reflect different benthic oxygen depletion tolerance. Throughout the succession, the Zoophycos Ichnofacies, as defined by Savdra and Bottjer (1987), dominates the shale units, whereas the Nereites Ichnofacies persists throughout the limestone and marl units. *Thalassinoides* appears to be an early, shallow, primary burrower in the shale because it has a mottled texture with burrow fill that is similar to the sediment at the anoxic-suboxic boundary above the shale. The variety of *Planolites* trace formers appear to have maintained an open conduit to more oxygenated waters to facilitate burrowing into deeper, anoxic deposits. *Zoophycos* is extremely abundant throughout the deposits and penetrates anoxic shale deeper than the previously mentioned burrows. *Zoophycos* appears to record the burrows of organisms that were more tolerant of low oxygen conditions of any other organisms except those that made *Chondrites* burrows, which penetrate the deepest into the anoxic shale. These organisms presumably maintained an open conduit to circulate oxygenated water.

Burrow diameter strongly correlates with depth of borrowing. The smallest *Chondrites* burrows (<1.0 mm) penetrating deepest into the shale from highest in the sedimentary column. The more oxygenated limestone and marl contain a wider diversity of larger ichnofossils including *Terebellina, Helicolithos, Scolicia-Subphyllochordo, Rhizocorallarium* and others still unidentified.

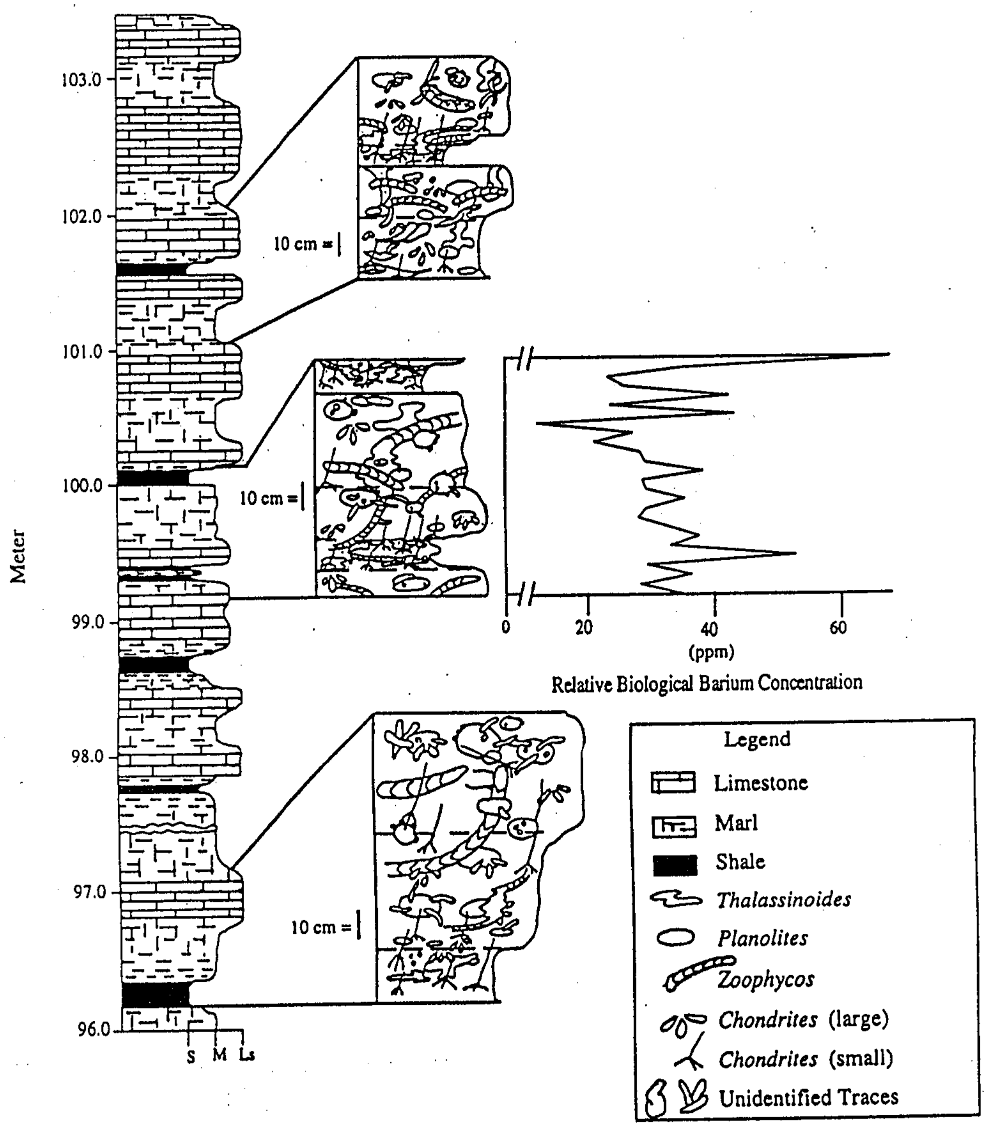

Figure 2. Stratigraphic column of Monte dei Corvi section of study with stratigraphic log of barium concentration and ichnofossil assemblages.

Barium. Barium concentration fluctuates between 30 to 37 ppm within the marl and limestone layers, but high concentrations of barium (>40 ppm) occur within and near shale layers (see Fig. 2). Two high barium peaks, 52 ppm at meter 99.30 and 42 ppm at meter 99.98, occur in the lower part of shale layers. A peak of 42 ppm occurs at meter 99.90, 10 cm below the shale, and one peak of 65 ppm at meter 100.14 occurs 14 cm above the shale layer. This high barium content in the shale beds and immediately adjacent strata may be related to algal blooms which acted to depress oxygen levels. Such a mechanism was speculated on by Kruge et al. (1994) and Montanari et al. (in press), and the data from the Monte dei Corvi section supports this idea.

The low terrestrial organic component found by Kruge et al. (1994) suggests that terrestrial barium did not have a significant effect on the barium signal. Authigenic pyrite found filling foraminiferal cavities, however, indicates the existence of a reducing environment during and after sedimentation (Kruge et al., 1994), possibly altering the barium signal through diagenic mobilization by microbial sulfate reduction of the organic matter. This may explain why barium peaks are not in perfect sync with the highly productive organic shale beds.

CONCLUSIONS

Facies transitions, ichnofossils, and marine barium chemistry of the Monte Cònero section of the Sardella Schlier Formation all indicate that the foreland basin experienced cyclical oxic to anoxic bottom water conditions. Ichnofossil tiering illustrates different oxygen level tolerances of benthic organisms and details the oxygen stratification history of the basin. The barium data suggests that the anoxic events were caused by periods of high marine productivity, possibly associated with algal blooms. The Monte dei Corvi section provides an example of cyclic stratigraphy, illustrating the role of ichnological tiering for determining variable redox conditions.

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