

## INTRODUCTION AND OVERVIEW

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### INTRODUCTION

The term “black shale” is a common expression widely used to describe any dark-colored, fine-grained sedimentary rock relatively rich in organic matter. As defined by Weissert (1981), the range of organic carbon in black shales is between 1 and 30%, but values outside this range exist. The term usually connotes at least partial lithification, yet this may not be true in young, shallow sediments. The most important characteristics conveyed by this descriptive expression are the dark color and the high content of organic matter in black shales, two features which distinguish these rocks from other modern and ancient fine-grained sedimentary deposits.

Episodes of black shale deposition have occurred sporadically throughout geological time. The Cretaceous Period contains the most extensive record of black shale formation in both shallow-water and deep ocean locations (Arthur and Schlanger, 1979; Weissert, 1981). Much of the world's oil production is sourced from Cretaceous rocks (Schlanger and Cita, 1982), and so there are economic reasons for interest in understanding the conditions leading to deposition of black shales. This interest, moreover, transcends the role of black shales as hydrocarbon source rocks. Knowledge of the factors involved in their deposition provides many clues as to the paleoceanographic conditions favorable to their formation. Geochemical and sedimentological data contribute to this understanding.

### THE DEEP SEA DRILLING PROJECT AND BLACK SHALES

Discovery of deep ocean black shales at a number of Deep Sea Drilling Project (DSDP) sites in the Atlantic Ocean has provided much of the impetus for interest in this subject over the past decade. The occurrence of organic-carbon-rich black shales of mid-Cretaceous age, in particular, is especially common in the Atlantic Ocean (Tucholke and Vogt, 1979; Tissot et al., 1980). A common observation in mid-Cretaceous black shale deposits is the interlayering of black and green claystones (Thierstein, 1979). These lithologic cycles may reflect periodic oxygen deficiencies and indicate repeated short-lived changes in the geochemistry of the depositional environment.

Although most black shales contain low amounts of carbonates, important deposits of organic-carbon-rich black limestones also occur. Arthur and Schlanger (1979) cite examples of mid-Cretaceous carbonate reefs rich in organic matter, and Dean et al. (1984a) describe mid-Cretaceous midwater limestones in the North Pacific. The general lack of carbonates in black shales reflects a combination of deposition below the carbonate compensation depth and postburial dissolution of carbonate material. The loss of carbonates can contribute towards enriching the remaining sedimentary components in both organic carbon and in associated heavy metals.

#### FACTORS IMPORTANT TO BLACK SHALE DEPOSITION

Because the North Atlantic Ocean has been studied more than other parts of the world's oceans, more is known of its paleoceanographic history. The distribution of black shale occurrences in the North Atlantic Ocean has been discussed by Arthur (1979), Tucholke and Vogt (1979), Thierstein (1979), Summerhayes (1981, 1985), De Graciansky et al. (1981), Weissert (1981), and Waples (1983), among others, with the intent of identifying the paleoceanographic factors involved in the formation of these unusual strata. Improved preservation of organic matter, increased contribution of continental organic matter to oceanic basins, and enhanced production of marine organic matter are some of the factors which have been suggested.

Both the type and the amount of organic matter contained within black shales and their adjacent strata provide information about the paleoceanographic processes which participated in the formation of Cretaceous black shales in the North Atlantic Ocean. Possible explanations of black shale depositional conditions are exemplified by De Graciansky et al. (1982), Summerhayes and Masran (1983), and Summerhayes (1985) and combine the effects of sea level changes, changes in continental climates, nutrient availability, and basin morphology to achieve periods of midwater or bottom anoxia in the Mesozoic North Atlantic.

The proportion of continental and marine organic matter present in black shale samples from the western North Atlantic varies considerably. Although most of the organic matter appears to be terrigenous (Katz and Pheifer, 1982), the marine fraction increases with distance from North America (Tissot et al., 1980; Summerhayes and Masran, 1983). This pattern has been explained by Summerhayes and Masran (1983) to reflect the decrease in turbiditic dilution of marine sediments with continental materials as distance from shore increases. An exception to the terrigenous dominance occurs in Cenomanian black shales, where large proportions of marine organic matter are found at Site 105 (Summerhayes, 1981) and Site 603 (Meyers, in press), which are both located on the continental rise and in turbiditic environments. This exception illustrates the regional and temporal variability that can exist in the mixture of organic matter types in black shales.

In contrast to the western North Atlantic situation, organic matter in black shales in the eastern parts of this ocean originated predominantly from

marine sources (Tissot et al., 1979; Katz and Pheifer, 1982; Summerhayes, 1985). Another significant difference between the organic matter contents of the Cretaceous sediments in the eastern and western parts of the North Atlantic has to do with their concentrations. Significantly higher percentages of organic carbon are found in black shales from the eastern half of this ocean. As an example of these elevated values, a Cenomanian sample from DSDP Site 367 in the Cape Verde Basin contained 37% organic carbon (Lancelot, Seibold et al., 1978).

Preservation of organic matter is an important element in forming organic-carbon-rich black shales. Anoxic bottom waters have been postulated to have enabled enhanced preservation of organic matter in the Cretaceous North Atlantic (e.g., Arthur and Schlanger, 1979; Tissot et al., 1980; Jenkyns, 1980; Summerhayes and Masran, 1983; Bralower and Thierstein, 1984). The abundant presence of burrowed, oxidized sediments above and below the black shales in this ocean argue against such bottom-water anoxia being extensive in either volume or duration (Katz and Pheifer, 1982; Waples, 1983). An alternative scenario leading to greater preservation of organic matter calls for the midwater oxygen minimum zone to become intensified and perhaps expanded through sluggish circulation or enhanced influx of organic matter (e.g., Demaison and Moore, 1980; Waples, 1983). Where a midwater anoxic layer intercepts the ocean bottom, sediments rich in organic matter can accumulate. Downslope movement of such sediments can result in formation of black shales within deep ocean turbiditic sequences, as suggested by Dean et al. (1984b) for Site 530 in the Angola Basin, if reburial is sufficiently rapid to preserve the organic matter. This scenario points out another factor important to preservation of organic materials — the sedimentation rate. Quicker burial results in better preservation, even under oxygenated bottom-water conditions, through establishment of anoxic conditions in the sediments whenever organic matter supplies are sufficient to deplete pore-water oxygen levels. This phenomenon has led Habib (1983) and Robertson and Bliefnick (1983) to suggest that Mesozoic black shales at Site 534 near the Blake Plateau result primarily from rapid sedimentation of terrigenous organic matter associated with turbidity currents and that the western North Atlantic need not have been anoxic during these episodes.

The higher concentrations of organic matter found especially in Cenomanian black shales from eastern Atlantic locations indicate that special paleoceanographic conditions prevailed at these times and places. A variety of processes have been implicated, including enhanced marine productivity (e.g., Summerhayes, 1981; Dean and Gardner, 1982; Summerhayes, 1985), higher sea level as a result of faster sea floor spreading rates (e.g. De Graciansky et al., 1984; Force, 1984), basin-wide anoxia (e.g. Bralower and Thierstein, 1984; De Graciansky et al., 1984), and expanded oxygen-minimum zones (e.g. Cornford, 1979; Dean and Gardner, 1982; Waples, 1983). Among these cited explanations of the eastern Atlantic black shales, there are convincing arguments against higher productivity, against the importance of broadened continental

shelves, against the possibility of deep-water anoxia, and against downslope redeposition from oxygen-minimum zones. As concluded by De Graciansky et al. (1984), a globally applicable explanation of the exceptionally rich black shales of the Cenomanian—Turonian times appears impossible. Local and regional factors evidently complicate the picture.

#### RATIONALE FOR THIS SPECIAL ISSUE

From this introduction, it is clear that a satisfactory and generally accepted explanation of the paleoceanographic and depositional conditions leading to the accumulation of black shales has not yet been achieved. Nonetheless, many researchers have investigated the inorganic and organic geochemistry, sedimentology and paleontology of these rocks, and much information on these aspects is now available. To convey some of these details, and the various interpretations that exist about the origin of black shales, a symposium on the topic "Deep Ocean Black Shales: Organic Geochemistry and Paleoceanographic Setting" was organized by the Organic Geochemistry Division of the Geochemical Society at the 1983 meeting of the Geological Society of America in Indianapolis. Most of the papers presented at this meeting are included in this special issue. These articles, taken together, are not intended as a comprehensive review of the subject. Rather, they are selected overviews and describe new research results that will provide further insight into the subject of black shales.

The seven papers constituting this Special Issue have been put into an order that should lead the reader through a sequence of material about black shales. The first two papers form a group which gives the general distribution of black shales in deep-sea settings and describes some of their geochemical characteristics. The next three papers deal with regional or local examples of black shales or analogous organic-carbon-rich sediments and provide many details about these specific deposits. The final two papers use geochemical balance approaches to explore the processes which may have contributed on a global scale to episodes of formation of black shales.

#### SUMMARIES OF RESEARCH PAPERS

Simoneit describes the chemical characteristics that can be used to discriminate between terrigenous and marine sources of organic matter. During the Early Cretaceous the organic carbon input was predominantly terrigenous in the North and South Atlantic Oceans. The character changed during the Late Cretaceous to predominantly marine in these ocean basins. The composition of the soluble components of this material indicates that these rocks have experienced a mild geothermal history.

Based on detailed organic geochemical analyses, Katz and Pheifer conclude that the variations in the type and distribution of organic matter in Cretaceous black shales of the Atlantic Basin indicate that the sediments were not deposited uniformly in anoxic settings. Together with sedimentary structures

the results suggest that some of the black shales were the products of redeposition of shallower sediment. Their evidence supports the view that synchronous basin-wide anoxic conditions during the Cretaceous were not prevalent, although more localized anoxic conditions existed.

Pratt, Claypool and King compare the organic geochemistry of laminated and non-laminated black shales. Organic matter which accumulated in oxygenated environments, as evidenced by the presence of bioturbation, is less suitable for hydrocarbon generation. Although bacterial modifications undoubtedly occur to the material accumulating in anoxic environments, this organic matter is more suitable for hydrocarbon generation. Laminated units are enriched in organic carbon, have higher Rock Eval hydrogen indices, and show more negative  $\delta^{13}\text{C}$  values in their organic matter.

Stanley has conducted a detailed sedimentological study of some organic-carbon-rich sediments deposited in the deep sea. He concludes that organic matter can be preserved in deep-sea oxic waters due to downslope transport and rapid burial of sediments that had previously accumulated in shallower environments more conducive to the preservation of this labile material. Evidently, deep-water anoxic conditions are not necessarily required for deposition of sediments enriched in organic carbon. Dilution of organic matter in deep basinal settings may also occur by the rapid and intermittent downslope emplacement of sediment.

Sheu and Presley present the results of their study of the Orca Basin in the Gulf of Mexico. This basin is a modern anoxic basin that formed due to the presence of a dense brine derived from underlying salt deposits. This basin has both similarities and differences to other modern anoxic settings. Despite the anoxic conditions, laminated sedimentary layers and enrichment in iron sulfides, the organic carbon content is only about 2%, which is less than that of most ancient laminated black shales and modern anoxic muds.

Dean, Arthur and Claypool find that marine organic carbon in Cretaceous black shales is several per mil lighter than terrigenous carbon in rocks of the same age and up to 7‰ lighter than comparable organic carbon of Miocene to Holocene age. The fractionation between carbonate and organic carbon during the Cretaceous was about 29‰, compared to about 23‰ at present. One possible explanation for this effect is a greater  $\text{CO}_2$  content during the Cretaceous.

Walker points out the inconsistency between models for the C-S-O system that are based on conservation of atmospheric oxygen and the data from modern sediments for which reduced C and S co-vary. Implicit in the latter relationship, if maintained over longer intervals, is that atmospheric oxygen levels would fluctuate. During times of significant burial of reduced C and S, drawdown of atmospheric oxygen could occur. Future models should consider this possibility.

## CONCLUSIONS

The study of black shales provides a special opportunity for the relatively young discipline of organic geochemistry to interact with better established

branches of earth science, such as sedimentology, mineralogy and micro-paleontology, in contributing towards solving an interesting, unresolved question in the geological record. Geochemical information generated in less than a decade has already provided valuable insights into the type of organic matter present in black shales and the extent of its preservation. Future studies, using new techniques and new applications of existing techniques, should add to these insights. Such future work will be more valuable if careful sample selection is used, so that geological information can be combined with the geochemical data. Synthesis of information from multiple disciplines will enhance understanding of the paleoceanographic conditions giving rise to black shale formation.

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