

Diagenetic Pyrite and Apatite as Indicators of an Abundant Supply of Iron and Phosphorus: Evidence for Controls on high Primary Productivity in the Triassic Shublik Formation, Alaska North Slope

K. J. Whidden¹ and A. Boehlke¹

¹ Central Energy Resources Science Center, U.S. Geological Survey, Denver, CO 80225

ABSTRACT

The Shublik Formation is a calcareous mudstone to muddy micritic limestone that was deposited in the Arctic Alaska Basin (AAB) during the Middle and Late Triassic. Organic-rich intervals occur throughout the Shublik, and these have been typed as sources of oil found in Prudhoe Bay and other accumulations in northern Alaska. In addition, the Shublik Formation currently is being tested and evaluated by industry as a self-sourced resource play. To better understand the resource-play potential of the Shublik, core and outcrop studies have focused on characterizing the depositional and early diagenetic mineralogy associated with organic-rich intervals. This approach allows for a better understanding of the controls on the production and preservation of organic matter, and may lead to new methods for identifying organic-rich "sweet spots" that were formed in regions of high productivity resulting from input of biolimiting nutrients.

Core samples from two wells in the National Petroleum Reserve in Alaska, Ikpikpuk-1 and Inigok-1, have been examined using petrographic (optical and scanning electron microscope [SEM]), X-ray diffraction (XRD) and X-ray fluorescence methods. Two end-member microfacies are described in the studied samples: (1) bivalve-rich packstone-grainstone to marl ("flat-clam facies"), and (2) bioclastic wackestone-packstone to marl. Gradations in texture, mineralogy, and bioclast composition between these two microfacies are common in samples from both wells. The flat-clam facies represents the organic-rich facies in the studied interval, with measured total organic carbon (TOC) values ranging up to 4 percent. Thermal maturity in both wells has been measured ranging between 1.2 and 2.0 percent vitrinite reflectance, which means that the original TOC content was likely much higher than the present-day measured values. The flat-clam facies contains recurring, horizontal layers of flat-clam shells and evidence for common diminutive burrows. This microfacies is interpreted as having been deposited during quiescent depositional conditions with high primary productivity in the overlying water column.

In contrast, the bioclastic calcareous mudstone has a chaotic texture, with broken and abraded fossil fragments, including bivalve shells, echinoderm plates, and rare benthic foraminifera. TOC values are less than 1 percent in these intervals. This microfacies is interpreted to represent storm beds with evidence for varying degrees of energetic disruption of the sediment-water interface.

Bivalve shells in the flat-clam facies occur within a mud matrix that is predominantly marine snow as identified in SEM. Authigenic calcite, dolomite, quartz and pyrite are abundant. Pyrite ranging from trace amounts up to 6.5 percent occurs in 88 percent of the Ikpikpuk samples and in 82 percent of the Inigok samples, as measured by XRD. The presence of abundant pyrite implies pore waters with high concentrations of iron and sulfur. Occurrences of iron chlorite, ferroan dolomite and ankerite suggest occasional overabundance of iron relative to sulfide. Apatite is present in both cores (occurring in 81 percent of pikpuk samples and 47 percent of nigok samples, respectively), with up to 34 weight percent in the Ikpikpuk samples, indicating that phosphate also was abundant in the pore waters. Apatite occurs within fecal pellets, within

shelter porosity under bivalve shells, and as nodules. At the micron scale, apatite is found adjacent to, and locally intergrown with, framboidal pyrite and with clay (likely originally marine snow that is now obscured). The co-occurrence of pyrite, apatite and authigenic calcite indicates that the pore waters of the flat-clam facies were controlled by carbonate equilibrium and were predominantly pH neutral.

Both phosphorus and iron are essential biolimiting elements necessary for high rates of primary productivity, which is a critical component in the development of organic-rich facies, and both were amply available in the AAB during the Triassic. Initial input of these biolimiting elements to the water column caused an increase in primary productivity such that some organic matter reached the sea floor and the upper sediment column before degradation. Iron and phosphorus were released during degradation of organic matter; these elements were either recycled into the water column when degradation occurred on the sea floor, or were trapped in pore waters when degradation occurred within the upper sediment column. Sustained high productivity led to increased oxygen consumption in the uppermost sediment column during degradation of organic matter, the development of dysoxia, and the continued release of iron and phosphorus into the pore waters. The dysoxic conditions further increased the rate of preservation of organic matter, leading to the formation of the highest TOC intervals. Pyrite precipitated in reducing conditions when both iron and sulfide were present, while apatite precipitated when sufficient phosphorus and calcium were available. The presence of both authigenic minerals throughout the organic-rich, flat-clam facies attests to the importance of iron and phosphorus in driving sustained high productivity in the Triassic AAB. Identifying potential sources of these biolimiting elements may aid in the prediction of the most organic-rich regions of this basin. The high concentrations of phosphate and iron may be due to river input of an eroded parent material rich in these elements or volcanic ash.