Abstract

Polar Sensitivity to Climate Change: Impacts on Reservoir Quality

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Controls on the fluid reservoir potential of most terrigenous clastic depositional systems are well-documented in the literature. Poorly represented, however, are reviews focusing on glaciogenic deposits of the high-latitudes. Nevertheless, glaciogenic deposits, ranging from Neoproterozoic to Pleistocene in age and distributed across the globe, constitute significant hydrocarbon reservoirs. As exploration expands into the polar latitudes, understanding the unique factors that control reservoir quality in the deposits of cold polar shelves becomes increasingly important.

Although protected from exploration by the Antarctic Treaty, the Cenozoic succession beneath McMurdo Sound, Antarctica provides a useful analog for exploration targets in glaciogenic successions elsewhere. This study focuses on a drillcore recovered during the Southern McMurdo Sound Project of the ANDRILL program. AND-2A, drilled in 2007, recovered a 1138.54 m long stratigraphic section through the Neogene succession of the Victoria Land Basin, Antarctica. ANDRILL is the first geological drilling program to include pore water analysis as part of routine coring efforts in shallow marine embayments around Antarctica. During recovery of the AND-2A core, 21 samples of pore water were collected to a depth of c. 1000 mbsf, providing a unique opportunity to examine relationships between interstitial fluids and diagenesis in a glaciomarine succession.

The stratigraphic succession comprises a range of lithologies, including diamictite, mudrock and sandstone with minor conglomerate and diatomite. Among the lithologies present, sandstones represent the best potential reservoir facies. Sandstones tend to be relatively thin (<5 m) and comprise a minor proportion of the total stratigraphic thickness, but they are laterally persistent and so represent viable reservoirs. The succession consists of more than 70 depositional sequences separated by erosional surfaces, with each sequence interpreted to represent a single glacial-advance retreat cycle. Six recurring stratigraphic motifs have been recognized, which reflect variations in climate regime ranging from the conditions of today, characterized by cold, dry-based glaciers, to warmer conditions characterized by minimal ice influence. Clean, mature sandstones are more prevalent in sections of the core deposited under less glacially austere conditions.

Thin section analysis of the core reveals a complex depositional and diagenetic history. Sandstones range from sublitharenties to litharenites, including volcarenites. The main source material for sandstones includes Lower Paleozoic crystalline basement and Neogene first-cycle volcanics. Sandstones contain a high proportion of labile framework grains that show little evidence of alteration despite evidence for significant physical reworking. Grain preservation is interpreted to reflect cold temperatures, which have slowed chemical reactions. Although secondary carbonate is present throughout the succession, its abundance, distribution, and morphology is highly variable. Most sandstones are densely cemented with various forms of carbonate cement, ranging from microgranular to blocky, to spheroidal, and radiaxial bladed rims on

grains. In addition, microcrystalline calcite replaces the fine-grained matrix of mudrocks and diamictites. Stable isotopic data show that these phases are characterized by lower $\delta^{18}O$ values (–10 to –18‰ VPDB) than might be expected in sediments that accumulated under freezing conditions. Such results led previous workers to postulate that connate fluids contain significant contributions of meteoric water derived from glacial melting, implying a fate for meltwater that involves its storage in the subsurface.

Interpretation of the AND-2A core, however, benefits from analysis of pore water samples recovered during drilling. Pore water geochemical profiles show that a body of dense, carbonate-saturated brine, with a salinity approaching six times that of seawater, resides in the subsurface at depths greater than c. 200 m below the sea floor. The brine is characterized by low $\delta^{18}O$ values (c. –10‰ VSMOW). Borehole temperature data, which reveal that temperatures of 10° – 25°C are maintained at depth, allows estimation of the composition of calcite that would precipitate from the brine. Modeling results confirm that the brine is the main cementing agent. The most likely mechanism for brine generation involves sea ice formation along ice sheet margins. The brine is subsequently distributed basinward through subsurface flow.

Although most sandstones are tightly cemented, there are significant exceptions. Some intervals of clean sand up to 25 m thick maintain porosities as high as 41% and show little evidence of diagenetic modification. Sequence stratigraphic relationships indicate that these sandstones are best developed in highstand delta systems that formed during ice minima, when substantial volumes of meltwater were released from glacier termini. Individual sandstone bodies, which likely extend laterally over several kms, tend to be enclosed by muddy lithologies. Porosity in these sandstones was retained due to discharge of dilute meltwater during deposition and subsequent isolation of sands between impermeable barriers.

Observations from the AND-2A core reveal that reservoir quality in the deposits of polar shelves is determined by factors that are absent or of reduced significance in lower latitude systems. For example, cold temperatures, which limit the rate of chemical reactions, are maintained to significant burial depth. Another key factor relates to climate change, the effects of which are amplified in polar settings. As glacial severity increases, so does the propensity for the formation of cryogenic brine in glaciomarine systems. The presence of such brines may impact reservoir quality by driving cementation that occludes primary pore space prior to significant burial. On the other hand, primary porosity can be maintained in deposits formed during warmer climate intervals, especially those formed when meltwater flux is high. In summary, it is evident the climate sensitivity characteristic of the high latitudes leads to changes in depositional systems, which can, in turn, produce significant heterogeneity in reservoir quality. Results of this study have the potential to change the way burial history and reservoir character are evaluated in sedimentary successions that formed in polar environments.