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Gas hydrate and permafrost controls on gas migration: Examples from the Mackenzie Delta and the North Slope of Alaska

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The application of surface geochemical prospecting techniques is complex in Arctic areas where large contrasts in vertical permeability may be induced by geologic phenomena associated with variations in near surface ground temperatures. In the Mackenzie Delta and northern Alaska, prolonged exposure to cold air temperatures over past millennia has formed permafrost (ground perennially below 0°C) beneath land areas. Ground temperatures may be as low as -9°C with permafrost thickness varying from 100 to750 meters. As a consequence of these cold ground temperatures, a thick gas hydrate stability field is also typical of northern Alaska and the Mackenzie Delta. For Structure I methane hydrate, thought to be the most common gas hydrate in nature, the pressure-temperature stability field may extend from a few hundred to over 1500 metres depth. A key consideration in terms of gas migration through permafrost or gas hydrates occurrences is the effect of ice or gas hydrate within the sediment matrix, creating a reduced effective permeability and ultimately limiting vertical gas flux. Quantitative analyses of the concentration and geochemistry of headspace gases collected from scientific boreholes drilled over conventional gas fields in the Mackenzie Delta confirm that ice-bonded permafrost can be a very effective barrier and almost certainly limit the utility of surface prospecting techniques. Field and laboratory data from the 3.7 TCF Mallik gas hydrate field, suggest that gas hydrates behave in a similar manner. In contrast however, in some warm permafrost settings (i.e. temperatures between -2° and 0°C), the physiochemical effects of the porous media (salinity, clay content, etc.) can prevent the pore water from freezing and thus maintain more typical permeability conditions. Similar effects can suppress gas hydrate formation even though the temperature and pressure stability conditions may be within the accepted stability envelope for pure methane-water systems. These areas are referred to as taliks when they are below 0°C but without frozen pore water. Typically water bodies greater than 2m depth, that do not freeze to the base in the winter, create either a talik or elevate ground temperatures suppressing gas hydrate formation. Given that lakes, ponds and rivers occupy 30 to 60% of the land area in many parts of the Arctic coastal plain, a comprehensive understanding of the near surface geothermal regime is paramount to interpreting conventional geochemical exploration data.

A geochemical exploration model is proposed for permafrost terrains of northern Alaska and the Mackenzie Delta that accounts for three dimensional changes in effective permeability caused by variations in the near surface permafrost and gas hydrate distribution. Given the same boundary conditions, vertical gas flux is expected to be greatly reduced in terrestrial areas where ground temperatures create thick, uniform, ice bonded permafrost and gas hydrate. Higher flux may occur beneath water bodies with sufficient thermal mass (dictated by the mean annual bottom temperatures and area of the lake) to create thawed conditions, or through combined physiochemical and porous media effects reduce or retard pore ice or gas hydrate formation. Geothermal modeling studies suggests that these high permeability chimneys should be similar to an hourglass in shape beneath the water bodies and that they should be effective conduits for preferential gas migration from deeper hydrocarbon sources. One possible exploration strategy is to fingerprint the chemistry of stagnant water bodies and determine the abundance and isotope signatures of dissolved hydrocarbon gases. Limnology studies of lakes from Alaska and Canada suggest that the chemistry of the Arctic lakes may shift during the winter period as the lake ice canopy retards atmospheric flux, causing the concentrations of dissolved gas in the water column to increase. This suggests that late winter sampling may be optimal. Field work during winter of 2001 will be undertaken in the Mackenzie Delta to assess this prospecting technique.