AAPG HEDBERG CONFERENCE
"Near-Surface Hydrocarbon Migration: Mechanisms and Seepage Rates"
APRIL 7-10, 2002, VANCOUVER, BC, CANADA

Seabed Slopes and Bathymetric Waveform Residuals as Quantitative Indices of Vertical Fluid Migration at Seep Sites in the Northern Gulf of Mexico

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In the northern Gulf of Mexico liquid and gaseous hydrocarbons, pore water and fluidized mud escape from reservoir intervals deep in the crust and are temporarily stored in shallow subsurface. The distinctive seabed morphology and bathymetric relief of seep sites is produced in response to a number of physical, chemical and biological processes triggered by the migrating fluids as they arrive near the sediment/water interface. These processes produce unique geomorphic features: hydrate mounds, authigenic-biogenic carbonate hardgrounds, fault scarps, and mud volcanoes, readily recognized by direct or remote visual examination of the seabed. These features, created and augmented by fluid migration, represent local positive volume anomalies. The magnitude of these anomalies, measurable on high-resolution multibeam and 3-D seismic water-bottom data, may directly correspond to seep activity over timescales of 100 – 10,000 years, based on the longevity of tubeworms, reported ^{14}C dates, and spatial wavelength correlations with paleoclimatic periodicities recorded in arctic ice cores and Gulf of Mexico deltaic gamma ray records.

Current investigations of seeps employ sampling, viewing and sensing strategies measure the character and flux of escaping fluids. Strategies to identify seep sites regionally employ seabed 3-D seismic amplitude and waveform mapping. A new approach described here employs an analysis of seabed waveform residuals derived from high-resolution bathymetric surveys to calculate the volume of positive relief anomalies related to fluid migration induced build-up of mass within seep sites. The quantitative analysis of relief anomalies in regional datasets also provides a potentially useful tool for identifying seep sites with predictable precision and reliability.

Test data from a ~0.3 mi^2 seep site in the Mississippi Canyon protraction area provide an indication of the magnitudes of relief anomalies caused by hydrate mounds, mud mounds, and chemical-biogenic precipitates at arbitrarily selected spatial wavelengths of 150 ft, 300 ft and 450 ft. Indicated volumes are 8.4×10^7 ft^3, 14.6×10^7 ft^3 and 10.2×10^7 ft^3, respectively. Hemipelagic sediment volumes deposited during the likely period of seepage ($<4 \times 10^3$ ft^3) are negligible.

Fourier analysis of the residual relief anomalies at seep sites provides a means of assessing the naturally occurring geomorphic wavelengths related to vertical mass migration. These natural seep wavelengths, which correspond to morphologic features that formed over different periods of time, are 350 ft, 450 ft, 500 ft, 550 ft, 650 ft, 1000 ft and 2700 ft. The longer wavelength features most probably reflect evolution over longer time periods while the shorter wavelength features reflect development over shorter time periods. Although the precise relationship between wavelength and time is not directly determined, Fourier spatial wavelength spectra appear to correlate with paleoclimatic periodicities recorded in oxygen isotope data from annually layered Greenland Ice Sheet ice-cores and with ^{14}C and $\delta^{18}O$ dated gamma ray records in Gulf of Mexico deltaic sediment cores. Suggested Fourier spectral correlations (wavelength = ~periodicity) are as follows: 350 ft = ~1500 yr; 450 ft = ~2600 yr; 500 ft = ~3500 yr; 550 ft = ~4000 yr; 650 ft = ~5000 yr; 1000 ft = ~7700 yr; and 2700 ft = ~10600 yr. Using this chronology as a guide, seep-related net vertical mass flux values associated with the arbitrarily selected 150 ft, 300 ft and 450 ft mapped volume anomalies are calculated to be 20.0×10^9 grams/yr, 10.0×10^9 grams/yr, and 2.8×10^9 grams/yr. Therefore, for the seep sites surveyed, the average total flux of gas (stored as hydrate), extruded mud and chemical-biogenic precipitates over approximately the last three millennia may be expected to be approximately 3.3×10^{10} grams/yr.