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Geochemical, isotopic and seismic indicators of fluid flow in pressurised growth anticlines and mud volcanoes in modern deepwater slope and rise sediments of offshore Brunei

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Integration of 3D seismic with seafloor sedimentology (from 187 piston cores collected across the slope and rise of Brunei Darussalam), organic geochemistry (gas analysis and chromatography) and stable isotopes of carbonate nodules in the cores, shows that seafloor sediment containing thermogenic gases and bitumens occur atop or adjacent to actively growing mud-cored compressional ridges, particularly where these pressurized fluids and muds periodically breakout onto the seafloor as mud volcanoes. Thermogenic signatures are not found where sediment is actively accumulating. There the sediment contains organic signatures and gases that are biogenic and related to the bacterial breakdown in the sulphate reduction zone. Seismic signature shows the volcanoes are regions of pressure build up and their incipient breakout is indicated by a combination of convex upward seismic reflectors and zones of discontinuity in the BSR (a seismic indicator of shallow levels of methane hydrates). This reflects the rise of warm fluids toward the surface and the consequent melting of the bottom parallel hydrate layer. Following pressure release at the seafloor and a period of inactivity, sediments layers within and adjacent to a mud volcano collapse, the reflectors bend downward into the neck of the volcano and a BSR re-establishes in the now inactive neck. Mud volcanoes in the continental slope and rise of Brunei occur in a downslope series of gravity-driven compressional ridges with seismic geometries similar to the salt-cored compressional ridges of the slope and rise setting of the circum-Atlantic salt basins. However, in the case of the shale-cored ridges and

mud volcanoes of Brunei the seismic image maps zones of sediment disruption created by the presence of gas and fluid. This is a fluid map not a lithology map (c.f. imaging actively flowing salt in salt cored compressional anticlines). It has a different set of rheotropic properties compared to salt, especially once fluid/mud breakout to the seafloor occurs and the mud-filled structure then depressurizes and flow freezes.