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The Yampi Shelf, Browse Basin, North-West Shelf, Australia: A test-bed for constraining hydrocarbon migration and seepage rates using a combination of 3D seismic data and multiple, independent remote sensing technologies

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The Yampi Shelf, northwest Australia, is located on the northern inboard edge of the Browse Basin (at a margin-scale relay system which separates the Bonaparte and Browse Basins). It comprises part of a Palaeozoic to Mesozoic flexural ramp margin which dips north-west, away from the flanking cratonic Proterozoic Kimberley Block. The Kimberley basement has a rugose topography, with some horst blocks elevated 500 m above the surrounding basement. Cretaceous seal-reservoir couplets are developed around, and over, this basement ramp topography, providing a range of play types which have been explored over the last few years. Progressive onlap of Cretaceous post–rift seals onto the basement ramp has resulted in the regional seal becoming both thinner and sandier margin-ward. In some of these more margin-ward locations, some prominent basement highs are 'bald' of seal, whereas in others, the seal thins dramatically onto the back of topographically prominent, landward-dipping tilt blocks. The region is presently receiving a very active hydrocarbon charge, which consists of both oil (Cretaceous-sourced) and gas (pre-Jurassic sourced).

A detailed research program on the Yampi Shelf over the last few years has investigated the hydrocarbon migration, leakage and seepage characteristics of this region using a combination of:

- 3D (and regional 2D) seismic data;
- oil seep remote sensing data, including five-fold coverage Synthetic Aperture Radar (SAR) coverage, two high-resolution (1,000-2,500 m line spacing) water column geochemical sniffer surveys, two Airborne Laser Fluorosensor (ALF) aircraft surveys, and an aircraft-mounted hyper-spectral survey;
- two geological sampling programs, which used combinations of cores, grabs, videos and side-scan sonar.

Natural hydrocarbon seepage was confirmed independently by all of the remote sensing technologies, though the relative response and sensitivity of each technology to seepage of varying rates and compositions was quite different. The first-order control on the distribution, and perhaps the composition, of the detected seepage was the thickness and capacity of the regional Cretaceous sealing units. Overall, the seeps could be broken down into a number of simple categories.

Gas chimneys (low flux)

Small, localised (<4-5 km across) dry gas seeps were found to be principally related to seismically-prominent gas chimneys which were associated with topographically prominent tilt blocks. These chimneys, whilst both sharp and spectacular on seismic data, typically only resulted in relatively small amounts of seepage, typically 2-4 times background (as measured by sniffer). This seepage related to the thinning of the regional seal, with attendant loss of seal capacity, across the tops of the tilt blocks, and low-flux seepage through relatively restricted zones. These gas chimneys often produced significant amplitude anomalies in the shallow (<500 msecs) section, though they typically had little apparent affect of the seafloor, either in relation to bathymetry or amplitude effects.

Areally extensive gas seeps (high-flux)

All of the major gas seepage, which in some areas reached >300 ppm in the bottom waters (>100 times background from the sniffer data), was closely associated with a broad region containing prominent and large basements horsts which were partially to completely bald of Cretaceous seal. The principal detected seeping hydrocarbon was dry (<1% wet), thermogenic gas ($\delta^{13}C$ = -42.45). These intense zones of seepage were measured repeatedly through time (over several years) tended to be very large (10 to as much as 30 km across), though their seismic expression was muted, and was often restricted to diffuse zones of relatively poor coherency, or the presence of very prominent amplitude anomalies at the seafloor. Comparison between methane concentration in the water column and the extracted seafloor seismic amplitude through the region of these dry gas seeps revealed an almost one-to-one relationship, apparently because of enhanced, seep-related carbonate cementation at, or near, the seafloor. Sediment samples through this area of gas seepage show molecular evidence for the presence of both aerobic and anaerobic methane oxidising microbial communities. Aerobic processes are signified by the presence of diagnostic hopanoids, while newly anaerobic methane oxidising consortia are revealed through their gylcerol ether signature lipids. Isotopically light carbonate cements were also detected within the sediments through this zone. No macro-seep communities were detected through these areas, though a series of prominent pockmarks were present. The locations of both the pockmarks and the massive gas seepage could be directly linked via the 3D seismic data to areas of thin, poor quality seal.

Areally extensive oil seeps (intermittent, high-flux)

The most prominent oil seeps on the Yampi Shelf (detected principally by SAR) were located ~10-15 km inboard of the intense gas-seeps. This oil seepage was focused along a zone corresponding approximately to the regional zero-edge-of-seal. Prolific seepage was observed on only two of the five SAR scenes interpreted, suggesting that this oil seepage was very intermittent, perhaps related to a progressive build-up and then release of hydrocarbons at the seal's edge. These seeps appear to be due to the leakage of relatively heavy, biodegraded oil, of a type similar to that found within the reservoir in the nearby Cornea oil discovery. Prominent macro-communities (detected on side-scan sonar data) appear to be developed all along this zone of oil seepage, which tends to be characterised by relatively low seismic amplitudes.

The offset between the location of seeping dry gas and heavy oil on the Yampi Shelf appears to be reflecting the differences in the relative mobility of gas and oil, controlled by differential seal capillary failure. The heavy, Valanginian-sourced biodegraded oil has migrated much further inboard, and only leaks to the seafloor once the seal is virtually gone. In contrast, the Palaeozoic/Early Mesozoic-sourced gas 'breaks through' the seal sooner because of its much higher relative mobility. As a consequence, dry gas seeps are developed in more basin-ward locations. Hence, on the Yampi Shelf, the progressive seal capillary failure towards the basin margin appears to have produced a large-scale, spatial compartmentalisation of the seeping hydrocarbons, in relation to both composition, and flux.

Overall, it appears that hydrocarbon seepage on the Yampi Shelf is controlled by a combination of low rates and volumes of secondary migration from basinal source rocks and high rates and volumes of tertiary migration of oil and gas displaced from accumulations (such as the Cornea trend) along the margin.