AAPG HEDBERG CONFERENCE
"Near-Surface Hydrocarbon Migration: Mechanisms and Seepage Rates"
SEPTEMBER 16-19, 2001, VANCOUVER, BC, CANADA

The Implications of Hydrocarbon Seepage, Gas Migration and Fluid Overpressures to Both Exploration and Geohazards – from Frontier Exploration to Slope Failure Risk Assessment

or

Gas Migration, Shallow Gas, Hydrocarbon Seeps and Overpressuring on Continental Margins: the Link Between Subsurface Processes, Mud Volcanism, and Slope Failure

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Seafloor seeps occur wherever overpressuring occurs and there is a conduit to the seafloor. We view seeps as the "pulse" of the hydrocarbon system, and in this presentation we will discuss the implications of seepage to frontier exploration and to geohazard evaluation.

Exploration:

Seafloor seeps provide samples of the fluids present in a basin without drilling. 3D multi-channel seismic (MCS) data can be used to infer the presence of conduits at depth. The seafloor rendering of 3D MCS seafloor data can be combined with seafloor amplitude picks to identify the surface manifestation of seeps. Alternatively, if 3D data are not available, 2D MCS data can be combined with comprehensive seafloor maps (obtained via hull-mounted mapping systems) to identifiy sub-surface conduits and seafloor features. Seafloor seeps can occur as both depressions (pockmarks) and as positive relief features (pinnacles, mounds). The combination of seafloor and sub-surface data can also be used to constrain the basin geometry and fluid compartments present in the field area.

Seafloor maps with 100% coverage can now be obtained at high resolution using hull-mounted multibeam systems. Such systems are capable of mapping 400 to 1000 km^2 per day (depending on hardware, frequency, and water depth). Furthermore, most multibeam systems are capable of collecting both bathymetry and seafloor backscatter data, thus providing data similar to seismic amplitude renderings. Due to the improvement in at-sea computational facilities, the data can be processed, gridded and mosaiced at sea.

The challenge to the seep scientist is identifying the range of seafloor features and interpreting activity level prior to ground-truthing. Regardless of the approach (3D MCS versus 2D MCS plus multibeam), the combination of seafloor and sub-seafloor data with sea-surface synthetic aperture radar (SAR) satellite imagery provides a cost-effective tool for high-grading seafloor seep targets. We note that in deep water, SAR imaged seeps may be significantly offset from their seafloor origins; the combination of SAR images and seafloor renderings can be used to tie sea-surface anomalies to their seafloor source.

Seep targets identified on MCS and/or multibeam data include those related to faults (high angle as well as thrust), mud volcanoes/diapirs, salt diapirs, and slope failures. At the seafloor, both gas hydrate and seep-related authigenic carbonate create anomalously high seismic amplitude and high backscatter. Biologic seep communities themselves can also create anomalous amplitude and backscatter.

We utilize a process-oriented approach to interpret the combination of sub-surface, seafloor, and satellite data. Our objective is to analyze the range of seafloor features and their relative activity levels (geologically youthful versus dormant). We tie these seafloor observations to subsurface conduits to infer the source horizon (if possible) and conduit (migration pathway). Finally, we prioritize a suite of seafloor seep targets to be groundtruthed with coring and/or direct observation. In our experience, seafloor targets can be interpreted in a matter of weeks to months, allowing rapid turnaround time between data delivery and coring and ground-truthing. The analysis of seafloor seeps (fluid geochemistry as well as precipitates) can be used to prove, or improve, the prospectivity of a frontier block.

The exploration approach outlined above can be used to decrease cycle time by rapidly collecting, analyzing, and groundtruthing seep data.

Geohazards:

Seafloor seeps are direct evidence of fluid overpressuring (or buoyancy instability). Slope failures can be grouped into those triggerred by external forcing versus those that are internally driven. Here we focus on internally driven slope failure related to overpressuring. Internally driven slope failures are characterized by a distinct mophology of a flat base and a steep, amphitheatre-shaped headscarp. If overpressures persist (i.e. if the failure doesn't drain all excess pressure), then subsequent failure may occur within the original feature, leading to headward migration and a linear canyon morphology. We can therefore use the relationship of active seepage to slope failures to evaluate failure mechanisms and subsurface hydrogeology.

In this presentation we will focus on overpressuring related to hydrocarbon migration, shallow gas, and gas hydrates. On hydrocarbon prone continental margins we document numerous examples of internally driven slope failure, and demonstrate the link between hydrocarbon generation, gas migration, gas hydrate formation, and slope failure. At all of these locations seep-related phenomena have been documented, including water-column gas plumes, enhanced biological activity and/or the occurrence of precipitates such as gas hydrate nodules/pellets and carbonate crusts/nodules. At several locations where large underwater slides have occurred in regions that are also characterized by gas hydrate, we also not the presence of associated mud volcanoes. Their role as possible porewater pressure-transmitters is uncertain.

We discuss the relationhips between gas hydrates, seepage, mud volcanoes, free gas, and slope failure, and arrive at a physical model for a potential relationship: The "hydraulic model". With this model we evaluate pressure transmittal from depth to the near-surface via conduits such as mud volcanoes or subsurface gas plumes. We will present examples from the Storegga Slope Failure Complex, the Cape Fear Slide, the Eel River Basin, the Gulf of Mexico and Santa Barbara channel.

We have used this geologic-hydrogeologic-geotechnical approach as the foundation of observational surveys as well sampling and analysis programs to collect seep fluds and precipitates. We have also used this approach to evaluate shallow water flow horizons, subsurface gas-charged horizons, and the magnitude of overpressuring at depth.

By understanding the processes that lead to slope failure, we can model the fate of future failures (debris flow runout, turbidity currents). Within the oil industry we have used this approach to determine the origin of slope failure, evaluate the risk of future failure and quantify the hazard posed to facilities by such failures.

In contrast to downcutting canyons and slope failures, internally driven failures may be unrelated to sea level. Such failures are active today, and as deepwater development efforts push farther out onto the continental slope these features will have to be evaluated and the risk they pose to facilities incorporated into facilities development plans. By understanding where these features come from, and what their fate is, deepwater developments can be built to withstand modeled impacts, or can avoid failure prone regions.

The Future of Seep Studies in the Oil Industry: More, Better, Faster, Cheaper.

Deepwater projects in the oil industry are striving for ever shorter cycle times. Major oil companies have stated that they are targetting 3 years for first production for deepwater efforts. The approach outlined above – combining seafloor, sea-surface, and sub-seafloor data – is applicable to both exploration and production geohazards. We have found that a preliminary geohazard analysis can be conducted using the same data utilized for exploration. Thus the geohazard program can be 'jump started' without additional data collection or the high cost of a second mobilization/demobilization.

If spec 3D data are available, these data should be plundered for both exploration and geohazard assessment. If such data are not available, we recommend combining existing 2D MCS data with high resolution seafloor maps. As companies strive to decrease project cost and cycle time, the collection of 100% seafloor maps provides a valuable exploration tool and a 'legacy data set' that will be utilized throughout the life of the project. Such data, however, need to be evaluated from a process standpoint to maximize their value to both exploration and geohazards.