

Seafloor Geomorphology, Gas & Fluid, and Slope Failure on the Southern Cascadia Continental Margin

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LONG TERM GOAL

Our long term goal is to understand the role of fluid flow and gas migration in the creation and modification of shelf and slope geomorphology and seafloor acoustic character. In addition, we are examining the interaction of tectonics, sediment accumulation and erosion in creating and modifying the morphology, stratal architecture and preservation potential of continental margins.

OBJECTIVES

We are examining how hydrogeology, natural gas, and tectonics interact and influence submarine geomorphology by combining seafloor data and subsurface imaging. Our goal is to determine the causes of anomalous seafloor bathymetry and reflectivity, and to relate reflectivity to gas migration, subsurface structure, and consolidation state.

APPROACH

Our primary data sets consist of both remote sensing and direct observations. Remote sensing data include both seafloor and sub-seafloor data. For the seafloor, we are using an EM-1000 multibeam survey (including both bathymetry and backscatter) as well as towed side scan data. For the subsurface, we incorporate a nested suite of subsurface geophysical data. The lowest frequency (deepest penetration and lowest resolution data) include a commercial multichannel seismic (MCS) reflection data provided by Amoco Corp. We use these data to interpret the deep (>1 km) subsurface geology in the Eel River Basin. By combining our analyses of these data with STRATAFORM high resolution MCS data (Craig Fulthorpe, UTIG and Greg Mountain, LDEO) and even higher resolution Huntec (Mike Field, USGS) and EdgeTech CHIRP data (Neal Driscoll, WHOI), we can examine structural and sedimentologic features at scales from several meters to kilometers sub-surface. These nested subsurface techniques are then be combined with seafloor bathymetry and reflectivity data to determine the relationship between structure, gas, bathymetry and reflectivity. To groundtruth our hypotheses we incorporate ROV observations, Excalibur geotechnical sites, and geochemical analyses of authigenic carbonate and cores. We integrate these observations with the remote sensing seafloor and subsurface data to analyze active vs. dormant processes, and constrain the role of fluid and/or gas migration in creating or modifying seafloor structures.

We are also carrying out a theoretical study exploring the lack of slope failure in the Eel River basin. Specifically, we are examined the relationship between seismicity and slope failure by evaluating the

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attenuation of seismic waves in shallow sediments. This work has been carried out in collaboration with Lincoln Pratson (Duke).

WORK COMPLETED

- * We have completed analyses of authigenic carbonate collected during both ROV and coring programs has been analyzed for its geochemical signature (in collaboration with T. Naehr, MBARI). Stable isotope compositions (carbon and oxygen) of samples from structural highs indicate a thermogenic (deep) gas source.
- * We have also analysed head space gas from cores and Excalibur geotechnical probes from the 1998 field season (in collaboration with T. Lorenson and K. Kvenvolden, USGS). The only anomalous methane samples came from slope cores; no shelf cores yielded anomalous methane, even though high resolution sub-bottom profiles in these areas showed evidence for subsurface gas.
- * We participated in three legs of the August, 1999 R/V Thomposon STRATAFORM cruise to the northern California study area to investigate the anomalous reflectivity on the subaqueous deltas. We are collaborating with Neal Driscoll (WHOI) and Chris Summerfield (WHOI) on the interpretation of these data, specifically correlating observations of gas in the subsurface and on the seafloor (seismic and side scan) with head space gas analyses.
- * We have assembled all available geophysical data, geologic base maps, well locations, and interpreted seafloor structures into a GIS database. We are collaborating with Larry Mayer (U. New Brunswick) in assembling a STRATAFORM GIS that we will press on CD and distribute at the 12/99 STRATAFORM meeting.
- * A detailed study of additional Hunttec data indicates that an upper slope region of localized sediment accumulation and intervening erosion ("the Ridge and Swale zone" is present on both the north and south side of the Little Salmon fault. We interpret this feature to represent upper slope contourite deposition, rather than a shelf edge delta.
- * Analysis of industry geophysical data on a Landmark workstation suggests that previously unknown high angle faults cross-cut the Eel River STRATAFORM field area, and that these faults are active. The relationship of these faults to sediment preservation potential and fluid seepage is under investigation.

RESULTS

In our previous analysis of ROV observations in the context of regional geophysical surveys we proposed two different mechanisms for fluid expulsion: continuous along structure vs. episodic (and catastrophic) between structures.

Geochemical Analyses:

On the MBARI-funded ROV dives in 1997 to the surface expressions of the Little Salmon and Table Bluff anticlines on the slope we identified a large number of seeps, extensive authigenic carbonate, and gas bubbling out of the seafloor. These observations indicated that the high backscatter on the Little Salmon fault was related to the surface exposure of seep-related carbonate.

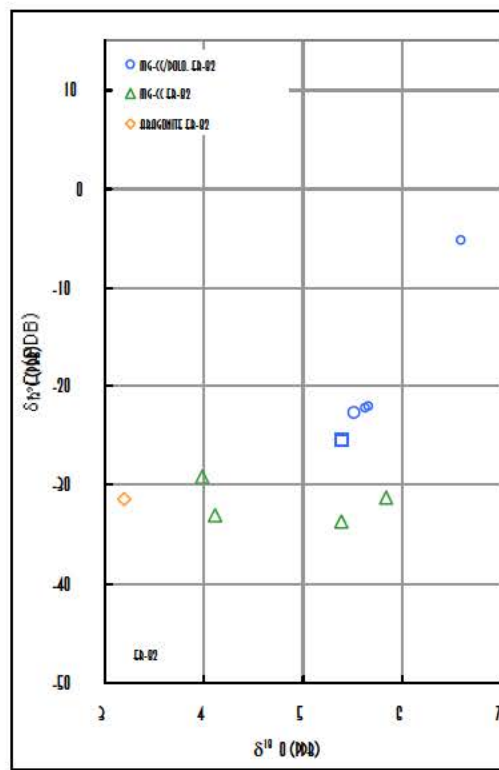
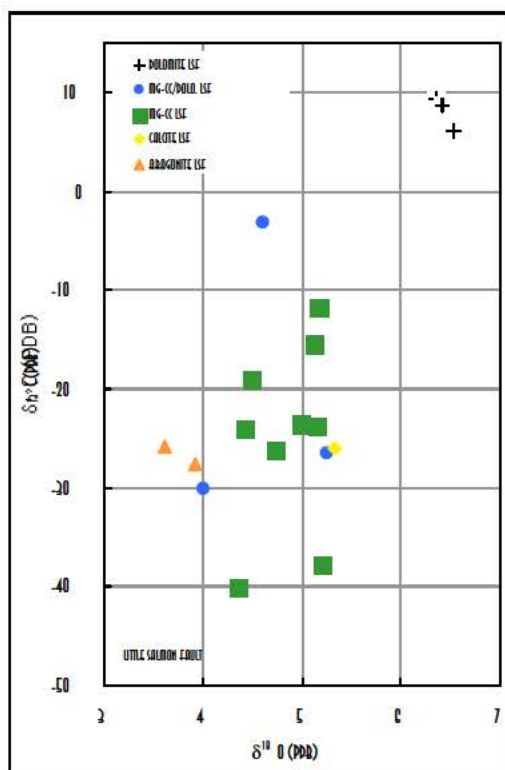
Authigenic carbonate clasts, slabs, and chimneys collected from both the Little Salmon Fault and Table Bluff Anticline sites (520m water depth, just southwest of the STRATAFORM study area) have a range of carbonate mineralogies, including calcite, high magnesium calcite, dolomite and aragonite.

Analysis of both the Little Salmon Fault and Table Bluff Anticline samples indicates a range of isotopic compositions (Figure), with most characterized by $\delta^{13}\text{C}$ of -15 ‰ to -30 ‰ and $\delta^{18}\text{O}$ of $+4$ and $+6$ (PDB). These compositions indicate precipitation from fluids with a strong thermogenic methane signature.

Isotopic Composition of Eel River Basin Authigenic Carbonate

LSF = Little Salmon Fault

ER-82 = Table Bluff Anticline



T. Naehr, written comm., 1999

Gas samples obtained with the ROV on the slope contained as much as 46,000 ppm methane, with minor but significant amounts of higher order hydrocarbons (gas and “head space” analyses conducted by T. Lorenson and K. Kvenvolden, USGS). “Head space gas” refers to a process whereby a gas analysis is obtained from a sediment sample. The sediment is placed in an airtight container and nearly filled with seawater, leaving a 100 cc gas “head space”, then sealed. The gas within the sediment sample is initially in solution in the pore fluid and/or absorbed onto the sediment particles. To get this gas into the sampleable head space (hydrocarbon gases are relatively insoluble) the can is vigorously agitated. The gas partitions into the head space to be drawn off for analysis by gas chromatography. Head space analyses can provide an assessment of the constituents in a gas (C1, C2+, etc.) as well as a relative determination of gas concentrations. Absolute gas concentrations require pressurized sampling equipment to keep gas from coming out of solution during ascent through the water column.

Although the gas obtained at structural highs was predominantly methane with a mixed biogenic and thermogenic signature, the isotopic signature of the carbonate indicates a thermogenic source, and the

ethane in the gas was identical to samples of thermogenic gas obtained from wells in the on-shore Thompkins Hill gas field (Lorenson et al., 1998; see publications). The Thompkins Hill field has produced 102 bcf of gas since 1937, with undiminished reserves estimated at 10 bcf even though current production equals 3.2 mcf/day. On ROV dives to the shelf above the projected location of a subsurface mud diapir/breached anticline we found extensive bacterial mats and bubbling gas, but no carbonate, consistent with the low backscatter in this region.

In 1998, as part of the slope coring and Excalibur program, we obtained sediment samples from a number of sites on the shelf and slope. Samples E50 and W50 were taken from the low backscatter Eel and Mad River deltas, with P50 and P70 from the intervening “normal” backscatter region. The L and O cores were obtained from the headwall and base of the Humboldt Slide, the S-series from the Ridge and Swale zone, and the Y cores from the northern gullied region. Headspace gas analyses indicated anomalously high methane in the O400 sample (base of the Humboldt Slide; Table), although O550 had background levels of methane. None of the shelf cores showed anomalous gas, although these locations were selected prior to the CHIRP and side scan program which pinpointed shallow gas zones on the subaqueous deltas. We continued our head space gas sampling program in 1999 on the shelf and slope coring program conducted with the R/V Thompson. We are specifically analyzing the distribution of gas with respect to the anomalous subsurface features present in the Huntec sub-bottom profiling data which we attribute to gas.

The Ridge and Swale Zone revisited: an upper slope contourite?

High resolution multibeam and seismic reflection data show a series of alternating seafloor highs and lows on the upper slope (water depths 150 - 300 m). These features, known informally as the “ridge and swale” zone, are oblique to the continental slope, have amplitudes of 5-10 m, wavelengths of ~500 m, and lengths of up to 8 km. The seaward (west-facing) slopes of the ridges have higher acoustic backscatter than the intervening swales. In our previous analyses we had stated that the southern boundary of the ridge and swale zone is associated with the Little Salmon fault. A critical re-examination of the data, however, indicates that these features are present on and above the headwall of the Humboldt Slide south of the Little Salmon fault, although their seafloor signature is more subtle than in the region to the north.

South of the Little Salmon fault the ridge and swale structures trend more or less parallel to isobaths, with the amplitude of the the features decreasing to the south (away from the fault). The presence of these features north and south of the Little Salmon fault precludes their being a shelf-edge delta. Instead, we favor a mechanism of upper slope contourite currents that alternately deposit and erode these features. The signature of these contourites is enhanced at the Little Salmon fault by the focusing of the along slope flow through the gap created by the en echelon offset of the fold. We are still examining the relationship between these features (their overlapping stratal geometry and backstepping pattern) and eustasy. Specifically, the geometry suggests sequence deposition during periods of relative sea level rise, which may allow upper slope contourite currents to be funnelled through the gap in the fault.

Compilation of a project GIS:

To facilitate the dissemination of the Eel River STRATAFORM data and to improve communication among the researchers, we assembled all available geographic coverages and are collaborating with L. Mayer (U. New Brunswick) in the production of a project GIS. Geographical Information Systems

(GIS) software provide a powerful and easy to use suite of tools for interrogating, cross-correlating, and visualizing spatially referenced data sets. As part of our efforts, we collaborated with S. Gullick (formerly of Lehigh University, now at U.T. Institute for Geophysics). Coverages include offshore structures (from Sam Clarke, USGS), ODP and industry wells, the on-land Thompkins Hill gas field, a geologic base map from the California Division of Mines and Geology. Offshore geophysical data include NOAA SeaBeam, Hydrosweep multibeam (funded by ONR), the STRATAFORM EM-1000 multibeam bathymetry and backscatter, the location of ROV dives and observations, core locations, Huntex seismic lines, interpreted gas distribution, pockmark distribution, and inferred gas columns in the water column. The project GIS will be available on CD-ROM in December, 1999.

IMPACT/IMPLICATIONS

In 1999 we presented several talks and published a manuscript demonstrating the utility of the nested geophysical and seafloor survey approach to industry applications, specifically hydrocarbon and telecommunications. We have shown that high resolution multibeam data can be used to document seafloor seepages, and such seepages in petroleum environments provide direct samples of the fluids and hydrocarbons in a basin without exploration drilling. Multibeam data are most effective when combined with high resolution sub-bottom profiling and multichannel seismic data.

Our seismic data interpretations, ROV surveys, core sampling, and gas analyses surveys, show that gas migration may significantly affect seafloor backscatter intensity. We have shown that structural highs on this gas-rich margin are regions of long term gas expulsion, and that the gas currently leaking out of the seafloor is similar to thermogenic gas being produced from the correlative on shore Thompkins Hill field. The bacterial oxidation of seafloor methane seeps leads to carbonate precipitation. This carbonate can armor the seafloor and significantly increase backscatter intensity. This phenomenon may be widespread on continental margins, leading to the prediction of increased backscatter on structural highs on any continental margin known to contain subsurface gas.

TRANSITIONS

By documenting tectonically uplifted regions where deep basinal reflectors approach the seafloor, our work will help define coring locations where reflectors can be sampled and extrapolated to the basin at large. This will aid in the interpretation of long-term sequence stratigraphic packages, and provide a methodology whereby numerous offset short cores can provide data on otherwise inaccessible deep reflectors.

Work on the tectonic history of the Eel Basin directly impacts STRATAFORM by contributing to the knowledge base about long-term ($> 10^5$ yr) strata preservation.

RELATED PROJECTS

Our work on the interaction of gas, seafloor morphology and reflectivity is now being expanded upon by high resolution sub-bottom profiling surveys (CHIRP sweep-frequency sonars) conducted by Neal Driscoll (WHOI). We are also working with Larry Mayer (U. New Brunswick) in assessing methods to associate the presence and amount of gas in near-surface sediments with the azimuthal variation of seafloor backscatter.

We are working with Mike Field and Jim Gardner (USGS) in analyzing and interpreting Hunttec high-resolution sub-bottom data, focusing on the Ridge and Swale zone both north and south of the Little Salmon fault. We are also working on reflector correlations between the multiple seismic and sub-bottom profiling data sets. We are collaborating with Craig Fulthorpe (U. Texas) and Greg Mountain (LDEO) in integrating our studies of the commercial MCS data with their high resolution MCS data.

ROV observations and sampling on both the shelf and slope are helping Larry Mayer and John Hughes-Clarke (U. New Brunswick) groundtruth acoustic reflectivity and swath bathymetry data. ROV samples within the Eel Canyon are assisting Clark Alexander (Skidaway Institute of Oceanography) in determining the importance of this system to sediment distribution on the Eel margin.

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