Heat flow and gas hydrates on the continental margin of India: Building on results from NGHP expedition 01

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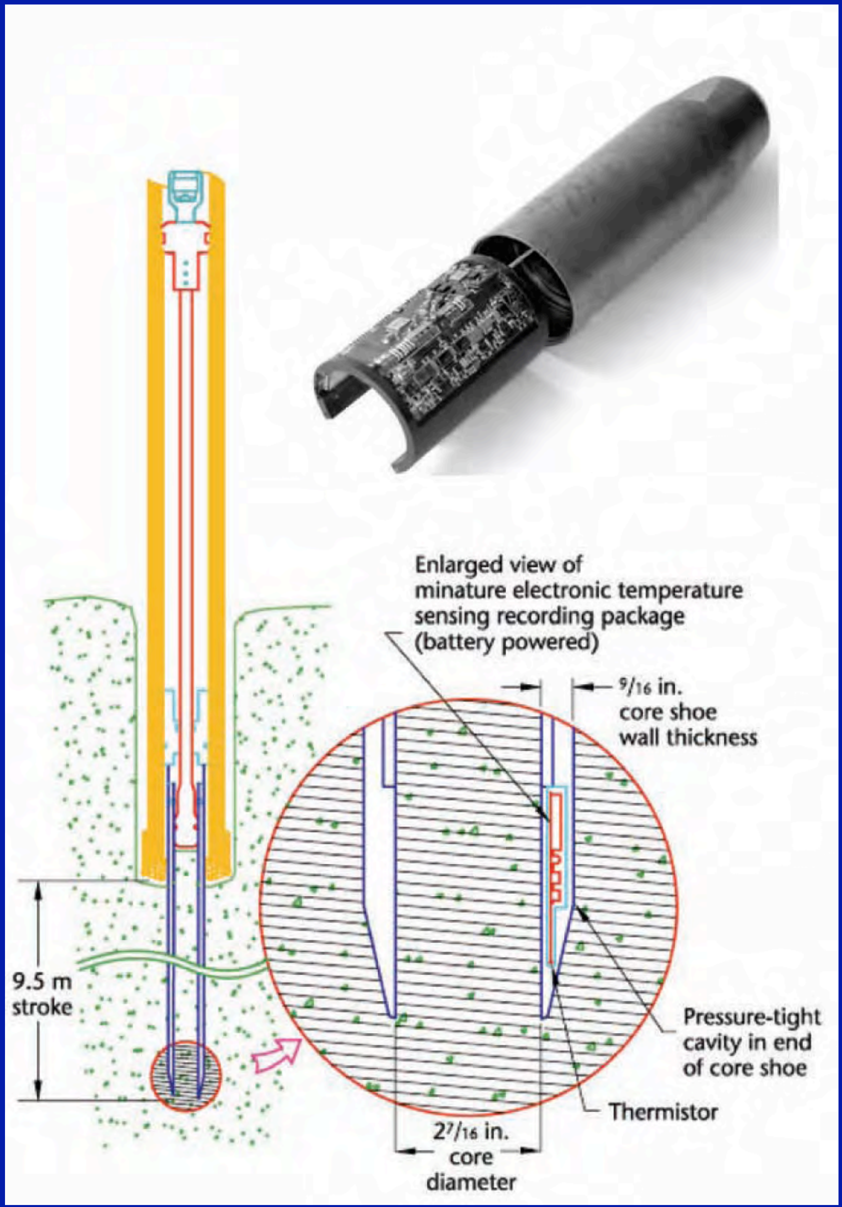
During the NGHP expedition, 72 in situ temperature measurements were attempted at 12 sites;
58 (81%) of these attempts provided useable data.

Outline

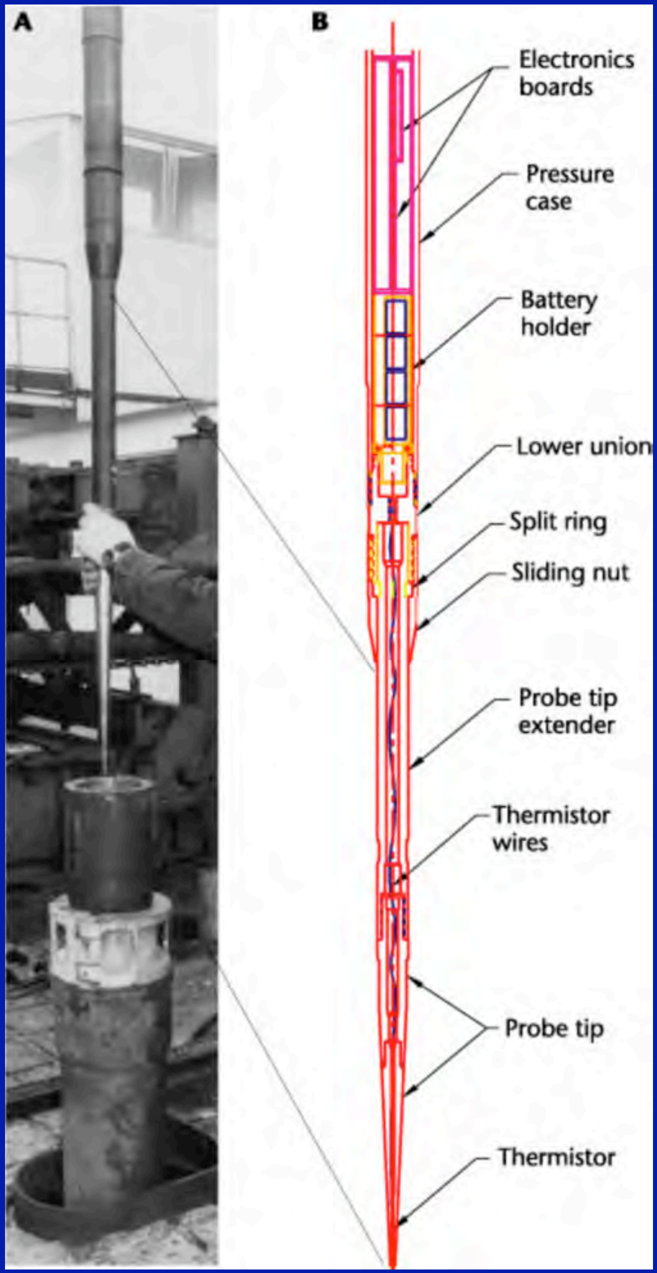
- Tools and techniques for measuring in situ temperature
- Interpretation of the measurements at individual sites
- Regional interpretation
- Update on status of work being performed for this project (Peter)

APCT/APCT3 for measurements in IODP boreholes.



•3rd generation of a temperature tool that fits into the cutting shoe of the Advanced Hydraulic Piston Core.
•Debut during IODP Leg 311; first large-scale use during NGHP.
•Designed by Andy Fisher (UCSC) and Heiner Villinger (Un. Bremen)

Advantages:
•No need for dedicated run.
•Larger memory.
•More battery power.
•Faster sample rates possible.
•More stable temperature sensor.
•Better calibration.

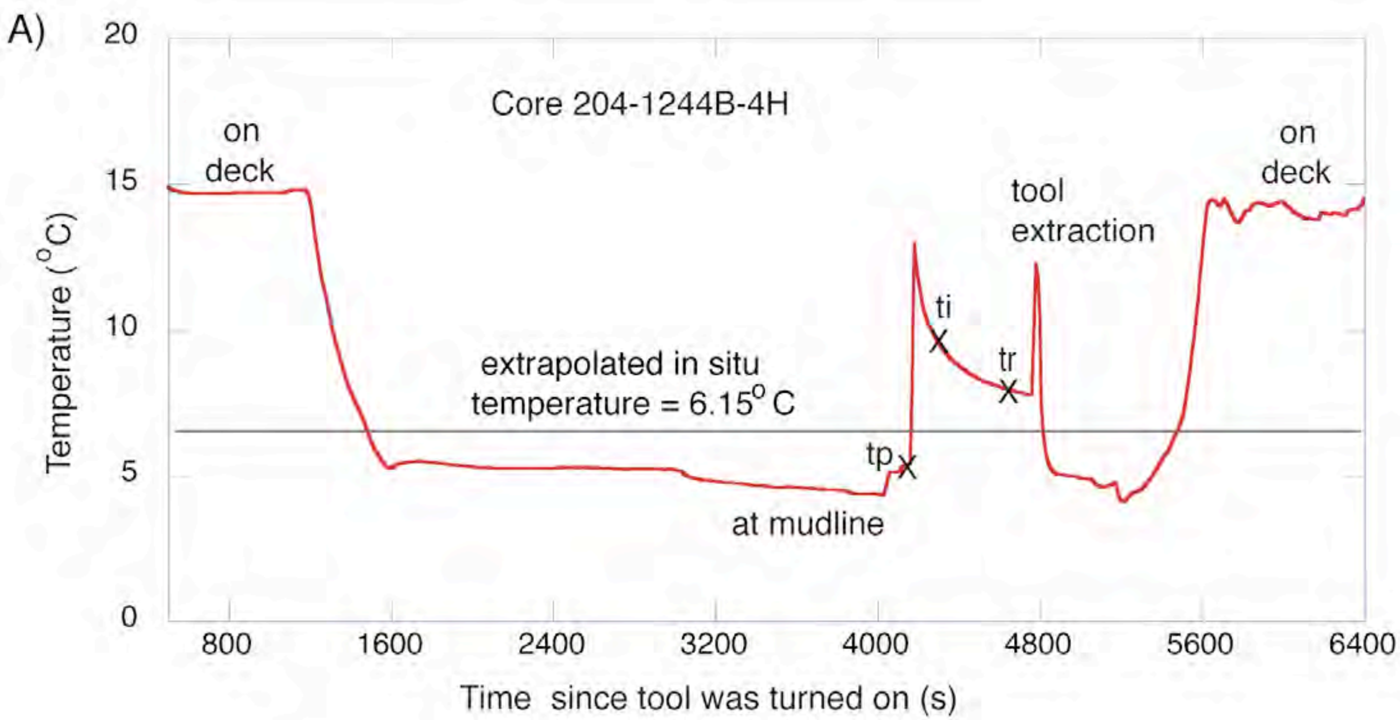


DVTP/DVTPP

Davis-Villinger Temperature (and Pressure) Probe.

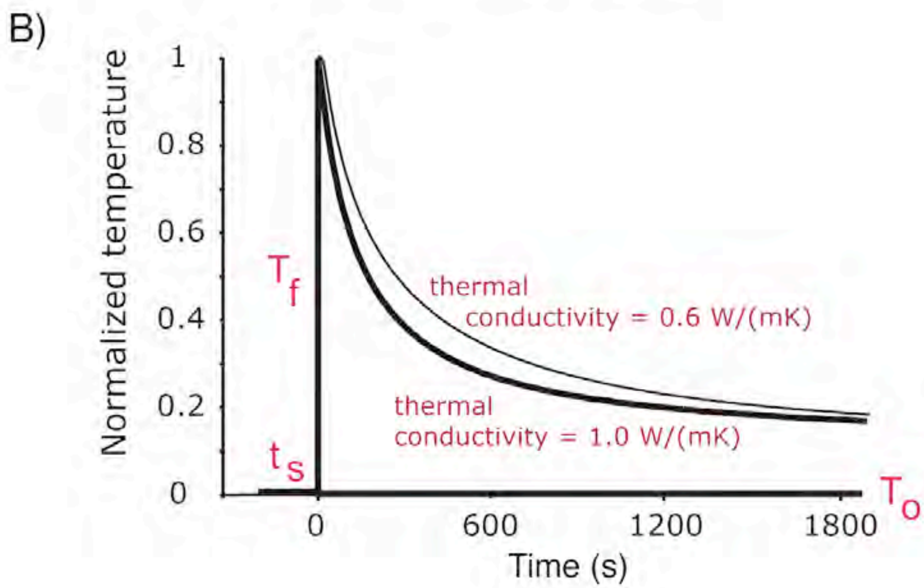
Use in sediments that are too stiff for the APC.
Requires a dedicated run.

Otherwise, analysis is similar to analysis of APCT/APCT3 data. Analysis for both data types have been integrated into a new software package called TP-FIT written by Martin Heesemann (Un. Bremen) to replace the old TFIT and CONEFIT software for the APCT and DVTP, respectively.

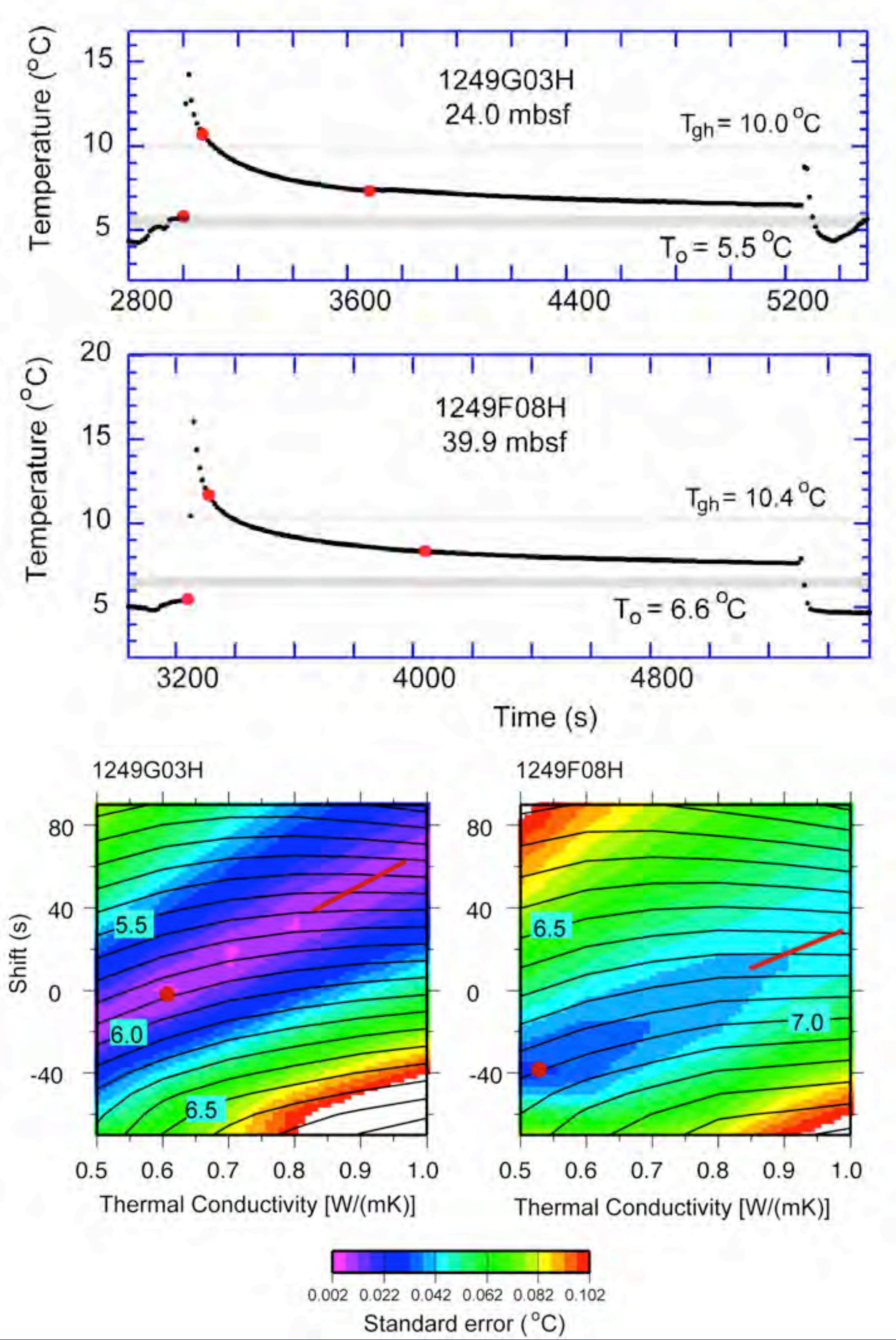


Example of the temperature history of a measurement.

Impulse response of the probe to frictional heating



Modeling the data: fit segment from ti to tr for a given thermal conductivity to extrapolate for To.



ANALYSIS:

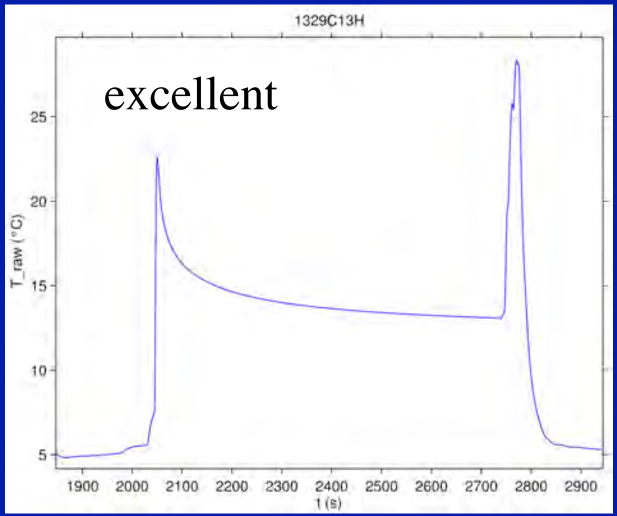
Free parameters are three time picks plus thermal conductivity.

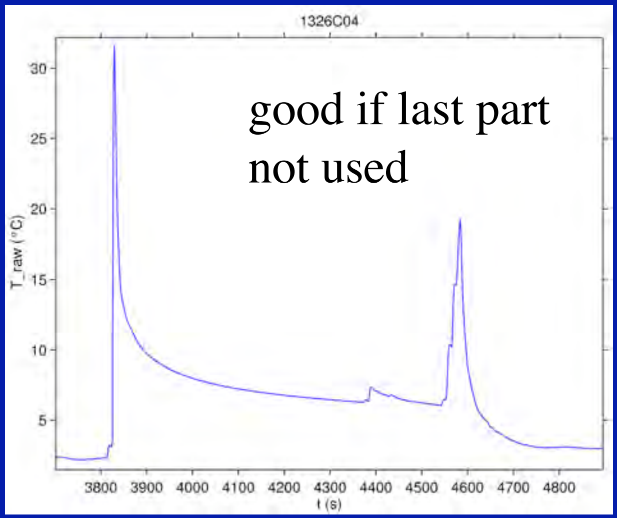
In most cases, there is a tradeoff between To and thermal conductivity.
Sometimes a surprisingly low thermal conductivity is indicated - may indicate local hydrate effect.

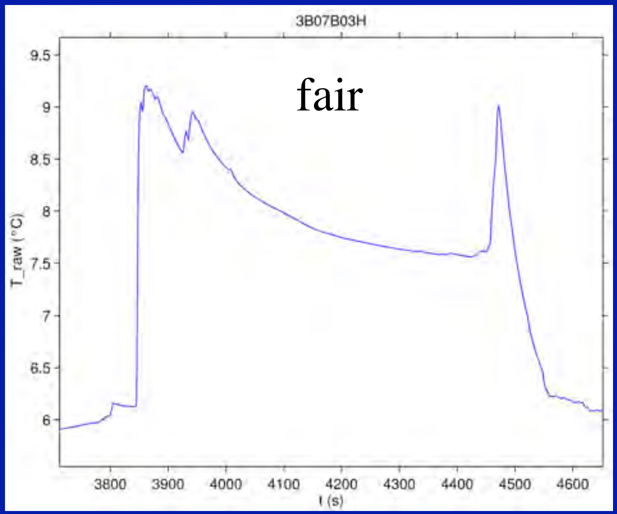
Near the hydrate stability boundary, temperature can rise enough to destabilize hydrate for several minutes (longer the closer you are to BGHS).

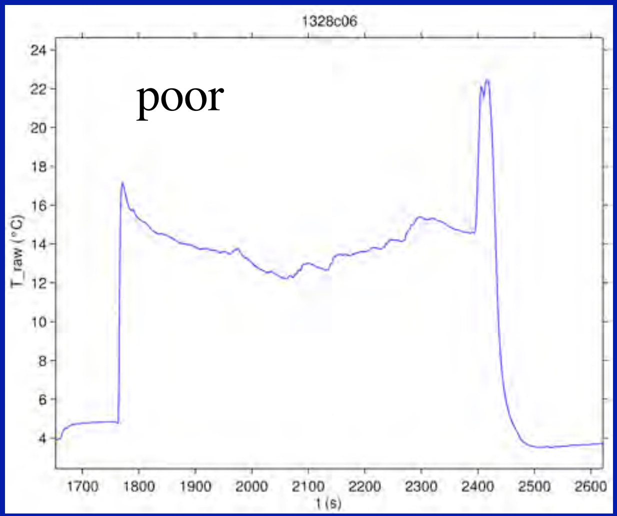
Prior to NGHP (and new analysis software by Heeseman and Villinger) analysis of trade-offs between free parameters was very laborious.

Qualitative rating scheme for data: problems occur if the tool moves relative to the sediment because of rough seas or if there is difficulty inserting the tool into the sediment (examples from IODP Exp311)







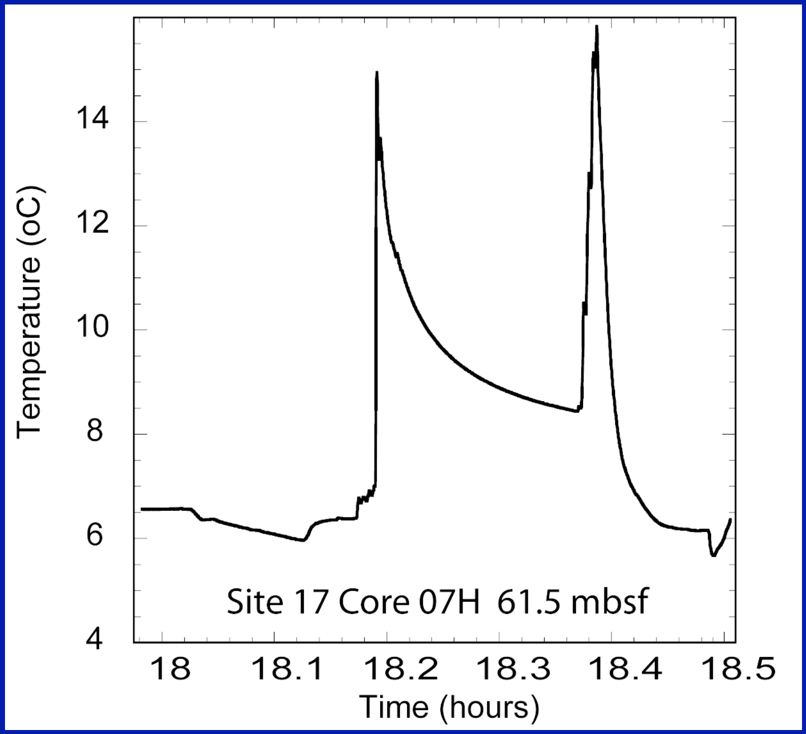


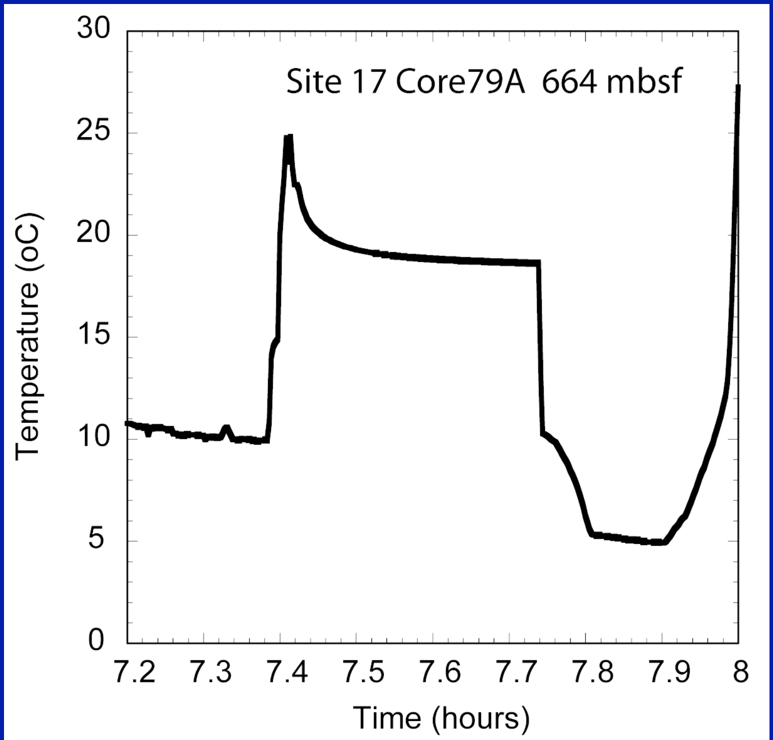
NGHP Data:

Generally excellent quality due to good calibration and good weather (58 out of 72 attempts good-excellent quality).

Depth range from 21 to 664 mbsf. Data obtained close to BSR at all sites.

Good calibration because of high resolution calibration of APCT-3 and careful cross-calibration of other instruments prior to the cruise.

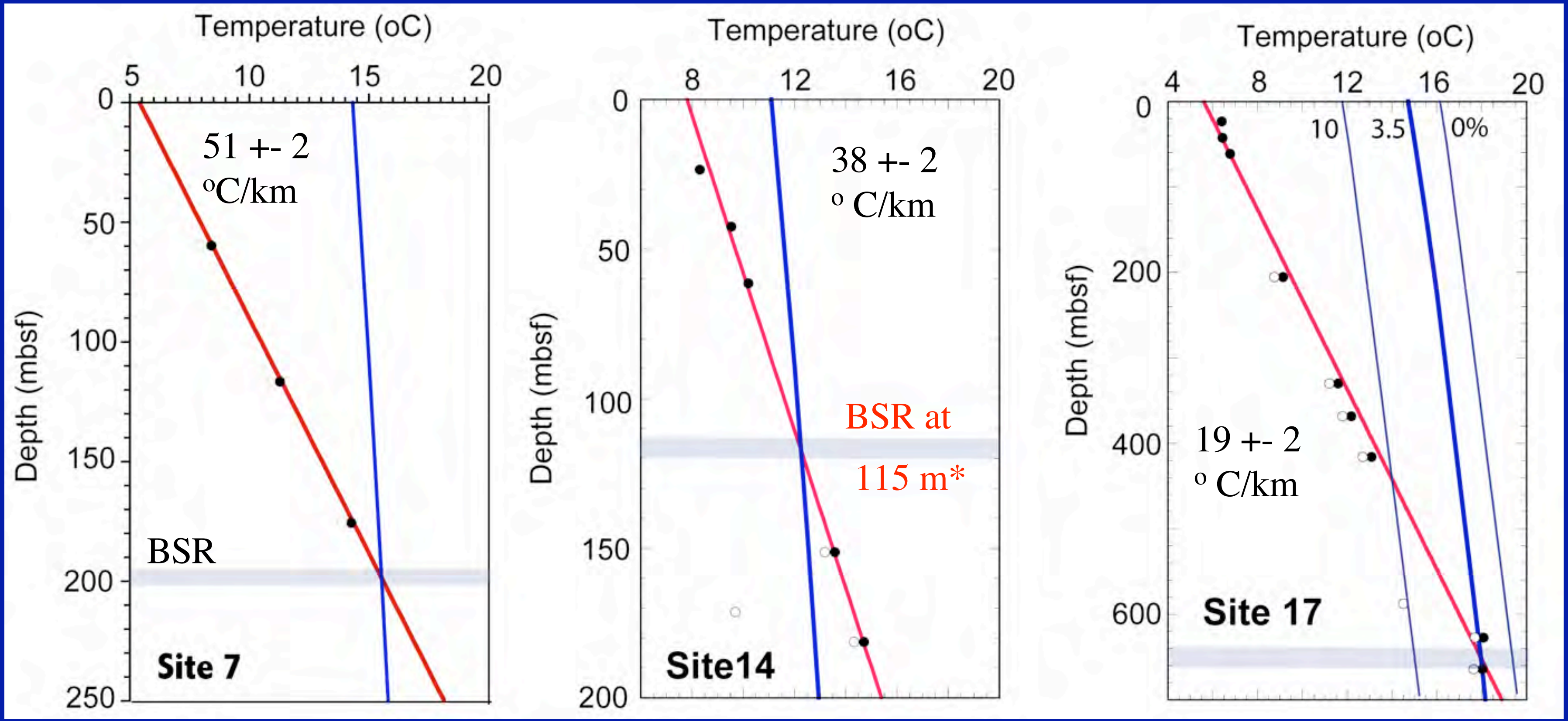




Some cartoons of different possible temperature profiles:

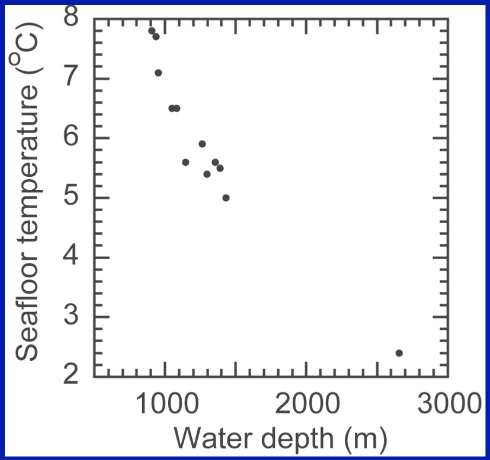
A. Conductive heat flow; constant thermal conductivity.
B. Conductive heat flow; layered thermal conductivity.
C. Flow of water fluid along a fracture.
D. Recent change in bottom water temperature.
E. Upward fluid flow (sensitive to rates of ~0.1-10 cm/yr)

Examples of Temperature v.s. Depth for NGHP data:

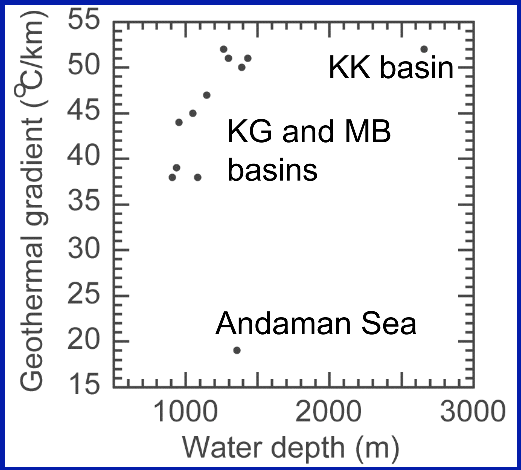


- •Data generally well fit by a straight line (i.e. a conductive thermal gradient in medium with constant thermal conductivity).
- •BSR depth predicted by intersection of stability boundary (blue line) with thermal gradient. Constrained to within 6-10 m assuming salinity 3-4%.
- •Some possible anomalies, but difficult to interpret their significance without more closely-spaced data. Need new tools (e.g. fiber optic DTS).

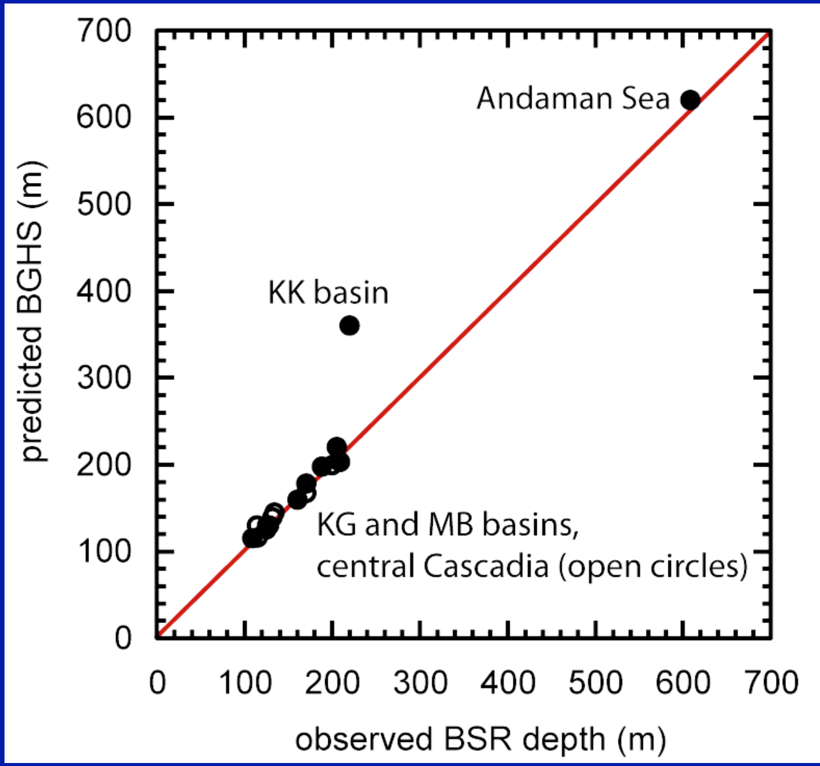
Results:



Decrease in water temperature with increasing depth as expected.

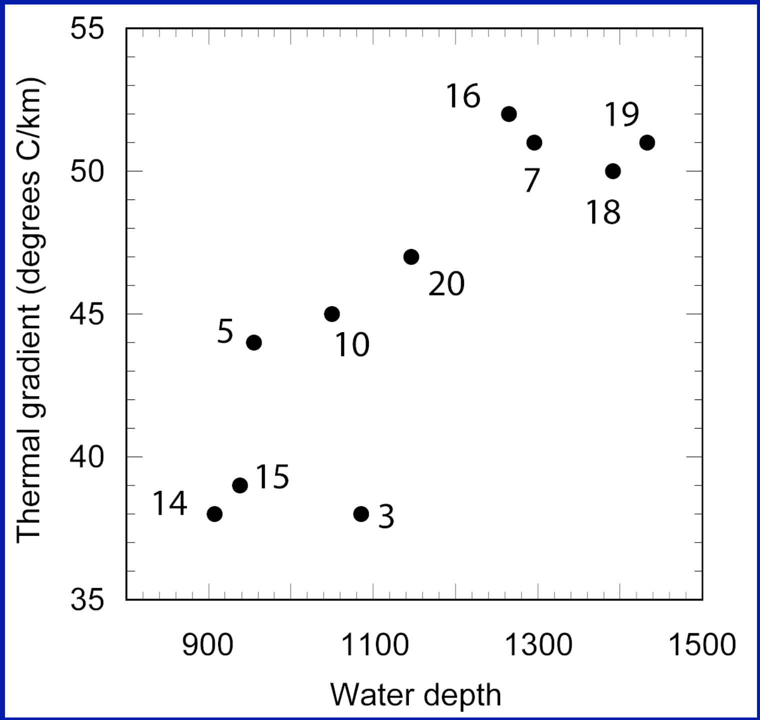


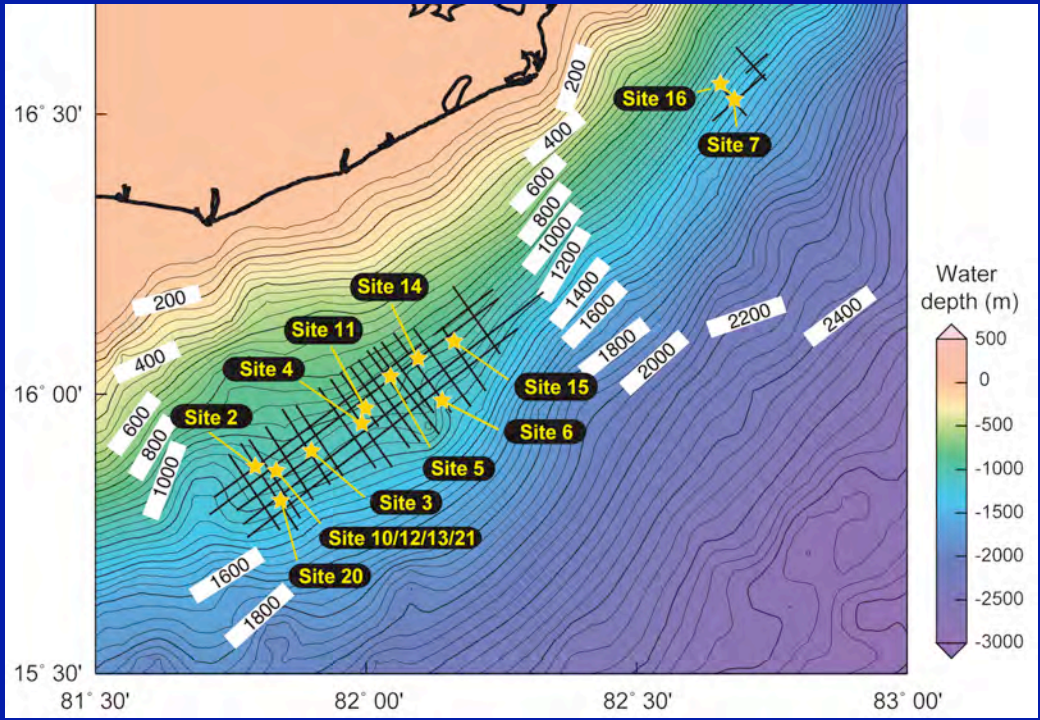
Increase in thermal gradient with increase in depth unexpected.



Base of gas hydrate stability predicted by in situ temperature data corresponds closely with observed BSR depth in almost all cases:

- Gas hydrate is in thermal equilibrium
- BSR can reliably be used as a proxy for heat flow if thermal conductivity, velocity and pore water chemistry are known.



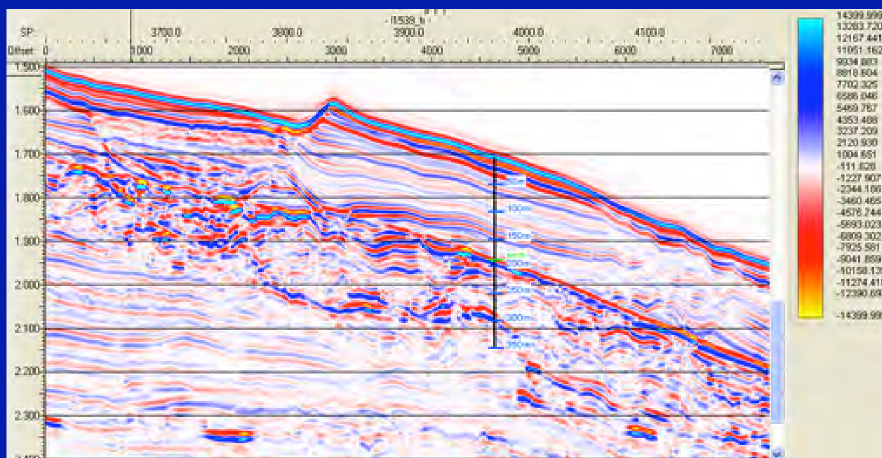


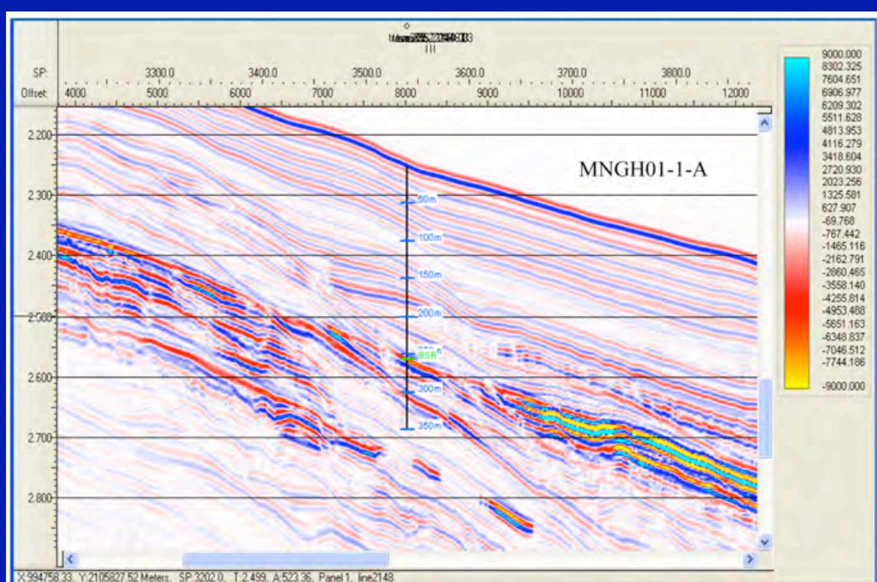
Heat flow = k dT/dz

•Constant heat flow; variations in k.

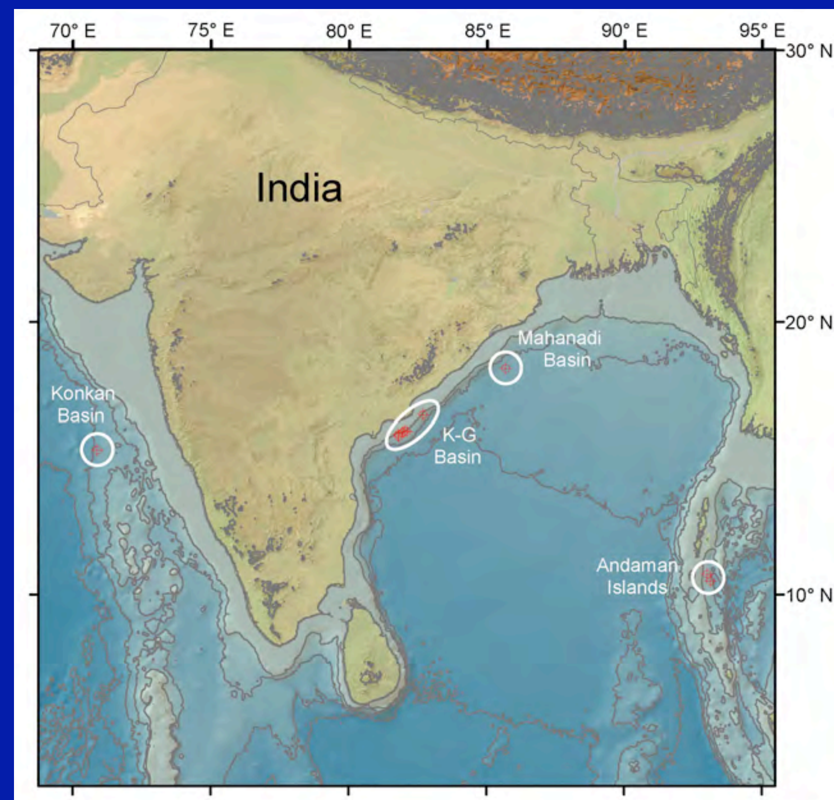
•Variations in heat flow due to topography, erosion/sedimentation, or advective heat transport.

To better constrain modeling, we would are using seismic data to map heat flow along the western margin of India.

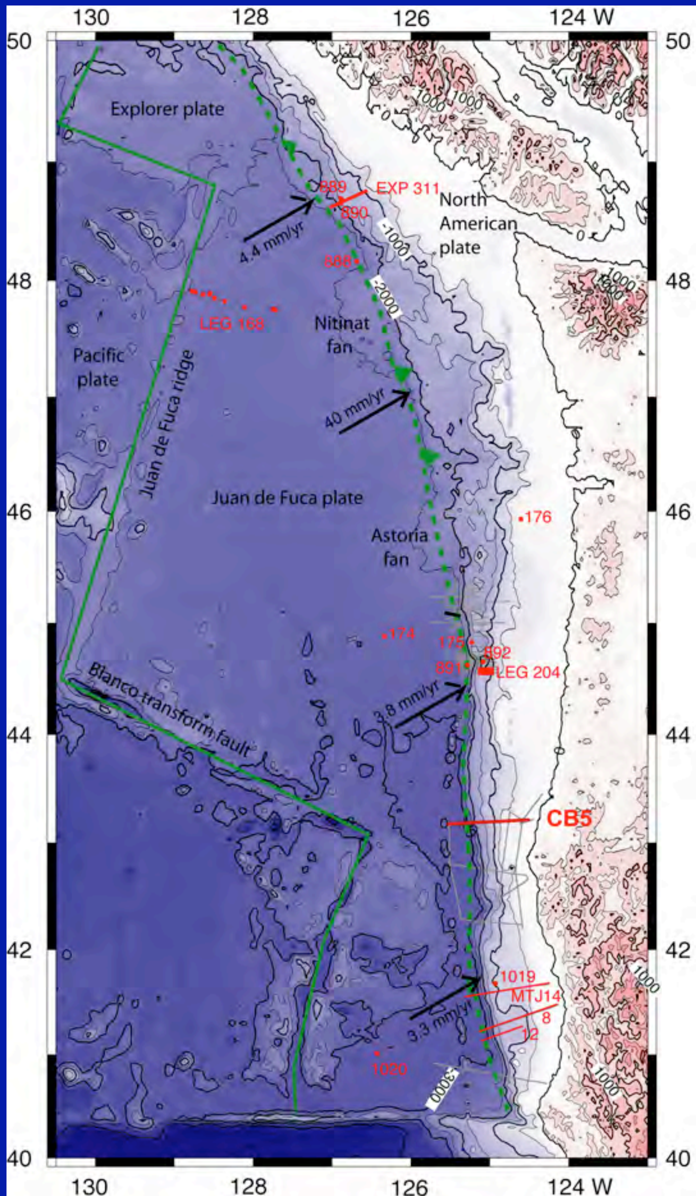


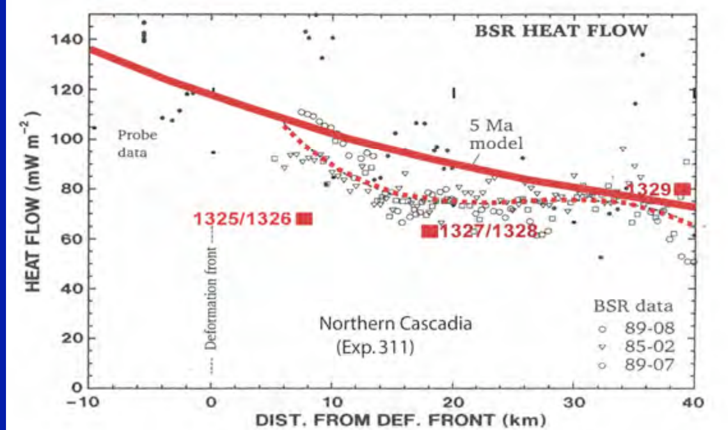


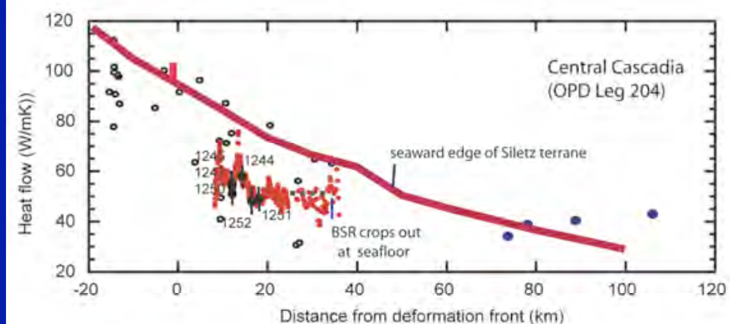
Without drilling constraints, uncertainty in heat flow from BSR is quite large (up to 50%). With drilling to constrain thermal conductivity and depth (velocity), data uncertainties are small (~5%).

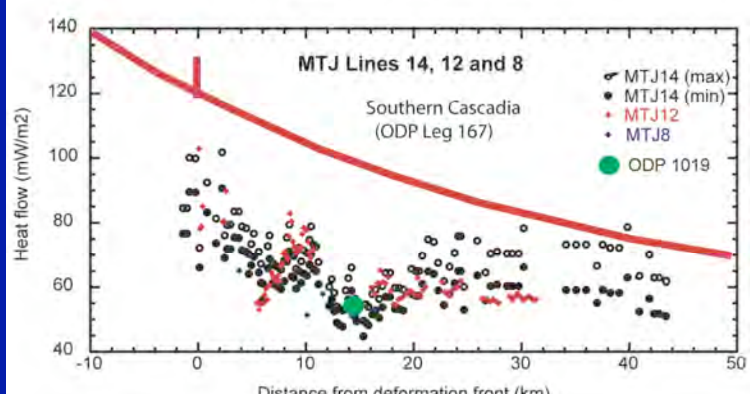


Example from the Cascadia margin: Heat flow is anomalously low near the trench and "recovers" to expected value 30+ km landward.

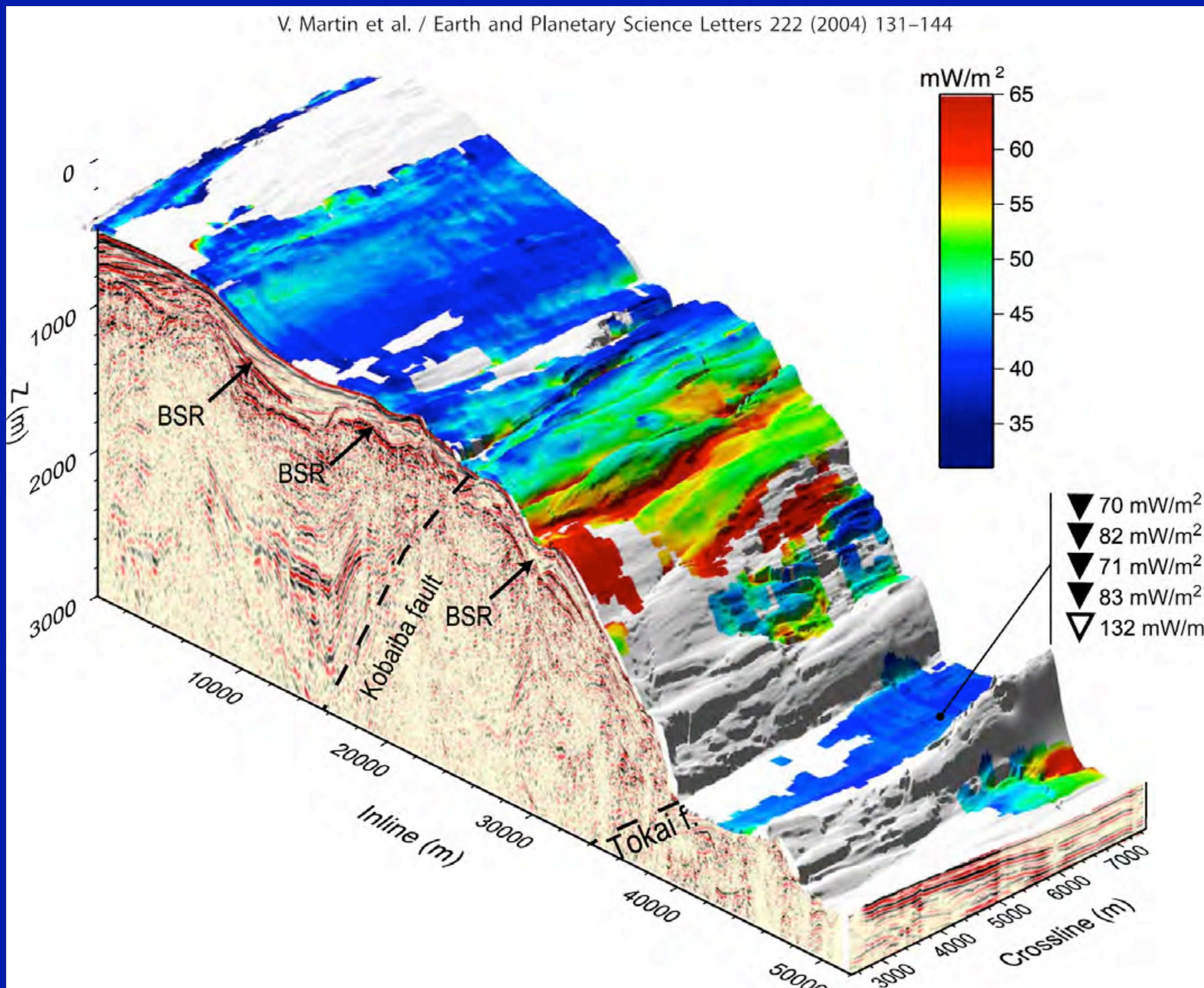


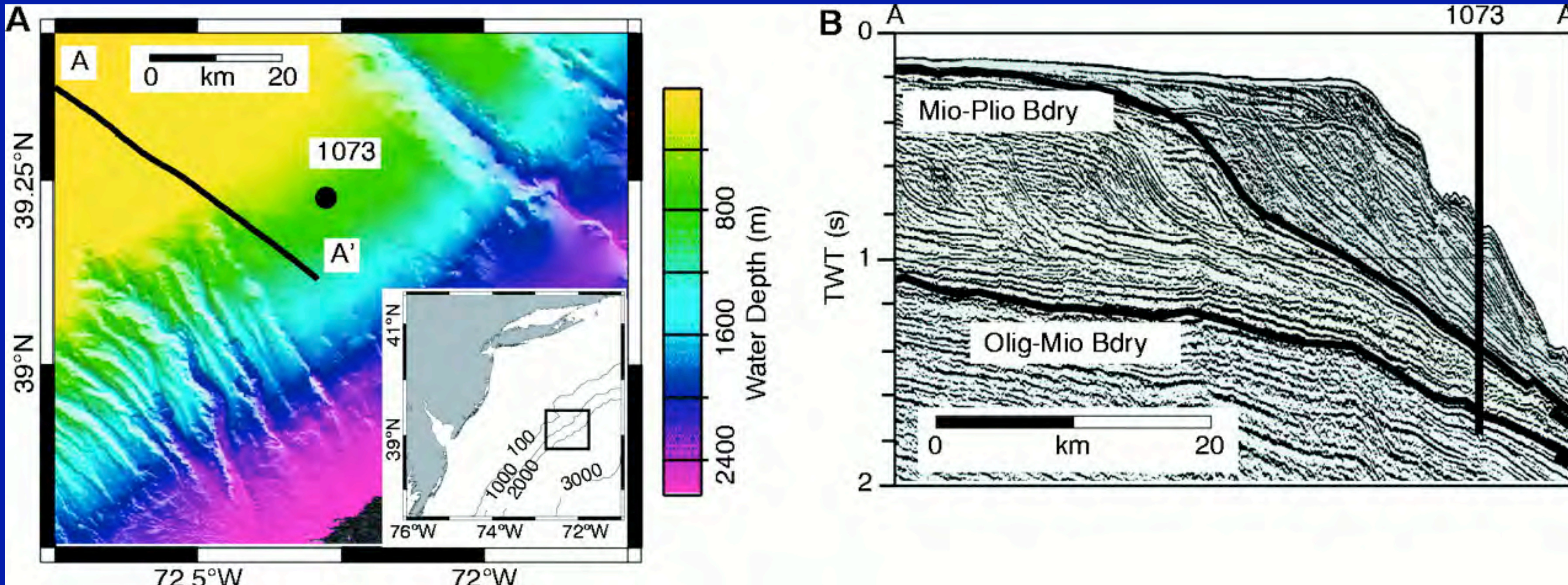






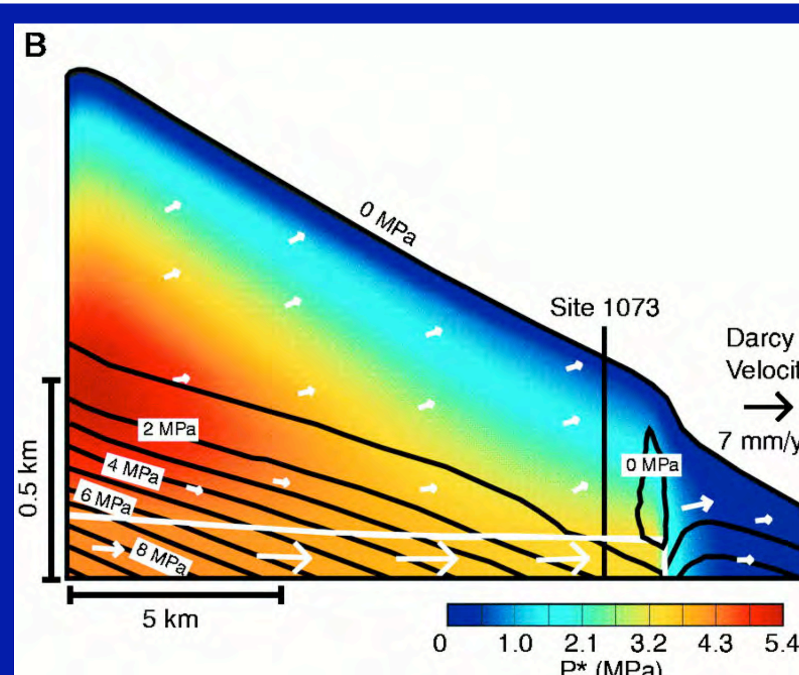
3D example from Nankai (Martin et al., 2004): Apparent heat flow high at the top of large slope failures.





Lateral flow rates of ~1 cm/yr should be induced in sediments by topographically and structurally generated pressure gradients with enhanced flow in permeable horizons.

Dugan and Flemings, Science, 2000



Summary:

1) Agreement between predicted base of gas hydrate stability and BSR indicates that gas hydrate is in thermal equilibrium.

2) Thermal gradient increases with increasing water depth in KG and MB basins. Not due to variations in thermal conductivity. Most likely explanation is fluid flow.

Next steps:

1) Map shallow thermal gradient using BSR and swath bathymetry data to refine relationship between water depth, topography, subsurface structure and heat flow (yr 1).

2) 2 and 3D models of fluid flow to predict heat flow and compare to observations. Tie to larger scale process responsible for feeding gas hydrate deposits (yr 2).

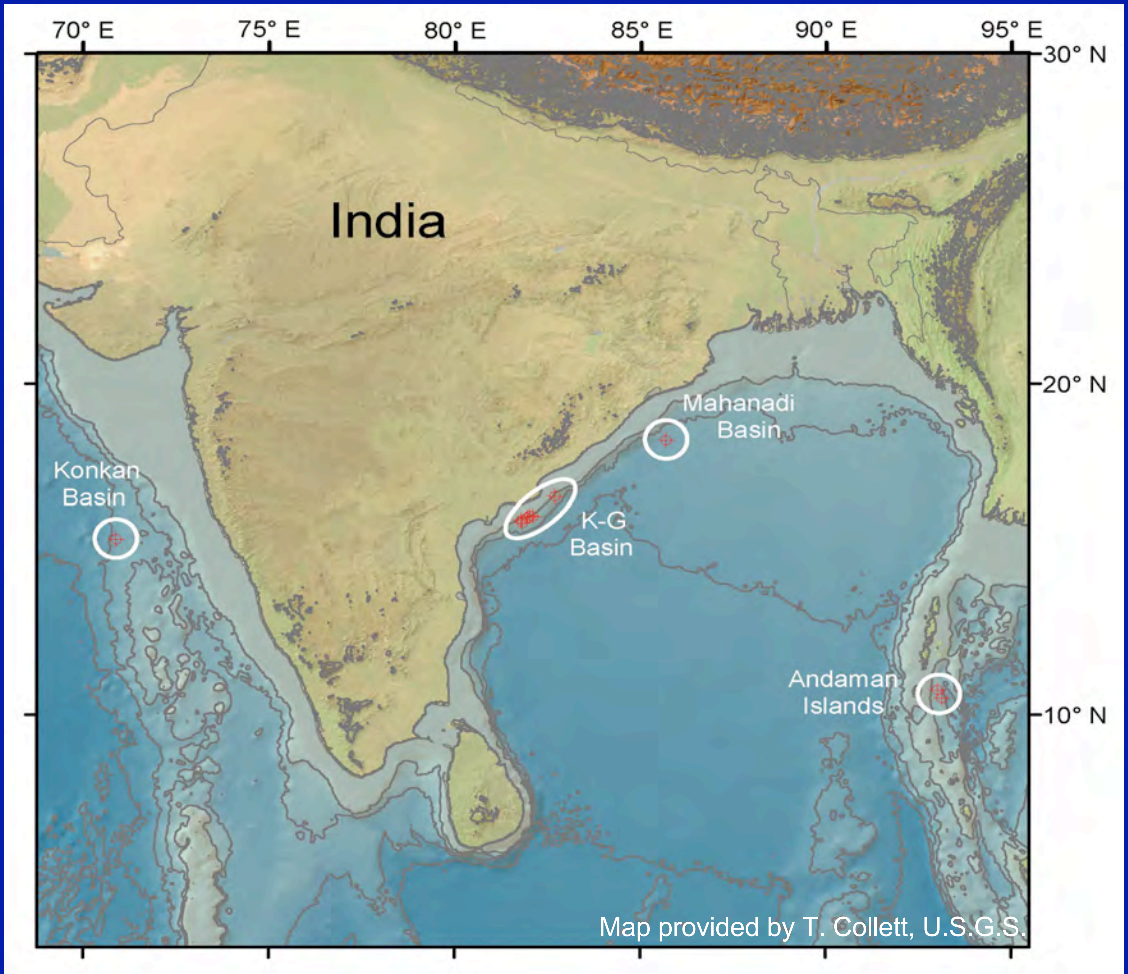
Work Breakdown Structure for phase 1

- Develop seismic maps
- Develop apparent heat flow maps
- Evaluate effects on the bathymetry on apparent heat flow

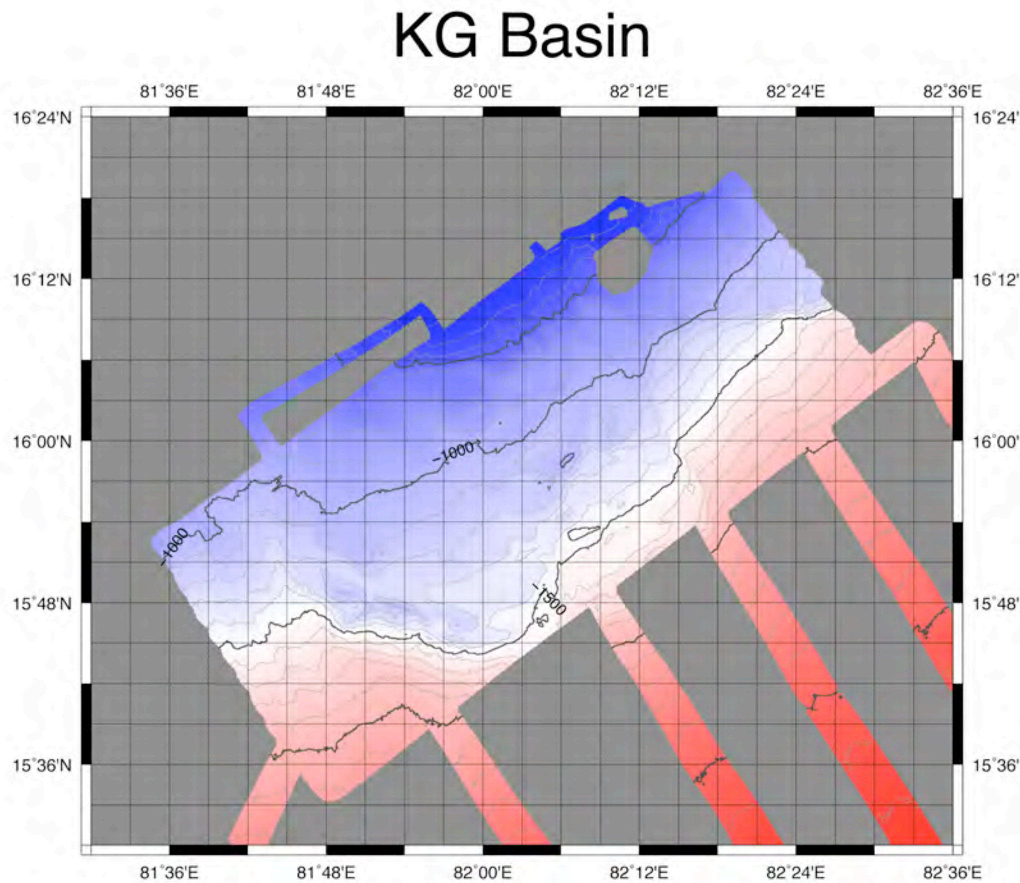
Develop Seismic Maps

- Obtain SEG-Y formatted seismic data
- Use Kingdom Suite software for seismic interpretation
- Pick and map BSR

NGHP Expedition 01 Sites

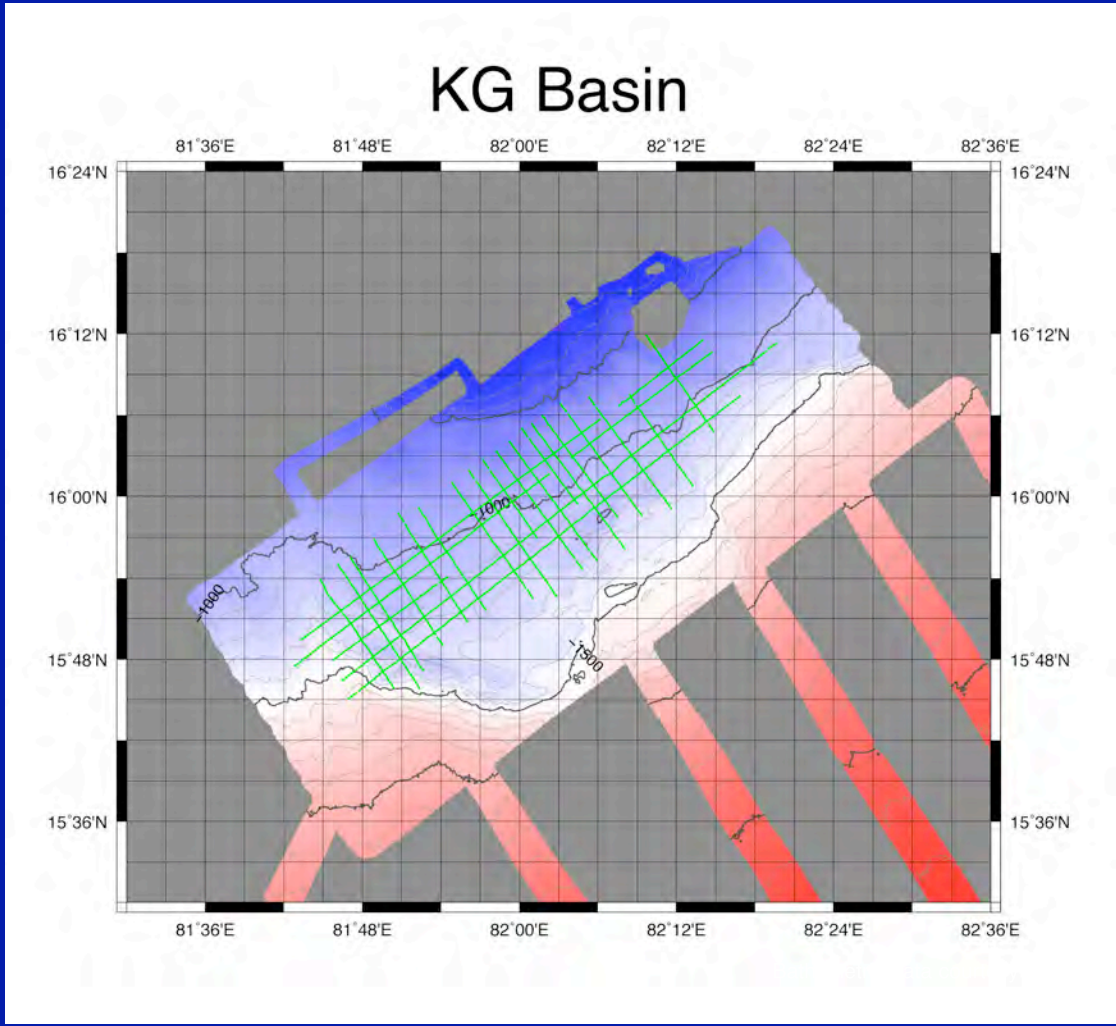


KG Basin Bathymetry

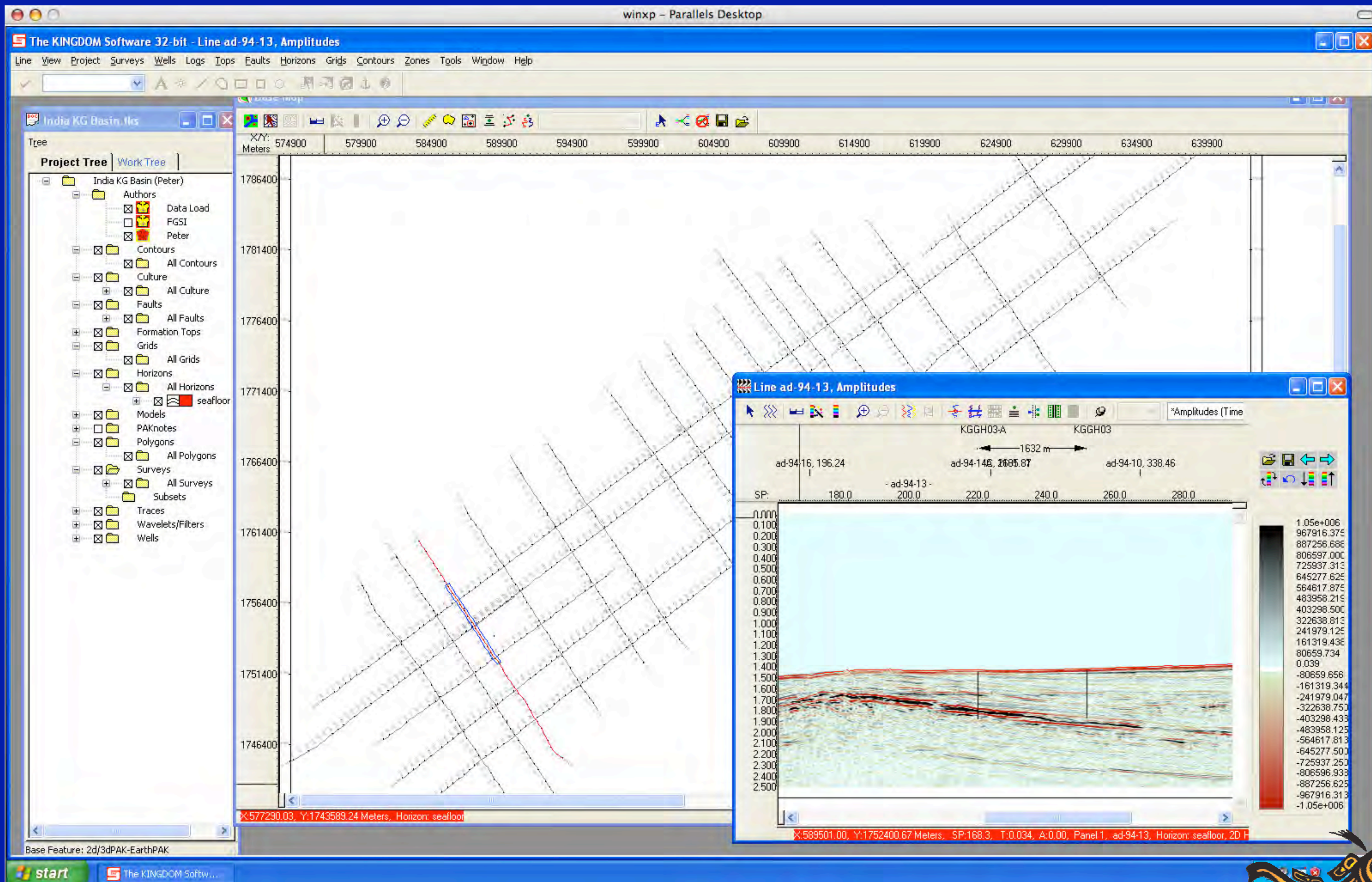


Swath bathymetric data courtesy of Dr. M. V. Ramana and T. Ramprasad

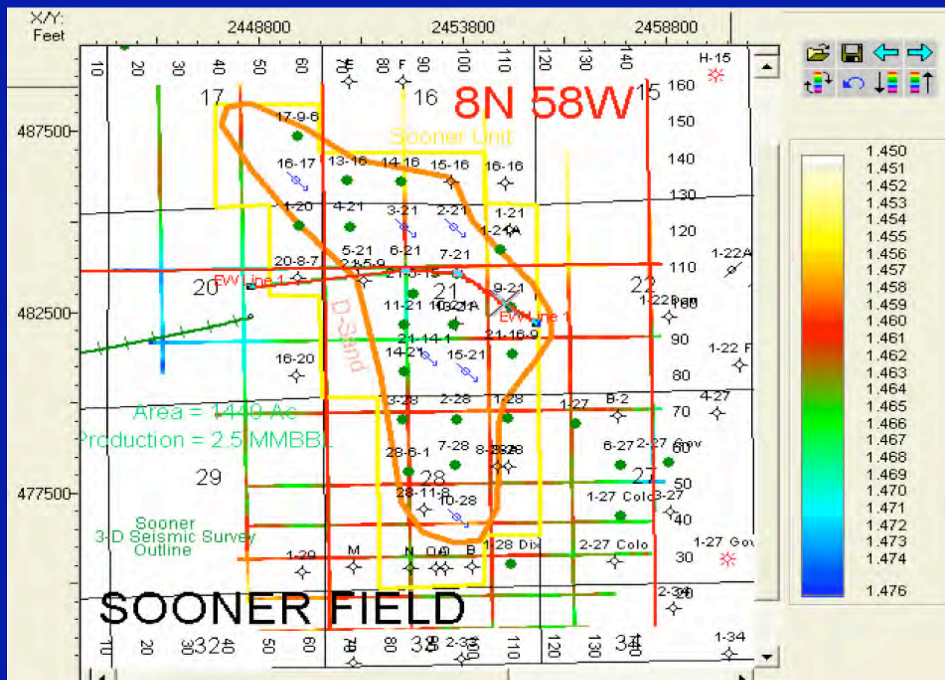
KG Basin site survey



Kingdom Suite for seismic analysis



Kingdom Suite



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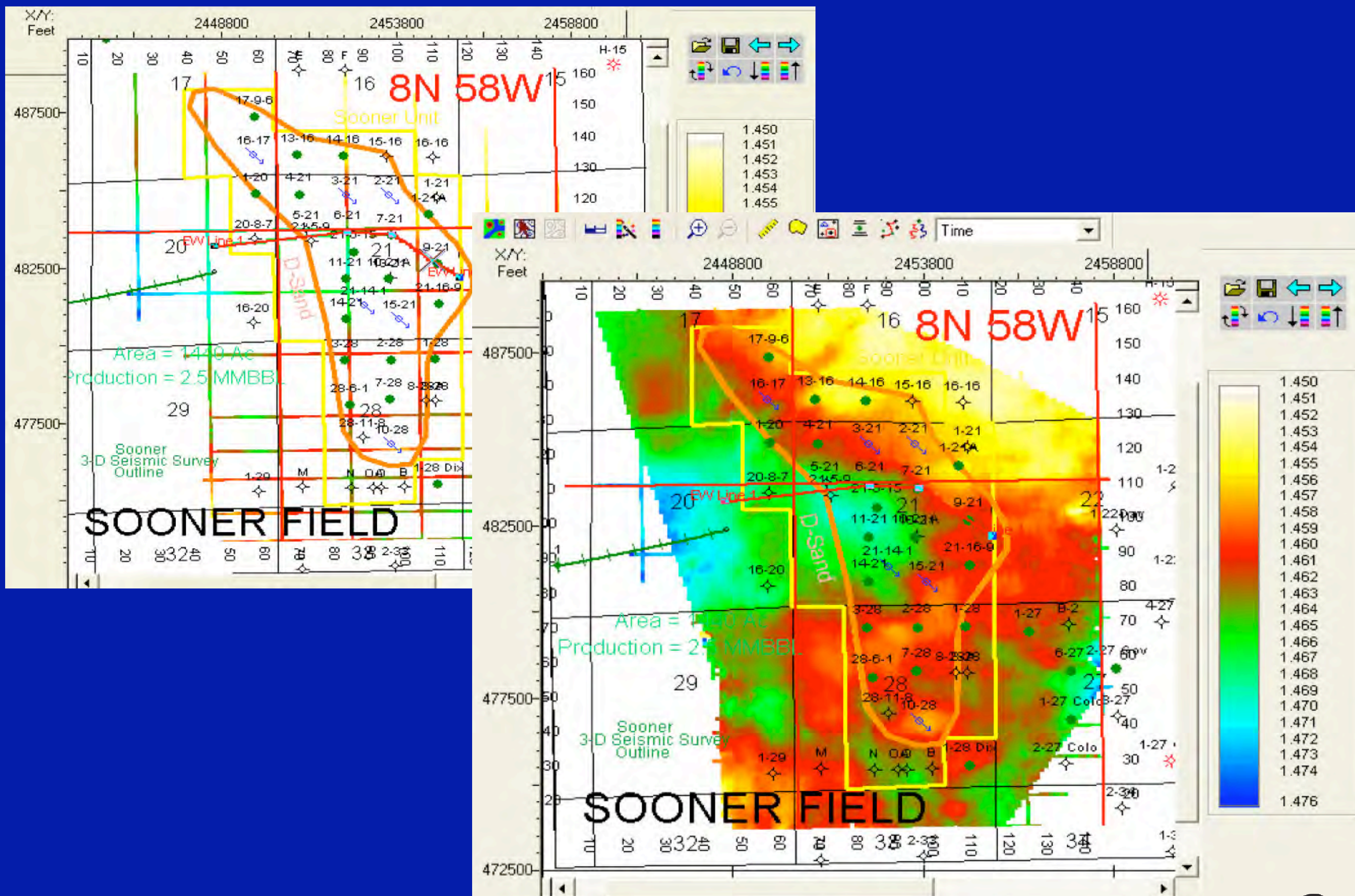
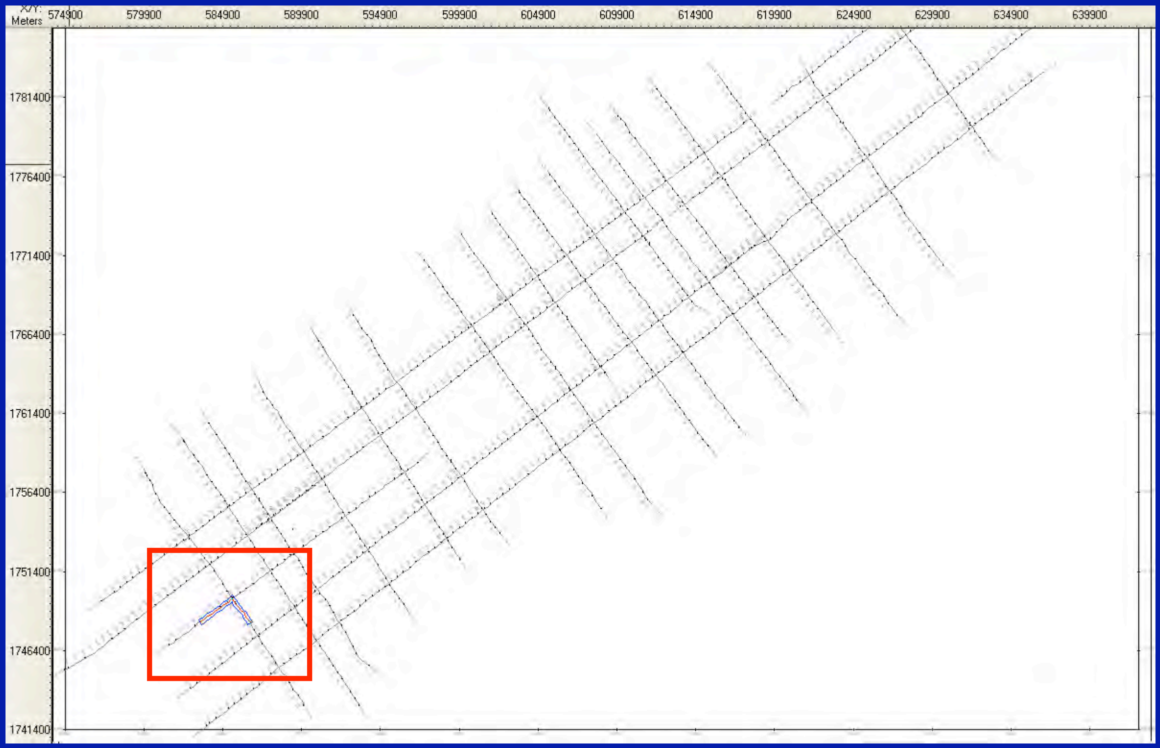


KG Basin Survey



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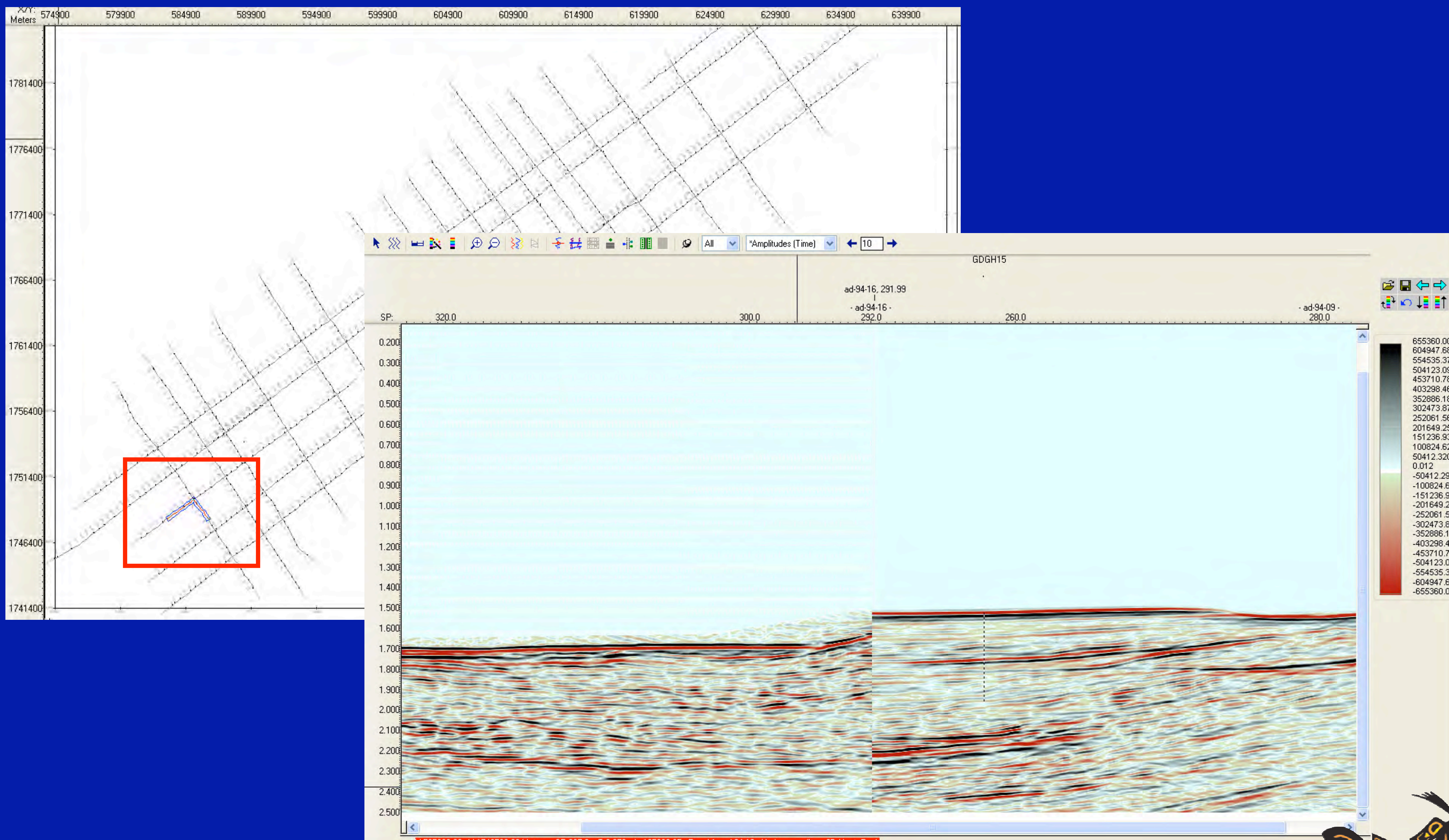

Develop apparent heat flow map

- Compile bathymetry seafloor temperatures, downhole temperatures, thermal conductivities, and sediment densities.
- Compute and map apparent heat flow based on these parameters.

Evaluate effects of bathymetry on apparent heat flow

- Evaluated using simple 2D analytical models
- Compare observed heat flow anomalies to predicted anomalies