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Heat Flow and Gas Hydrates on the Continental Margin of India: Building on Results from NGHP Expedition 01

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EXECUTIVE SUMMARY:

In October 2008, graduate student Peter Kannberg and professor Anne Trehu began working on the National Energy Technology Laboratory (NETL) funded project entitled *Heat flow and gas hydrates on the continental margin of India: Building on results from NGHP expedition 01*. This project is designed to complete analysis, interpretation and modeling of downhole temperature data that were acquired in spring 2006 at 21 sites drilled in gas hydrate-bearing sediments on the continental margin of India. In addition to finding several rich gas hydrate deposits, this expedition provided a number of important new insights into the geologic conditions leading to such deposits . One new insight is that buried channels and turbidite deposits are important for providing pore space in which hydrate crystals can nucleate. We hypothesize that these channels also have an influence on fluid flow and transport of methane into and through the gas hydrate stability zone (GHSZ). The objective of this project is to construct a map or regional heat flow by using the borehole data to calibrate heat flow estimates derived from observations of a bottom simulating reflection (BSR) in regional seismic data. Expedition NGHP 01 confirmed that the BSR near the boreholes reflected the base of the GHSZ on the eastern continental margin of India and in the Andaman Sea. We will then use these observations to model fluid flow and collaborate with sedimentologists working on the cores recovered from these boreholes to test this hypothesis. The project also supports development of human resources for hydrate studies by supporting tuition for Kannberg to take courses leading to a Masters degree in oceanography and geophysics.

The second quarter was spent compiling data necessary to compute heat flow, then generating apparent heat flow maps. Recent 3D bathymetric data have been received and have been added to the existing bathymetric dataset. An overview of the project, as well as initial seismic and bathymetric data were presented at the NETL project kickoff meeting on January 6, 2009. In addition to continuing research on this project, Peter Kannberg took courses in Matlab based computer modeling, sedimentary processes, igneous and tectonic processes, and is currently enrolled in a geophysical research techniques course as well as a class dedicated to the study of heat flow. All of these courses provide additional intellectual background for this project.

PROGRESS, RESULTS AND DISCUSSION:

Phase 1 – Task 3, Develop Apparent Heat Flow Maps:

Swath bathymetry grids have been received and maps have been generated using Generic Mapping Tool (GMT) software package (Figure 1). Swath bathymetry data are available as map images and grid files.

All available data needed to compute heat flow have been compiled. These data, comprised of swath bathymetry, seafloor temperatures, down-hole tool measurements, thermal conductivities, and sediment densities were compiled into a model showing regional variations in heat flow.

Heat flow in upper oceanic sediments is dominated by conduction. One dimensional heat flow is described by Fourier's Law of heat conduction, and is directly proportional to the thermal gradient.

Fourier's law of heat conduction in one dimension:

$$q = -k\frac{\Delta T}{\Delta z}$$

where q is heat flow, k is thermal conductivity of the medium,
T is temperature and z is depth.

The BSR is recognized as the lower limit of the gas hydrate stability zone. The hydrate stability curve is a function of pressure and temperature. Given the pressure at the BSR, which is a function of depth, temperature can be calculated. Seafloor temperature data are then used to calculate the temperature gradient from the seafloor to the BSR. Multiplying this gradient by the bulk thermal conductivity will give heat flow, as shown in the equation above.

The dominant control on heat flow is thermal conductivity. Thermal conductivity is used to determine temperature derived from downhole temperature tool decay curves. These tools are used to find the ΔT, and subsequently the temperature gradient. So heat flow is affected by the thermal conductivity measurement value twice, once in the determination of temperature at depth, and again in Fourier's law of heat conduction.

Unfortunately shipboard measurements of thermal conductivity are unreliable in hydrate bearing sediments. Gas pockets form as samples are brought to the surface as hydrate dissociates or dissolved methane comes out of solution due to decreased pressures. The result is that dependable thermal conductivity measurements of hydrate bearing sediments must be carried out in a laboratory or in situ. For instance shipboard calculations of thermal conductivity varied from 0.6 $Wm^{-1}K^{-1}$ to 0.9 $Wm^{-1}K^{-1}$. These values are lower than what is generally considered reasonable for the sediment types found in the study region. For the heat flow maps shown in figs 5 and 6, the bulk thermal conductivity used was 1.05 $Wm^{-1}K^{-1}$. This value was chosen on the basis of: a) thermal conductivities measured and averaged over multiple Ocean Drilling Program continental margin drillsites (Grevermeyer and Villinger, 2000), b) porosities measured during logging-while-drilling correlated with thermal conductivites of sediments with similar porosity (Davis et al, 1990; Collett et al, 2008). As shown above in Fourier's law of heat conduction, thermal conductivity is simply a scalar, so a 15% increase in calculated thermal conductivity will lead to a 15% increase in heat flow.

Figure 1. Swath bathymetry with seismic survey lines overlain

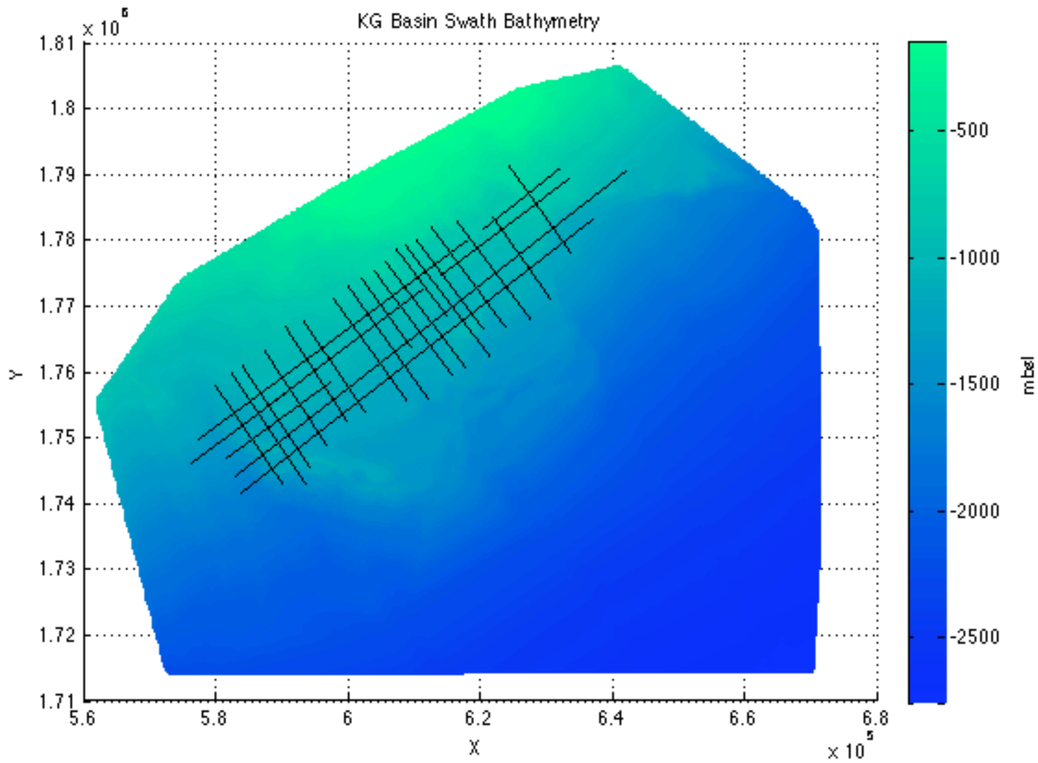


Figure 2. Seafloor temperature from World Ocean Atlas, 2005 (Locarnini et al, 2006)

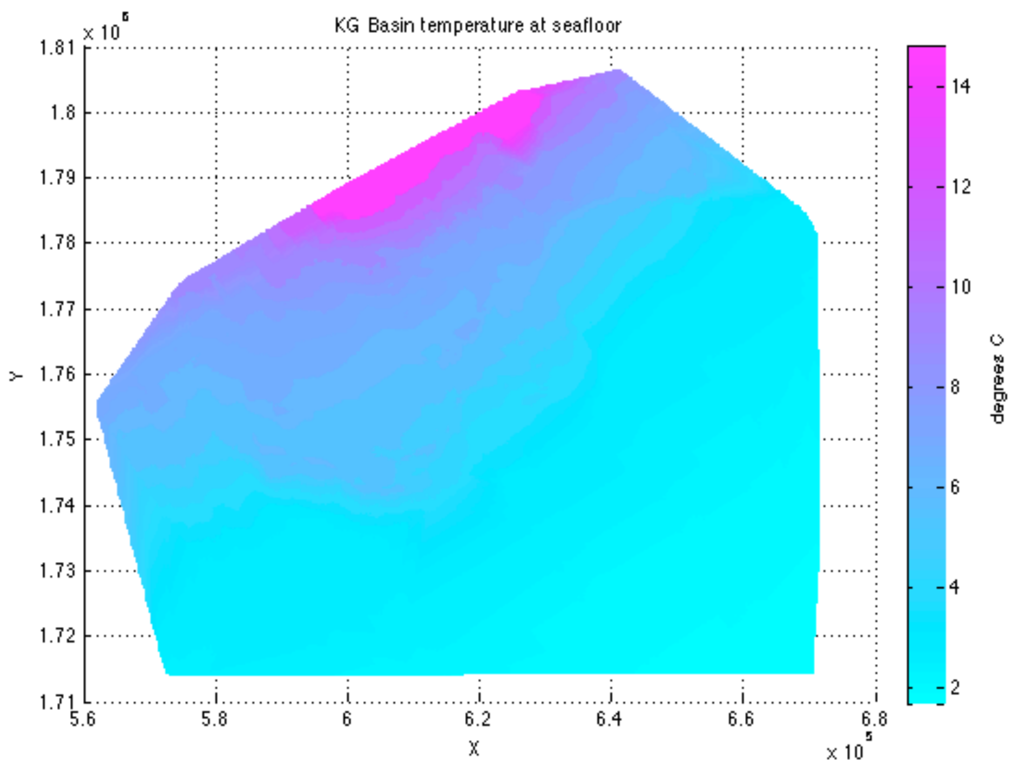


Figure 3. BSR depth in meters below sea level

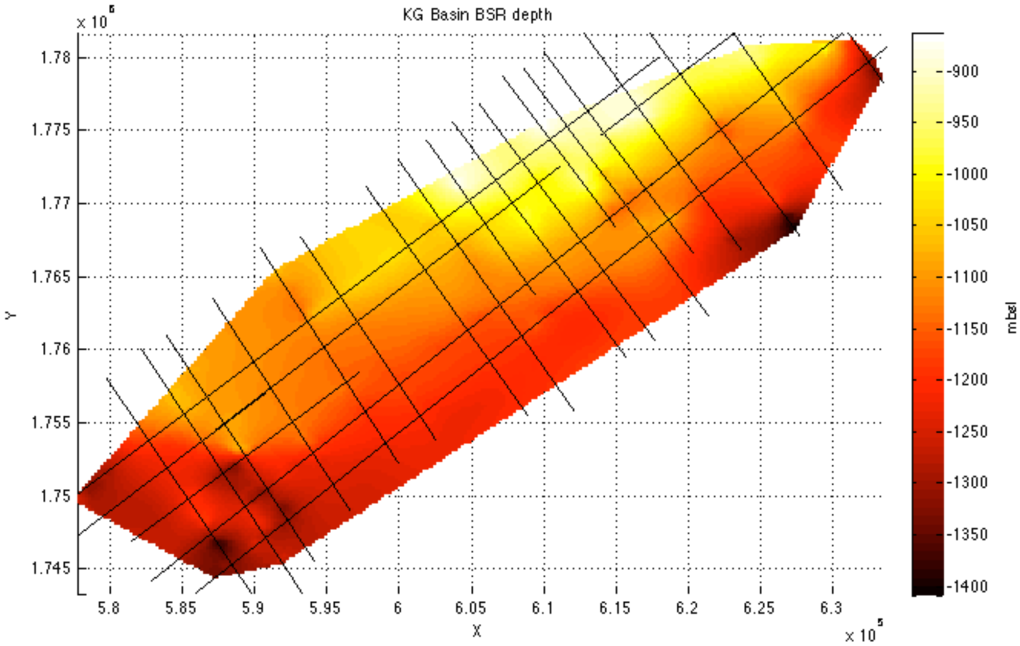


Figure 4. Apparent heat flow based on swath bathymetry. Well locations are shown as open circles

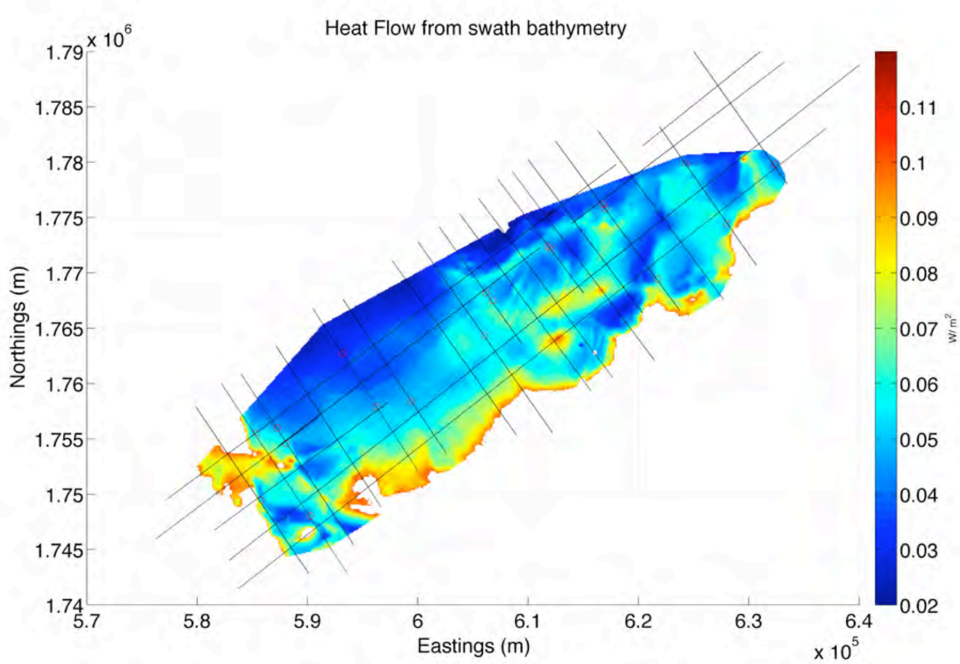


Figure 5. Apparent heat flow based on seismic bathymetry. Well locations are shown as open circles.

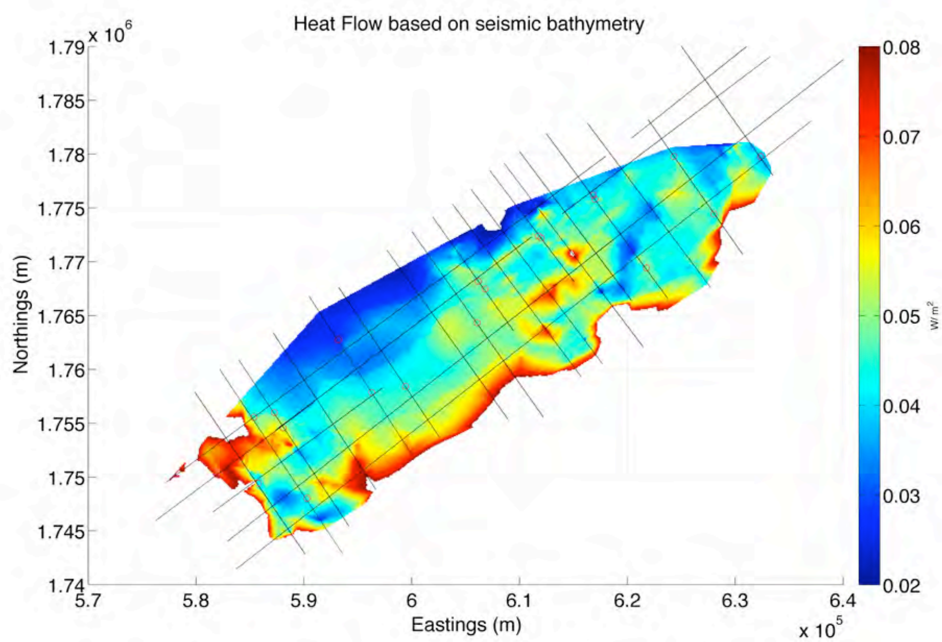
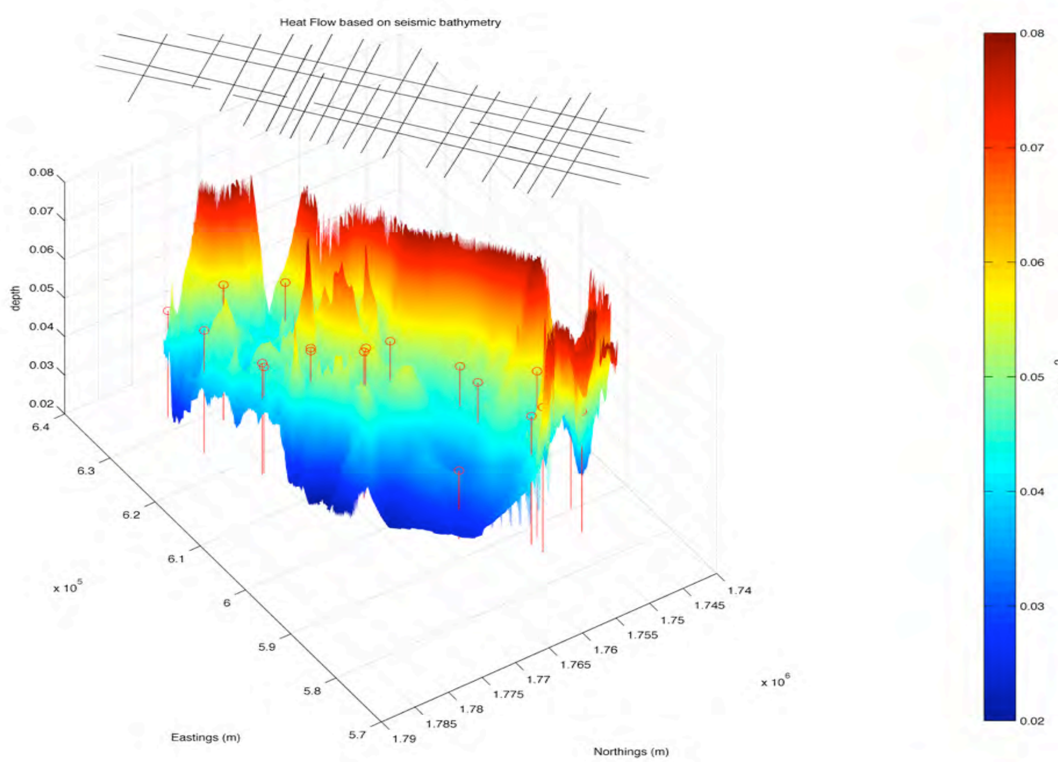


Figure 6. Three dimensional view of heat flow as viewed from the northwest looking southeast. Well locations are shown as vertical red lines.



A comparison of heat flow based on both seismic bathymetry and swath bathymetry is included because of irregularities in the seismic bathymetry data. Problems such as seafloor muting and seismic line vertical offsets create discrepancies between the actual bathymetry (in this case the swath bathymetry) and the bathymetry interpolated from the seismic survey. However, the BSR is calculated using the seismic survey, so any discrepancies between the seismic and swath bathymetry would also be present in the BSR depth. As a result, heat flow was calculated using swath bathymetry (fig 4) as well as seismic derived bathymetry (fig 5). The two maps show similar trends, but the values of the peaks are slightly higher in the swath bathymetry derived heat flow. This issue is in the process of being resolved. The differences also show the effects of seismic data problems illustrated in the first quarterly report. The increased apparent heat flow seen at the southern edge of the map is the result of gridding extending beyond the lateral limits of BSR data.

The above maps are available as png, tiff, or pdf files. The maps are gridded at 100m x 100m resolution, and the grids used to construct these maps are available as xyz ascii files.

Phase 1 – Task 4, Evaluate Effects of Bathymetry on Apparent Heat Flow:
This task is scheduled for the third and forth quarters of Phase 1 of this project.

Phase 2 – Task 5, Develop Numerical Model:
This task is scheduled for the second year of the project provided the project goes forward after a go/no go decision based on preliminary results from Task 4.

Phase 2 – Task 6, Interpret Modeling Results:
This task is scheduled for the second year of the project provided the project goes forward after a go/no go decision based on preliminary results from Task 4.

COST STATUS:

Table 1. Project costing profile for Budget Period 2.

	Jan (planned)	Jan (actual)	Feb (planned)	Feb (actual)	Mar (planned)	Mar (actual)
PI salary & fringe benefits	1,627	0	1,627	2,735	1,627	508
GRA salary & fringe benefits	2,271	2,419	2,271	2,119	2,271	2,119
Computer subscription	250	250	250	250	250	250
Travel	1,153	1,153	0	0	0	0
Tuition	0	3,132	0	0	0	0
Indirect Costs	2,160	1,766	2,160	2,358	2,160	1,329
	9,206	8,720	6,308	7,462	6,308	4,206

PUBLICATIONS, CONFERENCE PRESENTATIONS AND OTHER PRODUCTS:

- A presentation was made at the Project Kickoff Meeting during the first week of the second quarter
- The Project Kickoff Meeting presentation is available online at the NETL website.
- Bathymetric, seafloor temperature, BSR depth, and apparent heat flow maps have been generated.

References:

Davis, E.E., R.D. Hyndman, H. Villinger. 1990. Rates of fluid expulsion across the northern Cascadia accretionary prism: Constraints from new heat flow and multichannel seismic reflection data. Journal of Geophysical Research, Vol 95, 8869-8889

Collett, Timothy S.; Riedel, M.; Cochran, J.R.; Boswell, R.; Kumar, P.; Sathe, A.V. 2008. Indian National Gas Hydrate Program Expedition 01 Initial Reports; Directorate General Hydrocarbons, Ministry of Petroleum & Natural Gas (India).

Grevemeyer, I., H. Villinger, 2000. Gas hydrate stability and the assessment of heat flow through continental margins. Geophys. J. Int., (2001), 145, 647-660.

Locarnini, R. A., A. V. Mishonov, J. I. Antonov, T. P. Boyer, and H. E. Garcia, 2006. World Ocean Atlas 2005, Volume 1: Temperature. S. Levitus, Ed. NOAA Atlas NESDIS 61, U.S. Government Printing Office, Washington, D.C., 182 pp.

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