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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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Progress Report

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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 fourth quarter was spent creating models of apparent heat flow for the Andaman Basin. Cross sections of the Andaman Basin were constructed to investigate bathymetric effects on heat flow. Simple two-dimensional models of heat flow were incorporated into applicable cross sections to determine the extent of topographic heat flow bias. The results show that the an increase in heat flow as water depth increases is not isolated to the Krishna-Godavari Basin, but is also present in the Andaman Basin. Additionally, this summer Kannberg had the opportunity to participate in three methane hydrate related geophysics research cruises, expanding his knowledge of geophysical tools used to study gas hydrates to include seismic reflection, ocean bottom seismology, and magnetotellurics.

PROGRESS, RESULTS AND DISCUSSION:

Phase 1 – Task 4, Evaluate Effects of Bathymetry on Apparent Heat Flow – application to the Andaman Sea:

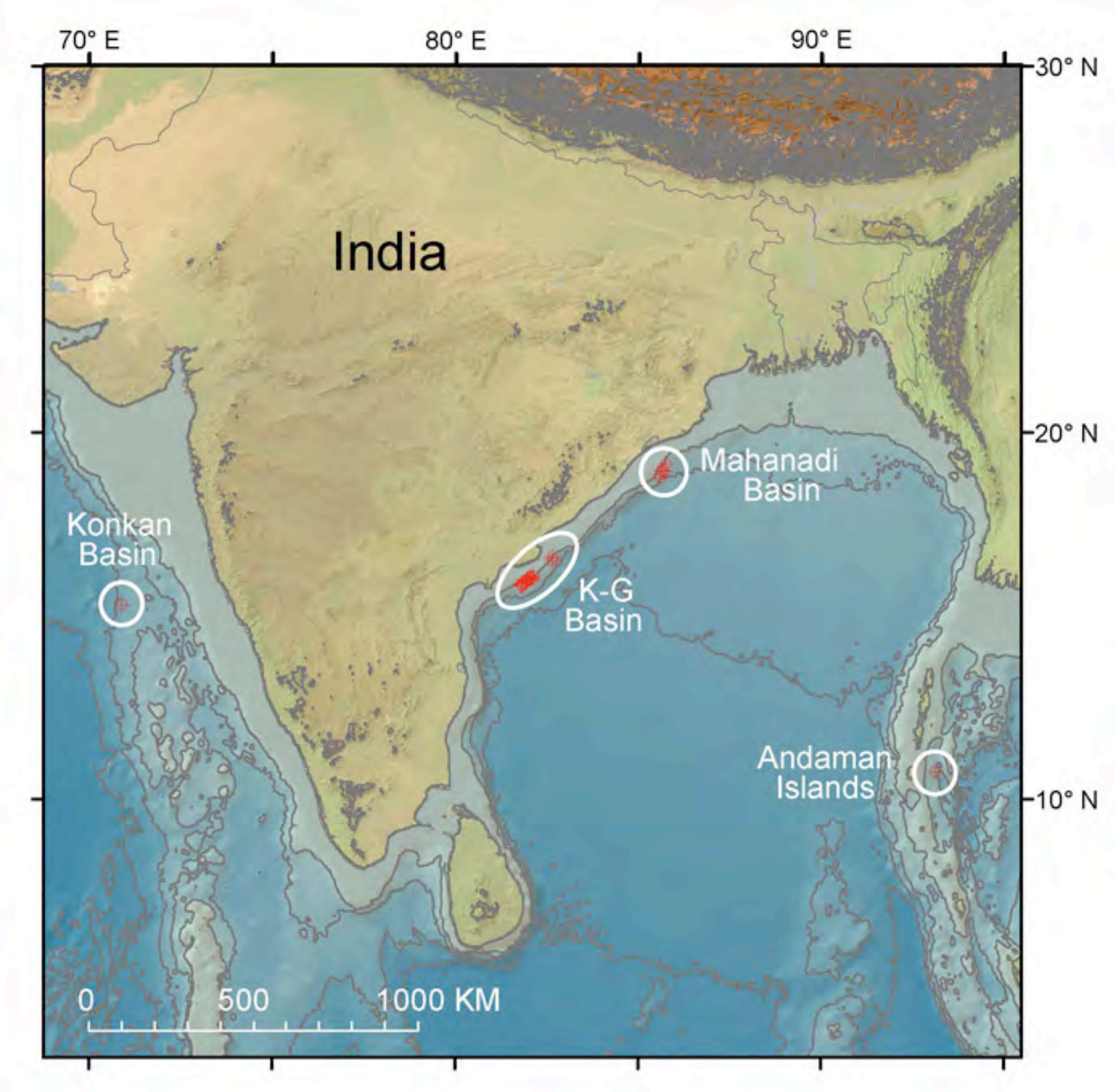

Figure 1. Regional map of National Gas Hydrate Program Expedition 01 study sites.

The Andaman Island study region is located southeast of South Andaman Island and due east of Little Andaman Island (fig. 1). Pre-expedition seismic surveys indicated an anomalously deep Bottom Simulating Reflector (BSR) in the Andaman Island region. The BSR is considered to coincide with the base of the gas hydrate stability zone (GHSZ). Subsequent drilling operations during NGHP1 found the depth of the base of the GHSZ to be 620 meters below sea floor (mbsf), roughly coinciding with the seismically derived base at 608 mbsf. Very low heat flow determined during NGHP1 in the Andaman Sea provided an explanation for the very thick gas hydrate stability zone. This low heat flow results in one of the thickest sediment sections yet discovered capable of harboring gas hydrate. To understand the regional context of this thick zone of gas hydrate stability, we constructed seafloor (fig. 2) and apparent heat flow (fig. 3) maps around the NGHP drill sites.

Conductive heat flow is a function of the geothermal gradient and the thermal conductivity of the sediment. A thermal conductivity of 0.85 was used for the Andaman Basin, derived from sediment core samples taken during drilling operations. As discussed in the previous report, bathymetry can affect the heat flow of a region by focusing heat flow into valleys, so one would expect to see increased heat flow in valleys and decreased heat flow at bathymetric highs. This can quantitatively be modeled in 2-D using equations developed by Lachenbruch (1968). Two-dimensional cross sections were pulled out of the 3-D volume (fig. 4), and where those profiles intersected heat flow anomalies, the bathymetric effect on heat flow was modeled to determine if the anomalies could be explained solely by bathymetry. These profiles are shown in figure 5.

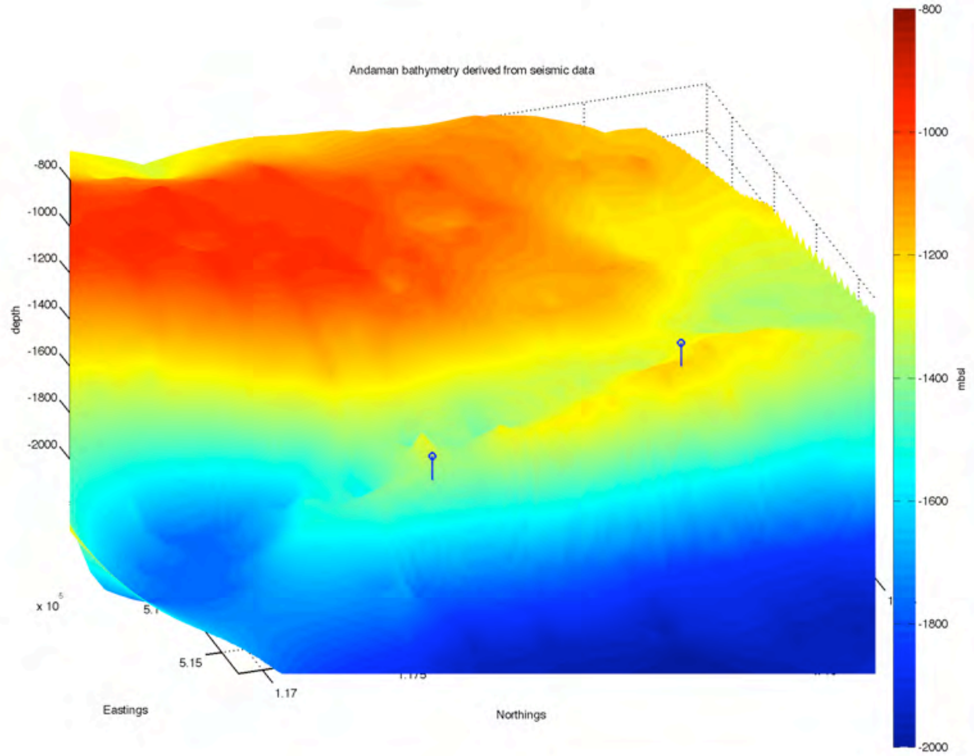

Figure 2 a. 3-D view of seafloor bathymetry around the NGHP1 drill sites (shown as vertical blue lines). The southeast drill site (lower left blue vertical line in the above image) was cored.

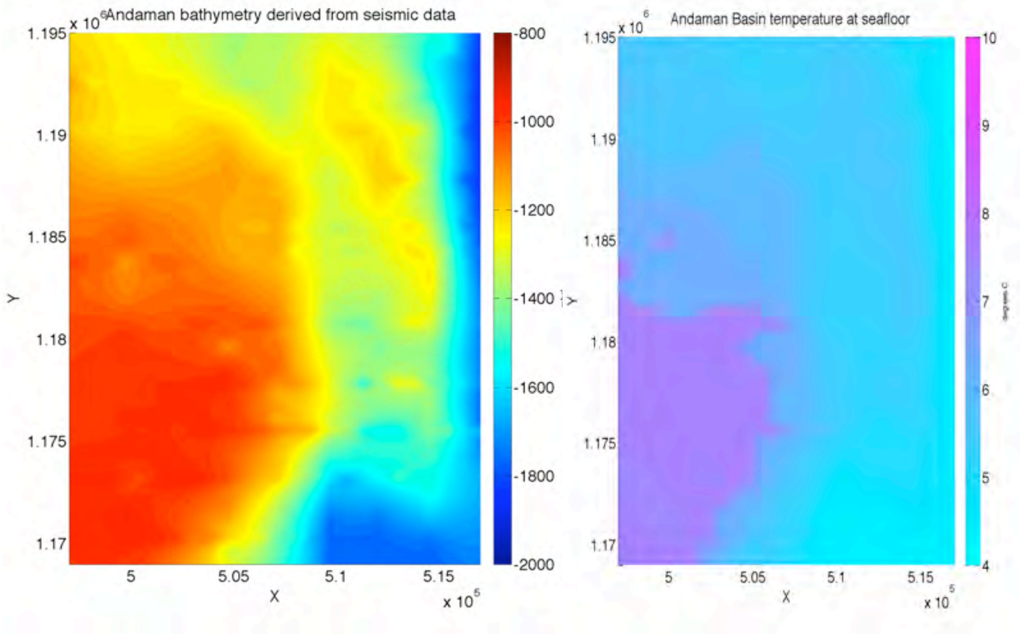

Figure 2 (continued). Map view of bathymetry (b) derived from seismic data and of seafloor temperature (c) from the World Ocean Atlas, 2005 (Locarnini et al., 2006).

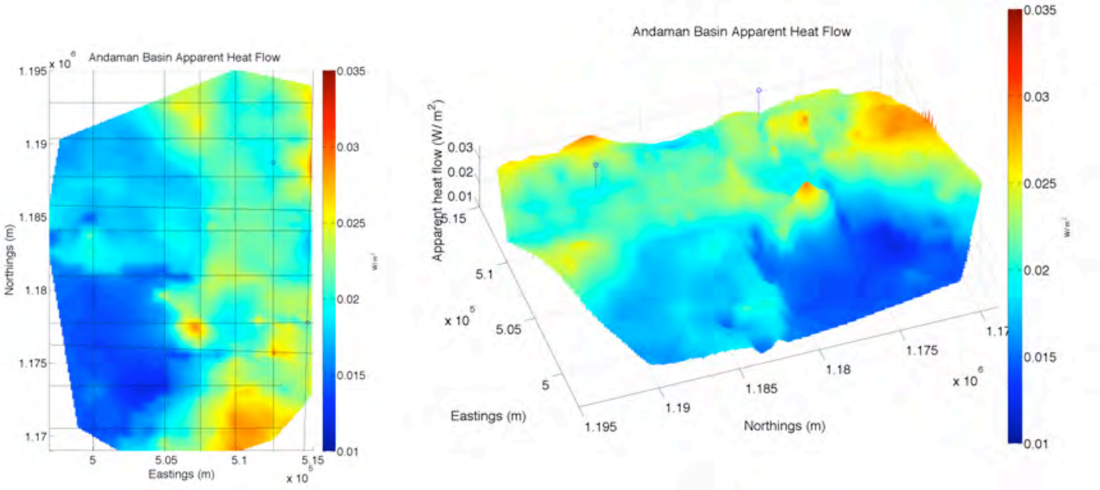

Figure 3. Map of apparent heat flow in the Andaman Basin. Blue circles indicate drill sites.

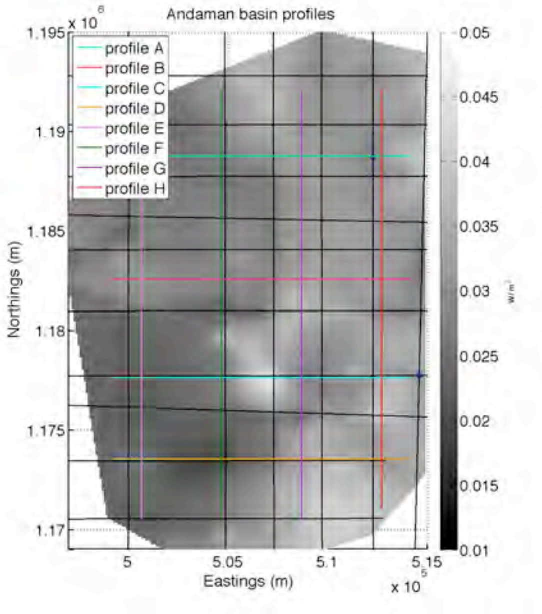

Figure 4. Gray tone map of apparent heat flow in Andaman basin. Colored lines correspond to profiles that were modeled, four of which are shown in figure 5. Blue dots represent NGHP Expedition 1 Drill sites.

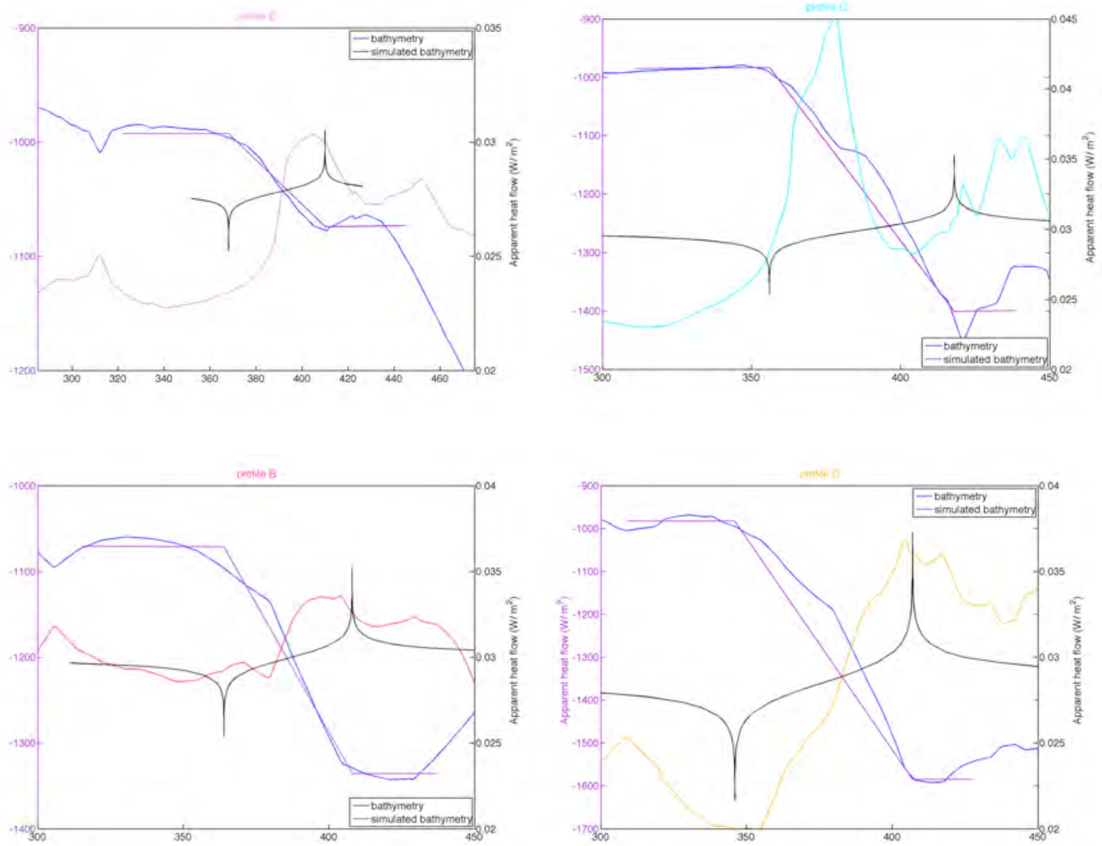

Figure 5. Observed and modeled bathymetric and heat flow profiles across the study region (see main text)

Locations of profiles selected for modeling in Figure 5 are shown on Figure 4 and were chosen to cross significant apparent heat flow anomalies. In Figure 5, the blue line is the observed bathymetry and the purple line is a simplified bathymetric profile used to model heat flow. The apparent heat flow is shown in a color that corresponds to Figure 4, and the solid black line is the modeled heat flow. Just as in the K-G Basin, bathymetric focusing can explain some of the anomalies, but not others. Deviations in apparent heat flow from the modeled heat flow are postulated to be the result of advective fluid flow.

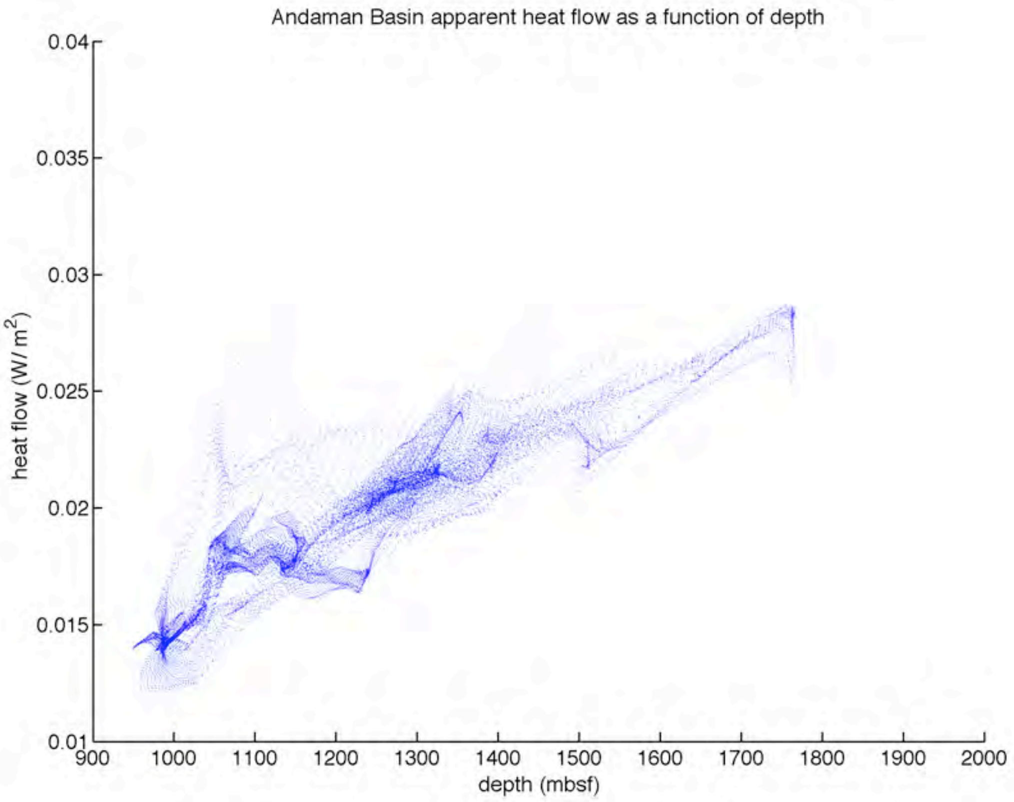

Figure 6. Cloud plot of heat flow as a function of depth for the Andaman study area.

The depth of the base of the GHSZ results from the very low geothermal gradient, which is a function of heat flow in the region. While heat flow was significantly lower in the Andaman Basin than the Krishna-Godavari Basin, it showed increasing heat flow with increasing depth (fig. 6,7,8). Heat flow at a given depth in the Krishna-Godavari study area is roughly 2.25 times the heat flow of the same depth in the Andaman basin. Likewise, heat flow increases with depth by the same factor, with heat flow in the K-G Basin increasing at 3.75×10^{-5} W•m^{-2} per meter of depth versus 1.67×10^{-5} W•m^{-2} per meter of depth in the Andaman Basin.

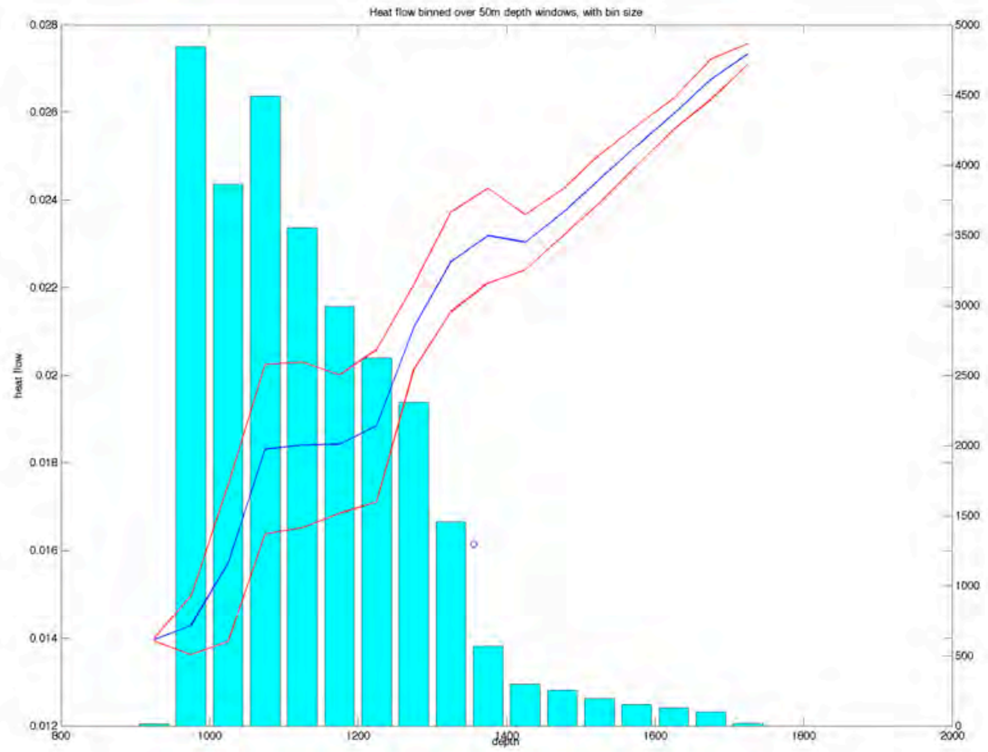

Figure 7. Heat flow as a function of depth binned over 50 meter depth windows. Blue line is heat flow with the red lines representing one standard deviation on either side. Cyan bars indicate how many samples were binned at each depth window. Open blue circle indicates drilling data derived heat flow for site 17.

Core samples taken at both sites showed that thermal conductivity values were lower in the Andaman Basin than in the K-G Basin, 0.85 W•K^{-1}•m^{-1} versus 1.05 W•K^{-1}•m^{-1}, respectively (Collett et al., 2008)). Thermal conductivity is a simple scalar in determining heat flow (see 2nd Quarter report), so while this will lead to lower heat flow values, it cannot explain the degree of variance. A 25% increase in thermal conductivity will not lead to a 125% increase in heat flow, as is the case here. Alternatively, high sedimentation rates could alter the flow of heat through a package of sediment. Down hole temperature measurements taken at site 17 show a nearly linear trend of temperature vs. depth below sea floor (R^2-value of 0.99 for the best fit line). If sedimentation were impacting heat flow, one would expect a non-linear trend of temperature vs. depth where heat flow increases with depth below sea floor. The sedimentation rate is known at site 17, and can be inferred to the rest of the Andaman Basin study area. Therefore, if the background heat flow and sediment thickness are known (derived from basement age and seismic data) the 1-D effect of sedimentation is capable of being modeled. Unfortunately, the study region is tectonically complex, and neither basement age nor total sediment thickness are well constrained. We will attempt to more accurately constrain these variables in the future.

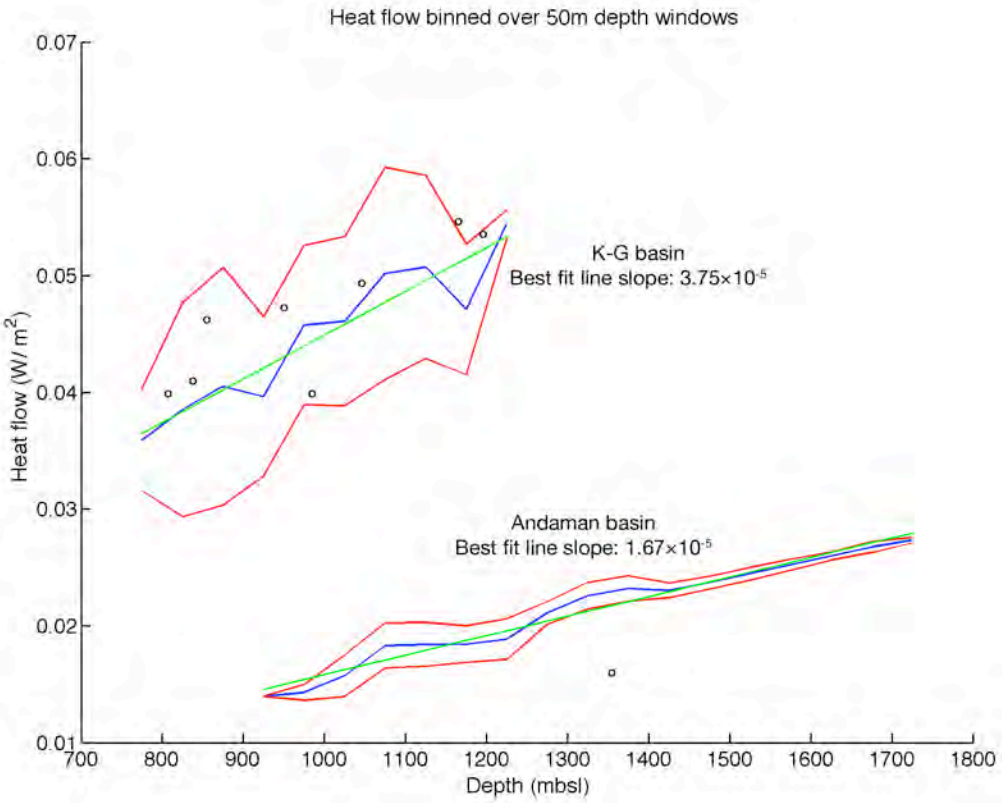

Figure 8. Krishna-Godavari (KG) Basin heat flow (upper plot) compared with Andaman Basin heat flow (lower plot). Blue line represents the average heat flow binned over 50 meter depth window, with the red lines bracketing the blue lines showing one standard deviation. The green line is a linear best fit line of the binned heat flow data. Open black circles are drilling derived heat flow data. Heat flow in the KG Basin increases with depth at over 2 times the rate as in the Andaman Basin.

Table 1. Project costing profile for Budget Period 3.

	July (planned)	July (actual)	August (planned)	August (actual)	Sept. (planned)	Sept. (actual)
PI salary & fringe benefits	1,627	552	1,627	553	1,627	526
GRA salary & fringe benefits	2,271	0	2,271	4,422	2,271	2,211
Computer subscription	250	250	250	250	250	250
Travel	0	0	0	0	0	0
Tuition	0	0	0	0	0	0

PUBLICATIONS, CONFERENCE PRESENTATIONS AND OTHER PRODUCTS:

- An overview of gas hydrate research, with a special emphasis on thermal modeling, given to students aboard the R/V Thomas Thompson during LUMEN ’09 Cruise

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