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HEAT FLOW ESTIMATION FROM BSR: AN EXAMPLE FROM THE ARU REGION, OFFSHORE WEST PAPUA, EASTERN INDONESIA

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ABSTRACT

The Aru region is located offshore West Papua, Eastern Indonesia. This region is a tectonically complicated area and close to an active tectonic plate boundary. It is a frontier exploration area with very limited well information. One of the main challenges in this frontier area is to estimate the heat flow in order to estimate petroleum generation and reservoir quality risk. In deeper water in the Aru region, a well-defined and extensive acoustic reflector is visible on seismic data that crosses other reflectors and mimics partially the surface of the seabed, a bottom-simulating reflector (BSR). The depth of this reflector corresponds well to the largest depth gas hydrate stability can be expected. Since gas hydrate stability is mainly a function of pressure and temperature, the location of the BSR may be used to estimate the heat flow.

An in-house study was conducted to understand the heat flow in the region. The BSR was mapped in detail on the 2415 km^2 3D seismic and calibrated well data and regional heat flow data. The BSR-seabed isochore was the primary input for the heat flow estimation. Variables such as water depth/temperature at seabed, sedimentation rates and the structural/stratigraphic development of the area are taken into consideration when evaluating the observed trends.

The heat flow estimates from the BSR mapping seem to be reasonable compared to other measurements in the region. Lower heat flow is observed in the northwest region of the study area and higher heat flow in the southeastern area.

This work indicates that heat flow estimates based on BSR mapping are feasible. These estimates can be used in 3D basin modeling to evaluate geological uncertainties and the effect of possible heat flow scenarios.

INTRODUCTION

The Aru region (Figure 1) is located offshore West Papua, Eastern Indonesia. The area is located at a continental margin adjacent an active plate boundary and comprises a frontier area for deep water petroleum exploration. The region is characterized by a major strike slip fault known as Tarera Aiduna Fault Zone (TAFZ) in the northern part and major normal faults of the Aru Trough (AT) in the southern part. Water depths in the region range from several hundred meters to about 3600m in the deep Aru Trough (Figure 1). A few shallow wells were drilled in the region in the 1970s. Meanwhile, in the deep water exploration point of view, until recently, little activity had occurred in this region. Estimating heat flow is one of the challenges when exploring in this region.

The bottom-simulating reflector (BSR) is characterized as an acoustic reflector that crosses reflectors which image geological layering. The BSR is identified on seismic in many parts of the area and was interpreted regionally. The BSR, likely associated with gas hydrates, is a thermal marker that can provide information about the thermal state of an area, including the lateral variations. Therefore, the location of the BSR can be used to evaluate likely heat flow scenarios.

METHOD

The gas hydrate phase equilibrium diagram (Figure 2) explains gas hydrate stability in marine sediments (Sloan, 1998). The phase equilibrium curve is defined by physical parameters of pressure, temperature, salinity, and gas molecular composition (Rao et al, 2001). The seismic BSR is associated with the phase transition between solid hydrates and liquid gas as shown in our phase diagram model in (Figure 2). This diagram uses the assumption of

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hydrostatic pressure conditions and methane composition.

We performed an in-house study of heat flow estimations in the region. The BSR boundaries are controlled by thermo-physical and thermo-chemical processes. Assuming the steady state approximation that heat flow and thermal gradients are independent of time, we developed a special formula based on an internal linear relation between heat conductivity and seismic interval velocity which is expressed in terms of the two-way seismic travel time (TWT), rather than true vertical depth (Hokstad, 2014).

The seabed temperature depends on latitude and water depth and this was taken into account during model building. A sea temperature near the equator model was used and calibrated with local temperature (Figure 3). Temperature at the BSR was estimated from phase diagram stability of gas hydrates.

Interpreted seabed TWT, BSR TWT, and the BSR-seabed isochore were the primary inputs for the heat flow estimation (Figure 4). The heat flow estimation really depends on the sensitivity of using the clay fraction (Vclay) when computed the heat flow model.

HEAT FLOW ESTIMATION FROM BSR

BSR Distribution from Mapping

The BSR has been carefully mapped from the entire seismic database in-house. The near angle stack seismic was used when mapping the BSR in case the BSR was being masked by far offset reflections present in full-stack seismic data. The 2D seismic data also have been used to map the BSR regionally. The BSR could not be interpreted everywhere. The BSR was mostly distributed in the northwest and southeast of the study area, with small portions distributed in the south. The time of the mapped BSR ranged from about 1000 ms to 6900 ms TWT (Figure 5).

Heat Flow Estimation and Calibrated with Measurement Data

The BSR temperature is estimated from hydrate stability phase diagram (Figure 2), whereas the seabed temperature is estimated from the calibrated temperature-depth model (Figure 3). The surface heat flow is then computed using the seismic TWT of the seabed and BSR. (Figure 6) shows measured heat flow from borehole measurements; most of them located onshore Papua. The range of measured heat flow in the area is 40 to 100mW/m2.

The heat flow estimation method is highly dependent on the clay fraction (Vclay). Typically the Vclay varies within a relatively narrow range between 0.4 and 0.6. The heat flow model was tested using Vclay of 0.3, 0.4, and 0.5. After calibration to the well data, a Vclay of 0.5 is selected as the most likely scenario.

The Deepest “BSR”

In general the BSR interpreted in the study area appeared parallel to the seabed. However, in the deep Aru Trough, the BSR dove deep with a high inclination to the seabed (Figure 7). Shankar et al. (2014) described in the Andaman Sea region that the BSR-Seabed isopach ranged from 518 to 861 m which they claimed as the deepest BSR depth below seafloor worldwide. Meanwhile, in this study the time thickness from seabed to the BSR was as high as 1900 ms TWT - much higher than reported from the Andaman Sea.

Temperature calculations from the heat flow model in the deep BSR locations gave temperatures 2-30 C lower than normal. These lower temperatures are interpreted to be the result of thermal disequilibrium due to recent and rapid sedimentation and they are unlikely to represent an actual (low) heat flow anomaly. It is important to distinguish between basal heat flow (e.g. input to basin modeling) and apparent surface heat flow due to advection effects and thermal disequilibrium.

Another BSR anomaly identified is related to a volcanic crater shaped vent feature (Figure 7). Such craters form as the hot fluids from deeper located volcanic sills or intrusions are expelled upwards and the morphology of such features are well described in the literature (Planke et al., 2005). The BSR is anomalous shallow adjacent to the crater where hydrothermal venting (upward moving hot fluids) may have taken place. In this case, the effect on BSR position is local and just very near the crater complex.

Observation of the Heat Flow Estimated from BSR in the Aru Region

(Figure 8) shows the surface heat flow estimated from the BSR. The results indicate two different heat flow regimes: relatively low heat flow in the northwest part of the study area and higher heat flow in the southeast area. Estimated heat flow is in agreement with borehole data. There are areas which stand out with a very high calculated heat flow, but with few data points (i.e seismic coverage and visible BSR). Therefore, it is difficult to determine the exact cause of this very high surface heat flow. High surface heat flow may be due to higher basal heat flow or a sediment package with higher thermal conductivity or combination of both factors.

It is likely that the variation of the heat flow between the two regimes is related to the tectonics in the region. The strike-slip plate boundary may have separated two different heat flow regimes, a fore arc-like situation on the northwest side of the strike-slip boundary of Tarera Aiduna Fault Zone (TAFZ, Figure 9), and a zone on the southeast side which is close to the active spreading zone of the Aru Trough (Figure 9). Cloos et al. (2005) pointed out that in the study area the most dominant major tectonic features are the Tarera Aiduna Fault Zone and the Aru Trough spreading zone.

EXPLORATION SIGNIFICANCE

The heat flow estimation from the BSR is the first study of its type in this area to our knowledge. The results suggest that the heat flow changes significantly laterally. This change is important to understand for petroleum exploration as it has consequences for the prediction of source rock maturation, reservoir quality and for well planning.

The heat flow estimations shown in this study can be used as input in 3D basin modeling and may further constrain geological uncertainty. The deepest BSR in the Aru Trough may also further constrain the age and sedimentation rate of the shallowest sediment layers; if the deep occurrence is due to thermal equilibrium it should be possible to constrain the minimum sedimentation rate in order to cause such deep BSR with similar lateral basal heat flow. Further work is needed to study this effect in more detail.

CONCLUSIONS

The heat flow estimated from BSR is reasonable compared to available data in the study area. Estimated heat flow and BSR temperatures are in agreement with borehole data in the area.

There is a change of heat flow regime across Tarera-Aiduna strike slip fault zone (TAFZ). Lower heat flow is observed to the northwest in the fore-arc north of TAFZ. Higher heat flow is observed to the southeast close to Aru Trough Spreading Zone.

Heat flow estimates based on BSR mapping can be used to constrain likely heat flow scenarios.

ACKNOWLEDGEMENTS

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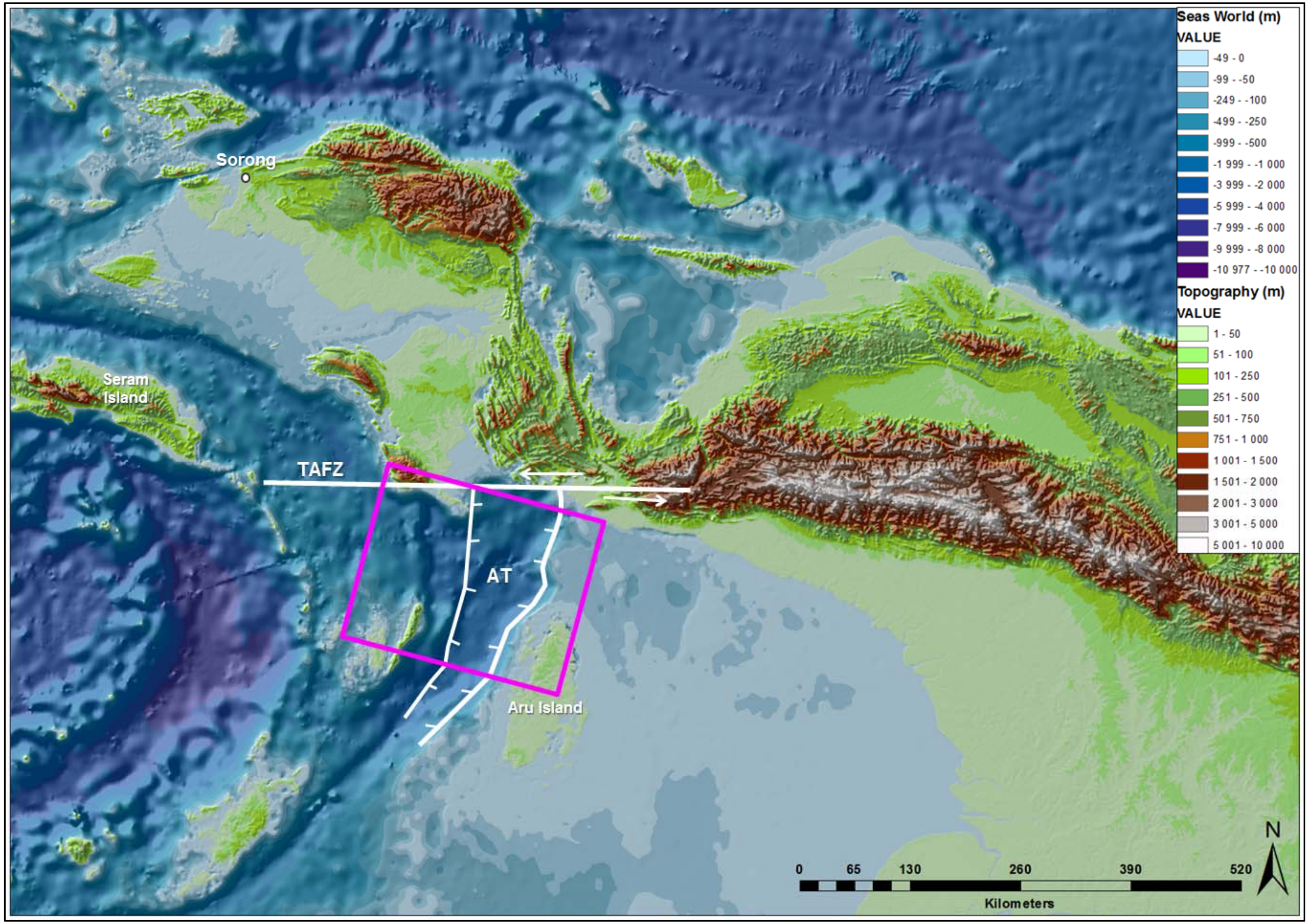


Figure 1 - A regional map of Eastern Indonesia with the study area indicated by the magenta rectangle with main tectonic features in the study area: TAFZ – Tarera Aiduna Fault Zone, AT – Aru Trough.

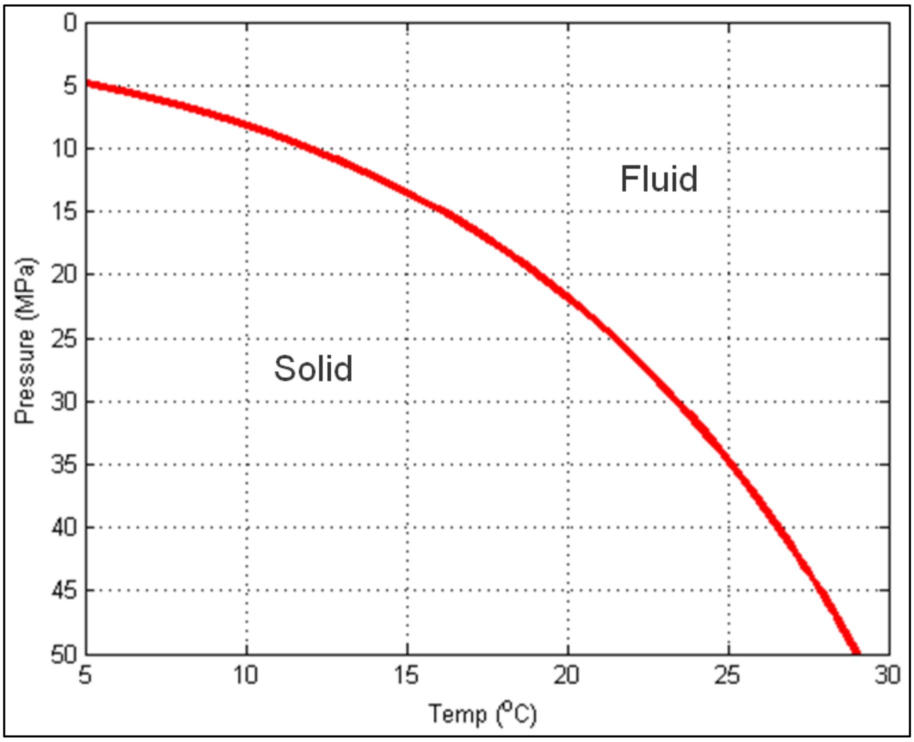


Figure 2 - Hydrate stability phase diagram used hydrostatic pressure condition and methane composition (e.g. Sloan, 1998).

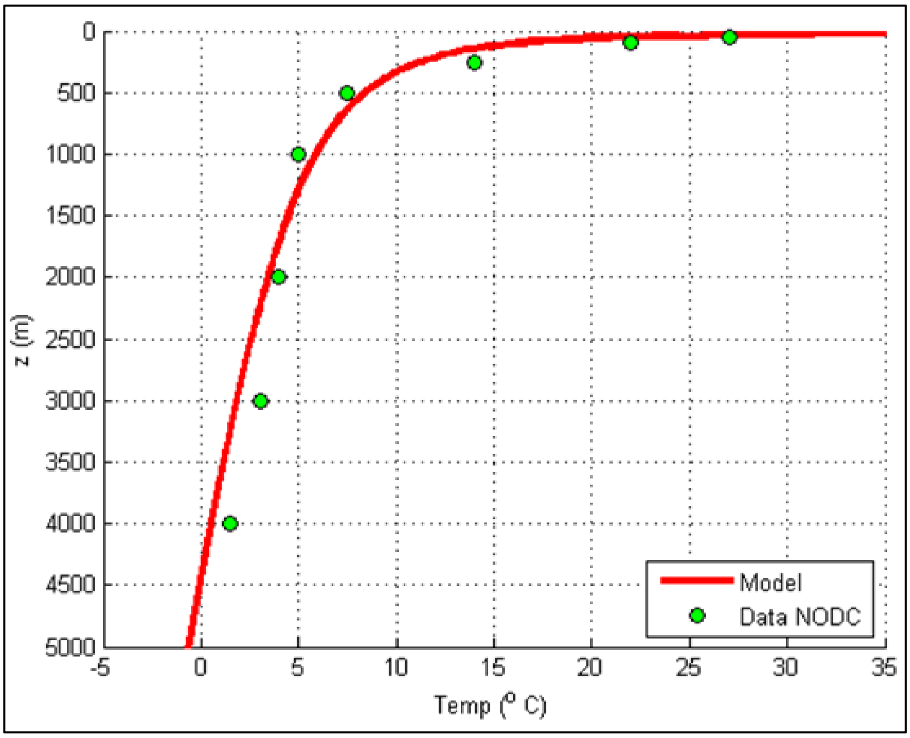
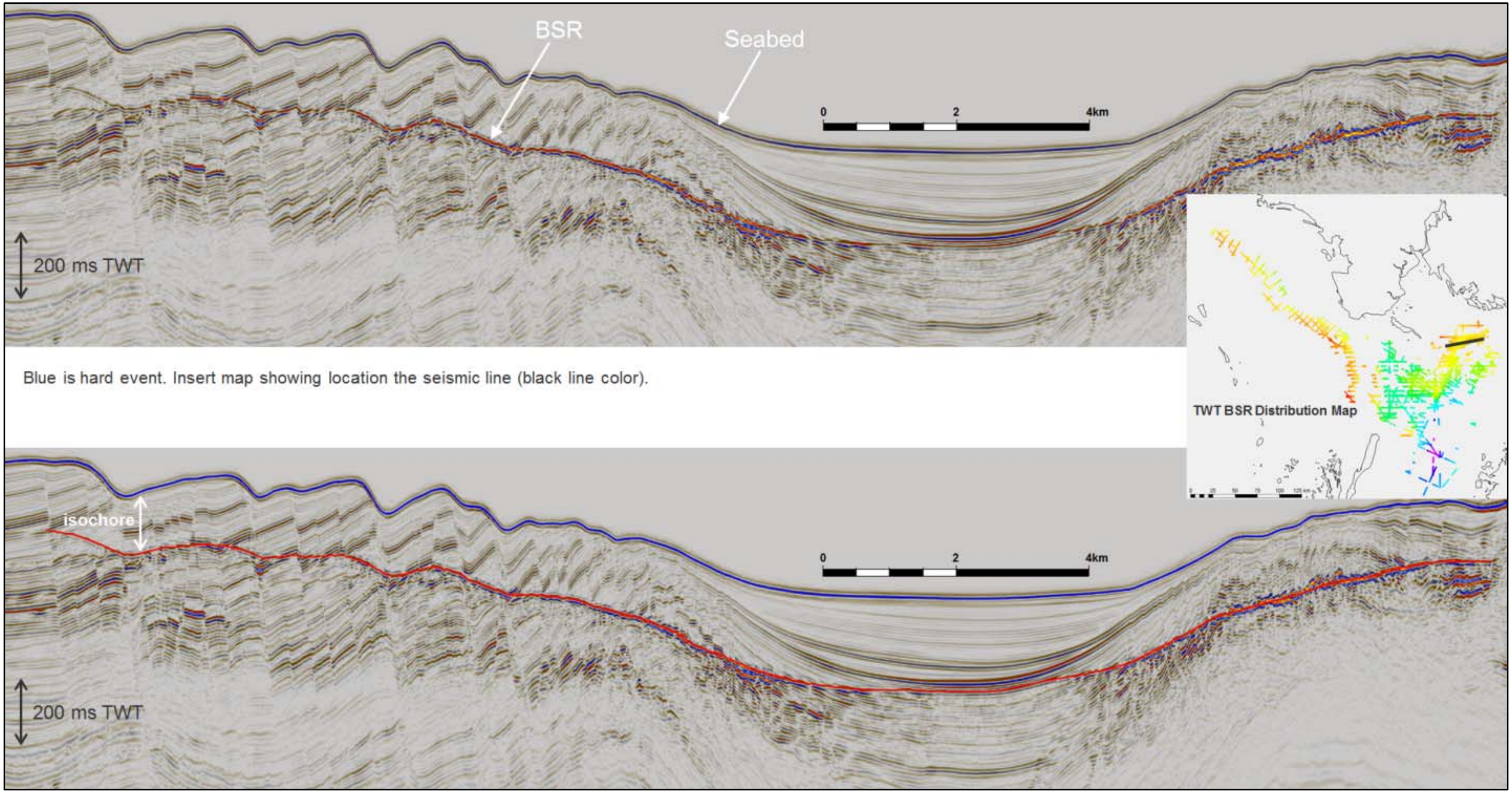


Figure 3 - Seabed temperature versus depth model with calibration data (Courtesy raw data from NODC - National Oceanographic Data Center, accessed on December 2014).



Blue is hard event. Insert map showing location the seismic line (black line color).

Figure 4 - The seismic line shows seabed (blue), BSR (red), and isochore BSR to seabed. Top part is without interpretation markers (Data acquired by CGG).

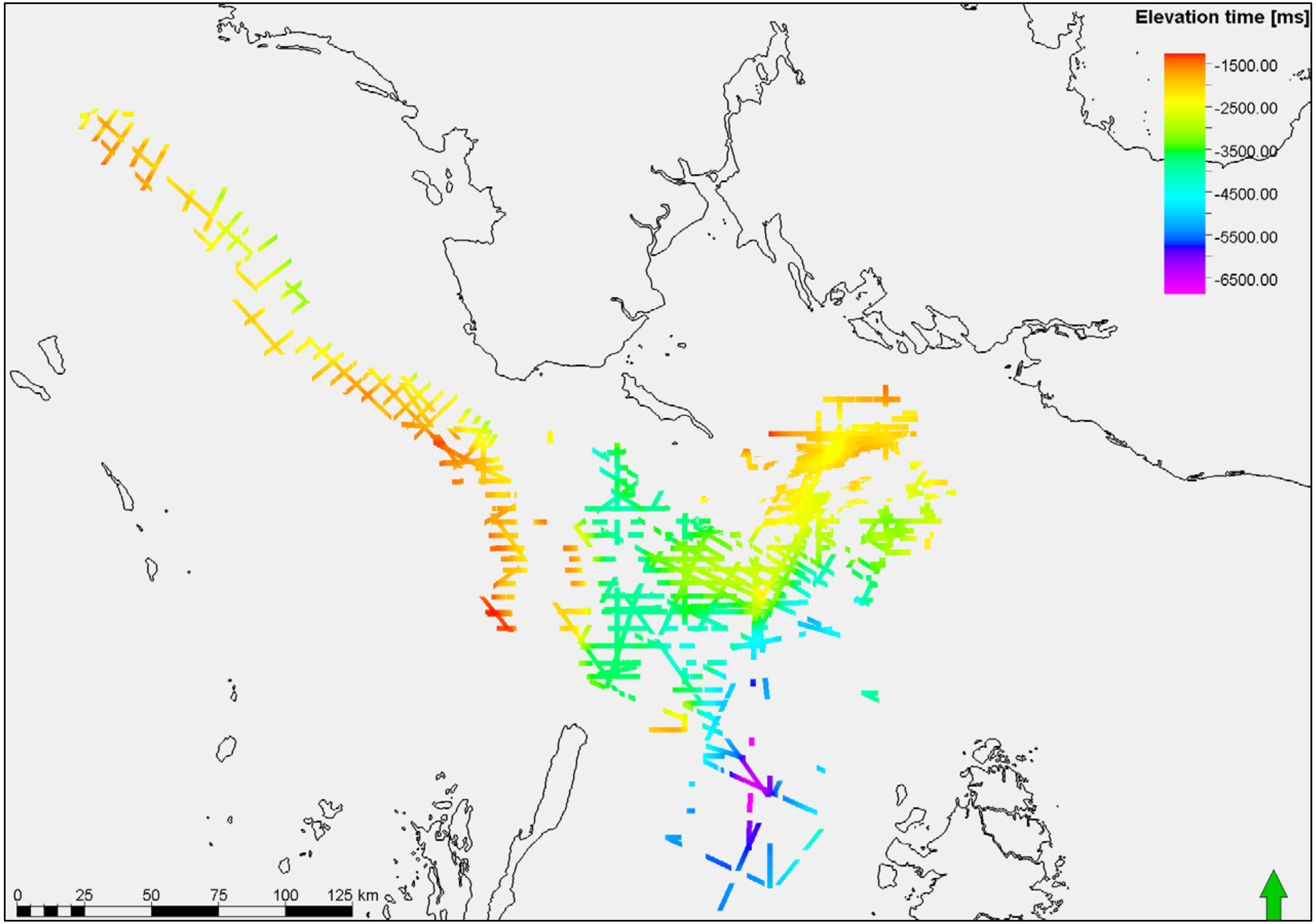


Figure 5 - The BSR distribution from mapping in 3D and 2D.

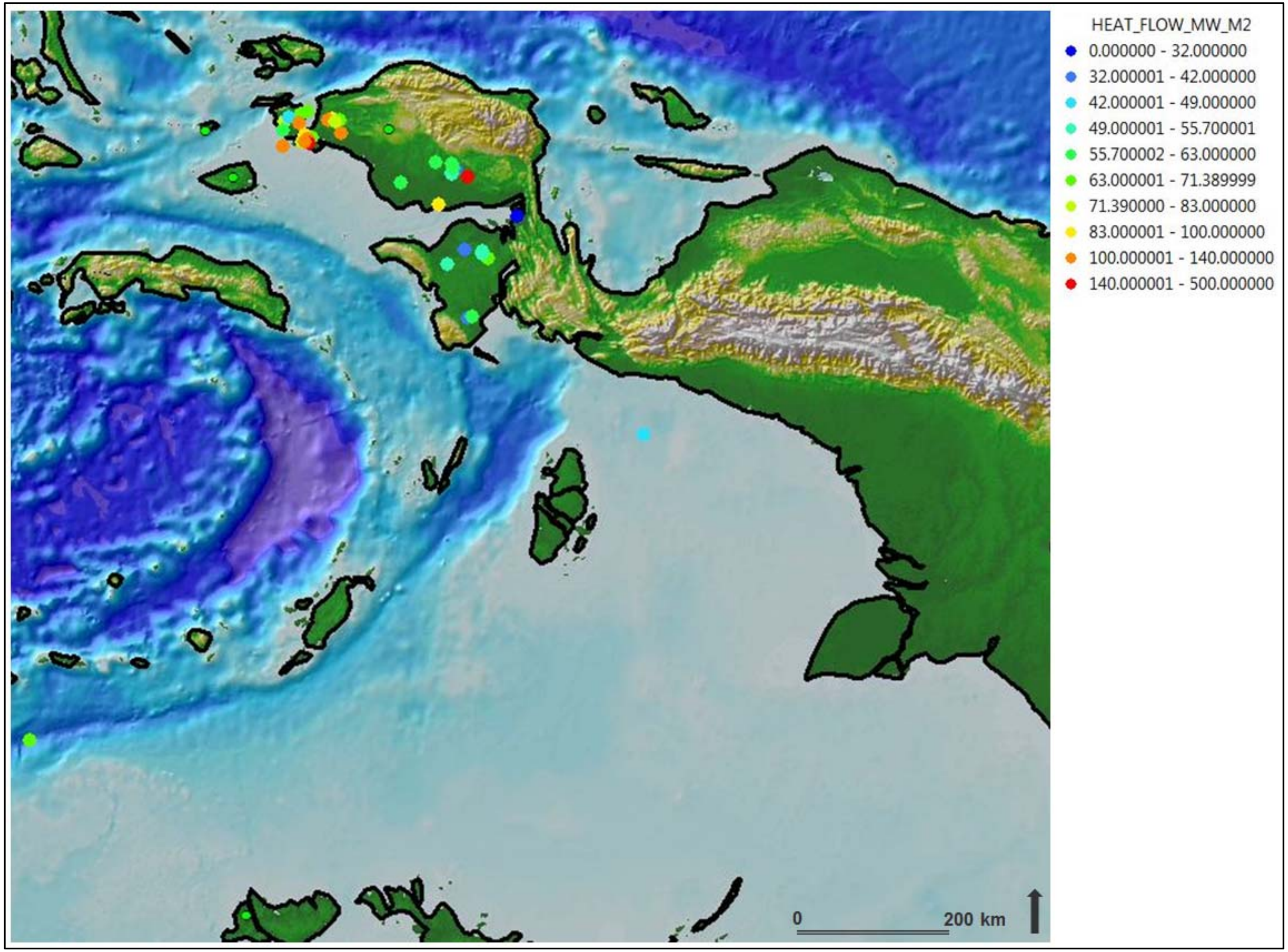
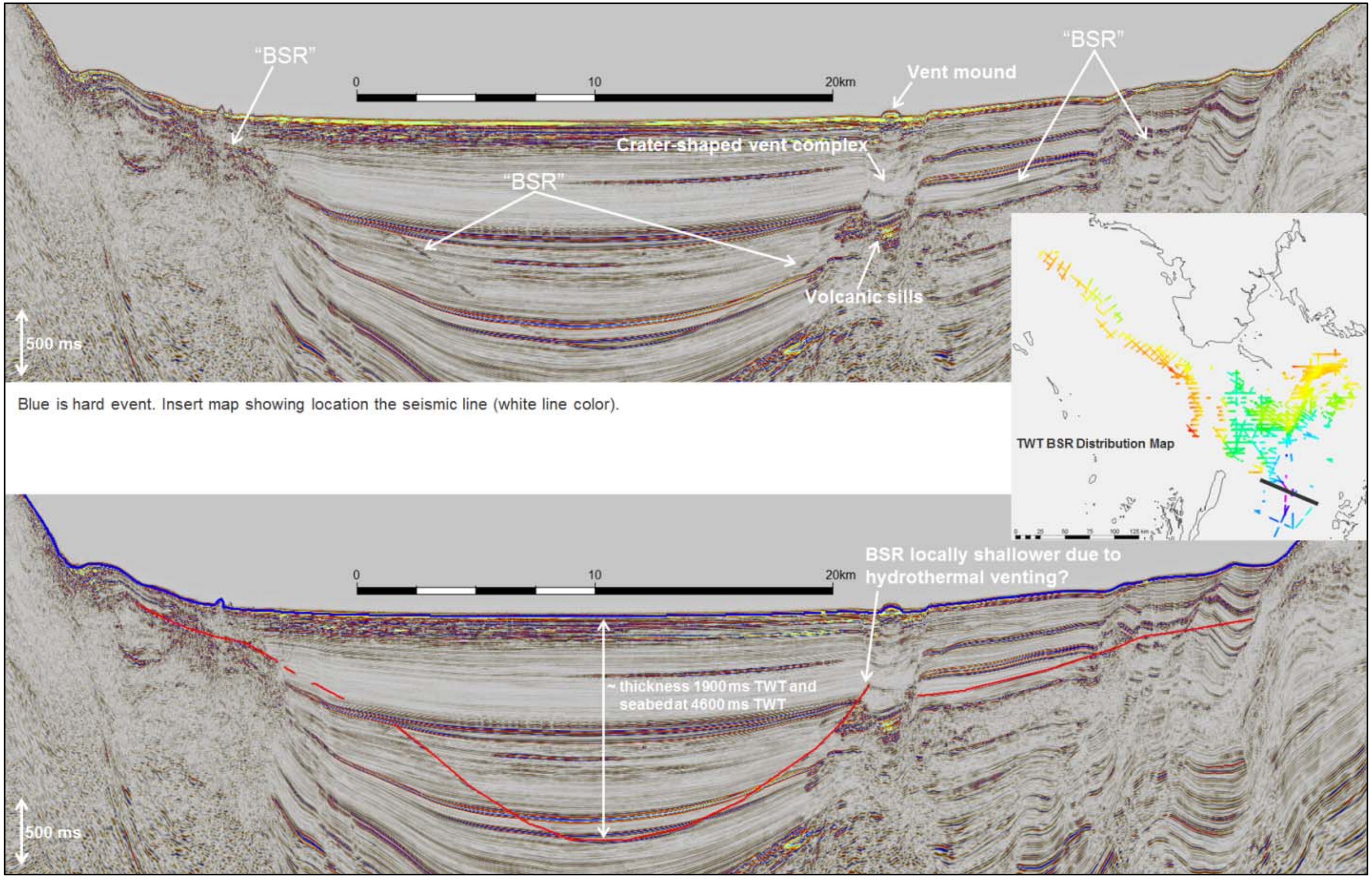


Figure 6 – The borehole heat flow data in the region.



Blue is hard event. Insert map showing location the seismic line (white line color).

Figure 7 - The sinking "BSR" in the deep of Aru Trough. The thickness time from seabed to this "BSR" about 1900 ms TWT (Data acquired by SpecPartners).

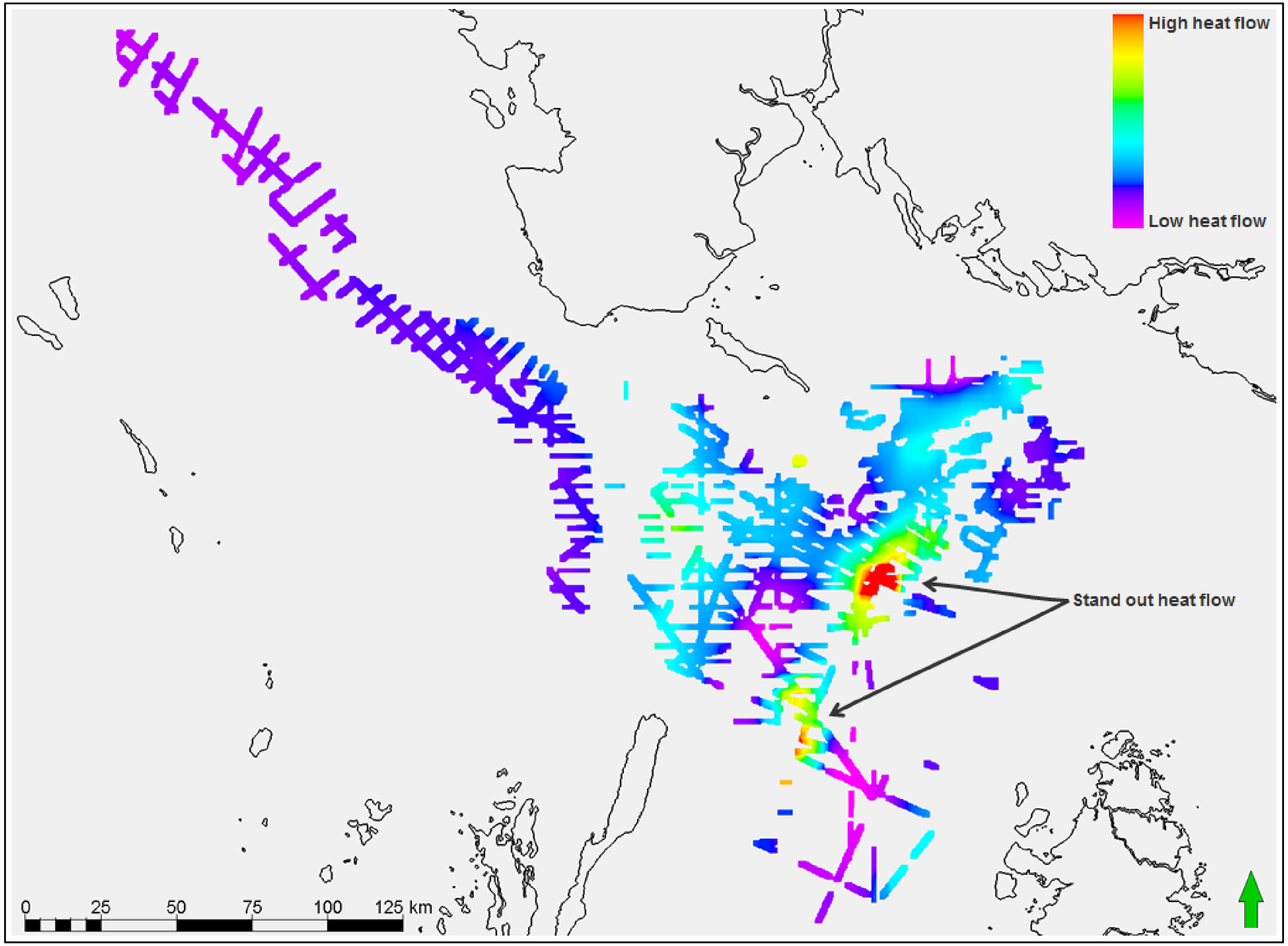


Figure 8 - The heat flow estimation map derived from the BSR. The estimated heat flow is consistent with borehole data located offshore West Papua.

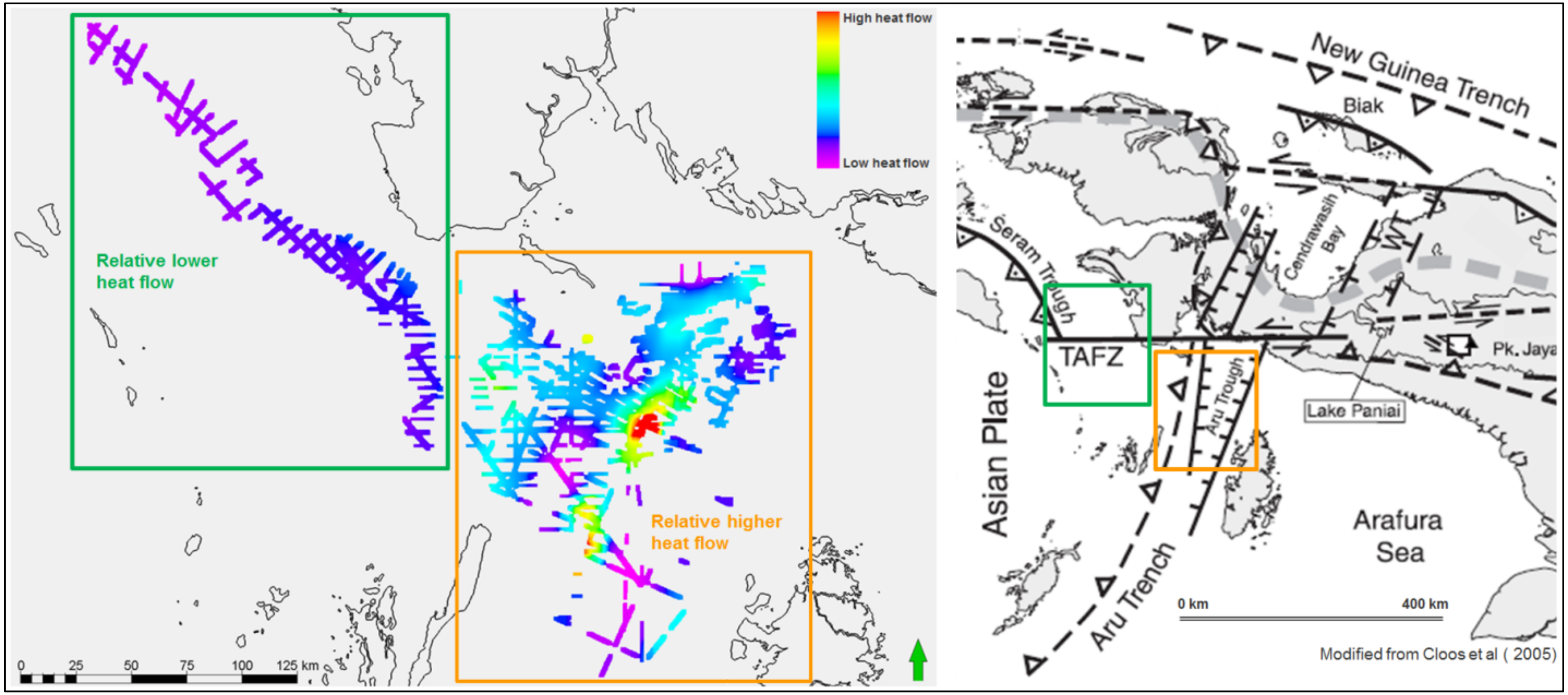


Figure 9 - The heat flow map and seismo-tectonic interpretation map showing two main heat flow regimes.