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Remote sensing heat anomalies

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ABSTRACT

Remote sensing heat anomalies directly deserves more attention. Many methods and instruments exist but results from these are largely ignored in the geothermal community. A calibration range is advocated in one or more of the more prospective regions to fasten better use of geophysical methods. Clever software is also required to bridge the gap.

Keywords: Heat flow, Aster, airborne survey, SQUID, surface temperatures, 3D modelling.

INTRODUCTION

There is only token use of remote sensing technology in Australia for heat resource exploration. This seems strange given that field mapping and drilling are orders of magnitude more expensive. It is also true that the quantitative values from remote sensing are not believed to reflect reality. This is a sad state of affairs. In estimating a thermal resource for a project, one is required to input a surface temperature or heat flow constraint. In the case of a surface temperature this is currently done either by applying a correction to the mean annual surface temperature gained from meteorological records or by using corrected, continuous temperature logs from the soil profile. In the case of surface heat flow, measured values need to be obtained.

These approaches do not directly account for local geological variations. There are several reasons why a well-calibrated and high resolution remotely sensed heat map of the surface can be of value.

The argument for measuring any independent variable that reflects a property of the sub-surface geology will always make a contribution to the 3D geology earth model. So along with gravity, magnetics and radiometrics, why not measure heat flow?

The rock properties required for a heat resource calculation are under sampled. The variability is very high. Measurements of surface heat flow may help elucidate these rock properties.

The counter argument often heard is that what happens at the surface has little to do with what might be happening at a depth of 3 kilometres, when there could be sedimentary layers “blanketing” the resource. Figure 1 illustrates this point. Different thermal gradients will exist in rock units of different thermal conductivity. This is the essence of the "hot dry rock" geothermal energy resource. Like any other geothermal energy resource, this requires elevated rock temperatures to occur at anomalously shallow depths. For instance, this is achieved if a highly radioactive granite (with medium to high thermal conductivity), is thermally insulated from above by sedimentary cover of low thermal conductivity.

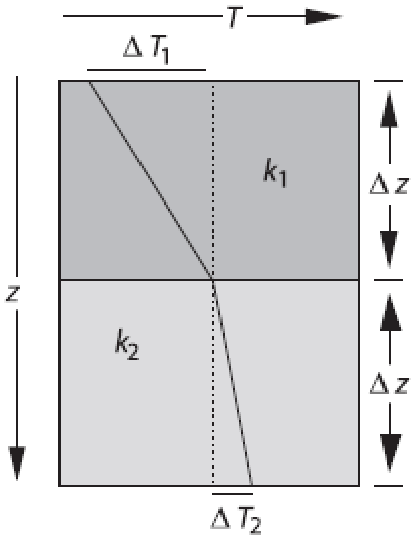

Figure 1. The principle of heat refraction - where the top layer has a low conductivity and therefore a large temperature gradient. This overlies a good conductor with lower gradient but higher temperature.

The thrust in Australia is to find high value heat resources that could provide significant bass load electricity economically. However, while this is admirable, it is perhaps not the most common case. For instance, in Holland, the thrust is towards finding lower temperature heat resources that can be used for direct heat applications such as commercial glass houses.

Remote sensing has an at least as important part to play in this scenario, as engineering and development budgets are much higher.

EXISTING EXAMPLES - SATELLITE

There are many contexts where either satellite, airborne or surface measurements clearly indicate unambiguous heat anomalies in the sub-surface geology. Scenes gathered at night time using thermal imagery often are quite good indicators of large scale surface heat flow anomalies.

Hydrocarbons do not conduct heat well and so may create local low heat anomalies.

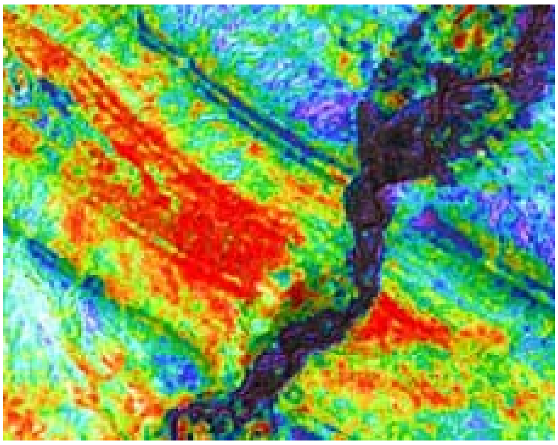

Figure 2. Shows strong thermal anomaly (cold) in the core of an anticline in the Middle East.

The Aster satellite system is used extensively by remote sensing specialists to help map geology. A considerable part of the measured signal is from the thermal band.

A paleo-channel with significant uranium content may generate local high heat anomalies. An example from the Beverly project is shown in Figures 3a & 3b.

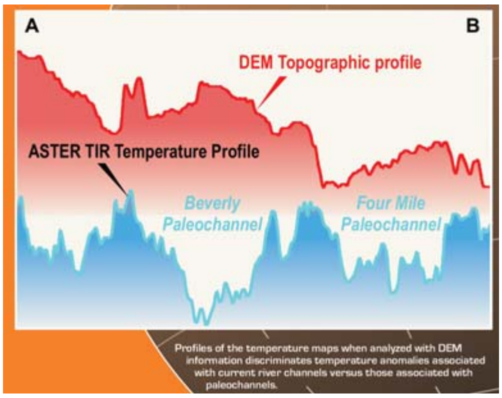

Figure 3a.

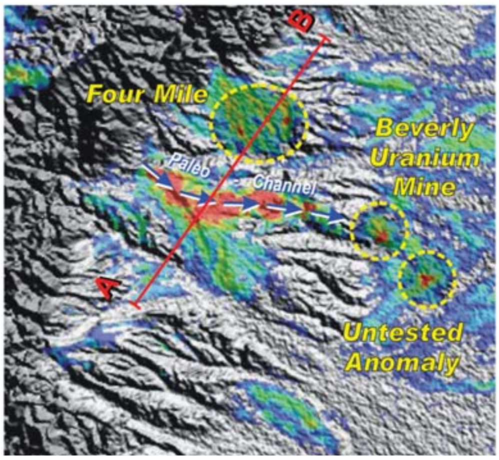

Figure 3b.

Figures 3a & 3b. Show the Beverly project in North Flinders where Aster is detecting heat anomalies in paleo-channels flowing from the nearby ranges.

Several groups have developed technology for adjusting the Aster signal to correct for “Black Body” radiation in order to predict surface temperatures and /or heat flow associated with the outcropping geology. The RASTUS system by Neil Pendock is one example.

Temperature effects must be removed from each Aster spectrum before the TIR imagery can be meaningfully interpreted,. This is achieved by fitting and removing a blackbody curve from each TIR spectrum.

There are thus two outputs: a temperature image and a blackbody corrected data set. The temperature image for the TIR scene is shown in Figure 4.

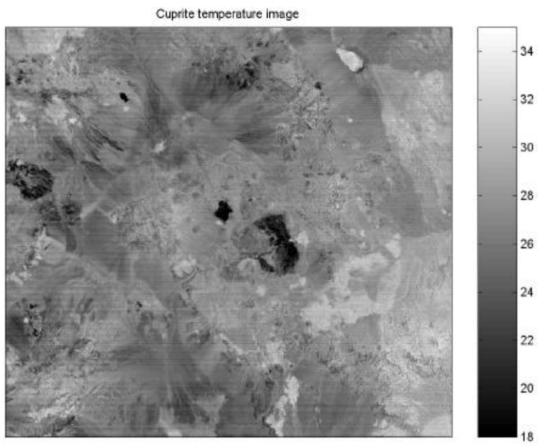

Figure 4 shows an example of surface temperature map derived from Aster data using the RASTUS system. It shows over 16 degrees Centigrade variation on the surface.

EXISTING EXAMPLES - AIRBORNE

The continental scale estimate of the temperature at 5 km depth mapped for Australia is due for another upgrade. This time the aim should be to extrapolate from the isolated deep well observations as before, but to also add in a blended contribution from the estimate of the depth to the Curie temperature (approximately 560 degrees). This estimate can be made using the aero-magnetic observations and seeking the bottom or greatest depth to magnetic basement. While this is very dependent upon the quality of the observed magnetic data, we are fortunate in Australia, to have arguably the best observed regional magnetic datasets. If any country can get it right, Australia should be first. Shell are currently preparing world temperature/depth maps based upon this idea. The sooner this work is published by Geoscience Australia the better for our industry.

Another approach is to look at surface expressions of mineralogy that indicate where high heat alteration conditions have existed in the past. The mineralogy can be directly sensed using the reflectance of light and analysing wave-lengths (hyper spectral). Regional mapping can be used to differentiate granites through mica chemistry and mafic mineral content. (eg Pilbara Geology Mapping, WA)

The HYVISTA system has been used in the North Kimberley region of Australia for the detection of hydrothermal alteration associated with deep seated high temperature granites. The question, "When did this alteration occur?" is not resolved by this system.

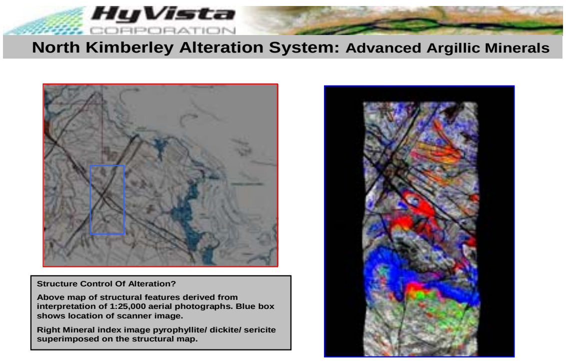

Figure 5. These images show methods adopted in the North Kimberley to analyse whether locations of mineral systems are controlled by structural features, or by alteration zones. Images courtesy of HyVista Corporation

The daughter products of natural radioactive decay in and around granitic rocks, includes radon gas. This is routinely observable during gamma ray airborne surveying, in Australia where there is granitic outcrop, on days of no rain and little wind.

This is thought of as noise and routinely discarded. The entire raw radiometrics surveying record for Australia contains quite a bit of this information. No systematic use of this record has been contemplated to date.

EXISTING EXAMPLES – GROUND SAMPLING

Another daughter product from deep seated radioactive decay is helium. This is not easily detected from an airborne system, but instruments do exist for ground surveying. This class of instrument is a chemical sniffer rather than an instrument based upon spectroscopy. Hot Dry Rocks market such an instrument.

In conventional geothermal systems, there is usually an easily discernable expression of near surface heat. The test range set up in Nevada by the Geological Survey (Kratt, et. al. 2008), shows Aster satellite data, pattern drilling of short length test holes, some deeper drilling and locations of known "hot" geological structures such as geysers.

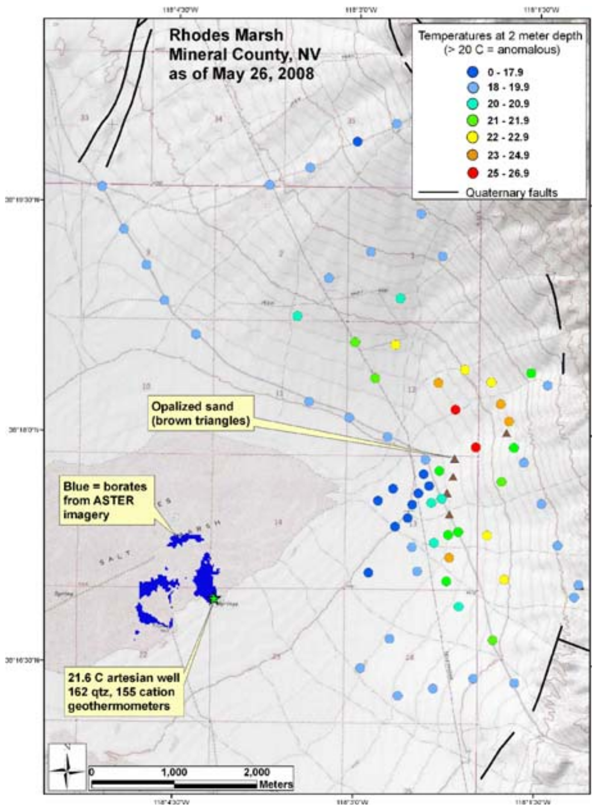

Figure 6. Shows the general layout for what can be seen as a calibration range in Nevada.

EARTH'S HEAT LOSS

Earth's Heat Loss at present is about:

74% from plate activity,
9% from hot spots, and
17% from radiogenic heat lost from continental crust.

Typical heat flows at the Earths surface are between 0.001 W m^{-2} and 0.1 W m^{-2}. The mean heat flow of all continents qc and that of the oceans qo , are:

$qc = 0.065$ W m^{-2}
$qo = 0.101$ W m^{-2}

Multiplied with the surface areas of the oceans and the continents, respectively, we can estimate the global heat loss of Earth to space to be some 10^{21} Joules every year (see Stüwe, 2007).

This energy is directly emitted at the surface, together with heat being absorbed and re-emitted from external sources. The direct sensing of this "irradiance" or heat emittance from the earth's surface (see Figure 7) is problematic.

Figure 7 shows a cartoon of the inputs and outputs of the surface heat situation and gives approximate quantities during normal daylight hours. The contribution of Earth heat loss is very small relative to all other factors.

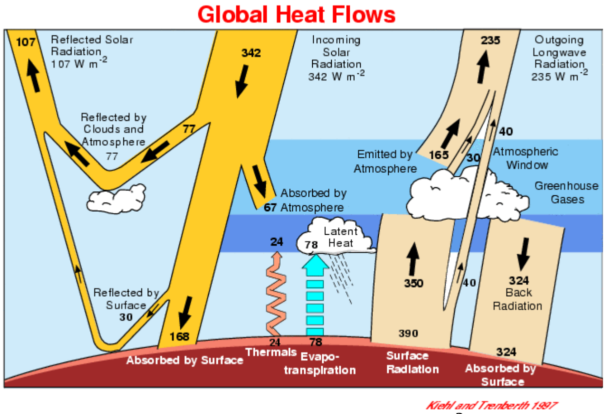

Figure 7. Global heat flows in Watts m^{-2} during daylight hours

PERIODIC SURFACE TEMPERATURE FLUCTUATIONS

Temperatures at the surface of Earth vary both in time and in space: daily and annual temperature fluctuations cause temporal variations and adiabatic gradients cause variations with surface elevation. While both may not be important in Australian geothermal energy problems, they are considered briefly here. The relevance of temporal fluctuations may be studied by assuming that the diurnal or annual temperature variation at the surface is simply described by a cosine function:

$T = \Delta T \cos(ft)$ at *the surface*

where f is the frequency (i.e. 1 per day or 1 per year).

For these boundary conditions, there is an analytical solution of the heat flow equation given by:

$$T = T_0 + \Delta T e^{\left(-z\sqrt{f/(2\kappa)}\right)} \cos\left(ft - z\sqrt{f/(2\kappa)}\right)$$

where *T0* is the starting temperature at $t = 0$, f is the frequency (e.g. 1 per year) and ΔT is the annual temperature amplitude (e.g. 20 °C between summer maximum and mean annual temperature.

The annual fluctuations only influence temperatures at depths down to about 5 metres. Thus, annual and daily temperature fluctuation have to be accounted for in any remote sensing work and removed before 3D modeling is performed.

INNOVATIONS IN REMOTE SENSING INSTRUMENTS

Many types of instruments are available. With the advent of SQUID's (Super Conducting Interference Device), the sensitivity and response time are now such that viable observation systems for heat can be evolved that are significantly more useful.

The classical direct heat measurement instruments are:
Thermometer – temperatures and gradients
Bolometer – heat radiance. This is the term coined by Langley of CIA fame for such an instrument, which he invented in 1886.

In the presence of significant water vapour, a bolometer is opaque to heat through much of the infrared band. This is illustrated in figure 8.

The greater the column of air, the more the heat signal would be attenuated, so satellite measurements are the least ideal. Low flying aircraft based systems are a good compromise for surveying. A downward looking "telescope" that is in fact a bolometer, will yield more sensitive and precise measurements. At least 5 of the above frequency peaks should be chosen for measurement.

The German group IPHT from Jena manufacture such an instrument that would be very suitable. This instrument has never been deployed upon an aircraft, but rather on satellites.

WHAT TO MEASURE?

There are many sceptics to the notion of remote sensing heat. They claim that surface temperatures, in a spatial sense, do not vary very much,when averaged over several days. Remote sensing work using thermal bands from satellite systems such as Aster indicate that there are significant spatial heat anomalies associated with locally outcropping geology. These two positions are not irreconcilable – we look to Physics to explain how both observations can co-exist.

For those familiar with gliding, thermals form over "Black Bodies" and strong updrafts can exist over areas of high heat emittance even though surface temperatures may not vary greatly.

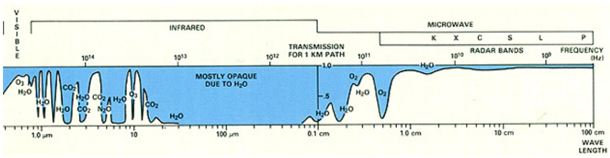

Figure 8. Shows the electro-magnetic spectrum and highlights in the thermal bands, those frequencies that cannot be measured due to water

KNOWN OBSTACLES TO REMOTE SENSING OF HEAT

Among the obvious issues to overcome are:

- effect of evapo-transpiration

- Albedo effect
- Black Body corrections
- ground water and its influence in masking
- clarification of transient vs. steady state measurements
- what quantity is being measured and how does it compare with other measurements using different physical principals.

There are already many examples of published techniques for dealing with these issues. The US Geological Survey via Ken Watson (1992) has investigated removal of the Albedo using innovative Fast Fourier Transform filtering techniques. There are many examples in observational geophysics where the anomaly to be measured is less than 10^{-5} of the gross amplitude. Heat anomalies are just another challenge of this nature.

PROPOSAL FOR AN AUSTRALIAN TEST RANGE

My proposal to the AGEG community is to set up test ranges in at least two settings representative of Australian conditions.

Case 1,
Northern Flinders Ranges (South Australia) where there are known high-heat producing granites, due to radiogenic contribution. The aim is to conduct a detailed field mapping exercise to acquire surface heat and temperature measurements and rock properties on say a 200m grid basis for a 5km x 5km area. The study area should cover both exposed and covered granites. The weather conditions, time of day, cloud cover and soil moisture are also factors to be recorded.

Case 2,
Onshore PortCampbell (south-western Victoria) where there are suspected oil seeps associated with faulting. There are also many deeper oil exploration wells in this area.

An initiative to get the ball rolling could be funded by government sources. All datasets go in to the public domain and any party that wants to try out their technique in the test range can have access to all the past data.

ACKNOWLEDGEMENTS

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