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# INFRARED AND SATELLITE IMAGES, AERIAL PHOTOGRAPHY

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## ABSTRACT

We will in the following mention a few remote sensing methods that are applicable in geothermal prospecting. Air photo interpretation has been practised in geology for 70-80 years. Infrared scanning became popular in the late nineteen fifties and satellite images followed in the seventies. Infrared sounds good as geothermal is concerned but its use has been limited. Satellite images have proved valuable in geology for recognizing all sorts of lineaments and also features have been discovered that were too large to be recognized from ground studies of conventional air photos. The Yellowstone caldera is an example. Several impact craters showed up around the world. In Iceland under-ice caldera volcanoes were detected. The stereoscopic view of air photos, however, is by far the most important for the geologist. Unfortunately access to them is limited in many countries as they are considered a kind of security information. Needless to say that ground check is needed to interpret the features correctly.

## 1. THERMAL INFRARED

Thermal infrared remote sensing (TIR) scans thermal surface activity, and difference in temperature (from tonal contrasts). Also heat loss through hot or warm ground by conduction can be calculated. The method requires temperature measurements in the topmost part of the soil to find the thermal gradient. This must be done at the same time as TIR. Changes in thermal areas can also be mapped and monitored by TIR. Infrared remote sensing of geothermal areas is preferably done from airplane before sunrise. At that time the contrasts come out best. The best conditions for application are in dry climate regions with minor cloud cover for days or weeks.

The method can be used also for mapping of thermal properties of different rock types. Then two flights are needed, one at about noon the other before sunrise. Sometimes considerable thermal radiation is found where no geothermal manifestations occur on the surface. In most cases this is due to insolation of dark rock. Obsidian flows are an example.

Two figures of the same area represent a sparsely vegetated and partly barren fumarole field and its surroundings at Hengill in SW-Iceland. Figure 1 shows thermal features above 25°C, from green to red (boiling). Lower than 25°C has been filtered out. The distribution, here NW-SE, correlates with a regional feature of that trend but of unexplained origin. A dominant NE-SW-fault pattern in this general area does not show up.

In Figure 2 the TIR has been superimposed on a geothermal map based on a ground survey. Here the pink spots mark hot ground (not hot springs as it says in the explanation), violet marks clayey alteration, and light brown marks low grade alteration. The latter two were defined as mainly cold. The ground survey would have been cheaper and it shows the alteration state of the ground. However, the TIR would make it possible to assess the heat loss, not done though for this small part of the geothermal field. On the other hand the natural heat output of 90% of the area of the Hengill geothermal field was calculated 470 MW from this survey.

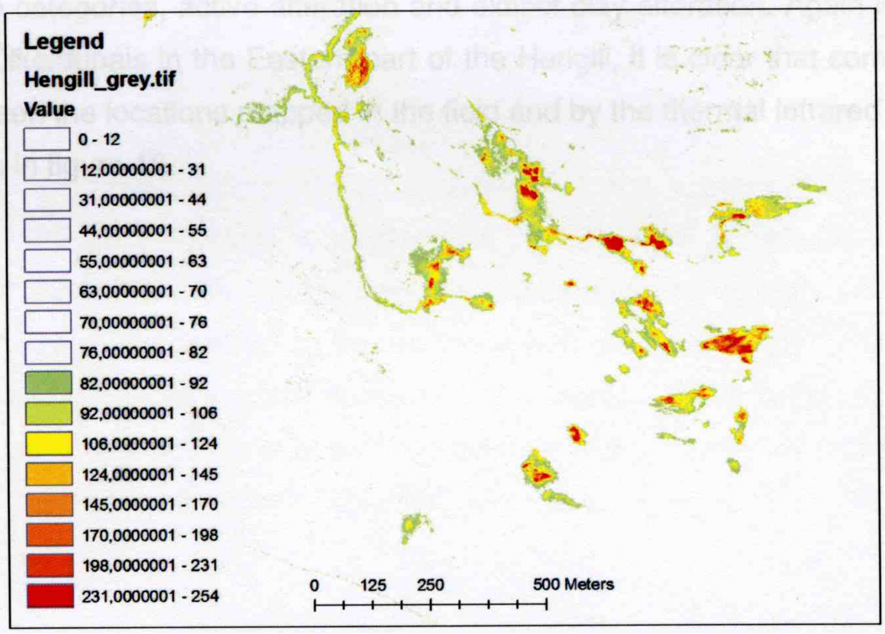

FIGURE 1: Thermal features of the Hengill area. The colours represent represent geothermal activity where the reflective temperature is above 25°C. Red represents the highest temperature. Temperatures lower than 25°C are filtered out

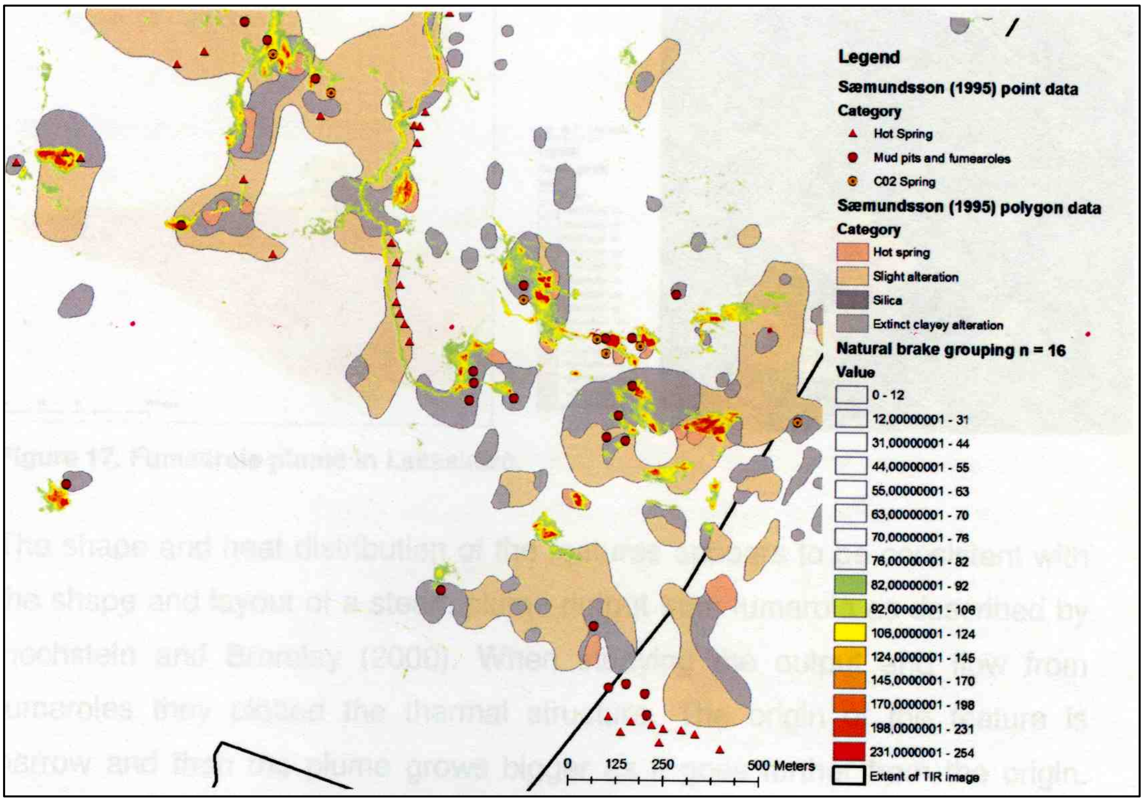

FIGURE 2: Comparison between geothermal mapping in the Hengill area and results from TIR imagery

Interestingly calculations of heat output have repeatedly shown that most of it is from the hot ground around the steam vents or mud pools.

## 2. SATELLITE IMAGES

Satellite images give a splendid overview where regional structures are prominent. Ground check and comparison with geological maps is important. The method has been successfully applied for over 30 years with increasing resolution from Erts, Landsat, Envisat to Spot-5 with resolution (pixels) down to 5 m. As an example the first ERTS-images of Iceland (in 1972) revealed several calderas in the ice-covered volcanoes up to then unrecognized (Figure 3).

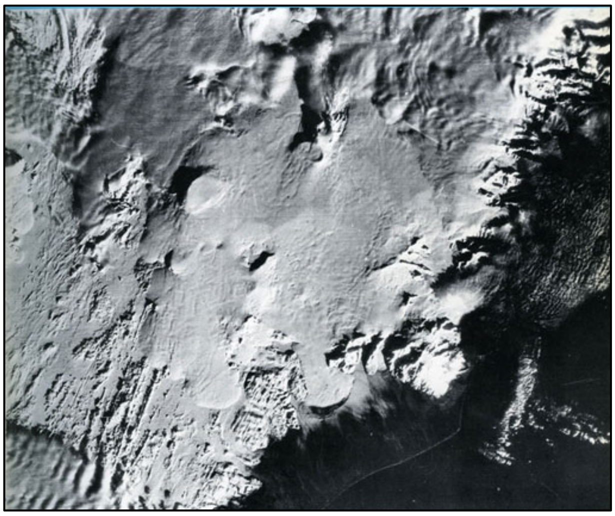

FIGURE 3: Vatnajökull glacier (9500 km²) is located in the smooth field in central part of the figure. Two central volcanoes with calderas were first recognized in its NW and SE part from this image. A third caldera to the north of these was also recognized here for the first time.

## 3. AIR PHOTOGRAPHS

Air photographs are an important aid for the geologist in geological mapping, especially as regards volcanic and structural features. There are several types of pictures, such as black and white, true colour, and false colour. In mapping of geothermal and volcanic areas the false colour photographs have proved superior to the others (Figure 4). Stereoscopic view is necessary.

Air photos reveal a wealth of surface features, primarily as regards structural elements. In geothermal areas also such features as are directly related to thermal activity show up. Among them alteration (light surface colours), slide on unstable slopes (clayey ground) hydrographic features (dominant trends) and lava flows with different vegetation cover (helps define relative age but roughness must be accounted for.

After locating a thermal manifestation - Role of the geologist:

- Define type: Fumarole, steaming ground, spring, seepage, $CO_2$ vent, alteration, type of surface clay (kaolinite or smectite). Type of efflorescence minerals. Temperature. Flow rate.
- Define local geological control.
- Correlate with ground temperature survey and soil gas survey if such is made.

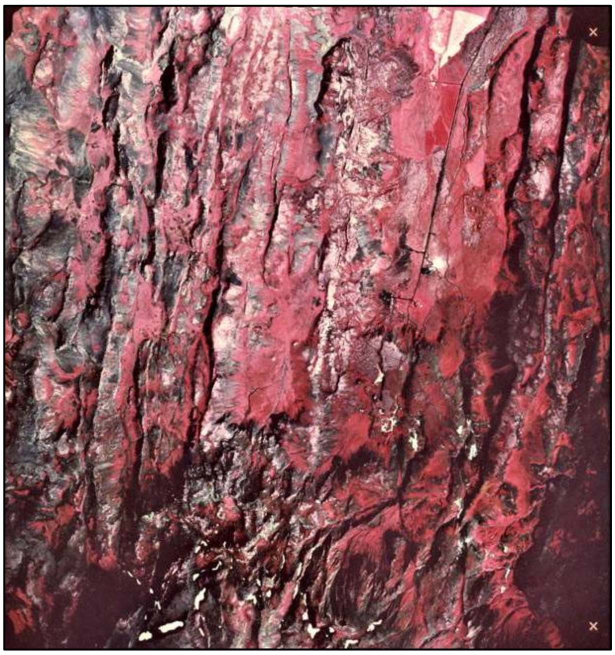

FIGURE 4: A false colour photograph of a 4x4 km area northeast of Hengill in SW-Iceland (northeast is up, vegetation is deep red (grass) and pale red (moss). Normal faults show up prominently. A zone of crater rows runs parallel to the faults through the upper two thirds of the photograph just east of the centre. This zone marks the main upflow of the geothermal system northeast of Hengill.

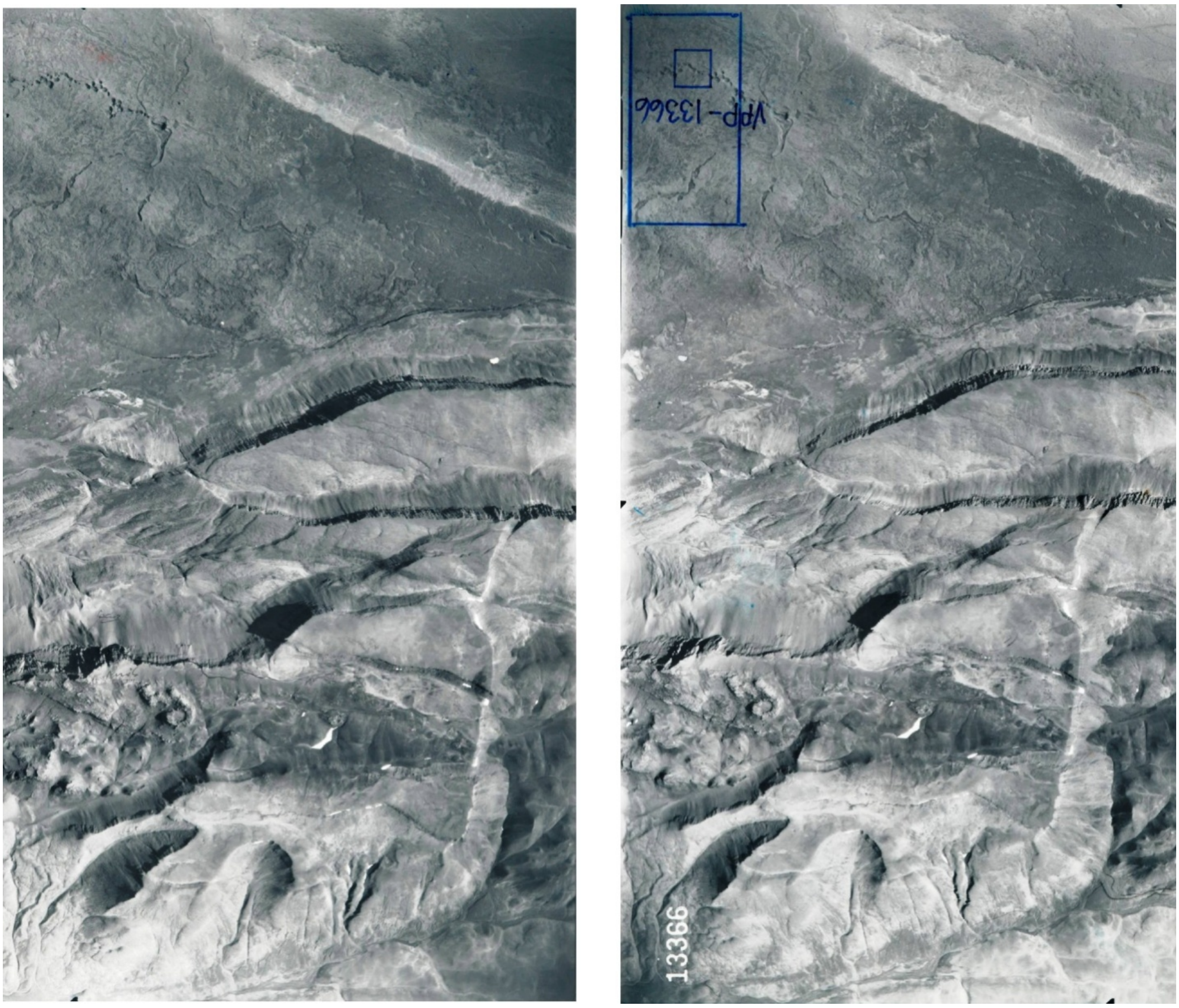

FIGURE 5: Stereopair of black and white air photographs. Large normal faults dissect the mountain complex in the lower two thirds of the pictures. A hyaloclastite ridge in lower one third overlies a tuya (subglacial lava shield) with glacial cirques. Holocene lava in upper one third. North is to the left.

## 4. InSAR

InSAR (synthetic aperture radar interferometry) is a powerful method of measuring mm scale crustal distortions from slight changes in the travel time of a radar beam played across the surface from a satellite. It is mainly used in surveillance of earthquake prone areas and volcanoes. It is also used to monitor ground level changes caused by exploitation (lowering of water level) of geothermal systems. Figure 6 shows an example from Askja, a central volcano in north Iceland.

An example is shown also from Reykjanes where drawdown of some 700 m the water level in the geothermal reservoir has caused subsidence. The mass extraction is about 400 l/s for a 100 MW power station over a period of 5 years. It is balanced partly by reinjection. InSAR observed a 5 cm subsidence of the ground during a four years interval (2005-2009) northeast of the main subsidence bowl. This agreed with a 12 cm subsidence at the production area shown by GPS between 2004 and 2010.

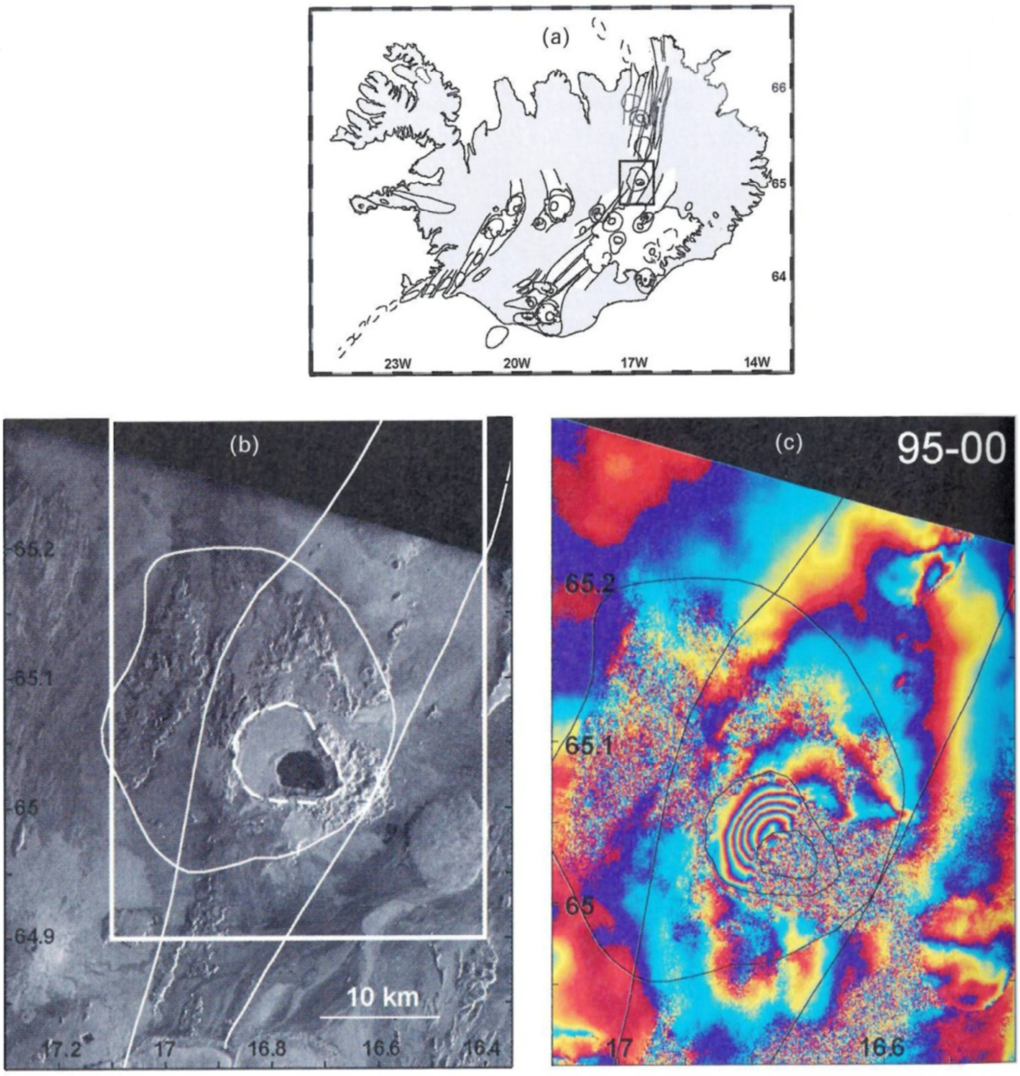

FIGURE 6: Askja volcano, Iceland and its calderas and associated fissure swarm. On the right: Interferogram spanning 1995-2000 shows subsidence centred on the main elliptical caldera. A full colour cycle corresponds to a change in range from ground to satellite of 2.8 cm (in total about 15 cm). Diffuse pattern is due to snow cover (F. Sigmundsson 2006: Iceland Dynamics. 209 pp. Springer).