Satellite data reveals pre-earthquake thermal anomalies in Killari area, Maharashtra

S. K. Srivastav, Manoj Dangwal, A. Bhattacharya and P. R. Reddy

Geosciences Group, National Remote Sensing Agency, Hyderabad 500 037, India

The analysis of satellite thermal infrared data obtained from Landsat-5 Thematic Mapper (TM) of Killari area for pre- and post-earthquake periods has indicated thermal anomalies (building up of temperature) prior to the earthquake. These thermal anomalies are associated with the major lineaments and match well with the locations of geothermal activity in the area reported immediately after the earthquake.

EARTHQUAKES are the natural disasters that kill thousands of people, destroy property and leave a long lasting impact on the environment. But, the forecasting and on-time warning of earthquakes remain one of the most important problems of earth and space sciences[1,2]. During the last couple of decades, studies have shown anomalous physical phenomena prior to the earthquake, which include various effects of heat, sound, light, electricity, magnetism, atmosphere and so on[3]. The sensors on-board space platforms provide appropriate information on some of these phenomena. Detection of thermal anomalies prior to the earthquake is one of the potential areas wherein remote sensing satellites play a significant role. Currently, the data obtained from remote sensing satellites are mainly used to identify and map the seismic zones[4,5] and to locate safer places for constructing the villages[6]. However, the studies related to earthquake precursors using satellite thermal images are still at infancy stage.

The study of pre-seismic geothermal anomalies is an important subject matter in earthquake-prediction research. According to Ma Zongjin *et al.*[3], all the nine major earthquakes of China, which took place between 1966 and 1976, were invariably associated with thermal anomalies of various kinds, such as heating of the ground (20–80 cm depth), melting of ice, increase in water temperature of springs by 10°C and sultriness felt by people. By comparing and analysing the main thermal anomalies before the nine major earthquakes and local weather variation data, they have concluded that in five of the nine earthquakes, the output of underground heat could not be discounted. According to Gold and Soter[7], major earthquakes are often preceded and/or accompanied by phenomena related to eruption of high pressure gas at the sites of magmatic activity in the form of heating of the ground, smell of sulphur or hydrocarbons, geosound and turbulence/bubbling in groundwater, rivers and lakes (from Rastogi and Rao[8]). However, the reasons for such pre-seismic thermal phenomena in non-volcanic terrain are not clear. Scholz *et al.*[9] and Sibson *et al.*[10] have proposed the dilatancy-diffusion model to explain migration of hydrothermal fluids through fractured rocks before and after the earthquake (from Chandrasekharam[11]).

The Killari earthquake of 30 September 1993, which jolted parts of Latur and Osmanabad districts of Maharashtra, was followed by post-earthquake geothermal activity in the form of (i) smoke/gas emanations from the ground/bore wells/water bodies, and (ii) heating of the ground and water in the bore wells/springs. This geothermal activity was reported from various places as far as 200 km away from the epicentre in the States of Maharashtra, Andhra Pradesh and Karnataka, and continued for about 3–4 weeks after the earthquake[6,8,11–15]. Figure 1 shows one such live smoke/water vapour emanation activity at Kothapally village, located 24 km north of Nizamabad town, AP. This activity was confined to an area of about 1.5 m radius. Temperature measurement carried out using digital thermal infrared radiometer has indicated that the temperature at the site of this activity was 42°C against the background temperature of 33°C and it went on increasing substantially with depth (about 10°C per ft). At 1 ft depth, the temperature was 52°C, at 2 ft depth it was 62°C and at 3 ft depth it became 70°C (ref. 6). Similar geothermal events in the form of steam emanation from ground at Bhatangli and gas bubbling in a lake and an open dug well at Warud were observed by Chandrasekharam[11]. It is quite likely that these geothermal anomalies were the manifestations of pre-earthquake warming which went unnoticed. Keeping this in view, a study has been carried out to detect the presence of pre-earthquake thermal anomalies, if any, using spaceborne thermal infrared data obtained from Landsat-5 TM.

Landsat-5 TM band 6, operating in thermal infrared region (10.4–12.5 µm) of electromagnetic spectrum, provide thermal (temperature) images of earth's surface once in every 16 days with the spatial resolution of 120 m and radiometric resolution of 0.5 K. The ground temperature measured by the satellites depends upon the solar heating, surface thermal properties, meteorological and near surface atmospheric conditions as well as on processes occurring in the upper crust of the earth. It is the latter which is relevant for studying the thermal anomalies in seismoactive regions[16].

For studying the pre-earthquake thermal anomalies in Killari area, two data sets of Landsat TM pertaining to 20.09.93 (pre-earthquake) and 06.10.93 (post-earthquake) periods covering about 7,000 sq km around the epicentre have been acquired and processed. Initially, both the data sets have been geometrically registered, and the thermal infrared (band 6) data have been normalized for changes in solar elevations and atmospheric condi-

Figure 1. Field photograph showing smoke/water vapour emanation at Kothapally village (Courtesy: K. Seshadri).

tions. The atmospheric corrections were done by taking water bodies in both the images as common features and band 6 DN (Digital Number) values were normalized taking post-earthquake data as reference. Image differencing of normalized band 6 of both the dates (pre–post) after removing the noise has brought out the pre-earthquake thermal anomalies, indicating building up of temperature prior to the earthquake. In other words, DN values of the pre-earthquake data are higher than that of post-earthquake at the locations of observed thermal anomalies. Since, there is only 16 days difference between the two data sets and the land use is the same as seen on satellite data at the places of observed thermal anomalies in both the dates, the thermal anomalies could not have arisen from any other imaginable cause.

Figure 2 shows the false colour composite (FCC) of Killari area (band 4 (0.76–0.90 μm) = red, band 3 (0.63–0.69 μm) = green, band 6 difference (pre–post) = blue) depicting the thermal anomalies in blue colour. Figure 3 shows the pseudo-colour image of Killari area indicating thermal anomalies in red against the background in cyan. The major lineaments interpreted from satellite image and locations of reported smoke/gas emanations are also shown on these images. The pre-earthquake thermal anomalies which are shown in blue in Figure 2 and in red in Figure 3 are observed to match well with the reported locations of geothermal activity, such as Bendkal, Rui and Takli. Though, smoke emanation from ground is reported at Nilanga and Umarga, the pre-earthquake thermal anomalies are found on their southern and western sides, respectively. The imagery also show several spots with thermal anomalies where post-earthquake geothermal activity is not reported. It is important to note that the observed thermal anomalies are pre-seismic and it is not necessary that at all the places, post-earthquake geothermal activity will be reported. The individual spots of thermal anomaly only indicate raising of ground temperature due to underground heat in the surrounding area selectively as a precursor of the present earthquake. Interestingly, the thermal anomalies also show correlation with the major lineaments existing in the area. This is in corroboration with the dilatancy-diffusion model[9,10] which explains the physical basis of pre- and post-earthquake geothermal activity along the dilatant/lineament zones.

The source of underground heat causing the thermal anomalies on the surface is not clear. The onset of

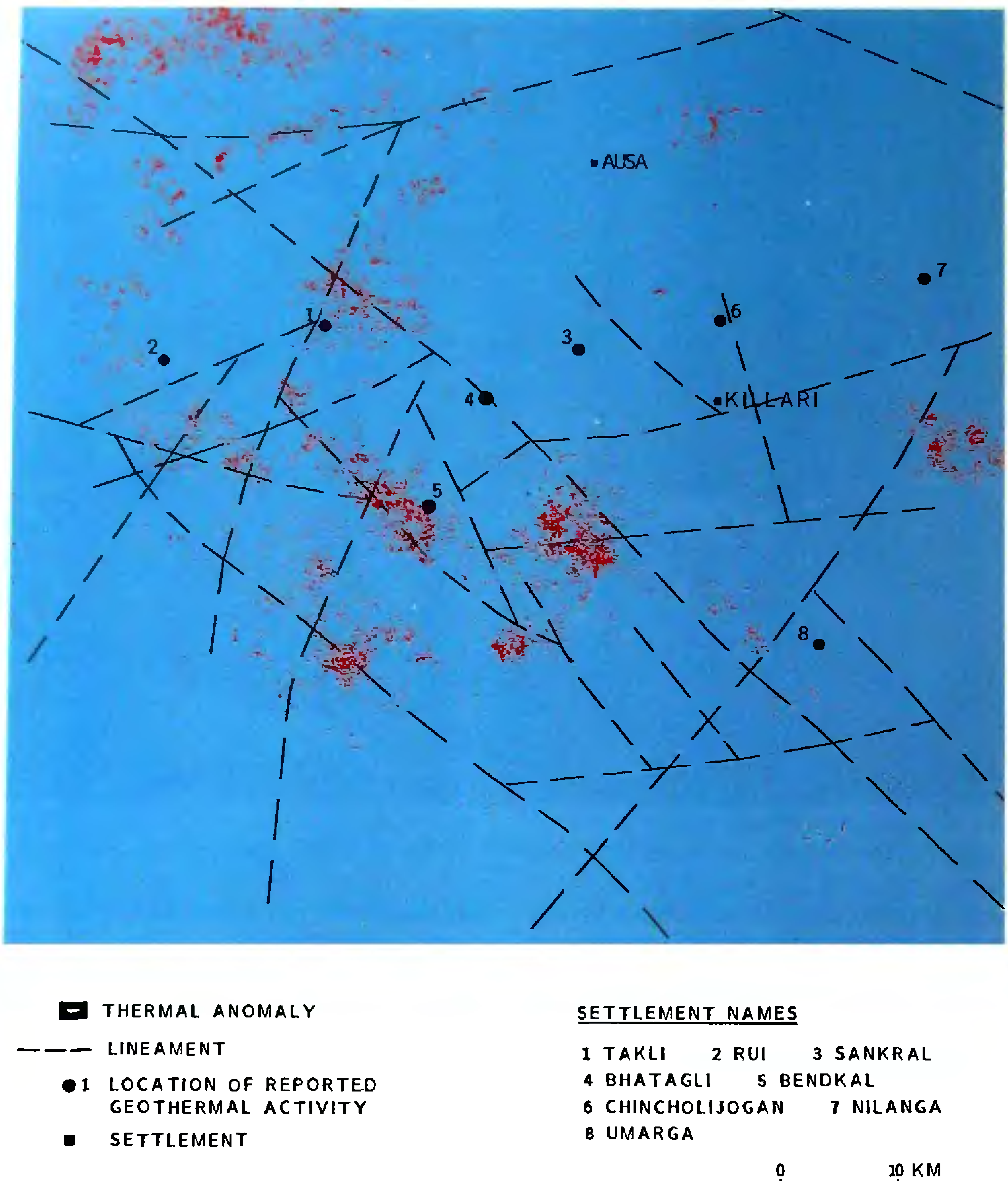

Figure 2. TM FCC of Killari area depicting thermal anomalies in blue (band 4 = red, band 3 = green, band 6 difference = blue).

fresh volcanic activity has been discounted[8,15]. Chemical analysis and silica thermometry of water samples, collected in the epicentral zone and in the surrounding areas where smoke/gas emanation and heating of the ground are reported, suggest the inflow of geothermal fluids from deep reservoir to the ground level[13]. Chandrasekharam[11] advocates seismic pumping mechanism as the reason for geothermal activity. According to him, the load pressure and compressional forces due to northerly movement of Indian plate would have squeezed out fluids from the surrounding Bhima sedimentary rocks. Due to prevailing pressure difference between the source region of these fluids and the dilatant zones, hot fluids (considering the focal depth of earthquake and normal geothermal gradient) entered or sucked into these zones prior to the main shock and later got ejected as steam on the surface. Therefore, it is quite likely that the pre-earthquake thermal anomalies detected through satellite data were caused by the presence of hot fluids/gases along the lineaments which were released subsequently as steam/smoke due to opening of cracks/fissures after the earthquake.

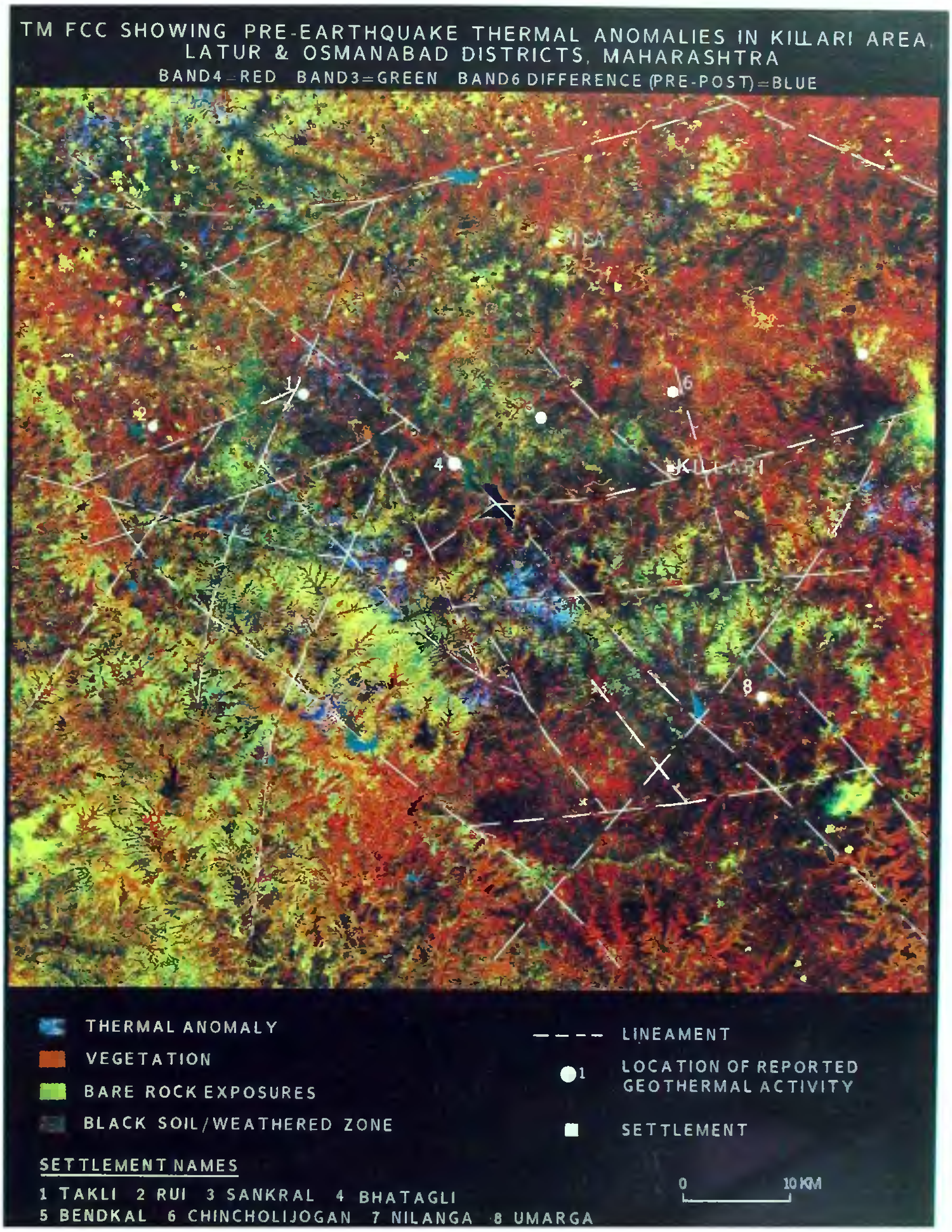

Figure 3. Pseudo-colour image of Killari area depicting thermal anomalies in red.

In the present study, two sets of satellite data (one 10 days prior to the earthquake and another 6 days after the earthquake) have been analysed, indicating that the thermal anomalies became noticeable at least 10 days before the earthquake took place. However, it has not been possible to establish how long before the Killari earthquake, the thermal anomalies in the area appeared because of the long repetivity (16 days in case of Landsat) of high (fine) resolution satellite, absence of thermal infrared sensor on IRS-series of satellites and non-availability of cloud-free images. TM thermal infrared data of 06.12.92, 24.02.93 and 31.05.93 have not revealed any thermal anomaly in the area, and the temperature variation observed in different periods was due to seasonal effect and changes in land use pattern. The study carried out in Central Asian Seismoactive region, Iran, Egypt, etc. using the National Oceanic and Atmospheric Administration (NOAA)-series satellite thermal images (10,000 numbers over a span of ten years) revealed positive infrared (IR) anomalies of few degree centigrade over large scale faults, and statistically significant correlation between the activity of IR anomalies and the seismic activity[16].

This study highlights the potential of satellite data for identifying thermal anomalies which may be used as precursors to earthquake. However, more intensive studies have to be carried out in other seismically active areas for establishing a relation between the appearance of the thermal anomalies and impending earthquakes.

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Fission track dating of obsidian artefacts from Columbia

H. S. Virk, G. S. Randhawa and A. S. Sandhu

Department of Physics, Guru Nanak Dev University, Amritsar 143 005, India

The fission track technique is useful for dating young obsidian artefacts owing to their high uranium content. It is being used for obsidian source identification and provenance studies. Fission track age of Columbian obsidian from an archaeological site, Rio Hondo near Popayan, is found to be 3.83 Ma.

THE fission track technique is found to be most suitable for dating natural glasses[1-10], namely, obsidians and tektites owing to their high uranium content despite certain limitations. Volcanic glasses commonly present two particular problems to fission trackologists: they have microlites and gas bubbles which, after etching, are easily confused with fission tracks. Another limitation is the thermal heating of obsidian artefacts, which results in track fading, thus yielding reduced fission track ages of source material. Obsidian artefacts from archaeological sites around the world are dated for their source identification. The purpose of this study is to determine the fission track age of obsidian artefacts discovered at Rio Hondo, near Popayan in Columbia. The samples were analysed by coupling of PIXE and fission trace dating for trace element analysis and source identification at Grenoble[11]. Identifying the source of obsidians often directly provides evidence of pre-historic human activity, trade routes and cultural communication that took place between the archaeological site and the obsidian source area[12].

Experimental technique used for preparation, etching, irradiation and counting of obsidian samples is the standard one described elsewhere[9-10]. The obsidian artefact samples were broken, polished and etched in 6% HF for 8 min at room temperature to develop the fossil tracks. The counting of fossil tracks is a tedious job and the first two authors performed their independent counting after polishing and etching a freshly cleaved surface. The individual counting differs by as much as 10% which is also the range of statistical counting error. The samples were annealed in a furnace at 500°C for 1 h to remove fossil tracks before irradiation in CIRUS reactor at BARC, Trombay. Both the annealed obsidian samples and a standard glass wafer (NBS-SRM 962, U content 37.38 ± 0.08 ppm) were irradiated simultaneously in a thermal neutron fluence of 10^{15} n/cm^2. Irradiated samples were etched under identical conditions as used for original batch samples for fossil tracks. The track density for both fossil and induced tracks was determined using a calibrated graticule in the Carl Zeiss binocular