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# Application of Aeromagnetic, Remote Sensing and Geological Data in the Delineation of the Geological Structures

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**Abstract:** Siloam village is well known for its hot springs that geologically lie in the Nzhelele Formation of the Soutpansberg Group rocks. About 1800 million years ago, the Soutpansberg depositional basin was formed as an east-west trending asymmetrical rift. These Soutpansberg group rocks were severely faulted which resulted in a number of major faults, like the Siloam fault. Faults provide channels through which the hydrothermal fluids can flow. These fluids are heat sources for the hot springs. With no evidence of recent volcanic activities in the Limpopo province, it is assumed that all the hot springs are of meteoric origin and the heating of the hot springs is due to the deep circulation along fault zones. The main objective of the study is to delineate the faults that are potential recharge zones of the hot springs above the ground at Siloam village using remote sensing, geological maps and aeromagnetic data. LANDSAT 8 (OLI, November 2015), scenes P69, R76 (path 69 and row 76) free of cloud cover were downloaded from the USGS website page. The data was reduced to remove excess noise. A number of processing techniques were done to further enhance the visibility of the image and locate the faults by the use of ERDAS IMAGINE software. The aeromagnetic data was used to locate the faults using the magnetic susceptibility of the rocks. Aeromagnetic data was acquired from the Council of Geoscience of South Africa, which collected it using a proton precession magnetometer mounted on a low plane flight at an average height of 150m. The traverses were oriented in the E-W direction, and the traverse separation was 1 km. The aeromagnetic data reduction was applied during the processing in order to produce a colour map using Geosoft Oasis Montaj. The geological data was obtained through digitizing and georeferencing of an existing geological map acquired from the Council of Geoscience of South Africa. The GPS was used to locate the hot springs at the Siloam village for correlation with the lineaments. The lineaments were interpreted from the remote sensing. The aeromagnetic data was correlated with the faults on the geological map. The main faults associated with the known hot springs were delineated along with the minor faults which were potential zones carrying hot water at the Siloam village. The results show that the two sets of data are capable of extracting lineaments in inaccessible areas and they can complement each other in locating faults. The results showed that the three known hot springs are associated with the major faults. Geologically the other faults are also playing a part in recharging the hot springs.

**Keywords**: aeromagnetic, remote sensing, geological data, geological structures, hot springs, faults

## 1  Introduction / Background

### 1.1  Background

The Siloam village is located north of Makhado in the Limpopo Province in South Africa and it is famous for its hot springs. A spring is described as a concentrated discharge of groundwater that appears at the surface as a current of flowing water (Todd 1980). Springs that discharge water at a temperature above that of the normal local groundwater are called thermal springs (Todd 1980).

There are geothermal hot springs in many locations all over the crust of the earth. While some of these springs contain water that is of suitable temperatures for bathing, others are so hot that immersion can result in injury or death (Kent 1969).

The known geothermal occurrence indicators in South Africa include approximately 74 hot springs spread almost over the whole country. There has been no recent volcanic activity in South Africa, and therefore all thermal springs are considered to be of meteoric origin and the heating of the water is believed to be due to deep circulation along main fault zones (Kent 1969).

Thermal springs are not confined to any specific type of geology. They are mainly located in the parts of the country receiving high to intermediate rainfall and where deep crustal faulting occurs. Geothermal hot springs occur where the earth's heat is carried upward by a convective circulation of naturally occurring water. Some high temperature convective hydrothermal resources result from deep circulation of water along the fractures of the rocks (Olivier et al 2011).

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Hot springs are primarily found above areas in the crust where magma or molten rock has risen to a shallow depth beneath the surface. In such instances, the magma may exist in a chamber or reservoir 5 to 10 kilometres beneath Earth's surface.

They are heated by the earth's interior which is known as a hot spot. A long, slim column called a plume feeds a hot spot. A plume takes debris from the mantle, and sends it up to the hot spot just below the earth's crust. The hot spot is a pocket just below volcanoes and hot springs where the hot debris from the mantle sits, heating the earth above it, in this case, the hot springs. The hot ground heats the water to a high temperature and this is how the hot springs become hot.

At some point, steam or vapour may appear on the surface. This is due to the boiling of the water at depth which is unable to pass through to the surface due to the low permeability of the rocks (Olivier et al 2011).

A fault may play different roles in fluid migration. A fault may act as a barrier (or seal), a conduit or a combination of both. A fault is a seal or a barrier when fluids are unable to flow laterally across it due to an impermeable layer along the fault plane (Olivier et al 2011).

A fault acts as a conduit when fluid passes vertically along the fault plane. A fault acts as a barrier and a conduit when fluid can pass partially across and partially along the fault at the same time (Olivier et al 2011). The parameters which result in a fault acting as a seal include, fault orientation, burial depth, fault displacement, net sand connectivity and age of faulting (Olivier et al 2011).

There are thousands of known thermal springs on Earth, with the most abundant located in volcanic areas. (Walter and DesMarais 1993, Bryan 2000). In geothermal systems, faults, fractures, or contacts between intrusive and surrounding rocks may become conduits for thermal water.

The use of remote sensing techniques has given a boost to the analysis of various geomorphic units, lineaments or linear features quite easily, because of its synoptic view and availability of data in different spectral bands (NASA 2000). Satellite images give an excellent visual presentation of various geological structures like faults, folds, lineaments and fractures, because of its synoptivity and multispectral nature. Remote sensing techniques have been employed for geological, structural and lineament mapping by many workers (Ramasamy and Balaji 1995).

## 1.2 Problem statement

The known geothermal indicators in South Africa include approximately 74 hot springs almost all over the country. With no evidence of recent volcanic activities in South Africa, it is assumed that all the hot springs are of meteoric origin and the heating at the hot springs due to the deep circulation along main fault zones. The known hot springs need to be correlated with the known faults using aeromagnetic data, remote sensing data and geological structures from geological maps.

## 1.3 Justification of study

This study was aiming at delineating the main faults associated with the known hot springs and the minor fault zones that could be potential fault zones carrying hot water at Siloam village. The number of minor faults plus the known faults could be an indicator of the size of the potential geothermal occurrence at Siloam.

## 1.3 Objectives

The main objective of the study is to delineate the faults that are potential recharge zones of the hot springs above the ground at Siloam village using remote sensing, geology and aeromagnetic data. The specific objectives of the study are to; use magnetic, remote sensing and geological mapping data in delineating the faults; determine the orientation of the faults in the area; integrate the aeromagnetic data, remotely sensed data and geological data along with the base map of the hot springs to delineate faults associated with known hot springs at Siloam and produce a map with new faults delineated from remotely sensed and aeromagnetic data.

## 2   Research Approach

Three sets of data were collected. These sets of data were: remote sensing data, aeromagnetic data and geological data. Each set of data was processed separately for data integration during analysis. LANDSAT 8 (OLI, November 2015), scenes P69, R76 (path 69 and row 76) free of cloud cover were downloaded from the USGS website. The ASTER images for the same area were also downloaded from the USGS website. The geological data was obtained through digitizing and georeferencing of an already existing geological map acquired from the Council for Geoscience, South Africa. Before the aeromagnetic data was collected, the survey parameters were selected. These parameters include flight elevation, traverse line spacing, traverse line orientation or direction, and the type of a magnetometer to be used. There were a number of considerations considered during the setting of the parameters. For this study, the data was acquired from the Council of Geoscience of South Africa, which had collected it using a proton precession magnetometer. The proton precession magnetometer was mounted on a flight which was at an average height of 150 m. The traverses were oriented in the East-West (E–W) direction, and the traverse separation was about 1 km.

## 3   Results of the Study

The results of the study outline detailed results on the geological map of the area, remote sensing data interpretation, False Colour Combination (FCC), index evaluation in identifying lineaments, magnetic colour map and occurrence of hot spring in the area.

## 3.1 Geological map

There is a widespread agreement that geothermal springs in extensional geothermal systems are concentrated at fault tips and fault interaction zones where porosity and permeability are dynamically maintained (Curewitz and Karson 1997). It

is clear that faults and fractures play a major role in the localisation and evolution of hydrothermal flows on several scales (Ramasamy and Balaji 1995).

A geological map for the study area, acquired from the Council of Geosciences of South Africa, was digitized and georeferenced for use as a base map to reference both the aerial images and magnetic images. The data of interest in the geological map was the geology and the fault systems of the area. In the analysis, the layer of faults was superimposed on the magnetic and remote sensing images for interpretation. Figure 1 shows the geological map with different lithologies along with their contacts and the faults within the lithologies. The results of the study have shown that the study area was dominated by the North East – South West (NE– SW) faults with a few faults trending in the North West – South East (NW–SE) direction. The faults in the NW–SE direction were in the same direction as the Siloam fault.

Further results of the study have indicated that Dopeni and Mphephu thermal springs are underlain by the Wylliespoort and Nzhelele Formations of the Soutpansberg group. These lithologies mainly comprise of sandstone and quartzite. Owing to that, it was also observed that the Siloam thermal spring was underlain by the basaltic lava of the Sibasa Formation. However, these observations were also supported by the previous study conducted by Oliver et al (2011), which indicated that the lava of Sibasa formation occurred through a basaltic process which had been noted to have occurred several years back.
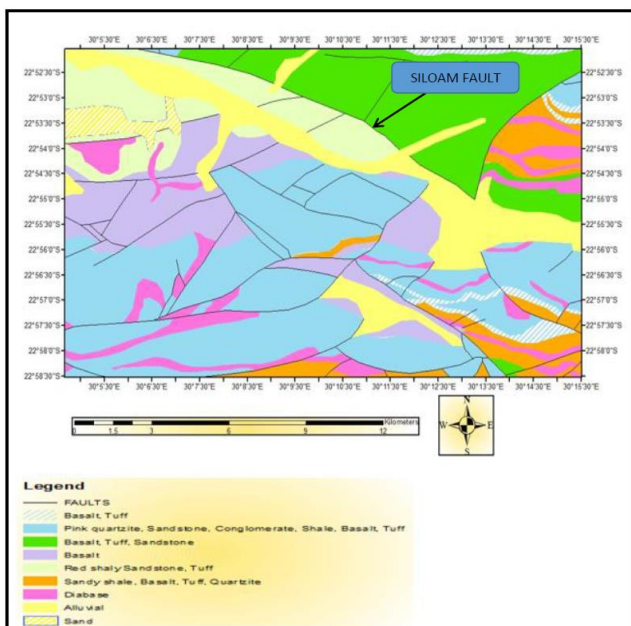


Figure 1 Map showing lithology and faults at Siloam village

## 3.2 Remote sensing data interpretation

In order to provide meaningful results concerning remote sensing analysis, the processed remotely sensed images were interpreted visually with the aid of two techniques,

which are, FCC and NDVI. They were used to enhance the colour and tonal differences in the images.

Faults were identified as lineaments. Lineaments can be joints, fractures, dyke systems or a straight course of streams or vegetation patterns. In hard rock, lineaments represent zones of dykes, and a series of or fold aligned hills. In this study, the true colour composite images with RGB ratio of 3:2:1 (where R=Red, G=Green and B=Blue bands, and the 3:2:1 is the ratio of the bands of colours whereby 3, 2 and 1 are for Red, Green and Blue, respectively) of the Landsat 8 multi-spectral image were used.

Based on the results of the study multiple faults were observed from the original satellite image, these faults were noted as lineaments (see Figure 2).



Figure 2 A LANDSAT image with an original RGB combination

### 3.2.1 False Colour Combination (FCC)

In the interpretation of the lineaments using false colour representation, a combination of RGB 7:5:1 was used. Lineaments observed from the image were indicated by linear reddish colouration (see Figure 3). For clear representation of the lineaments, a colour ramp and gamma stretching were also used to improve the colour differences between the lineaments and areas with no lineaments. In Figure 3, the enhancement introduced made the lineaments more visible compared to the one with a true colour composite. The lineaments observed on the FCC image had a reddish colour. Generally the lineaments had two sets of striking direction. These striking directions are NE–SW and NW–SE (see Figure 3).
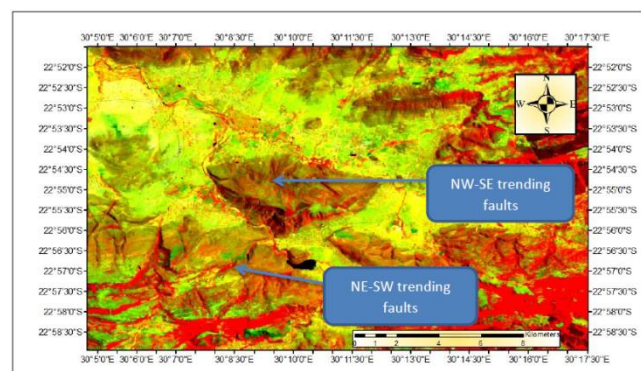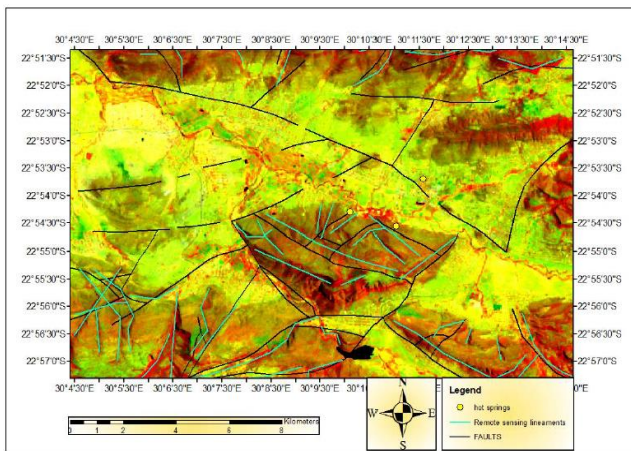


Figure 3 A false colour combination of 7:5:1 of the study

To eliminate the non-geological elements such as paths, roads, power cables and field boundaries in the study area, geographical map and field checking were undertaken by the method suggested by Yassaghi (2006).

The lineaments or faults observed on remotely sensed images were traced and then digitized using Quantum GIS. This was done in order to be able to compare with the faults observed from the geological map by superimposing the digitized faults from the geological map on the remote sensing image. It was noted that there were additional faults which were not discovered when using a geological map. Most of the faults from the geological map and the lineaments from the remote sensing image coincide, however, in some areas they were not exactly in the same position but had similar orientations and lengths. In Figure 4, the faults from the geological map are represented by black lines while the lineaments traced from the remote sensing image are represented by a blue colour (see Figure 4).



Figure 4 A false colour combination of 7:5:1 showing remote sensing lineaments and geological faults

### 3.2.2 Index evaluation in identifying lineaments

The Normalised Difference Vegetation Index (NDVI) method was used for the identification and mapping of geological linear features (Lineament) in hard rock terrain. This was based on tone, colour and textural pattern; as well as on a previous study conducted by Boyer and McQueen (1964). When using an NDVI method, an NDVI image is created by ARCMAP and assigned different colours based on the amount of vegetation on the ground. However, since NDVI is an indicator that uses visible and near-infrared bands of the electromagnetic spectrum, it was mainly used to assess the vegetation cover of the area.

An NDVI image created from this study shows the lineaments on the image with most of them having the same orientation of the fault line on the geological map. A related study by Boyer and McQueen 1964 indicated that in similar geological terrain the usefulness of NDVI is revealed by detecting fractures and faults that could affect the occurrence of vegetation associated with proximity of groundwater. Boyer and McQueen (1964) concluded that remotely sensed linear features are a reflection of rock

fractures, emphasized by vegetation and topography. They interpreted the NDVI images and areas with denser and active vegetation defining linear features. Areas with light tones showed active vegetation along fractures. The high vegetation areas can be observed by the blue and purple colour (see Figure 5), whereas the low vegetation areas were identified by the yellow and orange colour. The striking directions of the faults had two sets of directions which are the NE–SW and the NW–SE. The image with the NDVI lineaments was overlain by the digitized faults from the geological map to see the resemblance. .
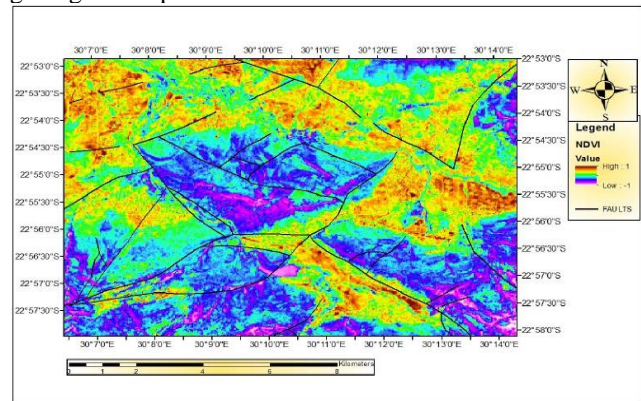


Figure 5 An NDVI image with faults

### 3.3 Magnetic colour map

The magnetic colour map of the total magnetic intensity was processed in the Geosoft Oasis Montaj software. The magnetic colour map (see Figure 6) shows low magnetic intensities are represented by a blue colour while high intensities by a red colour. The magnetic anomaly map from the study area showed high and low magnetic anomalies being fairly distributed within the study area (see Figure 6). These were indicative of the presence of magnetic rocks, non-magnetic rocks and discontinuities or geological structures covering the study area. The change in the magnetic intensities on the map represent a change in the lithology. The magnetic data with high and low magnetic anomalies next to each other were interpreted as contacts between the rocks. The faults on the magnetic colour map had two sets of striking directions which are NE–SW and NW–SE. There was a clear dominance of the NE–SW trending lineaments. To study the lineaments from the magnetic anomalies, the magnetic map was overlaid with digitized faults from the geological map. The faults identified on the magnetic colour map had the same orientation to the geological faults. Similar results have been observed by the study conducted by Mattsson and GeoVista (2010), which showed that low magnetic intensities coincided with known existing faults. Mattsson and GeoVista (2010), Nordiana et al (2014) and Adagunodo and Sunmonu (2012), conducted similar studies and in their studies they concluded that the low magnetic values are due to the presence of structural features such as faults or fractures, and that the high magnetic values are also due to a fault which was infilled by materials with more magnetism

than the surrounding rocks. High magnetic anomalies could also be due to shallow basement and low magnetic intensities could be associated with relatively deep sources (Amigun 2013).

Mattsson and GeoVista (2010) did work in a similar environment at Sagole's hot spring and interpreted the Reduced-To-Pole (RTP) data as an area swarmed with North East trending dykes and East to West and North West geological structures using the magnetic anomalies. Mattsson and GeoVista (2010) also determined the heat source depth for the Soutpansberg basin from filtering the magnetic data. The magnetic source at depths of approximately 2 km can be attributed to shallow volcanic dykes and sills.
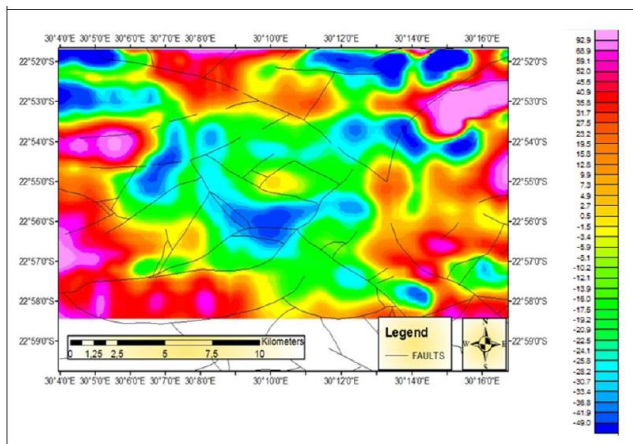


Figure 6 A magnetic anomaly map

### 3.4 Occurrence of hot spring in Siloam village

Geothermal hot springs occur where the earth's heat is carried upward by a convective circulation of naturally occurring hot water. Some high temperature convective hydrothermal resources result from deep circulation of water along the fractures of the rocks (Olivier et al 2011). A fault may act as a conduit where fluid passes vertically along the fault plane.

There are three hot springs in the study area namely; Siloam, Mphephu and Dopeni hot springs. To determine the relationship between the faults, hot springs and the lineaments from the remotely sensed and magnetic data, the three layers were overlaid on top of each other (see Figure 7). In Figure 7, it was observed that each hot spring was associated with a fault. The hot springs HS1, HS2 and HS3 were the Siloam, Mphephu and Dopeni hot springs, respectively. The Siloam hot spring is located on the Siloam fault which is the longest fault oriented in the in the NW–SE direction, which was named F1 in Figure 7. The Mphephu hot spring is located on a fault oriented in the NE–SW direction, the fault was named F2. The last hot spring is the Dopeni hot spring which is located very close to a NW–SE trending fault which has the same orientation as the Siloam fault. This fault was named F3 (see Figure 7). However it was noted that these faults might be the ones recharging the above mentioned hot springs.

However, it must be acknowledged that within the study area, there are some faults which are not associated with surface hot springs (see Figure 8). Scientifically, almost all faults within the vicinity of the hot spring might be channelling water to the faults which then exposes the thermal springs to the surface. It was then concluded that these faults might interact and link the hydrothermal outflow which then channels water to a single exit spring on the surface.
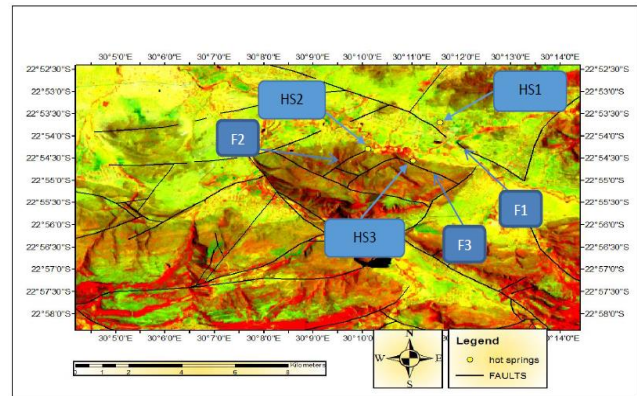


Figure 7 A remotely sensed image with faults and location of hot springs (HS1, HS2, HS3 for Siloam, Mphephu and Dopeni respectively)
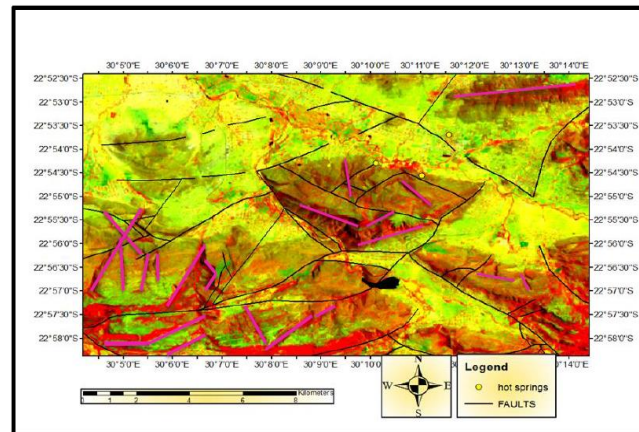


Figure 8 The lineaments that were only identified from the remotely sensed image overlaid with the geological faults

## 4  Conclusion

The remotely sensed, magnetic and geological mapping data delineated the faults that recharge the three hot springs in this study area as well as other faults that could have the potential for hot springs. The delineated lineaments from the remotely sensed data correlated with most of the faults on the geological map. The magnetic data also showed that the faults could be interpreted from the magnetic anomaly map. Most of the faults were located on the high magnetic areas with a few on the low magnetic areas.

The results from the study show that the remote sensing data, magnetic data and geological data were capable of extracting lineament trends in inaccessible areas. It can be

concluded that remote sensing, magnetic and geological data complement each other in locating faults.

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