# Use of Geological Lineaments Results in Groundwater Exploration of Crystalline Rocks, Zomba, Southern Malawi.

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**ABSTRACT**
Locating aquifers in Precambrian crystalline rocks offers major problems unless areas of intense weathering or fracturing are targeted. These normally occur along geological lineaments which can be identified during groundwater exploration. Major geological lineaments were identified in the Zomba area, southern Malawi, using landsat imagery and aerial photographs for groundwater exploration. In addition, areas of deep and intense fracturing identified by Very Low Frequency (VLF) geophysical technique were selected for borehole drilling. VLF results were able to locate areas with good resiststivity values which yielded borehole with water yields between 2.0 - 4.0 litres per second.

**Key words:** Aquifer yields; fractured zones and Very Low Frequency (VLF) technique.

## 1 INTRODUCTION

Groundwater is increasingly becoming an important source of water in Malawi because of the frequent drought occurrences. Malawi has one of the highest population in Africa. The population growth has increased from 2.8% in 1911 to 3.3% in 1987 (N.S.O 1980, 1987). This has led to considerable pressure on the natural resources base. Some of the consequences of this is rapid deforestation which leads to siltation of rivers. The location of reliable groundwater resources and tapping of high yielding aquifers are therefore very important.

Potential aquifers in areas underlain by crystalline rocks, in tropical countries, depend on the development of secondary porosity in the rocks. These can be in the form of weathered regolith (Wright 1989 ) or along fractured zones or lineaments (Dijon 1989, Greenbaum1989, Malomo 1989).

To date there is no well documented study in Malawi on the application of geological lineaments in groundwater exploration. The aim of this study is to describe the methods used in locating geological lineaments for groundwater exploration. Exploration work was done in the field in the eastern part of Zomba District of southern Malawi (Fig.1). This identified major geological lineaments using aerial photography and satellite imagery

of the study area. In addition, areas of intense fracturing were located along the lineaments using Very Low Frequency (VLF) geophysical technique.

### 1.1 Types of Aquifers

In Malawi, there are two main types of aquifers:

a. weathered basement aquifers located in plateau regions and

b. alluvial aquifers of the lakeshore plains and Shire Valley (UNDP-Malawi Government 1986). The type of aquifer in the study area belongs to the first type, that is, weathered basement aquifer.

The available data suggests that the total mineralization of groundwater in basement aquifers is very low. This indicates a highly leached weathered zone with groundwater derived from recent recharge (UNDP - Malawi Government 1986).

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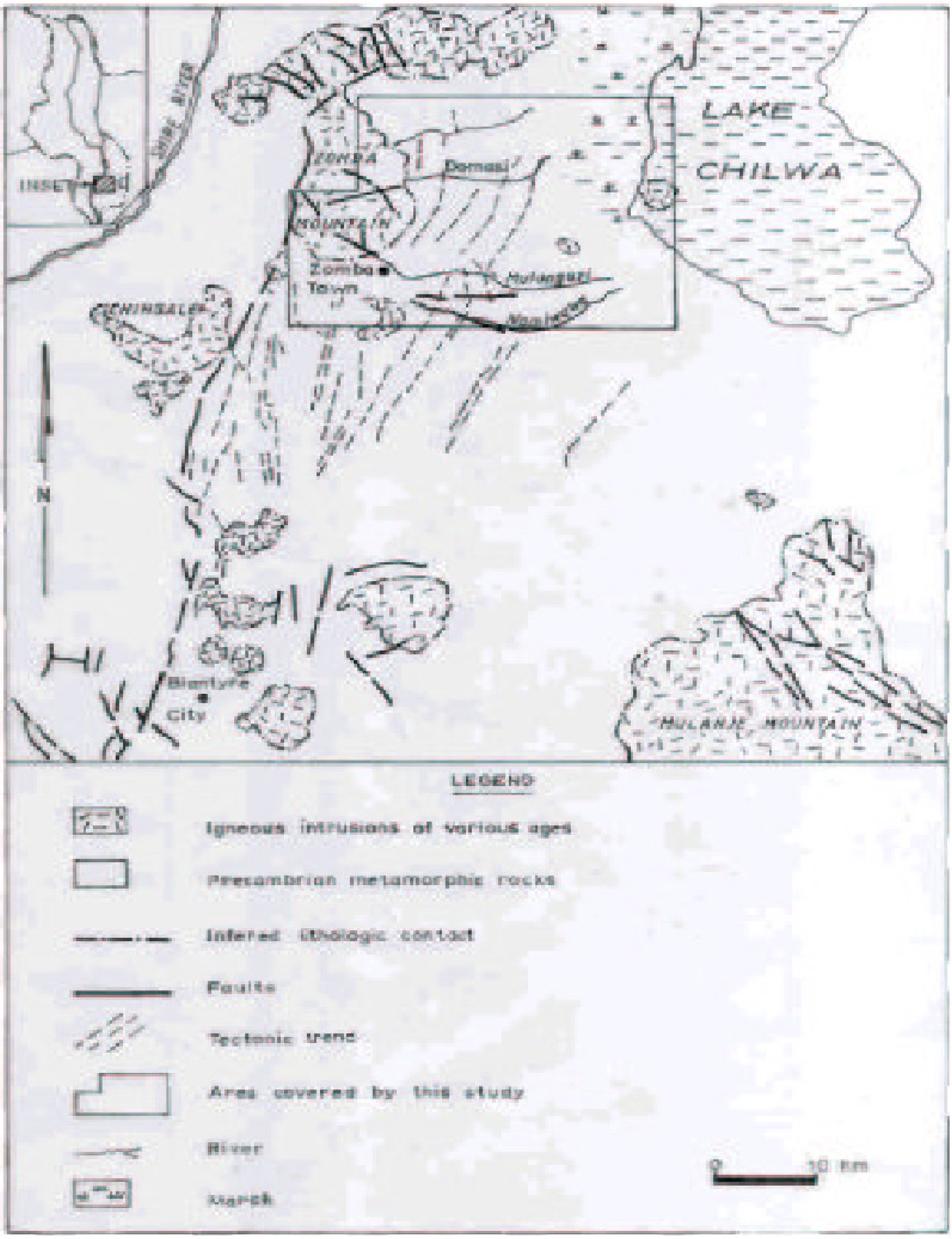


Figure 1: Location of study area (inset). Major Geological Lineaments inferred from landsat image (landsat 4 - MSS) are shown. Area of Fig. 2 is shown by boxed area.

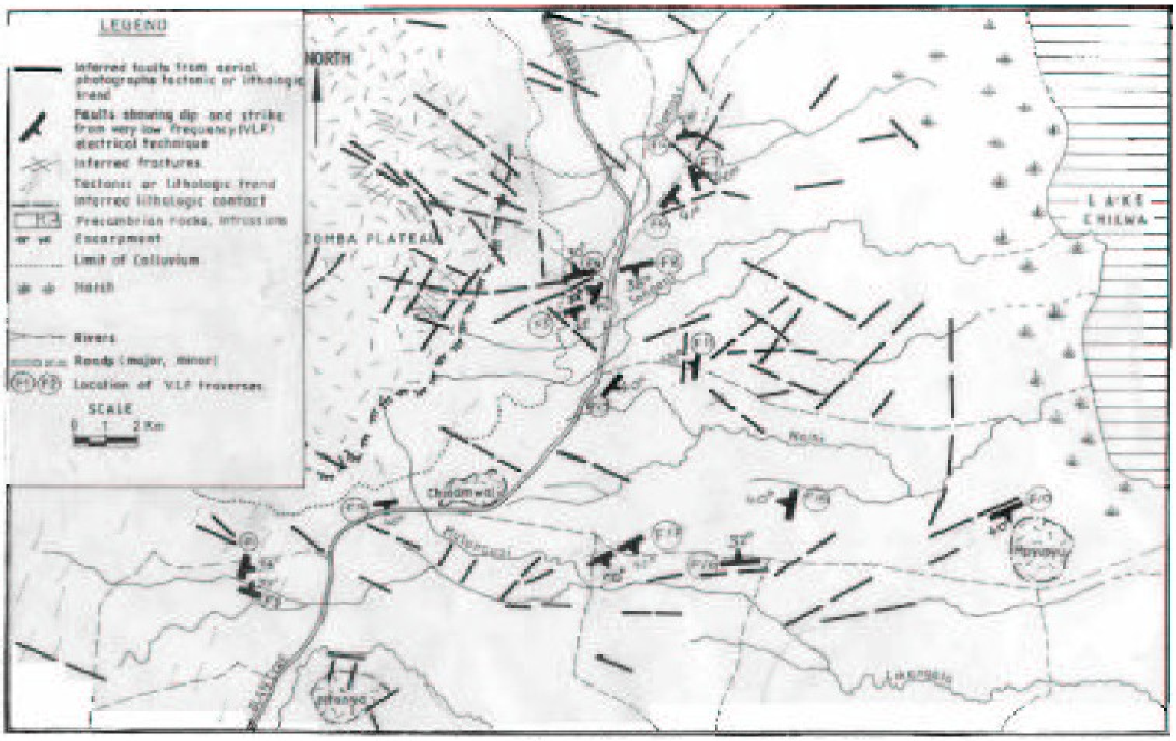


Figure 2: Map Showing major geologic features of the study area as shown in Fig 1. Field locations of Very Low Frequency (VLF) traverses are indicated by F1 to F18.

However, in areas underlain by rocks rich in sulphide minerals such as parts of Lilongwe, high sulphur content in the groundwater is common. On the other hand, alluvial aquifers are heterogeneous in quality but on the whole have high salinity (UNDP - Malawi Government 1986). Rainfall in the Zomba area ranges from 900mm per year in the Phalombe Plain to 1300mm per year on Zomba Mountain. This forms the source of groundwater recharge in the area.

### 1.2 Geological Setting

The geology of the area consists of crystalline Precambrian gneisses and granulites. These were intruded by Mesozoic rocks of the Chilwa Alkaline Igneous Province (Carter & Bennet 1972). Soil cover and weathered regoliths lie over bedrock.

The physiography of the area is dominated by Zomba Mountain, a syenite pluton, of the Chilwa Alkaline Igneous Province, to the west of the study area. It stands at an elevation of 2,000 metres due to differential weathering and uplift between the syenite and the surrounding Precambrian gneisses and granulites which are at an elevation between 700m - 1000m. Steep faces bound both the eastern and western part of the pluton. The eastern face passes on to 0.5 - 4.0 km wide zone covered by colluvium (Fig. 2). This was formed

by rock mass wasting in places enhanced by landslides. The colluvium grades into a vast plain of fairly low relief, the Phalombe Plain. This is punctuated by a few hills mainly intrusions such as Mpyupyu Hill (Fig. 2). Further to the east of Zomba District is Lake Chilwa which occupies a depression within the Phalombe Plain and is surrounded marsh land.

## 2 METHODOLOGY

### 2.1 Remote Sensing

A landsat imagery of southern Malawi (Landsat 4.0- MSS) at a scale of 1:1,000,000 was used to identify major lineaments of the area. More lineaments were obtained using aerial photographs at a scale of 1:40,000. Lineament act as conduits for groundwater movement. Lineament intersections were therefore targeted for groundwater drilling.

### 2.2 Very Low Frequency (VLF) Techniques

A Swedish made "WADI" Very Low Frequency (VLF) equipment manufactured by ABEM was used for this technique (Benson et al 1999). It records electromagnetic signals reflected from plains formed by fractured rocks in fault zones. This enabled the location and determination of the extent of fracturing along lineaments identified by Remote Sensing. The traverses were at right angles to the major lineaments identified through landsat imagery.

### 2.3 Borehole drilling

Ten boreholes were drilled in the study area. The parameters indicated are:

1. Pumping tests results.
2. Drilling log of soil/rock types below ground.
3. Blow yields.
4. Resistivity measurements.
5. VLF results showing fractured zones.
6. Transmissivity values.

## 3 RESULTS

In order to asses the aquifer potentials of the lineaments, they were characterized in terms of length and orientation. The fractures obtained by VLF technique were characterized by their depth, orientation and frequency of fracturing.

### 3.1 Lineaments

The major lineaments identified from the Landsat imagery are shown on Figures 1 and 2. The main features of these are:

a. The rift fault bordering west of Zomba Mountain.

b. The strong NE - SW lineaments to the east of the Rift Valley.

c. Major faults along the Namiwawa, Mulunguzi and Domasi Rivers.

d. Relatively subdued structural features in the Phalombe Plain close to Lake Chilwa.

Several lineament features can be identified from this map. These features are summarized in Table 1.

Areas likely to have fractured rocks and hence conduct groundwater movement were selected for further hydro- geological investigations were (a) intersection of linear features and (b) areas showing convergence of faults or lineaments. These areas were targeted for VLF and electrical resistivity surveys.

### 3.2 Very Low Frequency (VLF)

Seventeen traverses were made in the areas with strong lineaments identified by Remote Sensing. An example of the fractured pattern obtained by VLF is shown in Figure 3. A summary of the important features of these fractured zones are presented in Tables 2 and 3. The total number of fractures measured by VLF were recorded as the intensity of fracturing.

Generally the fracture patterns in the area west of Blantyre Road and close to Zomba Mountain on the Phalombe Plain show relatively moderate dips ranging from 25 degrees to 42 degrees. Their directions of dip are variable. On the other hand the area near Lake Chilwa on the Phalombe Plain have relatively steeper dipping fracture patterns ranging from 32 to 50 degree and occur at greater depth between 30-40 meters. The analysed fracture zone parameters given were the intensity of fracturing and their maximum depth. Figure 4 shows the frequency curves for the occurrence of rock fractures.

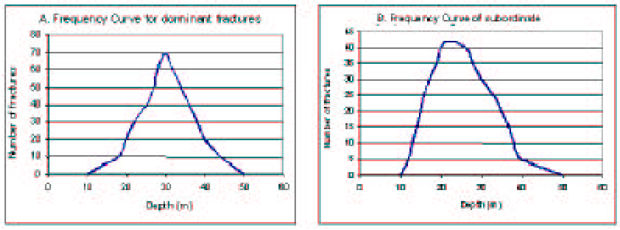


Figure 4: Frequency curves of number of fractures versus maximum depth for dominant Fractures (A) and subordinate fractures (B) of tables 2 and 3.

Dominant fractures give a normal distribution with most of the fractures at a depth of 21-30 meters. Subordinate fractures give a skewed distribution with most if the fractures at 11-20 meters below ground.

### 3.3 Aquifer Yields

Boreholes were drilled in the targeted areas with good fractured zones and backed by

good resistivity measurements. Figure 5. shows the results of borehole drilling

parameters at a field locality at Chancellor College (F18 in Figure 2.). This was selected

because of the need and convenience to monitor the borehole yield and water quality at

the end of the project.

In the drilling log, of great interest is the fractured zone below ground. VLF shows subordinate and dominant fractured zones. The pumping tests shows changes in the water yields represented by

Table 1: Summary of Geological Lineament Features in the Study Area

| Area on | Dominant Lineament | | Subordinate Lineament | |
|---|---|---|---|---|
| Landsat image | Trend | Length (km)[1] | Trend | aLength (km) |
| West of Blantyre Road | NW - SE | 1.0 - 4.5 | NE - SW | 1.0 - 2.0 |
| East Blantyre Road | NE - SW | 1.0 - 3.0 | NW - SE | 1.0 - 1.5 |
| Near Lake Chilwa | NE - SW | 1.0 - 6.0 | NW - SE | 1.0 - 1.5 |
| Zomba Plateau | NW - SE | 2.0 - 5.0 | NE - SW | 1.0 - 3.0 |

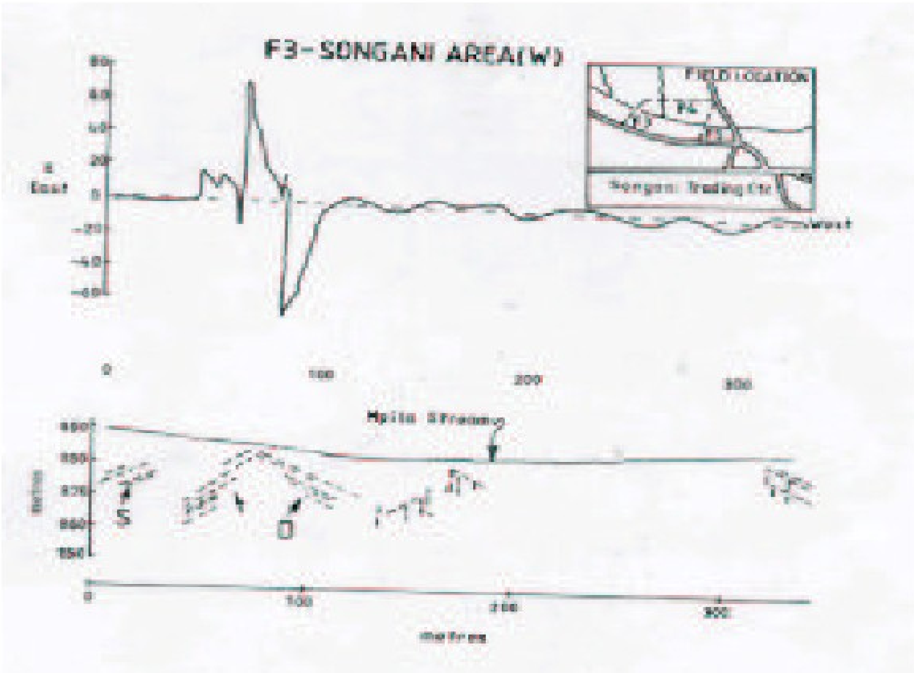


Figure 3: Upper figure is an example of a Very Low Frequency (VLF) record of a fractured zone obtained from the Songani field area (F3). Location is shown in the inset. The x-y axis represent the horizontal and vertical distances. The lower figure is an illustration of the vertical profile showing the fracture pattern, intensity and orientation. The first two highest values are designated as dominant (D) and subordinate (S) respectively.

the changes in the slope of the curve but stabalizing at 3.0 l /s. These changes correspond to the rock material encountered below ground (drilling log results); below yields; resistivity measurements and transmissivity values. These results confirm the importance of targeting fractured zones below ground by VLF measurements.

## 4 DISCUSSION

Zomba Mountain, at a higher elevation than the rest of the surrounding area, receives more precipitation. The igneous rocks forming Zomba Mountain are heavily jointed and have a number of fault zones. The combination of good rainfall and fractured rocks makes this a good re-charge area for groundwater in the areas of low elevation.

The data obtained shows that fractured zones extend from the surface to a depth of up to 40 metres. This gives the criteria for selection of drilling sites on the basis of the intensity of fracturing and potential maximum depth of drilling.

There are deeper fractures in the Phalombe Plain close to Lake Chilwa than close to Zomba Mountain (Fig. 1). These range from 1 - 6 km as opposed to 1 - 3 km (Table 1). This suggests that the fractures in the Phalombe Plain are more intense or prominent than those close to Zomba Mountain. The hydrological significance of this may need further investigations. Odeyeni et al (1985) classified geological lineaments according to their lengths. The lineament lengths of about 6 km obtained in this study for the Phalombe Plain (Table 1) correspond to class C and the rest of 2

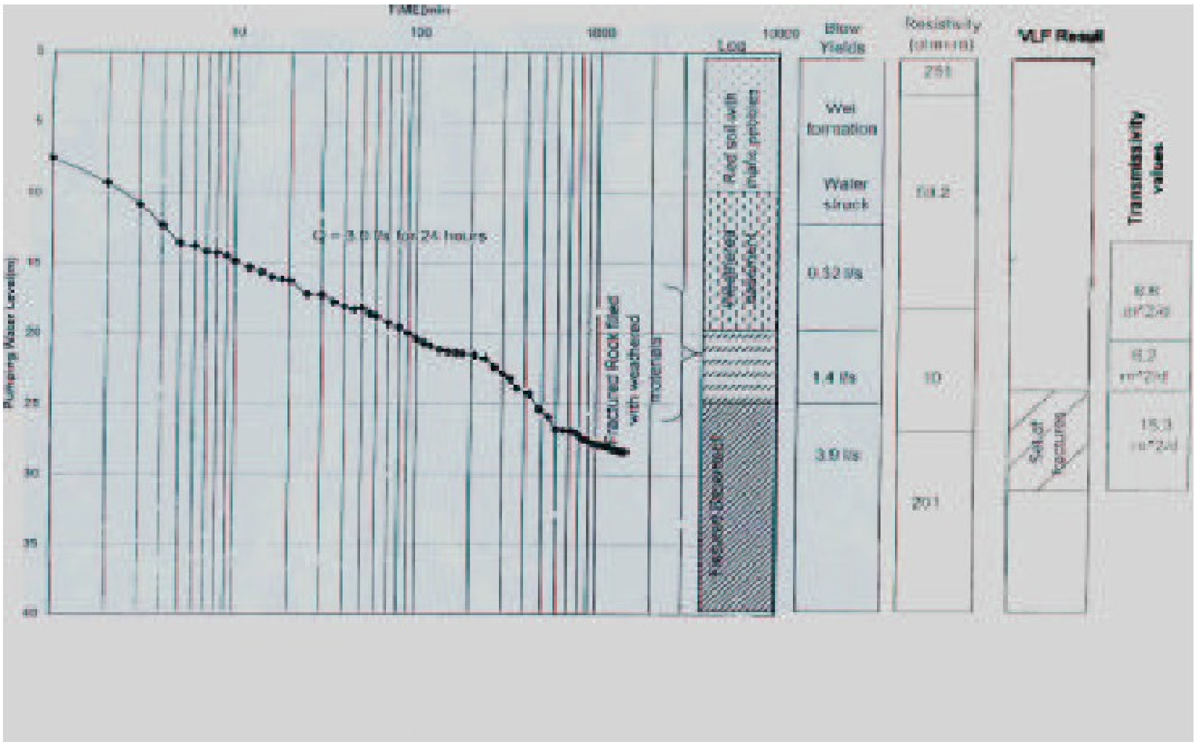


Figure 5: aquifer test for Chancellor College Borehole showing various measured parameters. These are from left to right: Pumping test; Drilling log; Blow yields at various depths, Resistivity values; VLF Results and Transmissivity values

- 5 km to class B). Malomo (1989) obtained water yields greater than 6000 litres/hour or about 1.7 litres/second for lineaments of this magnitude. Lewis (1950) observed that yields vary a lot in crystalline basement aquifers but typically are of the order of 0.25 - 1.0 litres/second. This suggests that the water yields for the boreholes of 2.0 - 4.0 litres/second obtained in this study were above average.

Proper location of fractures is very important for ground water exploration. Botha et al (1994) showed that boreholes within short distances differ greatly in water yields depending on intersection of fractured zones below ground. This study shows this to be true.

Maini and Hocking (1997) have illustrated that a flow through a porous medium of 100m thick with transmissivity values (K) of K = 0.0086m/d would come from a fracture aparture of ¡0.2mm. On the other hand, a flow of K=8.6m/d in a medium 10m thick would be experienced from an aparture 1.0mm. This shows the great importance of fractures in a rock mass, that is, a borehole which intersects more fractures may have a greater potential to yield enormous amount of water. Targeting areas of intense fracturing by VLF technique and lineaments give good water yields.

## 5 CONCLUSIONS

The area studied, shows that areas underlain by crystalline rocks have good aquifer potentials along major geologic lineaments. The Phalombe Plain close to lake Chilwa shows longer geologic lineaments with deeper fractured zones than those close to Zomba Mountain and west of Blantyre Road. The fractured zones extend to a depth of 40 metres which is the expected depth for drilling for optimum water yields. Water yields of boreholes along lineaments were between 2.0 - 4.0 litres per second and this is considered to be good for crystalline basement aquifers.

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A. Dominant Lineaments

Table 2: Summary of important parameters of fractured zones from very low frequency (VLF)

| Field Location | Area | Depth Range (m) | Dip (degrees) | Intensity of Fracturing |
|---|---|---|---|---|
| F1 | Likangala, Upper | 3 - 15 | 35 E | 1 |
| F2 | Likangala, Upper | 1 - 30 | 38 N | 5 |
| F3 | Songani, W | 1 - 25 | 42 E | 6 |
| F4 | Songani, W | 2 - 22 | 30 N | 4 |
| F5 | Songani, W | 8 - 18 | 32 E | 6 |
| F6 | Songani, NE | 6 - 19 | 41 E | 6 |
| F7 | Songani, NE | 6 - 25 | 40 E | 4 |
| F8 | Songani, T. C. | 5 - 23 | 35 S | 5 |
| F9 | Ruthdrum (I) | 5 - 30 | 50 S | 4 |
| F10 | Mpyupyu | 5 - 35 | 40 S | 8 |
| F11 | Alexander Liti | 2 - 40 | 43 W | 4 |
| F12 | Namasalima | 2 - 29 | 25 N | 9 |
| F13 | Jokala | 6 - 35 | 40 E | 5 |
| F14 | Mulunguzi | 2 - 33 | 45 S | 7 |
| F15 | Govala (I) | 5 - 35 | 40 W | 6 |
| F16 | Govala (II) | 10 - 35 | 32 N | 3 |
| F17 | Ruthdrum (II) | 20 - 40 | 41 S | 6 |

B. Subordinate Lineaments

Table 3: Summary of Important Parameters of Fractured Zones from Very Low Frequency (VLF) Results

| Field Location | Area | Depth Range (m) | Dip (degrees) | Intensity of Fracturing |
|---|---|---|---|---|
| F1 | Likangala, Upper | 23 - 30 | 25 E | 3 |
| F2 | Likangala, Upper | 6 - 23 | 35 S | 4 |
| F3 | Songani, W | 3 - 15 | 26 W | 5 |
| F4 | Songani, W | 3 - 23 | 39 N | 7 |
| F5 | Songani, W | 10 - 15 | 40 E | 6 |
| F6 | Songani, NE | 9 - 25 | 32 E | 4 |
| F7 | Songani, NE | 7 - 25 | 33 W | 3 |
| F8 | Songani, T. C. | 15 - 19 | 32 S | 1 |
| F9 | Ruthdrum (I) | 5 - 20 | 41 N | 4 |
| F10 | Mpyupyu | 3 - 30 | 44 S | 4 |
| F11 | Alexander Liti | 6 - 30 | 55 W | 3 |
| F12 | Namasalima | 17 - 30 | 33 S | 4 |
| F13 | Jokala | 5 - 35 | 37 W | 3 |
| F14 | Mulunguzi | 1 - 39 | 40 N | 6 |
| F15 | Govala (I) | 15 - 36 | 31 W | 5 |
| F16 | Govala (II) | 6 - 20 | 43 N | 2 |
| F17 | Ruthdrum (II) | 10 - 25 | 30 N | 4 |