DENSITY AND ORIENTATION OF FRACTURES ALONG THE GAGAK FAULT AND FEED ZONES IN THE DARAJAT GEOTHERMAL FIELD.

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ABSTRACT

Eight wells intersected the Gagak Fault in the Darajat Geothermal Field. Of these wells, seven are capable of producing 10-30 MWe per well. An extensive study using Formation Micro Scanner (FMS) was conducted to identify density and orientation of the open fractures associated with the Gagak Fault.

At subsurface, the Gagak Fault Zone is characterized by the appearance of high-density minor fractures (open fractures with narrow width size) and less dense major fractures (open fractures with larger width size). These fracture zones are usually associated with lost circulation zones, drilling breaks and steam entries during drilling. The density of open fractures increases with greater depth and this may be related to the rock type encountered (more abundant brittle lava and microdiorite at greater depth).

The orientation of open fractures (major and minor fractures) is predominantly north-northeast to south – southwest. Surface traces of the Gagak Fault also indicate a similar trend, which is northeast to southwest. The FMS data shows that most of the open fractures are high angle fractures in the range of 70^0-80^0, and dipping to the east or southeast. The distribution and orientation of deep Micro Earthquakes (MEQ) support this interpretation. Higher volume steam entries or feed-zones are principally associated with the main Gagak Fault Zone at an elevation of 500 – 800 meters above sea level. Outside of the main fault zone, the steam is produced from the high-density minor fractures at a lower elevation. Along the Gagak Fault Zone, healed fractures (fractures filled by mineralization) occur mainly above 1000 meters above sea level.

Study of the density and orientation of open fractures along the Gagak Fault Zone will assist to define the most permeable parts of the zone. Similar fracture studies can be applied in other geologic structures to define the most permeable areas in the field.

1. INTRODUCTION

1.1. Background

Permeability is one of the most important parameters in geothermal systems. It provides paths that allow fluid (steam or liquid) to flow to the surface. Open fractures are a very common type of permeability in geothermal systems and most of the steam entries or feed zones are always associated with these fractures. This paper describes how to determine the distribution, orientation of open fractures and their relationship with the production rate from wells along the subsurface Gagak Fault in the Darajat Geothermal Field.

1.2. Location

The Darajat Geothermal Field is located 150 km southeast of Jakarta (capital city of Indonesia) , and 35 km southeast of Bandung (capital of West Java) (**Figure-1**). The average elevation of the field is between 1750 – 2000 meters above sea level. Physiographically, the Darajat field lies within a 25 kilometer long arcuate mountain range (un-named) in West Java, consisting entirely of Quaternary volcanic rocks. The range includes three well-known thermal areas: Kamojang to the northeast, Darajat and Papandayan in the center and southern portions respectively.

1.3. Source of data

Several FMS (Formation Micro Scanner) data from eight (8) wells which intersected the Gagak Fault, have been used to identify and determine the density and orientation of the open fractures. Additional data from deep Micro Earthquake (MEQ) data were also used to support the interpretation.

2. SURFACE AND SUBSURFACE GEOLOGY OF DARAJAT AREA

The Darajat geothermal field is situated on the eastern side of Kendang valcano, which is part of an arcuate range of Quaternary volcanoes extending 25 kilometers from Papandayan volcano in the southwest to the Guntur volcano in the northwest. There are numerous eruptive centers within the mountain range and volcanic activity has occurred in historic times (Guntur volcano, 1840 and Papandayan volcano, 1772) (Amoseas Indonesia Inc., 1989).

The broad tectonic setting of the Darajat–Kamojang region is shown in Figure 1. The most significant structural feature is the Kendang fault, which strikes northeast from Darajat along the high axis of the volcanic range, disappearing on the north side of the Kamojang field, 10 kilometers away. To the west of the Darajat field, the Kendang fault is slightly offset by the Gagak Fault, which is considered to be a major permeability target (Amoseas Indonesia, 1998). The surface geology of Darajat field is shown in **Figure-2**.

Stratigraphically, the Darajat field is dominated by several hundred meters to more than 1000 meters of pyroclastic rocks (breccias and tuffs) interbedded with minor andesitic lava flows. This sequence is underlain by a zone of relatively fresh to moderately altered andesitic lava flows and intrusions ("andesite complex"). The bulk of the steam reservoir is associated within this andesite complex.

Argillization is most intense in the clastic layers within the pyroclastic sequence, whereas interbedded lava flows show much lower intensity of alteration. This argillized zone generally overlies a zone of intensely silicified rocks. The geothermal reservoir rock is characterized by propylitic alteration and the occurrence of chlorite, epidote, calcite, quartz, pyrite and sometimes wairakite. These minerals occur both in the rock matrix (replacement) and as veins and veinlets (Amoseas Indonesia Inc., 1998).

Permeable zones in the reservoir have been interpreted primarily from drilling records and water-loss surveys and supported by FMS (Formation Micro Scanner) log analysis. Major producing zones have been recognized during drilling by sudden losses of circulation and drilling breaks. The surface traces (lineaments) of faults show predominant northeast – southwest and possible northwest – southeast strikes (**Figure-1**). FMS logs also show fracture orientations with predominant northeast-southwest trends. Less common north – south trends have also been recognized.

3. DENSITY AND ORIENTATION OF OPEN FRACTURES ALONG THE SUBSURFACE GAGAK FAULT ZONE

3.1. Identification of subsurface Gagak Fault Zone

The surface trace of the Gagak Fault is clearly shown northeast to southwest orientation in digital elevation model (DEM) (**Figure-1**). The FMS data from wells intersected the Gagak Fault indicates that most of the open fractures have similar orientation, ie. north - northeast to south-southwest strike and dipping east–southeast with high magnitude (70^0 – 80^0) (**Figure -4**). The deep micro earthquake (MEQ) data also supports the existence of a northeast to southwest structure with relatively high angle dip (**Figure-3**).

Based on the above information, the Gagak Fault Zone should have a similar strike and high angle dip (70^0 – 80^0) at subsurface. **Table-1** summarizes the characterization of the Gagak Fault Zone encountered from the eight wells, based on drilling information (lost zones, drilling break) and existence of open fractures .

3.2. Density and orientation of open fractures along the Gagak Fault Zones

The density of open fractures (both major and minor fractures) is calculated by adding the number of those fractures at different elevation (every 400 meters elevation interval). **Chart-1** summarizes the number of major and minor fractures from different wells at different elevation. The Gagak Fault Zones are mostly penetrated at an elevation of 500 – 800 meter asl.

The orientation of open major and minor fractures mostly shows a north - northeast to south-southwest and dipping 70^0 to southeast. **Table-2** summarizes the general orientation of major and minor fractures from different wells.

3.3. Relationship between fracture density and feed zones

Feed zones or steam entry zones in wells along the Gagak Fault Zones indicate a strong relationship with the fracture density encountered in that zone. For highly productive wells (more than 20 MWe), the feed zones usually associated with the main Gagak Fault Zone. This zone is characterized by the appearance of high-density minor fractures and less dense major fractures. For moderately productive wells (less than 20 MWe), the feed zones are not associated with main fault zones. The feed zones usually associated with the moderate to high-density minor fractures with very rare or absent of major fractures. The orientation of these fractures is similar with fractures in the main fault zone. **Table-3** summarizes the relationship between fracture density and feed zones from wells that penetrated the Gagak Fault.

4. DISCUSSION AND CONCLUSION

The most productive part of the Gagak Fault Zones is found at an elevation of 500 – 800 meter asl. This interval is characterized by the occurrence of a high density of minor fractures and a low density of major fractures. Major steam entries, drilling breaks and total lost circulation usually accompany this fault zone. DRJ-14, 17,18 and 22 are wells with feed zones associated with the main Gagak Fault Zone. It is very common that a series of parallel minor fractures also occurred together with the main Gagak Fault Zones. This type of minor fractures also provides good permeability, instead of the main fault zones. DRJ-10, 16 and 20 are wells with the feed zone associated with parallel minor fractures. DRJ-15 penetrated the Gagak Fault at a shallower depth (750 – 1150 meter asl) and indicated that the open fractures, had been partially mineralized.

The fracture density tends to be greater at depth and this may relate to the occurrence of more brittle andesite lava and in some wells microdiorite. The fracture density in the well also depends on whether the well is vertical or deviated. More fractures will be encountered if the well is drilled deviated than vertical. DRJ-17 is a vertical well and penetrated a lesser amount of fractures compared with the deviated wells.

The fracture orientation is dominantly north-northeast to south-southwest and dipping sub-vertically to the southeast. The orientation is similar with the surface trace of the Gagak Fault trend. The deep Micro Earthquake (MEQ) data (approximately 3 to 4 km depth) shows similar orientation and high dip angle structure. The FMS data from DRJ-15 and 17 (both wells provided long intervals of FMS data) shows that dip magnitude of open fractures tend to increase with depth (the deeper, the greater the dip magnitude).

DRJ-14, 17 and 22 are wells which penetrated the main Gagak Fault Zones and produced high steam rate (>20MWe). However, DRJ-18 also penetrated the main Gagak Fault Zones, but produces at a lower rate (< 20 MWe). The reason is because DRJ-18's trajectory, after penetrating the main Gagak Fault Zone, started to be parallel to the structure. This condition will reduce the chance of encountering additional permeabilities at depth. DRJ-10, 15 and 16 are wells with feed zones that correlate with minor fractures associated with the main Gagak Fault. DRJ-10 and 16 are productive wells, but DRJ-15 is non-economic well. DRJ-15 penetrated Gagak Fault at shallower depth and showed high mineralization in the upper portion of the fault zone. The well's trajectory started to be parallel to the structure after being drilled approximately 1000 meters.

Identification of the density and orientation of open fractures assists to define the most permeable parts of the Gagak Fault and can be applied to other geological structure in the field.

5. ACKNOWLEDGEMENT

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Chart-1 : Fracture Density vs. Elevation

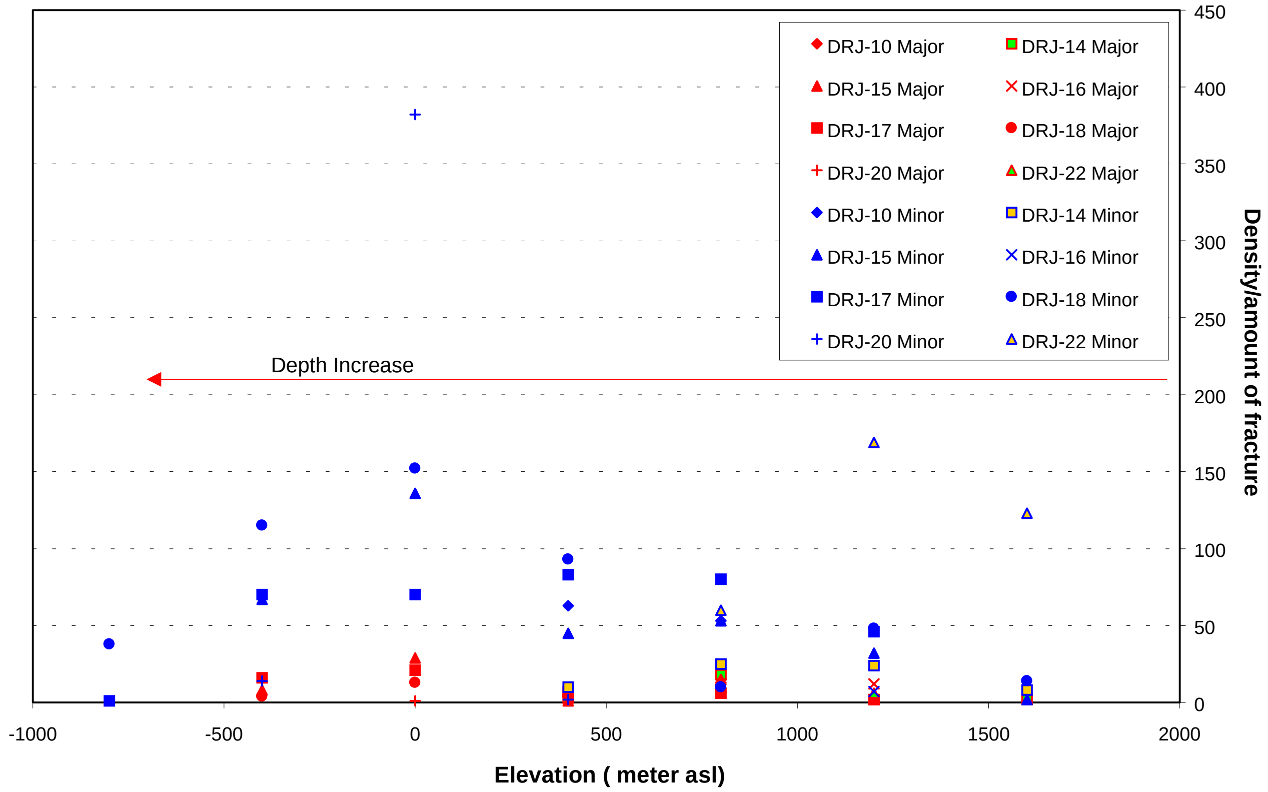

Table-1

Characterization of Gagak Fault Zone encountered from eight wells

Well	**Elevation of Gagak Fault (masl)**	**Characterization**
DRJ-10	450-700	Steam entries, total lost circulation (TLC) , open fractures
DRJ-14	550-900	Steam entries, open fractures
DRJ-15	750-1150	Weak steam entries, TLC, sealed by mineral at the upper part of this fault
DRJ-16	450-800	Steam entries, drilling breaks, open fractures
DRJ-17	450-800	Steam entries, drilling breaks, open fractures
DRJ-18	350-550	Steam entries, drilling breaks, open fractures
DRJ-20	300-475	Drilling breaks, open fractures, no steam associate with this fault (steam entry occurred outside the fault zone)
DRJ-22	475-800	Steam entries, TLC, drilling breaks, no fracture data at this interval

Table-2

Orientation of open fractures in different wells along Gagak fault zone

Well	**Elevation (masl)**						
	(1800-1400)	**(1400-1000)**	**(1000-600)**	**(600-200)**	**(200-(-200)**	**(-200-(-600))**	**(-600-(-1000))**
	Open Fracture Orientation						
DRJ - 10			Minor : N 15^0-67^{0}E / 85^0 Major : N 195^0-215^{0}E / 85^0				
DRJ - 14		Minor : N 0^{0}E / 75 (average) Major : N 30^{0}E / 80^0					
DRJ - 15		Minor : N 50^{0}E / 45^0 Major : None	Minor : N 25^{0}E / 65^0 Major : N 25^{0}E / 60^0	Minor : N 15^{0}E / 75^0 Major : N 35^{0}E / 70^0	Minor : N 25^{0}E / 85^0 Major : N 65^{0}E / 65^0		Note : the greater depth, the greater dip magnitude
DRJ - 16		Minor : N 0^{0}E / 65^0 Major : N 25^{0}E / 65^0					
DRJ - 17		Minor : N 215^{0}E / 45^0 Major : N 25^{0}E / 65^0 or N 205^{0}E / 65^0		Minor : N 255^{0}E / 55^0 Major : None	Minor : N 15^{0}E / 65^0 Major : N 25^0 E / 75^0	Minor : N 205^{0}E / 75^0 Major : N 215^0 E / 65^0	Note : the greater depth, the greater dip magnitude
DRJ - 18			Minor : N 45^{0}E / 85^0 Major : N 35^{0}E / 85^0				
DRJ - 20					Minor : N 75^0-185^{0}E / 30^0-50^0 Major : N 37^0-58^{0}E / 22^0-35^0		
DRJ - 22		Minor : N 45^{0}E / 45^0 Major : N 15^{0}E / 70^0					

Table-3

Relationship between fracture density , feed zones and production rate

Well	Fracture density		Permeability associate with feed zone	Production rate (MW)
	(Major)	(Minor)		
DRJ-10	Low	Moderate	Minor fractures	Moderate (< 20)
DRJ-14	Moderate	High	Main Gagak fault zone	High (>20)
DRJ-15	Low	Moderate	Minor fractures, shallow Gagak penetration	Non-economical, low WHP
DRJ-16	Low	High	Possibly minor and major (?)(No data)	High (>20)
DRJ-17	Low	High	Main Gagak fault zone	High (>20)
DRJ-18	Low	High	Main Gagak fault zone, well deviated parallel with structure	Moderate (<20)
DRJ-20	Low	High	Minor fractures (outside the fault zone)	Moderate (<20)
DRJ-22	Low	High	Main Gagak fault zone	High (>20)

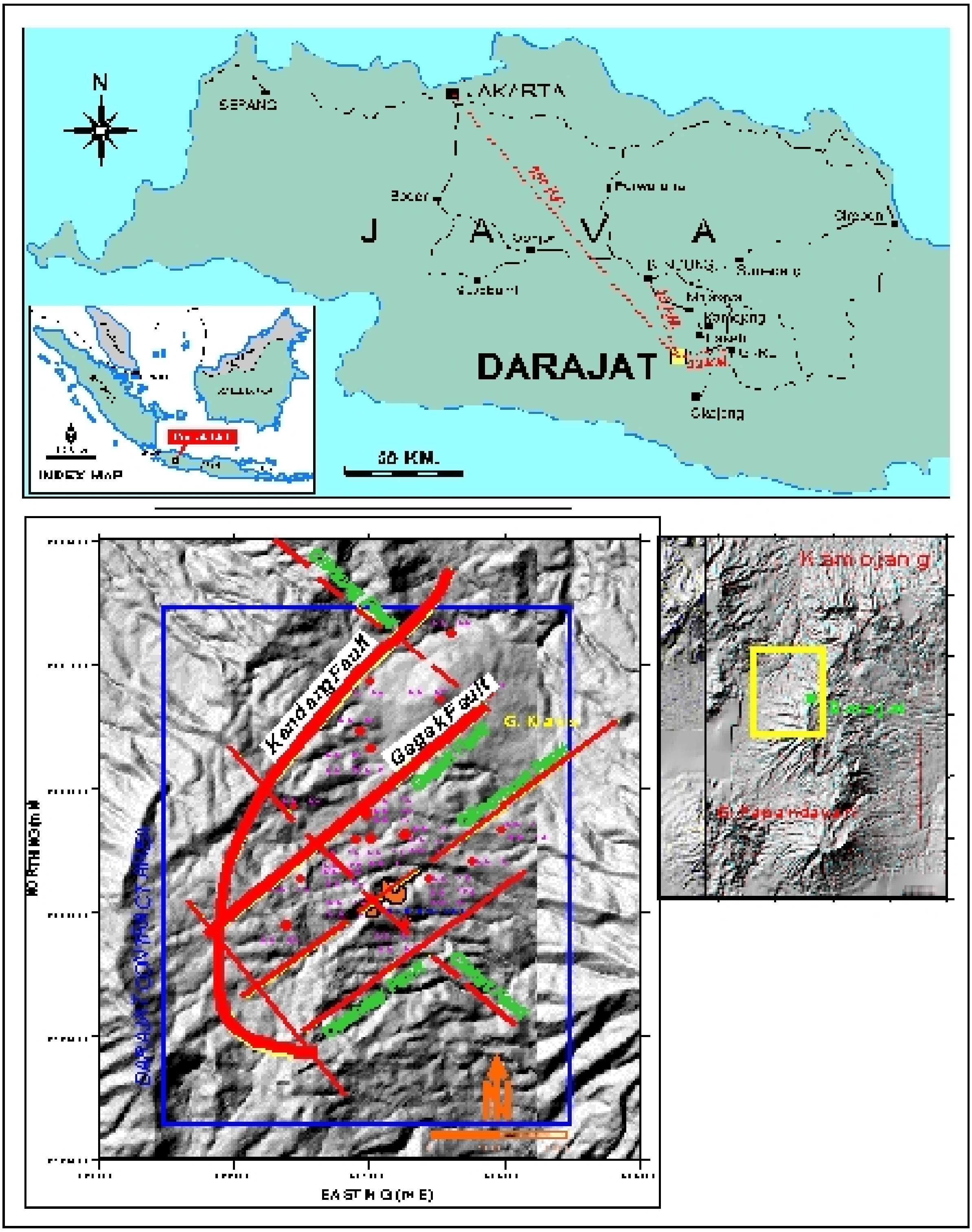

Figure-1
Location ofDarajat Geothermal Field

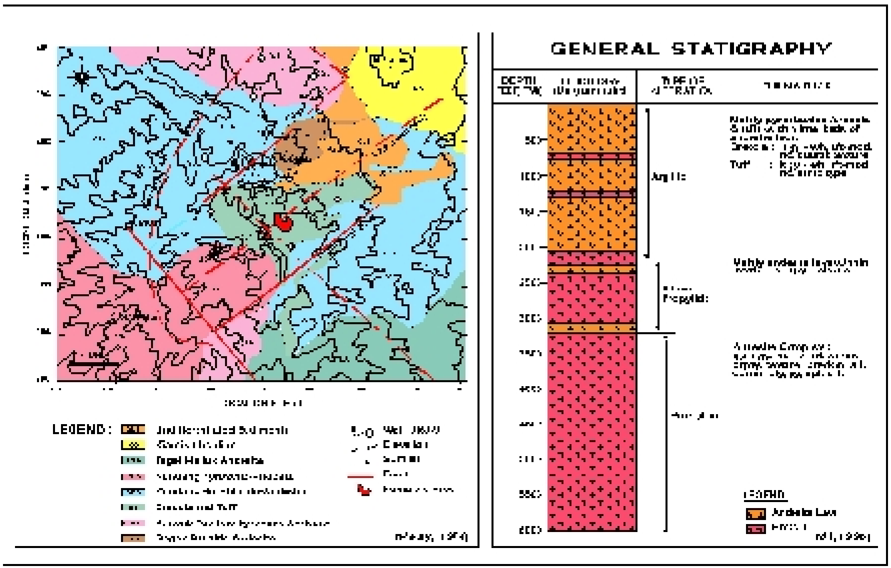

Figure 2 : Surface & subsurface geology of Darajat geothermal field

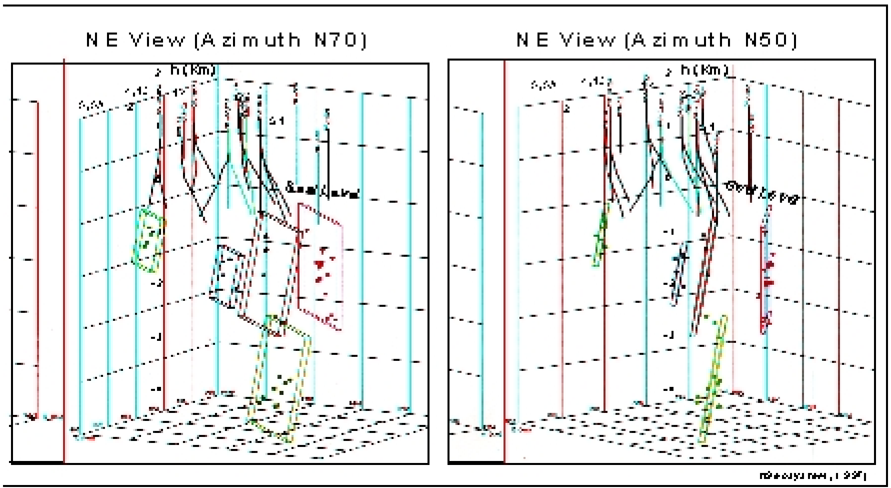

Figure : 3 D View of Micro Earth Quake (MEQ) and interpreted faults

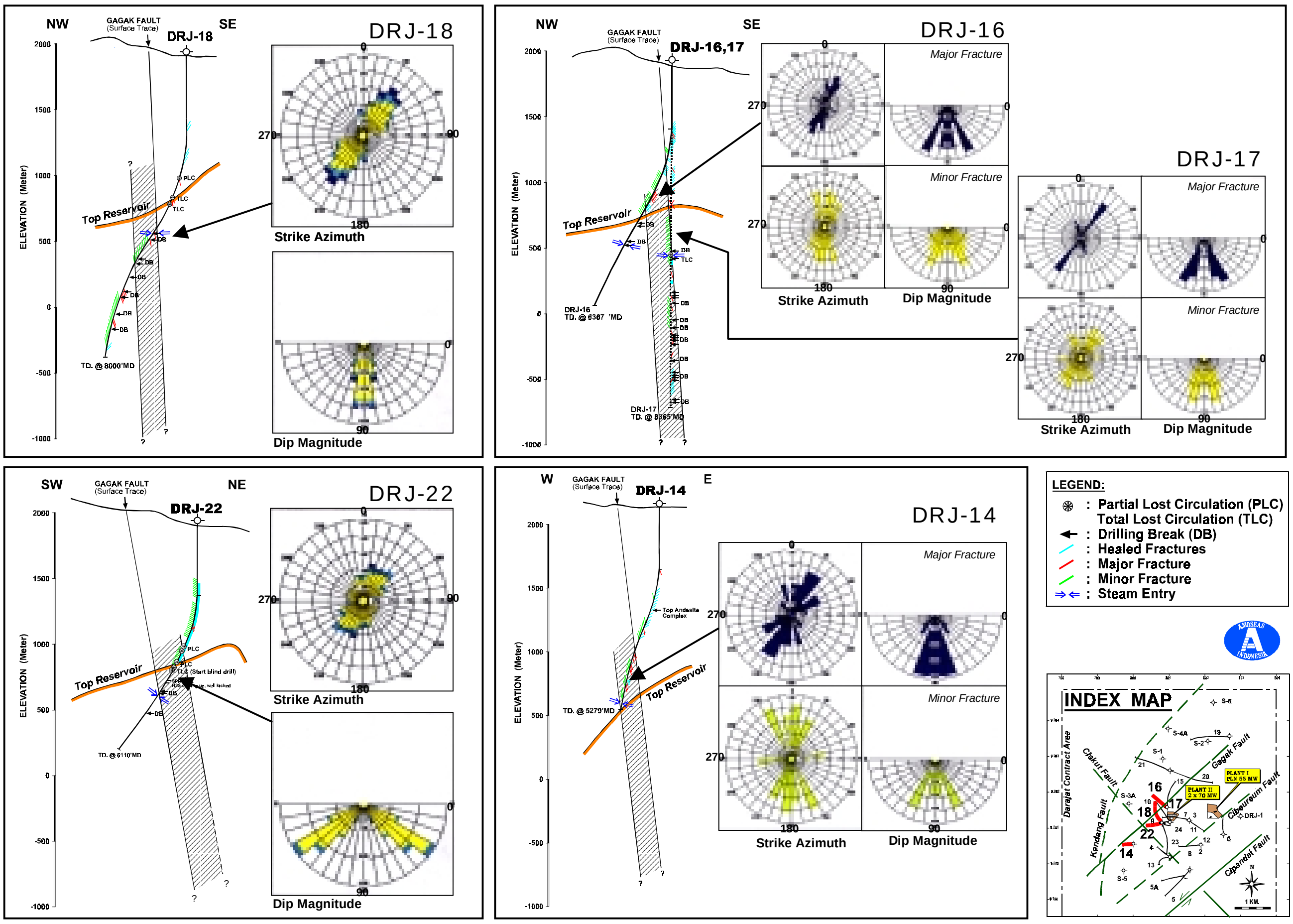

Figure 4 : Cross section and fractures orientation along the Gagak fault