Fracture pattern simulated statistically in the Sumikawa geothermal system, northeast Japan

Mitsutaka Bamba, Yasuhiro Kubota, Akira Ueda, Yasushi Kihara and Yoshiyuki Yamagishi

Central Research Institute of Mitsubishi Materials Corporation
1-297 Kitabukuro-cho Omiya, Saitama Pref. 330, Japan

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Abstract

The Sumikawa geothermal field is located in northern part of Mt. Yakeyama, **Akita** Prefecture, Japan, a 50MWe power station has been operating since 1995. To date, twenty wells have been drilled in **a** 5km^2 area from 1981 to 1994, and much information on fractures **has** been obtained. In this area, fractures appear frequently in Neogene rocks beneath a caprock. The fractures are typical fissure type with druse such **as** observed in ore veins. Distribution patterns of ore veins suggest that the distribution of fissures may be approximated by a plane. On this assumption, fracture-pattern analyses have statistically been done with computer simulation. As a result, the fractures were recognized to be distributed along five planes (strike/dip N80°E, 54° ~ 66°).

1. Introduction

A 50MWe geothermal power station at Sumikawa geothermal field constructed by Mitsubishi Materials Corporation, Mitsubishi **Gas** Chemical Corporation and Tohoku Electric Power Company has been operating since March 1995. Four exploration wells were drilled between 1981 and 1983 in this field and some evidence of geothermal activity was obtained. Therefore, the development of geothermal energy has been started in earnest by rotary drilling since 1986. Six production wells and ten reinjection wells were drilled before the start of operations. About 36 kilometers have been drilled in a total of twenty wells, including exploration wells (Figure 1). Many excellent feed points were obtained from these wells and much information on subsurface fractures has been accumulated during development. The fracture-patterns were analyzed statistically with computer simulation and were analyzed with respect to their 3-dimensional distribution, providing basic information useful for future drilling and analyzing interference between production wells and reinjection wells.

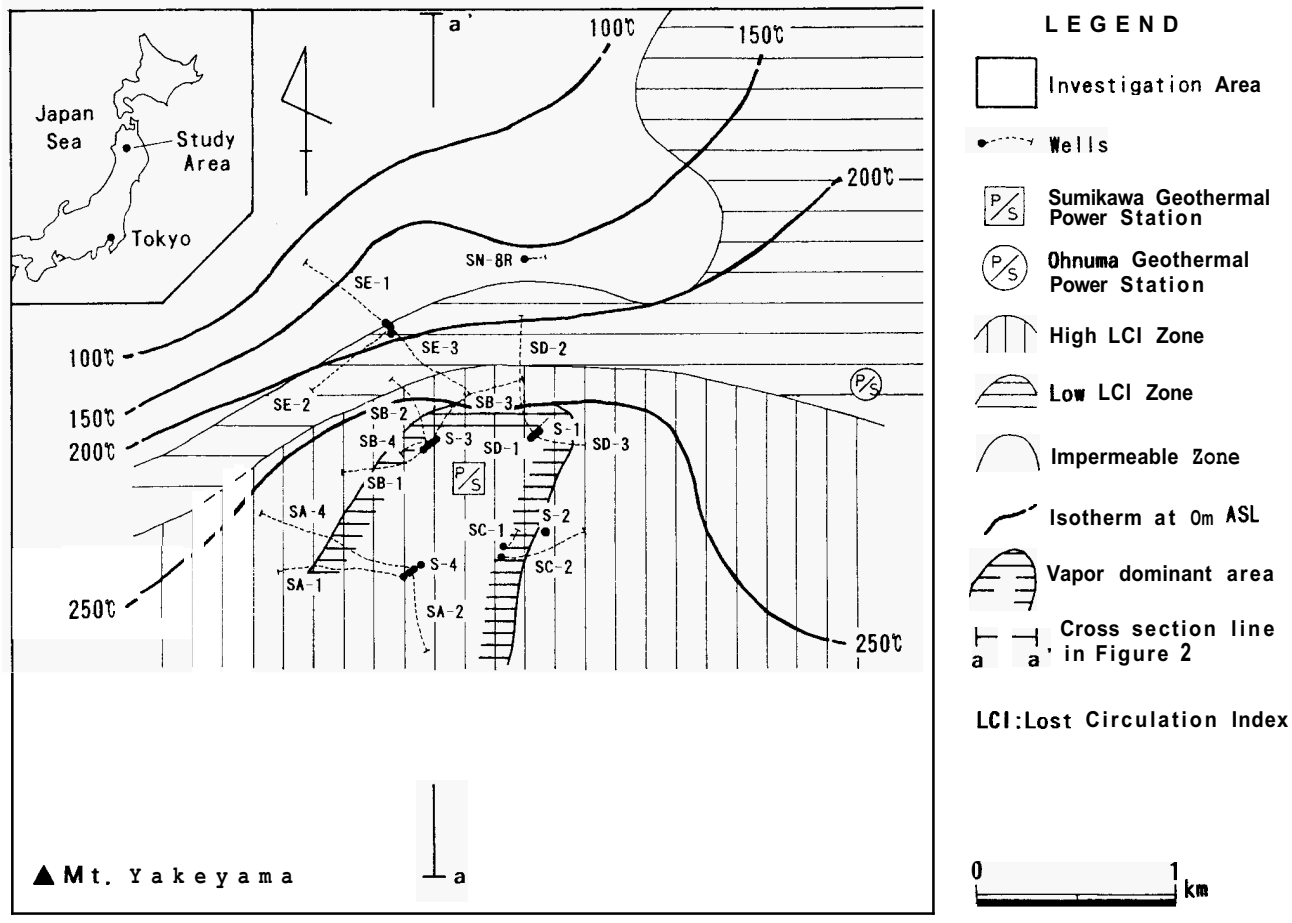


Figure 1 General features of the Sumikawa geothermal field

2. Geothermal structure and fracture

2.1 Outline of conceptual geothermal model

Conceptual geothermal model in this field is summarized as follows (Kubota,1985 ; Uedaet al.,1991 ;Sakai et al.,1993) :

. The heat source is lying beneath the Yakeyama-Hachimantai east-west volocanic chain located to the south of Sumikawa (Figure 1).

. The up-flow area of the geothermal fluid is located above the heat source. On the other hand, the down-flow area is located in the northern part of this field, and as a whole, geothermal fluid is forming a large convection cell.

. Geothermal resources are of the liquid-dominated type accompanied by the vapor-dominated area which is located at shallow depths of high temperature area with a thickness of several hundred meters.

. This vapor-dominated area is capped by low-permeability formation composed of lacustrine sediment and montmorillonite altered area.

. The flow of geothermal fluid is controlled by open fractures.

. The fluids are mainly of the NaCl type at near neutral pH and are of meteoric origin with minor magmatic contribution.

. The geothermal system is thought to be young in view of the fact that most liquids are not in chemical equilibrium with country rocks and homogenized temperatures of liquid inclusion are identical with present static temperature.

2.2 Geology and fracture

Geology in the Sumikawa field is composed of Quaternary volcanic rocks and Neogene formations. The Neogene is divided into three units : B formation (altered andesite lava and its pyroclastics), alternation of C formation (dacitic lava and its pyroclastics) and E formation (black shale) , and F formation (dacitic pyroclasitics) in ascending order. The Neogene is unconformably overlain by the K formation (lacustrine sediment) composed of soft silt, tuff and the L formation (andesitic volcanic rocks). A part of B,C and E formations are intruded by granitic rocks (Z formation) and have undergone contact metamorphism (Maeda,1991). Figure 2 shows geological and isothermal profiles of north-south direction in the Sumikawa field.

The frequency of appearance of main feed points is very low (2,350m/point) in K formation and high (350-650m/point) in the Neogene.

2.3 Reservoir permeability

Kubota (1985) defined a lost circulation index (LCI) at North Yakeyama-Hachimantai area, and reported that the high LCI zone was identical with high temperature zone in the southern part of Sumikawa (Figure 1).

Bamba et al. (1988) estimated that the upper limit of the temperature of stability of montmorillonite was 220℃ by analyzing altered minerals. The distribution of monmorillonite is identical with the distribution of low LCI zone. These results suggest that some fractures are selfsealed with secondary minerals such as monmorillomte in the low temperature zone.

2.4 Fracture characteristics

Fractures were characterized from core samples at a depth where circulation was totally lost. Their characteristics are summarized as follows (Kubota,1985; Figure 3) :

. The fracture causing total lost circulation is a typical fissure type.

. A part of the fissure contains druse as is observed in hydrothermal ore veins.

. The boundary between the fissure and country rock is generally not accompanied by fault clay and shear zone.

. The fissures dip at relatively high angles and are 1～10mm in width.

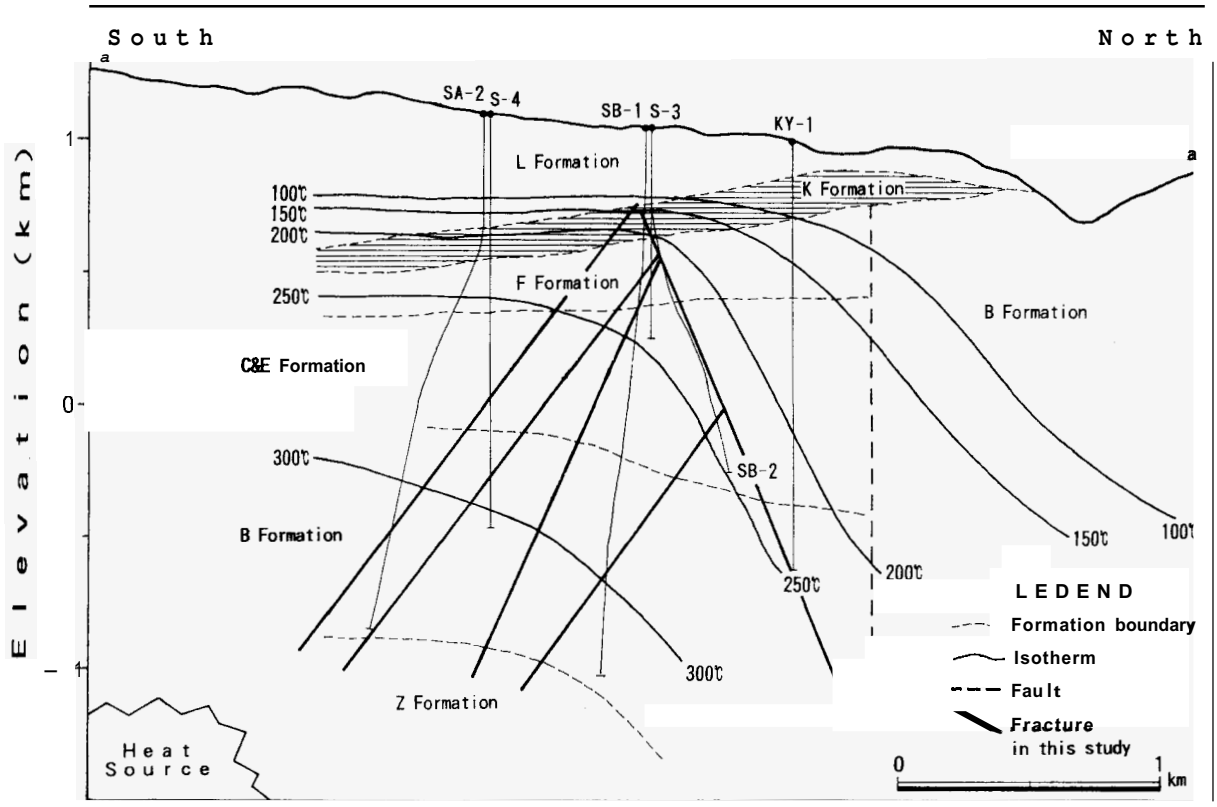


Figure 2 Geological section with isotherm and fracture profiles of the Sumikawa geothermal field

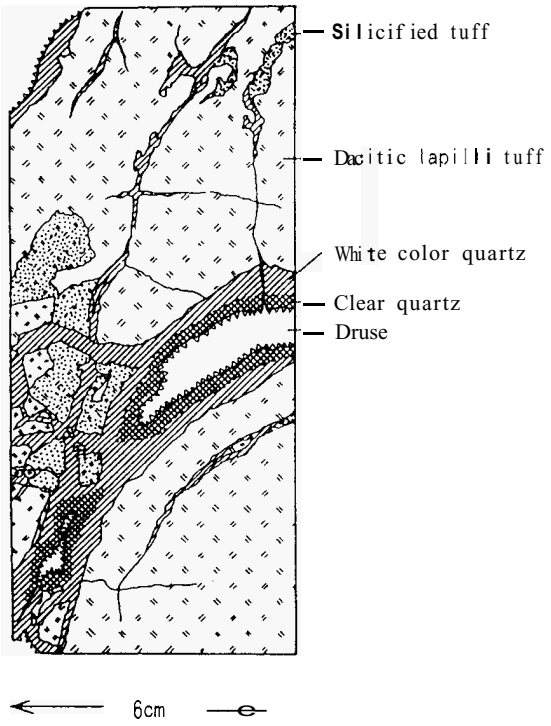


Figure 3 Sketch of fissure type fracture in a core sample (Kubota,1985)

3 Analytical methods

3.1 Ore vein fracture as fossil geothermal system

Ore veins form by hydrothermal fluids moving through fractures and mineral deposition resulting from changing temperature, pressure and chemical characteristics during the process of boiling and flowing. The ore veins may be said to be "the products of a fossil geothermal system". In the case of the present geothermal system, subsurface fractures are covered by a caprock, so that fracture infomiation is limited. In contrast, fractures of ore veins are visible in 3-dimentions with respect to their distribution and characteristics, and their descriptions can be applied to be study on the present geothermal structure. The important feature of the vein fractures is that ore veins are distributed along several parallel planes (Figure 4).

3.2 Analyses of the Sumikawa geothermal system

Sixty feed points are selected carefully to simulate the subsurface fracture pattern. The location of feed points were detected mainly from lost circulation information during drilling and/or anomalies of temperature logging after drilling. The computer program for fracture pattern analysis was statistically constructed in order to verify approximation of feed points to a plane. Figure 5 shows a schematic profile of this algorithm.

Outline of the algorithm is as follows :

. STEP 1: Calculation of every combination of planes from optional three feed points.

The formulas for the calculation of a plane which consists of some feed points are as follows :

$$z=ax+by+c \quad (1)$$

$$a=(Sxz*Sy^2-Sxy*Syz)/(Sx^2*Sy^2-Sxy^2) \quad (2)$$

$$b=(Sx^2*Syz-Sxy*Sxz)/(Sx^2*Sy^2-Sxy^2) \quad (3)$$

$$c=Z-aX-bY \quad (4)$$

where x,y,z are coordinates in three-dimentional space;
a,b,c are coefficients; X,Y,Z are averages of x,y,z ;
Sx^2,Sy^2 are variances; Sxy,Sy,Sxz are covariances.

. STEP 2: Calculation of normal distances (ND) from remaining feed points to the plane.

$$ND=(z_n-a*x_n-b*y_n-c)*\cos\theta \quad (5)$$

where
x_n,y_n,z_n: composed of n optional feed points :
θ : angle of dip.

. STEP 3: Setting up optional normal distance.

Grouping by number of feed points which were selected within optional normal distance (Hereinafter the number of selected feed points is abbreviated to NSF.)

Selection of feed point swarms with abundant NSF (e.g. NSF≧ 17).

. STEP 4: Calculation of fomiulas for planes which are closest approximation of the data of selected feed point swarms.

Calculation of multiple correlation coefficient (MCC).

$$MCC=\sqrt{(a*Sxz+b*Syz)/Sz^2} \quad (6)$$

Calculation of ND.

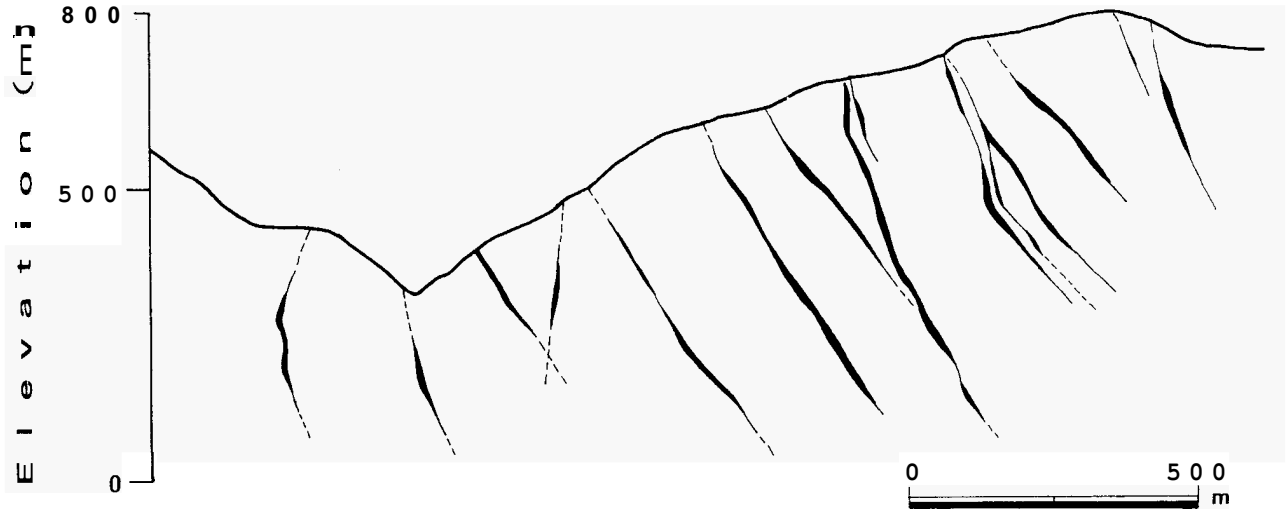


Figure 4 The distribution of ore veins in eastern parts of the Akenobe mine (Kubota et al.,1987)

. STEP 5: Evaluation of each selected plane.

Selection of a feed point swarm which is most certainly a fracture as determined by :

1.Proximity to the plane (e.g. MCC, ND, examination by maps);

2. Relationship between each well and the location of feed points forming the plane;

3. Influence of well distribution such as the drilling sites:

4. Evidence of phenomena suggesting continuity of feed points etc.

. STEP 6 Deletion of the feed point swarm data whch were obtained in STEP 5 from analytical data.

Recalculation from STEP 1 to STEP 5 with remaining feed point data in order to bring out an independent plane which is not duplicate of a selected fracture in STEP 5.

If recalculation is not of great meaning in analyzing fracture from the veiwpoint of number of remaining feed points, shift to STEP 7.

. STEP 7: If plural fracture planes are determined by the process of STEP 1-6, examine remaining feed point data by using the following method:

Separate the analyzing field into some blocks along the borders of the selected fracture planes and examine the remaining feed point data in those blocks.

Examine the presence of continuous feed point swarm in each block by statistical analyses. At this time, add not only the main feed point data, but also small-scale feed point data to the analytical data.

4. Results of analyses

Results of analyses are summarized as follows :

. When the optional vertical distance from the plane in STEP 3 was set to within fifty meters, maximum NSF became twenty.

. Nine planes selected under the condition of more than seventeen NSF, those strikes were dominant in E-W direction (five planes). Six planes dip at relatively high angles of 58-71" and others dip at very high angles of more than 80" in STEP 3.

. The planes with very high angles are composed of feed point swarms along the line of the drilling sites. This shows that these planes selected are strongly under the influence of well distributions.

. The plane which is NSF20 and strike/dip N82°E/66°N have highest certainty as a fracture in STEP 5. Judging from the evidence which proved that feed points are continuous (Cement cuttings for lost circulation job obtained from the feed point of another well), the number of this feed point swarm was reduced to seventeen. As a result, multiple correlation coeffient was 0.997.

. The plane, which is NSF18 and strike/dip N78°E/66°S, was obtained in STEP 6.

. Three fracture planes were obtained in STEP 7 and those strike/dip are N83°E/54°S, N81°E/54°S and N77°E/56°S.

Figure 6 shows a schematic profile in which were projected in a vertical plane S10°W-N10°E direction selected feed points swarms as fractures in the Sumikawa field.

5. Conclusions

The conclusions are summarized as follows :

. This study was carried out statistically with computer simulation, based on the knowledge that a subsurface fissure may be approximated by a plane.

. As a result of the statistical analyses, five feed point swarms were selected as fractures close to planes of strike/dip N80°E, 54–67°. These results show that this method is useful for distribution pattern analyses of geothermal fractures overlain by caprock.

. Almost all of the feed points could be explained by five feed point swarms and several feed points outside of the 5 swarms suggest that other fracture planes potentially may be present.

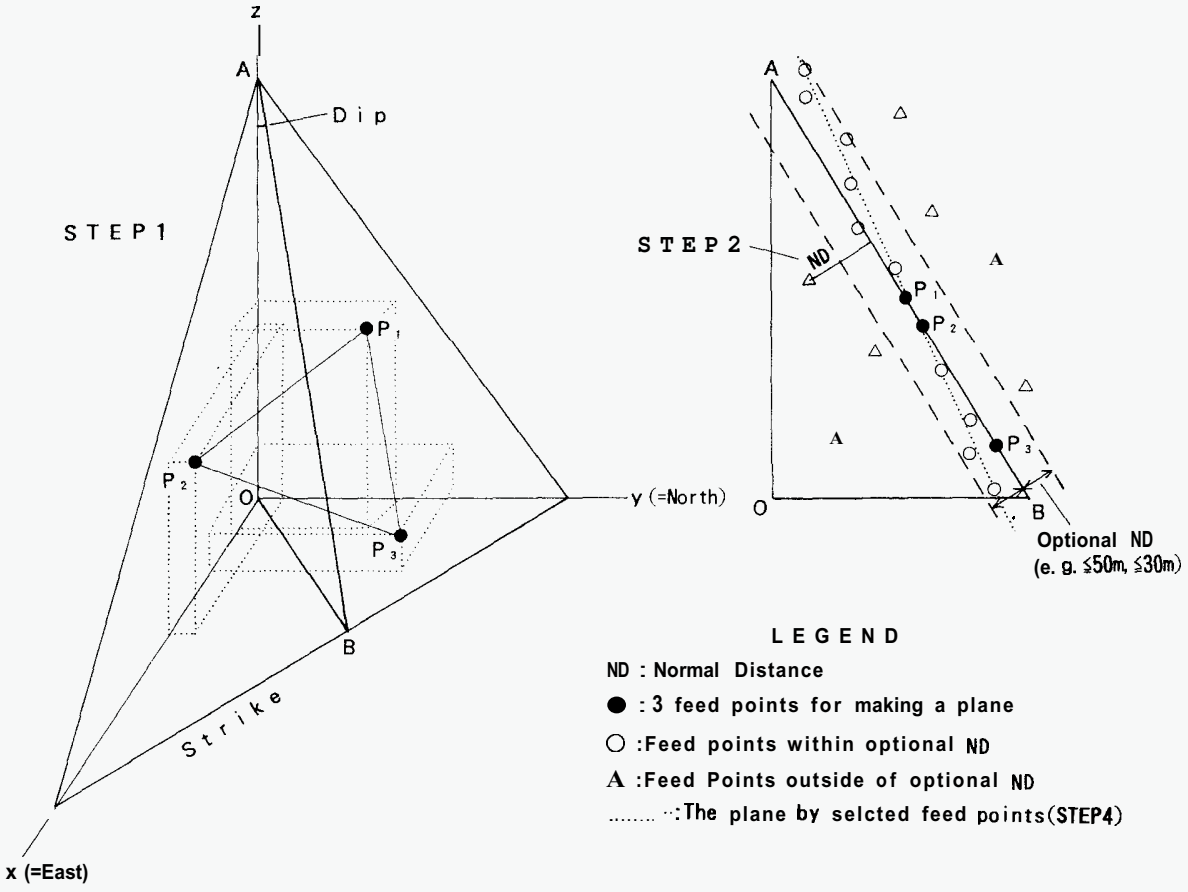


Figure 5 Schematic profile of the fracture analyses method

. If fractures are fissure type, the direction of maximum horizontal stress (S_H) is parallel to the direction of fissure. Therefore, S_H in this area is N80°E.

Otsuki(1989) tried to reconstruct the Neogene tectonic stress fields of Northeast Honshu Arc from ore veins. He suggested that σ_1 or σ_2 was NE-ENE in direction throughout the period from 15Ma to late Miocene, thereafter it was replaced by a different stress field with σ_1 oriented EW-ENE. The present axis of σ_1 is estimated to be EW from geophysical evidence. The direction of σ_1 in this area is in harmony with the stress of the period from late Miocene to the present.

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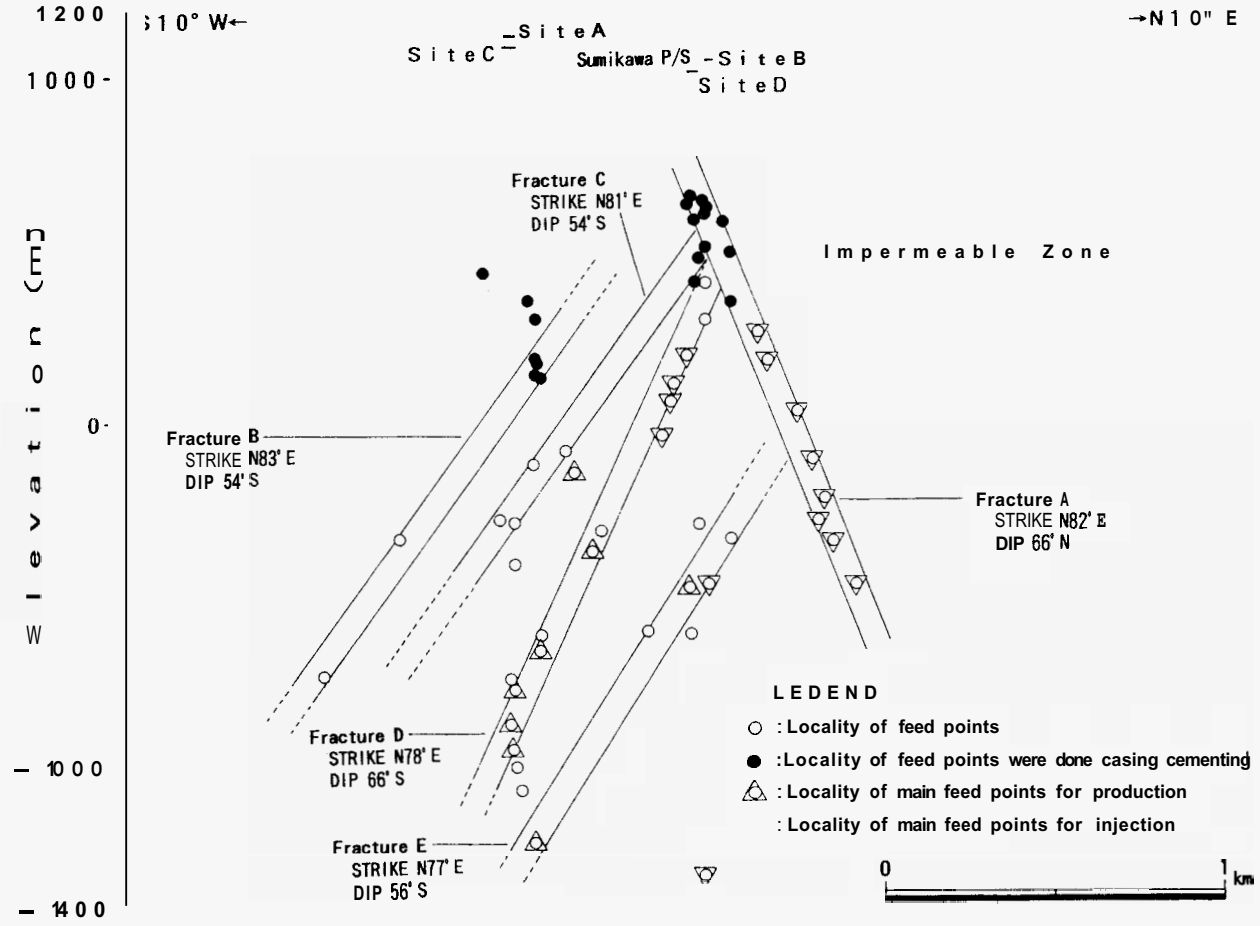


Figure *6* Summary of the fracture analyses in the Sumikawa field