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KAMOJANG FIELD CASE STUDY - USING FORMATION IMAGES TO RESOLVE RESERVOIR DELINEATION AND DEVELOPMENT ISSUES IN WEST JAVA, INDONESIA

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SUMMARY

The Pertamina Kamojang geothermal field in west Java produces high temperature *(250°C)* steam fiom fractured volcanic reservoirs. Understanding the lithofacies, fracture density and the orientation of the fracture systems using electrical images fiom the Formation MicroScanner™ have proven critical to the successful development of the field.

The analysis of the strike direction of the fracture system in the subsurface has helped Pertamina explain the unexpectedly low production some of the wells drilled in the central parts of the field (away fiom faulting associated with the margin of the collapsed caldera). The dominant fracture direction in the subsurface proved to be at **90**" to that initially interpreted fiom conventional surface techniques. Retargeting wells to be drilled across the strike of the dominant fracture system resulted in significant **(6** fold) production improvements.

INTRODUCTION

The Pertamina Kamojang geothermal field is located in west Java, **100 km** southeast of Bandung (Figure **1).** Exploration for geothermal energy in Kamojang started in **1918** followed by **5** exploration wells in **1926.** Development of the Kamojang field started in **1978** and since **1983** has been operated by Pertamina. **65** wells have been drilled with **26** production wells, **3** injection wells, **13** unproductive wells and **23** monitoring wells. **Today,** the field is producing 140 Megawatts of electricity (MWe) with **3** power plant units. There are plans to develop a further two 30 MWe units in the eastern part of the field.

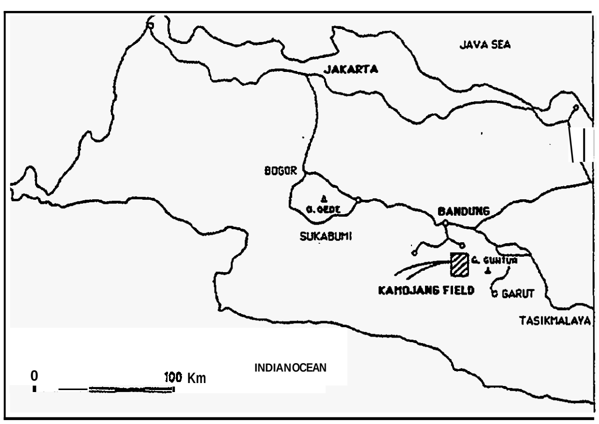

Figure 1. Location Map of Kamojang Field

The main technical problem in understanding the subsurface geology has been that there are no cuttings returns fiom below the lost circulation zones associated with the producing reservoir intervals. **This** has resulted in a paucity of information on lithology type and alteration intensity. There has also been limited information about the producing zones themselves. The conventional method for identifying them (through drilling breaks and changes in pump pressure) clearly yields no **data** on fracture density or strike direction.

To address these issues oriented, high resolution (0.2"- **0.3")** electrical images of the formation have been made with the Formation Microscanner (FMS™). Since **1991 6 FMS's** have been logged in the Kamojang field.

GEOLOGICAL FRAMEWORK

Kamojang Geothermal Field is developed in association with the Pangkalan Caldera (diameter fiom **2.5** to **4 km**). The wall is about 50 m high and is a consequence of collapse faulting, figure **2.** Within the caldera grabens and strike slip faults are developed. The complex faulting relationships control both production and permeability barriers across the field (Robert, D., **1988).**

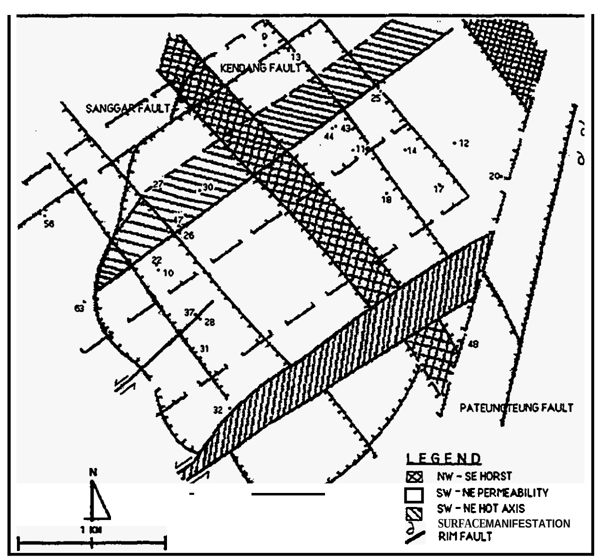

Figure 2. Structural Map of Kamojang Field

IMAGE ACQUISITION & INTERPRETATION

The measurement principle and basic processing of the FMS™ has been described by Lloyd et al., 1986 and Ekstrom et al., 1987. Due to the hostile logging environment various techniques have been developed to assure good data acquisition; these include pumping cooling water into wells during logging. Failing this, the use of a specially modified imaging tool rated to 500°F/260°C is now an option. A minimum borehole size of 4 1/4" can be logged, and with the new Fullbore Formation MicroImager (FMI™) borehole coverage can be increased from 40% to 80% in 8 1/2" holes.. A temperature log is typically run in combination to help recognize thief zones or fluid entry.

Figure 3 shows, on a 1/20 vertical scale, three main lithologies. There is a highly conductive (dark coloured) generally featureless interval across the upper 3'. This is characteristic of altered argillaceous tuffaceous material; such tuffs can often be quite badly washed out. The middle 8' on the images are quite resistive (light coloured) but there are some thinly developed low angle conductive features which cut across the borehole. These are interpreted as flow/cooling surfaces in a lava. In the lower 3' the images look quite heterogeneous with conductive and resistive textures. This is a typical response across coarser grain volcaniclastics.

Figure 4 shows a more detailed view (at 1/7 compatible vertical and horizontal scaling) of a volcaniclastic section with more resistive clasts, 1"-6" in diameter, set in a more conductive, tuffaceous matrix.

Figure 5 represents a series of interbedded tuffs, with some local patchy (more resistive) cementation. The sinusoids cutting the image represent bast fit planes to the bedding surfaces as they cut across the borehole; across this section they dip from 15°- 30" towards the west southwest. Note that the caliper (the red dotted and green dashed cures in the right hand track) show some hole ovalization. The calipers on pad 1 & 3 are measuring the shorter axis of the hole; the pad 1 azimuth (black) curve shows (that across this interval) this is oriented northwest to southeast, so the long hole axis is northeast-southwest.

Figure 6 represents a more deeply buried and resistive (cemented) pyroclastic sequence; a brecciated texture can be made out even on this somewhat compressed 1/20 vertical scale. The most striking feature on the image is the steeply dipping conductive zone across 5' of the wellbore. The best fit planes at the edges of the feature dip at 80" to the northwest; striking northeast to southwest. It is interpreted as a major fracture; invasion of the relatively conductive drilling fluid into the more resistive formation explains the strong conductivity (dark coloured) contrast.

Figure 7 shows an even more extreme megafracture feature on a vertical scale of 1/50; the hole is washed out and there was lost circulation during drilling. Despite the washout and resultant poor image definition across 25', high angle dipping features at the boundaries show the zone strikes northeast to southwest.

Figure 8 is a strike histogram of the major fracture network through the reservoir section.

The FMS™ images can be used very much as oriented core photographs to understand the basic changes in lithology, variations in cementation, and to analyze fracture and joint systems. Knowing the strike direction of the major fracture systems is of critical importance in drilling directional development wells. It assures that the optimum number of fractures are penetrated and can result in a six-fold production improvement compared with wells which are drilled subparallel to the local fracture strike.

APPLICATION

Five structural elements have now been defined (figure 2).

- Rim System; tensional (collapse structure), acuate and swinging around the southern extension.
- Kendang System; normal faults striking northeast to southwest.
- Strike Slip System, striking northeast to southwest.
- "G" System; northwest to southeast striking fault graben.
- Pateungteung System; north northeast to south southwest striking normal fault (developed to the east of the main caldera).

While well developed to the southwest of the field, the Kendang system was poorly defined (using conventional surface methods) in the main caldera. It is, however, prominent on the electrical images in the subsurface as an open fracture system, and appears to contribute (with the Rim System) to most of the production of the field.

This explains why deviated wells drilled towards the northwest or southeast hit more fracture zones and have better production than deviated wells to the northeast or southwest (the apparently more prospective "G" system interpreted from conventional surface techniques). The northeasterly deviated 29, 33, 34 & 35 wells were all disappointing whereas 36, 52 & 62 (deviated towards the northwest) were all successful. Figure 9.

The fact that well developed and productive lineaments in the subsurface are poorly defined by conventional surface techniques, and that those surface trends believed to be productive are in fact healed in the subsurface is extremely significant.

Pertamina have integrated FMS™ fiacture interpretations as part of their planning strategy for future development wells. Note that the fiacture directions in such volcanic sequences are often the result of quite local, as distinct to regional, stress regimes and so they may vary quite significantly across a field.

CONCLUSIONS

The use of electrical imaging techniques has proven invaluable in identifying lithology variations and analyzing induced and natural hcture systems in the Kamojang Geothermal Field in west Java.

The analysis of the strike direction of open fracture systems in the subsurface has helped explain why some development wells have had disappointing results. These wells were deviated subparallel to the strike of the open fracture systems and therefore rarely crossed productive units.

This means that structural lineations dehed by conventional surface techniques need not necessarily correspond to productive lineations in the subsurface.

Knowledge of the predominant strike direction of open fracture systems in the subsurface is critical in the successful exploitation of the reservoirs. In Kamojang these trends have been successfully identified with electrical imaging.

ACKNOWLEDGMENTS

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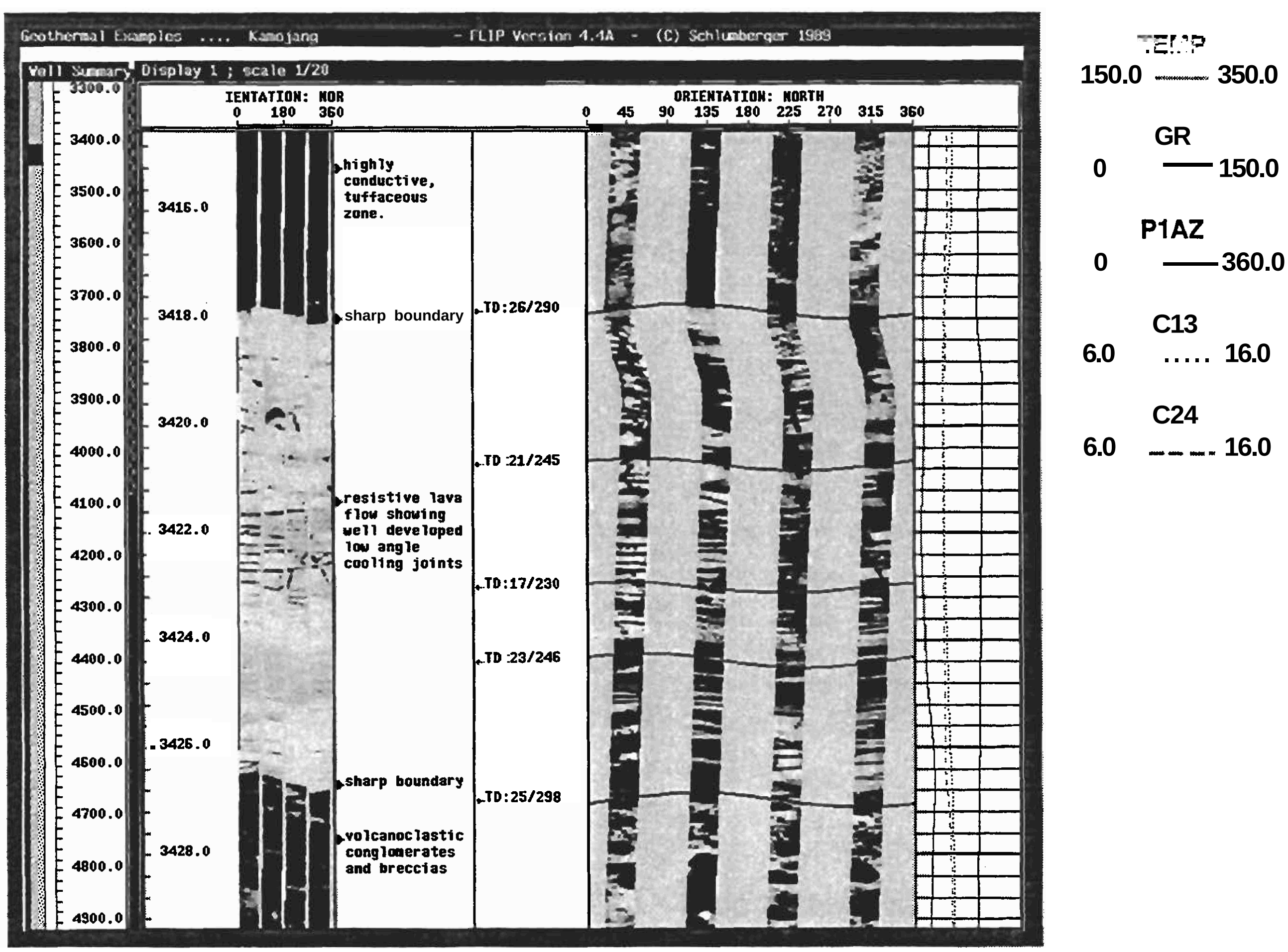

Figure 3. Formation MicroscannerTM images showing the three main lithologies in the Kamojang field.

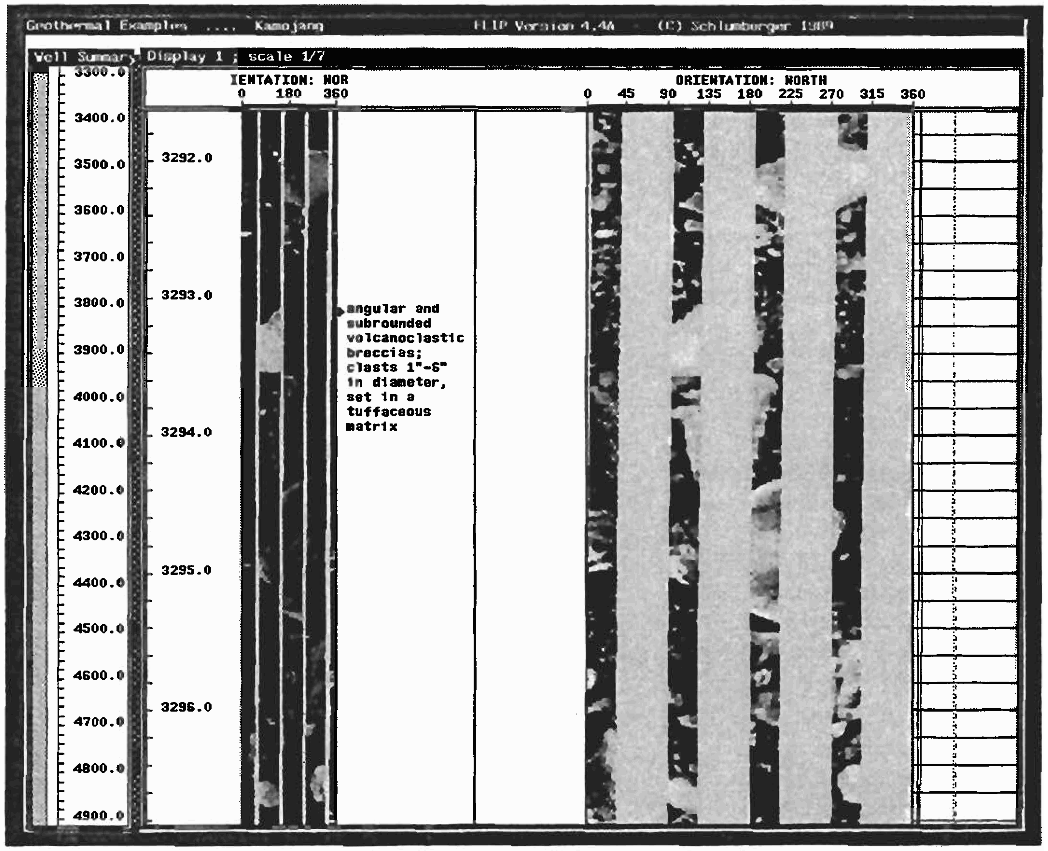

Figure 4. Volcaniclastic breccias with angular and subrounded clasts.

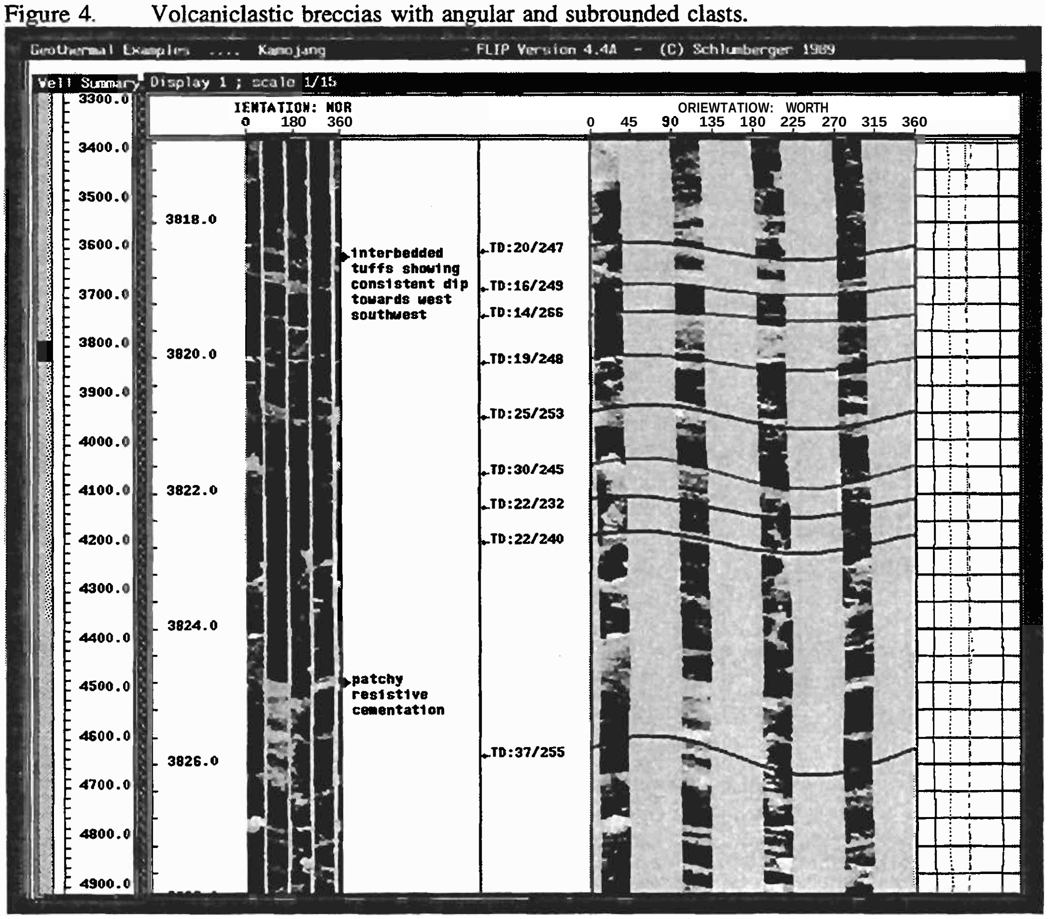

Figure 5. Interbedded tuffs dipping to the west southwest

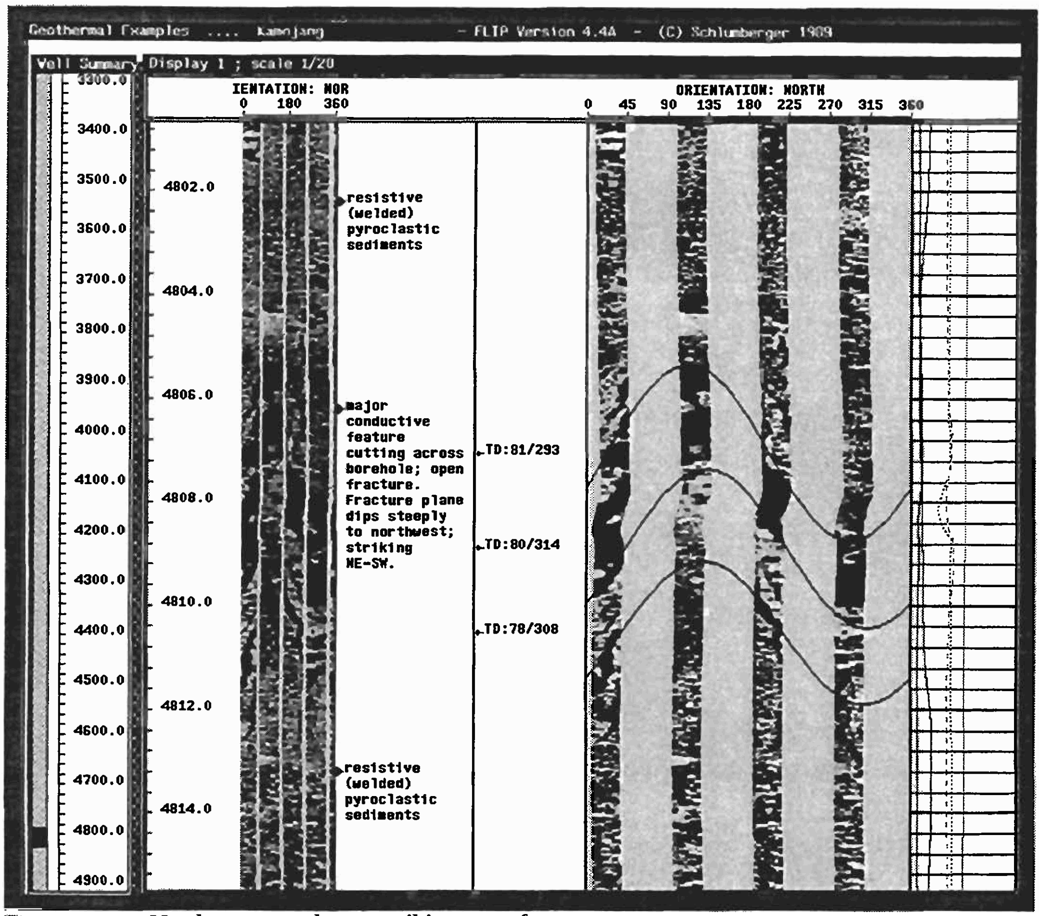

Figure 6. Northeast - southwest striking open fracture.

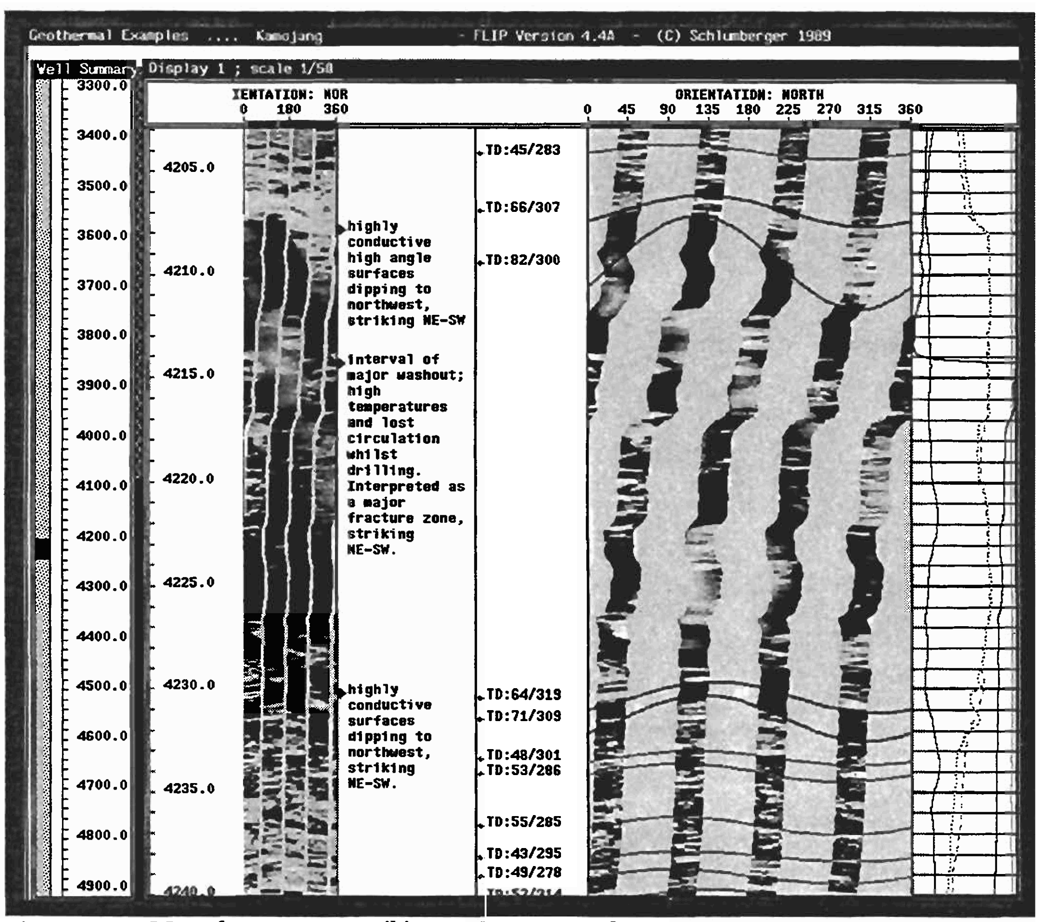

Figure 7. Mega fracture zone striking northeast to southwest.

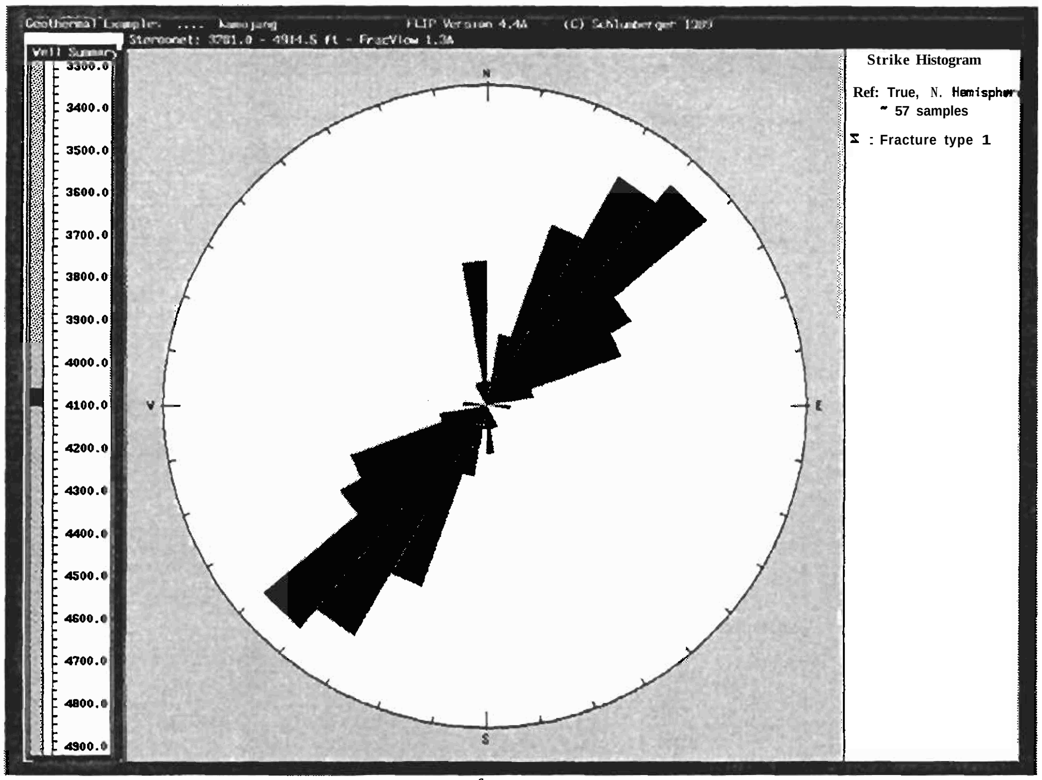

Figure 8. Strike histogram showing open fracture trends.

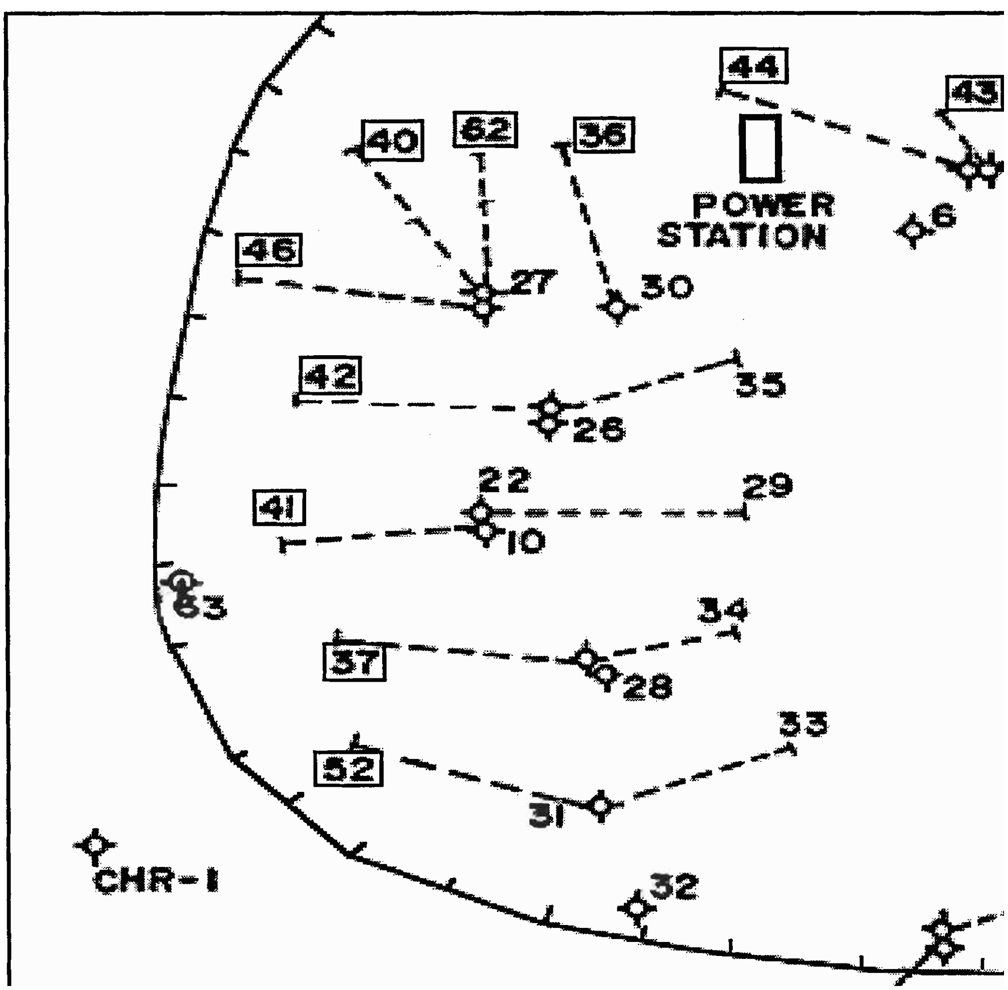

Figure 9. Successful wells in the western area of **Kamojang** field are highlighted in the boxes.