GEOTHERMAL PLUMBING SYSTEM OF PUHAGAN, SOUTHERN NEGROS GEOTHERMAL FIELD, PHILIPPINES

Arturo P. Alcaraz

PNOC Energy Development Corporation
Fort Bonifacio, Metro Manila, Philippines

ABSTRACT

Productivity in the Puhagan area of the southern Negros geothermal field comes from four sources: (a) intraformational permeability in the Southern Negros Formation consisting of volcanics and volcaniclastics, and in the Okoy Sedimentary Formation; (b) lithological contact between the two formations; (c) fracture permeability induced by intrusive bodies; and (d) faults. This productivity now supports the steam requirements of a 3 x 37.5 MWe power plant designated Palinpinon I.

Faults that transect Puhagan are believed to be the major contributors to its production capability because they serve as the main trucklines of a geothermal plumbing system that conveys the hot fluids to the other sources of productivity that act as distributaries.

The fault system was worked out by determining the attitude of individual faults from well intersections, using graphical solutions. Eleven faults constitute the system —four of these are major faults, and the remaining seven are splays of three of the majors. The majors are compressional while the splays are tensional in character. This model will be useful in interpreting the results of tracer and interference tests, and the siting of later replacement wells.

INTRODUCTION

The southern Negros geothermal field of the Philippines (Figure 1) was developed by the Energy Development Corporation, a subsidiary of the Philippine National Oil Company. Steam produced from the area runs a 112.5 (3 x 37.5) MW generating plant put up by the National Power Corporation to supply the electrical needs of Negros Island.

The production and reinjection wells were drilled in the Puhagan sector of the field where productivity is believed to come from (a) intraformational permeability, (b) formational contacts, (c) fractures induced by intrusive bodies, and (d) faults.

Faults that transect Puhagan are believed to be the major contributors to its production capability as they serve as channelways for the hot fluids to ascend from the geothermal reservoir. They may be regarded as the main trunklines of a geothermal plumbing system, with the other sources of productivity serving only as distributaries. For this reason, a clear picture of the fault network is necessary for a better understanding of productivity in Puhagan. Application of certain principles of structural geology can help attain this objective.

APPROACH

Geologic information on any one area is built up by extensive field mapping, which includes among others areal distribution of various lithologic units and their stratigraphic relationships, and identification of structures inherent to their formation or induced on them subsequently by stress. Rock fracturing resulting in the generation of faults is of the latter category. Pornuevo and Obusan (1983) drew a structure map of the southern Negros geothermal field by collating data from field surveys, aerial photos and drilling operations. This map was used as a base map to (a) review the individual faults and, on a reassessment of surface and drilling date, come up with refinements of their location and attitude; and (b) find a plausible stress field to explain how the faults collectively may have been formed.

METHODOLOGY

The tracks of four vertical and 26 directional wells drilled in Puhagan were considered, together with their drilling histories, geology and completion tests, to provide the information necessary to arrive at a more definitive graphical solution of the faults they intersected. Three cases were considered:

Case I: Where sufficient clear intersections were identifiable, three of these were used to solve for the fault attitude as a three-point problem;

Case II: If only two good intersections were on hand, the third point necessary for a three-point-problem solution was provided by a point on the mapped surface trace of the fault; and

Case III: Where only one clear intersection was available, a point on the known surface trace of the fault was considered and the strike of the fault as mapped through this point was assumed correct. Thus, in this case, only the dip of the fault was solved for.

As a check, the intersection of other wells was plotted against the calculated strike and dip of the fault. Good results were invariably obtained to thus give confidence in the calculated values.

THE ODLUMON FAULT

Case I was used to determine the attitude of the Odlumon fault. A scrutiny of productive zones of Puhagan wells drilled to the southeast of the power plant showed that not all these zones could be accounted for by just the faults earlier drawn in the area and lithological permeabilities. The possibility of another fault was, therefore, considered. Accordingly, a northeasterly fault was postulated to exist southeast of the recognized Ticala fault. The postulated fault was named the Odlumon fault.

The points at which blind drilling (no drilling fluid returns) commenced in PN-20D, PN-13D and OK-10D were assumed to be points of intersection by the wells with the postulated fault. These points were plotted by their azimuths, throws and vertical depths. The three points, since they were considered as points on the fault plane, were then used to graphically solve for the strike and dip of the fault. A strike of N.44° E. with a dip of 79 degrees to the NW was obtained. Projection to the surface of the calculated fault attitude showed that its surface trace coincided with a lineation detected from aerial photos by earlier workers, thus indicating that the Odlumon is not a blind fault.

To verify the existence of the Odlumon fault, the points where blind drilling occurred at other wells (PN-22D, PN-21D, and OK-9D) were plotted. The points fell squarely on the Odlumon fault plane as previously determined, thus providing confirmatory evidence of its existence.

Angle of Intersection and Bit Walk

Besides solving for the intersection of a well with the postulated fault, its angle of intersection was also calculated by descriptive geometry. The angle of intersection of eight

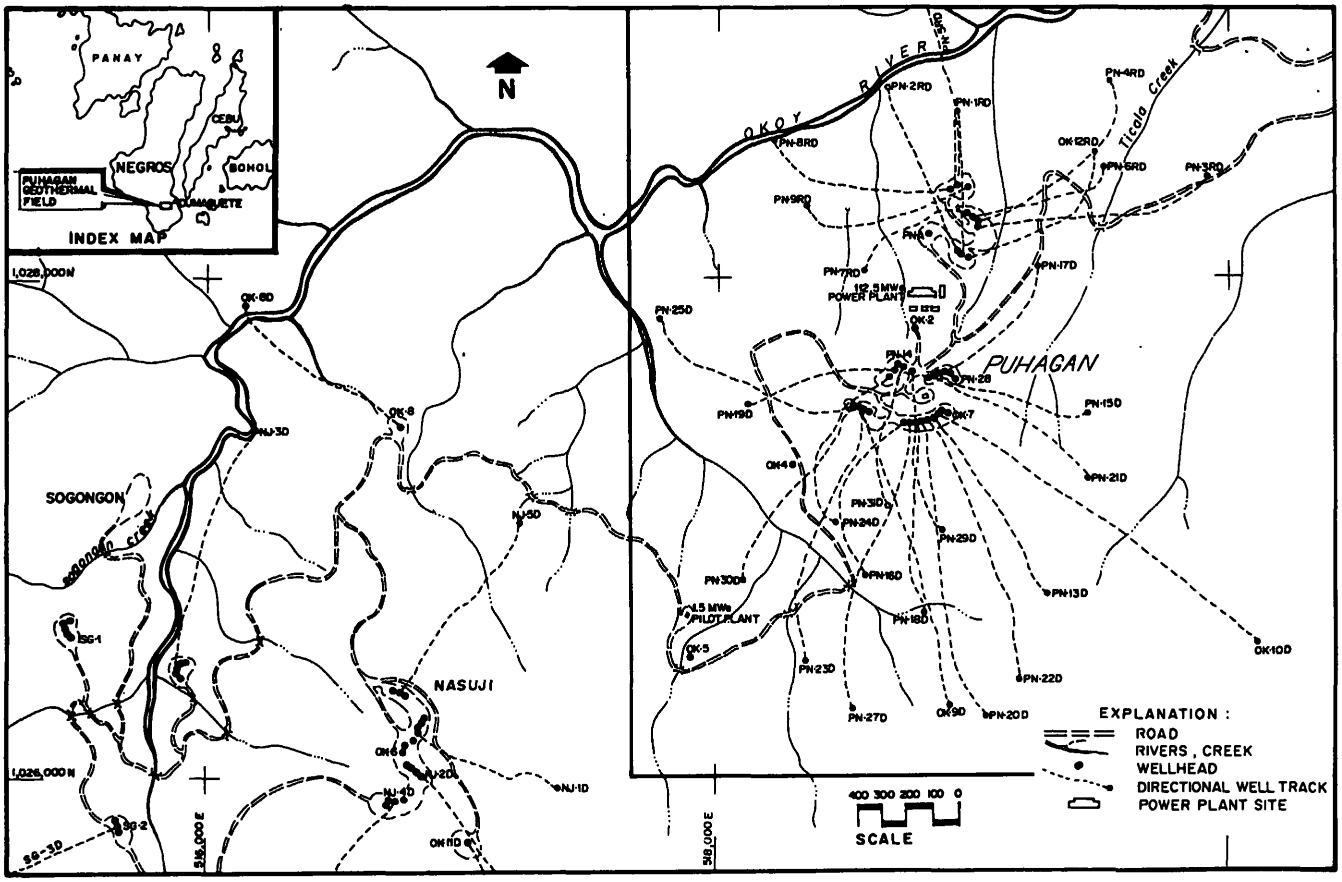

Figure 1. Puhagan location map, southern Negros geothermal project

wells that intersected the Odlumon fault ranged from a high 50 to a low 22 degrees. Of interest is the finding that the seven wells with intersection angles greater than 22 degrees did not walk (a condition where the well track progressively deviates from a straight-forward direction), while PN-15D with a 22 degree angle did walk. The conclusion was drawn, therefore, that if a well intersects a fault or a strong structure at an angle less than 25 degrees, it will have a tendency to walk. This was proven to be the case by other wells that mainfested the same drilling effect.

Odlumon Fault Splays "A" and "B"

The Odlumon fault apparently has two splays. However, for lack of confirmatory drilling data, the trend of these splays as mapped on the surface was assumed essentially correct.

The north northeast-south southwest splay "A" has likely an 85 degree west-northwesterly dip, and could account for the production zone encountered by PN-22D at 2620 m VD. The east splay, or splay "B," with an almost north-south trend also has a westerly dip of about 86 degrees, and may have been intersected by OK-10D at a depth of 1920 m VD.

THE TICALA FAULT

The Ticala fault is one of the earliest northeast-southwest faults recognized in Puhagan by field mapping. It is a long and strong structure. However, because of its proximity to the only adequate power plant site in Puhagan, coupled with the need imposed by severe terrain conditions to drill directional wells from multi-well pads located nearby so as to shorten the steam gathering and effluent disposal systems, the productive potential of the fault was not fully explored.

Case III was used to solve for the attitude of this fault due to a paucity of clear uncased well intersections. The major loss zone encountered by PN-IRD at 1460 m VD together with a point of elevation 700 m AMSL on the surface trace of the fault were utilized. The fault strike of N.40° E. through this surface point was assumed essentially correct. A dip of 77 degrees to the N.50° W. was obtained.

Ticala Fault Splays "A" and "B"

Like the Odlumon fault, the Ticala fault also has two splays. Splay "A" was intersected by several wells directionally drilled to the southeast. However, because of an adopted policy not to produce from shallow depths to minimize drawdown and in-flow of colder fluids into the reservoir, most of these holes were cased below their intersection with the fault. Again using Case III, the two points selected were the intersection of PN-29D at a depth of 1501 m VD with the fault, and a point (elevation 850 m AMSL) on the recognizable surface fault trace with a strike of N.22° E. A dip of 85 degrees to the N.68° W. was measured. Drilling data from OK-7, PN-28, and PN-21D were used to check the calculated dip of the fault splay. Plot

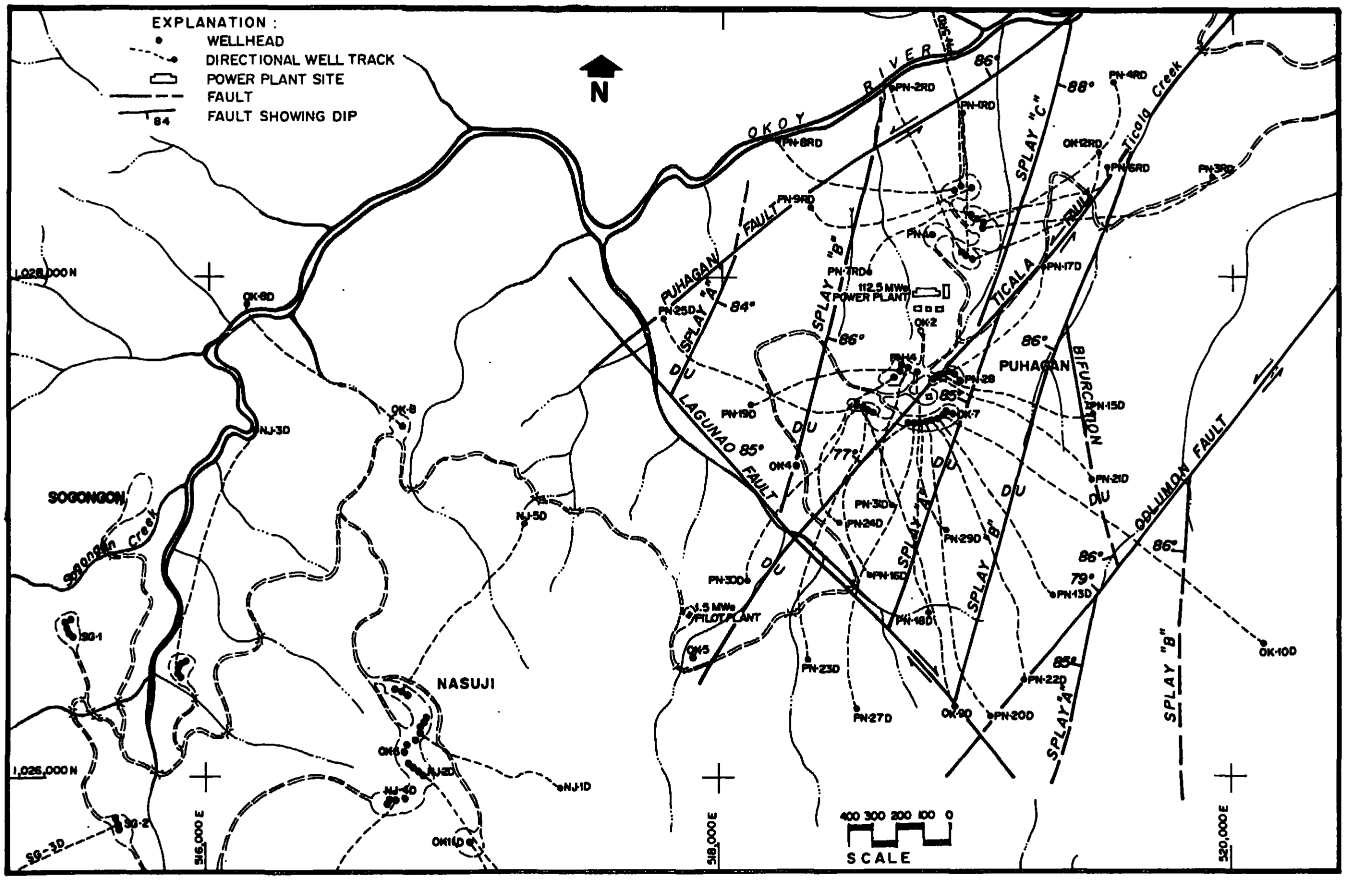

Figure 2. Fault system of the Puhagan area, southern Negros geothermal project

of the tracks of these wells indicated that they did intersect the splay at points marked by circulation losses.

The attitude of Ticala fault splay "B" was determined graphically under Case II by using drillhole data from OK-12, PN-17D and a point on the surface trace of the splay with an elevation of 675 m AMSL. A strike of N.20° E. and a dip of 85° NW were calculated. From the tracks of OK-12D, PN-17D, PN-4RD and PN-6RD, it was apparent that their intersections with this fault splay at angles less than the critical 25 degree angle earlier established could have been the cause of the bit walk experienced in these wells.

The Ticala spray "B" fault has a *bifurcation* that was intersected by PN-15D at 1850 m VD, and PN-21D at 1755 m VD. Its calculated attitude is a strike of N.6° W. and a dip of 86 degrees to the S.84° W.

THE PUHAGAN FAULT

The northeast-southwest fault northwest of the power plant is one of three major faults of similar trend (the other two being the Odlumon and Ticala faults) that traverses the Puhagan area. It was the target of reinjection wells drilled to the northwest of the power plant. By means of the graphical methods earlier employed for the other faults, the attitudes of the Puhagan fault and its splays were determined. The Puhagan fault was found to have a strike of N.66° E. and a southwesterly dip of 86 degrees.

Puhagan Fault Splays "A," "B," and "C"

Three splays of the Puhagan fault were identified in the field. From possible well intersections, graphical solutions gave the following attitudes: splay "A" dips 84 degrees to the S.70° E.; splay "B" dips 86 degrees to the S.73° E; and splay "C" dips 88 degrees to the S.72° E.

THE LAGUNAO FAULT

The Lagunao fault is the only northwest-southeast trending major fault in Puhagan. It is located about 1 km southwest of the power plant, and more or less serves as a structural boundary that separates Puhagan from the Nasuji and Sogongon sectors of the southern Negros geothermal resource area. Its calculated attitude indicated a strike of N.45° W. and a northeasterly dip of 85 degrees. It has no identified splay.

THE PUHAGAN FAULT SYSTEM

After the attitude and orientation of the various significant faults in Puhagan were determined as accurately as possible by graphical methods, the information was plotted to obtain their spatial relationship with one another. The result, shown in Figure 2, is the Puhagan fault system.

In the area of information, the system is characterized by three distinctive components: (1) a northwest-southeast trending fault with a northeasterly dip (Lagunao fault); (2) three northeast-northwest faults with northwesterly dips (Odlumon, Ticala and Puhagan faults); and (3) north northeast-south southeast trending splays of the northeast-southwest faults.

It may be opined that the pattern of the system can be the result of a couple acting in northwesterly and southeasterly directions, as deduced from experimental data on the relation of ruptures due to a couple (Billings, 1974). In this analysis, northwest-southeast and northeast-southwest components of the Puhagan fault system would be compressional, while its north northeast-south southwest component (represented by the splays) would be tensional in character. Productivity-wise, the tensional fractures will likely be better producers geothermally than the compressional ones because they are more open than the latter. The upward flow of geothermal fluids through the Puhagan fault system is visualized schematically in Figure 3.

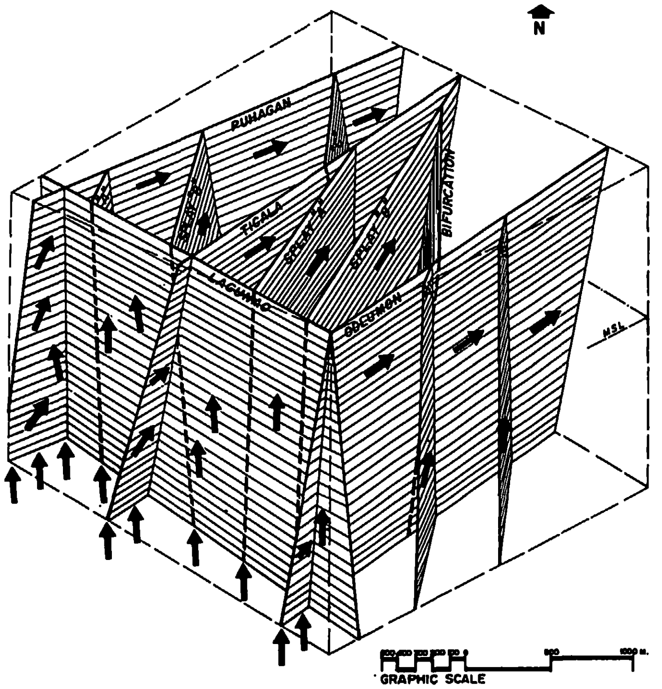

Figure 3. Puhagan fault plumbing-system diagram, southern Negros geothermal project

Rotational Movement of Ticala Fault

An interesting deduction of rotational movement of the Ticala fault was made after the attitude of the fault splays was worked out. The Ticala fault splays dip to the northwest, while those of the Puhagan fault dip to the southeast. They should all dip northwesterly by the above analysis.

The dip reversal can easily be explained if a rotational movement is ascribed for the Ticala fault (Figure 4). A graphical solution for the amount of rotation involved shows that a 15 degree counter-clockwise rotation of the Puhagan block relative to the Ticala block is sufficient to account for the dip reversal as the splays have close to 90 degree dips.

Two other observations lend support to the analyzed rotational movement: (1) 3-degree counter-clockwise shift in average strike of the Puhagan fault splays vis-a-vis that of the Ticala fault splays, and (2) an approximately 200-m vertical separation of the Okoy Formation as seen in the Puhagan block relative to its position in the northern end of the Ticala block (Seastres, 1983).

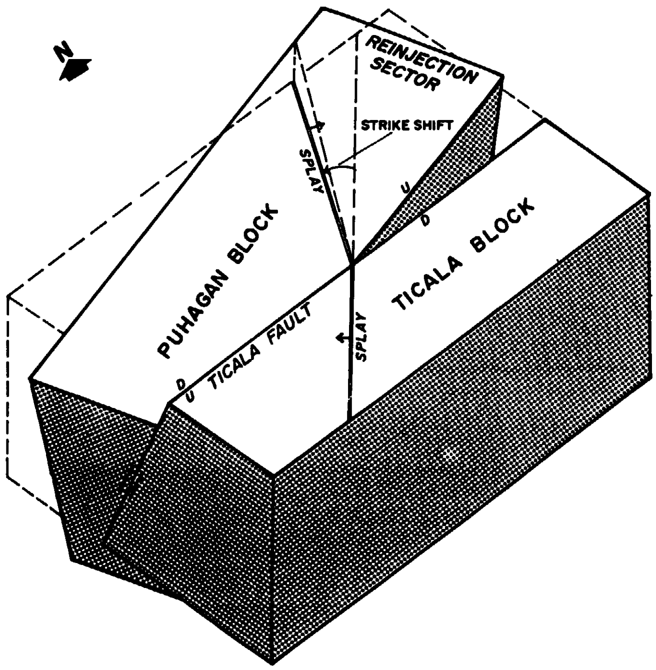

Figure 4. Diagram illustrating counter-clockwise rotation of Ticala fault. Amount of rotation is about 15 degrees counter-clockwise measured on the Ticala fault plane. Evidence of rotation: (1) reversal of dip of Ticala fault splays (85° NW average) vis-a-vis that of Puhagan (86° SE average); (2) strike shift of 3° (average) counter-clockwise of Puhagan splays vis-a-vis that of Ticala splays; and (3) Okoy Formation vertically displaced about 200 m in Puhagan reinjection sector (Seastres, 1983).

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