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DEFORMATION IN THE LEYTE GEOTHERMAL PRODUCTION FIELD, PHILIPPINES BETWEEN 1991 AND 1999

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ABSTRACT

Global Positioning System (GPS) observations in Central Leyte, eastern Philippines, from 1991 to 1999 indicate considerable deformation along a segment of the Philippine Fault that cuts through the Leyte geothermal production field. Displacements computed at 9 core stations within the field, from 1991 to 1994, depict a left-lateral slip rate of about 2.6 cm/yr. A GPS survey conducted in 1998 at 10 sites within the geothermal field reveals the occurrence of a lower slip rate of about 1.3 cm/yr between the intervals 1994-1999. Though this suggests that less deformation has occurred during the last 4 years, our current GPS observations probably underestimate the true deformation field within the area. There is a need to apply network adjustments and address the problem of measurement uncertainties to our GPS data. The most recent GPS campaign forms part of a multi-agency project between the Philippines and Japan and is intended to complement results derived from SAR interferometry in studying crustal deformation and geologic hazards in the island of Leyte.

1. INTRODUCTION

The island of Leyte belongs to the Visayan island group in central Philippines. PNOC-EDC has been exploring and developing geothermal resources in Leyte since 1976 and is currently operating 4 major geothermal projects in the island with a total installed capacity of about 650 MW. These projects draw geothermal energy from a large geothermal field located in central portion of the island, the Leyte geothermal production field, which is intended to supplement the power requirements of the neighboring islands of Cebu and southeastern Luzon through submarine interconnection grids.

The Leyte geothermal production field (Figure 1) is situated in a tectonically active region between two branches of the Philippine Fault that cuts across central Leyte. The Philippine Fault is generally considered to be the major seismic hazard in this region and the likely occurrence of a large magnitude earthquake poses a threat to lives and infrastructure located within the geothermal field. Measuring the deformation along this major structure using Global Positioning System (GPS) is the primary objective of continuing geodetic studies in central Leyte. It is through measured deformation that we may be able to detect anomalous strain build-up and evaluate the potential for a large earthquake in this area.

2. GPS OBSERVATION

The data presented here were obtained in a series of GPS field campaigns in 1998 and 1999 under a joint study between Japan and the Philippines, and are intended to complement results derived from SAR interferometry in studying crustal deformation and geologic hazards in the island of Leyte.

A total of 10 geodetic benchmarks were occupied at least twice each year, beginning July 1998. Trimble 4600LS single-frequency receivers were used for all data collection, operating in static mode. The GPS antenna was typically set on a tripod over the survey mark and its slant height measured from the center of the benchmark to a hook at the base of the antenna. Each single observing session consisted of at least 3 hours of tracking, with the carrier phase and C/A-code pseudorange for each frequency recorded every 30 seconds.

3. DATA PROCESSING AND ANALYSIS

Data from each survey campaign were processed with the GPSurvey software developed by Trimble. Coordinates of a base station located at the center of the GPS network (LEY-8) were fixed adopting the coordinates established from the 1991-1994 surveys (Duquesnoy, facsimile communication, 1997). We used only L1 phases, and only considered data obtained from an elevation angle (above the horizon) greater than 20º during the processing. Since all baseline lengths were less than 10 kms, we assumed the differential ionospheric delay was zero. The tropospheric delay was calculated from standard meteorological conditions, i.e. using the default parameters for temperature, humidity, and air pressure. Satellite ephemerides were taken from the broadcast orbits with no refinement attempted.

4. RESULTS

Seven of nine core stations previously established in 1991 were occupied during the 1998-1999 campaigns due to time and logistical constraints. Observations at 2 other GPS sites constructed after 1994 were carried out to augment the present network.

The series of estimates shown in Figures 2, 3 and 4 were obtained through a 1-day baseline pair solution of the July and November 1998 and July 1999 experiments. In general, the measurements reported here are not sufficiently redundant to develop reliable statistics. Furthermore, all statistics were calculated without applying any weights. Table 1 gives the results of our GPS data reduction, namely the components for each independent line relative to station Ley-8.

4.1 Station displacements (1991-1994)

GPS monitoring was first established in central Leyte in 1991. Its implementation was part of a cooperative research project between France and the Philippines through various government agencies that included the Mines and Geosciences Bureau (MGB), Philippine Institute of Volcanology and Seismology (PHIVOLCS), Institut de Physique du Globe de Paris (IPGP) et de Strasbourg (IPGS) and the Institut Geographique National.

Station movements between 1991 and 1994 are illustrated in Figure 5 (Duquesnoy, 1997). The analysis of vector displacements within a nine-station GPS network clearly demonstrates left-lateral strike-slip northwest trending motion across the Philippine Fault. Duquesnoy *et al*. (1994) attribute this motion to aseismic fault creep of approximately 2.6 cm/yr and have found this value to be in close agreement with rates established from geological estimates and regional kinematics solutions.

4.2 Station displacements (1994-1999)

GPS displacement vectors for the 1994-1999 interval (Fig. 6) show that although considerable deformation has taken place during the last 5 years, the orientations of the displacements do not appear to be consistent with the expected motion along the direction of the faults. Notable are the southwest-trending vectors (as opposed to southeast) for sites west of the Philippine Fault and northeast trending vectors (as opposed to northwest) for stations located on the eastern block. This creates an appearance that the entire network has undergone a systematic counter-clockwise rotation. Although these unusual movements cannot be attributed to a simple coordinate rotation, this observation is probably an inherent feature when all measurements are made internal to the network. Without an external frame of reference, all observations will likely produce an ambiguous displacement field (Prescott, 1981). There is a need to further adjust the data by adopting a method of an outer coordinate solution (Prescott, 1981) to minimize the components of displacement normal to the fault. This adjustment was successfully applied to the 1991-1994 data (Duquesnoy *et al.*, 1994) and produced an apparent deformation parallel to the fault.

Moreover, there is a possibility that systematic errors may have corrupted our present data. This is evident if we plot the horizontal vector components in a coordinate system parallel (N40ºW) to the Philippine Fault as a function of the distance normal (N50ºE) to the fault (Figure 7). Since all plots are relative to LEY-8, left-lateral strike slip motion is indicated by positive trends for the y component. Motion perpendicular to the Philippine Fault should theoretically be indicated by non zero trends for the x component. As Figure 7 illustrates, north-trending displacements resolve into left-lateral strike-slip motion. As for the east-trending displacements, we attribute the significant scatter about the zero line as partly due to measurement errors. The nature or source of these measurement errors cannot be ascertained at present, but we suspect that imperfect adjustments in the instrument may have made a significant contribution to our errors.

5.0 DISCUSSION

We determined a linear least squares fit through all of the displacement vectors to obtain the average rate of change during the 1994-1999 interval. The overall displacement across the network is inferred to be about 1.3 cm/yr. While this indicates that less deformation has taken place across the central Leyte, our observations are influenced by significant measurement uncertainties and probably underestimate the true displacement field. Certainly, GPS data from the 1991-1994 experiments are more reliable than our most recent campaigns. We attribute this to differences in observing strategy: the 1991-1994 campaigns tracked satellites 6 hours per session for 2 days for each baseline, whereas the 1998-1999 campaigns consisted of 3 hours of tracking on a single day. Kinematic models by Barrier *et al*. (1991) predict velocities between 1.9 to 2.5 cm/yr along the Philippine Fault in this region but still cannot account for our lower slip rates. We speculate, however, that if the scatter in the east-trending components is resolved, possibly by applying network adjustments, our rate should not be significantly different from the 2.6 cm/yr rate obtained from prior GPS experiments.

Our near-field geodetic studies find their relevance in field infrastructure planning and development activities. Secular movement established by recent GPS surveys has an impact on critical facilities, particularly on the fluid collection and disposal system (FCDS) pipelines that cut across portions of the Philippine Fault. Further detailed monitoring coupled with observations from other geodetic methods such as EDM and precise leveling can be anticipated in the future. By acquiring a long record of frequent measurements, the patterns and rates of deformation can be more confidently outlined in detail.

6.0 CONCLUSION

GPS measurements from central Leyte indicate 2.6 cm/yr and 1.3 cm/yr displacements across the Leyte geothermal production field for the intervals 1991-1994 and 1994-1999, respectively. The latter rates may contain significant measurement uncertainties and probably underestimate the true deformation across the field. Regardless, secular deformation is clearly observed for both intervals.

ACKNOWLEDGEMENTS

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REFERENCES

Barrier, E., Huchon, P., Aurelio, M. (1991). Philippine Fault: A key for Philippine kinematics. *Geology*, 19, pp. 32-35.

Duquesnoy, Th. (1997). *Contribution de la geodesie a l'etude de grands decrochements actifs associes a des zones de subduction a convergence oblique: exemples de la grande faille de Sumatra et de la faille Philippine*. Doctoral dissertation, Universite de Paris-SUD, 210pp.

Duquesnoy, Th., Barrier, E., Kasser, M., Aurelio, M., Gaulon, R., Punongbayan, R.S., Rangin, C., and the French-Philippine Cooperation Team. (1994). Detection of creep along the Philippine Fault: first results of geodetic measurements on Leyte island, central Philippines. *Geophys. Res. Lett.*, Vol. 21 (11), pp. 975-978.

Prescott, W.H. (1981). The determination of displacement fields from geodetic data along strike-slip faults. *J. Geophys. Res.*, 81, pp. 3518-3524.

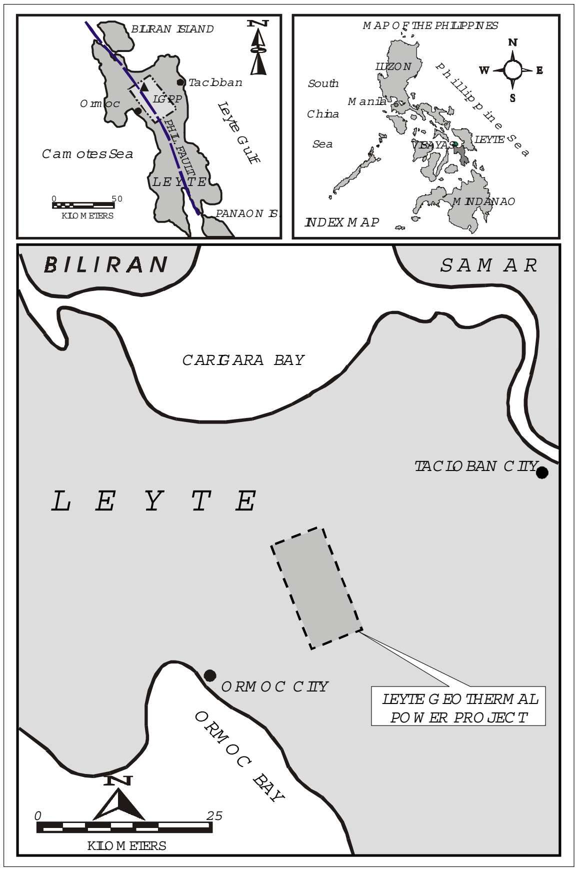

Figure 1. Location map of the Leyte Geothermal Field.

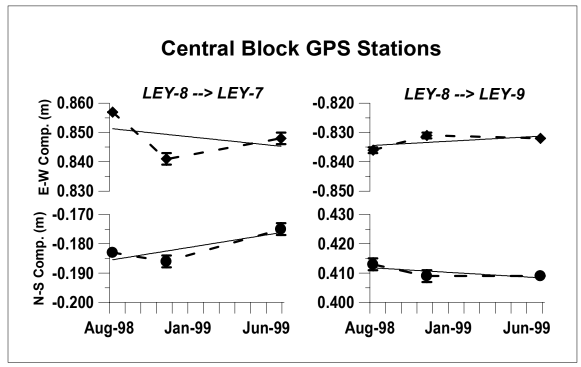

Figure 2. Plots of East and North components of the central block GPS stations as a function of time. Error bars come from standard deviations to a linear trend.

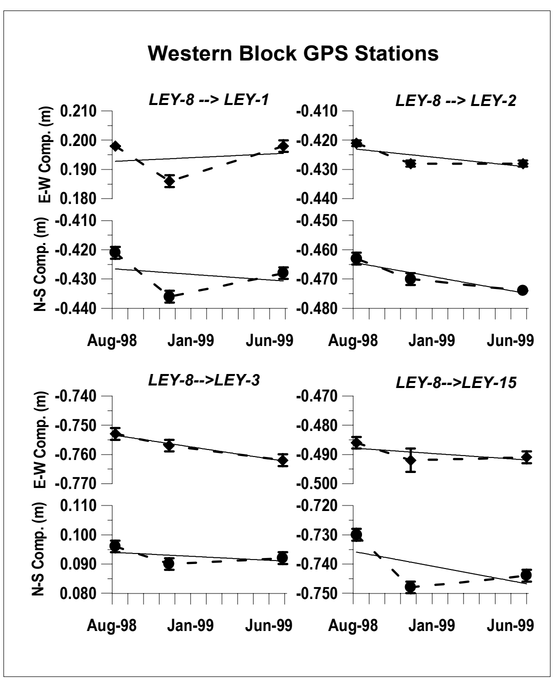

Figure 3. Plots of East and North components of the GPS stations west of the Philippine fault within the Leyte Geothermal Field as a function of time. Error bars come from standard deviations to a linear trend.

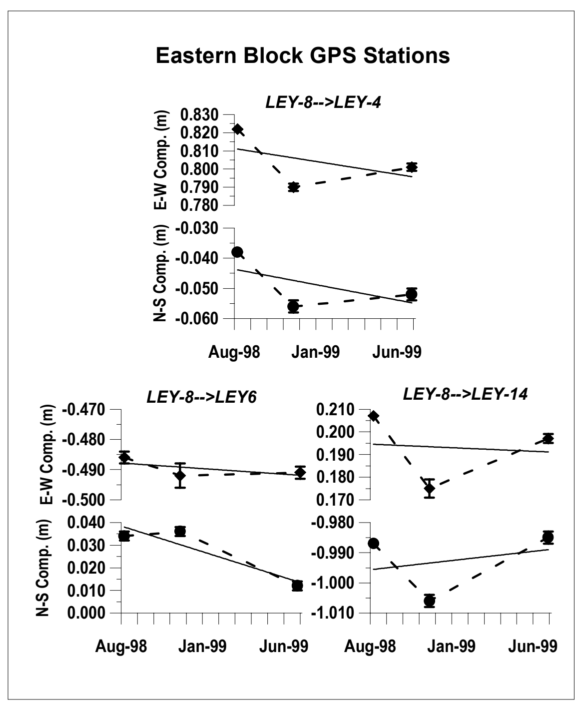

Figure 4. Plots of East and North components of the GPS stations east of the Philippine fault within the Leyte Geothermal Field as a function of time. Error bars come from standard deviations to a linear trend.

Table 1. Summary of estimates of baseline components for all GPS stations relative to LEY-8.

To STN	North (m)	S.D. (mm)	East (m)	S.D. (mm)	Vertical (m)	S.D. (mm)	Baseline (m)	S.D. (mm)
LEY-1	-3604.428	8	1348.194	7	162.120	19	3851.729	5
LEY-2	-355.452	29	-1519.426	4	59.482	23	1561.586	5
LEY-3	1234.093	3	-2266.757	5	118.435	12	2583.641	3
LEY-4	-1162.049	9	3148.804	16	396.676	38	3379.745	8
LEY-6	4712.027	13	-1817.178	10	188.879	4	5053.812	13
LEY-7	-2076.181	6	1658.849	8	37.140	37	2657.760	7
LEY-9	1988.410	2	-1722.833	3	58.737	17	2631.611	3
LEY-14	-2620.993	12	3729.193	16	310.095	71	4568.659	6
LEY-15	-2410.741	9	-980.490	3	-37.536	19	2602.776	10

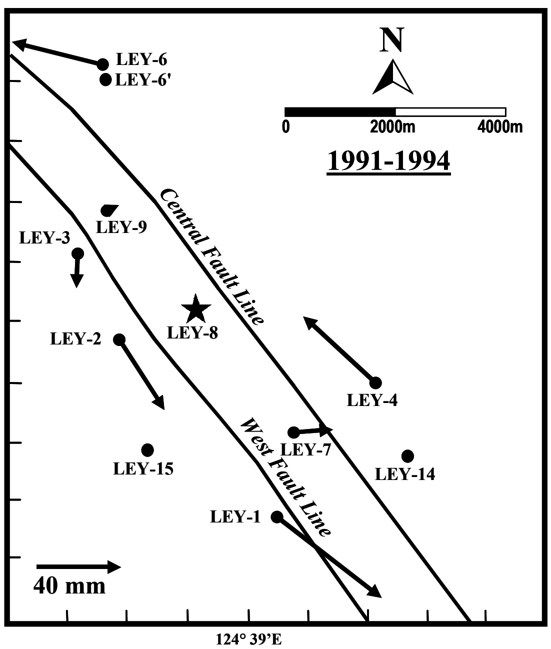

Figure 5. GPS station displacements for the interval 1991-1994 (after Duequesnoy, 1997). All measurements are made relative to LEY-8 (represented by star symbol).

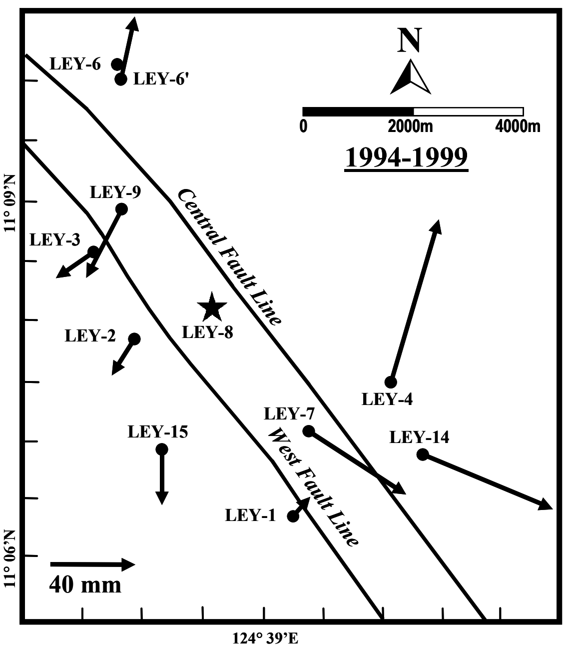

Figure 6. GPS station displacements for the interval 1994-1999. All measurements are made relative to LEY-8 (represented by star symbol).

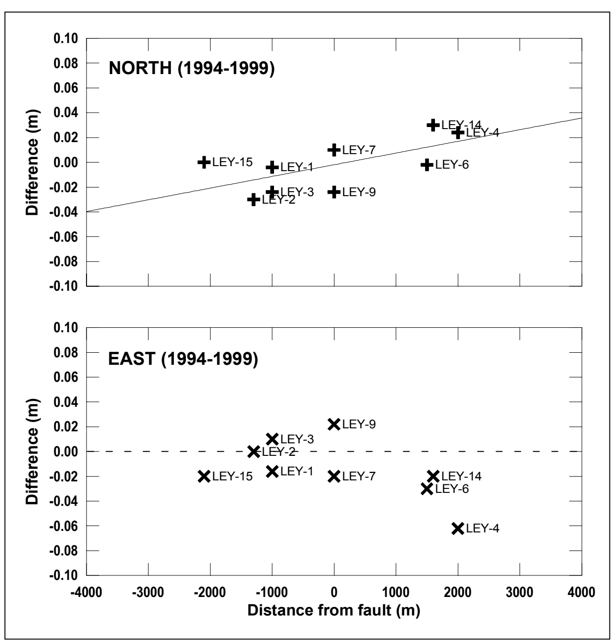

Figure 7. Plots of the north- and east-trending displacement components for the 1998-1999 interval. All distances are made relative to LEY-8 on a cross-section trending N50ºE, perpendicular to the Philippine Fault.