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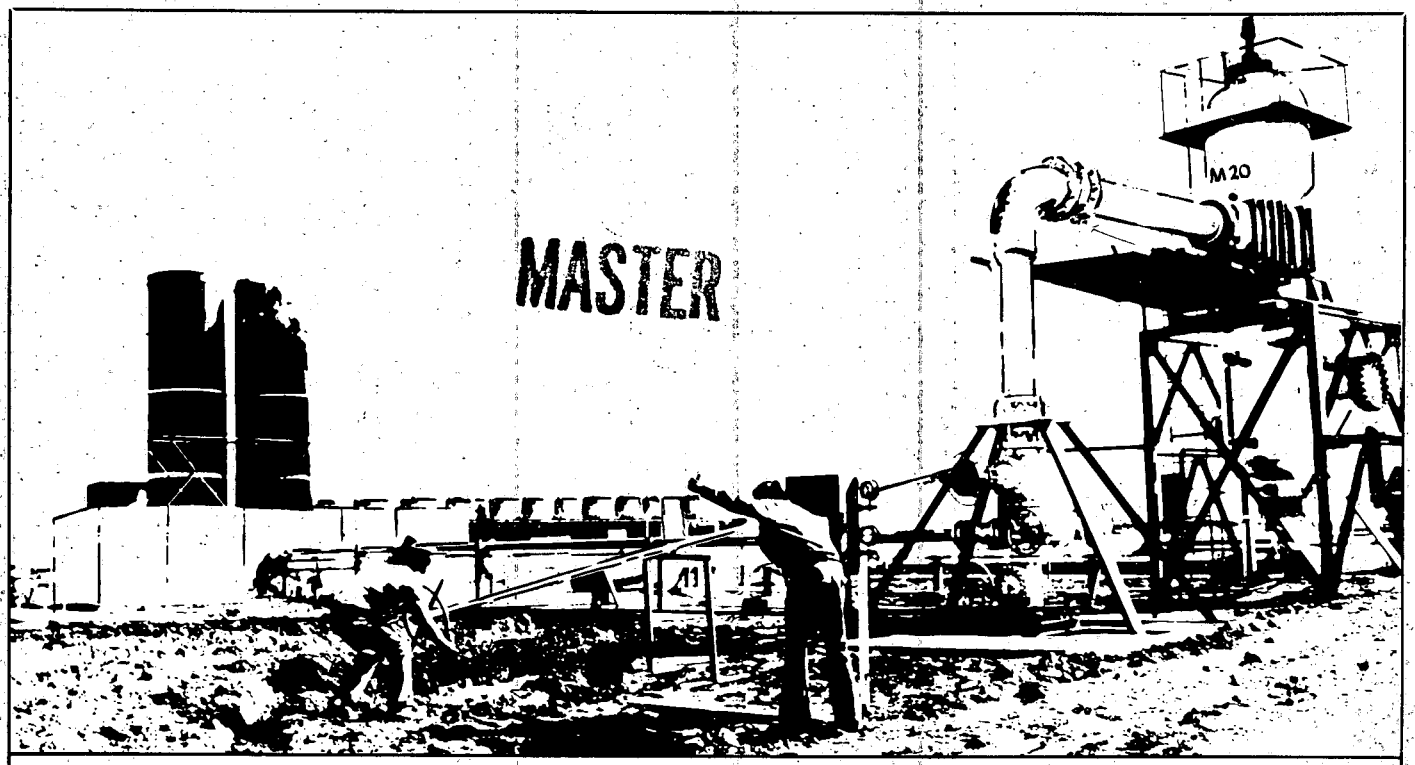
CONF-7910166--5

# MEXICAN-AMERICAN COOPERATIVE PROGRAM AT THE CERRO PRIETO GEOTHERMAL FIELD




MASTER

## PRECISION GRAVITY STUDIES AT CERRO PRIETO — THE SECOND YEAR

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FEBRUARY 1980

A Joint Project of

COMISION FEDERAL DE ELECTRICIDAD
Mexico

DEPARTMENT OF ENERGY
Division of Geothermal Energy
United States of America

Coordinated by

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Operating for the U.S. Department of Energy under Contract W-7405-ENG-48

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Submitted to the Proceedings of the Second
Symposium on the Cerro Prieto Geothermal Field,
Baja California, Mexico, October 17-19, 1979

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## INTRODUCTION

Precision gravity measurements (accompanied by first- and second-order leveling) were initiated at Cerro Prieto in 1978. At that time, 60 permanent stations were established on concrete pads within a 500-km$^2$ area centered in the geothermal field.

The primary purpose of the study is to detect gravity changes that might be manifestations of changing reservoir conditions--notably, net mass depletion, compaction and subsidence, densification by secondary mineral precipitates, and formation of a steam cap because of reduced reservoir pressures. The time scale of these changes would depend on the rate of fluid production, and resulting reservoir dynamics, and chemical kinetics. The measure of gravity used to detect these temporal changes is the so-called observed gravity value.

A secondary purpose for the precision gravity survey was to prepare a Bouguer anomaly map from the appropriate reduction of the data. Bouguer anomaly values are the measure of spatial variations in the gravity field, and can be interpreted in terms of subsurface lateral density variations.

This paper will concentrate on the first purpose of the work, as outlined above, and in particular on interpreting the first annual repetition of the measurements during January through March 1979. A presentation of Bouguer anomaly values and a qualitative interpretation of these values (the second purpose outlined above) was presented in the Proceedings of the First Symposium on the Cerro Prieto Geothermal Field, Baja California (Chase et al., 1979); nothing new will be added here to that initial work.

The repetitive gravity observations are being accompanied by second-order leveling conducted by the Comisión Federal de Electricidad. This precise leveling, when repeated, allows us to separate gravity changes due to mass effects from those which may be due to elevation changes; i.e. local subsidence due to compaction and regional tectonics. Indeed, for precise results, leveling and gravimetry must proceed together, since the proper interpretation of observed elevation changes depends on the magnitude and nature of any simultaneous gravity change (Whitcomb, 1976).

## FIELD PROCEDURES

During the first repetition of gravity measurements in early 1979, we followed essentially the same field procedures as in the initial occupations. A detailed description of those procedures has been published (Chase et al., 1979), and a summary is provided here.

The gravity network consists of 60 stations, 4 located on bedrock (2 in the Sierra Cucapa west of the field, 2 on Cerro Prieto volcano at the northwest corner of the field), and the remainder on valley fill sediments. The bedrock stations are presumed to be stable and unchanging, at least over time intervals of a few years.

Each station was occupied an average of four times, twice each with two La Coste and Romberg G model gravity meters, and each occupation consisted of a minimum of four readings taken by two persons. Possible leveling and orientation errors were distributed by picking up, rotating, and releveling the meters between readings, and the occupations were distributed in time to minimize the effects of instrumental drift, wind and external temperature shifts, and small tares due to transportation over rough roads. We used the looping technique, in which an internal base was occupied, located near the main road to the geothermal field, at the beginning and end of each loop (spanning five hours at most). No station was occupied more than once within an individual loop.

Nearly all of the original 60 stations were reoccupied. Those not occupied had been lost to road construction in the intervening year, and had not yet been replaced in time for the reoccupation effort.

In addition to the station reoccupations, three days were devoted to continuous tidal monitoring at a sheltered location on the side of Cerro Prieto volcano. The output from one of the two gravity meters used in the 1979 effort (G 300) was continuously recorded during that time interval using a strip chart recorder. The second meter (G 423) was operated at night, readings taken manually every 15 minutes. These data were needed to establish values of the tidal constants for later data reduction.

## DATA REDUCTION

A tidal analysis was required before we could reduce the data. The tidal data were converted to gravity values using the meter calibration constant for the appropriate gravity interval. These raw gravity values were then plotted and compared with tidal constants calculated for the same time interval (Longman, 1959). Comparison of the calculated versus observed gravity curves confirmed that the use of two tidal constants--a value of 1.16 for the conformance factor, and an assumption of zero phase lag--is appropriate for the Cerro Prieto area and causes maximum errors of only 1 or 2 μgals.

The station gravity data were reduced to observed gravity values by the following set of steps:

1. The raw meter readings were multiplied by the appropriate calibration factors, converting the readings into mgals and parts of mgals (the values were obtained to thousandths of mgals, i.e. μgals).

2. Tidal drift was removed from the calibrated values by using Longman's (1959) algorithms and the tidal constants of 1.16 and 0 respectively.

3. The portion of the drift remaining after tidal corrections were performed was presumed to be linear and was distributed linearly to all stations in a loop between base station occupations. Although the drift is probably composed of tares of varying amounts, and in reality is at least partially nonlinear, the application of this dedrifting procedure greatly improved the precision of measurement when statistics were performed.

4. Means were obtained for the four values available for each occupation. The station means were then subtracted from the base mean for each loop, producing gravity differences between the base and individual stations. Since four occupations were performed at each station, producing four gravity differences, these four differences were then averaged, producing a mean gravity difference value. These means were referenced to the base in the Sierra Cucapa.

The mean value for each station calculated by the above procedure should remain constant from year to year if no geothermal, tectonic, or culturally induced changes occur beneath or adjacent to that station. Alternately, if changes due to either mass or elevation effects occur, the gravity differences calculated in this fashion should change in magnitude with time.

An additional step was taken with the gravity differences calculated above, in that standard deviations were obtained for the four difference values associated with each station. Comparison of the precision from year to year for individual stations allows some determination as to whether or not changes in magnitude of the gravity value are significant.

## DATA INTERPRETATION

Although small gravity changes of up to tens of μgals were seen at a few stations, these changes can be explained by lack of accuracy in those data sets. Accuracy in the measurements did improve during the second year. During 1978 half the stations were characterized by standard deviations of 15 μgals or less, whereas in the 1979 data set, this figure was reduced to 10 μgals. In general, then, changes in the gravity differences would have to exceed approximately 20 μgals to be considered significant (more in specific instances) and such changes were not seen. We therefore conclude that no significant changes in gravity occurred during the interval. Leveling values conducted by CFE confirm this result; no significant elevation changes in the second order level lines occurred during this time interval either.

The question arises as to why no changes were detected in spite of our ability to detect changes of 0.02 to 0.03 mgals and changes larger than this have been observed in other producing geothermal fields; e.g., the 0.12 mgal maximum change reported by Isherwood (1977) at The Geysers. Several possibilities can be advanced to explain their absence:

1. Insufficient time may have elapsed to detect a gravity change. Until recently, The Geysers produced approximately eight times the amount of electricity as Cerro Prieto. Even now, electrical output at The Geysers plants is four times greater. Thus the total mass removal at Cerro Prieto may need to be increased (with time) to produce detectable results.

2. Unlike The Geysers, there is adequate recharge to the reservoir, albeit this may be temporary. Truesdell et al. (this volume) report recharge from an overlying aquifer. Also, there is evidence of horizontal inflow of colder waters recharging the producing reservoir.

3. The gravity coverage at Cerro Prieto may not be adequately dense, particularly away from the production area. It may be that the area of aquifer depletion and compaction is or will occur first at depths of 2 to 3 km and well outside the geothermal field, as has been observed at Wairakei, New Zealand (Hatton, 1970).

## FURTHER PRECISION CONSIDERATIONS

The improvement in precision from 1978 to 1979 was made possible by (1) avoidance of high ambient temperatures and concentration of the survey into a shorter time interval in the cooler months of 1979; and (2) speedy data reduction by computer during the course of the gravity work so that stations characterized by lesser precision could be identified and reoccupied. Two problems still remain, however: (1) transporting gravity meters over rough roads accounts for tares, sometimes sizeable, which reduce accuracy because of their nonlinear

affect on the data; and (2) at some stations located close to producing wells, oscillations of up to 0.05 mgals occur. (A similar problem is encountered at stations on levees when heavy trucks pass by.) To solve the first problem, a spring mounted or air-compression transport box, which dampens out the vibrations in the frequencies generated by automobiles on rough roads, could be utilized. For the second, the only solution appears to be a larger number of repetitions restricted to shorter-time loops (perhaps loops containing only one "noisy" station). Both of these changes are expected to be implemented during the 1980 field season.

## ACKNOWLEDGMENTS

This work has been supported by the U. S. Department of Energy, Division of Geothermal Energy, under contract W-7405-ENG-48 to the Lawrence Berkeley Laboratory. Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U. S. Department of Energy to the exclusion of others that may be suitable.

We would like to acknowledge the assistance of Alfredo Mañon M., Armando de la Peña L., and Pafael Molinar of CFE for their help in establishing and maintaining the gravity monuments. We also acknowledge the support and encouragement of Norman Goldstein of LBL.

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This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

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