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DOE - CFE GEOTHERMAL AGREEMENT

PROCESSES IN CERRO PRIETO GEOTHERMAL RESERVOIRS

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Progress Report for 1994

The Cerro Prieto I power plant is producing 180 MWe from mainly the deeper beta reservoir. The alpha reservoir is largely abandoned but some wells are still flowing. A few alpha wells show little change in temperature or chloride (e.g., M-42), but almost all show entry of cooler waters, probably descending along the L fault as described in earlier papers. Typical cool water entry is shown by well M-35. Even wells previously noted for boiling show dilution (M21A, M-31). The beta reservoir wells also show cool water entry (E-4) because this reservoir is also connected to cooler waters along its W margin, close to the CP-I wells.

Results to Date

The Cerro Prieto II and III power plants are fed exclusively by steam from the beta reservoir. The most interesting maps of this reservoir show the influence of the H fault on the properties of the reservoir. Movement along the fault has elevated the NW upthrown block (containing the CP-III part of the beta reservoir) by about 700 meters relative to the SE downthrown block as indicated by the depth to the top of the reservoir (Figure 1). Most wells of CP-II are in the downthrown block but some are in the hanging wall of the fault or in the upthrown block. There is a radical difference in the behavior of the beta reservoir in the NW and SE blocks.

In 1991 wells just NW of the fault produced high-enthalpy fluids with from 0.4 to >0.9 inlet vapor fraction (IVF) while almost all fluids from wells SE of the fault had <0.1 IVF (Figure 2). Fluids from the fault itself had intermediate values. Other quantities also differ between the upper and lower parts of the reservoir. 1991 reservoir chloride concentrations in the downthrown block were uniformly high (10,000 to 12,000 mg/kg except for two wells) and reservoir temperatures ranged between 300 and 320°C (Figures 3 and 4). In the upthrown block both temperatures and chloride vary widely. The maximum values (14,000 mg/kg Cl and >310°C) are similar to or slightly above those in the SE block, but several parts have low chloride and temperature (to 6000 mg/kg Cl and 280°C). These lower values are aligned along the upper fault intersection (wells M-193 and E-22) or in the zone of highest IVF values (wells M-107, M-125 and M-102). Some of these wells have normal temperatures with very high enthalpy and very low chloride due to high-temperature adiabatic steam condensation. The total discharge $\delta^{18}O$ map (Figure 5) shows fairly uniform gradient from -10.5 in the SW to -7.5 in the NE except for an elongate zone of fluids depleted in O-18 ($\delta^{18}O$ as low as -10.5). The lowest $\delta^{18}O$ fluids are also low in chloride and temperature (wells M-193, E-25 and M-107), but not all low temperature, low Cl fluids are low in $\delta^{18}O$ (well M-102) and vice-versa (well E-41).

The changes observed in the 1991 maps have continued in 1993. The most interesting difference is the apparent entry of isotopically heavier waters at the intersection of the fault H with the downthrown block in the CP-II area centered on well E-39 and affecting wells E-18 and M-73 (Figure 6). There is no evidence of higher chloride or higher enthalpy in these wells suggesting that isotopes and chloride are decoupled (enthalpy is buffered by heat conduction with rock) or that there are errors in the isotope analyses. The final interpretation should be confirmed by repeat analyses which are planned. The decrease in chloride, $\delta^{18}O$ and enthalpy along fault H observed in 1991 intensified in 1993.

The interpretation of these 1991 and 1993 observations on the Cerro Prieto beta reservoir is quite straightforward. The 700 m difference in elevation between the blocks must result in lower pressure in the upper block than in the lower one. Before exploitation, the fluid in the shallower block was probably at the boiling point, and that in the deeper block, significantly below boiling. In addition the upper block probably has closed boundaries related to the displacement of the H fault preventing flow from the SE. The NE part of this block is also relatively distant from the W edge of the reservoir, where lower $\delta^{18}O$, temperature and chloride suggest a leaky boundary. The downthrown block may connect to cooler aquifers to the S as suggested by lower $\delta^{18}O$ and chloride, and more importantly is at greater depth and has higher pressures. These factors have combined to produce general boiling (not just near wells) in the upthrown, NW block (high IVF), and little boiling in the SE block (IVF near 0). The highest IVF values are near the fault intersection, with lower values to the W and N probably as a result of pressure support from entry of cooler fluids at the reservoir margin.

The localized occurrence of cooler, less-saline, isotopically-depleted waters at the NE end of the fault H intersection and in a parallel zone to the NW is most probably due to the entry down the fault of cooler waters from above the beta reservoir. This is similar to the observed entry of cooler waters down the L fault into the shallow alpha reservoir, which started soon after the start of production. The entry of this cooler water will ultimately cool the reservoir, but will also recharge fluids and decrease the amount of boiling. The increase in reservoir liquid will maintain pressures, decrease gas and prevent the production of corrosive HCl.

At Cerro Prieto, extensive drilling, wellhead measurements, and collection and analysis of chemical and isotopic samples have allowed a good understanding of both near-well and reservoir processes over its 20 year history. The response to pressure drawdown in the shallow alpha reservoir was principally entry of cooler water, with boiling limited to the vicinity of certain wells. In the deeper beta reservoir drawdown has caused mainly general boiling in the upthrown NW block as a result of its lower pressure and relative isolation. In the downthrown block and at the W margin of the upthrown block much less boiling is observed, probably because cooler waters are being drawn in at reservoir margins. The increasing entry of cooler water down fault H into the NE end of the upthrown block is causing reduced boiling and may locally reduce the need for injection to maintain reservoir pressures.

Plans for 1995 (subject to DOE funding)

New data will be incorporated in the study as it becomes available. A suite of samples will be analysed for noble gas isotopes by Mack Kennedy at LBL. These samples from the alpha and beta reservoirs will include normal reservoir waters, inflowing cooler waters, and possible upwelling deeper water A short report will be presented at the World Geothermal Congress and a comprehensive report including 1994 data will be published in a refereed journal.

Figure captions

Figure 1. The depth to the top of the Cerro Prieto beta reservoir based on drilling data from CFE (in meters) showing the location of the H-Fault at reservoir level (shaded).

Figure 2. Inlet vapor fraction (IVF) for 1991 Cerro Prieto production. IVF is a measure of excess enthalpy. See text for explanation.

Figure 3. Calculated 1991 chloride concentrations in the Cerro Prieto beta reservoir based on Na-K-Ca geothermometer temperatures (in mg/kg).

Figure 4. Calculated 1991 temperatures in the Cerro Prieto beta reservoir from the Na-K-Ca geothermometer (in degrees Celsius).

Figure 5. Calculated 1991 total discharge $\delta^{18}O$ values in permil SMOW for fluids from the Cerro Prieto beta reservoir.

Figure 6. Calculated 1993 total discharge $\delta^{18}O$ values in permil SMOW for fluids from the Cerro Prieto beta reservoir. The greater complexity compared to Figure 5 is due to substantially more data.

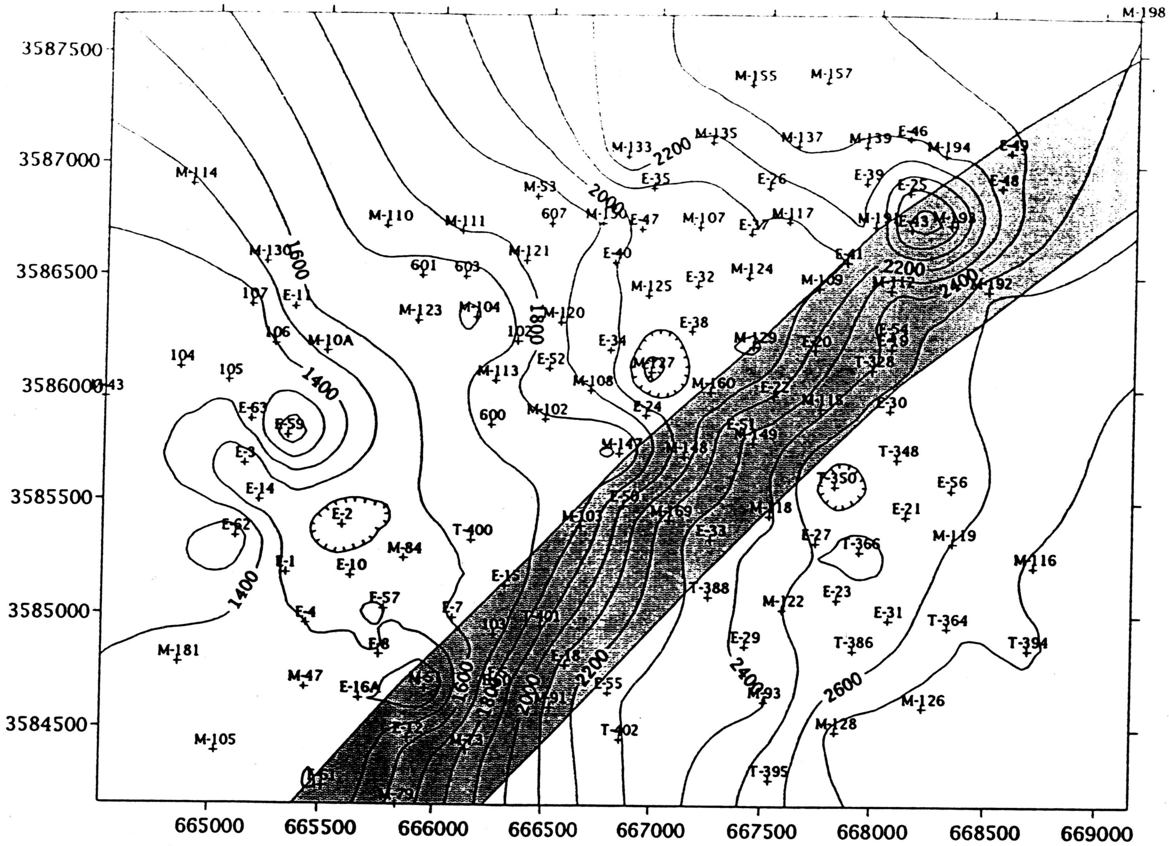

Figure 1.

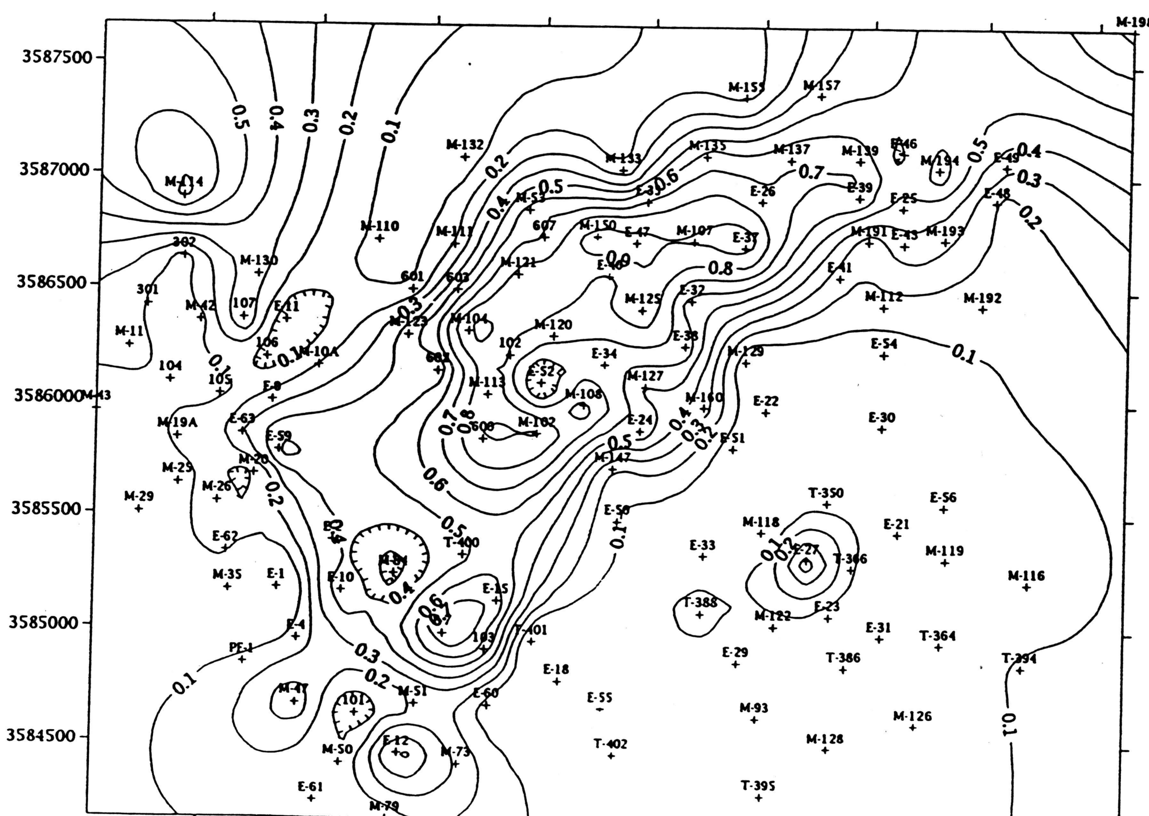

Figure 2.

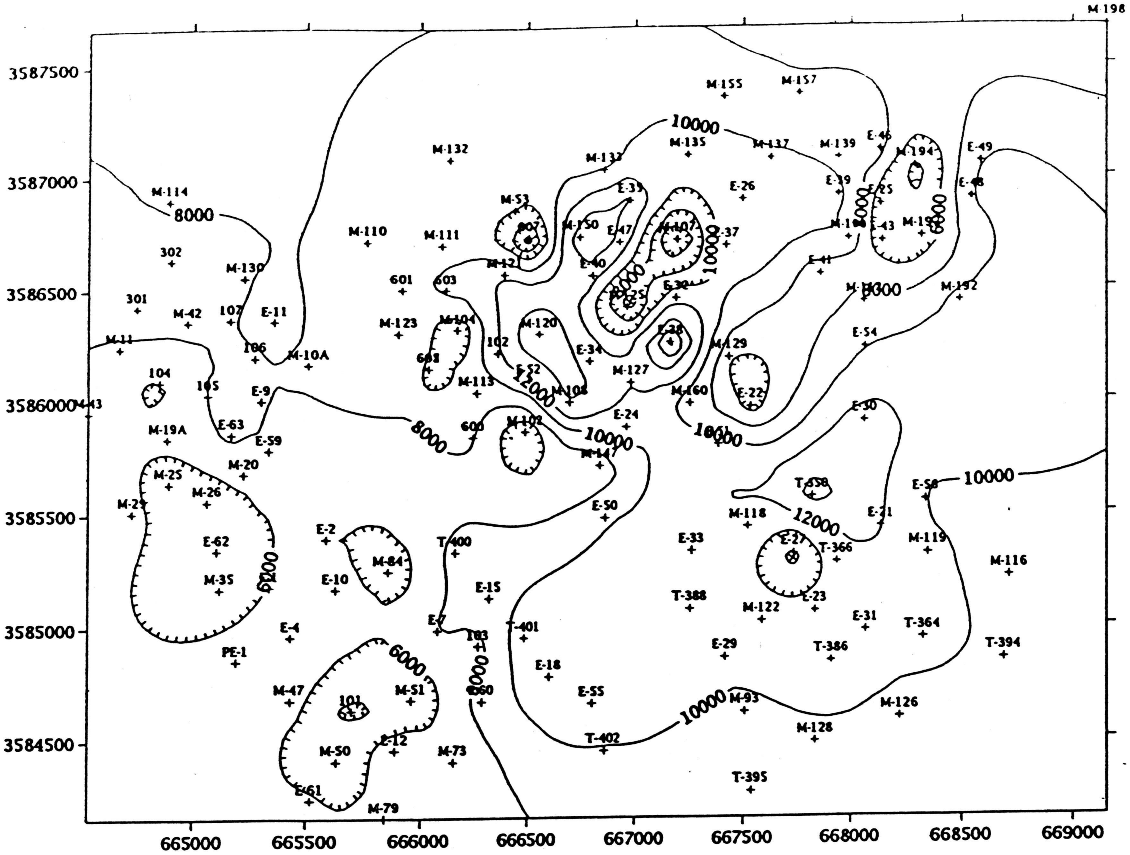

Figure 3.

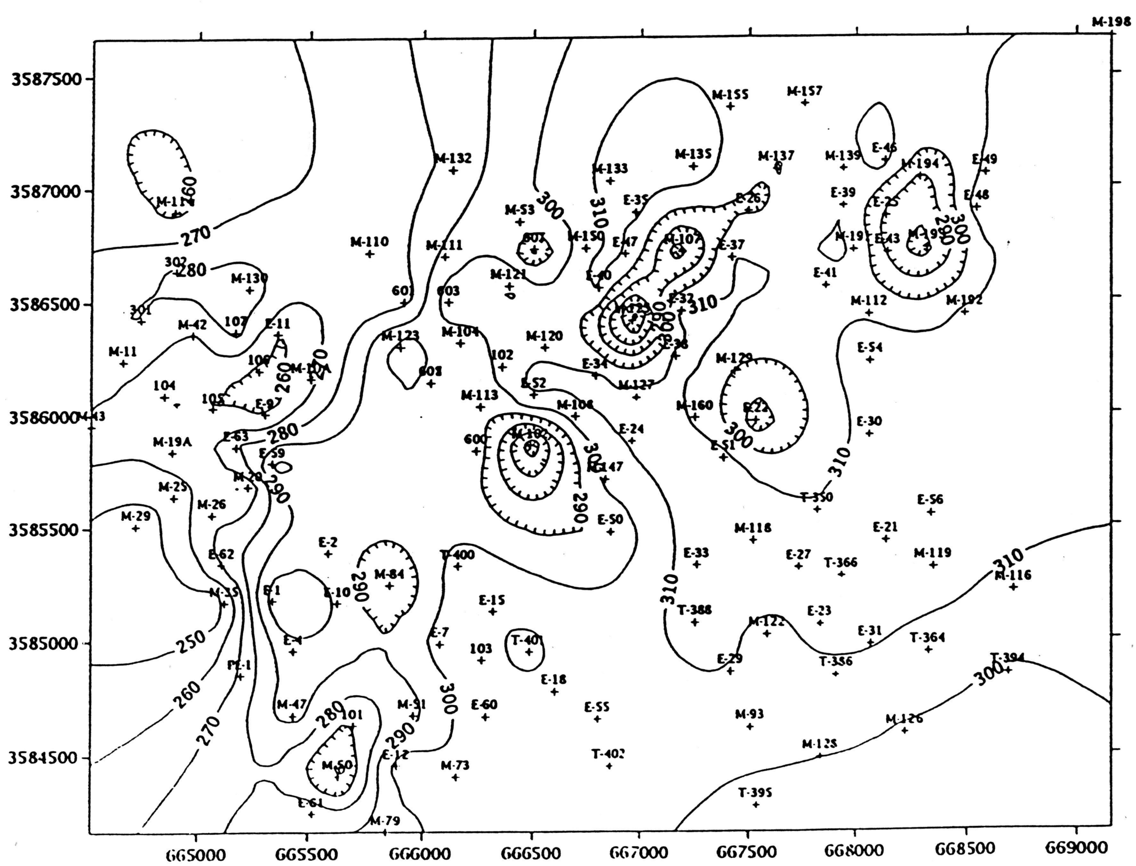

Figure 4.

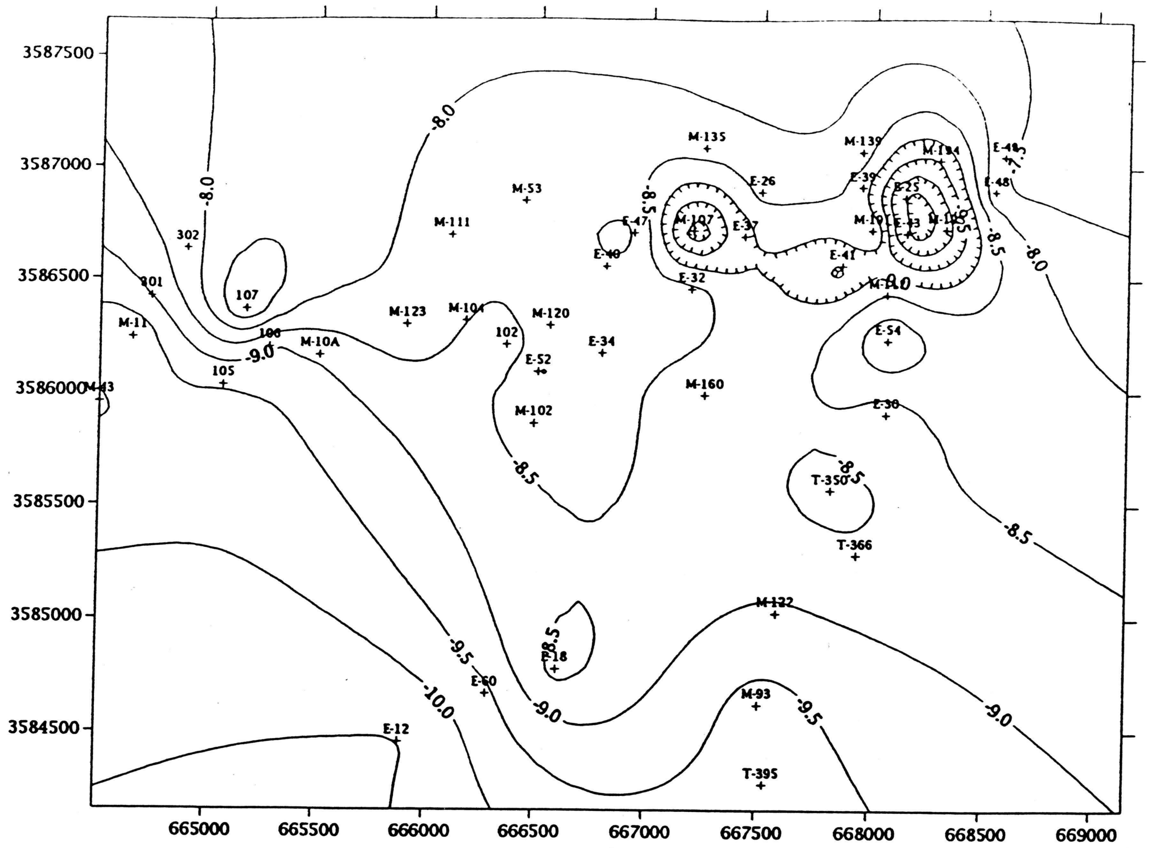

Figure 5.

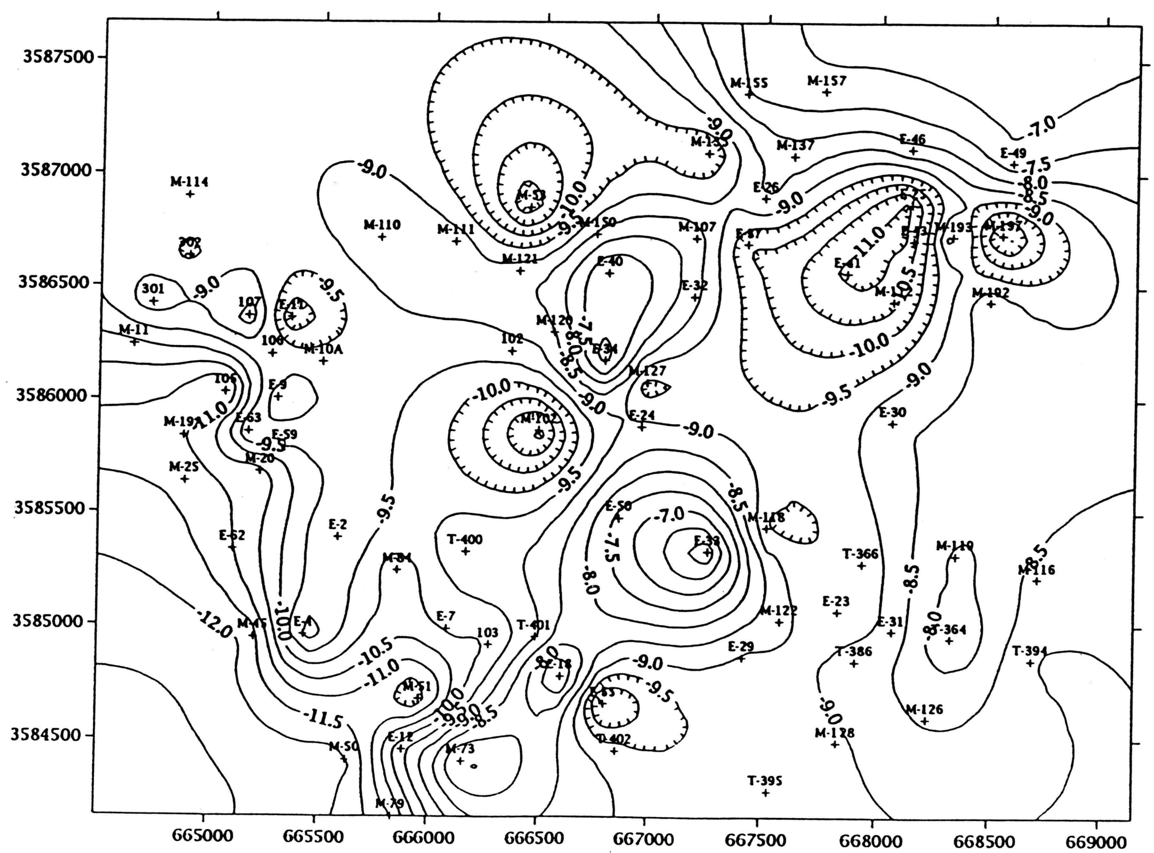

Figure 6.