Fracture Distribution and Permeability Around Ore Bodies in a Dolomite Aquifer

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ABSTRACT

Application of the results of an aquifer fracturation analysis to selection of pumping test holes and interpretation of pumping test results is described. The aquifer considered is a highly permeable dolomite aquifer in north-western Australia. The purpose of the investigation was to determine the magnitude of de-watering problems which would occur if ore bodies in the dolomite were exploited by open pit mining.

INTRODUCTION

Drilling to determine reserves in ore bodies usually results in large quantities of core which can be examined for fracture spacings and signs of water movement. Missing core and other evidence of difficulty in recovering core can indicate shear zones or regions of intense fracturing which may act as significant water carriers.

Although it is well recognised that not all fractures will carry significant quantities of groundwater to a de-watered mine, a useful correlation might still exist between fracture intensity and permeability. This would require some relation between the number of fractures per unit volume of rock and/or the number open to the passage of water. Detailed field evidence for such a relation is scarce since both pump testing of the aquifer with a relatively large number of observation holes and careful examination of a lot of core is necessary.

An investigation of potential inflow to open pit mines to extract lead/silver/zinc ore from a dolomite aquifer in north-western Australia included long term pumping from a decline driven to extract bulk ore samples, three long term borehole pumping tests and the examination of core from a large number of drill holes. The locations of the three pumped boreholes in separate ore bodies were selected after examination of the results of analysis of the core fracture data. The isopleths indicating fracture intensity and drawdown of the piezometric surface during pumping were subsequently compared to see if any useful correlation might exist.

Permeabilities and flow rates induced during testing of the aquifer around the ore bodies were sufficiently high to cause significant non-Darcy head losses to develop around the pumped test holes. Similarity of the distribution of fractures around the peripheries of the proposed open pit mines and around the test holes was taken as evidence that similar non-Darcy effects would occur during de-watering of the proposed open pits. These effects would restrict inflows to manageable quantities despite the high Darcy permeabilities. They would also cause relatively steep gradients in the vicinity of the pit walls and thus have a significant effect on slope stability.

THE AQUIFER

The aquifer under consideration is on the south-western fringe of the Bonaparte Gulf Basin which is in the north-western part of Australia. Figure 1 shows a diagrammatic cross-section from west to east. The weathered surface beneath the recent sediments is irregular and the upper part of the aquifer is somewhat karstic. At depth the aquifer is fractured to a variable degree. Lead/silver/zinc ore bodies are present in some of the well fractured zones. Water in the aquifer has a generally high electrical conductivity.

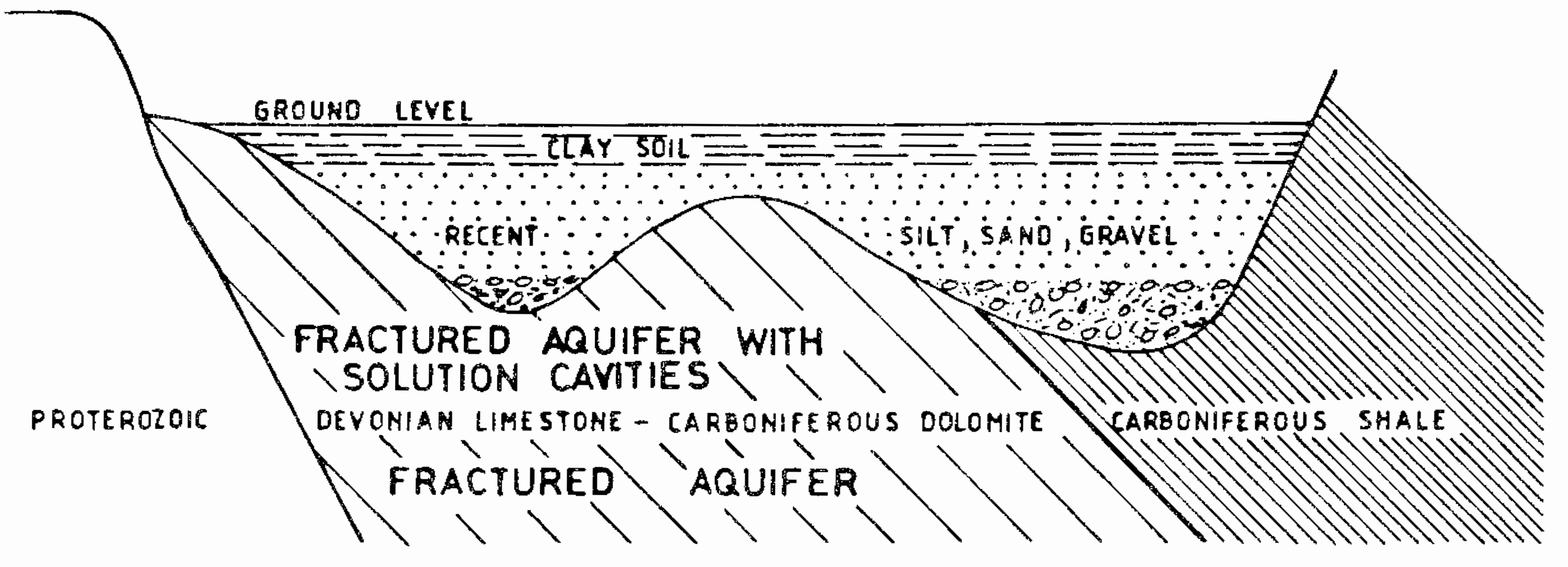

Figure 1. Diagrammatic cross-section through aquifer.

GROUNDWATER INVESTIGATION.

An attempt to obtain bulk ore samples from one of the ore bodies encountered problems in de-watering a decline driven from an open pit excavation. Analysis of the combination of steep drawdown cone and high inflow rate led to the conclusion that a non-linear relation between flow velocity and hydraulic gradient existed near the pumped hole.

Sites for boreholes to be used for further pumping tests were selected at three other proposed mine locations. The purpose of the tests was to determine not only regional aquifer characteristics (transmissivity T and storage coefficient S) but also local non-Darcy flow characteristics (Forchheimer coefficients a and b). The latter were considered important because of the potential for Non-Darcy flow near the pits to have a strongly limiting effect on water inflows.

FRACTURE INVESTIGATION.

A comprehensive examination of a large amount of diamond drill core was made for the exploration company (Aquitaine Australia Minerals Pty Ltd) by B. Le Theoff and P. Sehans. The results of fracture examination were expressed in terms of several indices. One of these provided a measure of the number of fractures per metre of core (total fracturation index) and another the ratio of open to closed fractures (effective opening fracturation index). A summary of the index classification system is given below.

Total Fracturation Index I_t

Index No	Fracture Frequency Criterion (per metre of core)
0	No fracture
1	one or two fractures
2	two to ten fractures
3	numerous fractures, some with small offsets
4	intense fracturation, with many fractures offset
5	tectonic breccia

Effective Opening Fracturation Index I_e

Index No.	Criterion
0,1,2,3,4,5	Index equals number of open fractures in five

Figures 2 to 5 are reproductions of parts of maps produced by Le Theoff and Sehans showing isopleths of mean values of the indices. The mean values for a given hole were calculated from data for the full length of core using the formulae:

$$\text{Mean total fracturation index } I_{tm} = \frac{(\Sigma\, l \times I_t)}{\Sigma\, l}$$

$$\text{Mean effective fracturation index } I_{em} = \frac{\Sigma \left[l \times \frac{I_t \times I_e}{5} \right]}{\Sigma\, l}$$

where l is the length of core to which a given index value I_t or I_e applies

PUMPING TESTS

The aim of using the fracturation data to select pumping hole locations was to achieve good hydraulic connection with the aquifer at about the centres of proposed open pit mines. Pumping rates were intended to be high enough to induce non-Darcy flow near the pumped holes while durations of pumping were intended to be long enough to extend the drawdown cones well beyond the proposed pit boundaries. A relatively large number of observation holes were drilled to allow the drawdown cone shapes to be determined with sufficient accuracy for areal and directional permeability trends to be assessed.

Figures 6 and 8 show piezometric surface contours at two of the sites before pumping. Figures 7 and 9 show the piezometric surface contours for maximum drawdown.

Less than satisfactory connection between the pumped hole and the most permeable part of the aquifer in the first case and mechanical and corrosion problems with the pump in the second case reduced the effectiveness of the pumping program. Such difficulties are not uncommon in this type of aquifer with saline water conditions.

DISCUSSION OF RESULTS

Results for only two of the areas tested are discussed because of space limitations in this paper.

Comparison of Figures 2 to 9 reveals some degree of correlation between intensity of fracturation and permeability as indicated by the shapes of the pre-pumping and drawn down piezometric surfaces. However, the correlation is not very distinct. Whether a larger number of piezometers and core samples examined for fractures would improve the correlation is a matter of conjecture. Since the extracts from the plots of fracturation and piezometric surface isopleths overlap it is difficult to determine the numbers of holes used to plot the data in each case. However for Area 1 the plots are based on approximately 20 cored holes and 20 piezometers. For Area 2 the numbers are approximately 30 and 25 respectively.

An additional complication is the fact that several formations were intersected in drilling. Because of the dip of the strata, different cored holes intersected different intervals of these formations. Separate fracturation plots were prepared by the Le Theoff and Sehans for different formations but these did not appear to afford much additional assistance in selecting pumping hole locations or interpreting pumping test results.

For Area 1, analysis of drawdown data from observation holes yielded consistent storage coefficient and transmissivity values (m^2/day), the ranges being $3x10^{-4}$to $5x10^{-3}$ and 2000 to 8000 respectively. For Area 2, values derived varied over wider ranges, $9x10^{-5}$ to $8x10^{-3}$and 2000 to 13000 respectively. The different levels of variability are reflected in the fracturation index and maximum drawdown plots.

In both cases, high non-Darcy energy losses were predicted for open pits de-watered by pumping from internal sumps. These losses restricted predicted inflows to manageable values, an order less than those predicted if non-Darcy flow were not taken into account. Forchheimer coefficients were estimated from the drawdown data from observation holes close to the pumped holes since non-Darcy flow is a local and not regional phenomenon.

Whether the cost of the fracture analysis referred to in this paper can be justified by benefits gained in locating pumping test holes and interpreting pumping test results is open to question. If it had been considered economically justifiable to pump more than one hole at each proposed open pit site it would have been possible to locate the holes to accord more closely with the fracture distribution data instead of selecting compromise locations. However, more closely spaced cored holes for fracture analysis would have been required to provide the necessary detail. The potential benefit to cost ratio would require careful consideration.

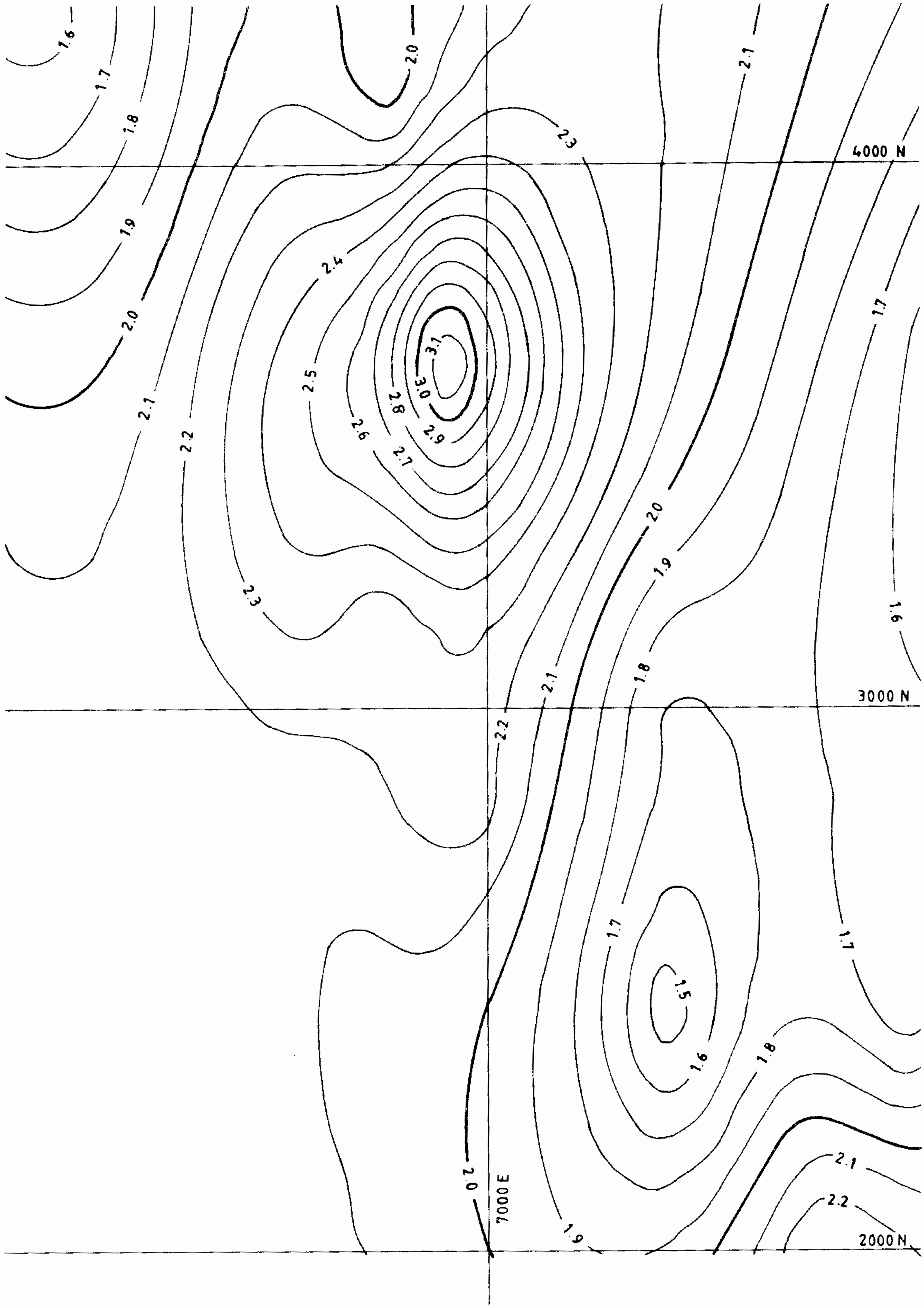

Figure 2. Total fracturation index for Area 1.

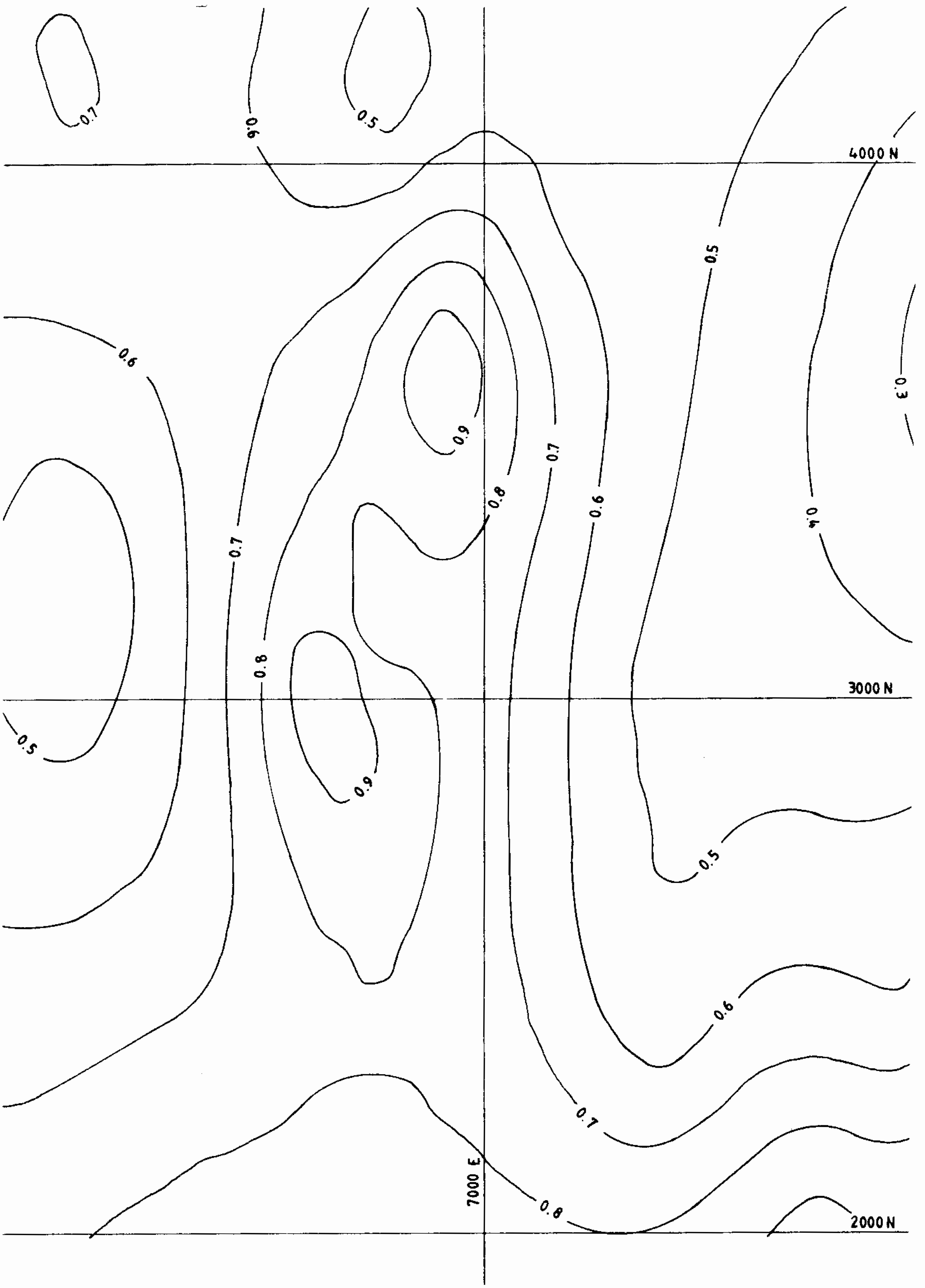

Figure 3. Effective opening fracturation index for Area 1.

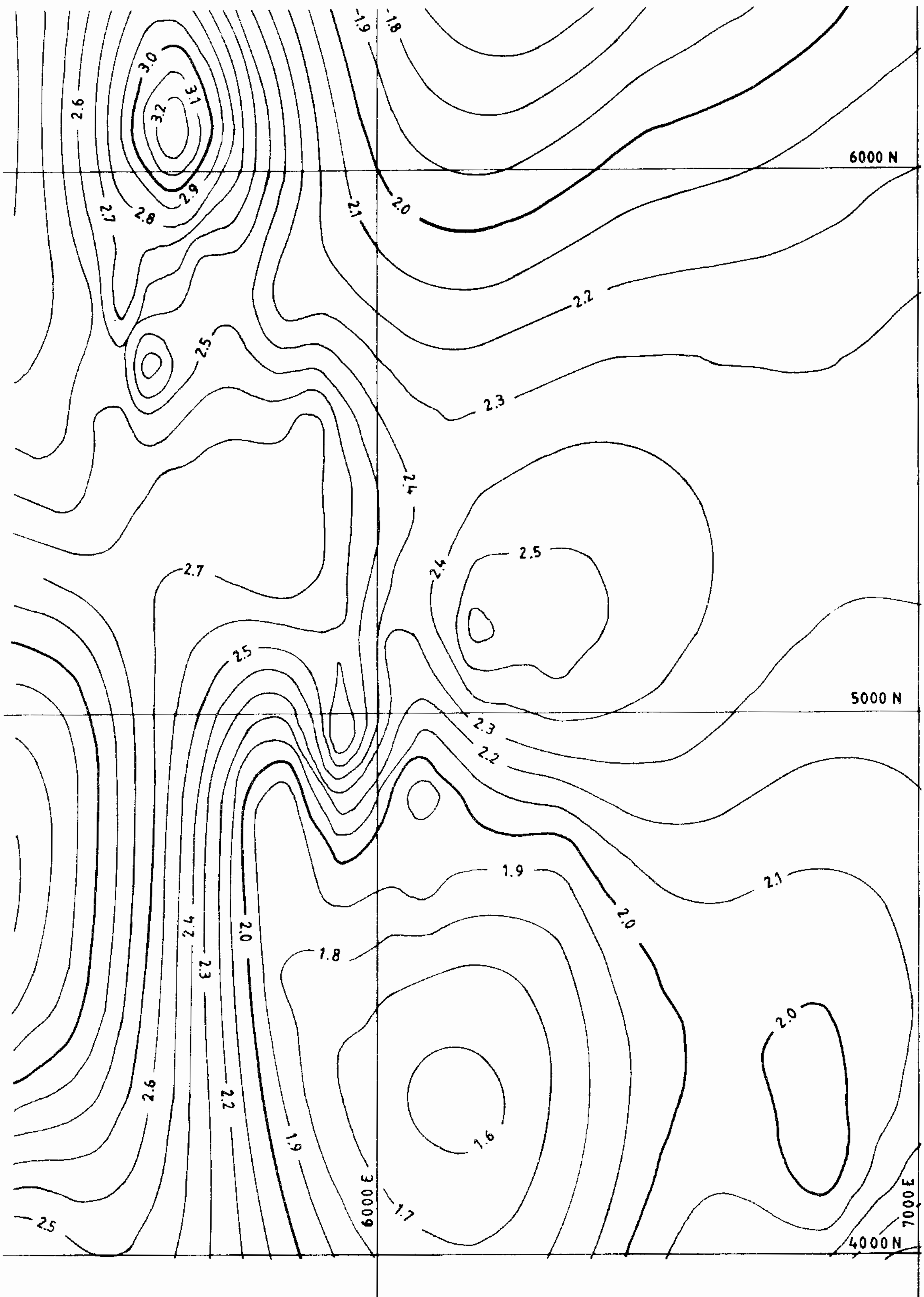

Figure 4. Total fracturation index for Area 2.

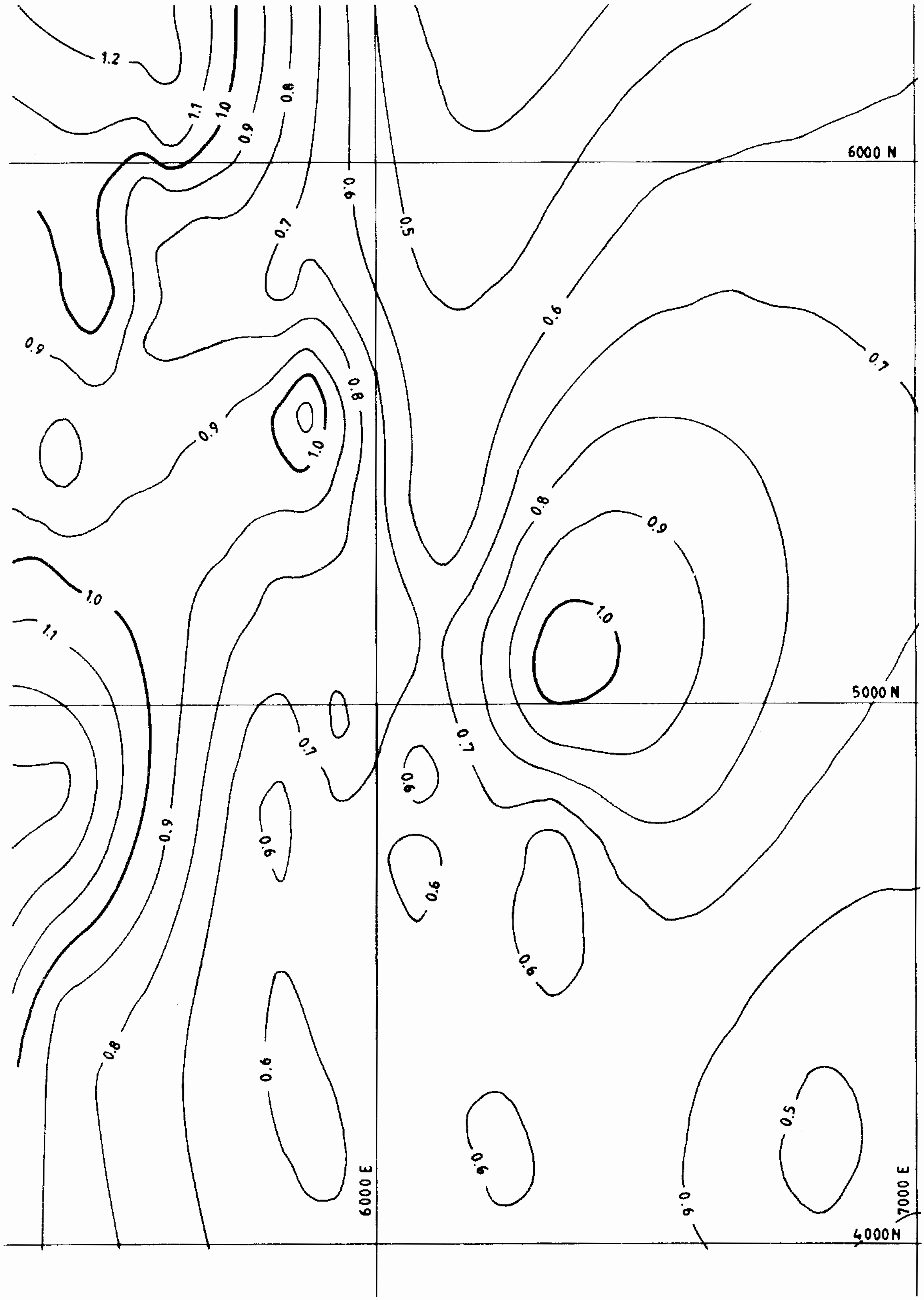

Figure 5. Effective opening fracturation index for Area 2.

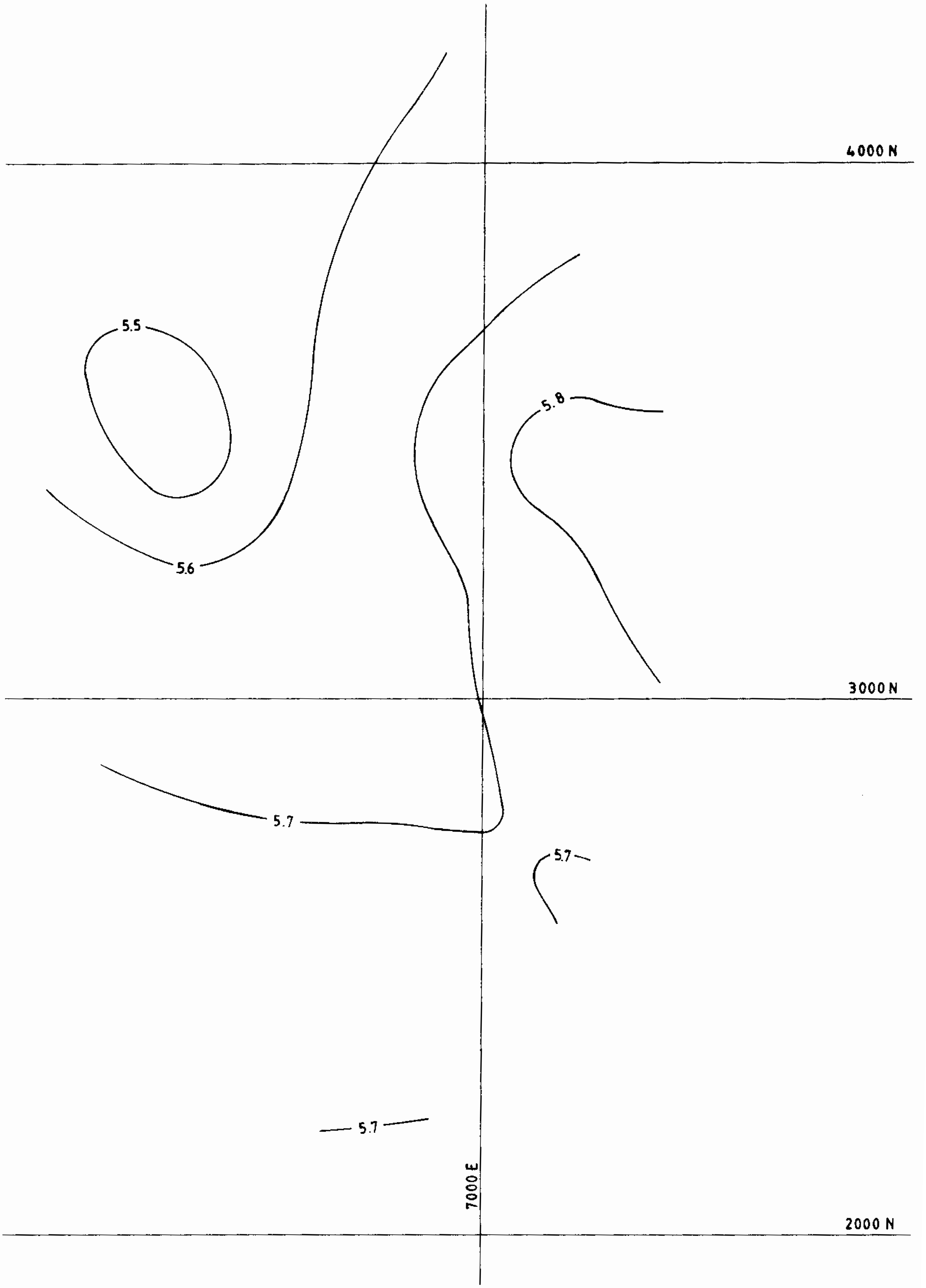

Figure 6. Pre-pumping piezometric surface for Area 1.

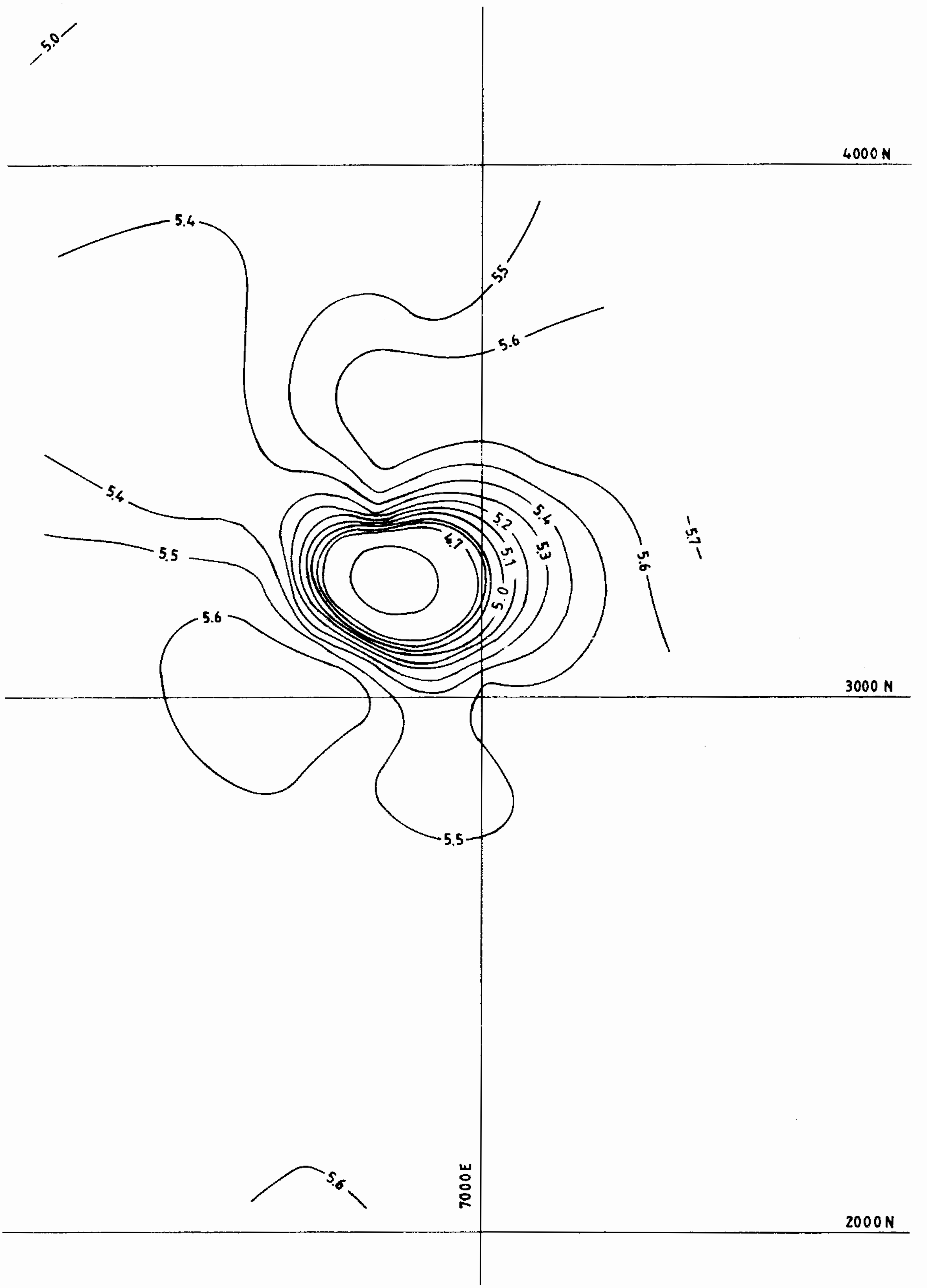

Figure 7. Maximum drawdown piezometric surface for Area 1.

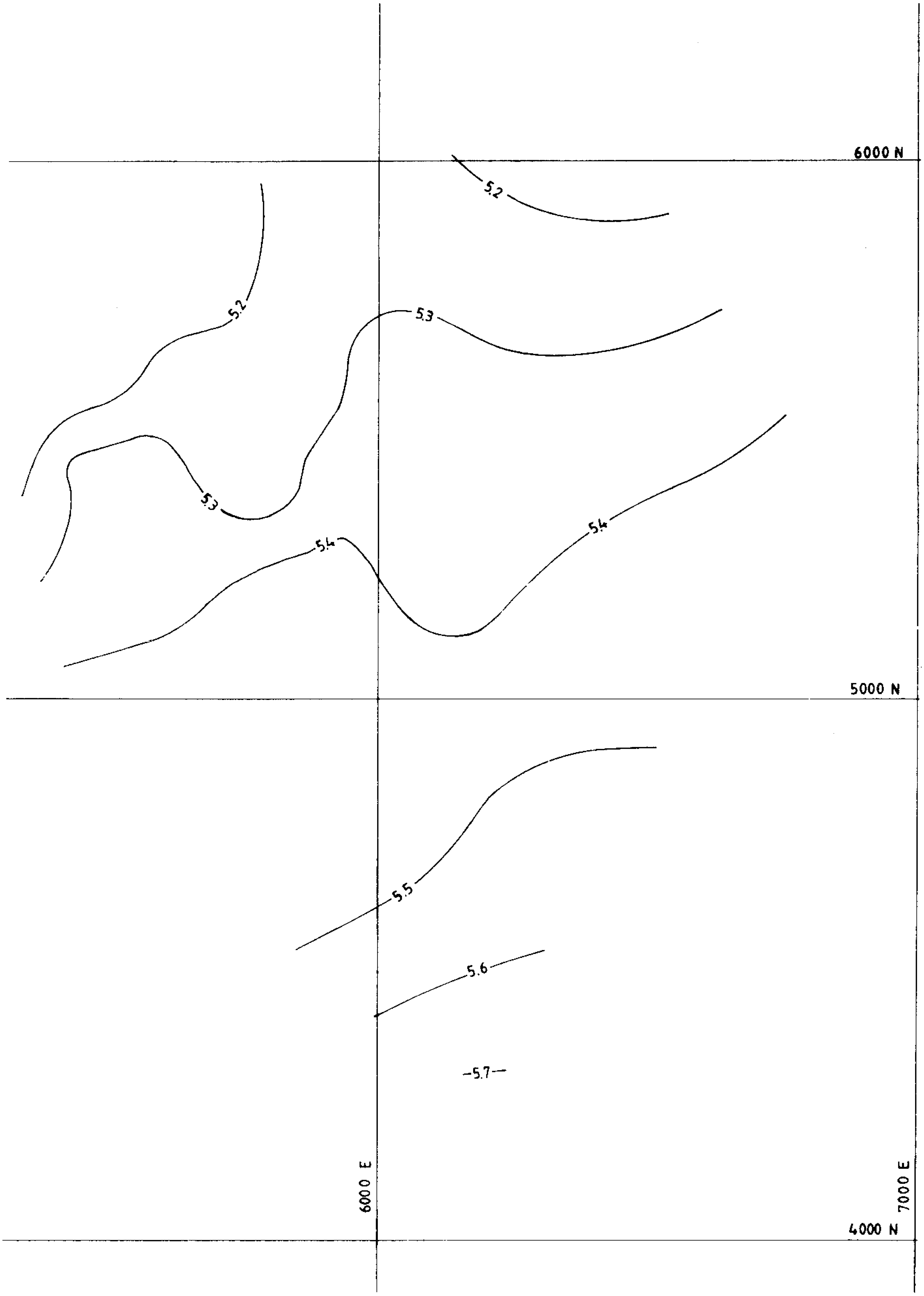

Figure 8. Pre-pumping piezometric surface for Area 2.

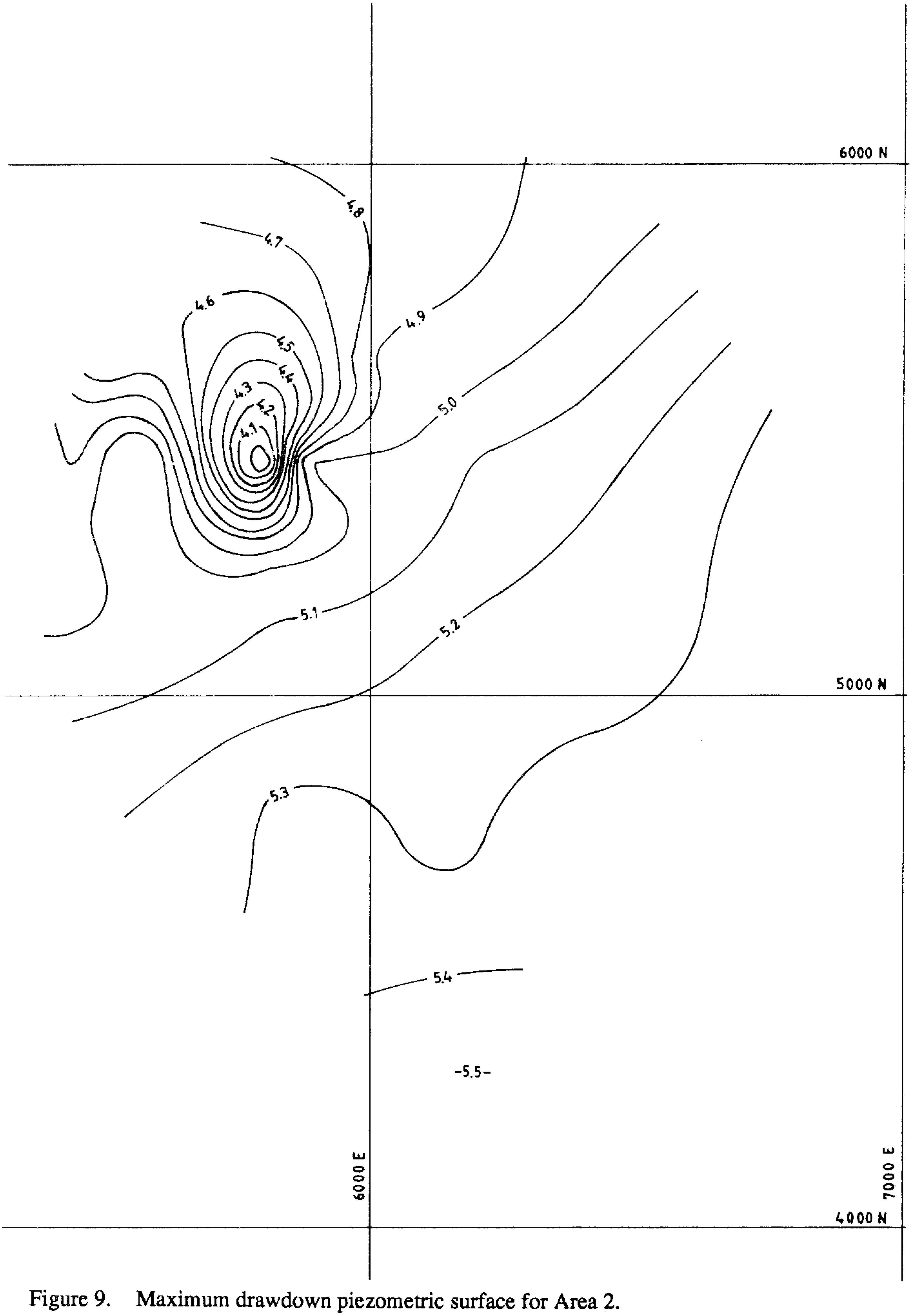

Figure 9. Maximum drawdown piezometric surface for Area 2.