Fracture Flow in Granitic Rock: Quarry Park

by

Tanya Leigh Fischer

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Abstract: Quarry Park, located in Stearns County, Minnesota has a water table anomaly in the southeastern corner of the park. Here the water table changes 30 feet over a distance less than 100 feet. The area in between is the sight of abundant fracture flow which does not allow the water to fill the lower quarry.

Introduction: The movement of water through fractures in a non-porous igneous rock is referred to as fracture flow. In an exposed igneous granite, the only course for water to travel is through a set of interwoven fractures.

Quarry Park, located southwest of Waite Park, Stearns County, Minnesota is comprised mostly of granitic rock of both the St. Cloud Red and Reformatory Gray types. It also contains Rhyolite, applites, and numerous basaltic dikes. The center of the park is covered by glacial till, but most of the park has a very thin cover or no cover at all. The only viable aquifer in the southeast corner is granitic.

The flow through fractures in this granitic mass creates interesting ground water table anomalies in the southeastern corner. Here there is a difference in the water table of nearly 30 feet over a horizontal distance of less than 100 feet. This study is to determine what aspects of the geology are influencing the anomalous water table in this area.

Body: The first step of the research was to collect water level measurements for 18 of the 20 quarries in the park. This was dome using a surveyed elevation mark on each quarry, a level, and a probe which will notify the user when it has made contact with the water. Using these tools, an accurate water level measurement could be made; the results are indicated on figure 6. The orange numbers represent the elevation above sea level of the quarries. The blue lines drawn in represent an interpretation of the potentiometric surface in the park using data from the quarries and the locations of perennial springs.

When this task was complete, a large groundwater anomaly became evident in the southeastern corner of the park in the vicinity of quarry numbers 5, 6, and 7. This encouraged further research of this area of the park.

In investigation this small area, an overview of the sight had to be made. The initial study included a thorough walking of the area in search of springs. This began in late April and continued until the end of May. In this area there is one outcrop of Red Granite that has always been wet, and the moss which covers it looks to be well developed from years of growing. It is located to the north and west of quarry 5. Conversation With Dr. George Shurr confirmed that this outcrop is to his recollection always "spongy".

All three quarries in this study had water leaking into them through fractures in the wall of the quarry. Quarry 5 has a stream of water pouring into the north end. The spring emerges from under an obvious trench, but the water does not fill this trench. It is hypothesized that the trench is either an eroded basalt dike or an ancient fault that has been eroded.

Quarry 6 has water seeping down the wall of the western cliff. The water is constant but not pouring down the precipice. Quarry 7 has only one small spring which emerges above the water level. It is located in the northwestern corner of the quarry. Again it is constant but not gushing.

There was also a spring located at the southeast corner of the spoils pile of on the northeast corner of quarry 7. This spring ran southeast towards quarry 6, but it dried up in May. One curiosity did persist however, the course that the spring ran ended at the precise location where water flows down the wall of quarry 6.

Surprisingly, there was no water to be found on the southern edge of the study area. On the contrary, this area appeared to be dry with numerous Oak trees which do not tolerate vast amounts of water happily.

The next step in this study was to identify prominent directions of the fractures in the area. This was done using a Brunton compass. All noticeable fractures were measured on the outcrops studied. Seven outcrops were studied with one of those outcrops being divided into three distinct sections due to its size and shape. These seven outcrops are labeled A - I on figure 3. By overlaying a grid over the outcrop map it was determined that only about 11% of this study area is visible outcrop. The remainder is buried under glacial till, spoils piles, or water which has filled the hole left from quarrying. However, the 11% were in convenient spots for finding fracture orientations and densities.

The fracture orientations were mapped using rose diagrams.

The angles were divided into 10 degree sections such that all fractures striking between N0° E and N9.99° E are located in the section between 0° and 10° . Using this method a predominant strike of the fractures on each outcrop can be determined. These rose diagrams are located on figure 5. Notice that for outcrops A, B, and C the predominant strike is in a north/south direction with virtually no trend in any other direction.

Assuming that the only movement of water in the sparsely glaciated area between quarries 6 and 7 occurs in fractures, observe that water approaching outcrop E has little choice but to follow the steep gradient of the rock and the fracture traces and head east. This water would then have virtually no chance to enter the quarry through the north wall, and it is not surprising that no water is apparent of the north cliff of this quarry. Outcrop I has two predominant strike directions. Both trend in a northwesterly direction. Remember the aforementioned spring? It also approached from this direction, and there is water seeping down the wall at this location.

Judging by the water table in figure 6, the highest head on quarry 7 would be in the northwest corner. Here there is a predominant northwesterly strike. This is the location of the spring, and it indicates that the fractures may be controlling the water table and not vise versa.

The final outcrop was separated into three distinct sections. The northernmost part of this outcrop is labeled F. It has two dominant directions of strike. The first is north/south and found in the northern outcrops. The other is a little north of east. Here the water is given two choices of movement. The first would be to travel south; the second would be to move to the southwest towards a swampy area. This trend is also apparent in outcrops G and H. For some reason, the water seems to be flowing to the southwest and ending up in the swamp. The reason for this deduction id the lack of springs and water at the south end of the study area. If the water were reaching this area through the fractures, there would be more visible water in the lowest area of the study.

The flow at the north end of the area is more complicated. The perennial spring mentioned earlier flow to the north. That is down the topography of the bedrock and therefore is not that surprising, but when one considers that there is a greater potentiometric gradient to the south, this is perplexing.

Even more perplexing is the stream entering quarry 5 at the north end. This stream is almost due east of the perennial north flowing spring. One suggestion would be that the bedrock topography has a minor high in the middle which does not allow for the water to pass straight to the quarry. Another possible explanation could be formulated if more was known about the trench from which the quarry stream flows. If this is a fault it would then be nothing more than a giant fracture. This fracture could then carry water down gradient after it is recharged to the north of the area.

In order to get a better understanding of the waters in the area, different water quality measurements were made. The first measurement was pH. First some quarries not in this area were measured. They had pH ranges of 7.54 to 8.53. Then measurements were taken of the three quarries in the area. The results of quarries 5, 6, and 7 are 7.09, 7.10, and 7.10 respectively. This implies that these three quarries may be hydraulically connected. However, to prove this more tests were conducted. The final battery of tests included temperature in degrees celsius, Total Dissolved Solids in milliliters per liter, and conductivity in micro-siemens. Three measurements were made in various places in each quarry, and the results were averaged. The three temperatures varied greatly, but judging by the differences in size and depth, this was expected. The temps were:16.97 C for quarry 7, 18.95 C for quarry 6, and 19.75 C for quarry 5. TDS (Total Dissolved Solids) for quarries 5, 6, and 7 were 31.8, 27.8, and 40.83 respectively. The conductivity is related, and therefore the variations were nearly proportionate with quarry 5 measuring 63.5, quarry 6 at 53.55, and quarry 7 at 80.63.

In all of these water quality tests, the only possible correlation comes between quarries 5 and 7, not 6 and 7. That is not what would be expected judging from their distances from quarry 7.

The location of the spoils pile tends to be a divide with some of the water heading southwest into the swamp, some heading due east past quarry 6, and much of the water moving north toward the perennial spring. This brings about the question of a mounded water table under the spoils pile as has been suggested by Dr. Jean Hoff. If there is a mound, then the three quarries may not be hydraulically connected at all. The increased head under the mound would not allow for the water from quarry 7 to rise over the mound, and thus the water from that quarry would only drain to the west. There may be significant head from the pile however to drive water through the fractures creating the stream found to the north.

Several instruments of study could be employed to test the mounded water table model. Piezometers could be placed around the pile to determine verticle movement of the water. Also, dye could be released either into quarry 7 or the pile to trace where it is found later. Both of these methods would create of abolish evidence of the mound.

Conclusion: In the end more questions arose. There is a possibility of one or more than one north trending fault cutting this area. This idea is brought about by the steep cliffs that align themselves in this direction, and the trench at the north of quarry 5. It is likely that a fault or fault zone would have the ability to transmit more water than narrow fractures. Mapping of lineaments (lines observable on aerial photos) could help determine strike of fracture zones to broad to be seen in a field study. These lineaments would likely be either faults, contacts, intrusions, drainage channels, or vegetation lines (including Poison Sumac).

Better understanding of how water moves through the rock in this area could have positive effects on people who must find water in igneous aquifers. By examining flow through the fractures drillers can better predict placement of well for ideal well yields. It could also prove beneficial in determining the course contaminants will take when moving through fractures.

References:

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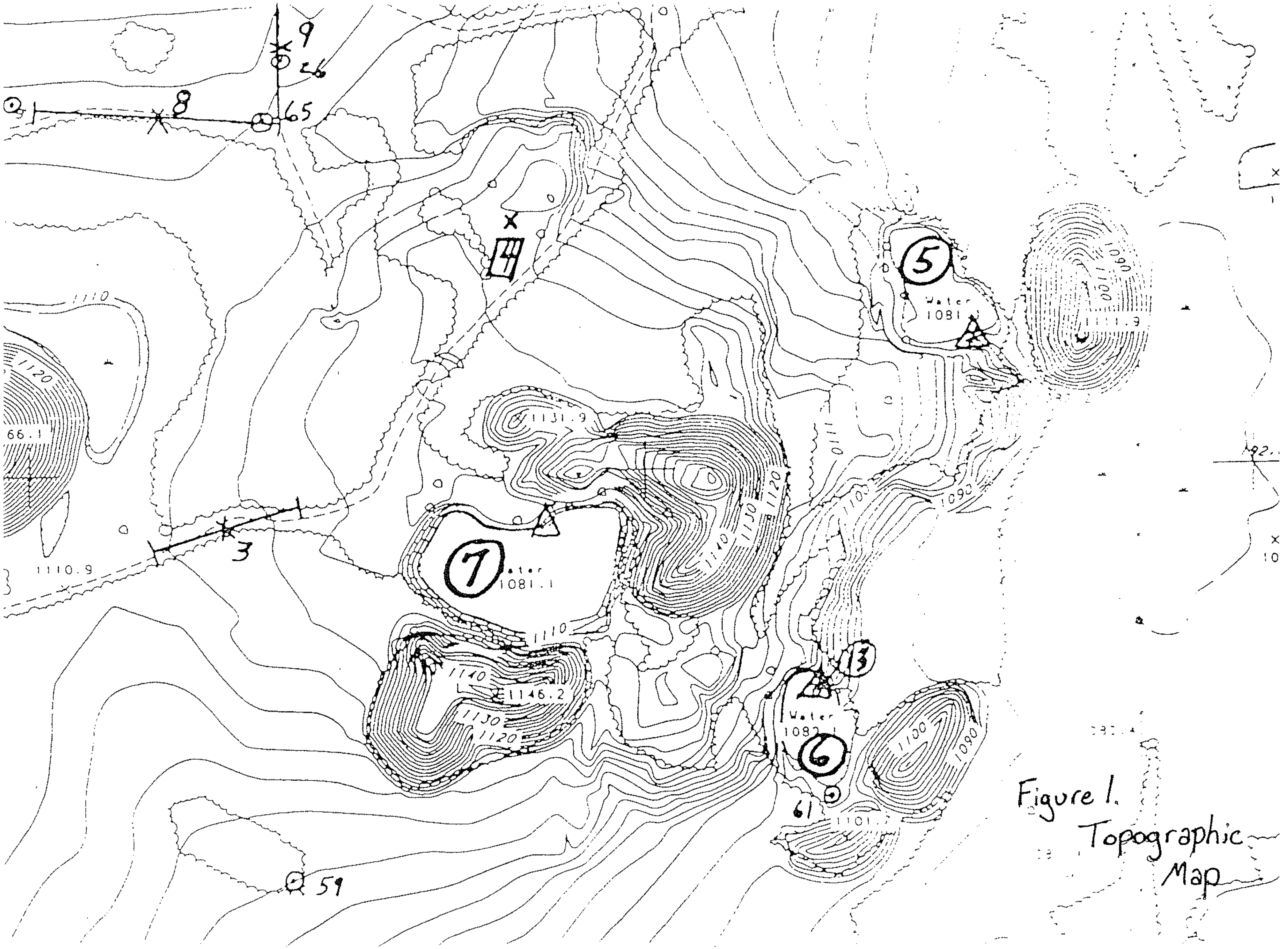


Figure 1. Topographic Map

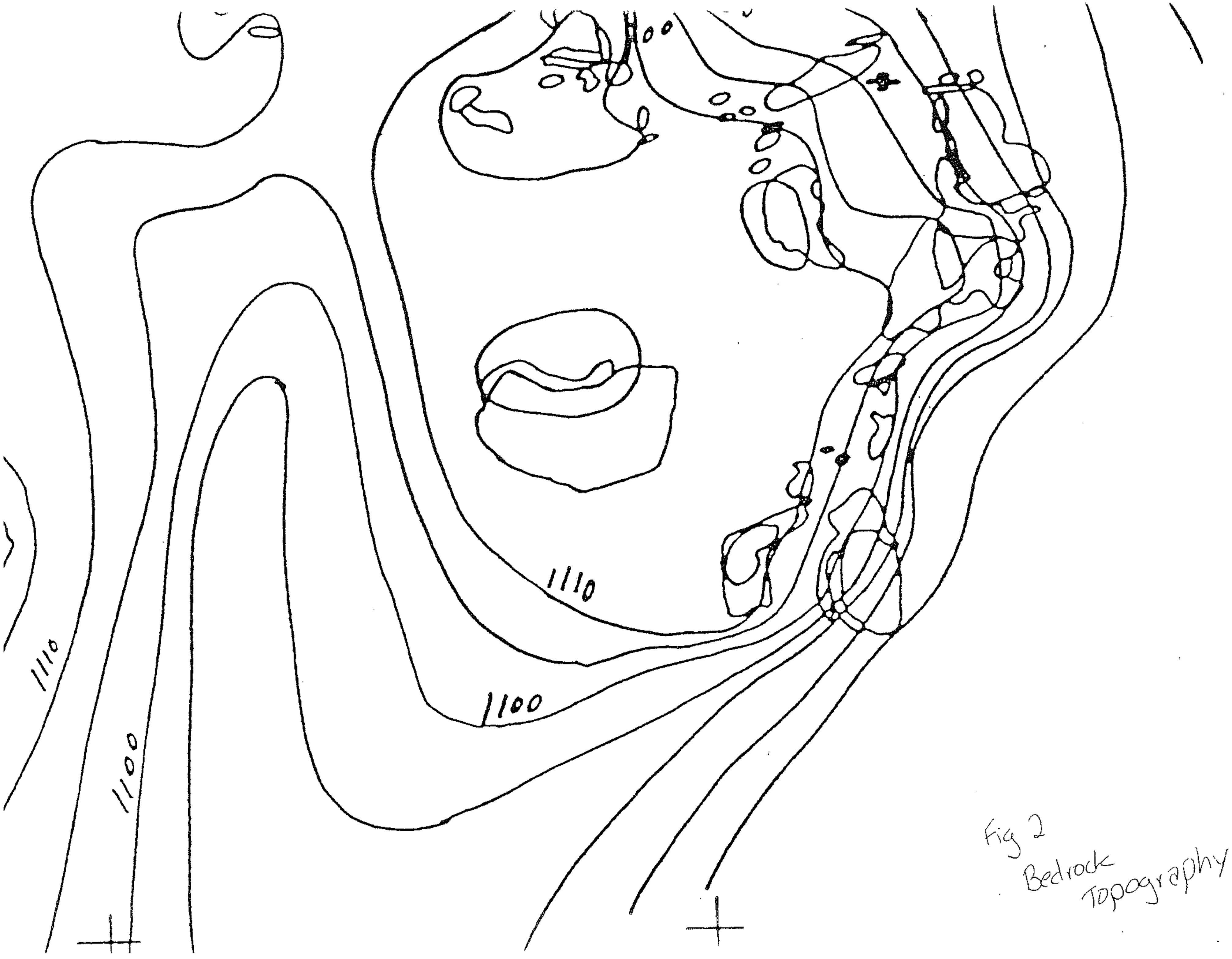
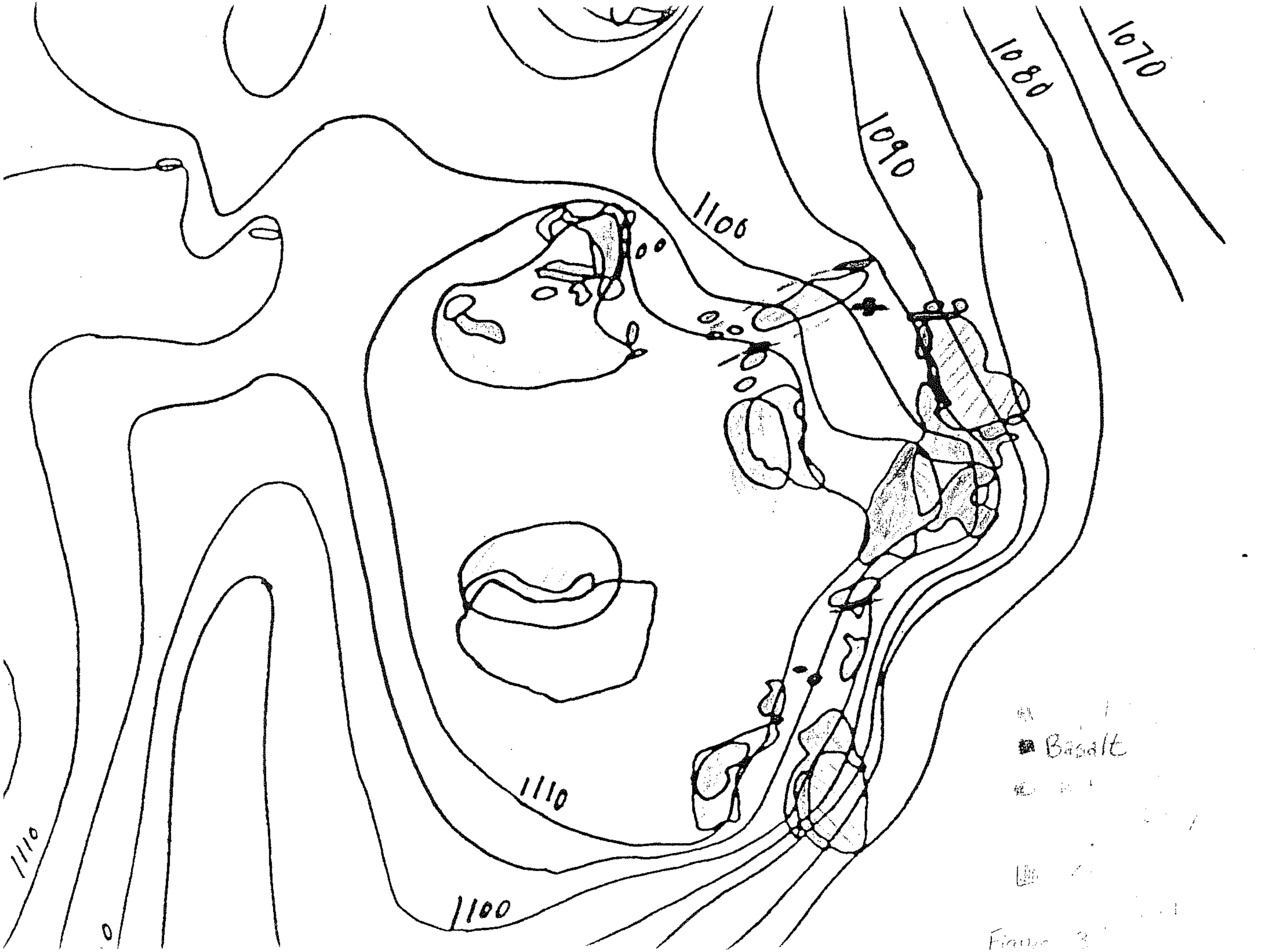


Fig 2
Bedrock
Topography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1080
1090
1100
1110
1100
1110
Basalt

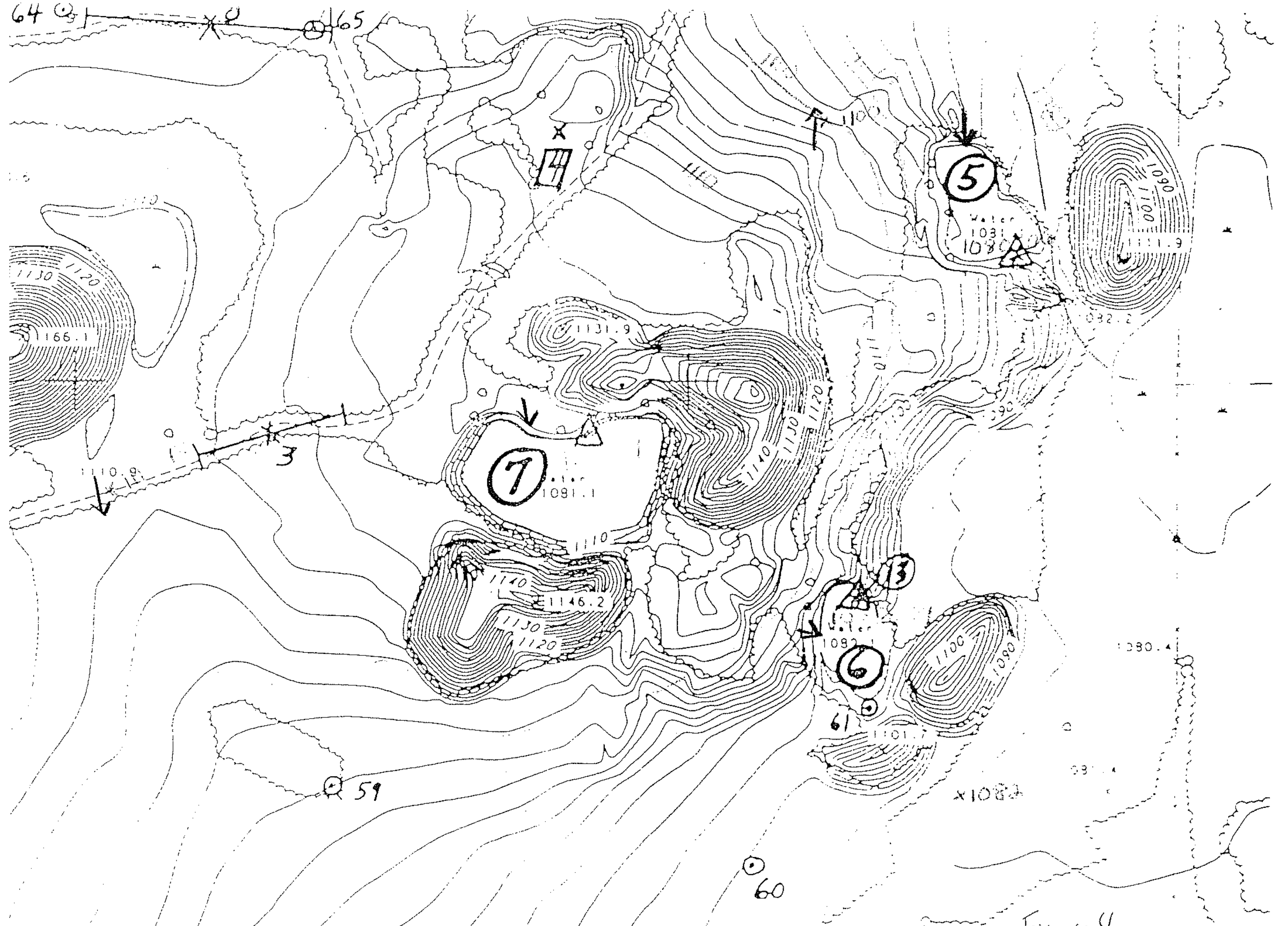

Figure 4.
Local Water

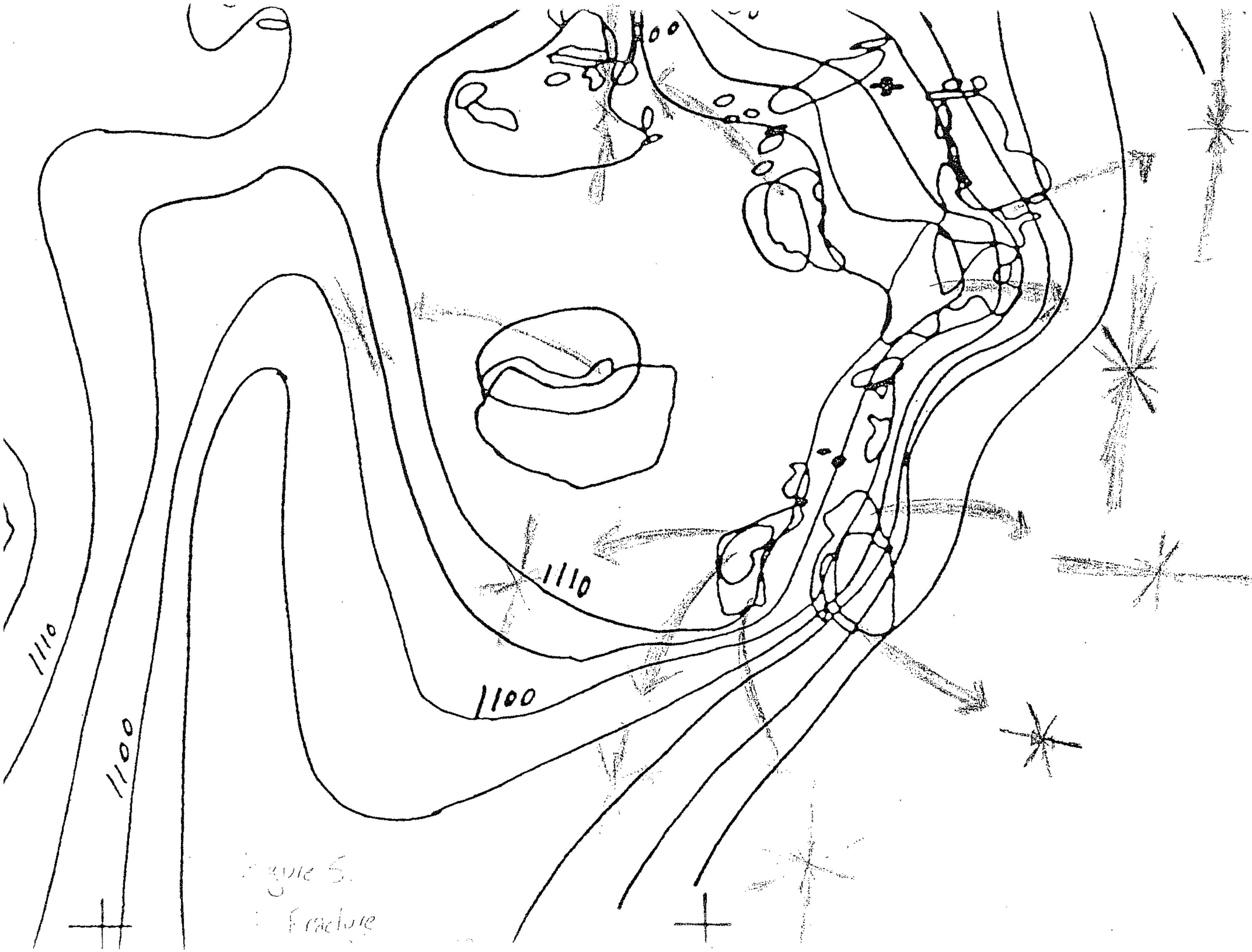

Figure 5. Fracture