ST. CLOUD STATE UNIVERSITY

EAS 405 Senior Thesis

Characteristics of Fractures in Granitic and Basaltic Bedrock Quarry Nine, Quarry Park and Nature Preserve, Waite Park, Minnesota

Krista Murnane

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PREAMBLE:

Acknowledgements –

I want to thank Chuck Woken and Quarry Park and Nature Preserve in their help with maps and park access. I want to thank Jason Testin for proof reading and assistance with the creation of the power point. Finally I want to thank the professors, Dr. Kate Pound, Dr. Jean Hoff, and Dr. Al Pekarek, which took the time to make it possible.

Table of Contents - Page 2

ABSTRACT:

This is a thesis detailing the fracture systems at Quarry Park and Nature Preserve, Waite Park, Minnesota. This paper will begin to answer the main question by looking at the trends in the orientation of the liner fractures around Quarry 9. The questions that will be answered are if there are any similarities in the trends and how does the data collected at Quarry 9 compare to previous data gathered at the park. These smaller questions will help answer the big question after some more study has been completed. This study was done by visual observations of jointing and crosscutting relationships. A Brunton compass was used to measure tends and of fractures and joints. The data was then compiled in a table and displayed on rose diagrams. With the original data (field observations), crosscutting relationships could be determined. After the data was colleted and analyzed it was then compared to the data collected and derived from other works. The data was viewed in a few different ways; the first sort was to identify patterns in joint orientation that are mapped on a rose diagram, see Diagram 1.

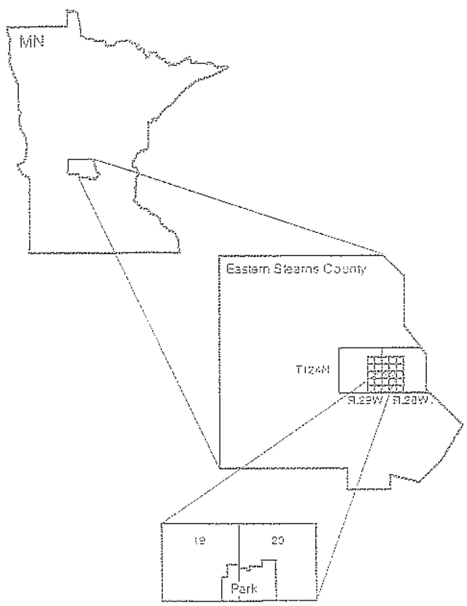
INTRODUCTION:

How do small-scale fractures relate to large-scale joint system fractures? Based on the characteristics of fractures in crystalline bedrock determined by surface surveys connections can be made between the published large-scale fractures and the data gathered on the small-scale fractures around Quarry Nine in Quarry Park and Nature Preserve, Waite Park, Minnesota. This data can also be compared to the large-scale faults. This paper will begin to answer the main question by looking at the trends in the fractures around Quarry 9. The questions that will be answered are if there are any similarities in the trends and how does this data collected at Quarry 9 compare to previous data gathered at the park. These smaller questions will help answer the big question after some more study has been completed. This thesis details the fracture systems at Quarry 9 in Quarry Park and Nature Preserve, Waite Park, Minnesota.

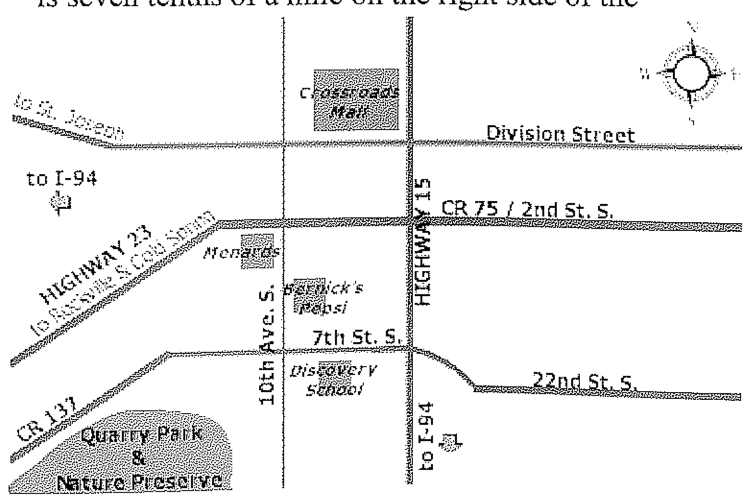
The bedrock lithology is of the early Proterozoic Penokean Orogeny and includes the gray Reformatory Granite and red St. Cloud Granite, which is part of the red Stearns Granite Complex along with Rockville Granite. "The Reformatory Granite is medium-grained, porphyritic, contains numerous schist inclusions and is vaguely foliated. It has a large amount of sodic plagioclase, biotite, and hornblende, but smaller amounts of potassium feldspar than the red St. Cloud Granite. The St. Cloud Granite is medium-grained, locally porphyritic, has few inclusions, and is massive. The formal type area for this map unit is located in Quarry Park" (Shurr & Anderson, 1995). "Quarry Park and the surrounding area are located within the convergent margin near the contact zone of the Reformatory Granite and the St. Cloud Granite. It is significant that faults, which are the logical consequences of this interpretation of a convergent margin, have not been recognized until recently" (Shurr & Anderson, 1995). See appendix A for age determination and composition.

This study was done by visual observations of jointing and crosscutting relationships. A Brunton compass was used to fractures trends and joints. The data was then compiled in a table and displayed on rose diagrams. With the original data (field observations), crosscutting relationships could be determined. After the data was colleted and analyzed it was then compared to the data collected and derived from other works.

Location -



Quarry Park is a part of the Stearns County Parks system. It is located in section 19, T.124 N., R.29 W. To drive there take State Highway 23 to 10th Avenue South in Waite Park. Then turn west or right onto 7th Street, which becomes County Road 137. The park entrance is seven tenths of a mile on the right side of the road. The park contains some of the best examples of granite outcrops in the area.



Regional Context -

Quarry Park is currently over 550 acres and includes woodlands, open prairie, wetlands, and bedrock outcrops. There are remnants of man-made grout piles left over from the extensive granite mining that took place starting in 1868. There are over twenty-five granite quarries in the park most of which are now filled with water. The park has been maintained in order to sustain its natural and historical value (Stearns County Parks, 2002).

The parent rock of this area is gray Reformatory granodiorite; it was used to construct the St. Cloud Reformatory, gray Reformatory Granite is centrally located in the park. Appendix B shows the bedrock geology around Quarry Park as mapped by Shurr & Anderson, 1995. The other major rock type in the area is red St Cloud Granite; many landmarks in St. Paul and all over the state of Minnesota have used this red granite in their construction. "The St. Cloud Granite is shown with a distinctive wishbone shape. It is elongated in a north-south direction and the two legs of the wishbone come into the western and eastern part of Quarry Park. The park therefore shows an overall variation from west to east of red granite-gray granite-red granite and this pattern is the result of the distinctive shape. The west leg of the wishbone is elongated northeast southwest in association with a number of faults" (Shurr & Anderson, 1995). There are two varieties within the red St. Cloud Granite, both contacts trend in an east-northeast direction. Shurr & Anderson stated that no crosscutting relationships have been observed or published. The unit in the west side of the park has more potassium feldspar and less quartz than its eastern counterpart (Shurr & Anderson, 1995). There are also some inclusions of gray granite within the St. Cloud Granite. The Reformatory Granite contains dikes of porphyritic diorite and a large basalt dike that is 2.5 feet thick and visible for ten feet on the west side of Quarry nine trending northeast. Smaller dikes of aplite, red granite, basalt, and dark metamorphic rocks are also contained within the gray Reformatory Granite. All igneous rocks were formed during the Precambrian (Morey, G. B., 1972). Appendix A shows the age and composition or these units. The red St. Cloud granite appears more resistant because is shows less wear than the Reformatory gray granite. Appendix B shows the bedrock geology around Quarry Park. The glaciers came through the region leaving till and polishing the outcrops in Quarry Park are from the Des Moines lobe and the St. Croix sub-lobe of the Superior Lobe (Shurr & Anderson, 1995).

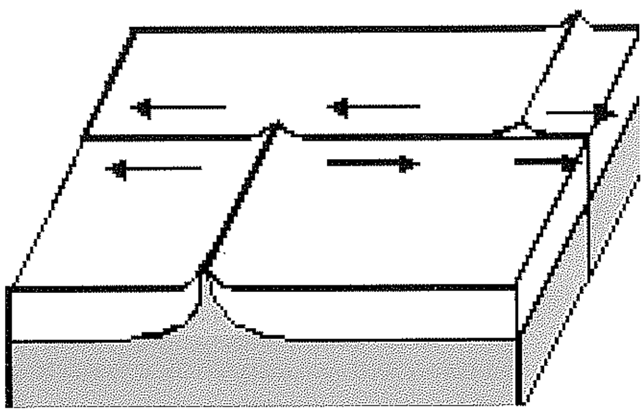
Focus-

The focus of this thesis will be on Quarry Nine on the south end of Quarry Park and Nature Preserve. See appendix D for a map of the park. Quarry 9 is in the south part of the park and has one of the best-exposed faults in the park, containing minimum modifications by the park system. See picture above. This fault is located on the west

wall, the lower half of the wall is composed of red granite but the wall is dominated by gray granite. It is a medium sized quarry in relationship to the other quarries within the park. It has a maximum depth of about 45 feet. The quarry has a good outcrop on the northwest side that exposes a large basalt dike along with a number of small aplite dikes. There are a number of smaller faults or shear zones, which will be incorporated in this report to create a more detailed history of the larger faults in the park. The display of glacial polish and some glacial overburden is also present around Quarry Nine (Stearns County Parks, 2002).

Minor Fractures –

Minor fracture nomenclature and age-relationship can be determined by use of criteria, including the presence or absence of infilling material or staining, interaction of fractures of different sets, morphology of fractures, aspect ratio of fractures, and fracture separation and bed thickness. The first criterion, presence or absence of infilling material or staining, can be very hard to identify out in the field because of weathering properties, therefore it will not be the focus of this research. The second criterion, interaction of fractures of different sets will determine the age relationship of the fractures. "The longer more dominant fractures in any set tend to be the oldest ones belonging to that set and the progressively shorter ones then also to be progressively younger representatives of the set" (Price and Cosgrove 1990). As for the morphology of fractures because all of the rock studied are igneous rocks, granite and basalt, the fractures appear brittle and none appear to have semi-ductile faulting. Aspect ratio, the fourth criterion, is also hard because almost all the fractures appear to be joints with no visible offset in the field.



There are however, are a few fractures that offset a visible amount and this will be taken into consideration. The final criterion is fracture separation and bed thickness (Price & Cosgrove, 1990). This was used in the quarry processes to determine the maximum size of block that could be obtained. The areas that have less economical value were left behind. Since the research is at a quarry and most, if not all of the choice blocks have been removed that leaves the out crop with the less desirable fracture separation and bed thickness, but enough remains that some information can be used for this criteria. By applying these criteria the relative age of fractures can be determined even if some of the criteria do not reveal much insight to the jointing relationships within Quarry Nine.

MAIN BODY:

Research -

First, in the field, measurements of the surface fractures trends with a Brunton compass, marking the larger features on a map. See map 1 f°or sketch. The trends of the joint measurements were taken as bearings then converted to Azimuth. The data is then complied in a table, Original Data, which includes all the observations made, see Table 1 – Original Data. One of the first observations made are the fracture trends. The second observations made are crosscutting relationships this was determined when a joint crossed a preexisting joint or has any visible off set. The letter A represents the oldest joint while letter C would be the youngest joint in Table 1. If there was a picture taken associated with the joints it was given a number in Table 1 (Original Data) and is included in the appendix. Next was offset, there were only two fractures with apparent visible offset. The fracture trending N30E had an offset of eighteen inches. See pictures 7 & 8 Appendix F. The other case are two fractures trending N10W, these were offset only three inches. See picture 9 Appendix F. The offset was determined when a joint was shifted because of another fracture cutting across it and moving the rock in opposite directions. The last thing listed in Table 1 was any comments made about the joint or fracture; this includes compositions other than gray Reformatory Granite.

Results -

The data was compiled and analysis using the criteria stated previously in the section entitled Minor Fractures. The data was viewed in a few different ways; the first sort was to identify patterns in joint orientation that are mapped on a rose diagram, see Diagram 1 page 28. To comparing this data more easily it is also displayed as a line graph in Diagram 2 page 29. Compare this to previous research by Shurr & Anderson with frequency in the focus areas throughout the park (Appendix E), I find that they don't line up with the highs, but there are some similarities in on either side of the high frequency. For example the first major peak is around twenty-five to thirty-five degrees east of north. Then the major peak on both is between seventy and one hundred degrees east of north. Then the final major peak is between 140 and 180 degrees east of north.

The next sort was to identify relative age of fractures from older to younger to find similarities. The first example set of crosscutting relationships shows the fracture N30E is the oldest because the next fractures younger, S70E and N50W, stop when coming in contact with this fracture. This is also the case when the youngest fractures, S60E and S10E, came in contact with the previous fractures. See pictures 7 and 8 appendix F. Picture nine shows that N10W is older than N80W and picture ten has N20W older than N10E. Picture eleven has N5E older than N20E but it is younger than N90E. In the basalt dike N80W is older that N10E, the picture is number 14. On the southwest side of Quarry Nine, Picture 22 shows the outcrop where S30E is older than S30W.

CONCLUSION:

In conclusion different comparisons can be made of the results from the fracture observations made at Quarry Nine in Quarry Park and Nature Preserve. Basic observations can be made about the lack of similar patterns in the aplite dikes. They were of different scales and placed unevenly around Quarry Nine with no apparent pattern. The joints trend evenly in all directions, with the exception at about 90 degrees, which exceeds all other directions. This is seen with the rose diagram. General conclusions can be made with the crosscutting relationships to determine age relations as description in the results section of this report and is also in Table 1. Most fracture sets are separated by about 60 degrees. Very little conclusions can be made about the offset because of the lack of visible offset. Further research needs to be done detailing the vertical fractures at Quarry Nine. Another suggestion for further research is to analyze the effects on the fracture system caused by quarrying at Quarry Park and Nature Preserve.

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Appendix A

Table IV-5. Summary of K-Ar age determinations of Middle Precambrian rocks.

Sample No.	Map No. (fig. IV-20)	Description	K (pct.)	$^*Ar^{40}$ (ppm)	Age[1] (m.y.)
		(A) Thomson Formation			
35 wr[2]	a	Slate. Thomson	3.00	0.553	1630
38 wr	b	Phyllite. Atkinson	1.03	0.191	1630
39 mu	c	Phyllite. Barnum	4.28	0.803	1650
40 mu	d	Phyllite. Moose Lake	3.79	0.685	1610
96 wr	y	Phyllite. Little Falls	1.90	0.336	1580
232 wr		Slate. Duluth	3.55	0.433	1220
233 wr		Slate. Duluth	3.34	0.387	1170
		(B) Rove Formation			
131 wr		Argillite. Gunflint Trail	4.06	0.410	1060
		(C) Virginia Formation			
137 wr		Argillite. Virginia	3.40	0.539	1470
212 wr		Argillite. West Mesabi	3.38	0.396	1180
		(D) Mahnomen Formation. Cuyuna district			
33 wr	o	Argillite	4.60	0.878	1670
132 wr	m	Phyllite	4.09	0.698	1540
134 wr	k	Argillite	3.84	0.677	1580
215 wr	n	Argillite	3.36	0.644	1670
408 (90-100)		Argillite	4.69	0.800	1550[3]
410 (100-110)		Argillite	3.11	0.548	1580[3]
410 (180-200)		Argillite	4.28	0.680	1470[3]
		(E) McGrath Gneiss			
41 bi	e	West of Denham	7.16	1.38	1670
43 bi	f	SW. of Denham	6.29	1.19	1650
164 bi	h	McGrath	6.82	1.36	1710
63 bi	g	Pliny (Dad's Corner)	7.38	1.21	1500
		(F) Intermediate granitic and related rocks			
1 bi	i	Quartz monzonite. Warman	6.91	1.44	1760
62 bi	j	Quartz monzonite. Isle	6.07	1.18	1680
64 bi	r	Tonalite. Hillman	6.44	1.35	1770
60 bi	p	Gneiss. Freedhem	6.47	1.28	1710
59 bi	p	Schist. Freedhem	6.18	1.14	1630
61 bi	q	Quartz monzonite. Pierz	6.96	1.41	1730
10 bi	x	Granodiorite. St. Cloud	5.04	1.06	1770
		(G) Granites			
6 bi	u	Porphyritic granite. Rockville	6.23	1.16	1640
RH-21 ho	t	do.	0.893	0.191	1800[4]
58 bi	s	Red Granite, St. Cloud	5.46	1.02	1640

Table IV-5---Continued

Sample No.	Map No. (fig. IV-20)	Description	K (pct.)	*Ar^{40} (ppm)	Age[1] (m.y.)
		(H) Basaltic dikes			
M8300 wr		Basaltic dike, St. Cloud	0.776 0.770	0.0991 0.101	1280[3]
M8301 wr		Basaltic dike, St. Cloud	2.00 1.96	0.309	1460[3]
M8302 wr		Basaltic dike, Rockville	0.568	0.0982 0.0986	1570[4]
MN-15 wr		Basaltic dike, St. Louis River	1.023 1.011	0.102	1050[5]

* Radiogenic Ar^{40}
[1] All ages from Goldich and others (1961) have been recomputed, using
$\lambda_e = 5.84 \times 10^{-11}\ yr^{-1}$
$\lambda\beta = 4.72 \times 10^{-10}\ yr^{-1}$
$K^{40}/K = 0.0119$ (atomic ratio)
[2] Abbreviations: wr, whole rock; mu, muscovite; bi, biotite; ho, hornblende
[3] Peterman (1966)
[4] Hanson (1968)
[5] Hanson and Malhotra (1971)
Analytical uncertainty in the ages is about 5 percent.

Table IV-6. Summary of Rb-Sr age determinations on biotites from Middle Precambrian rocks.

Sample No.	Map No. (fig. IV-20)	Description	Rb (ppm)	Sr_n (ppm)	Sr^{87}/Sr^{86} [1] (Atomic)	Rb^{87}/Sr^{86} (Atomic)	Age[2] (m.y.)
164	h	McGrath Gneiss, McGrath	515	10.5	4.21	142	1750
41	e	McGrath Gneiss, W of Denham	413	5.40	6.11	221	1740
1	i	Quartz monzonite, Warman	427	16.9	2.57	73.2	1810
64	r	Tonalite, Hillman	484	17.2	2.73	81.5	1760
58	s	Granite, St. Cloud	886	8.48	8.06	302	1730
10	x	Granodiorite, St. Cloud	372	53.0	1.23	20.3	1820
532	v	Quartz monzonite, Rockville	571	4.29	10.1	385	1730
536	w	Quartz monzonite, SW. of St. Cloud	617	6.09	7.78	293	1720

[1] Calculated from spiked runs
[2] Computed with initial ratio = 0.710
$\lambda\beta = 1.39 \times 10^{-11}\ yr^{-1}$; $RB^{87}/Rb^{85} = 0.386$ (atomic)

Table IV-13. Modes, in volume percent, of tonalite and related rocks in east-central Minnesota.

	Hillman tonalite	Freedhem granodiorite	Freedhem quartz monzonite	St. Cloud granodiorite
Quartz	27	7	21	16
Andesine	51	43	27	45
Microcline	4	13	35	12
Biotite	13	18	10	7
Hornblende	2	12	2	12
Accessories				
Pyroxene	X	2	2	3
Apatite	x	x	X	x
Zircon	x	x	x	x
Sphene	X	x	X	X
Opaque	X	X	X	X
Secondary				
Carbonate	x	X	X	x
Chlorite	x	X	x	x
Epidote	X	X	x	x
Sericite	X	X	X	X

X, generally less than 1 percent
x, generally less than 0.5 percent

St. Cloud Gray Granodiorite

Granodiorite, commonly referred to as St. Cloud gray granite, has been quarried for many years in the vicinity of St. Cloud (fig. IV-20). The rock is dark gray, but has a slight reddish hue imparted by K-feldspar. It is medium grained and massive, but contains numerous small inclusions which define a vague foliation locally. The granodiorite is cut by dikes of aplite and red granite, and Woyski (1949, p. 1012) described a pink phase of the granodiorite which she attributed to alteration (granitization) by the younger red granite of the area. The mode of the granodiorite in Table IV-12 is comparable to the composition given by Woyski (1949).

Younger Granitic Rocks (Stearns Magma Series)

A red, medium-grained augite-hornblende granite, commonly called the St. Cloud red granite, is quarried at several localities in Benton and Stearns Counties in the vicinity of St. Cloud. Outcrops of similar granitic rocks also are known in western Mille Lacs County and in central Morrison County. Woyski (1949, p. 1006) considered the granite one of the younger, larger intrusive masses, for it cuts and contains inclusions of the granodiorite of St. Cloud, the tonalites near Freedhem and Hillman, and the Thomson Formation. Woyski (see Skillman, 1946, *op. cit.*, p. 33) noted that east of the Mississippi River the granite is pink, whereas west of the river it is red. She also noted that the rock is darker red or green along joints, owing to the presence of chlorite- and epidote-bearing veins, and that the dark red color can be related to alteration spatially associated with the veins. She described cataclastic textures in the rocks, and attributed the red color to hydrothermal activity rather than to surficial weathering.

At several localities the augite-hornblende granite clearly transects the St. Cloud gray granodiorite and contains inclusions of it, but contacts with the coarse porphyritic quartz monzonite in the vicinity of Rockville are lacking; hence the age relations of these two granitic rocks are not known. Woyski considered that the two rocks probably are similar in age, but noted that the mineralogical compositions (table IV-14) differ somewhat, especially with respect to the ratio of plagioclase to microcline.

Table IV-14. Modes, in volume percent, of augite-hornblende granite of St. Cloud and quartz monzonite of Rockville.

Locality	St. Cloud	Rockville
Quartz	29	23
Oligoclase-andesine	10	36
Microcline	52	24
Biotite	4	
Accessories		
Hornblende	3	x
Pyroxene	x	
Apatite	x	x
Zircon	x	x
Opaque	x	x
Secondary		
Carbonate	x	x
Chlorite	x	x
Epidote	X	x
Fluorite	x	x
Sericite	X	x
Sphene	x	x
Pyrite	x	x

X, generally less than 1 percent
x, generally less than 0.5 percent

Appendix B

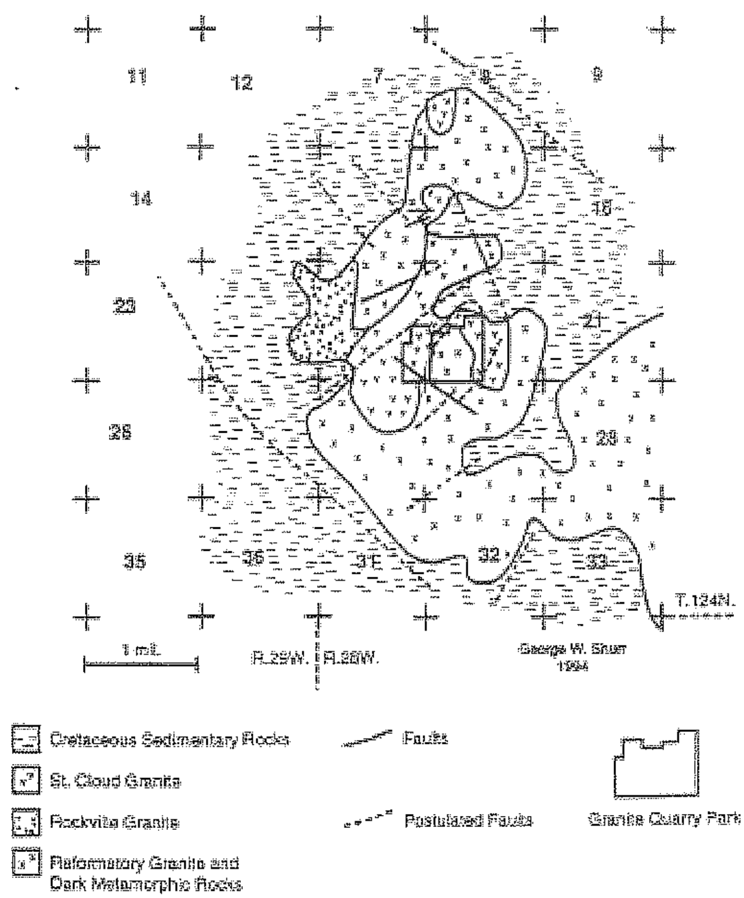


Figure 12 Bedrock geology in the twenty-five square miles surrounding Quarry Park. Faults are interpreted from linear bedrock lows (see Figure 10).

Appendix E

Geology of Quarry Park & Nature Preserve *Shurr & Anderson 1995*

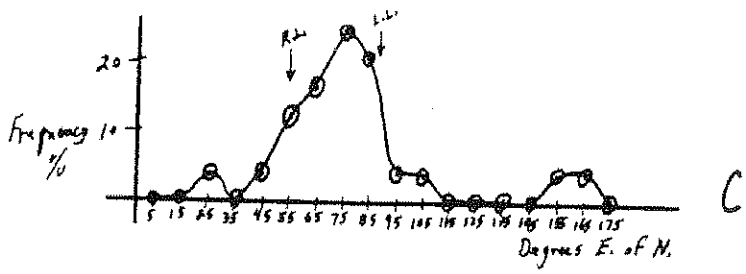


Figure 27 Frequency plots of the azimuths of shear zones within each of the four focus areas. (Average trend for left-lateral and right-lateral shears shown by LL and RL, respectively.)

A	Northeast Area	N=56
B	Southeast Area	N=15
C	South Area	N=24
D	West Area	N=52

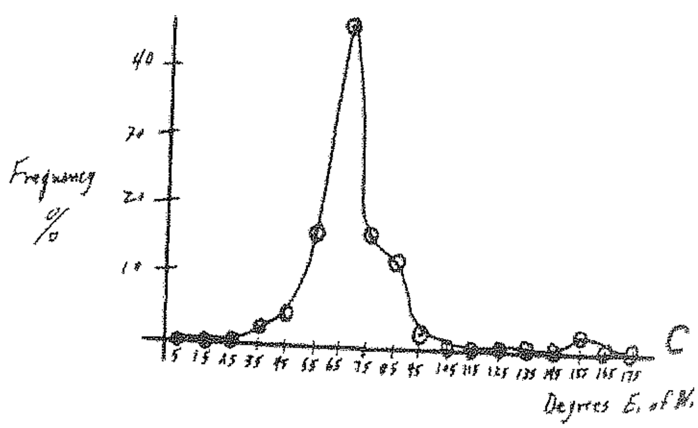
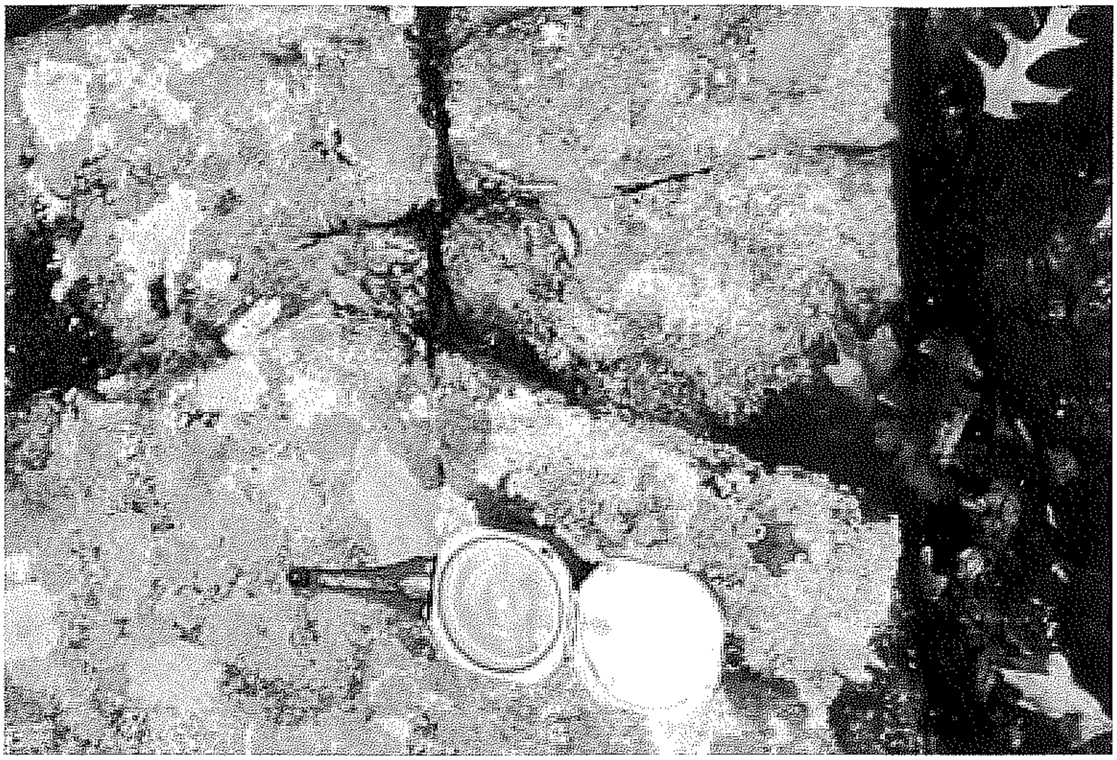


Figure 28 Frequency plots of the azimuths of basalt-dike margins within each of the four focus areas.

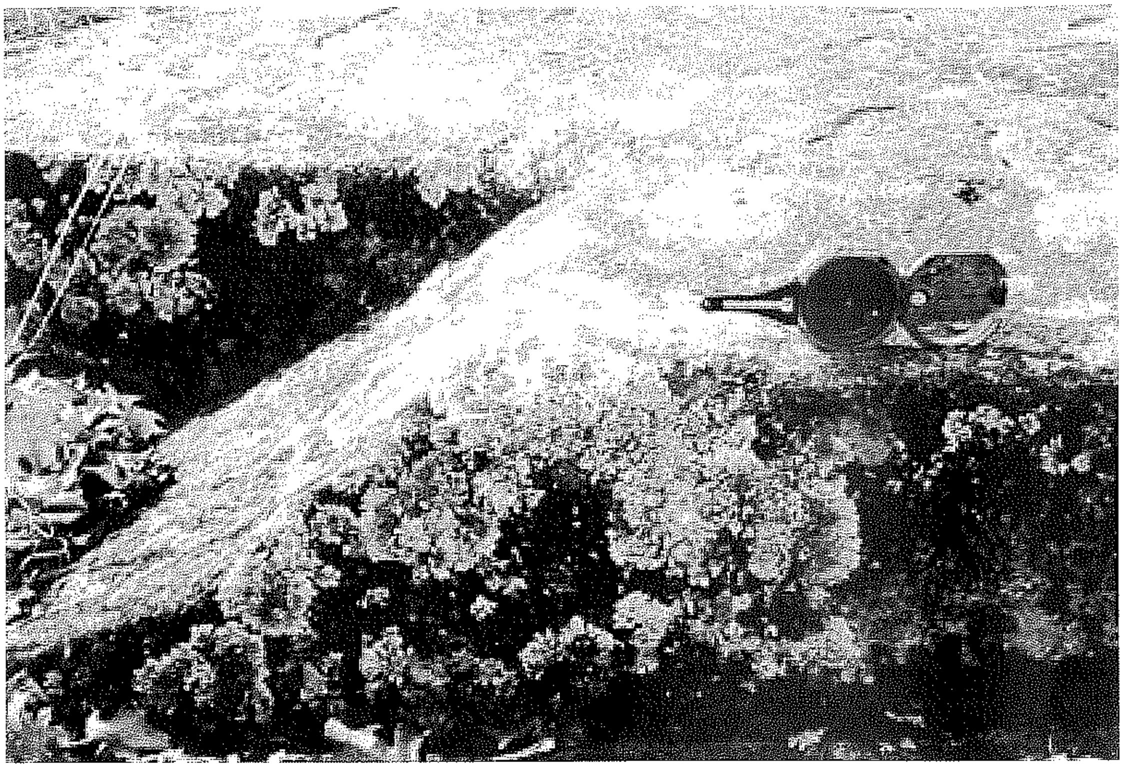
A	Northeast Area	N=10
B	Southeast Area	N=9
C	South Area	N=12
D	West Area	N=51

Appendix F – pictures



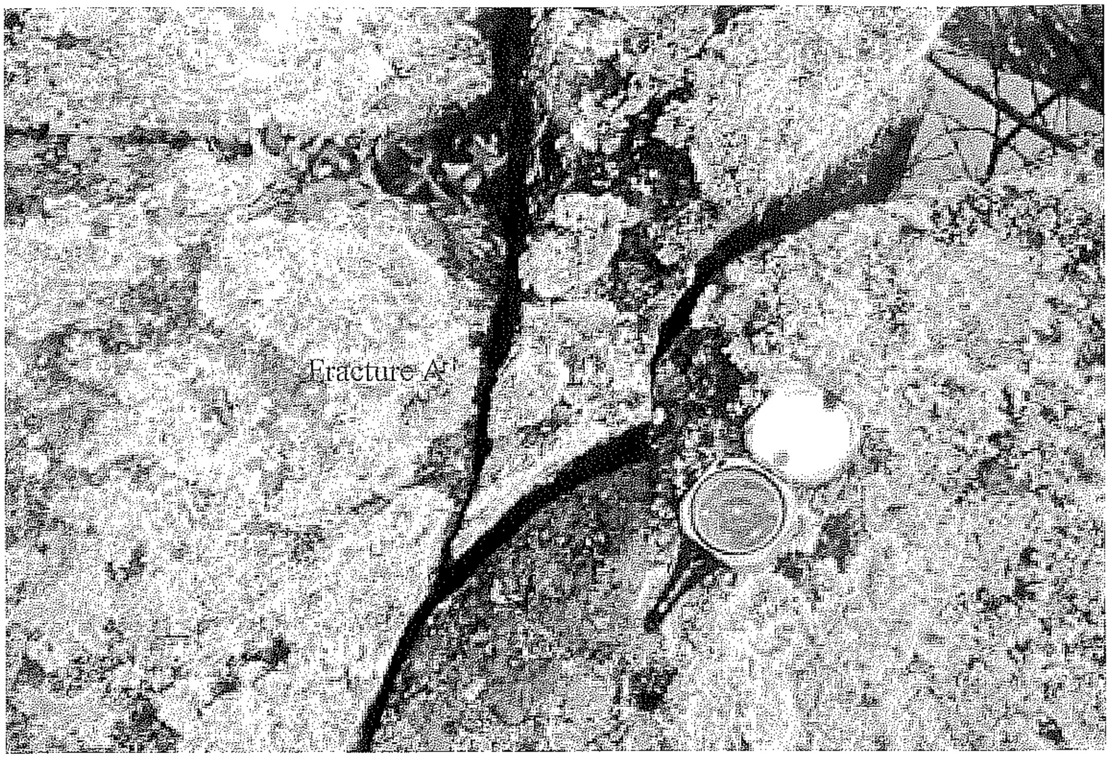
Picture 7

Picture 8 - The fracture trending N30E had an offset of eighteen inches.



Picture 9 - N10W is older than N80W

Picture 10 - N20W older than N10E

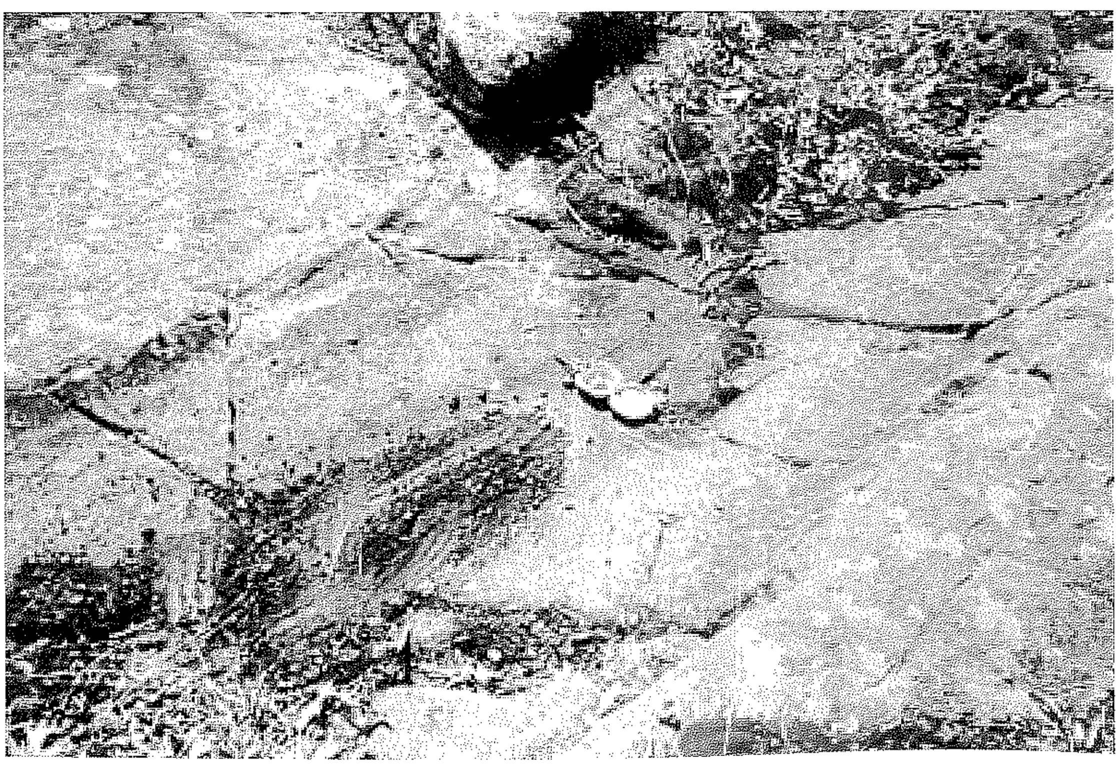


Picture 11 - N5E older than N20E but it is younger than N90E

Picture 13 – Aplite dike

S75W 8" thick

Picture 14 - the basalt dike N80W is older that N10E



Picture 15 – Basalt dike

Picture 21 – Aplite dike

Picture 22 - S30E is older than S30W

Table 1

ORIGINAL DATA

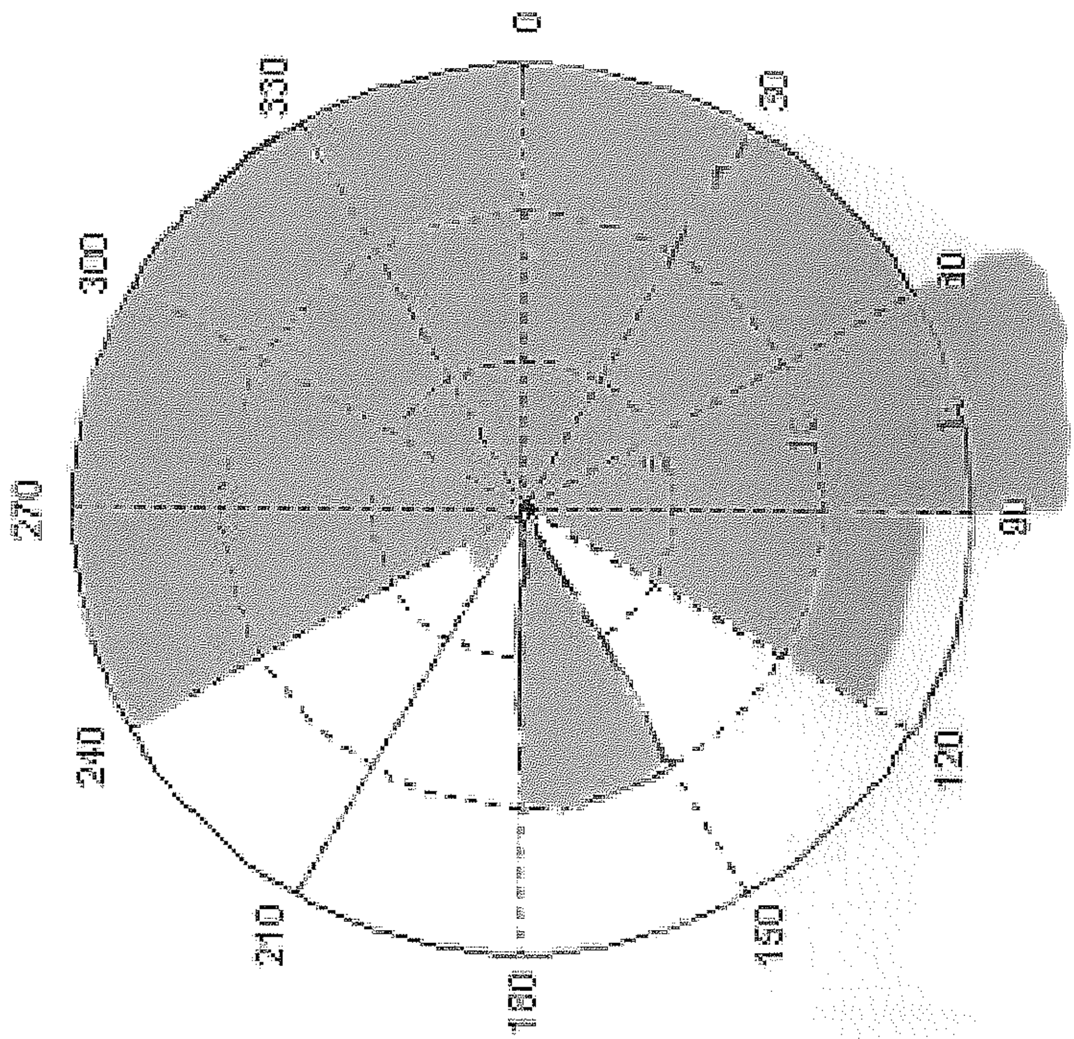
Quantity	Trend			Azimuth	Crosscutting	Off-set	Picture	Comments
DAY 1								
2	S	70	E	110	B		7	
	N	30	E	30	A	18"	7 & 8	
2	S	60	E	120	C		8	
2	S	10	E	170	C			
2	N	50	W	310	B			
	N	65	W	295				
2	N	50	E	50				
2	N	10	W	350	A	3"	9	
	N	80	W	280	B		9	
	N	30	W	330	A			
	N	5	W	355	B			
	N	70	W	290				
	N	60	E	60				
2	N	10	E	10	B		10	
2	N	20	W	340	A		10	
4	N	90	E	90	B			
	N	45	W	315				
	N	90	E	90	A			
	N	5	E	5	B/A		11	
	N	20	E	20	/B		11	
DAY 2								
	N	60	E	60	A			
	N	90	E	90	B			
	S	75	W	255			13	Aplite dike 8" thick
	S	75	W	255				
3	N	60	W	300				
	N	45	W	315	B			
	N	55	W	305	A			
	S	55	W	235	B			
	N	55	W	305	A			
3	S	70	W	250	C			
2	S	60	W	240	B			Aplite dike 8"thick
3	S	75	W	255	C			

2	N	30	W	330	B			
3	S	80	W	260	A			
	S	60	E	120	C			
2	S	65	W	245	B			
3	N	65	W	295	A			
	S	5	W	185	A			
	N	70	W	290	B			
BASALT DIKE	S	60	W	240			15	Basalt dike 2.5' THICK
2	N	50	W	310	B			In basalt dike
2	N	0	E	0	A			In basalt dike
	N	80	W	280	A		14	In basalt dike
	N	10	E	10	B		14	In basalt dike
3	N	0	E	0	A			In basalt dike
2	N	90	E	90	C			In basalt dike
	N	20	E	20	B / A			In basalt dike
	N	40	W	320	/ B			
S/W SIDE								
3	S	30	E	150	A		22	
2	S	30	W	210	B		22	
2	N	55	W	305	A			
4	S	65	W	245	B			
3	N	90	E	90				
2	S	50	E	130				
	N	65	E	65				
2	N	35	E	35				
	S	70	W	290	A			
	S	10	E	170	B			
3	N	50	E	50	C			
	N	15	W	345				Aplite dike 1" thick
	S	50	E	130			21	Aplite dike 3" thick

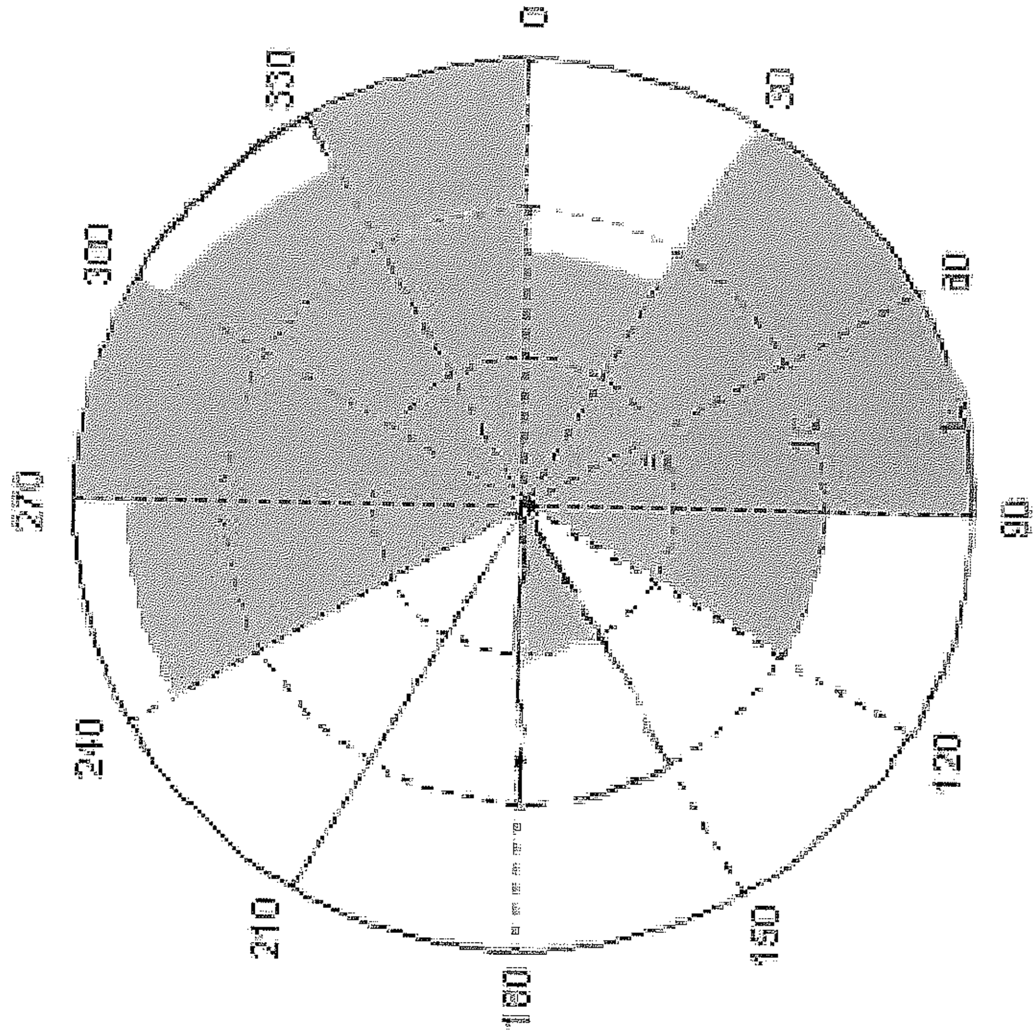
Table 2

SORTED DATA									
Quantity	Trend			Azimuth	Crosscutting	Off-set	Picture	Comments
5	N	0	E	0	A			In basalt dike
2	N	5	E	5	B/A		11	
3	N	10	E	10	B		10 &14	In/out basalt dike
2	N	20	E	20	B / A		11	In basalt dike
3	N	30	E	30	A / B	18"	7 & 8 &22	
2	N	35	E	35				
5	N	50	E	50	C			
1	S	55	W	235	B			
4	N	60	E	60	A / B			Aplite dike 8"thick
1	S	60	W	240			15	Basalt dike 2.5' THICK
7	N	65	E	65	B			
3	S	70	W	250	C			
6	S	75	W	255	C		13	Aplite dike 8" thick
3	S	80	W	260	A			
11	N	90	E	90	B/A/B/C			C - in basalt dike
2	N	80	W	280	B/A		9&14	In basalt dike
5	S	70	E	110	B/A		7	
4	N	65	W	295	A			
6	S	60	E	120	C		8	
4	N	55	W	305	A			
2	S	50	E	130			21	Aplite dike 3" thick
4	N	50	W	310	B			In/out basalt dike
2	N	45	W	315	B			
1	N	40	W	320	/ B			
6	S	30	E	150	A / B		22	
2	N	20	W	340	A		10	
1	N	15	W	345				Aplite dike 1" thick
5	S	10	E	170	A/C/B	3"	9	
1	N	5	W	355	B			
103								

Diagram 1

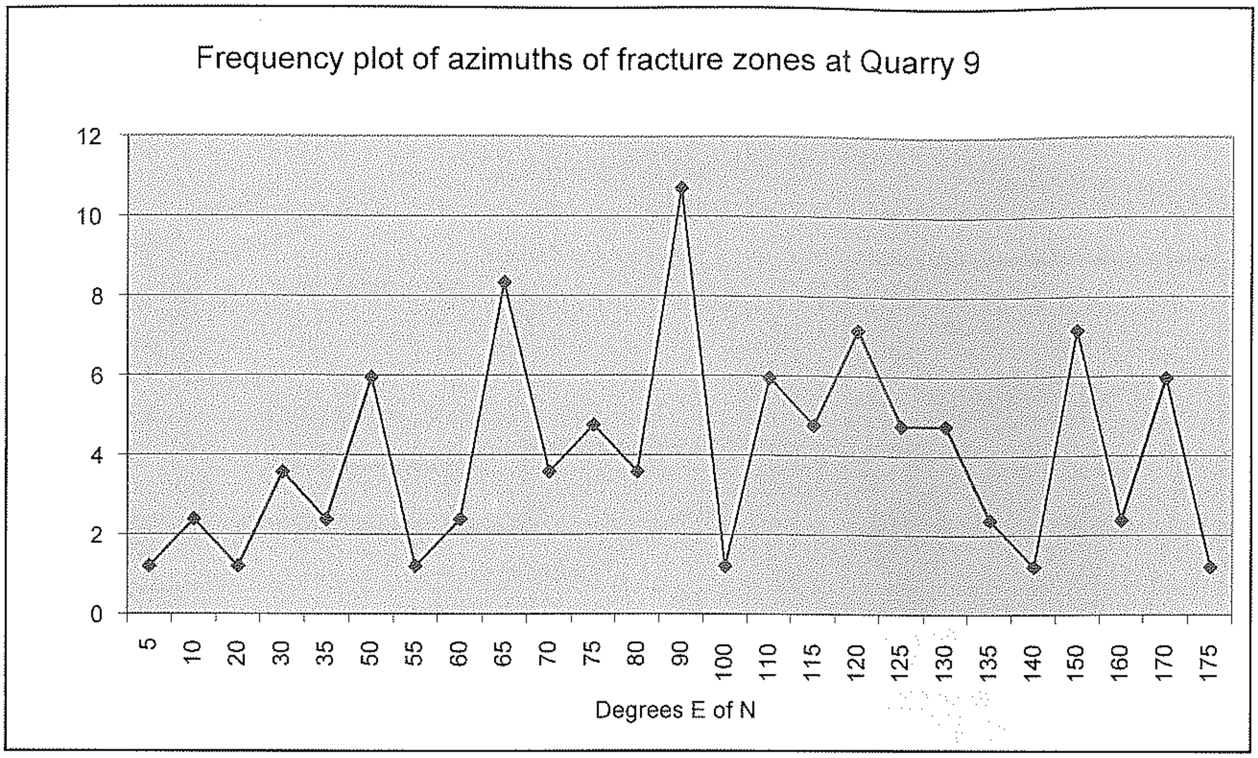


All joint fractures (filled and not) measured at Quarry 9 for this project.



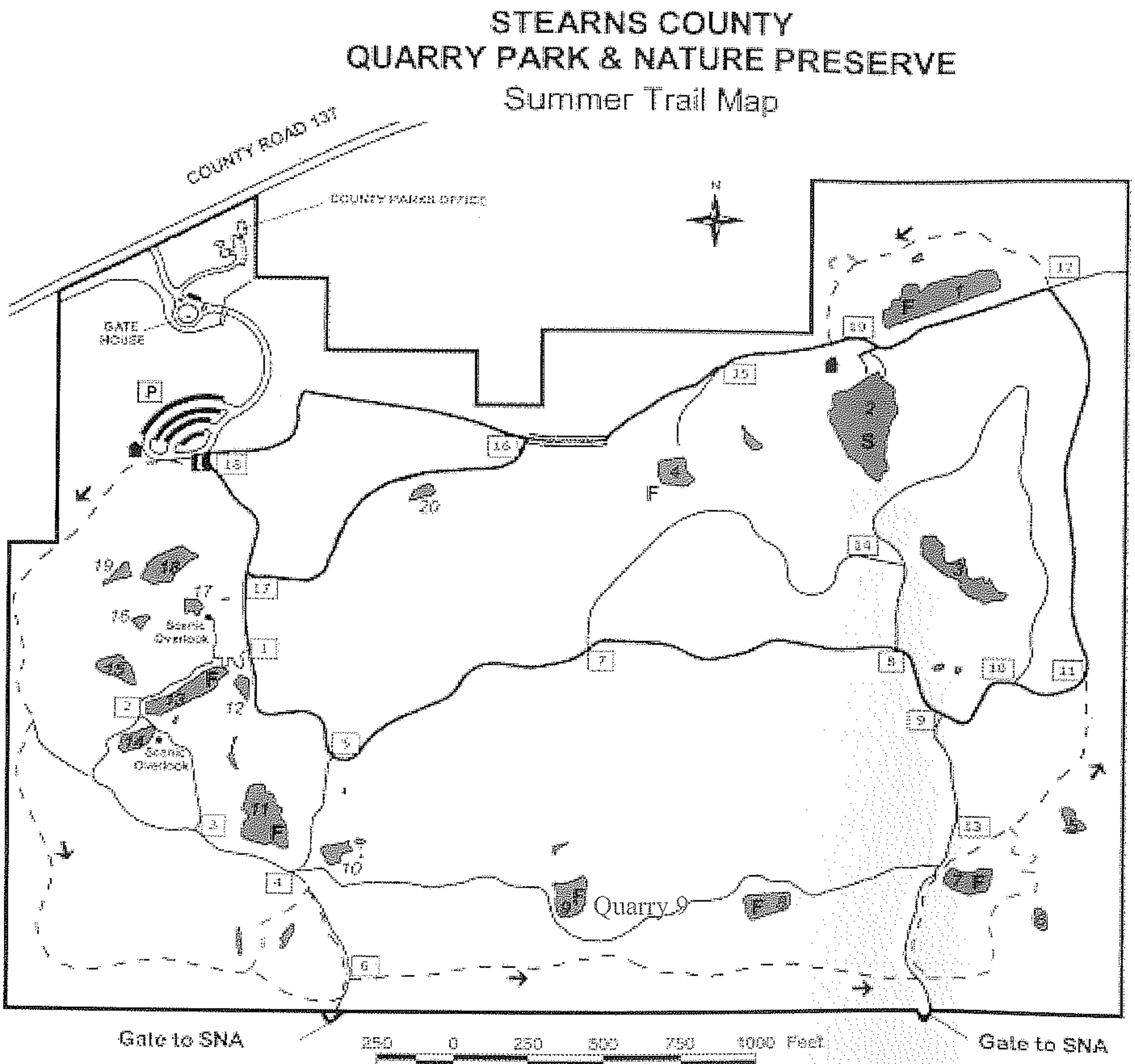
There area no fractures containing aplite or with in the basalt dike, only joint fractures.

Diagram 2

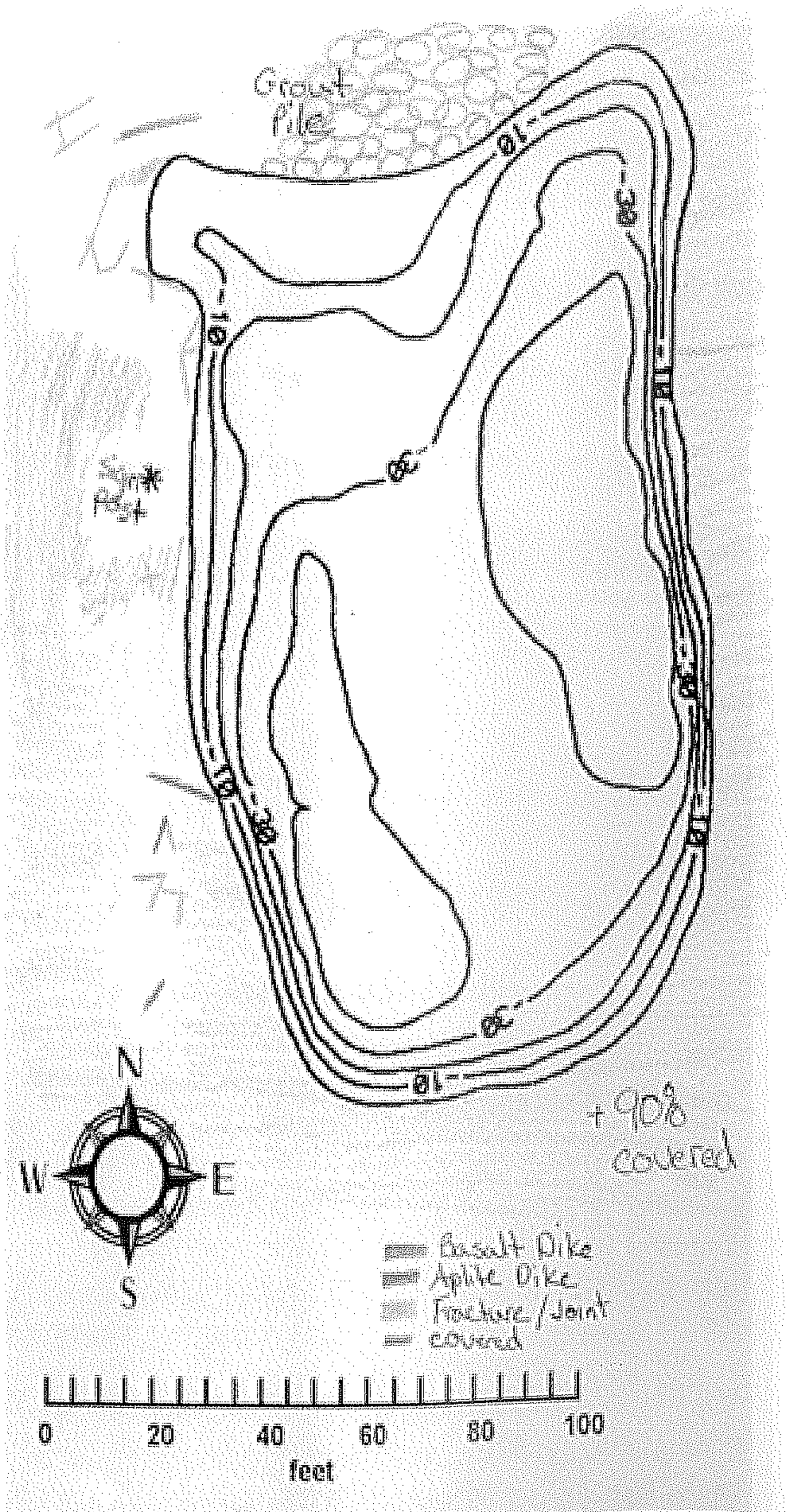


Frequency plot of azimuths of fracture zones at Quarry 9
12
10
8
6
4
2
0
5
10
20
30
35
50
55
60
65
70
75
80
90
100
110
115
120
125
130
135
140
150
160
170
175
Degrees E of N

Park Map


STEARNS COUNTY
QUARRY PARK & NATURE PRESERVE
Summer Trail Map
COUNTY ROAD 137
COUNTY PARKS OFFICE
GATE HOUSE
P
Scenic Overlook
Scenic Overlook
Quarry 9
Gate to SNA
Gate to SNA
250 0 250 500 750 1000 Feet

Quarry 9


Grout Pile
+90% covered
N
W
E
S
Basalt Dike
Aplite Dike
Fracture/Joint
covered
0
20
40
60
80
100
feet