Flambeau Project pit slope design. 1988

West, R. J.
Arizona: Call & Nicholas, Inc., 1988

FLAMBEAU PROJECT PIT SLOPE DESIGN

Prepared for

BP Minerals America

Prepared by

R. J. West
R. D. Call, P.E.
W. K. Walker
C. L. Evans

Registered Professional Engineer (Geological)
CERTIFICATE No.
7104
Richard D. Call
Date Signed
Arizona U.S.A.

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CALL & NICHOLAS, INC.

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1.0 INTRODUCTION

Results of the Call & Nicholas, Inc. (CNI) pit slope design study for the BP Minerals America (BPMA) Flambeau open pit copper project are presented in the following report.

1.1 Purpose of Study

The purpose of this study was to recommend an optimum bench design and interramp slope angles for the BPMA project, based on an assessment of pit slope stability.

1.2 Scope of Study

The CNI portion of the study consisted of the following phases for the project site:

1) reduction of both geologic structure and rock strength data;

2) geologic structure analysis (fabric analysis) and development of a suitable engineering geology model;

3) analysis of bench stability using rock fabric data;

4) assessment of multibench stability using geologic maps and cross sections provided by BPMA;

5) recommendations of bench geometry and interramp slope angles; and

6) preparation of a final report.

Because of the absence of outcrops in the Flambeau project area, no detailed surface mapping of structure was possible. However, core drilling, core orienting, geomechanical logging, and point load testing were carried out by BPMA during 1987 and early 1988. Specifically, work done by BPMA included:

1) orienting, point load testing, and geomechanical logging of eight diamond drill angle holes at Flambeau;

2) point load testing and geomechanical logging of an additional 20 diamond drill holes; and

3) directing and performing a rock testing program at the University of Utah.

A limited size small scale direct shear rock testing program was conducted at the University of Arizona Rock Mechanics Laboratory in Tucson. Triaxial compression, uniaxial compression and disk tension testing was conducted on rock samples at the University of Utah in Salt Lake City. In addition, two geotechnical consulting groups located in Wisconsin, conducted soils testing on overburden material in various programs during the 1970s and 1980s. Rock fabric analysis and stability analyses were conducted in Tucson, Arizona.

Results of subsurface structure data collection, fabric analyses, and pit geology (developed by BPMA), and stability analyses are included in this report. Supporting documentation is included in a separate structure and rock strength appendix.

2.0 SUMMARY

During this engineering study, CNI evaluated slope stability for the BPMA Flambeau project and provided geotechnical input for mine planning. Recommended slope angles were based on evaluations of the expected impact of foliation on bench and multibench geometry. The work included core drilling, rock testing/strength properties evaluation, geologic fabric analysis, and probabilistic slope stability analysis.

CNI completed most of the data processing and stability analyses were conducted in our Tucson office. BPMA conducted core orienting and geomechancial logging. Pincock, Allen & Holt, Inc., for BPMA, developed and made available to CNI the design pit plan. The surface geology plan and design cross sections used in this study were developed by BPMA geology personnel. Rock testing was conducted at the University of Utah, under the direction of BPMA, and at the University of Arizona, under the direction of CNI engineers. Soils testing was conducted by Foth and Van Dyke in Wisconsin, and Soil Testing Services, Inc. in Wisconsin and Chicago, Illinois.

2.1 Design Recommendations

Slope Angles

CNI recommends the following design parameters for indicated wall orientations of the proposed Flambeau design pit (Table 2-1 and Figure 2-1).

Table 2-1

Recommended Flambeau Design Parameters

Pit Sector Designation	Interramp Slope Angle (deg)		Bench Height (ft)	Design Bench Configuration: Catch Bench Width (ft) Minimum	Catch Bench Width (ft) Mean	Mean Bench Face Angle (deg)	Basis of Design Recommendations
Footwall	Rock:	50	60	27.0	28.7	70.2	Foliation controls bench face angle (BFA)
	Overburden:	36	Continuous Slope	N.A.	N.A.	N.A.	Optimum geometry for limited equilibrium
Hanging Wall	Rock:	50	60	27.0	28.7	70.2	Steep BFA resulting from step path geometry
	Overburden:	36	Continuous Slope	N.A.	N.A.	N.A.	Optimum geometry for limited equilibrium
Northeast Wall	Rock:	50	60	27.0	28.7	70.2	No adversely oriented structure
	Overburden:	36	Continuous Slope	N.A.	N.A.	N.A.	Optimum geometry for limited equilibrium
Southwest Wall	Rock:	50	60	27.0	28.7	70.2	No adversely oriented structure
	Overburden:	36	Continuous Slope	N.A.	N.A.	N.A.	Optimum geometry for limited equilibrium

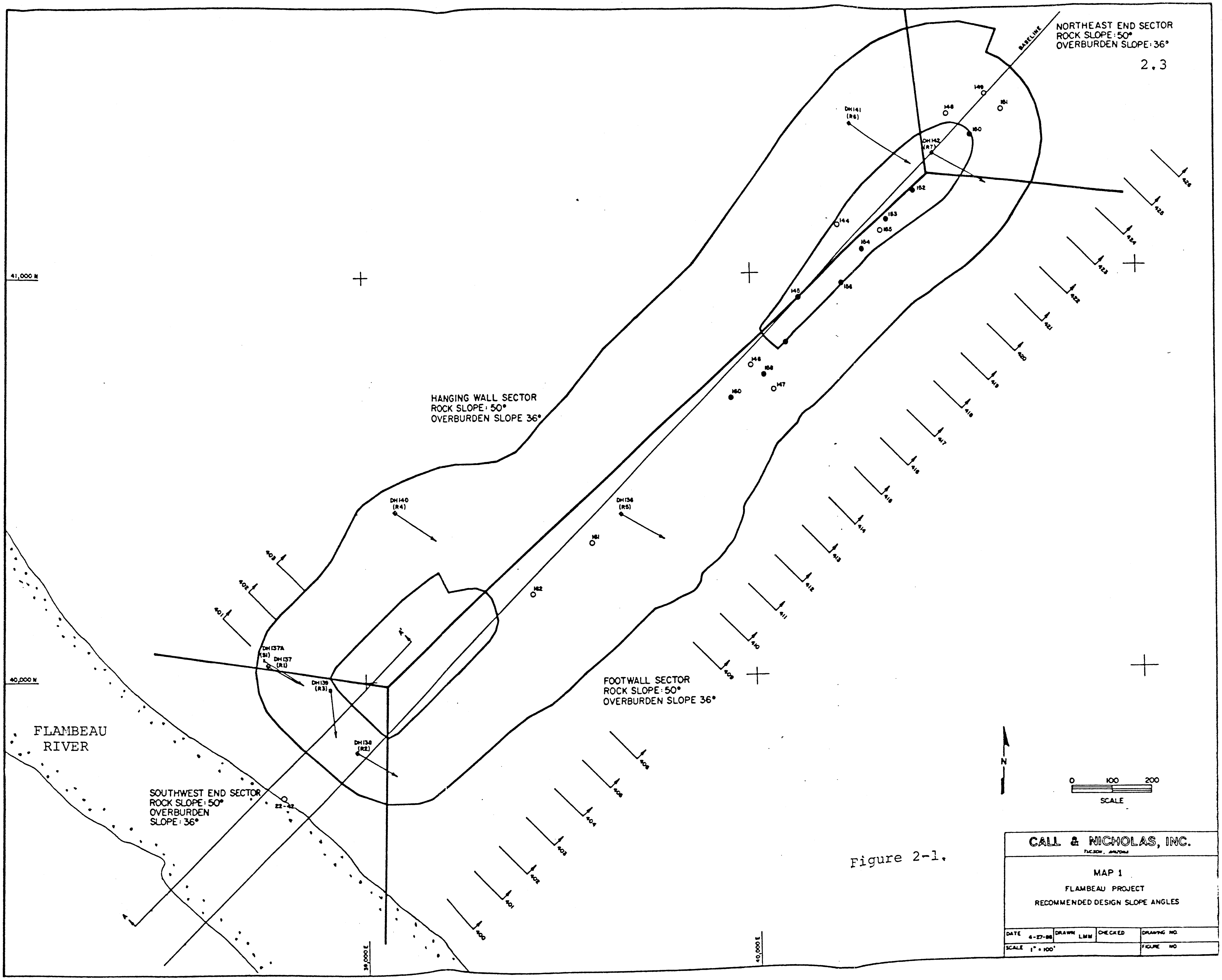

NORTHEAST END SECTOR
ROCK SLOPE: 50°
OVERBURDEN SLOPE: 36°
BASELINE
HANGING WALL SECTOR
ROCK SLOPE: 50°
OVERBURDEN SLOPE 36°
FOOTWALL SECTOR
ROCK SLOPE: 50°
OVERBURDEN SLOPE 36°
SOUTHWEST END SECTOR
ROCK SLOPE: 50°
OVERBURDEN
SLOPE: 36°
FLAMBEAU
RIVER
41,000 N
40,000 N
39,000 E
40,000 E
DH141
(R6)
DH142
(R7)
DH140
(R4)
DH136
(R5)
DH137A
(S1)
DH137
(R1)
DH139
(R3)
DH138
(R2)
0
100
200
SCALE
N
CALL & NICHOLAS, INC.
MAP 1
FLAMBEAU PROJECT
RECOMMENDED DESIGN SLOPE ANGLES
DATE
DRAWN
LMM
CHECKED
DRAWING NO.
SCALE
1" = 100'
FIGURE NO.

Figure 2-1.

2.2 Engineering Geology

The Flambeau volcanogenic massive sulphide copper deposit is located in northwestern Wisconsin approximately 130 miles northeast of Minneapolis-St. Paul and 220 miles northwest of Madison. Immediately north of the project site is the town of Ladysmith, county seat of Rusk County.

The N45E trending economic mineralized zone is conformable to a series of steeply NW dipping (71°) schistose metavolcanic rocks of Precambrian age. The schist varieties are metamorphic and hydrothermal alteration products of an original volcanic pile consisting of variably textured and multicompositional pyroclastic and extrusive flow units.

An extensive supergene zone has altered the Precambrian volcanoclastic rock to depths up to 225 ft below the surface. A variably thick, intensely weathered saprolite-gossan unit caps the supergene alteration zone to a maximum depth of 30 ft. Overlying the weathered unit is a 35 to 90 ft thick layer of Pleistocene overburden consisting of glacial till, outwash and fluvial deposits. A discontinuous, thin layer of Cambrian sandstone separates the saprolite-gossan zone and the Pleistocene soils.

Several E-W trending (Strike: 100° to 110°) faults have been interpreted along the 2500 ft strike length of the ore body. These structures have been interpreted from results of closely spaced diamond drilling that indicated offsetting of the massive sulfide mineralization and metavolcanic rock units. One of these interpreted faults has been observed in core holes drilled on Section 408.

Foliation is well developed throughout the project area, is assumed to be continuous in length, and has a calculated spacing of about 2 ft. Because of the paucity of other closely spaced, adversely oriented fracture sets, CNI anticipates that foliation will control overall bench scale and probable multibench geometry.

2.3 Rock Strength

Table 2-2 summarizes Flambeau natural fracture and rock substance shear strength. Intact rock strength, elastic properties, and densities are shown in Table 2-3, and soil strength properties and densities are summarized in Table 2-4. This data is derived from testing conducted at the University of Utah, the University of Arizona (Tables 2-2 and 2-3) and in Wisconsin (Table 2-4). In Table 2-3 the estimated uniaxial compressive strength has been determined from point load testing conducted on core samples by BPMA personnel. Additional soil test results, such as permeability properties, Proctors and sieve analyses, were obtained from a report completed by Foth & Van Dyke.

In addition to the usual geologic and structural logging, as well as point load testing, geomechanical information such as RQD, rock hardness, and core length was collected from the drill core. Table 2-5 summarizes the calculated mean values for the indicated geomechanical parameters.

2.4 Hydrology

According to Zavis Zavodni of BPMA, the primary groundwater aquifer in the Flambeau project area "is believed to occur within the till and outwash deposits and the thin Cambrian sandstone that overlie the generally poor Precambrian basement aquifer." These overlying Pleistocene gravels and sandy units are expected to produce significant quantities of groundwater during initial mining excavation. However, the inflow should fall off rapidly.

Table 2-2

(1)Rock Natural Fracture and Rock Substance Shear Strength Properties

Rock Type	(3)Test Type	Number of Samples	Mean Cohesion (psi)	Mean Phi (deg)
(Foliation)(2)	D.S.	6	7.78	18.30
2a(Joint)	D.S.	1	0.81	32.41
1a	T.C.	3	145	51
S1a	T.C.	3	500	55
2a	T.C.	5	120	58
2c	T.C.	3	620	44
3a	T.C.	1	240	28
4c	T.C.	2	135	64
5	T.C.	1	1065	24

(1) Data Source: Natural fracture strength (D.S.) data - University of Arizona

(2) Rock types included 1a, 2b, 2c, 3a, 4a, and 5.

(3) D.S.: Small scale direct shear
T.C.: Triaxial compression

Table 2-3

Intact Rock Strength, Elastic Properties and Rock Densities

Rock Type	Number of Samples	Uniaxial Compression (psi)	Density (pcf)	(1) Estimated Compressive Strength (psi)	Number of Samples	Disk Tension (psi)	Density (pcf)	Number of Samples	Young's Modulus x10^6 psi	Poisson's Ratio
Massive	1	5943	302	5376	-	-	-	1	11.083	0.22
1a	6	1545	146	2912	3	206	148	1	1.215	0.31
S1a	6	2274	186	2934	3	322	183	2	4.322	0.25
1b	1	10313	166	-	-	-	-	-	-	-
S1b	-	-	-	29142	-	-	-	-	-	-
2a	8	2136	148	1702	2	223	142	4	1.865	0.15
2b	-	-	-	1456	3	112	169	-	-	-
2c	2	6543	164	1949	1	504	153	-	-	-
3a	-	-	-	1501	3	134	157	-	-	-
4c	-	-	-	1994	1	697	141	-	-	-
5	2	1223	135	1904	-	-	-	-	-	-

(1) Estimated compressive strength calculated by multiplying point load data times 22.4.

Table 2-4

(1)Soil Shear Strength and Densities

Soil(2) Type	Test Type	Number of Samples	Effective Strength Phi (deg)	Effective Strength Cohesion (psi)	Wet Density (pcf)	Dry Density (pcf)
ML	Triax C.	3	24.3	2.89	145.0	127.5
SM	Triax C.	1	28.5	3.56	144.8	131.8
SM	Direct Shear	1	33.0	0.00	-	124.0
SP	Direct Shear	1	36.0	0.00	-	113.8

(1) Data Source - Foth & Van Dyke (1988)

(2) ML: Low plasticity silt
SM: Sand to silty sand
SP: Clean sand to gravelly sand

TABLE 2-5

FLAMBEAU PROJECT CORE DATA*
POOLED GEOMECHANICAL STATISTICAL DATA
BY ROCK TYPE (LENGTH VALUES IN FEET)

ROCK TYPE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS
1A	83.43	5.69	0.53	2.42	0.82	37.61	2.09
ORE	76.46	3.75	0.68	2.08	0.84	42.50	2.68
S1A	79.78	4.49	0.68	2.00	0.77	34.30	2.27
1B	87.07	6.98	0.43	2.70	0.69	33.24	3.34
S1B	97.00	4.77	0.51	2.07	0.92	63.30	3.66
2A	88.65	5.10	0.60	1.95	1.03	55.84	1.79
2B	85.67	6.13	0.55	2.18	0.87	45.30	2.02
2C	93.28	5.05	0.69	1.69	1.10	60.28	2.04
3A	89.62	4.24	0.69	1.75	1.11	59.29	1.53
4C	91.93	11.77	0.58	2.48	0.89	42.68	2.69
5	90.07	11.27	0.89	1.39	1.15	43.60	1.66
CSS	49.50	13.05	0.73	1.45	0.39	6.18	2.73
GOS	45.52	4.16	0.96	1.21	0.85	30.42	2.13
SAP	31.50	0.00	1.23	1.59	0.21	0.00	0.00

* Drill Holes 136-137, 137A, 138-162.

ROCK TYPE KEY

"1A" : SERICITE-QUARTZ SCHIST (ORE ZONE)
"ORE": ORE (ORE ZONE)
"S1A": SEMI-MASSIVE ORE (20-50 WEIGHT % SULPHIDE)
"1B" : META-CHERT (ORE ZONE)
"S1B": META-CHERT (ORE ZONE)
"2A" : ANDALUSITE-BIOTITE-QUARTZ-CHLORITE SCHIST (MINOR SERICITE); BIOTITE-SERICITE-QUARTZ-CHLORITE SCHIST
"2B" : ANDALUSITE-BIOTITE-CHLORITE-QUARTZ-SERICITE SCHIST
"2C" : BIOTITE-QUARTZ-CHLORITE PHYLLITE (LOCALLY MINOR SERICITE)
"3A" : QUARTZ-AUGEN SCHIST
"4C" : AMPHIBOLE-CHLORITE SCHIST
"5" : META-DACITE (ANDESITE?) AND PORPHYRITIC META-DACITE
"CSS": CAMBRIAN SANDSTONE: WELL ROUNDED AND SORTED QUARTZ ARENITE
"GOS": GOSSAN: WEATHERED ORE ZONE (SULPHIDE RICH) MATERIAL - SIMILAR TO SAPROLITE)
"SAP": SAPROLITE: WEATHERED Pc SCHIST MATERIAL (SIMILAR TO GOSSAN)

CNI recommends a minimum 10 ft wide bench along the pit crest near the overburden-Precambrian bedrock interface to accommodate a drainage ditch to divert groundwater flow away from the mine. Due to anticipated permeability along foliation planes, coupled with the presence of cross jointing, groundwater flow in the Precambrian rocks, though quite low, should be adequate to preclude significant pore pressure buildup in the pit walls.

2.5 Seismicity

CNI did not conduct a formal seismic study of the Flambeau area since it is relatively seismically inactive. Published material on earthquakes in the United States indicates a site acceleration of only about 3 percent *g* will occur in the next 500 to 1,000 years. Since the 3 percent *g* is considerably lower than an acceleration necessary to cause damage to pit walls (approximately 10 to 15 percent *g*), seismic loading was not considered in the Flambeau stability analyses.

2.6 Slope Design

The Flambeau pit was divided into (1) the Footwall Sector, (2) the Hanging Wall Sector, (3) the Northeast End Sector, and (4) the Southwest End Sector. The slopes comprising these four sectors were analyzed for bench configuration only. This is because, although E-W trending faults (Strike: 100° to 110°) which might impact multibench stability have been interpreted, no data is available regarding their dip or continuity. When more information concerning major structures is known, an evaluation of their presence and effect on slope stability should be made.

Bench Design

CNI recommends the bench design shown in Figure 2-2 at Flambeau. This design, a modification of Ritchie's highway cut design, provides a practical method for preventing significant spill over from rock fall to benches below. The bench increments, as indicated in the figure, are in 20 ft intervals. CNI recommends that 60 ft high triple benching be utilized at Flambeau, with a nominal 27 ft wide minimum catch bench width.

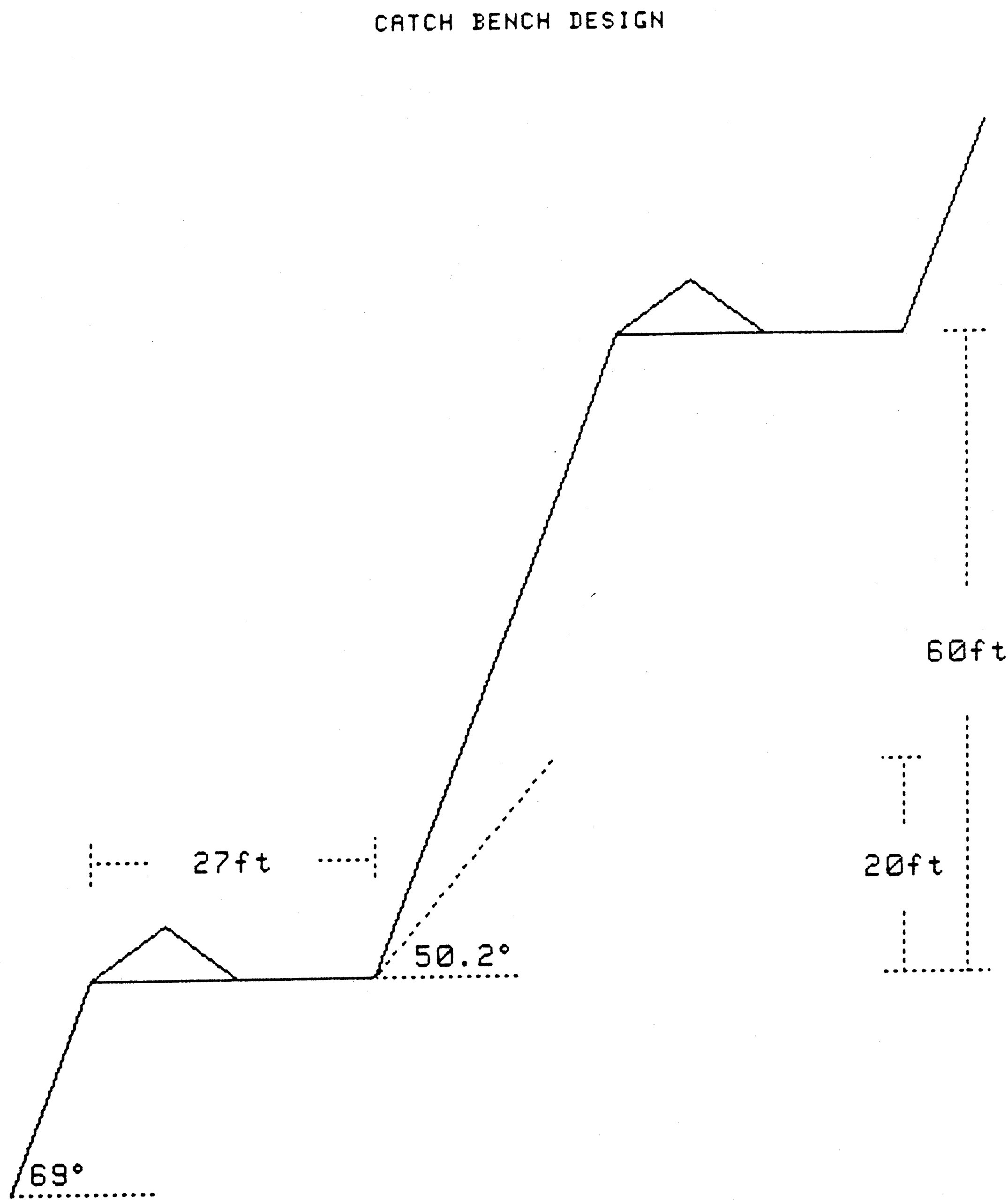
A bench face angle of 69° should be attainable in all design sectors at Flambeau. This face angle will be controlled by foliation structure, which is oriented roughly N45E, dipping 70° NW, and parallel to the footwall and hanging wall pit slopes.

The 60 ft bench height, 27 ft minimum catch bench width, and 69° bench face angle result in a 50° interramp slope angle.

CNI addressed the potential for two failure modes, buckling and slab failure in the footwall. These failures are sometimes observed in bedded or foliated rocks, particularly when the bedding or foliation planes are well developed, closely spaced, and relatively continuous.

The analysis of both geometries indicates failure is unlikely in Flambeau pit walls. In areas of localized thinning of folia and/or pitward dipping rolls in the schist units, some plane shear failure is possible.

The hanging wall was evaluated for plane shear, wedge, step path, and toppling. None of these failure modes produced a critical geometry that would control the bench face angle. In the absence of a bench face angle structural control, the same bench face angle and interramp angle are recommended for the hanging wall to allow for backbreak resulting from blasting or toppling.



MINING HEIGHT	20	ft
CATCH BENCH INCREMENT	3	
BENCH HEIGHT	60	ft
CATCH BENCH WIDTH	27	ft
BERM HEIGHT	5	ft
BERM WIDTH	14	ft
OFFSET	0.0ft	
FACE ANGLE	69.0°	
BENCH FACE ANGLE	69.0°	
INTERRAMP ANGLE	50.2°	

Figure 2-2: Flambeau Pit Catch Bench Geometry.

Overall Slope Design

Several E-W oriented faults are thought to exist in the south central part of the proposed Flambeau pit area. However, these structures have generally not been observed in drilling, and no information is available concerning dip or continuity of these structures.

Once the Precambrian rocks are exposed during mining, major structure mapping should be conducted to establish the locations of these features.

Rotational shear and sliding block analyses were conducted on the overburden material to determine potential failure geometries and optimum slope angles. Based on the analyses, CNI recommends a 36° continuous slope for the overburden material at Flambeau. An angle steeper than 36° is not recommended because of the potential for raveling of sand and gravel lenses. As indicated earlier, a minimum 10 ft wide bench should be left near the base of the overburden slope and the bedrock interface.

A rotational shear analysis was conducted on the southwest end of the design pit to assess the overall stability of the "pillar" between the pit and the Flambeau River.

According to the analysis, only 6 percent intact rock is required along the rotational failure path for limited equilibrium (factor of safety = 1.0). Since the failure path cuts across jointing, we estimate there is considerably more than 6 percent intact rock along the potential failure path.

3.0 ENGINEERING GEOLOGY

The Flambeau volcanogenic massive sulphide copper deposit is located in northwestern Wisconsin approximately 130 miles northeast of Minneapolis-St. Paul and 220 miles northwest of Madison. Immediately north of the project site is the town of Ladysmith, county seat of Rusk County.

The following synopsis on regional and local geology is derived from papers provided CNI by BPMA.

3.1 Regional Geology

The deposit is located within the southern lobe of the Canadian Precambrian Shield. The Precambrian basement consists of deformed and slightly to intensely metamorphosed alternating intermediate to felsic fragmented metavolcanics of Penokean age (approximately 1.9 billion yrs old). The rocks trend east-northeasterly, are steeply dipping, occur as moderately to highly schistose belts, and are interpreted to be within a Penokean-age isoclinal fold. Subsequent regional metamorphism produced upper greenschist to lower amphibolite mineral suites. Surrounding the "greenstone" belts are large, intrusive bodies ranging in composition from granite to gabbro; granodiorite and tonalite are the most common. Overlying the Penokean-age rocks are scattered outcrops of gently dipping Barron quartzites (Middle Proterozoic age: 1.5 to 1.8 billion yrs old). Outliers of Cambrian sandstone, which form a continuous unit to the southwest, occur throughout central Rusk County.

Development of a variably thick horizon of soil occurred during the latter stages of the Wisconsin Glacial Epoch (Pleistocene age). The soils consist of either alluvial or glacio-fluvial deposits, outwash plains, or glacial till material.

Topographically, Rusk County is characterized by gently rolling sub-parallel ridges striking generally in an east-to-northeast direction. Greatest relief is normally found along the outside bends of the major rivers, although banks greater than 50 ft are uncommon. The Flambeau River cuts diagonally across the county, meandering through the town of Ladysmith and across the southwestern end of the project site.

3.2 Local Geology

The original volcanic pile at Flambeau was a complex interfingering of variably textured, multicompositional volcanics with abrupt vertical and horizontal facies changes.

The crudely tabular-shaped 50 to 100 ft wide deposit is stratiform and, as indicated earlier, trends northeast (N45E) and dips roughly 70° to the northwest. The principal mineralized zone consists of a massive sulphide zone made up primarily of pyrite with subordinate amounts of chalcopyrite and sphalerite. A gossan-oxide supergene enriched zone has been developed and preserved along most of the 2500 ft strike length of the deposit. Several smaller satellite mineralized zones lie in footwall rocks parallel to the principal deposit.

The following is a brief description of major lithologic varieties. The terms "hanging wall" and "footwall" are used to imply spatial, not stratigraphic, sequences. Rocks have been classified based on their characteristic metamorphic mineral assemblages which have developed as a result of both metasomatism and regional metamorphism.

In general, Flambeau rocks fall near the average compositions of dacites and calc-alkaline rhyolites.

3.3 Hanging Wall Rocks

Andalusite Schists

A review of several cross sections provided by BPMA indicates that, in general, the dominant metavolcanic varieties comprising the hanging wall side of the design pit include the andalusite (± biotite ± quartz ± chlorite ± sericite) schists. Specifically, these units, designated "2a," "2b," or "2c," comprise 40 to 50 percent of the NW side pit wall. These schist varieties are apparently unique among Flambeau rock units in that they display a mixture of andalusite and biotite porphyroblasts, making up 10-15 and 5-25 volume percent, respectively. Locally, the andalusite porphyroblasts are strongly clay-chlorite altered.

The presence of the andalusite/biotite porphyroblasts and chlorite matrix diminishes noticeably to the northeast, giving way to a corresponding increase in quartz and sericite. Sulphide mineralization is often associated with quartz-sericite fragments or as conformable thin lenses within the rock matrix.

The andalusite-bearing schists commonly lie in contact with the ore zone on the hanging wall side of the deposit.

Quartz-Augen Schist

Quartz-augen or so-called "quartz eye" schist, designated as "3a" or "3b," comprises roughly 10 to 15 percent of the hanging wall side of the design pit. The distinctive "eyes" are made up of two types of fragments. First, aggregates of quartz grains may form the characteristic augen features. Second, lithic fragments are observed as elongated thin bands which are generally conformable to the foliation.

The matrix is fine grained and well foliated. Both chlorite and sericite, each of which can constitute up to 50 percent of the rock volume, occur in thin layers with quartz.

Chlorite Schist

The general term chlorite schist includes three principal subvarieties: (1) quartz-chlorite schist, designated "4a," (2) spessartite garnet-biotite-quartz-chlorite schist, designated "4b," and (3) actinolite-chlorite schist, designated "4c." The "4a" and "4b" varieties are well foliated and contain felsic volcanic fragments in a finely crystalline matrix of quartz, biotite, chlorite, and garnet.

The actinolite schist ("4c") is sometimes, though not always, located at the base of the quartz-augen schist (3a, 3b). Up to 45 percent of this rock consists of actinolite that occurs as long, somewhat randomly oriented needles or rosettes up to 2 mm in size.

The chlorite schist varieties comprise roughly 10 to 15 percent of the hanging wall side design pit wall.

Meta-Dacite

A final mappable unit that occurs in variably thick horizons within the hanging wall has been designated "5." These sequences of conformable felsic to intermediate volcanic rocks were apparently not altered enough to obscure their original igneous genesis. Locally, they exhibit a porphyritic texture and range compositionally to andesite.

In general, these units will comprise up to about 10 percent of the hanging wall side design pit wall. A review of the sections indicates that, in general, they occur some distance away from the massive sulphide deposit, relative to the other volcanic varieties.

3.4 Ore Zone Rocks

Two rock type designations have been applied to units hosting economic sulphide mineralization. The principal ore bearing unit is a sericite-quartz schist and has been designated "1a"; a subordinate unit, associated with the mineralization, is made up of discontinuous beds of meta-chert, and has been designated "1b." The designations have further been subdivided into "semimassive ore" (i.e., "S1a" and "S1b"), based on the weight percent of sulphide.

In general, the ore horizon is a light grey, fine-grained, well foliated rock having a matrix of quartz (up to 60 percent) and sericite (up to 50 percent) with accessory chlorite, biotite, and andalusite. Quartz/sericite lensoid to subrounded fragments make up an average 5 to 10 percent of the rock, though locally they may comprise up to 60 percent of the rock.

As indicated above, the principle massive sulphide mineralized zone is variably thick, ranging from 50 to greater than 100 ft.

3.5 Footwall Rocks

All the aforementioned rock varieties occurring in the hanging wall also appear in the footwall section of the mine area stratigraphy according to recent data provided by BPMA, although a paper written by Ed May (also provided by BPMA) indicates that the footwall units are composed primarily of more intermediate composition and chlorite phyllites and schists, and quartz-augen schists.

Andalusite Schist

The andalusite schists, described earlier, will also comprise 40 to 50 percent of the footwall side pit rocks.

The other major volcanic units also described earlier will comprise the remainder of the footwall design pit slope, excluding the Cambrian and younger soil horizons described below.

3.6 Saprolite/Gossan

Late during the Precambrian period, a portion of the weakly mineralized folded Flambeau volcanics exposed to the effects of surface weathering decomposed completely, forming a clay-rich zone called saprolite. The saprolite, varying in thickness from 6 to 30 ft (averaging around 18 ft), apparently is best preserved under the Cambrian sandstone. Similarly, weathering effects form a gossan zone directly above the massive sulphide deposit.

3.7 Cambrian Sandstone

Up to 5 to 10 percent of both the hanging wall and footwall pit slopes will be composed of Cambrian sandstone, a weakly to moderately cemented, relatively flat discontinuous unit that unconformably overlies the Precambrian volcanics. Maximum thickness appears to be around 25 ft, averaging about 13.5 ft. Directly over the ore body, sandstone thickness is less, averaging about 8.5 ft.

3.8 Pleistocene Glacial Cover

Overlying the Cambrian sandstone is a sequence of soil units consisting of alluvial, outwash, and glacial till material ranging up to roughly 90 ft thick over the ore body. This horizon represents between 15 and 20 percent of the hanging wall/footwall pit slopes. Where the pit wall cuts the overburden, bench heights averaging 30 to 35 ft composed of the soil horizon will result. In general, soil depths increase somewhat to the northeast of the ore body.

4.0 ROCK FABRIC ANALYSIS

Because of the paucity of rock outcrops in the Flambeau study area, no surface cell mapping was possible.

Oriented Core

A total of eight oriented core holes were completed at Flambeau. These holes were strategically located to probe both the footwall and hanging wall rocks, as well as the ore zone along the deposit and the river pillar. Holes were generally oriented in a southeastern direction so as to intersect the trend of the dominant structural feature, foliation, at nearly right angles. Table 4-1 summarizes the specifics of the geotechnical drilling program conducted at Flambeau. The hole locations are shown in Figure 4-1.

Site selection, core orientation and geomechanical evaluation were conducted under the direction of BPMA.

4.1 Determination of Structural Domains

At Flambeau, under the direction of Zavis M. Zavodni, fractures observed in core were qualitatively assessed based on planarity, roughness, and continuity. Specifically, surfaces were identified as either smooth joints, rough joints, smooth breaks, rough breaks, or shear or fault zones.

A smooth or rough joint represented a natural fracture surface, generally trending with the foliation (i.e., either jointing or bedding). Breaks represented fractures that generally did not trend with the foliation planes; some of these were likely artificially or mechanically produced during drilling or handling.

Table 4-1

Summary of Flambeau Project Diamond Drilling Program(1)

Drill Hole	Total Depth(ft)	Hole Bearing	Hole Inclination	Oriented (yes/no)	Geomechanically Logged yes/no)
136(R5)	250	120°	-60°	Yes	Yes
137(R1)	164	121°	-60°	Yes	Yes
137A(R1A)	230	123.5°	-61°	Yes	Yes
138(R2)	255	120°	-63°	Yes	Yes
139(R3)	240	177°	-61°	Yes	Yes
140(R4)	275	125°	-62.5°	Yes	Yes
141(R6)	390	123°	-62.5°	Yes	Yes
142(R7)	290	122°	-58°	Yes	Yes
143	210	NA	-90°	No	Yes
144	200	NA	-90°	No	Yes
145	180	NA	-90°	No	Yes
146	165	NA	-90°	No	Yes
147	120	NA	-90°	No	Yes
148	190	NA	-90°	No	Yes
149	150	NA	-90°	No	Yes
150	130	NA	-90°	No	Yes
151	80	NA	-90°	No	Yes
152	190	NA	-90°	No	Yes
153	120	NA	-90°	No	Yes
154	100	NA	-90°	No	Yes
155	70	NA	-90°	No	Yes
156	100	NA	-90°	No	Yes
157	94	NA	-90°	No	Yes
158	80	NA	-90°	No	Yes
159	80	NA	-90°	No	Yes
160	110	NA	-90°	No	Yes
161	60	NA	-90°	No	Yes
162	44	NA	-90°	No	Yes

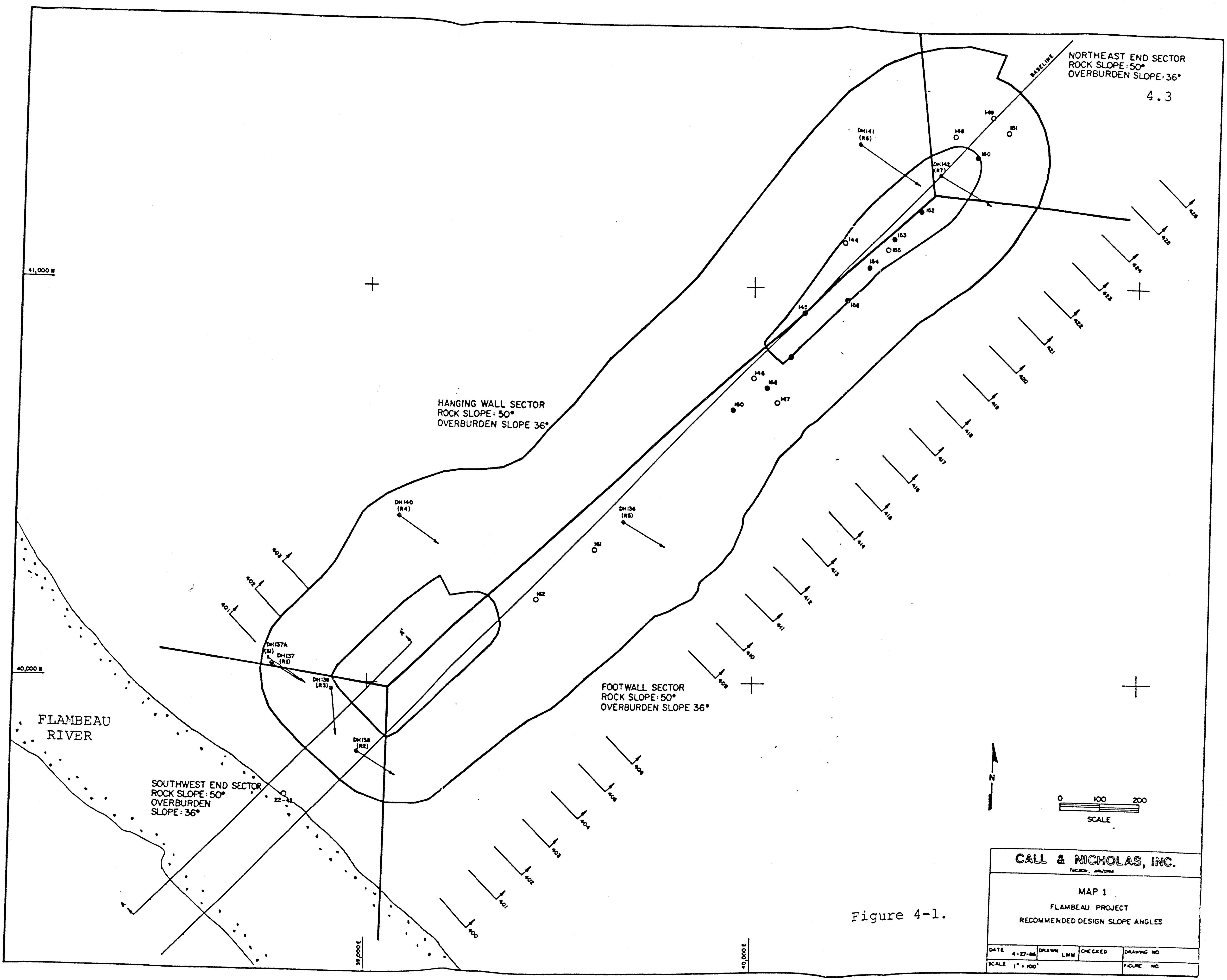

NORTHEAST END SECTOR
ROCK SLOPE: 50°
OVERBURDEN SLOPE: 36°
BASELINE
HANGING WALL SECTOR
ROCK SLOPE: 50°
OVERBURDEN SLOPE 36°
FOOTWALL SECTOR
ROCK SLOPE: 50°
OVERBURDEN SLOPE 36°
SOUTHWEST END SECTOR
ROCK SLOPE: 50°
OVERBURDEN
SLOPE: 36°
FLAMBEAU
RIVER
41,000 N
40,000 N
39,000 E
40,000 E
SCALE
CALL & NICHOLAS, INC.
MAP 1
FLAMBEAU PROJECT
RECOMMENDED DESIGN SLOPE ANGLES

Figure 4-1.

The following iterative process was used to determine structural domain boundaries at Flambeau: Schmidt plots representing intervals of similar rock types were compared to each other in individual holes to assess structural changes vertically. Plots of similar rock types from distinct holes were then compared. Finally, pooled data plots for similar lithologic units from all holes were compared with plots of other units in order to assess differences between rock types.

Since all the Precambrian rocks in the project area are stratigraphically conformable to each other, and have relatively similar compositions, one would expect to see similar fracture patterns between the schist varieties.

Indeed, no significant differences were observed, with several minor exceptions, in comparing Schmidt plots of structure data for individual rock types by hole, particularly when comparing plots consisting of "joint" data.

Foliation

Foliation appears to be widely dispersed at Flambeau, both in terms of dip direction and dip. Figure 4-2 is a lower hemisphere pole plot of "joint" structure. The broad band in the SE quadrant, identified as Set #1, is interpreted to represent the foliation. Dip direction ranges from 265° to 355°; dip ranges from 49° to 88°. The fabric analysis indicated maximum density lies at: DDR=309°, dip = 71°. Interpreted maps provided CNI suggest that foliation in

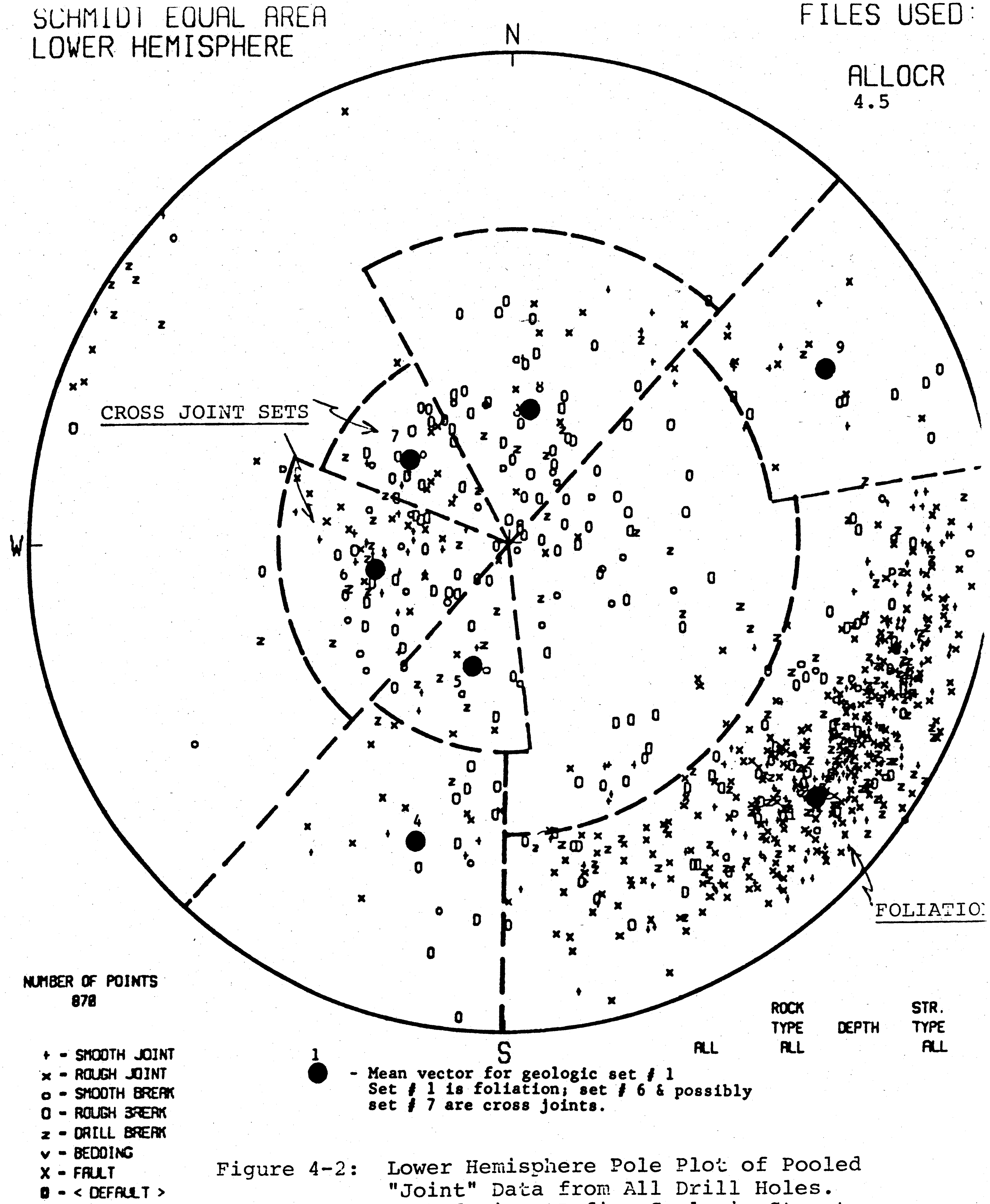


Figure 4-2: Lower Hemisphere Pole Plot of Pooled "Joint" Data from All Drill Holes. Dashed Lines Define Geologic Structure Sets Observed in Various Holes.

the project area is well behaved on a large scale. However, the foliation may be quite wavy on a small, say 10 ft interval, scale. Orienting rock core having a diameter of 2 in. would result in a highly dispersed data base, as suggested by Figure 4-2.

Deviation of core holes during drilling from design bearing (DDR=133°) was approximately 13° counterclockwise, resulting in holes being completed at azimuths around 120°. Interestingly, the foliation maximum central tendency is parallel to drilling (i.e., 129°). This data suggests that the interpreted foliation orientation trend of N43E may be off by around 7°.

Cross Jointing

A well developed cross joint set, identified as Set #6, observed in core samples is apparent in Figure 4-2. The contour high indicates the following orientation: DDR = 80°, Dip = 24°. Significant dispersion occurs in the cross jointing also, reflecting the attitude change in foliation discussed above. Set #7 may also be cross jointing related to the foliation (DDR = 128, Dip = 21°).

Other Joint Sets

The foliation and cross joint set are, by far, the most obvious and well developed structure sets at Flambeau. Several additional, less well defined joint sets became apparent during a review of the structure Schmidt plots.

The first set trends NW-SE, dipping NNE. Specifically, the average DDR is 17°, dipping 54° (Set #4). The set is best developed in Drill Hole 141; however, "fractures" in a similar orientation are present in holes 136, 138 and 142.

A second anomalous set, also best developed in hole 141, has a mean DDR of 15°, dipping 21° north (Set #5). Its presence is also suggested in holes 137A and 142 by "fractures" logged with a similar orientation.

A weak but anomalous band of "joint" and "fracture" structures (Set #8), oriented E-W, dipping 10° to 40° south, was observed in holes 137A, 138, 140, 141 and 142. These may represent cross joint structures, reflecting localized extreme dispersion in orientation of foliation discussed earlier.

A fourth anomalous cluster of structures (Set #9) is oriented roughly N45W, dipping SW. Set #9 has a mean DDR of 242 and dip of 64° SW. This set is well developed in holes 140 and 141, less so in hole 138.

Blind Zone

The likelihood of intersecting a structure parallel to the plunge of drilling in a 2 in. hole is small. Within this so-called blind zone, structural data collection is minimal, unless structure sets have a very close spacing (i.e. <2 in.).

Since all but one angle drill holes were oriented roughly perpendicular to foliation, the blind zone forms a 20° band (10° steeper and flatter than the plunge angle of roughly 60°, by convention).

There is no indication from any of the plots that a steep (>70°) structure set exists, other than foliation, in the Flambeau project area.

Change of Foliation Attitude with Depth

Histogram plots of both dip and dip direction were completed for four of the eight oriented core drill holes to determine whether a change in orientation occurs with dip. The exercise indicated that locally, extreme dispersion of either dip or dip direction may occur, but that the overall mean orientation changes very little for dip direction (<15°) and dip (<5°).

Conclusions

Some differences were observed in both individual hole and pooled data central tendencies, and in degree of development of specific sets and minor orientation changes with depth; these differences, however, were not considered significant enough to subdivide into distinct structural domains.

Therefore, for design purposes, a single structural domain, represented by structure data for all Precambrian rock types for all oriented core holes, was established. The composite plot of interpreted joint and foliation structure is shown in Figure 4-3. Figure 4-3a, a plot of all structure data, is presented to illustrate that, despite a much greater dispersion, principal central tendencies are essentially identical, as indicated by contour intervals 0.5 percent, 1 percent and 2 percent respectively.

Flambeau Project Geomechanical Data

During the core drilling program conducted at Flambeau, geomechanical data, including Rock Quality Designation (RQD), fracture frequency, length of longest piece, rock hardness,

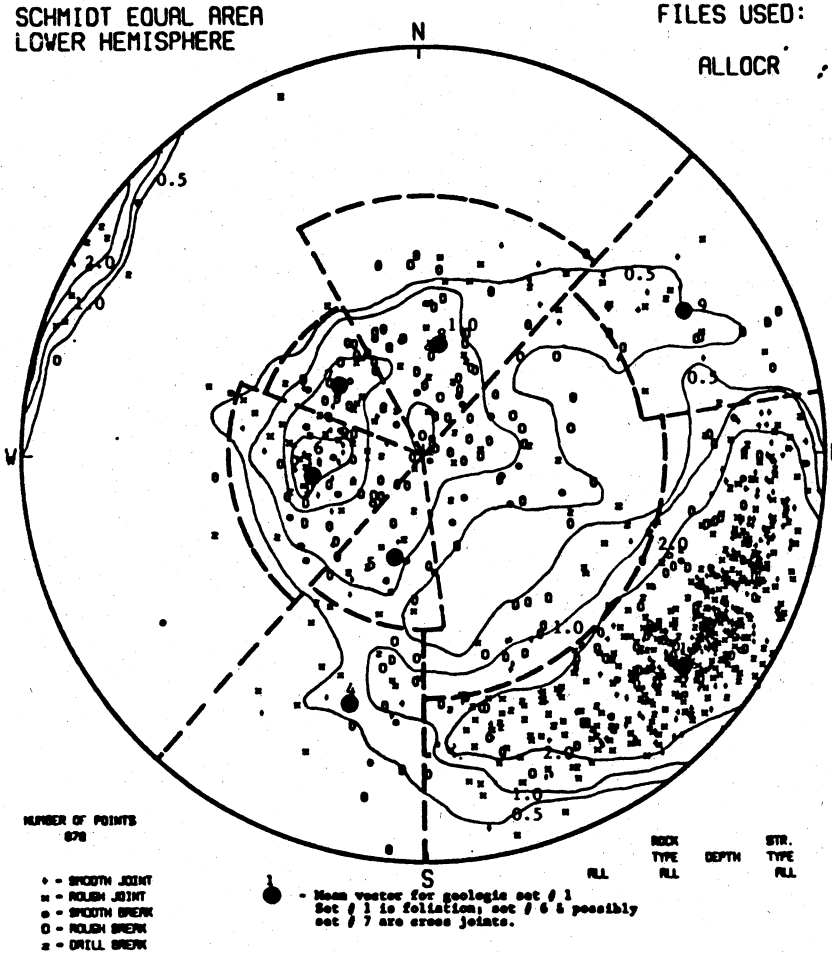


Figure 4-3a: Pooled Structure.

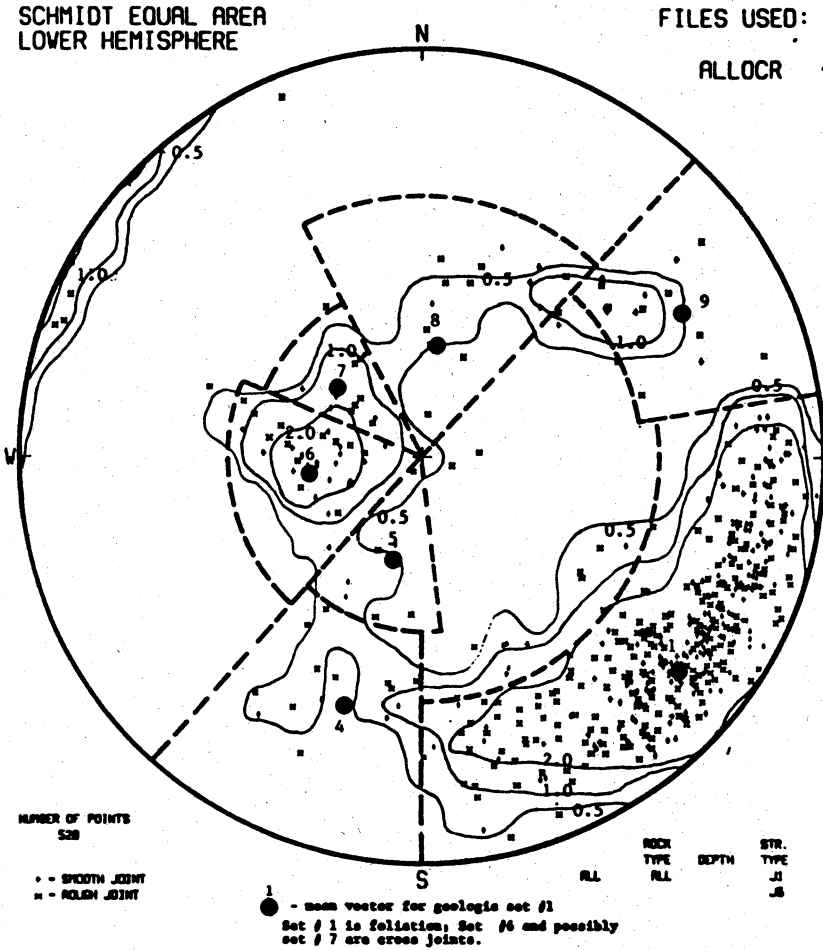


Figure 4-3b: "Joint" Structure.

Figure 4-3: Flambeau Precambrian Volcanics Structural Domain - Pooled Structure Data from all Oriented Core Holes (Contour Intervals at 0.5 Percent, 1 Percent and 2 Percent).

and broken zone length measurements were taken on core. The RQD, an indirect measure of fracture intensity, is calculated by dividing the sum length of all core pieces equal to or greater than approximately 4 in. (for NQ core) by the length of that particular drilling interval. This measurement, as well as the other geomechanical data collected, is not directly used in the slope stability analysis, but serves as an input parameter for classifying the rock mass strength.

Rock substance strength influences core breakage and, thus, affects RQD measurements. Low RQD values indicate either closely spaced fractures, low rock strength, or both. Conversely, high RQD values usually indicate widely spaced fractures and/or high strength.

A review of Flambeau geomechanical parameters suggests the following:

1) RQD values within the ore zone are extremely variable resulting in a high dispersion. This variability no doubt reflects the change in rock quality due to factors such as varying silicification, degree of sulphide enrichment, etc. within the ore zone.

2) Based on limited data, the ore zone appears to be bounded on the hanging wall side by a 20 to 35 ft thick interval of strongly fractured rock and on the footwall side by a somewhat thicker 40 to 70 ft strongly fractured zone. The hanging wall fractured zone RQD ranges 0 to 30 percent; the footwall zone RQD ranges 30 to 45 percent. The fractured halo about the massive sulphide zone is usually present, regardless of rock type.

Table 4-2 summarizes geomechanical averages calculated by rock type, by hole, and pooled averages. The "interval" column is the approximate total length of each rock type intersected, which gives the reader a feel for the weighting. The far right column, "Location," indicates the relative location of the rock type in the deposit, be it hanging wall, ore zone, or footwall. The dispersion of geomechanical characteristics for the ore zone (OZN) rocks, particularly hardness and RQD values, is noted in Table 4-2.

Pooled ore zone lithologies average 38 percent RQD; the overlying weathered gossan zone averages 30 percent RQD. The remainder of the deposit Precambrian rock stratigraphy ranges 43 to 60 percent RQD, notwithstanding the footwall/hanging wall fractured "halos" about the central ore zone.

Table 4-2

FLAMBEAU PROJECT CORE DATA
POOLED GEOMECHANICAL STATISTICAL DATA
BY ROCK TYPE (VALUES IN FEET)

ROCK TYPE 1A (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D138	75.00	30.00	0.00	0.00	0.00	0.00	3.00	4.0	OZN
D139	95.27	6.61	0.54	2.36	1.12	46.06	2.25	75.0	"
D141	89.09	2.49	0.58	1.91	1.23	77.12	2.25	46.0	"
D142	68.74	18.05	0.36	3.32	0.53	12.71	1.69	38.0	"
D143	95.09	6.14	0.44	2.45	0.74	42.28	1.89	34.0	"
D144	96.85	4.12	0.60	1.73	0.95	63.23	2.31	28.0	"
D145	74.30	3.38	0.30	4.15	0.45	6.25	2.10	55.0	"
D146	84.00	4.38	0.34	2.99	0.39	6.51	2.16	15.0	"
D147	56.61	3.05	0.99	1.28	0.36	5.55	2.00	46.0	"
D148	90.94	3.93	0.47	2.26	0.98	61.91	2.15	17.0	"
D152	39.50	0.00	0.22	0.90	0.41	5.74	2.00	10.0	"
D159	77.67	0.00	1.51	1.63	0.86	28.33	1.18	15.0	"
AVE.	83.43	5.69	0.53	2.42	0.82	37.61	2.09		

(1) ORE HORIZON: SERICITE-QUARTZ SCHIST

ROCK TYPE ORE (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D138	73.00	0.00	1.68	0.91	0.32	0.00	3.15	6.0	OZN
D139	80.37	6.80	0.46	2.30	0.82	37.62	3.00	27.0	"
D141	92.25	2.76	0.47	1.63	1.16	64.09	2.17	24.0	"
D142	95.00	13.39	0.41	2.46	1.21	40.71	3.13	10.0	"
D143	90.34	3.05	0.82	1.74	0.95	52.61	2.35	29.0	"
D144	94.67	4.08	0.54	1.92	1.12	59.69	2.41	15.0	"
D145	99.67	2.01	0.72	1.50	1.35	83.67	2.83	15.0	"
D146	72.00	1.74	0.53	2.12	0.81	44.74	3.29	56.0	"
D148	85.00	5.63	0.60	1.80	1.04	41.37	2.00	13.0	"
D150	80.67	7.02	1.44	1.03	0.57	22.15	2.33	15.0	"
D151	74.13	0.00	1.41	0.51	0.64	12.65	1.84	8.0	"
D152	74.45	2.26	0.81	1.55	0.80	34.02	2.34	53.0	"
D153	76.77	7.28	0.32	5.41	0.60	39.47	3.20	35.0	"
D154	46.00	11.30	0.52	2.69	0.84	32.09	2.41	35.0	"
D155	20.00	0.00	1.00	1.00	0.30	0.00	2.50	5.0	"
D156	89.17	1.46	0.41	2.52	0.67	36.47	2.57	23.0	"
D158	95.81	1.49	0.50	2.22	0.75	53.67	2.98	16.0	"
D159	12.00	0.00	0.90	1.11	0.22	0.00	1.00	15.0	"
D160	80.44	0.00	1.33	0.84	0.95	41.12	1.88	25.0	"
D161	86.13	3.37	0.79	1.50	0.53	29.80	3.66	23.6	"
D162	32.25	0.00	0.40	3.10	0.23	0.00	2.14	4.0	"
AVE.	76.46	3.75	0.68	2.08	0.84	42.50	2.68		

(1) ORE HORIZON: ORE
(2) OZN: ORE ZONE HWL: HANGING WALL FWL: FOOTWALL

Table 4-2(Continued)

ROCK TYPE S1A (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D136	81.67	17.05	0.56	1.93	0.67	36.13	1.48	18.0	OZN
D138	95.01	7.01	0.38	2.88	0.66	32.94	2.47	71.0	"
D141	92.06	1.36	0.74	1.52	1.2	71.74	2.56	32.0	"
D142	59.85	20.18	0.37	2.88	0.67	19.34	3.08	19.0	"
D143	94.67	3.59	0.60	1.79	0.91	48.22	2.53	45.0	"
D144	91.29	2.85	0.52	2.01	1.09	59.32	2.46	39.0	"
D145	74.10	0.00	0.47	2.25	1.09	34.17	2.49	30.0	"
D148	57.74	0.00	0.55	2.29	0.55	12.98	1.93	53.0	"
D149	84.10	6.63	0.53	1.94	0.62	17.82	2.10	50.0	"
D150	72.10	1.57	0.69	1.26	0.68	25.93	1.95	50.0	"
D151	87.67	5.11	4.15	0.25	0.22	0.00	1.66	15.0	"
D152	78.61	2.37	0.84	1.31	0.92	36.20	2.13	44.0	"
D153	90.00	2.61	0.47	2.25	0.62	36.40	2.12	20.0	"
D154	90.86	10.45	0.36	3.79	0.77	49.75	2.42	14.0	"
D157	92.00	0.00	0.51	1.96	0.39	0.00	2.50	5.0	"
D158	100.00	0.00	0.50	2.00	0.62	100.00	3.00	1.0	"
D160	42.35	0.67	1.22	1.14	0.35	3.47	2.23	34.0	"
AVE.	79.78	4.49	0.68	2.00	0.77	34.30	2.27		

(1) SEMI-MASSIVE ORE (20-50 WEIGHT % SULPHIDE)

ROCK TYPE 1B (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D136	91.88	40.24	0.32	3.93	0.90	23.12	4.00	8.0	OZN
D139	81.20	16.98	0.33	3.55	0.44	11.78	3.78	10.0	"
D143	97.71	0.00	0.24	4.39	0.47	14.38	2.37	7.0	"
D145	97.75	3.54	0.47	2.18	0.84	52.04	2.87	20.0	"
D153	91.38	0.00	0.41	2.46	0.81	53.68	3.66	8.0	"
D156	70.31	6.45	0.35	2.96	0.51	14.44	2.64	13.0	"
D157	84.35	1.05	0.55	2.02	0.69	34.49	3.80	31.0	"
AVE.	87.07	6.98	0.43	2.70	0.69	33.24	3.34		

(1) ORE ZONE: META-CHERT

ROCK TYPE S1B (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D146	97.00	4.77	0.51	2.07	0.92	63.30	3.66	30.0	OZN
AVE.	97.00	4.77	0.51	2.07	0.92	63.30	3.66		

(1) ORE HORIZON: META-CHERT
(2) OZN: ORE ZONE HWL: HANGING WALL FWL: FOOTWALL

ROCK TYPE [illegible]A (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D136	99.00	0.00	0.78	1.36	1.17	72.61	1.85	15.0	FWL
D137	90.91	4.40	0.93	1.20	1.37	62.58	1.86	31.0	HWL
D137A	97.14	3.38	0.63	1.98	1.15	61.36	1.69	74.0	"
D138	93.11	4.51	0.55	2.15	0.91	49.35	1.86	95.0	FWL
D139	89.67	5.21	0.59	2.01	1.06	63.01	1.97	64.0	HWL
D140	77.84	7.97	0.52	2.05	0.92	48.47	1.66	131.0	"
AVE.	88.65	5.10	0.60	1.95	1.03	55.84	1.79		

(1) ANDALUSITE-BIOTITE-QUARTZ-CHLORITE SCHIST (MINOR SERICITE); BIOTITE-SERICITE-QUARTZ-CHLORITE SCHIST

ROCK TYPE 2B (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D139	60.50	22.21	0.84	1.68	0.53	22.30	1.92	20.0	HWL
D141	91.16	5.40	0.54	2.16	0.97	55.54	2.14	160.0	"
D143	86.32	15.68	0.45	2.35	0.87	29.20	1.41	25.0	"
D144	85.83	1.10	0.45	2.53	0.89	45.84	2.08	58.0	"
D148	67.60	0.00	0.69	2.37	0.27	0.00	2.00	15.0	"
D149	73.53	8.32	0.86	1.13	0.30	0.00	1.31	17.0	"
AVE.	85.67	6.13	0.55	2.18	0.87	45.30	2.02		

(1) ANDALUSITE-BIOTITE-CHLORITE-QUARTZ-SERICITE SCHIST

ROCK TYPE 2C (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D136	95.46	6.41	0.73	1.52	1.15	56.48	1.91	105.0	FWL
D137	92.63	5.66	0.74	1.60	1.15	63.08	1.63	90.0	HWL
D137A	90.00	4.82	0.49	2.27	0.87	52.72	1.83	66.0	"
D142	96.49	3.02	0.73	1.54	1.22	71.85	2.74	92.0	FWL
D147	72.42	6.49	0.53	2.05	0.38	9.72	1.37	12.0	"
AVE.	93.28	5.05	0.69	1.69	1.10	60.28	2.04		

(1) BIOTITE-QUARTZ-CHLORITE PHYLLITE (LOCALLY MINOR SERICITE)

ROCK TYPE 3A (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D138	99.22	4.02	0.79	1.52	1.36	73.95	2.00	46.0	FWL
D140	84.93	4.37	0.63	1.88	0.96	50.91	1.26	94.0	HWL
AVE.	89.62	4.24	0.69	1.75	1.11	59.29	1.53		

(1) QUARTZ-AUGEN SCHIST

ROCK TYPE 4C (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D141	86.00	2.09	0.37	2.89	0.71	33.43	2.06	24.0	HWL
D142	93.97	16.69	0.49	2.64	0.83	45.71	3.13	54.0	FWL
D148	92.83	8.11	1.03	1.69	1.22	43.61	2.12	25.0	"
AVE.	91.93	11.77	0.58	2.48	0.89	42.68	2.69		

(1) AMPHIBOLE-CHLORITE SCHIST

Table 4-2 (Continued)

ROCK TYPE 5 (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D136	93.92	10.69	0.92	1.35	1.19	45.77	1.70	57.0	FWL
D137	54.29	20.66	0.52	2.17	0.41	8.68	0.99	15.0	HWL
AVE.	90.07	11.27	0.89	1.39	1.15	43.60	1.66		

(1) META-DACITE (ANDESITE?) AND PORPHYRITIC META-DACITE

ROCK TYPE CSS (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D155	31.00	0.00	0.52	1.94	0.30	0.00	3.00	5.0	HWL
D159	68.00	19.00	0.82	1.22	0.43	9.00	2.60	5.0	"
AVE.	49.50	13.05	0.73	1.45	0.39	6.18	2.73		

(1) CAMBRIAN SANDSTONE: WELL ROUNDED AND SORTED QUARTZ ARENITE

ROCK TYPE GOS (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D136	55.00	9.09	0.45	1.82	0.64	66.36	5.00	4.0	HWL
D138	6.80	0.00	0.34	2.94	0.20	0.00	5.00	4.0	"
D142	30.16	21.94	0.39	2.59	0.64	17.16	1.65	15.0	"
D150	70.00	0.00	2.29	0.14	0.43	8.57	1.29	10.0	"
D151	35.00	0.00	0.00	0.00	0.00	0.00	1.00	5.0	"
D152	72.65	0.00	0.90	0.90	1.00	34.22	2.43	20.0	"
D154	39.00	0.00	0.66	1.53	0.57	18.62	2.56	10.0	"
D155	21.25	0.00	0.57	1.76	0.48	10.00	2.00	8.0	"
D157	100.00	12.00	0.50	1.99	0.50	38.00	1.30	4.0	"
D158	20.00	0.00	0.00	0.00	0.00	0.00	2.00	5.0	"
D162	55.00	0.00	1.11	0.91	2.09	63.82	1.96	10.0	"
AVE.	45.52	4.16	0.96	1.21	0.85	30.42	2.13		

(1) GOSSAN: WEATHERED ORE ZONE (SULPHIDE RICH) MATERIAL - SIMILAR TO SAPROLITE)

ROCK TYPE SAP (1)

HOLE	% RECOVERY	% B. ZONE	LENGTH	F. FREQ.	L. PIECE	% RQD	HARDNESS	INTERVAL	(2) LOCATION
D140	31.50	0.00	1.23	1.59	0.21	0.00	0.00	6.0	HWL
AVE.	31.50	0.00	1.23	1.59	0.21	0.00	0.00		

(1) SAPROLITE: WEATHERED Pc SCHIST MATERIAL (SIMILAR TO GOSSAN)
(2) OZN: ORE ZONE HWL: HANGING WALL FWL: FOOTWALL

5.0 ROCK PROPERTIES

CNI derived rock strength results as well as data on soil characteristics for the Flambeau project from various sources.

The earliest geotechnical report on the Flambeau project made available to CNI was published in late 1972 by Soil Testing Services of Wisconsin, Inc. A subsurface investigation of soils in the mine area included permeability tests, density determination, and direct shear tests of soil samples.

More recently, Soil Testing Services of Wisconsin, Inc. has published geotechnical reports completed in December 1975, January 1976, and February 1976. These reports provide information on the Cambrian sandstone, Pleistocene soil horizon and Precambrian saprolite zone. Specifically, information on soil permeability tests, compressive strengths of materials, sieve analysis and Proctor tests were collected.

In March 1988, Foth & Van Dyke and STS Consultants, Ltd., completed a triaxial compression testing program of Flambeau soils. Sieve analyses, Proctor tests and permeability tests were also carried out on some samples.

As part of the overall rock strength data base, in addition to geomechanical logging, BPMA completed point load testing on angle and vertical core holes completed in the mine area. Most of the point load testing was done on core oriented roughly perpendicular to foliation trends. However, some samples were also tested parallel to foliation.

In March 1988, CNI completed a small scale direct shear testing program on foliation planes (6 samples) and cross joint fractures (1 sample) providing natural fracture shear strengths for the Precambrian rocks.

During 1987 and early 1988, BPMA conducted uniaxial compression, disk tension, and triaxial compression tests on Precambrian rock core samples at the University of Utah.

Table 5-1 summarizes composited natural fracture shear strength and intact rock strength (triaxial compression) values for the indicated Precambrian rock types. Table 5-2 summarizes individual and composited uniaxial compression, disk tension and rock density tests conducted at the University of Utah. Accompanying point load values, converted to estimated compressive strength (using a multiplication factor of 22.4), are also shown in Table 5-2.

The compressive and tensile strength of schist is sensitive to the orientation of the foliation relative to the direction of loading. For this reason, the tested strengths may be lower than the strength of intact rock where the failure occurs across foliation.

Table 5-3 summarizes individual and composited soil strength and density parameters for representative soil types overlying the Flambeau deposit. Foth & Van Dyke provided this data in early 1988.

Table 5-1

(2) Natural Fracture and Rock Substance Shear Strength Properties

Rock Type	No. of Samples	Power Combiner K	Power Combiner M	Linear Combiner Mean C (psi)	Linear Combiner Mean B	Linear Combiner S.D.	Linear Combiner Mean φ (deg)	No. of Samples	Triaxial Compression Internal Residual Strength Cohesion (psi) Mean	Triaxial Compression Internal Residual Strength Frictional Angle Mean
(1)(Foliation)	6	1.2304	0.7694	7.78	0.3308	0.0221	18.30	-	-	-
2a (Joint)	1	0.6817	0.9877	0.81	0.6349	-	32.41	-	-	-
1a	1	2.1388	0.6701	12.11	0.3241	-	17.96	3	145	51
S1a	-	-	-	-	-	-	-	3	500	55
2a	-	-	-	-	-	-	-	5	120	58
2b	1	0.9740	0.7945	5.59	0.3083	-	17.14	-	-	-
2c	1	1.3406	0.7355	8.11	0.2925	-	16.31	3	620	44
3a	1	1.2452	0.8055	7.41	0.4166	-	22.61	1	240	28
4a	1	1.4760	0.7498	9.95	0.3480	-	19.19	-	-	-
4c	-	-	-	-	-	-	-	2	135	63
5	1	0.6121	0.8716	3.54	0.2954	-	16.46	1	1065	24

(1) For the foliation plane testing distinct lithologic varieties were pooled since strength values were so similar. The lithologies included 1a, 2b, 2c, 3a, 4a, and 5; individual strength results are also indicated in the table.

(2) Data Source: Fracture strength data: University of Arizona
Triaxial compression data: University of Utah

Table 5-2

FLAMBEAU PROJECT
SUMMARY OF INDIVIDUAL UNIAXIAL COMPRESSION & DISK TENSION TEST RESULTS
(ROCK TYPE DESIGNATIONS AT BOTTOM OF TABLE)

ROCK TYPE	SAMPLE #	DRILL HOLE	HOLE DEP(FT)	COMP STREN(PSI)	E (PSI*EE6)	V	DENSITY (PCF)	DISK TEN(PSI)	DENSITY (PCF)	PT LOAD (1) Is50(PSI) DIAM	PPD	PLL	SOURCE	(2) COMMENTS
MASSIVE	161/58	161	58	5943	11.083	0.22	302	-	-	-	-	-	U OF UTAH	
AVE.				5943	11.083	0.22	302			240 (5376)	137 (3069)	1120 (1120)		
1a	6/332a	141	332	1334	-	-	153	-	-	-	-	-		
1a	6/332b	141	332	2218	-	-	169	-	-	-	-	-		FF
1a	2/83a	138	83	1094	-	-	160	189	161	-	-	-		
1a	2/83b	138	83	-	-	-	-	253	154	-	-	-	"	FF
1a	7/134a	142	134	1796	-	-	130	176	130	-	-	-		
1a	7/134b	142	134	1281	1.215	0.31	134	-	-	-	-	-		
1a	159/71	159	71	1061	-	-	128	-	-	-	-	-		
AVE.				1545	1.215	0.31	146	206	148	130 (2912)	-	112 (2509)		
S1a	6/387a	141	387	4051	-	-	198	521	176	-	-	-		FF
S1a	6/387b	141	387	-	8.171	0.22	178	-	-	-	-	-		(3)
S1a	153/102	153	102	3963	-	-	266	-	-	-	-	-		
S1a	7/102b	7	102	-	0.472	0.28	146	-	-	-	-	-		
S1a	2/38	138	38	1370	-	-	176	268	182	-	-	-		
S1a	152/150	152	150	2420	-	-	194	177	191	-	-	-	"	FF
S1a	160/101	160	101	619	-	-	166	-	-	-	-	-		
S1a	154/92b	154	92	1222	-	-	167	-	-	-	-	-		FF
AVE.				2274	4.322	0.25	186	322	183	131 (2934)	305 (6832)	125 (2800)		
1b	157/63	157	63	10313	-	-	166	-	-				"	FF
AVE.				10313			166			780 (17472)				
S1b	-	-	-	-	-	-	-	-	-	-	-	-	BP MINERALS	
AVE.										>1301 (>29142)	-	1008 (22579)		
2a	3/179a	139	179	2657	-	-	162	-	-	-	-	-		
2a	3/179c	139	179	-	3.450	0.20	164	-	-	-	-	-		FF
2a	2/184a	138	184	2277	-	-	146	279	143	-	-	-		(4)
2a	2/184b	138	184	-	-	-	-	166	140	-	-	-		
2a	4/275	140	275	684	-	-	153	-	-	-	-	-		FF
2a	3/70	139	70	1236	-	-	131	-	-	-	-	-		FF
2a	1/192b	137	192	977	-	-	150	-	-	-	-	-		FF
2a	4/226a	140	226	-	1.245	0.05	142	-	-	-	-	-		FF
2a	4/226b	140	226	2288	-	-	139	-	-	-	-	-	U OF UTAH	
2a	2/124b	138	124	3677	1.743	0.30	143	-	-	-	-	-		(5)
2a	5/168	136	168	3289	1.021	0.06	152	-	-	-	-	-		(6)
AVE.				2136	1.865	0.15	148	223	142	76 (1702)	-	-		
2b	6/250a	141	250	-	-	-	-	167	173	-	-	-		
2b	6/250b	141	250	-	-	-	-	47	178	-	-	-	"	
2b	6/145a	141	145	-	-	-	-	121	156	-	-	-		
AVE.								112	169	65 (1456)	-	-		

Table 5-2 (Continued)

2c	7/225	142	225	2818	-	-	153	504	153	-	-	-		
2c	7/227a	?	227	-	3.653	0.20	149	-	-	-	-	-		
2c	7/287	142	287	10268	-	-	176	-	-	-	-	-	"	
AVE.				6543	3.653	0.20	164	504	153	87 (1949)	-	-		
3a	2/254	138	254	-	-	-	-	151	156	-	-	-		
3a	2/243a	138	243	-	-	-	-	122	158	-	-	-	"	
3a	2/243b	138	243	-	-	-	-	128	157	-	-	-		
AVE.								134	157	67 (1501)	-	-		
4c	7/180	142	180	-	-	-	-	697	141	-	-	-	BP MINERALS	
AVE.								697	141	89 (1994)	-	-		
5	5/72	136	72	618	-	-	124	-	-	-	-	-		
5	5/150b	136	150	1829	-	-	145	-	-				U OF UTAH	FF FF
AVE.				1223			135			85 (1904	-	-		
GOS	-	-	-	-	-	-	-	-	-				BP MINERALS	
AVE.										186 (4166)	1481 (33174)	-		

MASSIVE : ORE ZONE ALSO KNOWN AS "ORE"; (GREATER THAN 50 WT. % SULPHIDE)
1a : " SERICITE-QUARTZ SCHIST
S1a : " SEMI-MASSIVE (20-50 WT. % SULPHIDE)
1b : " META-CHERT
S1b : " SEMI-MASSIVE (20-50 WT. % SULPHIDE)
2a ANDALUSITE-BIOTITE-QUARTZ-CHLORITE SCHIST (MINOR SERICITE); BIOTITE-SERICITE-QUARTZ-CHLORITE SCHIST
2b : ANDALUSITE-BIOTITE-CHLORITE-QUARTZ-SERICITE SCHIST
2c : BIOTITE-QUARTZ-CHLORITE PHYLLITE (LOCALLY MINOR SERICITE)
3a : QUARTZ-AUGEN SCHIST
4c : AMPHIBOLE-CHLORITE SCHIST
5 META-DACITE (ANDESITE?) AND PORPHYRITIC META-DACITE
GOS GOSSAN - WEATHERED ZONE OVER OREBODY

(1) COLUMN 1: DIAMETRAL LOADING; COLUMN 2-3: DIAMETRAL VARIABLE LOADING; PPD=PERPENDICULAR TO FOLIATION, PLL= TO FOLIATION. DATA COLLECTED BY BP MINERALS CO.: VALUE IN PARENTHESES IS THE ESTIMATED UNIAXIAL COMPRESSIVE STRENGTH COMPUTED BY MULTIPLYING Is50 * 22.4.

(2) FF: FAILURE OF COMPRESSION SAMPLE OCCURED PARALLEL OR SUBPARALLEL TO FOLIATION.

	Eb (PSI*EE6)	Ea
(3)	0.756	7.323
(4)	1.102	9.888
(5)	0.877	1.622
(6)	0.558	2.655

WHERE: Eb=E PERPENDICULAR TO FOLIATION
Ea=E PARALLEL TO FOLIATION

Table 5-3

FLAMBEAU PROJECT: SUMMARY OF
SOILS TEST RESULTS

TEST TYPE	SOIL TYPE	SAMPLE #	HOLE #	DEPTH (FT)	EFFECTIVE PHI(DEG)	STRENGTH C(PSI)	(W PORE PRESSURE) TOTAL PHI(DEG)	STRENGTH C(PSI)	(CONSOLIDATED-PCF) WET DENSITY	DRY DENSITY	DATA SOURCE
(UNDRAINED) TRIAX	ML	S-1	(4)	25-27	25.0	4.27	19.0	5.40	143.0	124.5	FOTH & VAN DYKE (3/88)
	ML	S-1	(4)	27-29					149.4	131.4	
	ML	S-1	(4)	23-25					143.3	127.0	
									145.9	127.7	
"	ML	3	S-3	36-37	22.0	3.56	16.0	4.41	140.2	121.5	"
	ML	S3	S3	37-38					137.7	122.1	
	ML	3	(4)	38-39					144.1	129.7	
									140.7	124.4	
"	ML	(5)	S5	45-46	26.0	0.85	20.0	2.70	144.8	124.8	"
	ML	(5)	S5	46-47					157.3	138.8	
									151.1	131.8	
	COMBINED ML MEAN				24.3	2.89	18.3	4.17	145.0	127.5	
"	SM	SS4	S-5	18-20	28.5	3.56	23.0	3.56	144.0	130.0	"
	SM	SS6	S-5	22-24					144.7	132.1	
	SM	SS4	S-5	25-27					145.7	133.4	
									144.8	131.8	
	COMBINED SM MEAN				28.5	3.56	23.0	3.56	144.8	131.8	
DIRECT SHEAR (DRAINED)	SM	S-2	(4)	5-7	33.0	0.00	-	-	-	124.0	"
"	ML	S-4	(4)	31.5-32.5	BAD TEST		-	-	-	121.0	"
"	SP	S-5	(4)	35-36	36.0	0.00	-	-	-	113.8	"

(1) ML: LOW PLASTICITY SILT
(2) SM: SAND TO SILTY SAND
(3) SP: CLEAN SAND TO GRAVELY SAND
(4) NO SAMPLE LOCATION INDICATED
(5) NO SAMPLE NUMBER INDICATED

6.0 HYDROLOGY

According to Zavis Zavodni of BPMA, the primary groundwater aquifer in the Flambeau project area "is believed to occur within the till and out-wash deposits and the thin Cambrian sandstone that overlie the generally poor Precambrian basement aquifer." This is based on hydrology-related work done in the early and mid-1970s, as well as more recent work in the 1980s by Kennecott-directed geotechnical groups.

Design assumptions for this study have been to regard the overlying gravel lenses and sandstone units as aquifers. During initial excavation into this stratigraphy, we expect significant groundwater inflow; however, this flow should fall off rapidly.

On the other hand, the weathered layer of Precambrian rocks, designated "saprolite," is expected to be a poor aquifer, draining very slowly when exposed in pit walls. Limited pit water inflow is anticipated through the Precambrian rock primarily along the prominent northeast-southwest oriented foliation planes.

Water Management

A basic design recommendation is the construction of a minimum 10 ft wide bench located near the overburden-Precambrian bedrock interface. This bench would provide a platform along which a drainage ditch should be constructed to transfer a portion of the groundwater flow out and away from the pit below. If vehicle access is required along the bench, a wider bench would be necessary to accommodate both the road and ditch.

Pore Pressure Buildup

Since groundwater flow is expected to be restricted in the Precambrian rocks, another concern at Flambeau is the potential buildup of pore pressure along foliation in the NE-SW oriented pit walls. However, based on CNI's experience at an open pit mine in Sweden with similar geology and orientation of foliation relative to pit walls, it is unlikely that pore pressure buildup will be significant enough to affect slope stability. The studies conducted in the Swedish mine indicated that although there was a much higher permeability along foliation, the cross joint sets allowed groundwater to flow between foliation planes in a pitward direction, precluding excessive pore pressure buildup.

Further, because of the extreme climatic conditions in the Swedish mine, a fully saturated slope condition was hypothesized, assuming a completely frozen face, during which time groundwater would not be allowed to free flow. However, observations at the mine indicated that even at -30° C, drainage was not totally impeded. Based on the above discussion, CNI does not anticipate excessive pore pressure buildup.

7.0 SEISMICITY

The potential for seismic disturbance in the Flambeau area during the life of the mine has not been formally assessed because the Canadian Shield, upon which the mine site is located, is relatively seismically inactive.

Literature on the area indicates a low seismic risk. For example, a study completed by Milne and Davenport (1969) indicates that the return period for a 0.10 g in the southern Wisconsin/ northern Illinois area is in the 500 to 1,000 year range; the expected seismic event would have an estimated acceleration of 2.5 to 3.0 percent g. A seismic zoning map completed by the Army Corps of Engineers (Figure 7-1) indicates the expected seismic event will have an acceleration of only about 2.5 percent g.

At the mine, the effects of a 3 percent g load would be minimal, with only minor ravelling occurring on the benches. Studies have shown that acceleration of 10 to 15 percent g must occur before pit walls are substantially damaged.

Therefore, seismic loading as a result of an earthquake was not considered in the Flambeau stability analysis.

7.1 Perimeter Blasting

Controlled perimeter blasting techniques should be utilized at Flambeau near final walls in order to attain optimum fragmentation while still limiting peak particle velocities (PPV) below 25 in./sec at final pit walls. It has been shown at other mining properties that exceeding a PPV of 25 in./sec causes excessive backbreak in bench faces.

7.2 Angle Hole Production Blasting

On the footwall side of the pit where the foliation dips into the pit, angled blast holes would produce a cleaner break to foliation than vertical holes. Normally the improvement in face condition is not great enough to justify the higher cost of angle hole blasting. However, where there is an additional benefit such as grade control, angle hole blasting would be appropriate.

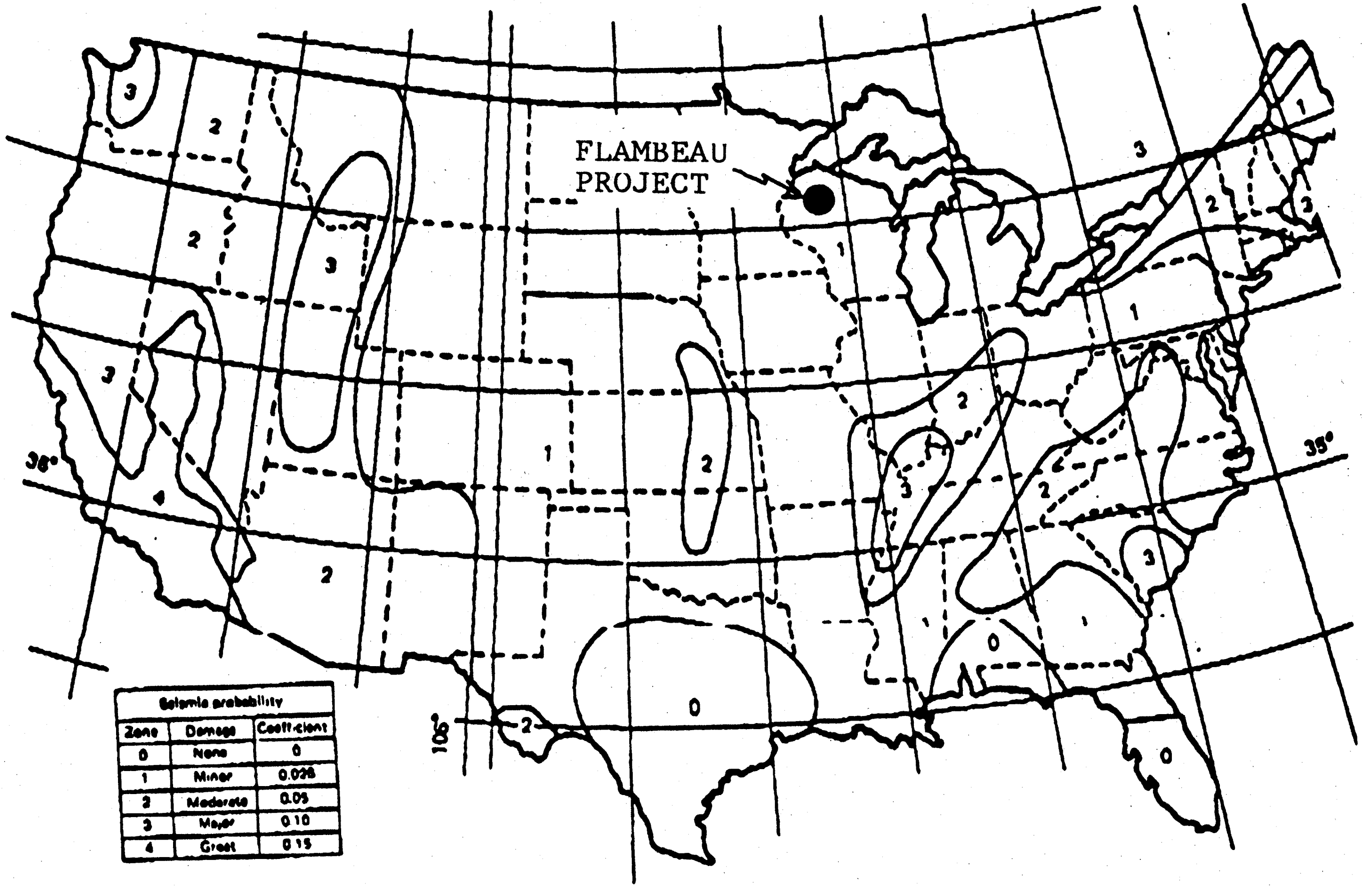


Figure 7-1: Seismic Zoning Map (From Corps of Engineers, 1977).

8.0 DESIGN

8.1 Flambeau Pit Design Sectors

Slope angles within an open pit mine are influenced by rock strength, geologic structure, hydrology, pit wall orientation, ore distribution, and operational considerations. Design sectors are zones where these parameters are similar or will have similar impact on slope design. The primary factors used to define the limits of a design sector are (1) structural domain boundaries, (2) rock contacts, and (3) pit wall orientation. In the Rock Fabric section (Section 4.0), it was concluded that the Flambeau study area consists of a single structural domain.

The design sectors established at Flambeau (Figure 8-1) include the following:

Sector Designation	Sector Wall Average Dip Direction (DDR)
Footwall	313
Hanging Wall	133
Northeast End	223
Southwest End	43

8.2 Flambeau Pit Design Sector Fracture Sets

With the sectors defined, the geologic structures to be used in the stability analysis can be determined.

Fabric-scale oriented core structure, composed of jointing and foliation data, form the data base representing all fabric-scale structure observed to occur in the study area.

The average sector wall orientation is then superimposed on the lower hemisphere structure pole plot of combined data present in the sector. Any structures dipping into the pit (as determined by the average wall orientation) are considered potential failure surfaces. These structures are subdivided into three design sets, one plane shear and two wedge sets, on the basis of the potential failure geometry they would probably form.

Figure 8-2 shows the wall orientation and fracture sets analyzed in the Flambeau study. The two left-most plots in Figure 8-2 are present to show the relationship between geologic set limits and design set limits. The large solid dots represent the mean vector of each geologic set.

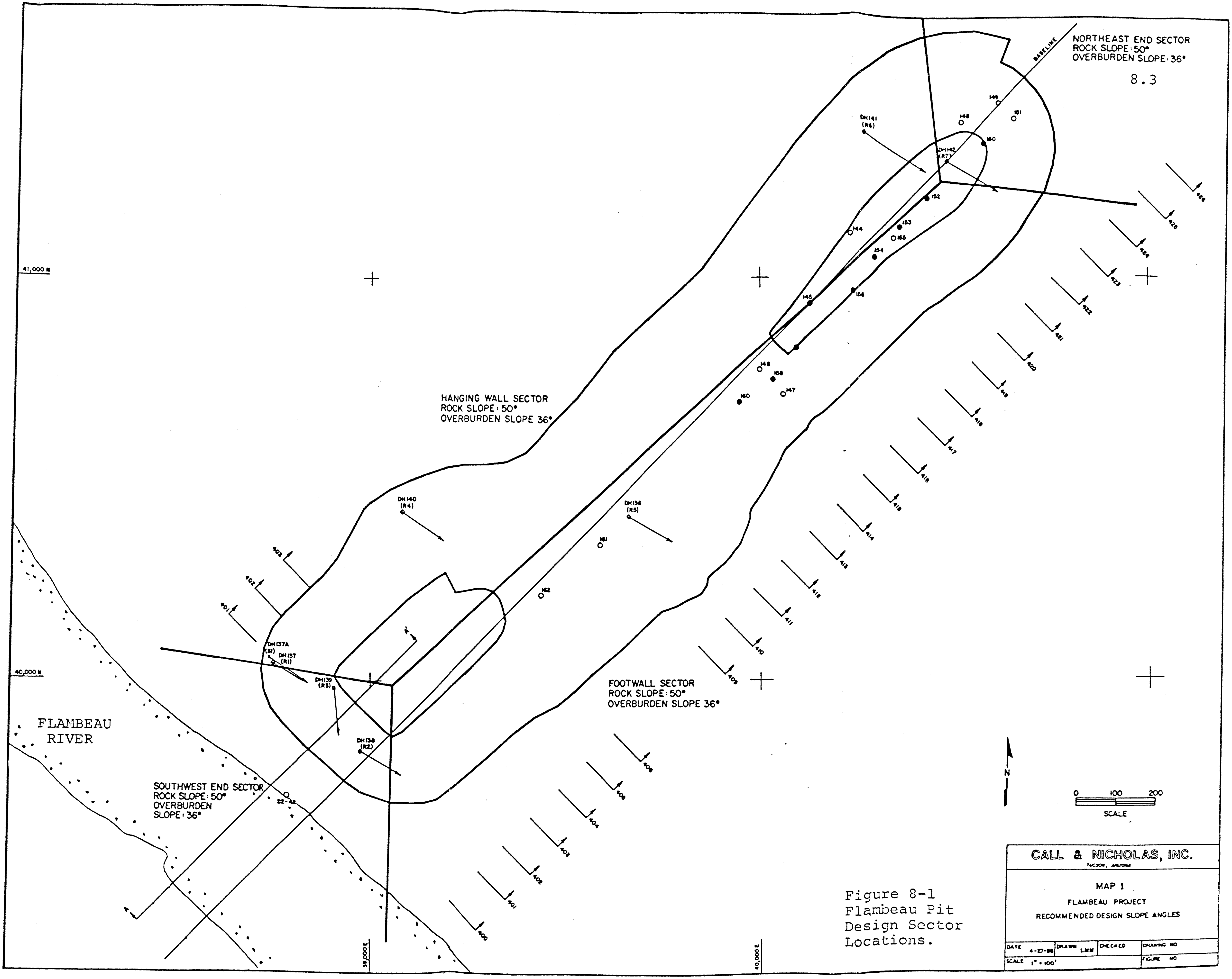


Figure 8-1
Flambeau Pit
Design Sector
Locations.

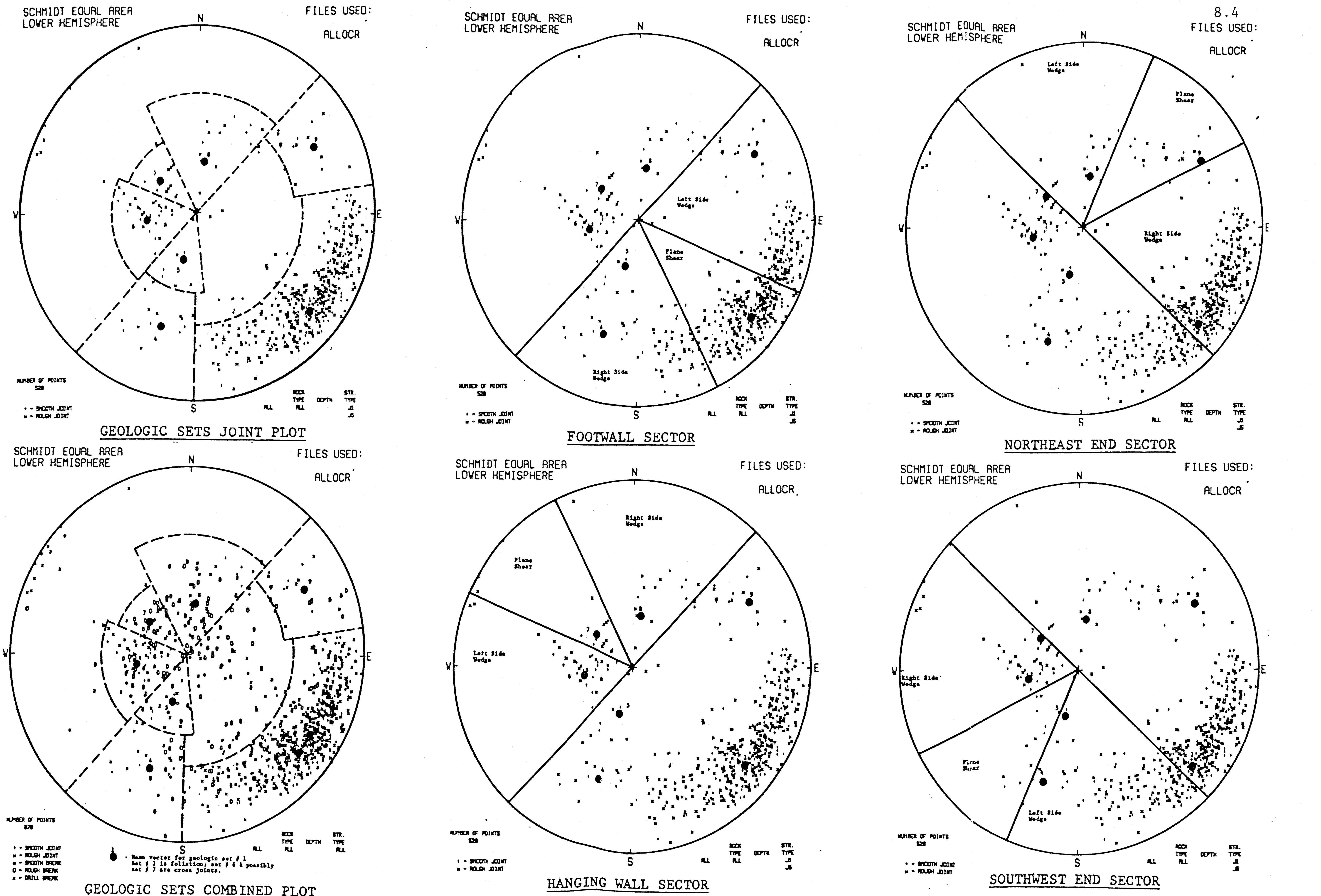


Figure 8-2: Flambeau Design Sets
(Left-most Sets Show Geologic Set Limits

9.0 BENCH DESIGN

9.1 Bench Configuration

Bench configuration is a function of bench height, width, and face angle. The bench height is primarily a function of mining equipment; the bench width is a function of bench height and safety considerations; and the bench face angle is controlled by the orientation of geologic structures and by excavation methods used at the mine, particularly blasting.

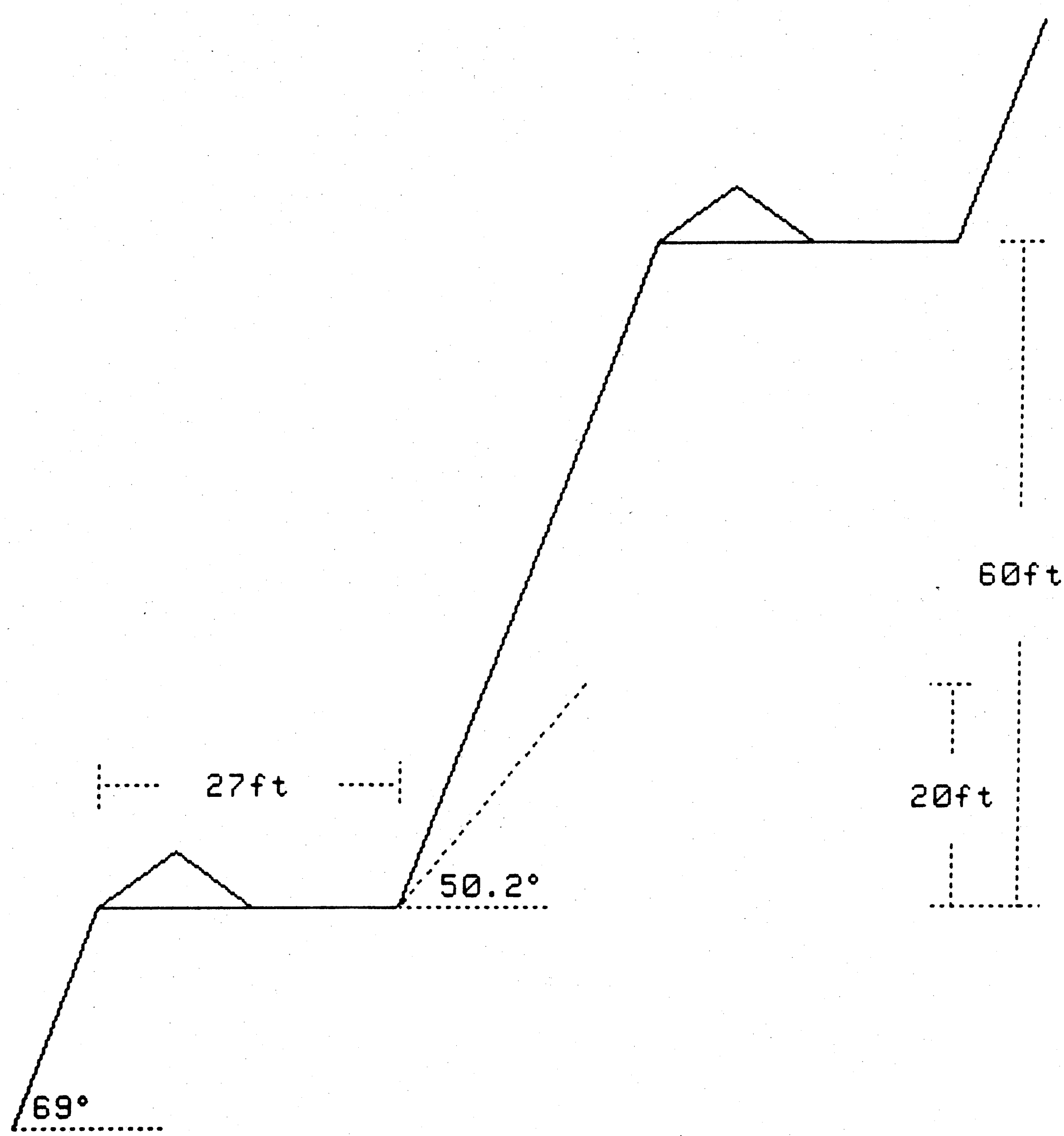
9.2 Bench Height and Catch Bench Width

Bench faces are usually mined as steeply as possible; as a result, rock falls and raveling are inevitable. Thus, it is customary, and in many cases mandated by mining regulations, that catch benches be left in the pit wall to retain rock falls and raveling.

Analysis of rock fall mechanics by Arthur Ritchie (1963) demonstrated that falling rocks impact relatively close to the toe of the slope, but because of horizontal momentum and spin, they can roll considerable distances from the toe. Based on his analysis, Ritchie developed width and depth criteria for a ditch at the toe of a slope to protect highways from rock fall. The concept was that the rock would fall into the ditch, and the side of the ditch would stop the horizontal roll.

To excavate a ditch in an open pit catch bench is impractical; however, the same effect can be achieved by casting up a berm (Figure 9-1). Assuming the berm can be emplaced with slopes of 1.3 to 1, the minimum bench widths

CATCH BENCH DESIGN



MINING HEIGHT	20	ft
CATCH BENCH INCREMENT	3	
BENCH HEIGHT	60	ft
CATCH BENCH WIDTH	27	ft
BERM HEIGHT	5	ft
BERM WIDTH	14	ft
OFFSET	0.0ft	
FACE ANGLE	69.0°	
BENCH FACE ANGLE	69.0°	
INTERRAMP ANGLE	50.2°	

Figure 9-1: Typical Rock Catch Bench Geometry.

presented in Figure 9-1 are recommended for bench heights corresponding to multiples of a 20 ft mining bench height. For a given bench height and corresponding bench width, the upper limit of the interramp slope angle becomes a function of the bench face angle.

9.3 Selection of Bench Face and Interramp Slope Angles Based on Reliability

Under ideal conditions (controlled blasting with vertical drill holes in unfractured rock), the bench face angle would be vertical. In actual conditions, however, the bench face breaks back to a flatter angle along jointing and other geologic structures. Uncontrolled blasting reduces the rock integrity, resulting in further backbreak. Because of the variability of the geologic structures, backbreak is not uniform, and the resulting bench face angles are a distribution rather than a unique angle. For a given interramp slope angle, the bench width is variable, as shown in Figure 9-2. Therefore, a reliability approach determines the appropriate interramp angle. The reliability is defined as the percent of the bench that will have a width greater than the minimum required width. The reliability is obtained by using the predicted bench face angle distribution, and is described in the following section.

9.4 Footwall Sector Bench Design (Precambrian Rocks)

As indicated earlier, the foliation is dipping into the pit in the Footwall Sector. Since the foliation is well developed and can be considered continuous, CNI assumed that the bench face would fail in plane shear, resulting in bench

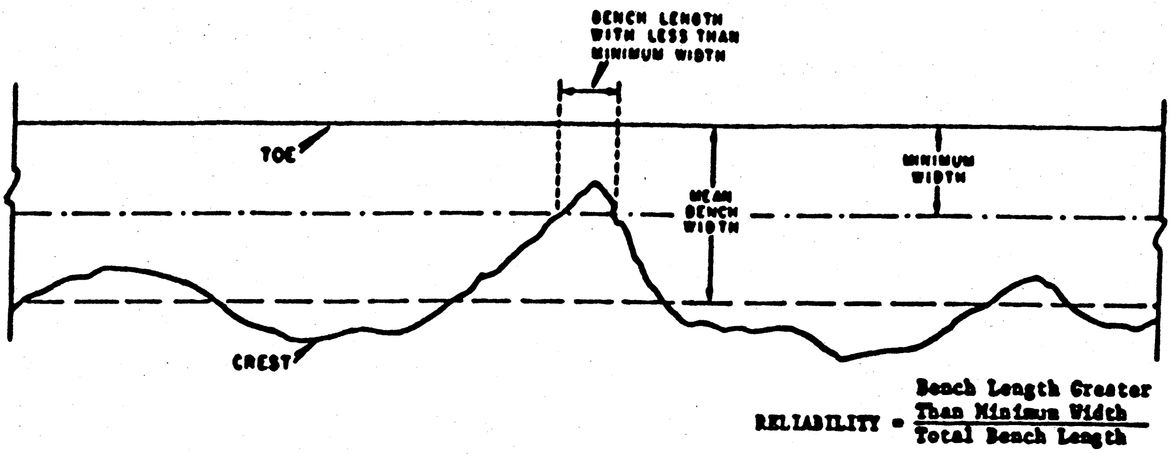


Figure 9-2: Catch Bench Reliability.

faces parallel to the foliation. In this case the dip distribution of the foliation becomes the bench face angle distribution. This distribution is shown in Table 9-1 and in Figure 9-3 for the combined oriented core data. Since the foliation is considered to be continuous, this distribution would apply for all bench heights.

Based on the distribution of foliation dips, CNI recommends a design mean bench face angle of 69° for the Footwall Sector of the Flambeau pit. Much of the orientation variability of foliation is due to the small-scale variability of attitude of the fracture surface in core specimens of 2 in. diameter. In other words, the structure dispersion, particularly the dip, would likely diminish significantly if an average orientation could be taken, say along a 6 ft diameter surface. The higher dispersion results in a lower reliability. Specifically, in the case of the 69° bench face determined above, a reliability of 56 percent results, based on a population standard deviation of 8.1° for the foliation. However, if the standard deviation of the dip mean is used as the dispersion, a reliability of roughly 85 percent results. The actual reliability for the 69° dip lies somewhere between the 56 and 85 percent values.

Buckling (Footwall Sector)

As indicated earlier, for design purposes, the foliation at Flambeau is considered continuous. On the footwall side of the pit, foliation dips pitward, averaging about 70°. Since these foliation discontinuities can be quite long and thin, they may behave like structural columns lying on their sides. Figure 9-4 shows a potential mode of failure in high

Dip	Prob	Dip	Prob
0.	0.0000	60.	0.1392
1	0.0001	61.	0.1477
2.	0.0001	62.	0.1676
3.	0.0002	63.	0.2102
4.	0.0002	64.	0.2358
5.	0.0003	65.	0.2642
6.	0.0003	66.	0.2983
7.	0.0004	67.	0.3409
8.	0.0005	68.	0.3835
9.	0.0005	69.	0.4375
10.	0.0006	70.	0.4915
11.	0.0006	71.	0.5625
12.	0.0007	72.	0.6136
13.	0.0007	73.	0.6563
14.	0.0008	74.	0.6903
15.	0.0009	75.	0.7358
16.	0.0009	76.	0.7869
17.	0.0010	77.	0.8125
18.	0.0010	78.	0.8580
19.	0.0011	79.	0.8807
20.	0.0011	80.	0.9063
21.	0.0012	81.	0.9233
22.	0.0012	82.	0.9375
23.	0.0013	83.	0.9517
24.	0.0014	84.	0.9574
25.	0.0014	85.	0.9716
26.	0.0015	86.	0.9830
27.	0.0015	87.	0.9858
28.	0.0016	88.	0.9915
29.	0.0016	89.	0.9943
30.	0.0017	90.	1.0000
31.	0.0018		
32.	0.0018		
33.	0.0019		
34.	0.0019		
35.	0.0020		
36.	0.0020		
37.	0.0021		
38	0.0022		
39.	0.0022		
40.	0.0023		
41.	0.0023		
42.	0.0024		
43.	0.0024		
44.	0.0025		
45.	0.0026		
46.	0.0026		
47.	0.0027		
48.	0.0027		
49.	0.0028		
50.	0.0028		
51.	0.0085		
52.	0.0114		
53.	0.0199		
54.	0.0398		
55.	0.0540		
56.	0.0653		
57.	0.0824		
58.	0.0966		
59.	0.1108		

Mean Dip: 70.2°
S.D. Dip: 8.1°
Max. Dip: 90°
Min. Dip: 51°

Table 9-1: Foliation Dip Distribution (Combined Data).

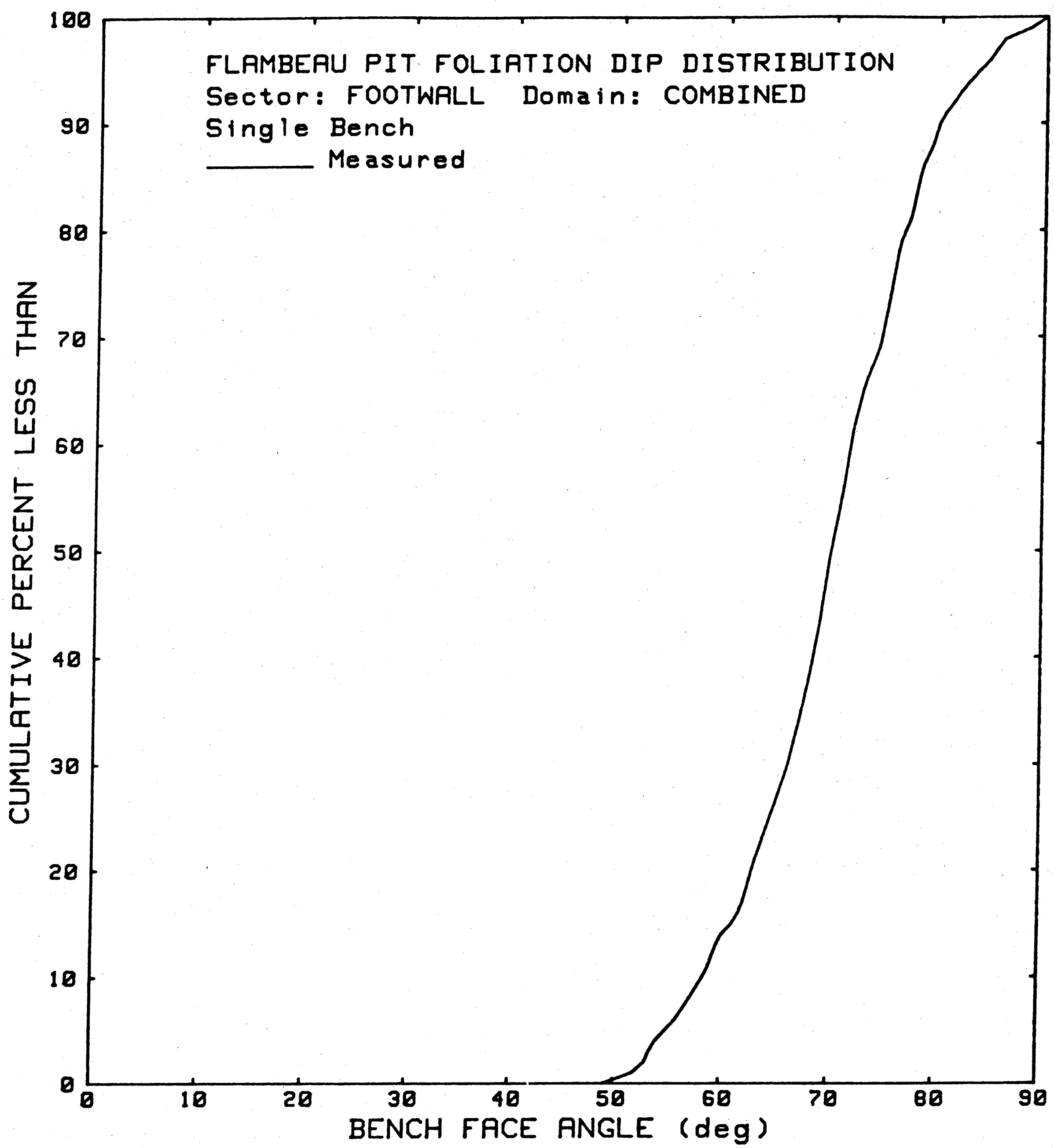
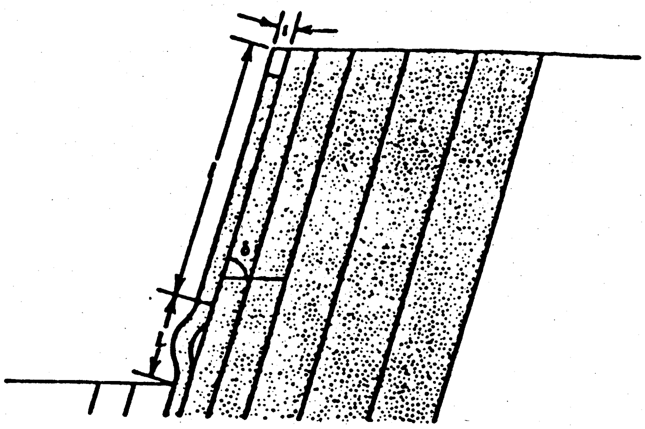
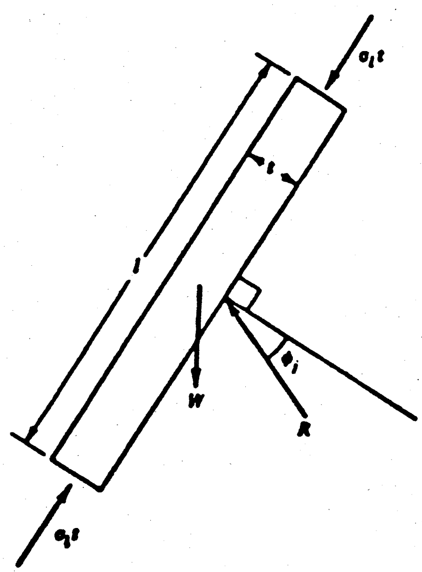


Figure 9-3: Foliation Data.





t = column thickness

L = column lengths

γ = density of material

δ = dip of column measured from horizontal

φ = friction angle

E = Young's Modulus

$$t = \sqrt{\frac{3L^2 \ \ell \ \max \ \gamma \ \sin\ (\delta - \phi)}{\pi^2 \ E \ \sin\ (90 - \phi)}}$$

Figure 9-4: Mechanics of Buckling of a Foliation.

dip slopes. According to most texts on strength of materials, buckling will occur when the axial stress exceeds the critical stress predicted by Euler's Equation:

$$\sigma_{cr} = \frac{\pi^2 Et^2}{3L^2}$$

where

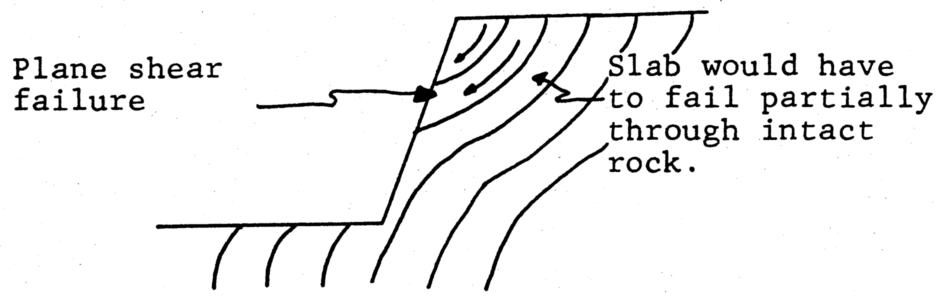
σ_{cr} = critical stress for the column;
E = Young's modulus;
t = column thickness; and
L = column length.

When this σ_{cr} equals the σ axial, failure is imminent. As shown in Figure 9-4, the thickness for this case would be calculated by using the following equation.

$$t = \sqrt{\frac{3L^2 \ \ell max \ \gamma sin \ (\delta-\phi)}{\pi^2 \ E \ sin \ (90-\phi)}}$$

This equation was used to calculate the critical slab thickness for a number of continuous columns with various dips for a 60 ft high slope.

The buckling analysis indicated that slab thicknesses of roughly 0.1 ft or greater would be stable. Incrementing through a range of 50° to 80° revealed that the thickest slab required for stability was in the 65° to 75° range. These results show that the potential for the buckling phenomenon is extremely low since it was determined from oriented core data that foliation spacing is in the 2 ft range. There may be some localized small-scale buckling or slabbing where foliation spacing is tight or in situations where folia roll pitward at a relatively flat inclination, as shown below.



However, these should be localized problems with backbreak not exceeding 2 to 3 ft.

Slab Failures

Although a slab analysis was not conducted, this failure mechanism is unlikely since point load testing conducted by BPMA indicates compressive strengths in the 6000 psi range. The results of compression testing on core oriented perpendicular to foliation are roughly three times as high as uniaxial compressive test results conducted at the University of Utah on core parallel to foliation. Apparently, actual failure on most of these specimens occurred either parallel to or along actual folia planes. Therefore, these compressive strength values may be unrealistically low.

Using an intact rock compressive strength in the 6000 psi range would preclude slab-type failure, assuming an average slab thickness of roughly 2 ft (i.e., foliation spacing equals 2.1 ft). As in the case of the buckling failure scenario above, there would be localized problems where folia are closely spaced and are extremely contorted.

Footwall Sector Recommendations

In the Footwall Sector, foliation will control the bench face geometry. Therefore, CNI recommends 60 ft triple benching (20 ft individual bench heights), a foliation controlled 69° bench face angle, and a minimum 27 ft wide catch bench for this sector, which will result in a 50° interramp slope angle.

9.5 Hanging Wall Sector Bench Design (Precambrian Rocks)

In the Hanging Wall Sector of the Flambeau pit, backbreak resulting from wedge, plane shear, and step path failure modes on jointing and foliation was assessed.

Plane Shear Geometry

Plane shear is not a viable failure mode along the Hanging Wall Sector pit slopes. A single geologic set, designated set #7, has a mean DDR of 128° and dips 21° SE. The dip is much flatter than the friction angle of 31° determined for joint surfaces. Further, because of the assumed short lengths of set #7, development of plane shear geometries is unlikely.

Wedge Geometry

Geologic sets #6 and #8 form a potential wedge geometry. However, the resulting wedge intersection is flatter than the friction angle. Additionally, the wide spacing and expected short length for both sets preclude the likelihood of many intersections in the pit wall.

Step Path Geometry

Since foliation at Flambeau dips into the hanging wall slope, no plane shear involving this structure is possible. Similarly, as indicated earlier, cross jointing, because of its assumed short length, would not form a bench scale plane shear geometry. However, the intersection of the foliation and cross jointing form a potential step path geometry.

The step path failure is similar to the plane shear in that it assumes displacement along joints or other failure surfaces subparallel to the bench face. However, the step path model assumes that the failure path consists of sliding along a number of surfaces dipping into the pit (the master joint set) and separation along structures approximately perpendicular to the master set (the cross joint set), whereas the plane shear assumes displacement on a single continuous structure. Where the master joint set lengths are short, a continuous plane shear failure surface is unlikely, and the step path is a more viable failure model.

Geologic sets #6 and #7 in Figure 9-5 and Table 9-2 represent cross jointing to the foliation. Although the sets were separated based on central tendencies as well as significant differences in spacing, their differences are probably related to the diverse range of orientations observed in the foliation. For the step path analysis, we have used set #6 statistics since they are more conservative, even though they fall in more of a wedge orientation.

Figure 9-6 simulates cross jointing and foliation planes in the pit wall. Figure 9-6b diagrams the cross cutting relationship between these two structures. We have assumed that cross jointing terminates against foliation;

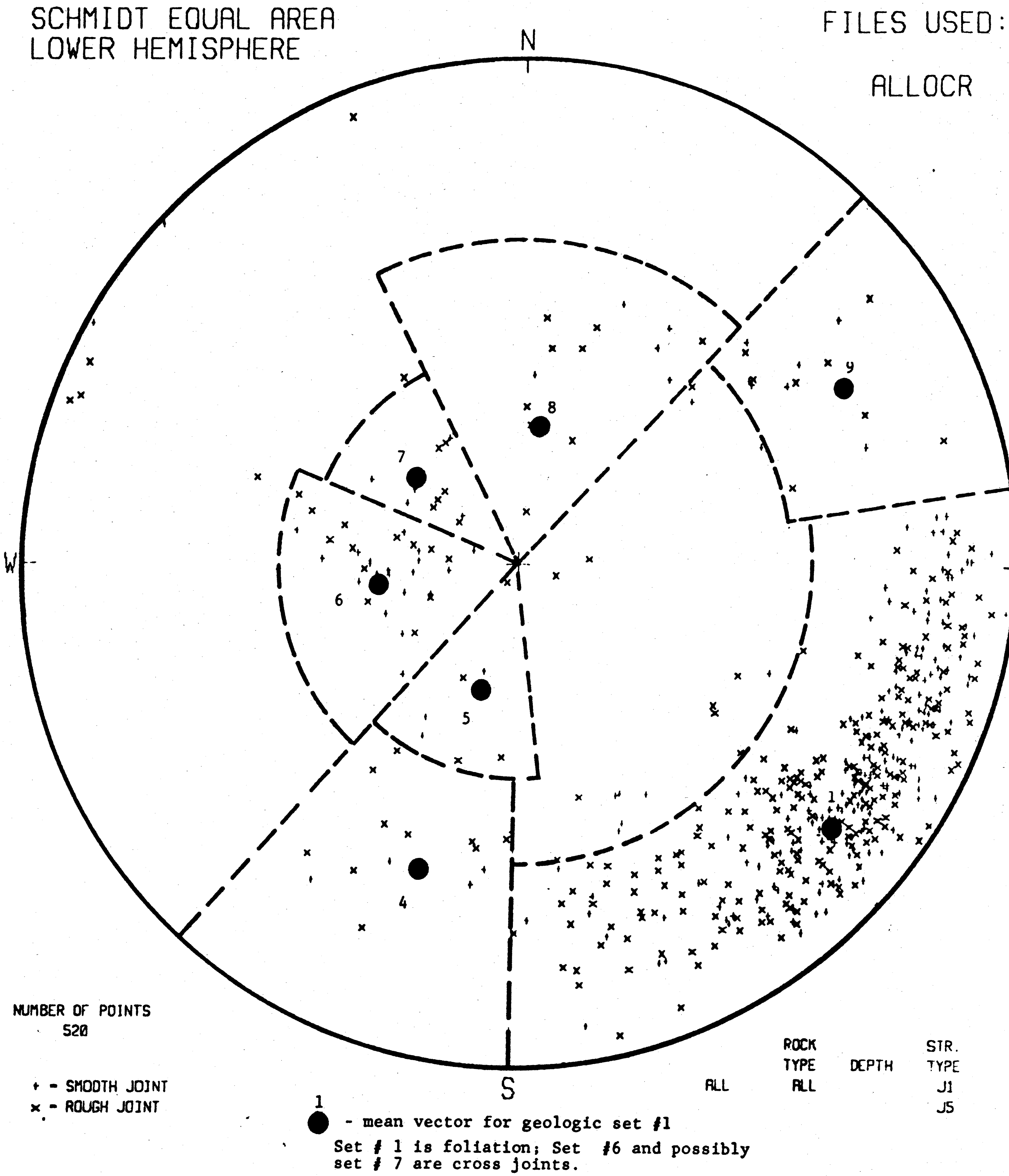


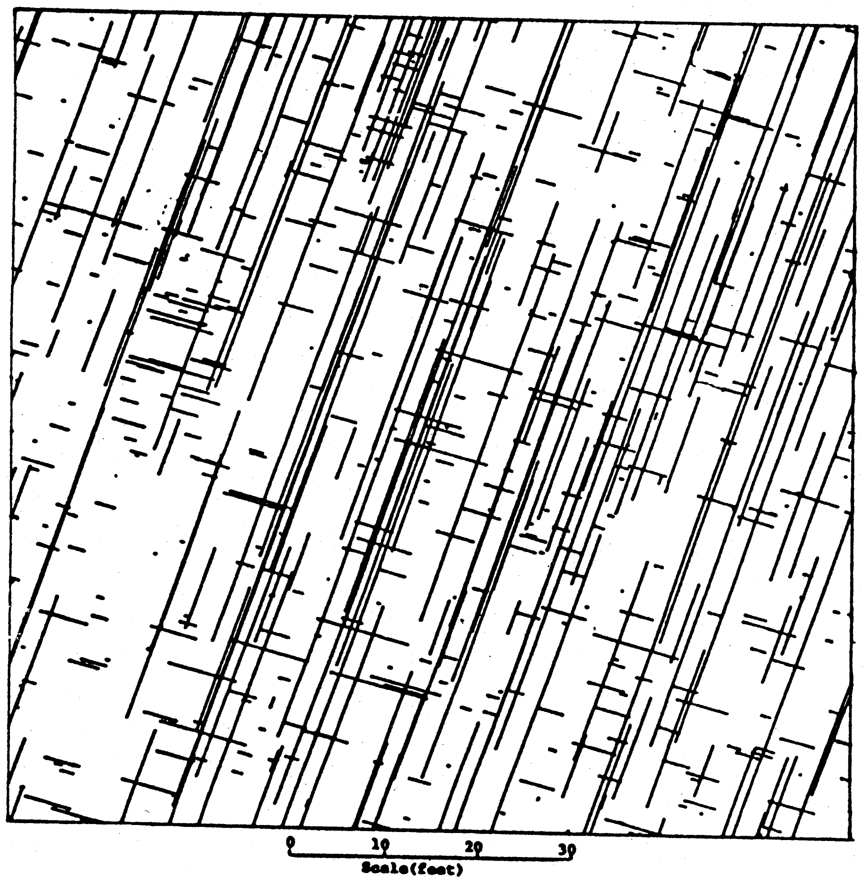
Figure 9-5: Flambeau Geologic Sets (note that this is plot of joints only).

Table 9-2

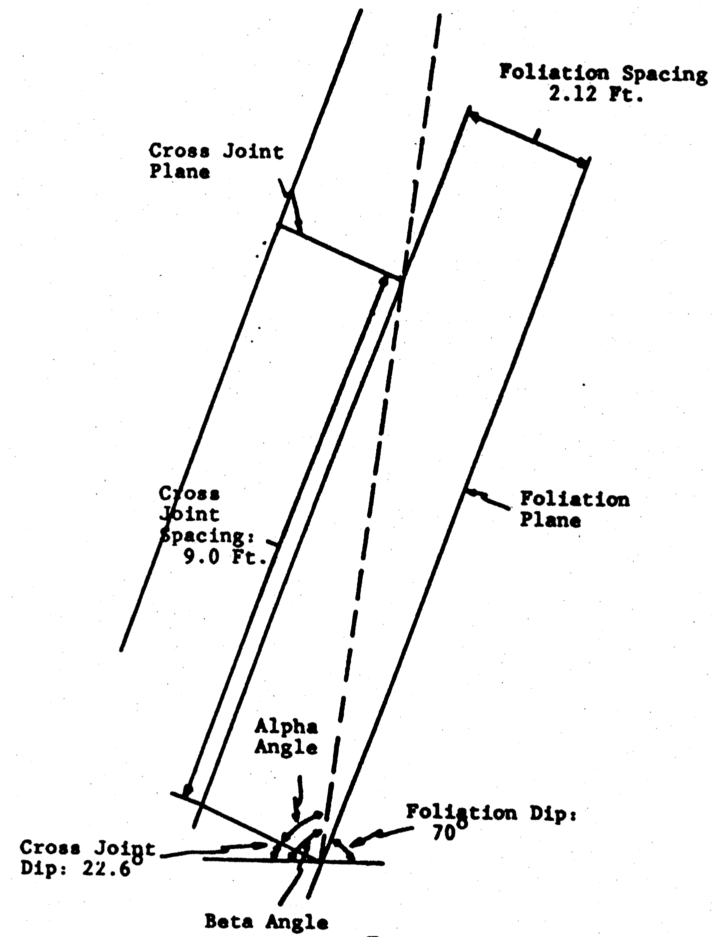
FLAMBEAU PROJECT ORIENTED CORE
SUMMARY OF STRUCTURE SET STATISTICS

SET NUMBER	DIP DIR MEAN	DIP DIR VAR(1)	DIP MEAN	DIP VAR(1)	SPACING MEAN	NUMBER IN SET
1.0	309.00	91.81 (88.82)	70.94	67.02 (62.38)	2.12	352
4.0	16.45	60.21 (120.98)	53.58	183.32 (122.83)	12.01	16
5.0	15.16	281.52 (312.77)	21.38	88.32 (83.85)	22.07	25
6.0	80.86	324.96 (303.55)	22.62	52.79 (52.66)	8.98	70
7.0	127.97	111.10 (145.11)	21.46	21.11 (31.96)	20.02	29
8.0	187.13	282.83 (297.91)	22.21	87.0 (129.71)	15.19	48
9.0	241.94	55.65 (86.82)	64.06	49.22 (90.75)	17.50	23
10.0	261.77	292.30 (391.26)	22.02	143.76 (199.04)	35.82	34
11.0	280.37	62.84 (61.57)	72.98	42.64 (42.85)	4.17	157

(1) VARIANCE WITHOUT PARENTHESES: ARITHMETIC MEAN
VARIANCE WITH PARENTHESES:
Var=Var*(N1-1)+Var*(N2-1)+..../(N1+N2+N3+...)-No. OF SAMPLES



Steep Set: Foliation-Flat:Cross Jointing
(Looking NE)
Figure 9-6a



Step Angle(Alpha)= Atan $\left[\frac{\text{cross joint mean spacing}}{\text{foliation mean spacing}}\right]$= 76.7°

Beta Angle(Beta)=cross joint dip + step path angle=99.3°

Figure 9-6b

Figure 9-6: Hanging Wall Sector Step Path (Colored).

therefore, the step geometry involves a potential continuous path up a foliation plane until a cross joint is intersected, thence across this structure until foliation is again intersected, and so on.

The beta angle is the resulting step path angle of the intersection of the two structure sets. An angle of 99° was calculated, indicating a nearly vertical and slightly overhanging geometry will exist in the hanging wall pit slopes.

Toppling

Although the length/width ratio of the blocks formed by the foliation and cross joint falls within the criteria for toppling, it is our opinion that simple toppling occurs during mining and is part of the normal backbreak of bench faces. Localized backbreak due to toppling may occur in areas where the foliation spacing is tight. However, the probability of toppling extending beyond the design bench face angle of 69° is very small (Figure 9-7). The empirical evidence from the hanging wall faces at Aitik, Pikwe and Tazadit, which are in similar foliated rock is that toppling is not a problem. Based on our experience and on the mechanics of slope deformation, we consider that toppling is almost always a post failure deformation rather than a primary failure mechanism.

CNI's assessment is that the bench faces should be stable and that a 69° bench face angle should be attainable along the hanging wall pit slopes.

Optimization of blasting is critical, and good digging practices should be maintained so as not to undercut and thereby oversteepen the bench slopes.

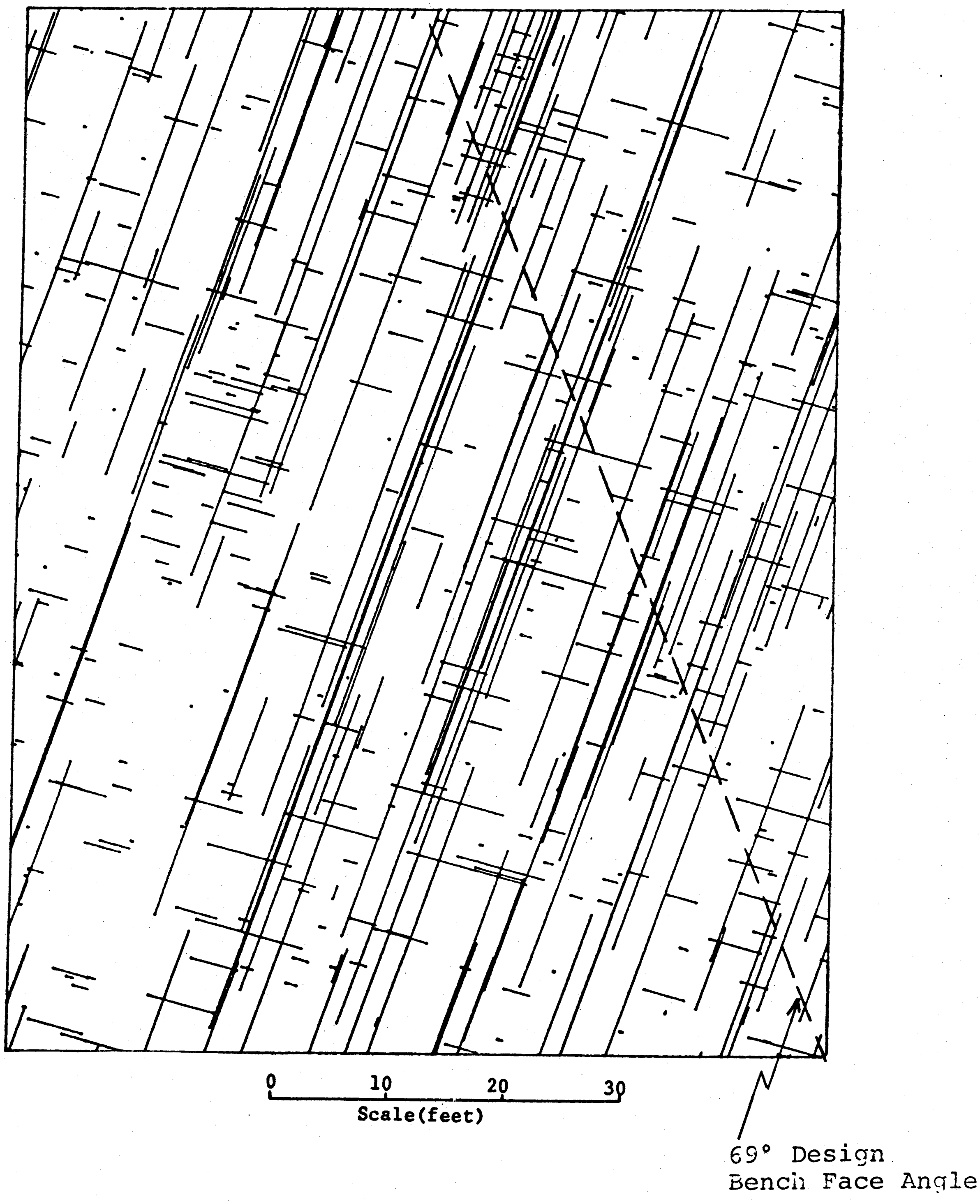


Figure 9-7: Hanging Wall Backbreak.

Hanging Wall Sector Recommendations

CNI recommends a triple bench, 27 ft minimum catch bench width, and a 69° bench face angle design for the Hanging Wall Sector, which also results in a 50° interramp slope angle.

9.6 Northeast End Sector Bench Design and Recommendations (Precambrian Rocks)

Analysis of structure occurring in the northeast end of the design pit indicates most sets are favorably oriented. One adversely oriented fracture set, set #3 (262,22) discussed earlier, has a mean spacing of roughly 36 ft. This set, coupled with more N-S oriented, west-dipping foliation, locally produces a step path geometry. However, the set #3 spacing precludes continuity of this geometry.

Therefore, CNI feels a 69° BFA is attainable and recommend a 50° interramp slope angle for the Northeast End Sector.

9.7 Southwest End Sector Bench Design and Recommendations (Precambrian Rocks)

Two types of failure modes were addressed for the Southwest End Sector: wedge geometry and full slope height rotational shear.

Wedges

Based on the fabric data for holes 137, 138 and 139, the only critical discrete structural failure geometry is a wedge formed by a foliation set (DDR = 349°, Dip = 57°) and the cross jointing (DDR = 81°; DIP = 23°) represented in Figure

9-8a. Since the cross jointing is not continuous, the cross joint side of the wedge would form a step path. Based on the measured 5 ft spacing of the cross jointing and an estimated length of 3 ft, the dip of the step path (i.e., beta angle) would be 82° (Figure 9-8b). This step wedge has an intersection plunge of 56°, so it would not be daylighted by an interramp slope of 50°. Furthermore, the plunge of the intersection between the cross jointing and the foliation is 22°, which is significantly below the friction angle and therefore stable.

Taking the conservative assumption that both the cross joint and the foliation are continuous, a stability analysis using fracture shear strength for a full wall height wedge gave a safety factor of 1.75 for the dry case and 1.15 when saturated.

Rotational Shear

A rotational shear stability analysis was performed on the SW wall of the proposed Flambeau Pit. The analysis was performed to determine the overall stability of the pit wall adjacent to the Flambeau River. The Modified Bishop's Method and Circular Search routine in the program STABL5 were used.

Slope Model

The slope geometry was constructed based on the ultimate pit plan presented in the June 1988, Slope Design Report. The interramp angle was 50° and the total slope height measured 192 ft. The sides of the model were extended 400 ft from both the crest and toe of the slope, and the bottom of the model was extended 300 ft below the toe of the slope.

FLAMBEAU - SW WALL

	DIP DIRECTION	DIP	
LEFT	349	57	
RIGHT	81	23	
INTERSECTION	63.7	22.1	119

FLAMBEAU SW WALL

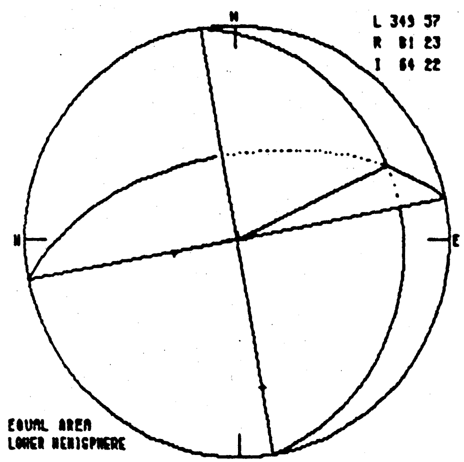


Figure 9-8a

FLAMBEAU - SW WALL

	DIP DIRECTION	DIP	
LEFT	349	57	
RIGHT	81	82	
INTERSECTION	3.1	56.2	93

FLAMBEAU SW WALL

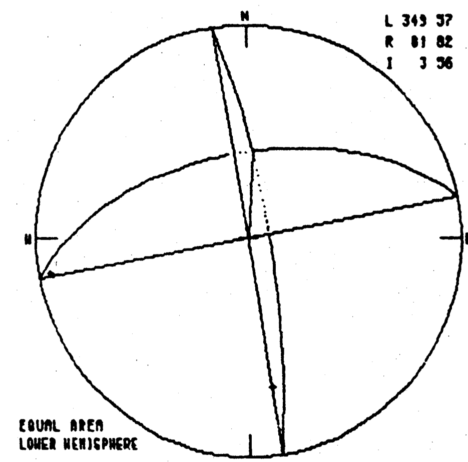


Figure 9-8b

Figure 9-8: Southwest End Sector Kinematic Wedge Analysis.

The center line of the river was located 215 ft behind the crest of the slope. The piezometric surface was assumed to be 15 ft lower than the crest and a simple linear drawdown into the upper portion of the slope or to the toe of the slope was assumed to exist.

A total of three rock types were used in the model. The thin, upper unit was composed of a soil layer. The "2A" schist comprised the upper half of the slope. The "1A" and "1C" ore zone rocks were grouped together to form the lower half of the slope and pit bottom (since no strength data is available for the "1C" unit).

Rock Mass Properties

The rock properties used in the analysis were taken from the June 1988, Slope Design Report. A summary of the properties used is shown in Table 9-3.

The percentages of intact rock strengths were based on a weighted average of joint shear strength and intact rock strength from triaxial testing.

Stability Analysis

A rotational shear stability analysis was run, using the STABL5 program, to determine the percent intact rock required on the failure surface for stability (safety factor = 1). According to this analysis, only 6 percent intact rock is required for rotational shear stability (Figure 9-9). Since the rotational shear surface cuts across the joint and foliation orientations, there is considerably more than 6 percent intact rock along the potential failure path so the slope would be stable with respect to rotational shear.

Table 9-3

Rock Mass Properties

Rock Type	Unit Weight (wet/dry)		Cohesion (psi)	Friction Angle
Intact Rock Analysis				
Soil	127.5	145.0	4.17	18.3
1A & 1C	146.0	146.0	145.00	51.0
2A	148.0	148.0	120.00	58.0
Joint Shear Analysis				
Soil	127.5	145.0	4.17	18.3
1A & 1C	146.0	146.0	0.81	32.4
2A	148.0	148.0	0.81	32.4
6% Intact Rock Analysis				
Soil	127.5	145.0	4.17	18.3
1A & 1C	146.0	146.0	8.60	33.1
2A	148.0	148.0	8.70	32.7

Run #7 6% Intact

10 MOST CRITICAL OF SURFACES GENERATED

MINIMUM FACTOR OF SAFETY = 1.035

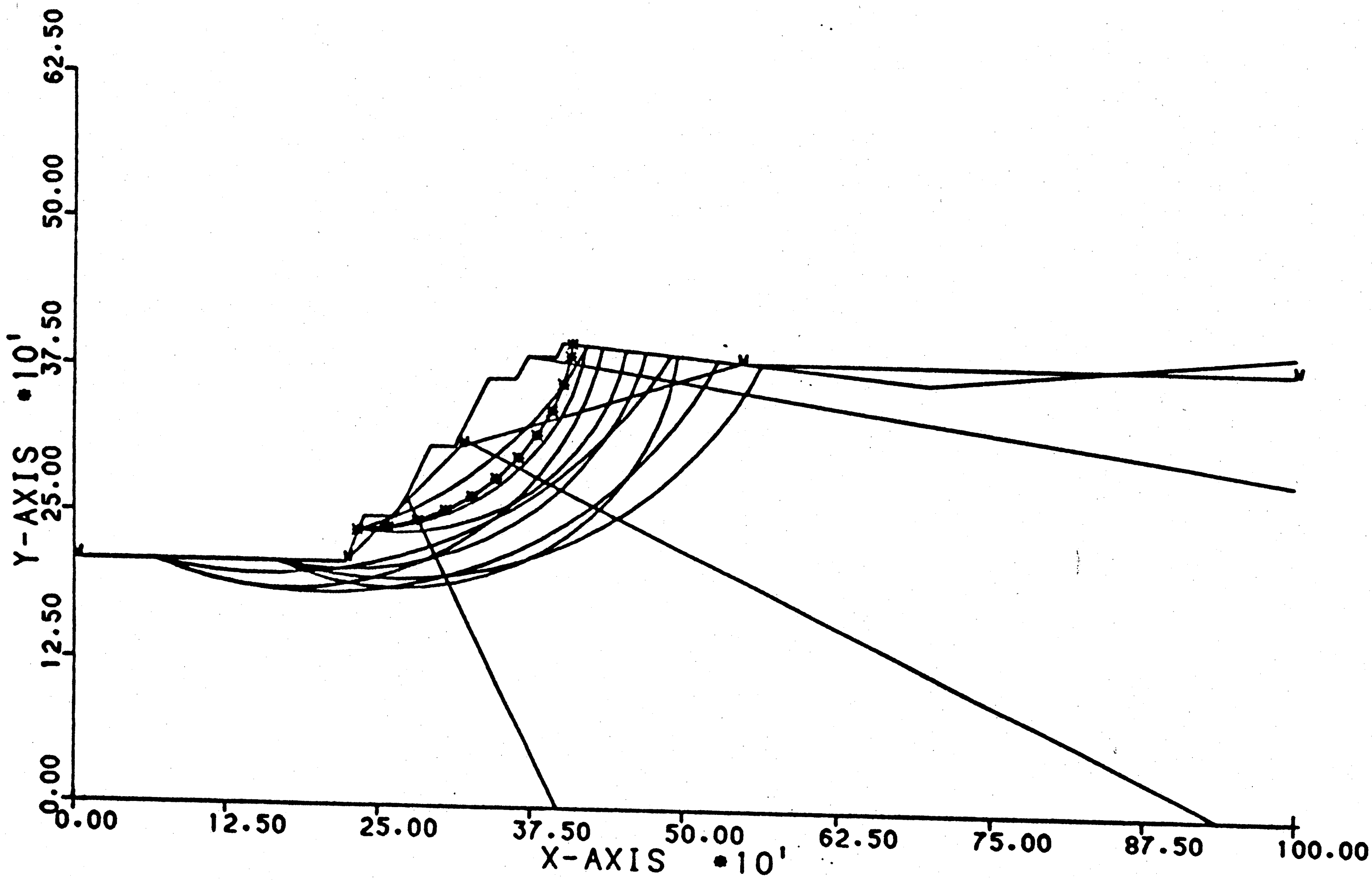


Figure 9-9.

Recommendations

Because of the absence of significant failure geometries, a bench face angle of 69° should also be attainable in the Southwest End Sector. Because this sector would have the same bench height and catch width design as the other sectors, a 50° interramp slope angle is also viable.

10.0 OVERALL SLOPE STABILITY ANALYSES

10.1 Major Structure

Although several long faults have been interpreted in the Flambeau deposit (Figure 10-1), these structures have not been projected onto cross sections developed by BPMA, indicating these features have not been observed in subsurface drilling.* If these structures are high angle, it is unlikely they would have been intersected by most of the angle holes since the drilling was oriented subparallel to the discontinuities. There would be even less chance of the vertical core holes intersecting the interpreted faults.

Without knowledge of dip of these structures, assessing potential for multibench failure is difficult. However, without the presence of N-NE oriented major faults or long jointing to complete a wedge geometry, multibench failure would not occur.

Obviously, when overburden is stripped off and bedrock is exposed, a preliminary major structure-geologic model needs to be developed as soon as possible in order to reassess the potential for major structure controlled multibench failure.

10.2 Overburden Slope Stability Using STABL5

This analysis was conducted to investigate the stability of the overburden at Flambeau, which consists of glacial till, sandstone, and a low plasticity silt unit (referred to as a

* Since preparation of this report, BPMA geologists have observed one of the structures in drill core along section 408.

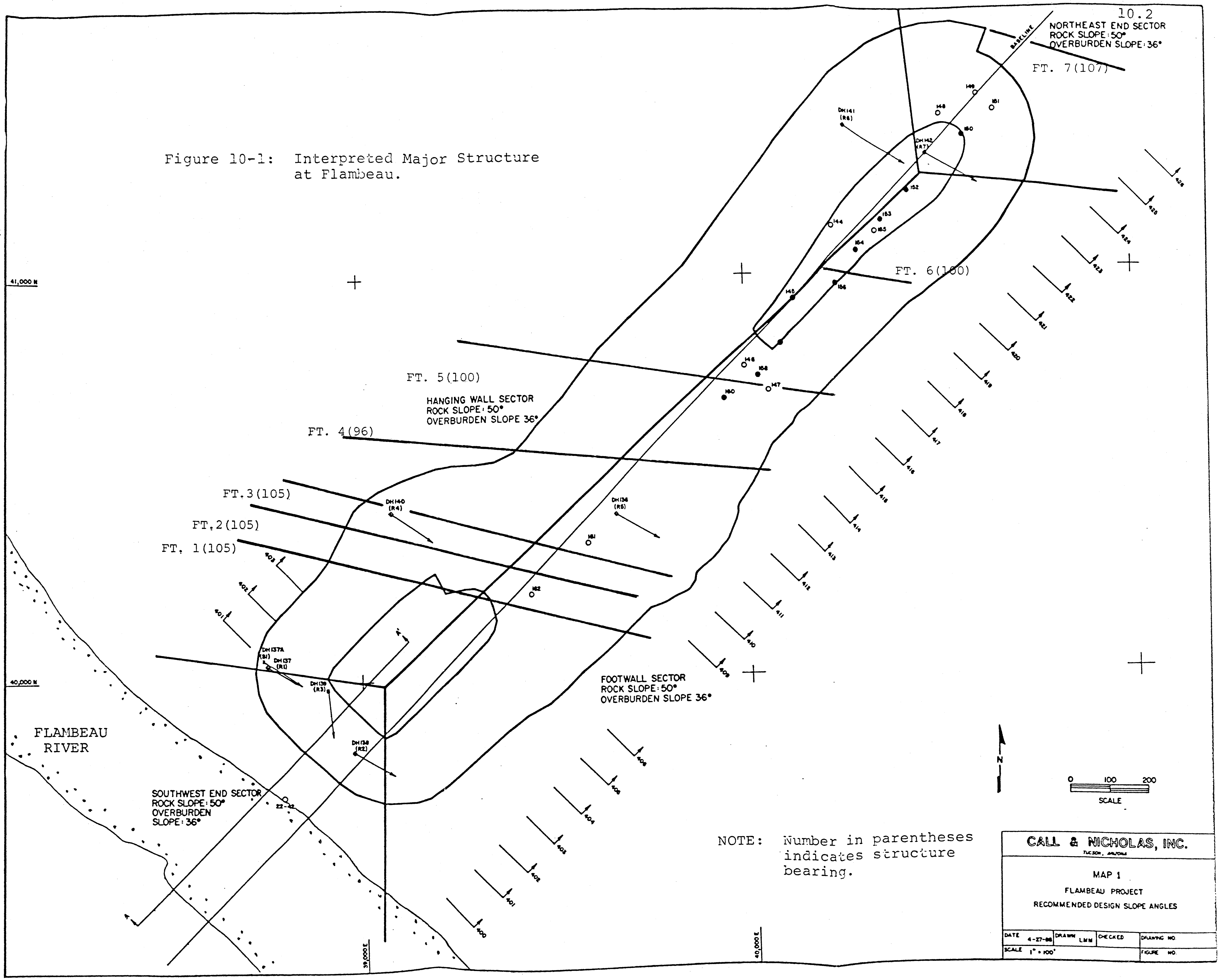


Figure 10-1: Interpreted Major Structure at Flambeau.

NOTE: Number in parentheses indicates structure bearing.

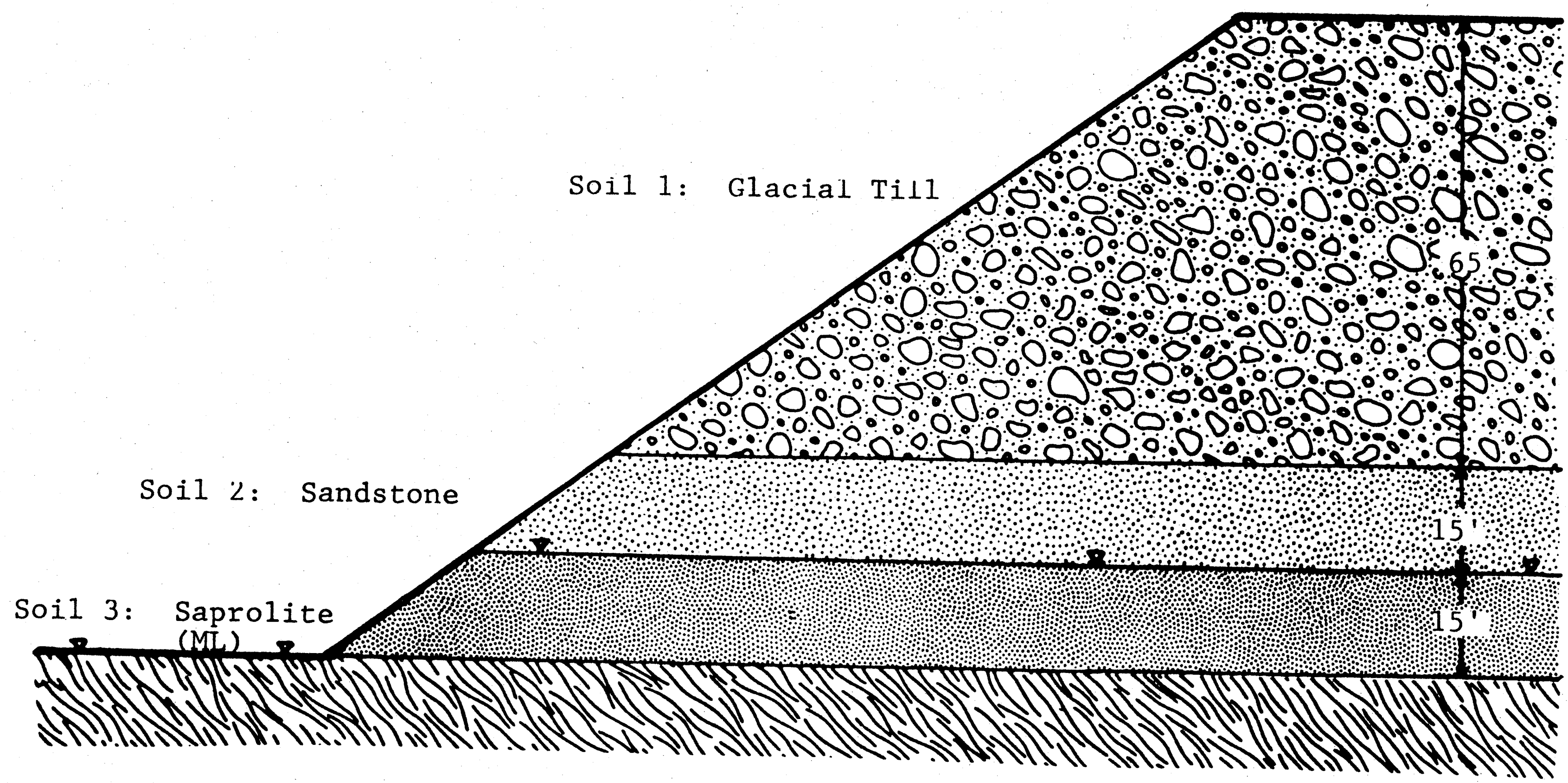
ML unit by its Unified Soil Classification system symbol). The model is shown in Figure 10-2. Foth and Van Dyke supplied the material properties and soil strength parameters used in the analysis. Although this data contained both total and effective strength information, only the latter was used in CNI's analysis.

In general, the glacial till was treated as a non-cohesive material with an effective friction angle of 36°. The sandstone, known to be generally cemented but locally uncemented, was modeled for both cases where the shear strength intercept was a minimum of zero and a maximum of 288.0 psf. The effective friction angle was given at 36°. For the ML unit, a range of strength values was reported, making a statistical analysis for this material possible. The values for friction angle and shear strength intercept were averaged, and their standard deviations were used for other cases.

Figure 10-2 shows that the geometry of the analysis consisted of, from top to bottom, a 65 ft layer of glacial till, 15 ft of sandstone, and 15 ft of the ML unit overlying competent bedrock. We understand this to be the maximum expected slope thickness at the Flambeau site. The slope angle for all analyses was set at 36°. Since the glacial till and sandstone are expected to be permeable, the phreatic surface was assumed to lie at the top of the ML unit within the slope and over the bedrock outside the slope.

10.3 Results of Analysis

Table 10-1 shows the results of the program STABL5 runs. Using mean strengths for the ML unit and a nominal cohesion of 288 psf for the sandstone, the safety factor was 1.26. The critical circle, as shown in Figure 10-3, was shallow, extending a maximum only 10 ft into the slope.



(Note: Triangles Delineate Assumed Groundwater Profile.)

Figure 10-2: Flambeau Overburden Slope Stability Design Model.

Table 10-1

Summary of Flambeau Overburden Stability Analysis

THIS SPREADSHEET CONTAINS RESULTS FROM THE SLOPE STABILITY ANALYSIS
CALLED STABL5 (BY RON SIEGEL) FOR THE FLAMBEAU PROJECT.
DATE OF ANALYSIS: APRIL 20-21, 1988

CNI RUN NUMBER	METHOD	FACTOR OF SAFETY (MINIMUM)	LITH & STRENGTH PARAMETERS UNIT-1 TILL	UNIT-2 SAND ST.	UNIT-3 ML UNIT	FAILURE MODE/COMMENTS
1	CIRCL2	1.063	C=0.0PSF PHI=36	C=0.0PSF PHI=36	C=157PSF PHI=22.3	SHALLOW CIRCULAR FAILURE MAX DEPTH=10FT PERP. TO SLOPE ML UNIT: PHI=MEAN-ONE STD.DEV. C=MEAN-ONE STD.DEV.
2	CIRCL2	1.066	C=0.0PSF PHI=36	C=0.0PSF PHI=36	C=157PSF PHI=24.3	SHALLOW CIRCULAR FAILURE MAX DEPTH=10FT PERP. TO SLOPE ML UNIT: PHI=MEAN C=MEAN-ONE STD.DEV.
3	CIRCL2	1.194	C=0.0PSF PHI=36	C=288PSF PHI=36	C=157PSF PHI=24.3	SHALLOW CIRCULAR FAILURE MAX DEPTH=12FT PERP. TO SLOPE ML UNIT: PHI=MEAN C=MEAN-ONE STD.DEV.
4	CIRCL2	1.261	C=0.0PSF PHI=36	C=288PSF PHI=36	C=416PSF PHI=24.3	SHALLOW CIRCULAR FAILURE MAX DEPTH=18FT PERP. TO SLOPE ML UNIT: PHI=MEAN PHI C=MEAN
5	CIRCL2	1.261	C=0.0PSF PHI=36	C=288PSF PHI=36	C=416PSF PHI=22.3	SHALLOW CIRCULAR FAILURE MAX DEPTH=17FT PERP. TO SLOPE ML UNIT: PHI=MEAN-ONE STD.DEV. C=MEAN
6	CIRCL2	1.125	C=0.0PSF PHI=36	C=0.0PSF PHI=36	C=416PSF PHI=24.3	SHALLOW CIRCULAR FAILURE MAX DEPTH=16FT PERP. TO SLOPE ML UNIT: PHI=MEAN PHI C=MEAN
7	CIRCL2	1.125	C=0.0PSF PHI=36	C=0.0PSF PHI=36	C=416PSF PHI=22.3	SHALLOW CIRCULAR FAILURE MAX DEPTH=15FT PERP. TO SLOPE ML UNIT: PHI=MEAN-ONE STD.DEV C=MEAN
8	BLOCK	1.169	C=0.0PSF PHI=36	C=0.0PSF PHI=36	C=157PSF PHI=22.3	DEEP CIRCULAR FAILURE MAX DEPTH=29FT. PERP. TO SLOPE ML UNIT: PHI=MEAN-ONE STD.DEV C=MEAN-ONE STD.DEV. FAILURE FORCED THROUGH 127X2 FT. BLOCK AT THE BASE OF THE ML UNIT
9	BLOCK	1.895	C=0.0PSF PHI=36	C=288PSF PHI=36	C=416PSF PHI=22.3	DEEP CIRCULAR FAILURE MAX DEPTH=40FT. PERP. TO SLOPE ML UNIT: PHI=MEAN-ONE STD.DEV C=MEAN FAILURE FORCED THROUGH 127X2 FT. BLOCK AT THE BASE OF THE ML UNIT

Table 10-1 (Continued)

THE FOLLOWING RUNS INCLUDE SENSITIVITY ANALYSIS AND SPECIFIC MODELING CASES

10	CIRCL2	1.208	C=0.0PSF PHI=36	C=288PSF PHI=36	C=416PSF PHI=22.3	SHALLOW CIRCULAR FAILURE MAX DEPTH=14FT PERP TO SLOPE SAP PHI=MEAN-ONE STD.DEV. FAILURE FORCED THRU BOTTOM OF SS
11	BLOCK	2.489	C=0.0PSF PHI=36	C=288PSF PHI=36	C=416PSF PHI=22.3	SHALLOW CIRCULAR FAILURE MAX DEPTH=10FT. PERP. TO SLOPE SAP PHI=MEAN-ONE STD.DEV. FAILURE FORCED THRU MID SAP TO MID SS W/ SHORT 21X2FT.BLOCK AT TOE
12	BLOCK	1.170	C=0.0PSF PHI=36	C=0.0PSF PHI=36	C=0.0PSF PHI=22.3	EXTREMELY SHALLOW CIRC. FAILURE SAP PHI=MEAN-ONE STD. DEV. FAILURE FORCED FROM TOE TO CREST W/127X2FT. BLOCK AT SAP BASE
13	BLOCK	2.857	C=0.0PSF PHI=36	C=288PSF PHI=36	C=416PSF PHI=22.3	EXTREMELY SHALLOW CIRC. FAILURE SAP PHI=MEAN-ONE STD. DEV. FAILURE FORCED FROM TOE TO CREST W/SMALL BLOCK AT EACH
14	BLOCK	0.954	C=0.0PSF PHI=36	C=0.0PSF PHI=36	C=0.0PSF PHI=22.3	EXTREMELY SHALLOW CIRC. FAILURE SAP PHI=MEAN-ONE STD. DEV. FAILURE FORCED FROM TOE TO CREST W/SMALL BLOCK AT EACH

NOTES: OTHER CONSTANT STRENGTH PARAMETERS USED:

	DRY DENSITY (PSF)	WET DENSITY (PSF)
TILL	132.5	144.5
SANDST.	126.5	143.0
SAP.	126.5	143.0

CIRCL2 IS A RANDOM CIRCULAR FAILURE SURFACE GENERATOR WHICH LOCATES CRITICAL FAILURE SURFACES AND CALCULATES A FACTOR OF SAFETY BASED ON THE MODIFIED BISHOP METHOD.

BLOCK IS A RANDOM SLIDING BLOCK FAILURE SURFACE GENERATOR WHICH USES ACTIVE AND PASSIVE PORTIONS OF THE SLIDING SURFACE ACCORDING TO THE RANKINE THEORY TO LOCATE CRITICAL FAILURE SURFACES. FACTORS OF SAFETY ARE CALCULATED USING THE MODIFIED JANBU METHOD.

To test for probability of failure, the cohesion and friction angle of the ML unit were both reduced to -1 standard deviation, and the sandstone cohesion was dropped to 0. This combination gave a safety factor of 1.06 which is approximately limiting equilibrium. Since the joint probability of both the cohesion and friction angle being less than the standard deviation is 3 percent, the conclusion is that the probability of failure is 3 percent, assuming the sandstone is uncemented (cohesion = 0).

Runs with a deeper failure surface forced through the ML Unit showed a higher stability.

The only condition which had a safety factor less than one was when all the cohesions were reduced to 0, the friction of the ML unit was reduced to -1 standard deviation and the failure surface was forced to a full slope shallow failure. this run was made to simulate ravelling assuming all the material was uncemented.

10.4 Conclusions

A slope angle of 36° is recommended for the following reasons:

1) Slope angles steeper than 36° could result in ravelling of uncemented glacial material and sandstone.

2) A slope angle of 36° is stable for rotational shear failure geometries.

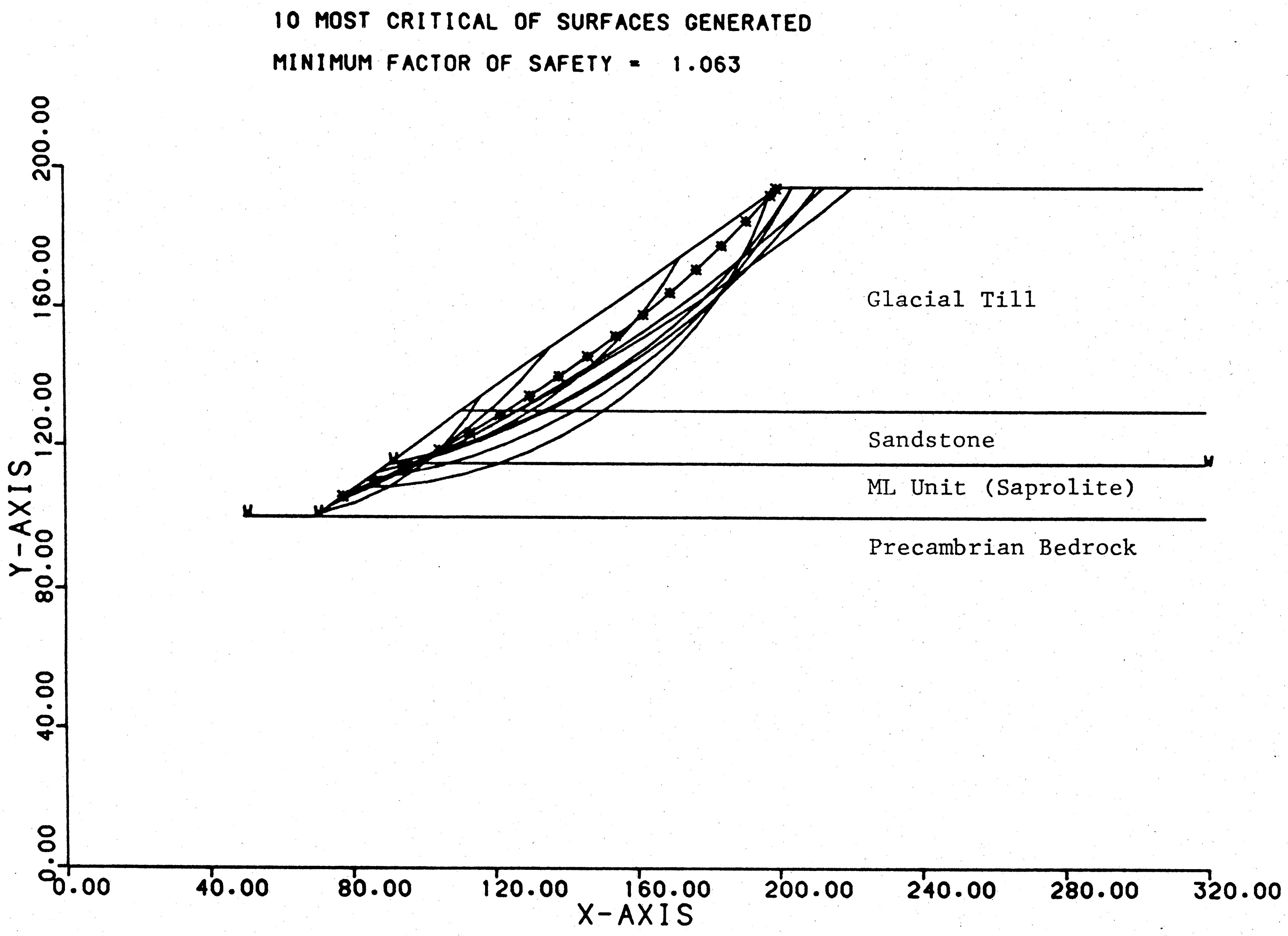


Figure 10.3: Critical Failure Path Geometry for Conservative Soil Strengths (Run 1).