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THE NATURE AND ORIGIN OF THE URANIUM MINERALIZATION AT THE FAY MINE, ELDORADO, SASKATCHEWAN CANADA

BY

© GIAMPAOLO SASSANO, Doctor of Geol. Sci. (Univ. of Milan, Italy)

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled 'The Nature and Origin of the Uranium Mineralization at the Fay Mine, Eldorado, Saskatchewan, Canada' submitted by Giampaolo Sassano, Doctor of Geol. Sci. (Univ. of Milan, Italy) in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

Supervisor

External Examiner

ABSTRACT

The Fay Mine uraniferous deposits occur within metamorphic rocks situated in the southwestern sector of the Churchill structural province. The region is underlain almost entirely by Precambrian rocks which have been divided in two major units, the Tazin Group and the Athabasca Formation, separated by an unconformity. In the Fay Mine the Tazin Group has been subdivided into:

3. Upper Tazin Group = The Fay Mine Complex
2. Middle Tazin Group = The Donaldson Lake Gneiss
1. Lower Tazin Group = The Foot Bay Gneiss

The lower part of the Fay Mine Complex is cut by discordant pegmatite dykes which are locally offset by diabase dykes; the apparent age of these pegmatites is 1975 $\pm$ 20 m.y. (Rb-Sr). The minimum age of the Donaldson Lake and Foot Bay Gneisses is 2100 m.y. (Rb-Sr).

Lying unconformably on the Tazin Group is the Martin Formation (lowermost unit of the Athabasca Formation) which is composed of a gently folded sequence of conglomerate, arkose and siltstone intercalated with basaltic and andesitic flows and sills. It is confined to a series of structural depressions trending NE-SW, the principal outlier of which is situated on the W shore of Beaverlodge Lake.

A detailed textural study of the Tazin rocks has demonstrated that:

a) all the Tazin rocks have been effected by strong postcrystalline (partly syncrystalline) deformation;

b) the deformation effected extreme cataclasis;

c) the deformation occurred in several stages (separated by considerable time intervals) and at successively higher structural levels;

d) all Tazin rocks are polydeformational.

Structurally the investigated area is dominated by Hudsonian folds whose axial traces trend NE-SW, affecting a relatively poorly developed set of folds (probably Kenoran in age) whose axes trend NW-SE or N-S. Some of the major faults of the district, such as the St. Louis Fault, trend NE-SW, and are thought to have been initiated either as F 2 shear joints or as F 2 tension fractures and have undergone multiple movements over a long period of time.

The Fay Mine is situated on that part of the gently folded southern limb of the Donaldson Lake antiform which occurs in the foot wall of the SE dipping St. Louis Fault. The Verna Mine and Bolger open pit are situated on the crest of a SW plunging anticlinal structure which is part of a major isoclinal overturned synform recognized at depth in the hanging wall of the same fault system.

The uranium bearing deposits of the Fay and Verna Mines may be described as U oxides + Cu-Pb-selenide + sulfide ores. The main epigenetic stage of the uranium mineralization is confined to the Fay Mine Complex and was probably emplaced during or subsequent to the development of the schistosity associated with the NE-SW trending folds. Pitchblende ± quartz ± carbonates ± hematite ± chlorite veins occur parallel to the S 2 foliation planes in the crest, troughs or limbs of the F 2 folds wherever minimal plunge is observed.

Fluid inclusion and stable isotope studies have revealed that the deposits were generated by metamorphic hydrothermal fluids having initial δO^{18} (SMOW) values of ±6 to + 8‰ which during cooling underwent isotopic exchange with the host metamorphics, becoming depleted in O^{18}. The final stages of mineralization were possibly effected by influx of isotopically lighter surface waters. It is suggested that the Fay Mine Complex might be thought of as the originally uraniferous 'donator' sequence which provided the metalliferous components to the ore-veins.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER 1 - INTRODUCTION

Several vein-type uraniferous deposits occur in the Beaverlodge area, on the N shore of Lake Athabasca. The region is characterized by the presence of severely metamorphosed folded and faulted Precambrian rocks which, despite extensive discussion in the literature, still represent a challenge to all the geologists working in the area.

In 1934 the discovery of gold, at Lodge Bay, in the N shore of Lake Athabasca initiated the first exploratory activity in the district. Alcock, in 1936, reported the occurrence of pitchblende at the Nicholson property (Goldfields area). The importance of this discovery became evident when, in 1944, the Canadian Government expropriated the shares of Eldorado Gold Mines Ltd., for strategic purposes, and formed a new independent Crown Corporation known as Eldorado Nuclear Ltd. A pressing demand for uranium stimulated the newly formed company to perform an intensive exploration program; several claims were staked E of the Nicholson property and around Fish Hook Bay. Within a few years, more than 1000 separate pitchblende occurrences were found in the district. The initial work was followed by detailed mapping, diamond drilling and underground workings, which reached a peak in 1948, with the outline of the Ace orebodies situated in the foot wall of the St. Louis Fault.

The important discoveries of the early 1940's were followed by a period when uranium exploration greatly decreased in the whole area, and several mines were forced to close down owing to poor market conditions.

Since that period, Eldorado Nuclear Ltd. has remained the only active producer of the district. In the early 1960's, the Company, following a sudden exploration boom, initiated a successful hydrogeochemical campaign which brought about the discovery of the HAB orebodies, situated ~8 miles from the main production plant. In the late 1960's Eldorado developed the Bolger open pit and sunk a 5 level shaft on the HAB property. In 1971 the HAB Mine was put into production and new plans to sink a deeper internal shaft, in the Fay Mine, were considered. The new declining price of uranium forced the Company to close down the low-grade Verna orebodies and to reduce the mill output to approximately 1000 tons a day.

Geological field work initiated by the writer in 1966, as geologist of the Fay Mine, was completed during the summer of 1970. Several geological surveys were performed in areas of interest on the Eldorado property and surrounding region, in order to check the geology and collect different rock types for analytical and age determinations. The underground survey of the Fay Mine, consisted of detailed mapping, on the scale of 1 inch to 20 feet, of the roof and one wall of several drifts of many levels (2nd L., 3rd L., 7th L., 16th L., 18th L., 19th L., 20th L., 21st L., 22nd L., 23rd L., 24th L., 25th L., 26th L., 27th L.) several stopes (355, 455, 1109, 1209, 1301, 1309, 1401, 1409, 1509, 1609, 1709, 1809, 1909, 2009, 2109) and raises in the '01', '09', '16' and '55' zones. The field study of the orebodies consisted of core logging more than 150,000 feet of exploration and development diamond drill cores, collected in the Fay Mine, Verna Mine and at surface. This work was followed by a complete reinterpretation of all existing geologic plans and sections of the Fay and Verna Mines, resulting in the compilation of a new surface geologic map, on the scale of 1 inch to 1200 feet, for the region S of Donaldson Lake and E of Fredette Lake. This map, based upon the geologic sheet published by Tremblay (1968), contains abundant geologic data collected by the writer and several staff members of the Exploration Department of Eldorado Nuclear Ltd.

In order to elucidate the nebulous features of the field relationships, laboratory research was performed at the University of Alberta during the period 1969-1972. The mineralogy, petrography and paragenetic sequence of the minerals present in the orebodies, were studied in detail by polished- and thin-section work augmented by X-ray diffraction, X-ray fluorescence spectrometry, and electron probe analysis. Whole rock Rb-Sr age determinations were conducted on 21 samples collected in the Fay Mine on surface. Stable isotope and fluid inclusion studies were performed on vein material collected in the Fay and Verna Mines and Bolger open pit. Finally, approximately 5500 structural readings (dip direction and dip), were collected on the 16th L., 22nd L., 23rd L., 24th L. and 25th L. of the Fay Mine and processed for structural studies.

Aims of the Project

After four years of field work, several reasons motivated the writer in the attempt to assemble a complete documentation of the mineralization present in the Fay Mine, Eldorado, Saskatchewan.

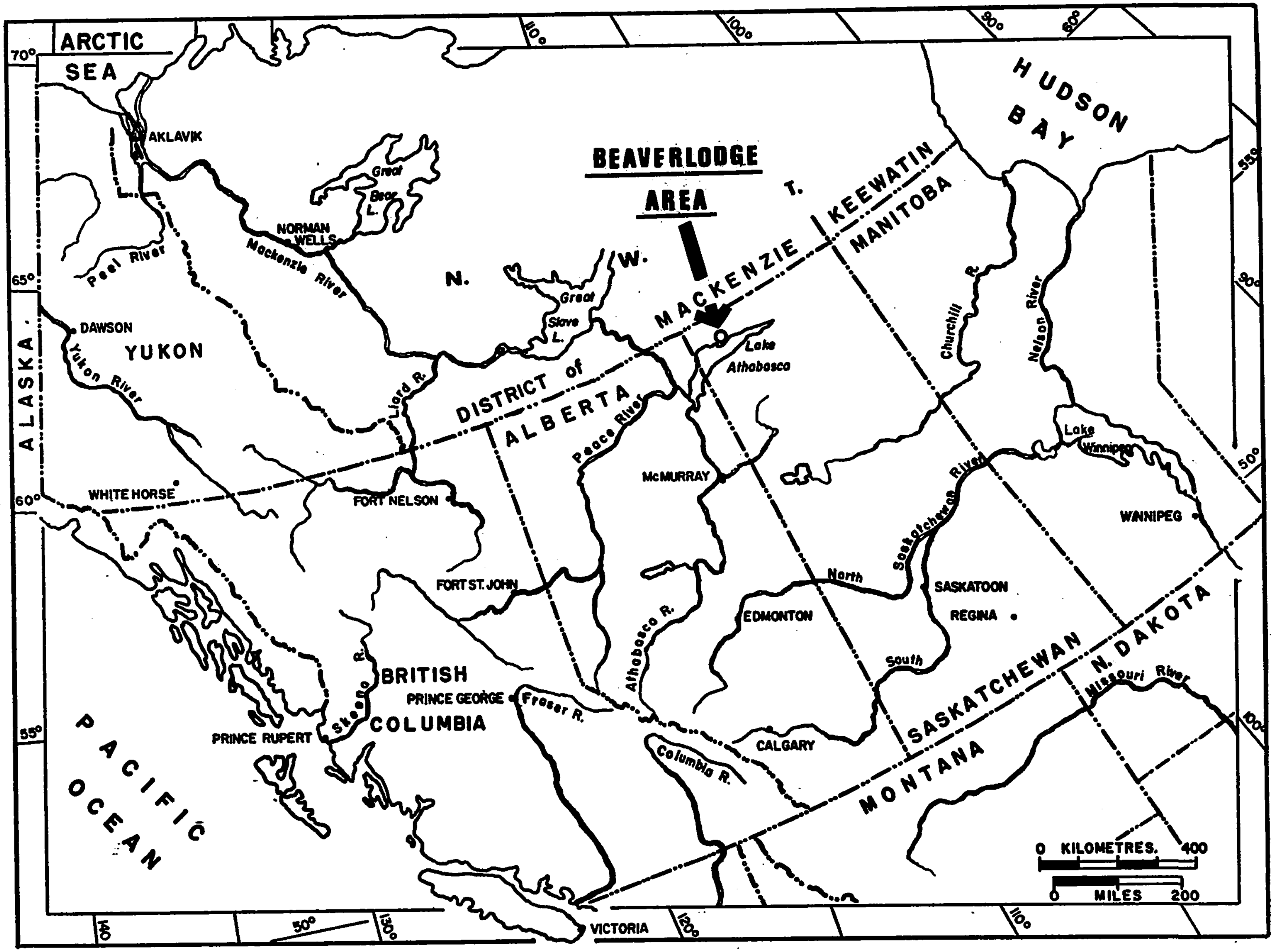
When the original idea to write a thesis was formulated, it was suggested that more emphasis should be put into laboratory studies regarding the possible origin of the uranium ores.

Having a unique basis of data in the form of underground maps and sections and possessing an intimate knowledge of the Fay Mine, the author felt well qualified to conduct geological research in the Beaverlodge area. Thus with this thesis the author proposes to present, with the aid of illustrations, the principal highlights of the regional and local geology which he considers to be significant with respect to the geochemistry, mineralogy, geochronology, structural and lithological controls and possible origins of the uraniferous orebodies and their immediate country rocks.

Location of the Fay Mine and Physiography of the District

The Beaverlodge operation of Eldorado Nuclear Ltd. is located on the NE shore of Beaverlodge Lake, NW corner of the province of Saskatchewan, about 30 miles S of the N.W.T. boundary, 55 miles W of the Alberta boundary, between latitudes 59°15' N and 59°45' N and longitudes 108°15' W and 108°45' W (Fig.1).

Fig. 1. Location map of the Fay Mine, Beaverlodge area, Saskatchewan, Canada.


BEAVERLODGE AREA
ARCTIC SEA
HUDSON BAY
PACIFIC OCEAN
AKLAVIK
Great Bear L.
NORMAN WELLS
Mackenzie River
Peel River
DAWSON
YUKON
Yukon River
ALASKA
WHITE HORSE
N. W. T.
MACKENZIE
KEEWATIN
MANITOBA
DISTRICT of
Great Slave L.
Lake Athabasca
Liard R.
FORT NELSON
ALBERTA
Peace River
McMURRAY
FORT ST. JOHN
Athabasca R.
EDMONTON
CALGARY
Columbia R.
BRITISH COLUMBIA
PRINCE GEORGE
Fraser R.
Skeena R.
PRINCE RUPERT
VICTORIA
Churchill R.
Nelson River
Lake Winnipeg
WINNIPEG
Saskatchewan River
North
South
SASKATOON
REGINA
SASKATCHEWAN
N. DAKOTA
Missouri River
MONTANA
0 KILOMETRES. 400
0 MILES 200
70°
65°
60°
55°
50°
140
130°
120°
110°
100°
90°
80°

About 8 miles of paved road connects the main production plant (Fay Mine) to Uranium City, the largest settlement in the district. Gravelled roads connect Uranium City with Bushell and various mines of the area. A new gravelled road connects the Fay Mine with the HAB Mine. An all weather air service, operated by Eldorado Aviation Ltd., Pacific Western Airlines and Sask. Govt. Airlines, connects the Beaverlodge operation with Edmonton, Fort McMurray, Prince Albert, occasionally Yellowknife, Hay River and local exploration camps and mines. During the summer, Northern Transportation Company Ltd., a subsidiary of Eldorado Nuclear Ltd., provides heavy freight and supplies services by boats and barges, via Athabasca River, to Bushell on Lake Athabasca.

The area studied is characterized by numerous lakes, muskegs and small creeks, which lie along the deeper parts of NE-SW trending valleys and depressions. Most of the ridges in the area are oriented parallel to the regional trend of the foliation of the rocks or to the main NE trending tectonic lineaments. A few short transverse valleys cut the most prominent ridges in an E-W direction and are usually the site of major regional faults, easily traced on the ground and via aerophotographic studies. The relief of the area, varying in altitude between 300 and 600 feet above the Beaverlodge Lake, is locally quite rugged due to differential erosion. Continental glaciation has removed most of the overburden material and at least 50% of the rocks are exposed. The area is moderately timbered with black and white spruce, jack pine being abundant in those valleys covered by a shallow layer of till; banksian pine and white spruce grow locally on bare rocks or on sand plains; aspen, poplar and white birch are quite common in the Martin Lake area.

The climate of the region is continental with extremely cold winters and mild summers. The annual precipitation is about 10 to 13 inches with an average snowfall of about 50 inches. The temperature in the Fay Mine ranges from 35°F. to 45°F. and may reach temperatures of 50°-60°F. in poorly ventilated stopes and drifts of the lower mine levels.

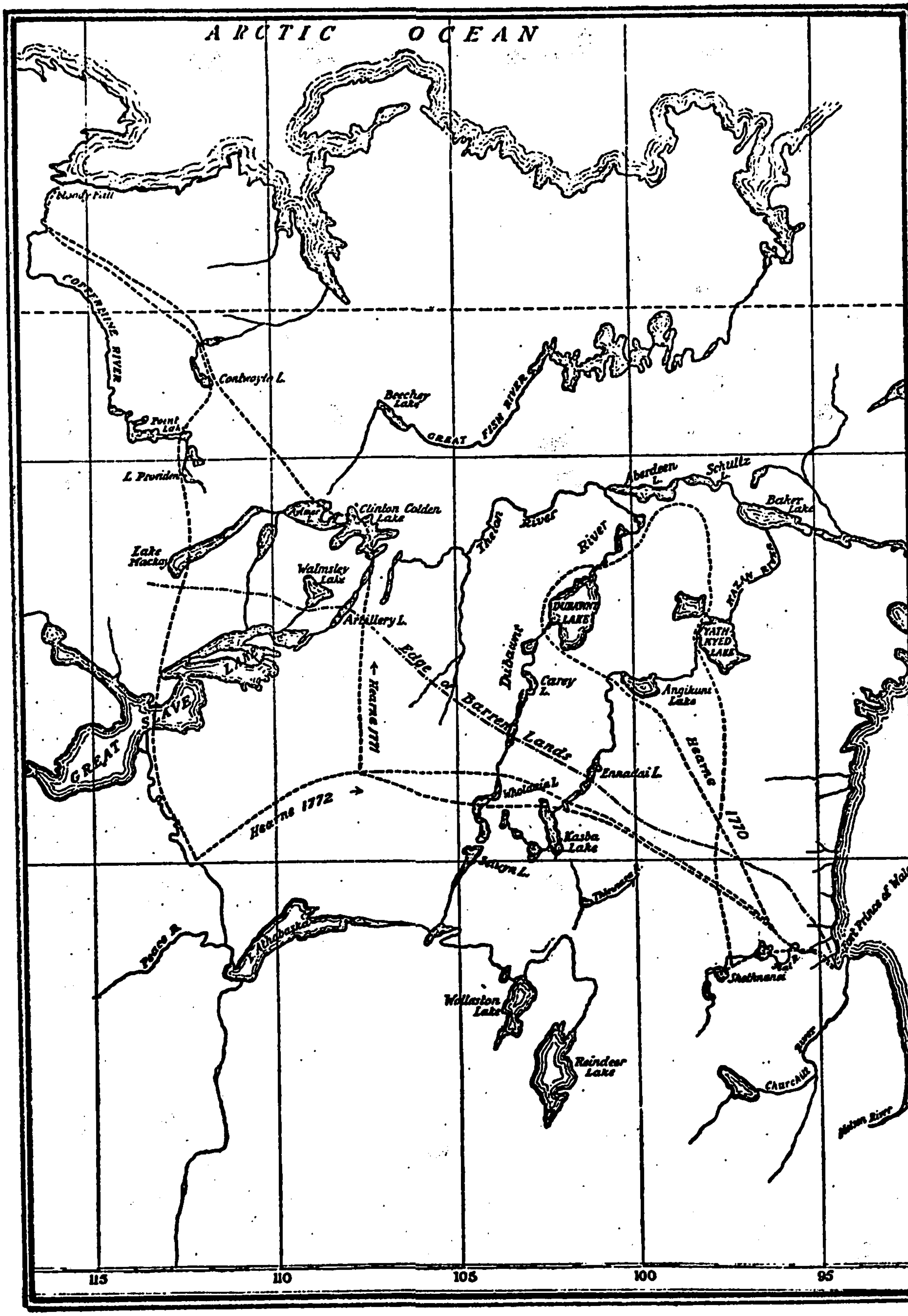
Summary of Past Literature

During the past 40 years a proliferation of literature concerning the geology of the Beaverlodge area and its uraniferous ore deposits has emerged, and as a consequence, the location of specific information has become a monumental task for anyone not familiar with the region. In view of this fact the following review of previous literature has been subdivided into sections which are chosen as a simplified guide which will enable future researchers to gain ready access to the topics of particular interest.

1 - General Geology

In 1772 Samuel Hearne, a young employee of the Hudson's Bay Company, on his return journey from Coppermine River, explored the region about 70 miles N of Lake Athabasca (Fig. 2). A few years later, in 1778,

Fig. 2. Samuel Hearne's journeys, after Tyrrell (1894).


ARCTIC OCEAN
Coppermine River
Contwoyto L.
Point Lake
L. Providence
Beechey Lake
Great Fish River
Clinton Colden Lake
Aylmer
Lake Mackay
Walmsley Lake
Artillery L.
Great Slave Lake
Edge of Barren Lands
Hearne 1771
Hearne 1772
Thelon River
Aberdeen L.
Schultz L.
Baker Lake
Kazan River
Dubawnt Lake
Dubawnt River
Yathkyed Lake
Carey L.
Angikuni Lake
Hearne 1770
Ennadai L.
Wholdaia L.
Kasba Lake
Selwyn L.
Peace R.
L. Athabaska
Wollaston Lake
Reindeer Lake
Shethnanei
Churchill River
Nelson River
Fort Prince of Wales
115
110
105
100
95

Peter Pond, a fur trader for the Northwest Company, established a fort known as the 'Fur Emporium', forty miles from the mouth of the Athabasca River. Alexander Mackenzie starting from Pond's fort, in 1789, undertook the famous expedition that led to the discovery of the outlet of Great Slave Lake.

In 1882, a cursory geological reconnaissance trip was undertaken in the Athabasca region by Cochrane, followed, in 1888, by the geologic survey of McConnell (1893) who, exploring the same area, recorded the presence of a series of 'flat-lying siliceous sandstones' which he named 'Athabasca sandstones'. In 1893, Tyrrell (1894), while surveying the N shore of Lake Athabasca, recognized the existence of granitic and gneissic rocks, locally covered by Athabasca sandstones. He also discovered 'iron-bearing rocks' in the vicinity of Fish Hook Bay. In 1914, Camsell (1916) carried out exploratory work in the region situated between Lake Athabasca and Great Slave Lake, and in particular along the Tazin and Taltson Rivers. During this expedition Camsell recorded the presence of a series of Precambrian rocks, mainly composed of 'schists, quartzite, conglomerate, limestone, argillite and volcanic rocks' which he named 'Tazin Series'. He also stated that rocks of the 'Tazin Series' and some granites were overlain by younger sediments belonging to the Athabasca series. Camsell revisited the area in 1915, to investigate some silver occurrences. His work was continued by Alcock, who, during the summers 1914-1916, outlined the geology of the N shore of Lake Athabasca.

In 1922 Allan and Cameron investigated some 'iron-bearing rocks' E of Lodge Bay; claims were staked but they were soon abandoned when the showings proved to be uneconomic. Some years later, in order to meet the sudden demand for maps and information caused by the discovery of gold NW of Neiman Bay, eight field parties, under the direction of Alcock (1935), were sent into the district to map, on the scale of 1 inch to 1 mile, the Goldfields region and the Beaverlodge area. The result of this work was published in 1936 (G.S.C. Mem. 196) with an accompanying map on the scale of 1 inch to 4 miles. In this memoir Alcock recognized the existence of three divisions of the local Precambrian sequence: 'the Tazin Group', 'the Beaverlodge Series', and 'the Athabasca Series' (Fig. 3). Alcock also reported pitchblende in a vein outcropping in the Nicholson property. Other geological work was carried out by Cooke (1937a, 1937b), Beavan (1938), Swanson (1945), Killin (1939) and by Jewitt (1940) during the years 1937-1945. More detailed work was performed by Christie and Jolliffe (1949) who mapped the Goldfields-Martin Lake region on the scale of 1 inch to 1 mile. The results of this survey were published in a G.S.C. Memoir. Christie (1953) abandoning the term 'Beaverlodge Series' included all the oldest 'sedimentary and volcanic rocks' of the area in the Tazin Group, for he did not recognize the unconformity separating the Tazin rocks from Alcock's 'Beaverlodge Series'. According to Christie (1953), the Tazin Group consisted of quartzites, crystalline carbonate rocks, diopside and tremolite rocks, amphibolite, schists and gneisses which in some places were injected by granite. He also believed that younger granites

Fig. 3. Geologic sequence, after Alcock (1936).

Proterozoic	Athabasca Series ...		Conglomerate, arkose, sandstone, shale, basalt flows and dykes
	Unconformity		
			Granite
	Intrusive Contact		
			Gabbro, norite, peridotite, amphibolite
	Intrusive Contact		
	Beaverlodge Series ...		Quartzite, conglomerate, iron formation
	Unconformity		
Archaean			Granite, granodiorite, quartz-syenite, pegmatite
	Intrusive Contact		
	Tazin Group		Dolomite, limestone, quartzite, argillite, conglomerate, micaschist and gneisses, volcanic flows and fragmental rocks

Fig. 4. Table of formations, after Christie (1953).

Era		Formations and lithology	Mixed rocks
Proterozoic		Basic dykes	
	Athabasca series	Basalt flows (a few may be sills) Arkose and sandstone Conglomerate	
		Unconformity	
Archaean or Proterozoic		Lamprophyre dykes	
		Granite and granite-gneiss (commonly contains inclusions of amphibolite)	Granite-gneiss, with bands of diopside or tremolite, believed derived from alteration of dolomite Granite-gneiss, with inclusions of quartzite
		Intrusive contact	
	Tazin group	Mafic rocks Amphibolite Biotite schist or gneiss Garnetiferous gneiss Chlorite-bearing rocks Epidote-bearing rocks Chlorite-epidote rocks grading to more siliceous types	Mafic rocks, with minor added granitic material
		Conglomerate Dolomite and dolomitic quartzite Ferruginous quartzite	Quartzite, with minor amounts of dolomitic material
		Quartzite	Quartzite, with minor added granitic material

and granitic-gneisses, commonly containing inclusions of amphibolite, were separated from the Tazin Group by an intrusive contact and were overlain by the Athabasca Series (Fig. 4). More than 50 per cent of the area was thought to be underlain by a complex composed of granite, granite-gneisses and granitoid-gneisses varying in texture from well foliated to almost massive types. The oldest material was thought to be a plagioclase-rich granite whilst a 'second phase of injection or replacement' led to the crystallization of abundant microcline and quartz, and was followed by several periods of albite-oligoclase introduction. Finally Christie described the largest single structure of the Beaverlodge area as a 'synclinorium' centered about Goldfields and plunging SW at about 25°. This feature was thought to be flanked on the W side by a large antiform (Milliken Lake antiform) plunging NE at 20°. Lang (1949, 1950, 1952) published several geologic notes and briefly outlined each uranium deposit present in the Beaverlodge area. Edie (1951, 1953) revised the geology of the Eagle-Ato-Mic claims, subdividing the so-called 'mafic rocks' into 'plagioclase amphibolite, slates, chlorite-sericite schist, garnetiferous-muscovite schist and structural breccia'. All the results were included in a Ph.D. thesis presented at the M.I.T., in 1951, and in three later papers (1952, 1953a, 1953b) in which he described the main rock types of the area. On the basis of quantitative spectrographic chemical analysis he also discussed their alteration and the probable genesis of the uraniferous mineralization. According to Edie's data, chemical changes, due to alteration, were in part governed by the original composition of the 'unaltered rocks'. In particular the area was characterized by an increase in Fe, K, Ca and Mg with a concomitant decrease in Na and Si. He also thought that on the Eagle-Ato-Mic claims the introduction of K had taken place during the formation of a 'black mylonite'. Smith (1949, 1952) gave a detailed description of the lithologies present in the 'Martin Lake basin' and of their conditions of deposition. During the same period Ross (1949) submitted a M.Sc. thesis to the University of Toronto in which he described the 'stratigraphy' of the Goldfields area.

During the period 1949-1956, several geologists studied the Beaverlodge district and published several papers on the uranium deposits of the area. Allen (1950) briefly commented on some mineralized fracture systems; Kirkland (1953) studied the Tazin-Athabasca unconformity; Evoy (1952) examined the granitic rocks and associated amphibolites outcropping in the Rix-Athabasca property; Fraser (1954) mapped the Crackingstone Peninsula, while Allen, MacDonald and Smith (1954) presented a paper on the orebodies situated along the St. Louis Fault. Silman (1953) prepared internal reports on the Nesbitt-Labine Mine; Dawson (1951, 1956) investigated the wall-rock alteration of some uranium-bearing veins of the Goldfields region. Hale (1954a, 1954b, 1955) studied the geology of the Black Bay area whilst Stee and Archer (1953) examined the Basca Uranium Mines. Blake (1949, 1951, 1952a, 1952b, 1955, 1956) mapped the Forget Lake environs, whilst Conybeare and Campbell (1951) studied the mylonites and the red-alteration associated with the uranium deposits of the district. Gussow (1957, 1959), reviewing the geology of the Athabasca district, distinguished between the sandstones outcropping on the S shore of Lake Athabasca and the folded sedimentary beds exposed on the W shore of Beaverlodge Lake. Naming the later series the 'Martin Formation', he postulated that it was Precambrian in age and possibly older than the typical Athabasca Formation. In the same year Buffam, Campbell and Smith (1957) presented a complete description of the various orebodies developed by Eldorado. A paper dealing with the detailed geology of the area was also prepared for the Members of the Sixth Commonwealth Mining and Metallurgical Congress (Beaverlodge, 1957) whilst in 1960, another paper described the Beaverlodge operation owned by Eldorado and the geology of the operating mines (Eldorado, 1960). In the same year Dudar (1960) presented a Ph.D. thesis to Michigan University, in which he described the uranium mineralization present in the Verna Mine and the mechanical and hydrothermal alteration of the so-called 'ore-bearing argillites'. He also stated that'major factors in the deposition of uranium minerals were the nature of the host-rock, the temperature and pressure reductions (which caused precipitation of the uranium minerals) and the structural folds which controlled the position of later faults and fractured zones'.

From 1954 to 1962 several reports and publications were written by Saunders (1957), Campbell (1957) and Bell (1959, 1961, 1962a, 1962b) who mapped on a scale of 1 inch to 500 feet the Crackingstone Peninsula. Preliminary maps on a scale of 1 inch to 800 feet and several papers describing the geology of the Beaverlodge area were published by Tremblay during the period 1954-1958 (1954, 1955, 1956, 1957a, 1957b, 1958a, 1958b).

Fahrig (1961), studying the Athabasca Series, proposed the name 'Martin Formation' for the sedimentary sequence outcropping on the W shore of Martin Lake, and restricted the term 'Athabasca Formation' to the flat-lying sandstones and arenites present on the S shore of Lake Athabasca. Lang, Griffith and Steacy (1962), describing the uranium deposits of Canada, gave a brief description of the Fay and Verna orebodies. In 1962, Smith presented an internal report to Eldorado Nuclear Ltd. on the geology of the Gil Group.

During the period 1960-1964 Trigg mapped some parts of the Eldorado property and rechecked the surface and underground geology of the Verna Mine. The result of this work was presented in a Ph.D. thesis to McGill University (1964). Describing the Tazin Group, Trigg recognized the presence of six major rock types some of which were believed to be of volcanic origin, whereas certain chloritic greenschists exhibited 'fragmental fabrics' suggesting a sedimentary origin. Illustrating the sequence of geologic events which have occurred in the Verna Mine, Trigg concluded that an early period of extrusion of lavas and sedimentation was followed by major folding, granitic intrusion and metamorphism. This stage took place 2000 m.y. ago and was followed by crushing and recrystallization. Soda metasomatism and retrograde metamorphism accompanied the deformational stage, which, in turn, was followed by a period of minor folding, shearing, silicification and chloritization. At the end of this stage, normal faulting, produced by tensional forces, developed along the previously formed mylonitic zones.

In 1968, to meet the growing interest in the Uranium City area, Tremblay (1968) published an advanced edition of a report written for the Geological Survey of Canada, which represented the result of several years of detailed field mapping and laboratory studies (G.S.C. Memoir 367, 1968). Although this advanced edition lacked many of the refinements and features normally associated with a conventional G.S.C. Memoir, it represents one of the most informative studies to date. According to Tremblay, all the rocks of the Beaverlodge area belong to the Tazin Group or to the Martin Formation and are Precambrian in age. The Tazin rocks, which were originally a thick Archaean sequence of interbedded 'greywacke, shale, sandstone, and basic tuffs' were metamorphosed to quartzite, amphibolite, garnet-bearing rocks, red granite, and quartzo-feldspathic gneisses (Fig. 5). Both the red granite and the quartzo-feldspathic gneisses were considered as granitized products of the regional metamorphism which took place isochemically. The gneisses were of different appearance and texture; they were considered to be granodioritic and quartzo-monzonitic in composition and were thought to be separated into two mappable units named the 'Foot Bay Gneiss' and the 'Donaldson Lake Gneiss'. The large area of 'ungranitized

Fig. 5. Table of formations, after Tremblay (1968).

EON	ERA	EPOCH		
	Cenozoic	Recent Pleistocene	Morainic material, gravel, sand, silt and clay	
	Proterozoic		MAP-UNIT 27: GABBRO and BASALT DYKES and SILLS; in part porphyritic and amygdaloidal	
			Intrusive Contact	
	Proterozoic and Archaean (?)		MAP-UNITS 20 to 26: <u>MARTIN FORMATION.</u> SILTSTONE, arkose, conglomerate UPPER ARKOSE, siltstone, conglomerate CONGLOMERATE INTERBEDS, arkose BASALT FLOWS, GABBRO SILLS, amygdaloidal and porphyritic LOWER ARKOSE, siltstone, conglomerate BASAL CONGLOMERATE and BRECCIA, siltstone and arkose	
			Unconformity	
			GRANITE and PEGMATITE DYKES and SILLS	
			Intrusive Contact	
PRECAMBRIAN	Archaean and/or Proterozoic(?)		<u>TAZIN GROUP</u> MAP-UNIT 19: METASOMATIC granite, quartz monzonite, monzonite, granodiorite, quartz diorite	
			<u>EASTERN AREA</u>	<u>WESTERN AREA</u>
			MAP-UNIT 6-9: Murmac Bay Formation: Quartzite, amphibolite, garnetiferous quartz-feldspar-biotite gneiss, crystalline dolomite and limestone.	MAP-UNIT 18: Uranium City amphibolite, some quartzite.
			MAP-UNIT 5: Buff quartzite, impure quartzite, chlorite-sericite schist, argillite.	MAP-UNIT 17: Cayzor Unit; Quartzite, impure quartzite, chlorite schist, quartzo-feldspathic gneiss.
			MAP-UNIT 4: Argillite, slate, and quartzite; hornblende-schist, amphibolite, chlorite-epidote rock.	
			Intrusive Contact	
	Archaean and/or Proterozoic		MAP-UNIT 3: Quartzite, chlorite-sericite schist	MAP-UNIT 16: Jean Lake amphibolite
			MAP-UNIT 2: Donaldson L. Gneiss quartzo-feldspathic gneiss, quartzite, amphibolite	MAP-UNIT 15: Rix Unit; Quartzo-feldspathic gneiss, quartzite, mafic schist, and gneiss.
				MAP-UNIT 14: Chance Lake Unit; amphibolite quartzite, schist and gneiss
			MAP-UNIT 1: Foot Bay Gneiss, quartzo-feldspathic gneiss, amphibolite	
				MAP-UNIT 13: Quartzo-feldspathic gneiss; some amphibolite, quartzite
				MAP-UNITS 11 and 12: Power Line Creek Belt; garnetiferous feldspathic quartzite, amphibolite
				MAP-UNIT 10: Quartzo-feldspathic gneiss, amphibolite, quartzite

metamorphosed Tazin sedimentary and tuffaceous rocks' outcropping about Murmac Bay was named 'Murmac Bay Formation'. According to Tremblay (1968) this formation was composed of coarsely interbedded, glassy, white, well-jointed quartzites and amphibolite intercalations, locally associated with quartz-biotite-garnet schists, 'limestones and dolomite'. The Martin Formation which overlies the Tazin Group was thought to be composed of basal conglomerate, arkose and siltstone interbedded with basaltic flows and gabbroic sills. Apparently it was not affected by metamorphism. The source for this red-bed sequence was thought to be situated in the region N or NE of the Lake Athabasca. In 1969 Tremblay (1970) published another paper in which he postulated, on the basis of somewhat cursory trace element study, that the uranium deposits of the Beaverlodge area were possibly derived from Tazin quartzite during metamorphism. The Th-U ratios in quartzite and 'argillite' suggested that granitization was the cause of the mobilization of uranium which itself was put into solution mainly as a result of the crystallization associated with granitization. In the same period other papers regarding the geology of the Beaverlodge district were presented by different authors as a consequence of the renewed activity and search for uranium (Trigg, 1968; Stephens, 1968; Heise, 1968).

In 1970 Beck (1970) presented a paper in which he extended and clarified the conclusions reported in his Ph.D. thesis, whilst Kornik (1970) published a paper dealing with quantitative interpretations of an aeromagnetic survey conducted over the Athabasca Formation. Finally, Fraser, Donaldson, Fahrig and Tremblay (1970) published a paper on the Helikian Basins and geosynclines of the northwestern Canadian Shield.

2 - Mineralogy

Detailed investigation of the mineralogy of the uranium-bearing deposits of the Goldfields region was undertaken by Robinson (1955a) as part of a general program being carried out by the Geological Survey of Canada, to provide data on the occurrence and geological environment of uranium in Canada. His work was included in the G.S.C. Bulletin No. 31 and published in 1955. According to Robinson three distinct types of uranium deposits were found in the Beaverlodge area, namely:

(i) 'Syngenetic deposits' in which uranium minerals were thought to have crystallized at the same time as the associated rock-forming minerals;

(ii) 'Epigenetic deposits' in which the uranium and the associated minerals were deposited in fractures within pre-existing rocks;

(iii) 'Supergene deposits' which had formed as a result of the weathering of the hypogene deposits.

Describing the Ace-Fay Mine, Robinson reported that pitchblende was virtually restricted to zones of oligoclase and hematite 'alteration'. The metallic minerals recognized in the orebodies were: hematite, pyrite, pitchblende , chalcopyrite, galena, clausthalite, bornite, nolanite, ilmenite, marcasite and sphalerite. They were associated with calcite, chlorite, quartz and traces of apatite and rutile.

In 1954 Joubin (1955) suggested that the mineralization present in the district was due to 'surface phenomena', whilst Hughson (1954) presented a special report on split-core samples collected in the Verna Mine, in which he stated that pitchblende , intimately mixed with anatase, was found to be associated with brecciated cubes of pyrite. Kaiman (1959, 1961) and Hughson (1960) prepared two internal reports for Eldorado Nuclear Ltd. dealing with the mineralogy of the uranium ores found in the Fay and Verna Mines. Kaiman observed that pitchblende was associated with unstained calcite or chlorite and was usually intergrown with anatase. He also mentioned that some of the radioactive samples did not yield good X-ray diffraction patterns suggesting that the uranium oxides were in metamict state. Other reports describing the mineralogy of some samples collected in the Fay Mine were written by the same authors during the period 1966-1967.

Koeppel (1968), on the basis of geochronological studies, presented a review of the paragenetic sequence within the deposits of the Beaverlodge area, and endeavoured to assign finite ages to certain phases of the mineralization.

In 1968, Tremblay (1968) briefly describing the mineralogy of the deposits of the district concluded that pitchblende was the most common mineral whilst thucholite was recognized in a few orebodies only; gummite and several secondary uranium-bearing minerals were identified in the supergene deposits. In 1969-1970, the same author made quantitative spectrographic determinations of the elements V, Cr, Cu, Co and Ni on 219 specimens collected N of the St. Louis Fault and NW of the Black Bay Fault. All the data obtained were tabulated by rock type and sampling area. After comparing each determination with published world averages, Tremblay arbitrarily considered unrealistic some of the higher values obtained and concluded that a general dissipation of the elements analyzed was due to granitization, although some concentration of the uranium and thorium oxides was noted. He then believed that the quartzites of the Beaverlodge area were the most probably source rock for uranium since they were the rock types most readily granitized.

3 - Structural Geology

The first serious attempt to study the uranium deposits situated along the plane of the St. Louis Fault was done by MacDonald (1954) and Kermeen (1956) who described these orebodies in relation to the general structural features of the Beaverlodge area. Their work was followed by the research of Campbell (1957) and Chamberlain (1958, 1959) who described the structural geology of the pitchblende mineralization occurring in the Eldorado property. According to Chamberlain, the folds present in the area trended

NE suggesting a compression in a NW-SE direction. Uplift in the northern part of the region, with concomitant subsidence to the S, had resulted in a rapid erosion of the exposed Tazin rocks and in the deposition of a thick series of sediments belonging to the Athabasca Series. The younger Athabasca rocks had then been subjected to localized horizontal compressions, whilst rocks of the Tazin Group had been refolded during the reactivation of the NW-SE compression initiated in the first event. Large-scale normal faulting had occurred throughout the area in 'post-Athabasca' time. Chamberlain also believed that data from D.D. holes, from a geophysical survey, and from field evidence demonstrated that the ABC and the St. Louis Faults were probably extensions of the same break despite a bend of 8 degrees between the two faults. Displacement of the 'Athabasca rocks' also provided sufficient data to permit a quantitative estimate of the net-slip of the St. Louis Fault (3.9 miles plunging 43° SSW). Finally, describing the ore controls which influenced the deposition of uranium ores, Chamberlain stated that deforming forces active during successive stages of tectonism, produced openings in the rocks. Such dilatant zones reduced the solutions and the pressure resulting in expulsion of CO_2 and in the consequent deposition of uranium ores.

In 1963, Allan describing the structural controls of the Ace and Fay Mines concluded that: 'a right-hand normal oblique movement along the St. Louis Fault produced dilatant areas which constituted the primary structural feature controlling the deposition of pitchblende in the '01' and '09' zones'.

Trigg (1964) studied in detail the St. Louis - ABC Fault junction. According to his findings, the ABC Fault bends into the St. Louis Fault whilst the St. Louis Fault itself continues westerly across the Beaverlodge Lake. It is noteworthy that Tremblay previously concluded that the St. Louis and the ABC Faults were a single structural lineament. In his Ph.D. thesis (1964) Trigg reported that the uranium minerals, occurring in the Verna Mine, were apparently deposited preferentially in openings along flat, shear fractures within mafic-rich sulfur-bearing rocks. Minor movements along normal faults offset the ore-bearing structures and brecciated the previously deposited minerals.

In the same year Beck (1964) presented, for the Prospectors' and Developers' Convention, a paper in which he described the structural environment of the uranium mineralization of the Athabasca region. Describing the origin of the uraniferous deposits of the area, he concluded that pitchblende was precipitated from mineralizing solutions which pre-date the deposition of the Martin and Athabasca lithologies and also the period of faulting which gave rise to such structures as the St. Louis and the Black Bay Faults.

In 1968, describing the structure of the Beaverlodge area, Tremblay (1968) recognized that major periods of folding affected both the Tazin and the Martin rocks. The folds found in the Tazin complex trend northeasterly; they are tight to open and generally more complicated. The folds found in the 'Martin basin' display a similar trend but they were thought to be more open and related to a younger tectonic cycle. Tremblay also recorded the presence of large areas characterized by extremely brecciated and mylonitized rocks which possibly indicated the existence of major thrust faults. They were thought to be related in time to the folding which affected the Tazin metamorphics. Late faults such as the St. Louis, the ABC and the Black Bay had apparently been formed shortly before the deposition of the Martin rocks and remained quite active for a long period of time. Furthermore, since the uranium mineralization was believed to occur in areas of heavily granitized rocks or in intensely brecciated, mylonitized and altered zones, Tremblay concluded that prospecting for uranium minerals should be restricted to regions near major faults where pronounced retrogressive metamorphism and intense alteration are found.

In 1970 Beecham, studying the major and minor faults situated along the ABC Fault, stated that a left-hand,normal,oblique movement had produced a net-slip of 12 x 10^3 feet. He also concluded that the ABC Fault was apparently initiated later than the St. Louis Fault.

4 - Geochronology

According to Robinson (1955a) the earliest introduction of epigenetic uranium mineralization occurred between 1500 and 1600 m.y. ago. Collins, Farquhar and Russell (1954) reported 'pitchblende' ages, based on Pb^{207}/Pb^{206}

ratios, concluding that the first period of mineralization lasted from 1860 to 1630 m.y. ago. They also noted that some of the orebodies of the Beaverlodge area had been 'reworked' during the intervals of 1100 to 900 m.y., 650 to 600 m.y. and 400 to 300 m.y. ago. Wasserburg and Hayden (1955) obtained an age of 1870 m.y. for uraninite collected at Viking Lake as well as a K-Ar age of 1950 m.y. for coexisting feldspar.

Eckelmann and Kulp (1957) stated that pitchblende was deposited 1900 m.y. ago and subsequently episodic lead losses occurred 1200 m.y. and 220 m.y. ago. Evidence from lead isotope ratios of galena and clausthalite supported their conclusions. In the same year, Aldrich and Wetherill (1956) plotted all the available data regarding the Beaverlodge area on a concordia diagram. They obtained a time of deposition for epigenetic pitchblende of 1900 m.y. with subsequent lead losses occurring 1200 m.y. and 200 m.y. ago. Their interpretation agreed with the conclusions reached by Eckelmann and Kulp. Russel and Ahrens (1957) reported an age of 1800 m.y. for the W orebody of the Ace Mine and a probable time of deposition of a second generation of pitchblende from other deposits of the Beaverlodge area of 940 m.y. Fahrig (1961) found a 'minimum' U-Pb age of 418-448 m.y. for pitchblende cutting Athabasca sandstone at Steward Island. During the period 1961-1963 various authors published K-Ar ages for different localities situated around Uranium City (Lowdon, 1961; Lowdon et al., 1963; Burwash et al., 1962; Koster, 1962). Some other K-Ar ages were obtained by

Wanless, Stevens, Lachance, Rimsaite and Edmonds (1965, 1966, 1967, 1968).

Beck (1966), describing the granitic rocks outcropping in the Beaverlodge area, concluded that the granites of the so-called 'stable blocks' were pre-Hudsonian intrusions at least 2200 m.y. old (whole rock Rb/Sr ages) whereas the granitic rocks of the so-called 'linear belts' were emplaced or rejuvenated about 1820 m.y. ago. The stable blocks apparently acted as rigid units, whilst the linear belts appeared to be strongly folded, faulted and intruded by pegmatites. The uraniferous ore deposits were thought to have been formed during the Hudsonian tectonism and therefore were believed to be restricted to the linear belts. Syngenetic systems were considered to have remained closed with low lead-mobility whilst epigenetic deposits were thought to have been rejuvenated several times by minor tectono-thermal events.

In 1966 and 1967 other authors presented whole-rock Rb-Sr ages from samples of granite and basement gneisses collected in several localities N of the Athabasca Lake (van Breemen, 1966; Baadsgaard and Godfrey, 1967). In 1968 Koeppel (1968) determined U-Pb ages for samples of pitchblende and uraninite collected in eight levels of the Fay Mine. According to his studies, the formation and evolution of the mineral deposits of the Beaverlodge area took place during six discrete periods, covering a time span of more than 2200 m.y. 'Syngenetic' (pegmatitic) uranium deposits were thought to be probably older than 'epigenetic' (hydrothermal) deposits. While the syngenetic deposits had suffered a continuous lead loss, it was thought that the epigenetic deposits had undergone three 'episodic reworkings' affecting the various orebodies to different degrees at about 1110 $\pm$ 50 m.y., 270 $\pm$ 20 m.y. and 0-100 m.y. ago. Koeppel's work established a new upper and lower age limit for the Martin Formation and the diabase dykes of the Beaverlodge area. The absence of metamorphism and syngenetic uranium mineralization in the Martin rocks would indicate an upper age limit of 1930 $\pm$ 40 m.y., while the presence of epigenetic uranium deposits would suggest a lower age limit of 1780 $\pm$ 20 m.y. According to Koeppel the cause for the different behavior between syngenetic and epigenetic deposits was due to two different environments: the first situated in competent host rocks, the second occurring near faults possibly reopened by movements and subjected to re-equilibration by circulating waters.

Beck (1970), in a paper dedicated to the genesis of uranium in the Athabasca region, briefly summarized the available radiometric data (Fig. 6). According to him the K-Ar ages (i.e. 1740-1795 m.y.) fall within the accepted range for the Hudsonian orogeny and are therefore believed to date the end of a major tectonism in the region. The 'survival' dates of 2350 and 2440 m.y. (hornblende) provide a minimum age for the original sedimentary and volcanic assemblage. Furthermore, Beck (1970), discussing the age of the unmetamorphosed sedimentary rocks lying unconformably on the eroded Hudsonian orogen, concluded that both the Martin and the Hale's 'Lower Athabasca Series' were cut by basic dykes probably intruded 1400-1500 m.y. ago. Basement tectonism

Fig. 6. Available radiometric ages, after Beck (1970).

Radiometric Ages

Number	Locality	Rock Type	Apparent Age on	Age in m.y.	Reference
		POTASSIUM — ARGON			
1.	5 miles E of Fond du Lac	Garnetiferous parageneiss	Biotite	1740	Lowdon, 1961, pp. 39-40
2.	Mickey Lake, 5 miles E of Uranium City	Quartz-feldspar-biotite gneiss	Biotite	1795	Lowdon, *et al.*, 1963, p. 64
3.	Gunnar Mine	Pegmatite	Muscovite	1815	Lowdon, 1961, p. 39
4.	Charlebois Lake, 35 miles NE of Stony Rapids	Quartz monzonite	Biotite, Muscovite	1830 1780	Lowdon, *et al.*, 1963, pp. 64-65
5.	Fontaine Lake, 59°43′ N:106° 30′W	Pegmatite	Muscovite	1740	Burwash, *et al.*, 1962, p. 1620
6.	Clut Lake, 6 miles NNE of Stony Rapids	Porphyritic granodiorite	Biotite	1720	Burwash, *et al.*, 1962, p. 1620
7.	Fredette Lake, near Uranium City	Diabase dyke cutting the Martin Formation	Whole-rock	1490	Wanless, *et al.*, 1965, pp. 72-73
8.	Martin Lake, near Uranium City	Gabbro sill in the Martin Formation	Whole-rock	1410	Wanless, *et al.*, 1965, p. 73
9.	Martin Lake	Basalt flow from Martin Formation	Whole-rock	1630±180	Wanless, *et al.*, 1966, p. 53
10.	Cree Lake, 175 miles SE of Uranium City	Diabase cutting (?) the Athabasca Formation	Hornblende	1230	Burwash, *et al.*, 1962, p. 1620
11.	Mary Lake, 20 miles NNW of Stony Rapids	Pyroxene-hornblende cobble	Hornblende	2350	Burwash, *et a.l*, 1962, p. 1620
12.	Nettel Lake, 59°59′N:109°37′W	Mafic inclusion in granite	Hornblende	2440	Koster, 1962, p. 10
13.	Cluff Lake, 58°21′N:109°30′W	Ultramylonite; probably a mixture of granite and Athabasca sandstone	Whole-rock	467±28 486±55	Wanless, *et al.*, 1968, pp. 84-85
		RUBIDIUM — STRONTIUM (isochrons)			
14.	Various localities N of L. Athabasca	Type Y granites	Whole-rock	1820±100	O. van Breemen *in* Beck, 1966
15.	Various localities N of L. Athabasca	Type O granites	Whole-rock	2200±100	O. van Breemen *in* Beck, 1966
16.	Various localities in NE Alberta	Basement gneisses and granites	Whole-rock	~1900 and 2250	Baadsgaard and Godfrey, 1967
		URANIUM — LEAD (concordia)			
17	Various localities in NE Alberta	Gneisses and granites	Mainly zircons	~1900 ~2250	Baadsgaard and Godfrey, 1967
18.	Various localities N of L. Athabasca	Syngenetic deposits	Monazite and uraninite	1930±40	Koeppel, 1968
19.	Stewart Island, 59°20′N:108°55′W	Pitchblende in Athabasca sandstone	Pb^{206}/U^{238}	418 and 448	Fahrig, 1961, p. 33

in the Phanerozoic was thought to be indicated by the radiometric ages reported for pitchblende cutting Athabasca sandstones at Steward Island (Fahrig, 1961). Finally Fraser, Donaldson, Fahrig and Tremblay (1970), in a paper regarding the Helikian basins and geosynclines of the Northwestern Canadian Shield, commented on the available radiometric ages. According to these authors, the Martin Formation unconformably overlies metamorphosed rocks dated at 2350 m.y. (Rb-Sr method, Aldrich and Wetherill, 1956). These rocks are cut by younger gabbro dykes, one of which yielded a K-Ar age of 1835 ± 50 m.y. Since these dykes do not appear to cut the overlying unconformably rocks, the authors speculated that the maximum age of the Martin Formation should be about 1835 m.y. On the other hand, since the Martin basalts have given a K-Ar date of 1630 ± 180 m.y. (Wanless et al., 1966) it is possible to establish a lower age limit for the Martin lithologies situated below them. As a conclusion Fraser et al. (1970) regarded the age of the Martin Formation to lie between 1830 m.y., and 1650 m.y., that is, very early Helikian or very late Aphebian.

CHAPTER 2 - GEOLOGICAL SETTING

General Statement

To avoid confusion and misunderstanding, the author will summarize the most recent theories regarding the general geology of the Beaverlodge area, although he does not necessarily agree with all the data reported in this chapter. Controversial points, special problems and the conclusions by the previous authors will be discussed in the pertinent sections.

Regional Geology

The uraniferous deposits of the Beaverlodge area occur within Precambrian rocks of the southwestern part of the Churchill structural province about 100 miles E of the Paleozoic cover. The severely folded, regionally metamorphosed Tazin complex, mainly composed of para-schists and para-gneisses (Beck, 1970) constitutes most of the region's bedrock. This basement complex, containing isolated relics of pre-Tazin lithologies, is locally cut by a series of granitic intrusions, few of which are undisputably of true igneous character. According to Beck (1966) the granitic rocks may be divided into two main groups:

(i) batholithic bodies of replacement-type, adamellitic and granodioritic in composition, thought to represent the 'old' or 'Type O' granites,

(ii) smaller bodies of granitic and pegmatitic composition ranging from quartz-diorites to alkali-granites, referred to as the 'young' or

'Type Y' granites.

The 'Type O' granites are considered syntectonic or pre-tectonic while 'Type Y' granites are considered syn-, late- or post-tectonic. The metamorphic grade of the rocks included within the Tazin complex range from 'greenschist' to 'amphibolite' facies.

Around Uranium City, the Tazin Group (Alcock, 1936) consists of an assemblage of regionally metamorphosed and granitized rocks. 'Greywacke','shale', 'sandstones', 'dolomite', 'banded iron formation' and volcanics of uncertain origin (Tremblay, 1957), were probably the dominant rock types of the original sequence. Rocks tentatively correlated with the Tazin Group, composed essentially of thinly bedded 'greywacke', 'shale' and 'chert' are present in the southern district of Mackenzie, where they have been metamorphosed to granitic gneisses or they are grading into them. Similar rocks and their 'granitized' equivalents are thought to occur in the Snowbird Lake area (Taylor, 1963). Metavolcanics are known to be present in the Stony Rapids area (Beck, 1970). In this region basic intrusives are locally related to plugs and sills of norite and similar rock types. According to Beck (1970) the basement complex is characterized by a dominant NE-SW trend imparted to the rocks by the Hudsonian orogeny. A minimum age for the Tazin rocks is about 1900 m.y. (basement gneisses and granites, NE Alberta, Baadsgaard and Godfrey, 1967). Survival dates of 2350 m.y. and 2440 m.y. could provide a 'minimum' age for the original sediments and volcanic rocks of the district (Burwash et al., 1962; Koster, 1962; Aldrich and Wetherill, 1956). Two younger Precambrian units lie unconformably upon the Tazin Group, namely the Martin and the Athabasca Formations. Many geologists have postulated that these two formations are lateral equivalents of one another, but this remains purely intuitive speculation.

The Martin Formation (Fahrig, 1961) is an unmetamorphosed or slightly metamorphosed, folded red-bed sequence of conglomerate, sandstone and arkose, usually intercalated with basaltic and andesitic flows. It is always confined to a series of structural depressions trending NE-SW, the principal outlier of which is situated at Martin Lake, on the W shore of Beaverlodge Lake. Tremblay (1968) estimated a maximum thickness of 19,500 feet, 3500 of which were thought to be composed of gabbro sills and basaltic and andesitic lavas. Unmetamorphosed sedimentary rocks are exposed on the Crackingstone Peninsula, on Laird Island and on the SE shore of Tazin Lake where no volcanics are found. Around Uranium City, the Martin Formation was apparently deposited on an erosional surface formed by the Tazin Group, during a late phase of the Hudsonian orogeny. The basal conglomerate contains angular to sub-angular fragments and boulders of basement rocks and mylonites cemented by an arkosic matrix. The Martin arkose is reddish to orange in color and consists mainly of quartz, feldspar and rock-fragments, generally poorly sorted and fresh in appearance, suggesting rapid deposition close to the original source-rock (Smith, 1952).

It is also generally cross-bedded, ripple-marked and interbedded with numerous lenses or beds of conglomerate. Deep-red to dusky-red siltstone horizons, feldspar-rich and mud-cracked are also present. The basin of deposition was probably a taphrogeosyncline (Fraser et al., 1970), fault controlled, for it is thought that deposition took place after, or possibly contemporaneously with fault movements. Paleocurrent studies (Tremblay, 1968) indicated a transport direction to the SE or SW suggesting a source situated in the northern part of the region. The Martin rocks have been gently folded about northeasterly trending axes; they are also displaced by late faults striking northeasterly, the most important of which are the St. Louis, and the Black Bay Faults. A minimum age for the Martin Formation is 1630 $\pm$ 180 m.y. (K-Ar age determinations on basalt flow from the Martin Formation, Martin Lake; Wanless et al., 1966).

The Athabasca Formation, conformably overlain by the Carswell Formation, occupies an area of about 30,000 square miles S of the Lake Athabasca. It is composed of a flat-lying sequence of unmetamorphosed, predominantly fluviatile, quartz sandstones and arenites separated from the Tazin Group by an unconformity. Recent seismic work in the region suggest a maximum thickness of about 5,500 feet (Hobson and MacAulay, 1969) composed essentially of orthoquartzite with rare interbeds of shale and quartz-pebble conglomerate (Fahrig, 1961). The sandstone is composed of rounded, moderately well-sorted quartz grains set in a quartz cement, displaying both trough and planar cross-bedding indicative of sedimentary transport from the E or SE or locally from the NE. Hale (1954), on the basis of a major unconformity noted in the Thluicho Lake area (25 miles NW of Uranium City), divided the Athabasca Series into a 'Lower part' and 'Upper part'. Many geologists correlate the latter with the Martin Formation but the stratigraphic position of the Athabasca Series 'Lower part' is doubtful because:

(a) it is more deformed than the Martin Formation

(b) it is metamorphosed, indicating a possible older age than the Martin Formation itself.

The Carswell Formation consists of a pink, finely-laminated dolomite, stromatolites and dolomite breccias, apparently deposited in a shallow-water, marine environment. At Carswell Lake it is deformed and forms a circular structure within which outcrops the Tazin basement. A swarm of late basic dykes, varying in composition from gabbro, diabase to syenitic rocks (Burwash et al., 1962), trending W to NW, cut the Precambrian rocks of the Beaverlodge district. According to Tremblay (1968) they might be genetically related to the sills and dykes present in the Martin Formation and may represent the last intrusive event in the region. The 'minimum' age of the Athabasca Formation is 418-448 m.y. (U-Pb ages from pitchblende cutting Athabasca sandstone at Steward Island; Fahrig, 1961). The Athabasca Formation is tentatively correlated with the Thelon Formation of the Dubawnt Group.

Regional Tectonic History

According to Beck (1970) the tectonic history of the Athabasca district may be summarized as follows:

(1) A thick sequence of sedimentary and volcanic rocks was deposited on an older basement at least 2500 m.y. ago.

(2) Rb-Sr data suggest that a thermal event may have taken place circa 2200-2300 m.y. ago.

(3) During the Hudsonian orogeny (1750-1950 m.y.) deformation was accompanied by regional metamorphism, mylonitization, emplacement of 'Type Y Granites' and partial remobilization of 'Type O Granites'. A set of thrust faults developed at the end of the orogeny and,as compression was released, normal movements occurred along some of these faults.

(4) After a period of erosion, local subsidence formed isolated basins, partly fault controlled in which sedimentary rocks were deposited. Volcanic activity was restricted to the Martin Lake area.

(5) Minor horizontal compression broadly folded the sedimentary rocks. Release of compression produced normal movements along the pre-existing faults.

Fig. 7. Postulated sequence of events in the Athabasca region, after Beck (1970).

PROBABLE DURATION OF EVENTS

	EVENT	ISOTOPIC EVIDENCE		Regional Metamorphism. Syntectonic granites	Syngenetic Uranium emplacement	Late- and Post-Tectonic Granites	Early faulting and Mylonitization	Normal or Block faulting	Pitchblende Mineralization	Diabase Intrusion
	12. Further fault movements and erosion. Glaciation and subsequent isostatic response. Supergene alteration of deposits by groundwater	0-100	U-Pb data						▮	
	11. Uplift. Fault movements. Erosion of Phanerozoic sediments. Rejuvenation of pitchblende	270	U-Pb data					▮	▮	
	10. Peneplanation. Subsidence and partial covering by Phanerozoic sediments.									
	9. Tectono-thermal events in Shield. Rejuvenation of pitchblende	1110	U-Pb data. Episodic lead loss					▮	▮	
	8. Deposition of cover rocks and intrusion of diabase	1410-1490 1630	K-Ar on gabbro and diabase K-Ar on basalt							▮
	7. Erosion of Hudsonian orogen and formation of basins of deposition							▮	▮	
Hudsonian Orogeny	6. End stages of orogeny. Retrograde metamorphism, hydrothermal alteration, emplacement of pitchblende	1780 1740-1795	U-Pb concordia on pitchblende K-Ar on gneisses	▮	▮	▮	▮	▮	▮	
Hudsonian Orogeny	5. Emplacement of late- and post-tectonic granites. Crystallization of uraninite	1815 1820	K-Ar on muscovite, Gunnar mine Rb-Sr isochron, Athabasca	▮	▮	▮	▮			
Hudsonian Orogeny	4. Widespread mylonitization and formation of thrust and tear faults			▮	▮		▮			
Hudsonian Orogeny	3. Regional metamorphism, formation of gneisses and syntectonic granites. Crystallization of uraninite	1900 1930	U-Pb concordia, and Rb-Sr isochron, Alberta U-Pb concordia, Athabasca	▮	▮					
	2. One or more orogenic periods	2200 2250 2350 2440	Rb-Sr isochron, Athabasca Rb-Sr isochron and U-Pb concordia, Alberta K-Ar on hornblende K-Ar on hornblende	▮	▮					
	1. Sedimentation and volcanic activity		Probably > 2500 m.y. ago							

Note: Events 3-6 would be probably transitional and overlapping and would not necessarily be of equal duration or extent in all parts of the orogen.

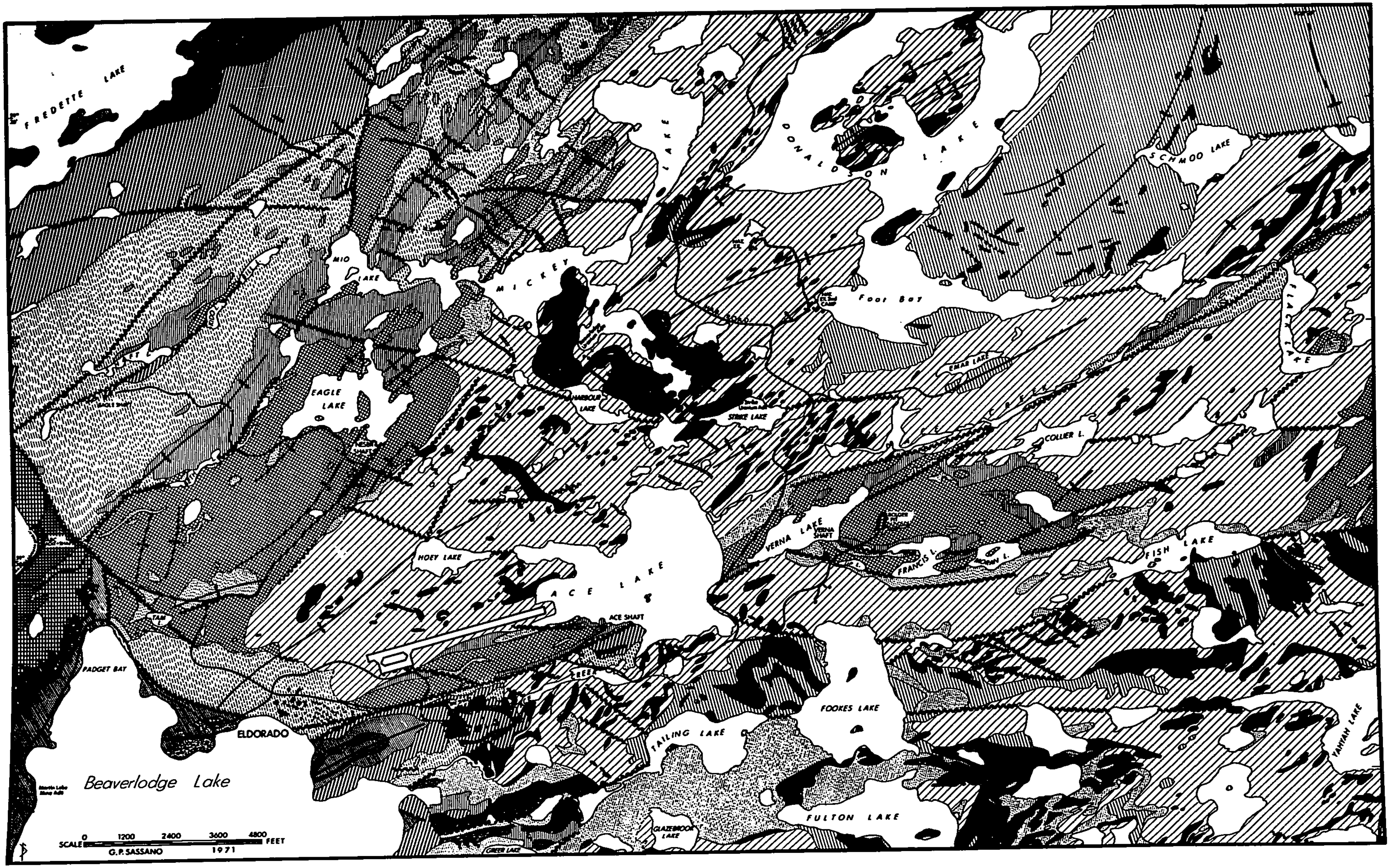
(6) Localized tectonism developed in the basement.

The sequence of geological events postulated by Beck (1970) is given in Fig. 7.

General Geology of the Investigated Area

The geology of the investigated area surrounding the Fay Mine is illustrated in Fig. 8. This map is essentially based upon Tremblay's 1 inch to 1200 feet feet sheet and shows numerous modifications by the writer in 1971. The brief geological description presented herein concerns a rectangular area of approximately 30 square miles lying between longitudes of 108 20'30"W and 108 32'30"W and latitudes of 59 32'40"N and 59 36'30"N. It is bounded by the SE shore of Fredette Lake, by Padget Bay, by the NE shore of Beaverlodge Lake, Fulton Lake, Goehring Lake, Yahyah Lake, Flack Lake, Raggs Lake and finally by the Donaldson Lake. About 60 to 70 per cent of the outcrop is constituted by the Tazin Group lithologies whilst the remaining part is covered by the Martin Formation or is occupied by lakes. The lithological units selected were based upon map legends of previous workers (Alcock, 1935; Christie, 1953; Tremblay, 1968) but are somewhat simplified or grouped together according to those lithologies recognized by the author during the underground survey of the Ace-Fay-Verna, HAB Mines and Bolger open pit (see Fig. 9).

Fig. 8. Geology of part of the Beaverlodge District, NW Saskatchewan (after L.P. Tremblay, 1968 and G.P. Sassano, 1971).


FREDETTE LAKE
DONALDSON LAKE
SCHMOO LAKE
FLACK LAKE
MICKEY LAKE
MIO LAKE
EAGLE LAKE
Foot Bay
EMAR LAKE
HARBOUR LAKE
STRIKE LAKE
COLLIER L.
VERNA LAKE
VERNA SHAFT
FRANCIS L.
FISH LAKE
HOEY LAKE
ACE LAKE
ACE SHAFT
PADGET BAY
ELDORADO
Beaverlodge Lake
TAILING LAKE
FOOKES LAKE
FULTON LAKE
GLAZEBROOK LAKE
GREER LAKE
YAHYAH LAKE
SCALE 0 1200 2400 3600 4800 FEET
G.P. SASSANO 1971


FREDETTE LAKE
DONALDSON LAKE
SCHMOO LAKE
FLACK LAKE
MIO LAKE
MICKEY LAKE
Foot Bay
EMAR LAKE
ACE CREEK
COLLIER L
EAGLE LAKE
HARBOUR LAKE
STRIKE LAKE
VERNA LAKE
VERNA SHAFT
FRANCIS L
MORAN L
FISH LAKE
HOEY LAKE
ACE LAKE
ACE SHAFT
PADGET BAY
ELDORADO
TAILING LAKE
FOOKES LAKE
YAHYAH LAKE
Beaverlodge Lake
FULTON LAKE
GLAZEBROOK LAKE
GREER LAKE
SCALE 0 1200 2400 3600 4800 FEET
G.P. SASSANO 1971

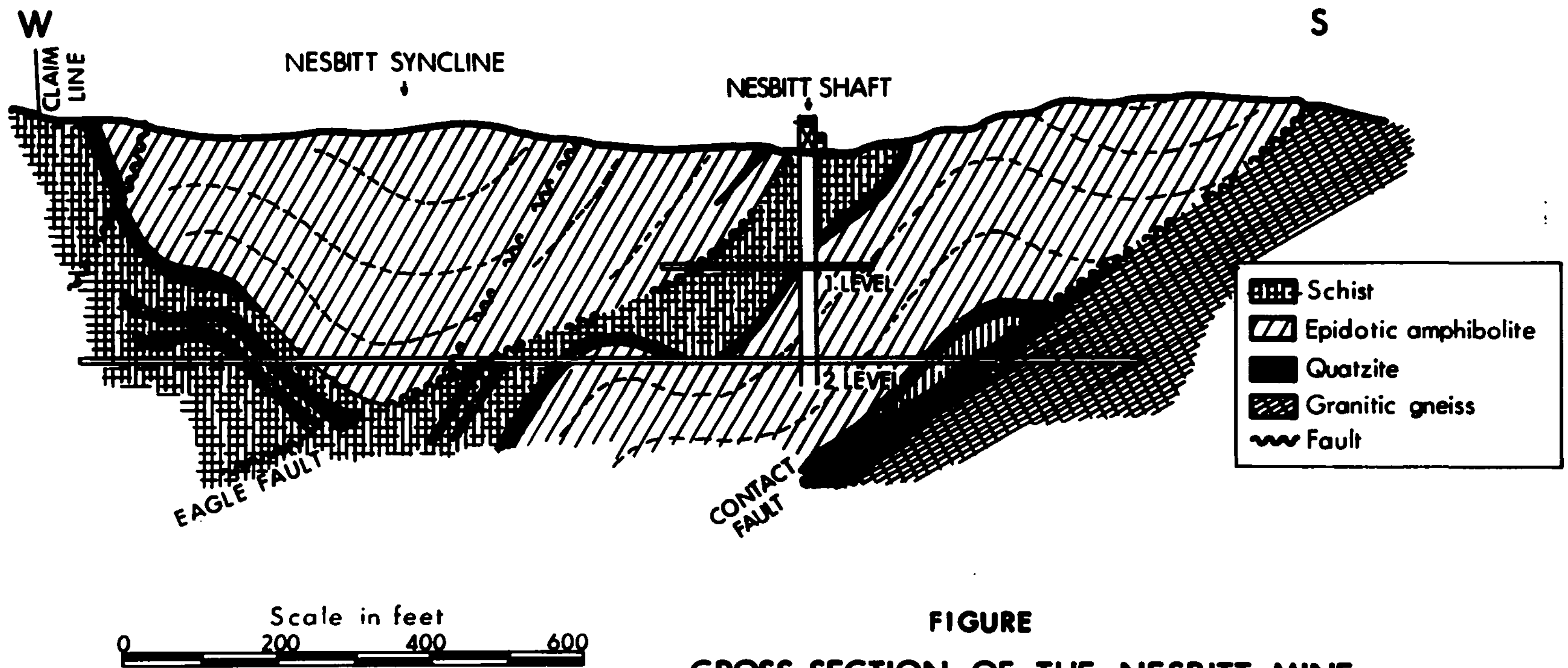
Fig. 9. Table of formations (after G.P. Sassano, 1971).

	EON	ERA	GROUP		FORMATION	SYMBOL	LITHOLOGY	AGE	THICKN.	ORE BEARING ZONES	
										FAY	VERNA
PRECAMBRIAN	PROTEROZOIC	HELIKIAN					QUARTZ PORPHYRY DYKES CUTTING DIABASE DYKES AND SILLS	? POST OROGENIC	10'-40'		
INTRUSIVE CONTACT											
					MARTIN FORMATION		UPPER SILTSTONE	DEPOSITED DURING THE LATE STAGES OF THE HUDSONIAN OROGENY (EARLY HELIKIAN)	200'-400'		
							CONGLOMERATE				
							UPPER ARKOSE				
							ANDESITE-BASALT FLOWS				
							LOWER ARKOSE				
							LOWER SILTSTONE				
							BASAL CONGLOMERATE			055 01	64(?)
MAJOR UNCONFORMITY											
		APHEBIAN					INTRUSION OF DISCORDANT PEGMATITE DYKES	1975 ± 20 m.y. EMPLACED DURING HUDSONIAN OROGENY LATE KINEMATIC	10'-30'		
			TAZIN GROUP	UPPER	FAY MINE COMPLEX (CATACLASTIC MYLONITIC PARTLY BRECCIATED)		UNIT IV - GRANITIC GNEISS	APHEBIAN SEDIMENTS METAMORPHOSED DURING OR AT THE BEGINING OF THE HUDSONIAN OROGENY	600'-1000'	01	
							UNIT III - ALBITE PARASCHISTS & PARAGNEISSES, MINOR QUARTZITE			09	079 073
							UNIT II - PHYLLONITIC-AND EPIDOTE-AMPHIBOLITE			016	076
							UNIT I - CALC-SILICATE ROCKS QUARTZITE-CONGLOMERATE				
				MINOR UNCONFORMITY ?							
				MIDDLE	DONALDSON LAKE GNEISS (CATACLASTIC)		BIOTITE ± MUSCOVITE-PLAGIOCLASE GNEISS, AMPHIBOLITE	EARLY APHEBIAN SEDIMENTS METAMORPHOSED AND UPDATED BY THE HUDSONIAN OROGENY	800'-1200'		
				EROSIONAL GAP ?							
	ARCHEAN			LOWER	FOOT BAY GNEISS (MYLONITIC & BRECCIATED)		BIOTITE ± GARNET ± HORNBLENDE-MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE	ARCHEAN SEDIMENTS METAMORPHOSED BY THE KENORAN OROGENY AND UPDATED BY THE HUDSONIAN OROGENY	2000'(?)		

The Tazin Group

The most important geological structure of the region is the Ace Lake - Donaldson Lake antiform (for brevity termed the 'Donaldson Lake antiform'), the axial trace of which extends from Padget Bay, where it is truncated by the ABC Fault, to Hoey Lake, Harbour Lake, ~1100 feet NW of Strike Lake, National Exploration's 2nd Camp to finally cut the E end of Foot Bay and the W shore of Schmoo Lake. It is discontinuous and appears to be offset, several times, by a set of E-W and NW-SE trending faults such as the Harbour Lake Fault, Foot Bay Fault and possibly the Schmoo Lake and the Hoey Lake Faults. In general the axial trace of this structure trends NE-SW and in some places it seems to parallel the St. Louis Fault. The Donaldson Lake antiform is flanked, towards the NW, by minor folds, probably subsidiary undulations situated on the western limb of the same structure. The SE limb of the Donaldson Lake antiform shows drag-folding on a large scale and it is believed to plunge 40° to 60° southeastwards (Tremblay, 1968). The W limb is less deformed and apparently passes westwards towards a zone in which the folding is less complex and open (Tremblay, 1968). Another feature of the area is the Nesbitt synform, extending from Tam Lake to Eagle Lake and to the SW shore of Mickey Lake where it is cut by the Harbour Lake Fault, Mickey Lake Fault, and by the Tom Fault. About 1200 feet NE of Padget Bay it is truncated by the Tam Lake Fault. This synform (Fig. 10), which was

Fig. 10. Cross section showing the Nesbitt synform, after Sillman (1953).



FIGURE

CROSS SECTION OF THE NESBITT MINE

(after Silman, 1953)

studied in detail by geologists working for the Nesbitt-Labine Mine (Sillman, 1953) is flanked on the NW by an open structure termed the 'HAB synform' (SE of the Edie Fault).

According to Tremblay (1968) the 'oldest' rock of the area is the 'Foot Bay Gneiss' which outcrops in the core of the Donaldson Lake antiform in the NE part of the Map (Fig. 8). The limitation of the outcrop area is due to a culmination in the axis of the antiform. In general the Foot Bay Gneiss is red to dark red, reddish, or black green in color, porphyroblastic and porphyroclastic, massive or well-jointed, locally foliated. It is characterized by a high mafic content, by the association with masses or bodies of amphibolite and by the presence of lenses, dykes and sills of coarse-grained granitic rocks (Tremblay, 1968). The Foot Bay Gneiss exhibits a sharp contact with quartzitic rocks, although some lenses may be found to be gradational with it. It also shows a gradational contact with the granitic rocks outcropping between the St. Louis Fault and the E shore of Foot Bay and Schmoo Lake. The Foot Bay Gneiss occurs in the region between the Basca Fault and the Yahyah Lake Fault and also S and E of Fulton Lake.

Above the Foot Bay Gneiss is the 'Donaldson Lake Gneiss' (Tremblay, 1968) which is well exposed in a broad 'U' shaped area, situated between Mickey Lake, Hoey Lake, Ace Lake, Strike Lake, Emar Lake, Raggs Lake and the St. Louis Fault. It is also present in the southeastern part of the map (Fig. 8) between Collier Lake and Flack Lake, between the Radiore Fault and the Basca Fault, S of Ace Lake, and W of Yahyah Lake. It is noteworthy to recall that Tremblay, unlike the present author, did not recognized the presence of the Donaldson Lake Gneiss, in the areas situated between the St. Louis Fault and the E end of the Foot Bay, or in the area surrounding Hoey Lake (Fig. 8). According to him, the Donaldon Lake Gneiss formed part of the W flank of the Donaldson Lake anticline, but disappeared abruptly or was thought to transgress into a granitic rock (Tremblay's map-unit 19) as a result of granitization or possible original sedimentary facies changes.

The Donaldson Lake Gneiss is generally white to light brown, or whitish to black green, usually coarse grained, granoblastic, mylonitic and porphyroclastic, well layered or foliated. It is a biotite-rich plagioclase gneiss, characterized by the presence of lenses, masses or layers of interbedded hornblende gneiss and amphibolite. Several of these basic bodies were mapped by Tremblay in the central island of Donaldson Lake, around National Exploration's 2nd Camp, Strike Lake, Harbour Lake and in the region situated S of the Basca Fault (Tremblay, 1954, 1955, 1956, 1957a, 1957b, 1958a, 1958b). Amphibolitic bodies and masses are also present in the immediate vicinity of the Fay Mine, S of the Ace Creek (Trigg, 1964). Within the Donaldson Lake Gneiss it is also possible to recognize the presence of small, but irregular masses of red granite and pegmatite dykes. Towards the W, the Donaldson Lake Gneiss exhibits a sharp contact with a sequence of metasedimentary rocks (Tremblay's map units 3-5) mainly composed of quartzite, paragneisses and paraschist, diopside and tremolite calc-silicate rocks, phyllonitic and epidote amphibolite and mylonitic granitic gneisses (Trigg, 1964). According to Tremblay (1968), the quartzites (Tremblay's map unit 3) are stratigraphically situated below the so-called 'argillites and slates' (Tremblay's map unit 4) but due to their lenticular nature, they may be found above or interfingering with them. This sequence of metasedimentary rocks, called by the author 'the Fay Mine Complex', forms a distinct belt which follows the upper contact of the Donaldson Lake Gneiss in a 'U' shaped pattern. Starting from the N boundary of the map, SW of Mickey Lake, the belt trends SW to almost Padget Bay where it is cut by the ABC Fault or by the Tam Lake Fault. It subsequently climbs the apex of the Donaldson Lake antiform NW of the Eldorado Campsite, to finally continue along the foot wall of the St. Louis Fault as far as Flack Lake. The same sequence of rocks is found underground in the Fay and Verna Mines (foot wall) where it constantly follows the plane of the St. Louis Fault submerging to a depth of at least 4,000 feet. In the hanging wall of the fault, from the Verna Lake sector to the E shore of Francis Lake, the same rock types constitute the flank of a large, partly covered isoclinal structure which acts as host for the mineralization present in the Verna orebodies. A very similar sequence of rocks, but less deformed, occurs in the southern part of the map (Fig. 8) S of Fookes Lake, Tailing Lake and along Ace Creek. These rocks which were originally thought to be part of the Tremblay's 'Murmac Bay Formation' are composed of quartzite, blue quartzite, conglomeratic quartzite, ferruginous quartzite, quartz-biotite schist, carbonate bearing rocks and Tremblay's 'argillites'. The quartzites are usually intercalated with hornblende schist or amphibolite. In some localities the quartzitic rocks change in composition to reach a 'metagreywacke' or they increase their mica content to approach a quartz-biotite schist. At Ace Creek they become conglomeratic and apparently submerge northwards under the Martin rocks since they have been encountered in several underground D.D. holes, drilled southeastwards into the hanging wall of the St. Louis Fault, from the upper levels of the Fay Mine (section 64+00 W, Fay Mine).

The upper part of the Fay Mine complex is characterized by a controversial unit that is widespread in the Beaverlodge district and outcrops in an area situated between the Tazin-Martin unconformity, the ABC Fault and a line which approximately joins the ABC Adit to Beth Lake, NW shore of Mic Lake and about the NW shore of Mickey Lake. This area was thought to be occupied by the 'Metasomatic Granite' (Tremblay's map-unit 19 and 19b) but field evidence and petrographic studies indicate that it is actually constituted by a reddish to brick-red or pinkish, well-layered, mylonitic granitic gneiss probably representing an original conglomeratic arkose possibly passing into greywacke, chert or into intensely brecciated quartzite. In places large angular boulders of red granite and white to buff and blue quartzite are found within the unit cemented by a feldspathic matrix. This unit which overlies gradationally or interfingers with the metasedimentary sequence described above, may be in sharp contact with albite paragneisses and paraschists belonging to the Fay Mine complex. It was often confused by previous workers with the Donaldson Lake Gneiss or with the so-called 'carbonatized granite' belonging to Tremblay's map-unit 19. The rock was also recognized and mapped by most of the geologists working in the Fay Mine. It was usually named 'orange mylonite' or 'feldspar rock' and was found to occur in the underground workings developed along the plane of the St. Louis Fault. This granitic gneiss, which lost most of its original characteristics through deformation, occurs also W of the Eldorado Campsite, in the Campsite and in thin continuous lenses along the St. Louis Fault as far as Flack Lake. It is also found between the Eldorado Mill and the Ace Creek where it overlies quartzite and paraschists and underlies rocks belonging to the Martin Formation. It is noteworthy to recall that Tremblay himself recognized the presence of such a rock while plotting map-unit 19b along the St. Louis Fault, E of the Eldorado campsite. Describing this unit, Tremblay stated that the rock is brecciated and mylonitized and resembles those rocks outcropping about the Eagle Shaft exhibiting various sized fragments of granite cemented by a dense cherty hematitic matrix. Tremblay also recognized that the rock itself includes many remnants of country rocks such as quartzite, chlorite schist, amphibolite, hornblende schist, pegmatite and fragments of rocks very similar to the Foot Bay Gneiss (Tremblay, 1968). The fragments generally stand out in relief; they may be sparse or abundant and are lighter than the matrix which is reddish brown or black. He also stated that the granitic bodies are more numerous in areas occupied by quartzites.

Some evidence that this mylonitized gneissic unit occupies the upper part of the Fay Mine Complex is given by recent exploration D.D. holes drilled around Eagle shaft and in the region around Mic Lake.

The Martin Formation

The NW and SW portion of the map (Fig. 8) is occupied by a sedimentary and volcanic sequence of rocks named the Martin Formation (Fahrig, 1961). The rocks of this formation unconformably overlie Tazin lithologies. In some places, however, they appear to be the gradational continuation of the Fay Mine Complex described above. This fact has been interpreted by Tremblay (1968) as due to 'basal detritus' derived directly from the Tazin rocks and situated in the same position that it occupied before erosion. In most cases the unconformity is sharp, well exposed by differential erosion and often flat-lying. E of Fredette Lake small remnants of Martin Conglomerate are in gradational contact with the underlying granitic gneiss and with quartzite. Gradational contacts between the deformed granitic gneiss and the basal conglomerate can be seen S of the Eldorado Mill and S of Ace Lake. In general the unconformity appears to be sharp indicating that the sedimentary rocks were deposited on a very rugged topography. In the investigated area the Martin Formation consists of basal conglomerate, arkoses, siltstones, sandstones and interstratified andesitic and basaltic flows (Tremblay, 1968). The basal conglomerate is a thick layer highly resistant, well consolidated, reddish to reddish-brown rock composed of angular to sub-angular fragments cemented by a reddish to brick-red arkosic matrix. The fragments, and locally the blocks, are derived entirely from the rocks that constitute the Tazin Group. Fragments, pebbles and blocks of Donaldson Lake Gneiss, Foot Bay Gneiss, pegmatites, red granite, quartzite, chlorite schist, amphibolite are common. Fragments of ferrugineous quartzites, reddish mylonitized rocks, 'phyllonitic amphibolite' and mafic gneisses were also observed by several workers. Several unmetamorphosed fragments of an allochthonous reddish arkosic sandstone were observed by Beecham and by the writer in the Eagle Shaft area. The conglomerate may be interbedded with arkose or conglomeratic arkose or with brown siltstone. Arkose is found above the conglomerate in thick massive layers interbedded with siltstone. Locally it is characterized by graded-bedding or by cross-bedding; in a few localities, such as E of Fredette Lake, ripple marks were observed. In several other localities the arkose is interbedded with andesitic or basaltic flows and contains few fragments of the underlying volcanic rocks. The chocolate-red siltstone occupying a somewhat higher stratigraphic position is a fine grained, well sorted feldspathic rock generally displaying graded-bedding or mud-cracks. In several places where the rock is less coarse grained, it is characterized by concentric structures due to a stromatolitic algae (Cloud, 1942). Several samples of 'Atakokenia' were collected by Mr. Don Ward and the writer just beside the eastern houses of the Eldorado campsite in the hanging wall of the St. Louis Fault. Sills of volcanic rocks are interlayered with bands of arkoses and conglomerates. They are dark brown, amygdaloidal, fine to medium grained andesites and basalts, occasionally associated with gabbroic sills. They outcrop in the SW part of the map around Martin Lake Mine Adit and in the foot wall of the Fay-Verna Mine. The shape of the amygdules is elongated or rounded. They are usually filled with calcite and chlorite or by a composite mixture of chlorite, quartz and carbonate. The gabbroic sills are dark brown or dark green in color, massive, fine to coarse grained, ophitic or diabasic in texture, locally porphyritic. Because of this they are thought to be strictly related with the lava flows and sills described above, although they probably formed in a different environment (Tremblay, 1968). A few quartz-porphyry dykes, characterized by white to pinkish feldspar laths and rare prisms of hornblende are present in the foot wall of the Fay Mine where they are seen to cut and offset diabase dykes and sills. These quartz-porphyries were probably emplaced along weak fractured zones, late faults or joints after the last movements had taken place, since they are not deformed or offset, but are only slightly fractured. In this case the quartz-porphyry rocks represent the last phase of intrusion of the Fay Mine environs.

Metamorphic Concepts According to Previous Authors

Regional metamorphism and alteration in the Beaverlodge district have been reported by several workers. According to Christie (1953) the lack of aluminous sediments in the area, replacement phenomena and strong retrogressive metamorphism did not permit an outline of distinct zones of regional metamorphism. Smith (1949) believed that some sedimentary rocks, in the Tam and Eagle Lake area,preserved their original sedimentary structures and showed relic fabrics that would not be present had they been subjected to a degree of metamorphism considerably higher than the chloritic facies. Beck (1966) stated that in the west part of the region, as far as Camsel Portage, the grade of metamorphism is considerably higher due to the presence of amphibolites and pyroxene bearing rocks. O'Nions, in an internal report written for Eldorado Nuclear Ltd., (O'Nions, 1967) noted that many rocks outcropping in the Beatrice Lake area, exhibiting mineral assemblages of the greenschist facies, coexisted with others that presented much higher grades. According to Tremblay (1968) all the rocks belonging to the Tazin Group have been regionally metamorphosed as they have been subjected to deep-seated processes involving the recrystallization of the rocks and development of characteristic suites of minerals. After the regional metamorphism, these rocks suffered repeated retrogressive kinematic metamorphism and metasomatism. Tremblay also believed that the mineral assemblages of certain lithologies could indicate the facies and the metamorphic grades present in the area. In such a case the rocks of the Tazin Group were believed to lie entirely within the almandine-amphibolite facies of Turner-Verhoogen (1960); more specifically Tremblay believed that the staurolite-almandine sub-facies was the grade represented in the area even if no staurolite was observed. In many parts of the district, the mineral assemblage typical of this sub-facies was thought to be destroyed or obscured by later retrogressive effects related to kinematic metamorphism and later phases of granitization. The Martin Formation was thought to be essentially unmetamorphosed (Tremblay, 1968; Fraser et al., 1970).

CHAPTER 3 - STRATIGRAPHY AND LITHOLOGY OF THE INVESTIGATED AREA

Introduction

This chapter deals with the general description, the petrography and the field relationships of the Tazin and Martin rocks found in the Fay Mine environs and underground workings as illustrated in Figs. 12, 13, 14, 15, 16 and in the original plans and sections contained in the 2nd volume of this thesis.

The modal analyses reported herein are based upon measurement of 1200 points (for each thin section) at a spacing of 0.5 mm.

The classification of deformed and recrystallized rocks proposed by Burwash and Krupička (1969) was adopted in this study. The petrographic description of a typical series of samples from the Fay Mine environs is presented in Appendix A and of other representative samples in Appendix B.

A. TAZIN GROUP

General Statement

No clear attempt has ever been made to divide the Tazin Group into stratigraphic units. Only Tremblay (1968) in mapping the region situated north of the St. Louis Fault recognized the presence of several units of Precambrian age. Field evidence and petrographic studies demonstrate that the Tazin Group is composed of:

3. UPPER TAZIN GROUP (= FAY MINE COMPLEX)

2. MIDDLE TAZIN GROUP (= THE DONALDSON LAKE GNEISS)

1. LOWER TAZIN GROUP (= THE FOOT BAY GNEISS)

In this study the author also proposes a revised terminology for the Fay Mine lithologies. A schematic representation of the Fay Mine stratigraphic sequence is given in Fig. 9.

1. Lower Tazin Group (The Foot Bay Gneiss)

a) Previous Studies

The name 'Foot Bay Gneiss' was first introduced by Tremblay (1968) for a quartzo-feldspathic gneiss outcropping in the core of the Donaldson Lake antiform (Foot Bay area, E shore of Donaldson Lake). This gneiss, considered to be the oldest rock of the district, forms a distinct stratigraphic unit also recognized in the Fay and Verna Mines along the foot wall and hanging wall of the St. Louis Fault. The Foot Bay Gneiss was first encountered in the underground workings constructed for the preparation of the Fay shaft station of the 19th Level (Fig. 13), and was subsequently encountered in the lower levels of the Fay Mine. Several geologists, mapping the west wall of the Fay shaft, described this rock as a 'banded chloritic and siliceous gneiss' or as a 'porphyroclastic mafic gneiss' characterized by a dark-grey color and by lenses of white silica intermixed with mafic-rich layers'. During the development of the main drifts, extending along mine coordinate 40 + 00 W

PLATE I

1. Foot Bay Gneiss, hanging wall, 25th Level, Fay-Winze sector. Typical example of blastomylonitic banding: the white bands consist of crushed and recrystallized quartz and deformed feldspar; the dark bands consist of garnet, epidote, hornblende and biotite. The deformation is very strong.

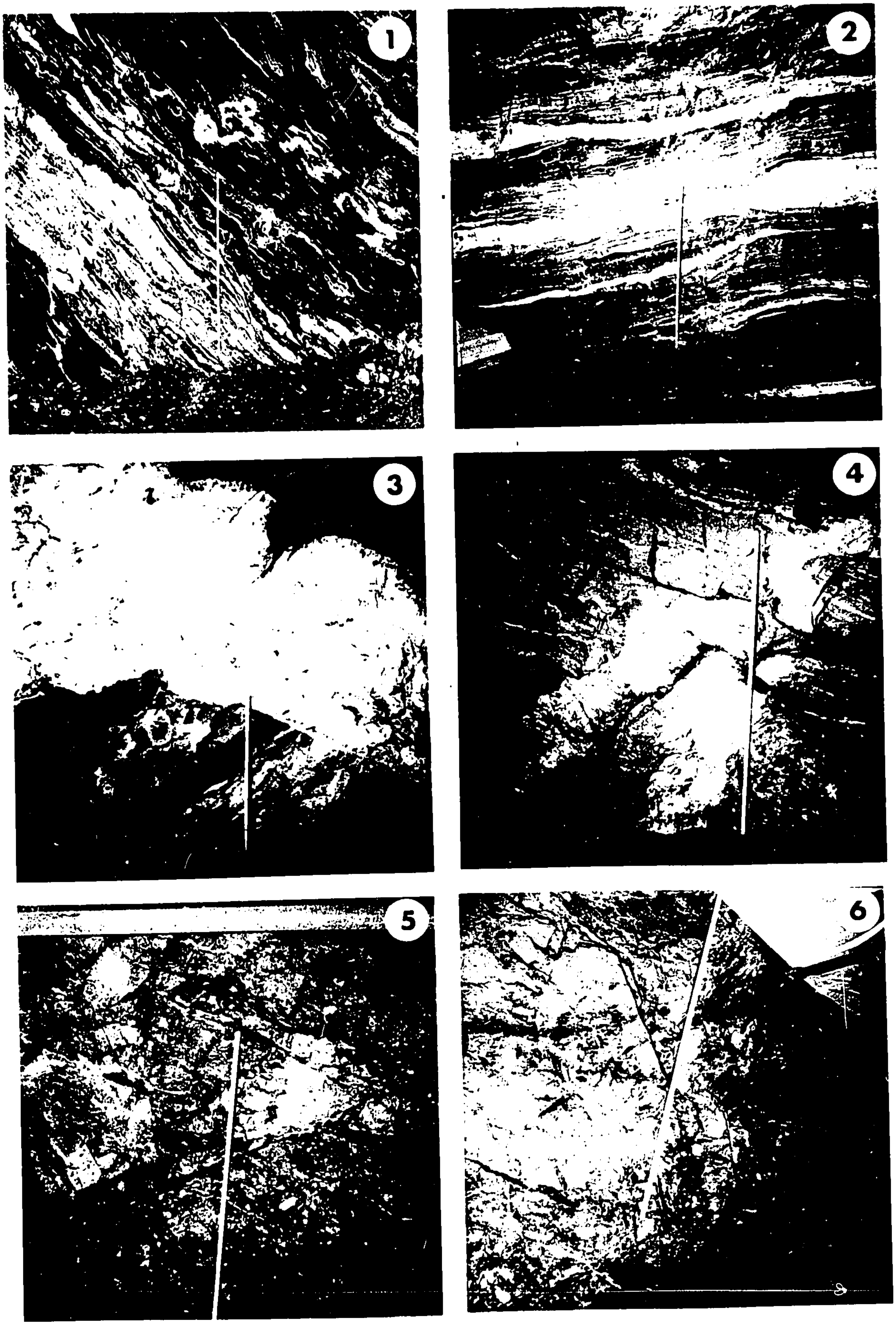
2. Donaldson Lake Gneiss, foot wall, 25th Level, Fay Mine. Alternating bands of felsic and mafic minerals conformable to 'endemic' pegmatites. The deformation is moderate.

3. Discordant pegmatite dykes cutting Foot Bay Gneiss, hanging wall, 25th Level, Fay-Winze sector. The deformation of the pegmatites is moderate.

4. Cross-cutting pegmatite dykes (in Donaldson Lake Gneiss) offset by later movements, hanging wall, 25th Level, Fay-Winze sector. The deformation is moderate.

5. Martin conglomerate occurring about 30 feet from the plane of the St. Louis Fault, foot wall, 21st Level, Fay Mine.

6. Conglomeratic arkose belonging to the Martin Formation occurring about 10 feet from the plane of the St. Louis Fault, foot wall, 21st Level, Fay Mine.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6

PLATE II

1. Foot Bay Gneiss: typical porphyroclastic (plagioclase) and porphyroblastic (microcline) mylonitic biotite ± garnet ± hornblende microcline-plagioclase gneiss. Sample F-25-102, 254191 Drift E, Fay Mine.

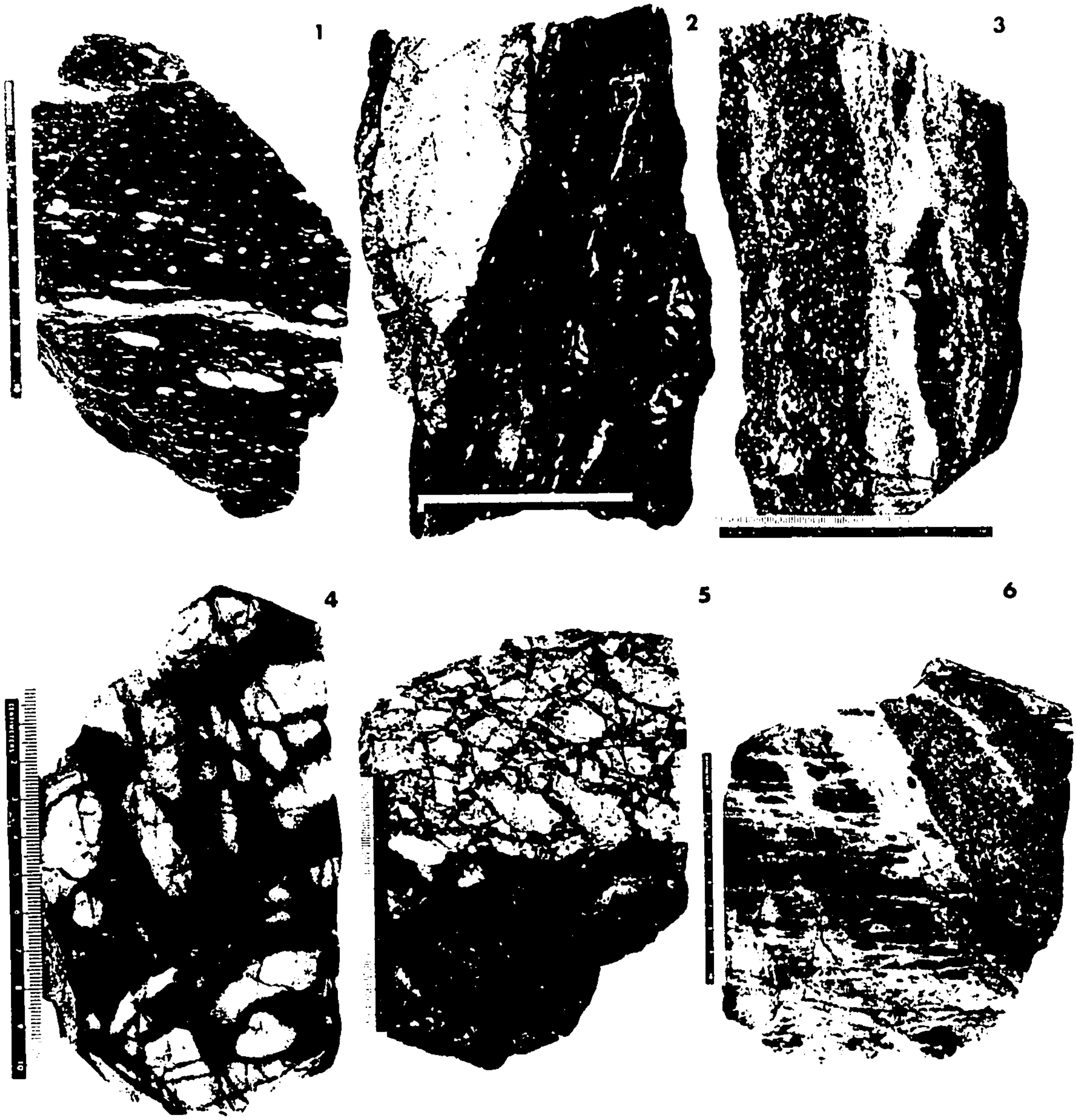
2. Foot Bay Gneiss; similar texture as in 1, but with alternating felsic and mafic bands. Sample F-25-001, 254191 Drift E, Fay Mine.

3. Donaldson Lake Gneiss: cataclastic biotite ± muscovite plagioclase gneiss. Sample FW-23-2, 23rd Level, Fay Mine.

4. Brecciated quartz conglomerate (Fay Mine Complex, Unit I). Sample F-25-071, 254191 Drift E, Fay Mine. Fragments of quartzite cemented by an hematite-rich felsic matrix.

5. Contact between Donaldson Lake Gneiss (amphibolite) and Fay Mine Complex (brecciated quartz conglomerate). Sample F-25-061, 254191 Drift E, Fay Mine. The matrix of the conglomerate is poor in hematite.

6. Poorly brecciated 'blue' quartzite (Fay Mine Complex, Unit I) cut by a red aplite dyke. Sample F-25-070, 254191 Drift E, Fay Mine. The 'blue' quartzite develops from the strongly brecciated quartz conglomerate described above.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6

PLATE III

1. Banded gneissic mylonite (Fay Mine Complex, Unit III). Sample VE-1, 13th Level, Verna Mine. Light-colored bands are composed of pulverized quartz and feldspar; dark-colored bands are rich in crushed garnet, chlorite and muscovite.

2. Mylonitic granitic gneiss (Fay Mine Complex, Unit IV). Sample F-25-046, 254191 Drift E, Fay Mine.

3. Slightly brecciated Martin conglomerate collected about 40 feet from the plane of the St. Louis Fault. Sample FW-19-1, Verna-Winze sector. The pebbles are composed of Tazin quartzite.

4. Martin conglomerate collected about 30 feet from the St. Louis Fault. Sample F-21-1, foot wall, Fay Mine. Narrow chalcedony veinlets are intersecting both the pebbles and the matrix; locally a chalcedonic matrix cements brecciated Martin conglomerate blocks.

5. Cross-bedded (trough-type) Martin arkose collected about 6 inches from the plane of the St. Louis Fault. Sample FW-18-2, Verna-Winze sector. The ruler lies on a unpolished portion of the sample.

6. Quartz porphyry dyke. Sample F-23, foot wall, Fay Mine. Large phenocrysts of sanidine and acidic plagioclase are set in a red-stained cryptocrystalline matrix.


1
2
3
4
5
6

PLATE IV

1. Outcropping surface of the St. Louis Fault, 200 feet NE of the manager's house, Eldorado campsite. Martin conglomeratic arkose, brecciated conglomerate and siltstone form the foot wall of the fault.

2. Detail of the outcrop described in 1. Tazin quartzite pebbles positively weathering-out set in arkosic matrix.

3. Martin conglomerate occurs in the hanging wall of the St. Louis Fault, S shore of Ace Lake.

4. Martin siltstone interbedded with the conglomerate described in 3 occurs about 60 feet N of the Eldorado Mill. Scattered small polymictic pebbles are visible.

5. Outcrop of mylonitic granitic gneiss (Fay Mine Complex, Unit IV) W of the Eldorado campsite.

6. Unconformable contact of mylonitic granitic gneiss (lower part) and Martin conglomerate (upper part) S of Ace Lake.

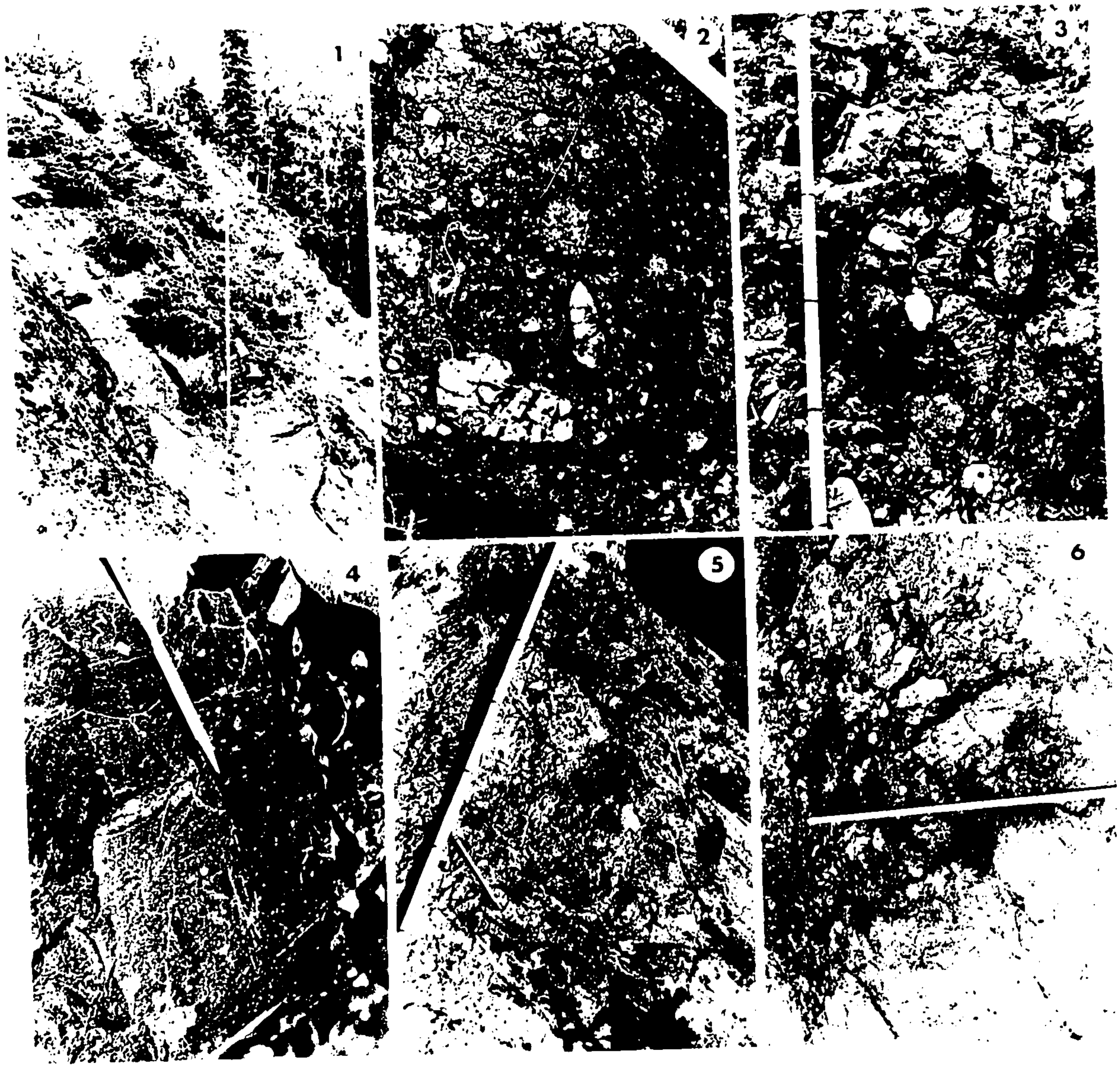
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PLATE V

1. Mylonitic muscovite paraschist (Fay Mine Complex, Unit III). Sample F-22-011, foot wall, Fay Mine. Crushed quartz pebble discordantly oriented to the schistose matrix which contains bent muscovite flakes. Crossed polarizers.

2. Foot Bay Gneiss. Sample 27-1-1, D.D.H. 27-1, 282 feet from collar. Band of crushed and recrystallized quartz and microcline offset by a narrow shear zone belonging to the brecciation stage. Crossed polarizers.

3. Anhydrite-gibbsite vein cutting Foot Bay Gneiss. Sample 27-1-2, D.D. H. 27-1, 1041 feet from collar. Crossed polarizers.

4. Discordant pegmatite dykes (cutting cataclastic Donaldson Lake Gneiss). Sample F-25-004, 254191 Drift E, Fay Mine. The pegmatite texture is markedly less deformed than that of the gneiss. Muscovite and plagioclase show slight fracturing and bending. Crossed polarizers.

5. Martin arkose. Sample FW-18-2, Verna-Winze sector. The clastic texture does not show any deformation. Crossed polarizers.

6. Diabase dyke. Sample 24-138-165, D.D.H. 24-138, Fay Mine. Ophitic texture showing large phenocrysts of labradorite in a matrix of chloritized pyroxenes and plagioclases. No deformation is noted. Crossed polarizers.

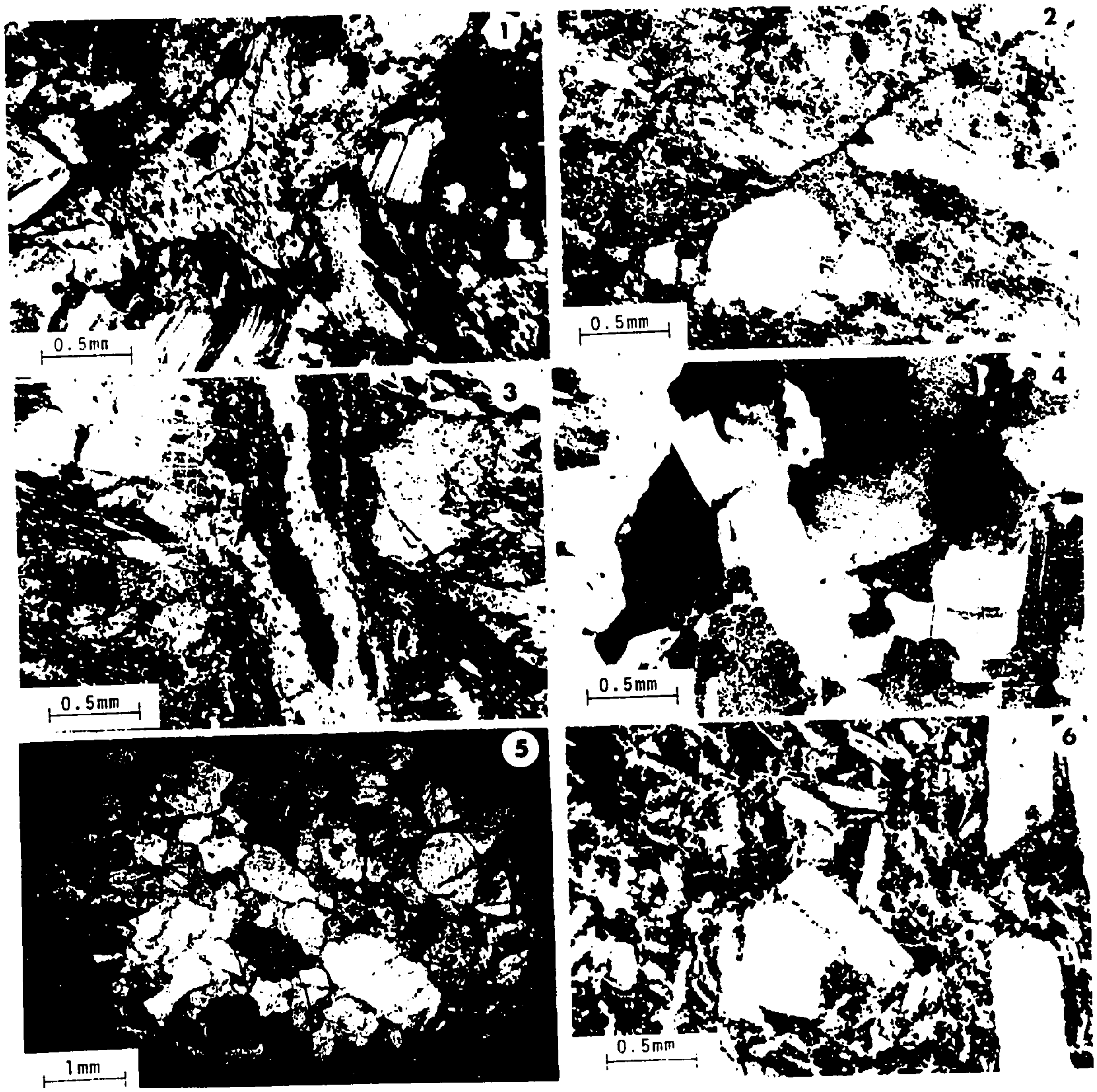
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PLATE VI

1. Cataclastic quartz-rich plagioclase gneiss (Fay Mine Complex). Sample F-22-156, Fay Mine. Fragments of broken plagioclase cemented by granulated quartz. Crossed polarizers.

2. Strained chlorite-muscovite plagioclase gneiss (Donaldson Lake gneiss). Sample F-25-013, 254191 Drift E, Fay Mine. Sinuous muscovite-chlorite slip zones. Plain light.

3. Epidotic mylonite (Fay Mine Complex). Sample F-22-006, foot wall, Fay Mine. Plagioclase porphyroclasts in a very fine-grained matrix composed chiefly of epidote-zoisite (dark bands) and quartz (light colored bands). Crossed polarizers.

4. Mylonitic garnet-biotite microcline-plagioclase gneiss (Foot Bay Gneiss). Sample 24-166-1, D.D.H. 24-166, 245 feet from collar. Plagioclase, garnet (upper left) and microcline (lower left) porphyroclasts in a granulated matrix of biotite + plagioclase (darker grey portions) and quartz. Crossed polarizers.

5. Mylonitic biotite-hornblende microcline-plagioclase gneiss (Foot Bay Gneiss). Sample F-22-023, foot wall, Fay Mine. Microcline (lower left), plagioclase (upper right) and hornblende (upper left) porphyroclasts in a fluidal granulated matrix of plagioclase +biotite +hornblende (dark bands) and quartz (light-colored bands). Crossed polarizers.

6. Mylonitic chlorite microcline-plagioclase gneiss (Foot Bay Gneiss). Sample 27-1-1, D.D.H. 27-1, 282 feet from collar. Older mylonite cut by a younger shear zone. Crossed polarizers.

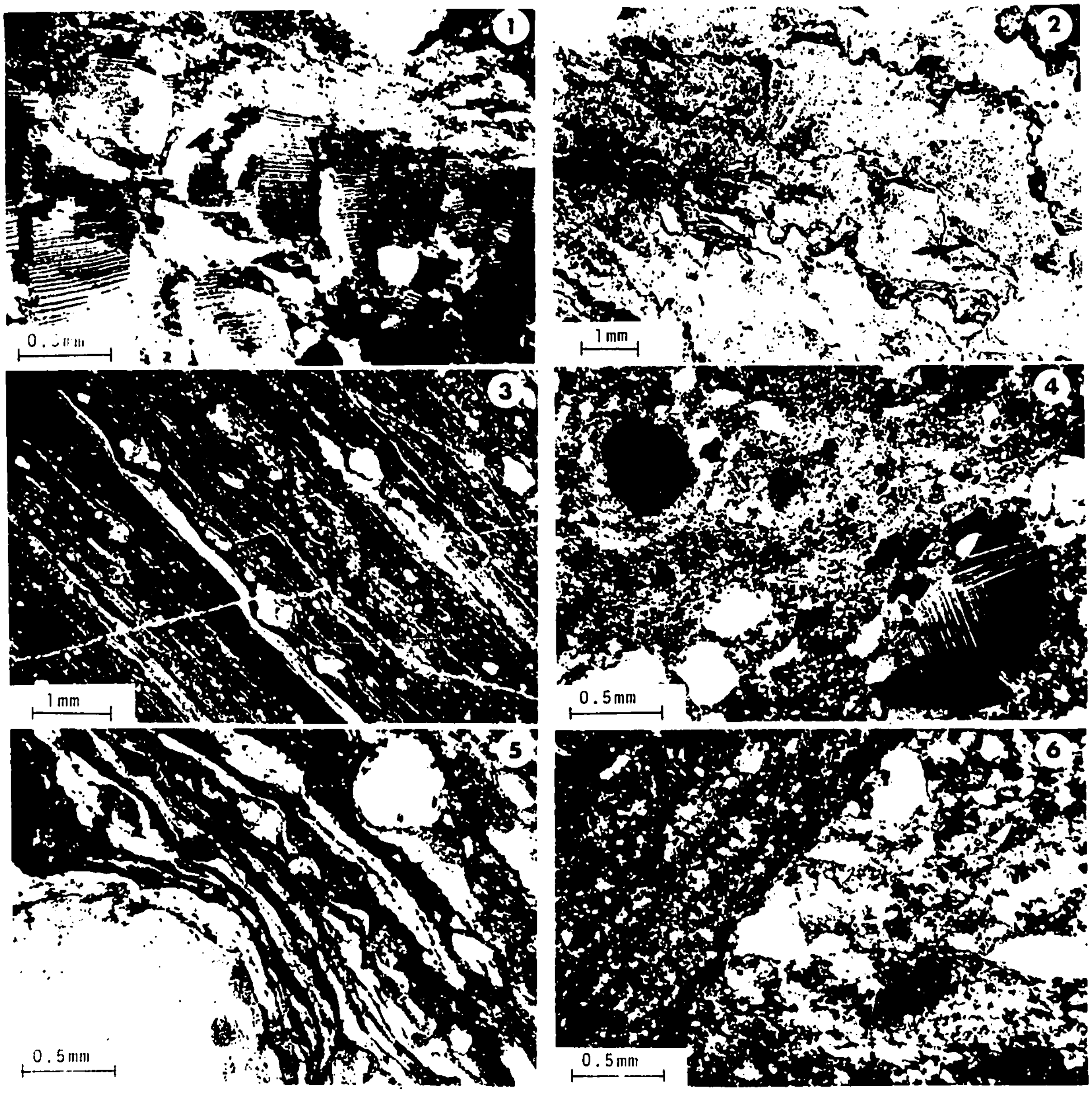

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PLATE VII

7. Brecciated gneissic mylonite-kakirite (Foot Bay Gneiss). Sample F-25-2-5, D.D.H. 25-2, 444 feet from collar. Mylonite (left side) traversed by pseudotachylytic ultramylonite (right side). Plain light.

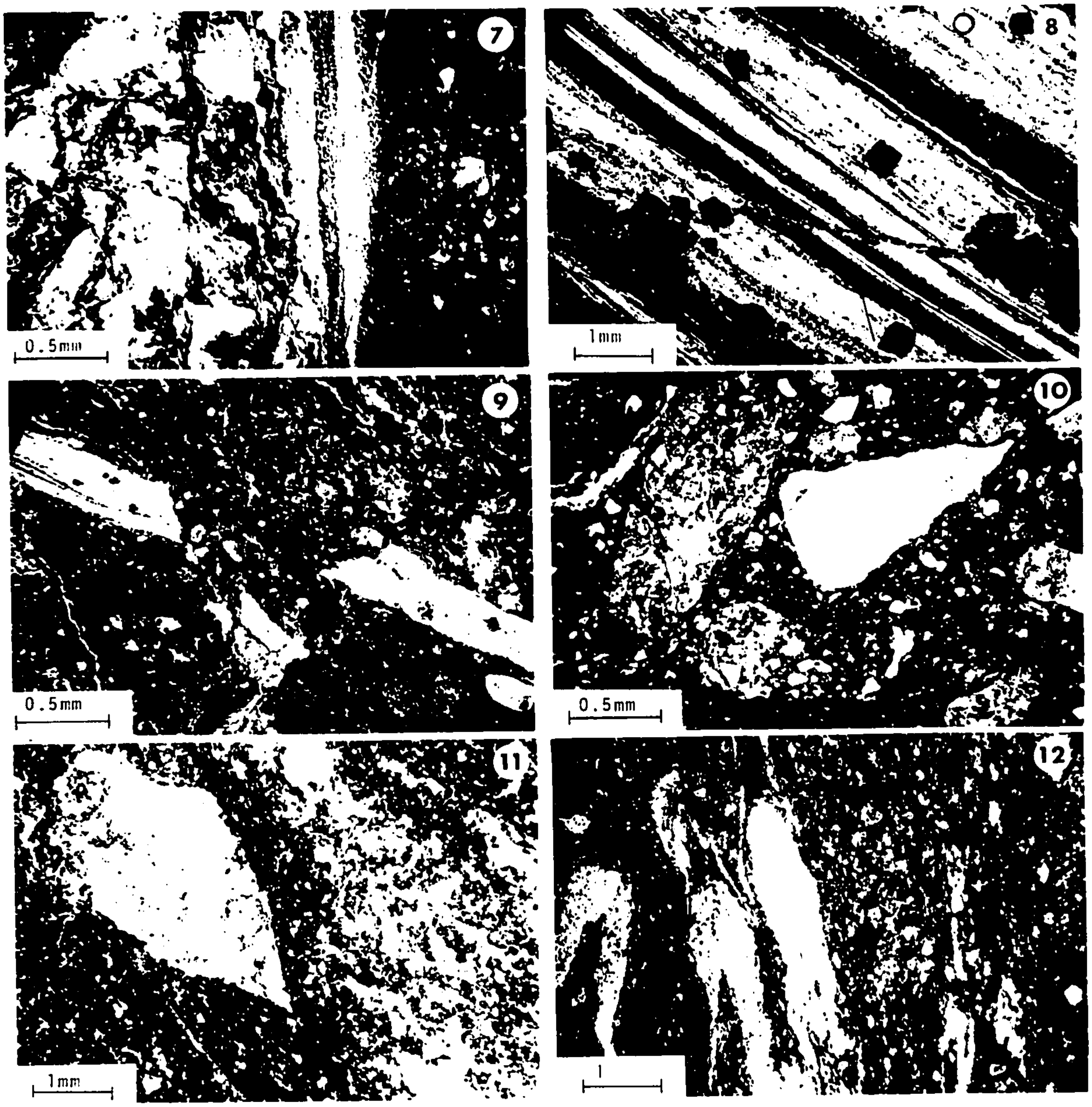
8. Laminated ultramylonite (Fay Mine Complex). Sample BO-11, Bolger pit. Ultrafine grain (0.01-0.001 mm). The white band in the center is composed entirely of sericite (100% optic orientation), the grey band of quartz, the dark bands of epidote and chlorite. A chlorite veinlet cuts and offsets the bands. Euhedral pyrite is also visible. Crossed polarizers.

9. Brecciated mylonite (Fay Mine Complex). Sample F-25-037, foot wall, Fay Mine. Fragments of felsic mylonite band in reworked mylonite matrix. Plain light.

10. Brecciated gneissic-mylonite-kakirite (Foot Bay Gniess). Sample F-25-2-6, D.D.H. 25-2, 531 feet from collar. Angular fragments of original mylonite in pseudotachylytic ultramylonite. Feldspar miniporphyroclasts in ultramylonitic matrix. Plain light.

11. Brecciated gneissic mylonite-kakirite (Foot Bay Gneiss). Sample F-25-2-3, D.D.H. 25-2, 396 feet from collar. Angular fragments of original mylonite in ultramylonite. Plain light.

12. Microfolding in mylonite (Fay Mine Complex). Sample F-22-012, foot wall, Fay Mine. Folded bands of granulated quartz (orig. pebbles?) in still finer-grained crushed matrix. Crossed polarizers.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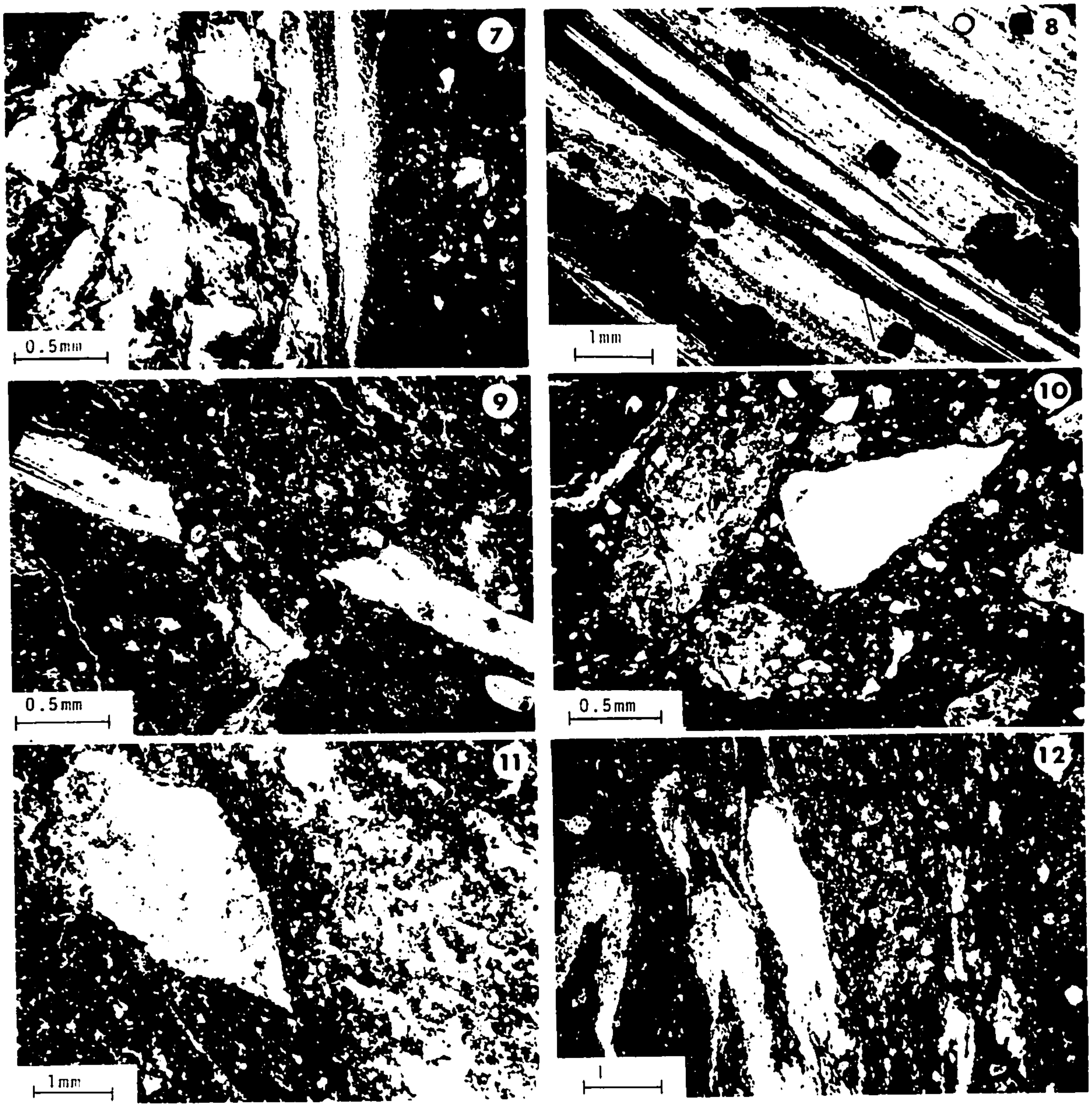
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(Fay Mine), the Foot Bay Gneiss was seen to advance towards the St. Louis Fault reaching (on the 23rd and 24th Levels) mine coordinate 40 + 00 W - 15 + 00 S (Fig. 13).

The same rock type is also present at the station of the 27th Level (Fay Mine) where it dips gently towards the S . The Foot Bay Gneiss was also encountered in several D.D. holes drilled southeasterly from the main hanging wall drifts of the 19th and 24th Levels (Drifts 19-47 and 24-30, Verna Mine) and in the hanging wall of the St. Louis Fault, about the position where the new internal Fay-Winze shaft is presently sunk (Plate I, 1). The deep pilot hole drilled in this location encountered the Foot Bay Gneiss only 80 feet away from the plane of the St. Louis Fault (32nd Level, Fay-Winze). In all these locations the Foot Bay Gneiss presents the same characteristics: it is composed of greenish-grey to dark-grey layers alternating with medium to large bands of whitish to red-orange material, usually intersected by abundant pistachio-green veinlets of epidote, white calcite and anhydrite. The layers vary in shape and do not keep a uniform width for long distances. They are reminiscent of sedimentary layering suggesting that the gneiss could have been derived from sedimentary rocks. It is well foliated and frequently fractured. Its joints are moderate to weak and usually discontinuous whilst small drag-folds or boudins parallel the banding. The rock in general contains more than 20% mafic material with lenses or bodies displaying even 60% of chloritic and amphibolitic minerals. Apparently the composition is variable, generally between that of a leucocratic gneiss and an amphibolite.

According to Tremblay (1968) the light colored bands of the typical Foot Bay Gneiss are generally coarse grained, granitic-looking and composed of glassy-grey to white quartz, microcline and albite-oligoclase. The dark colored layers do not show granitic texture; they are fine to medium grained with a typical porphyroclastic texture (Plate II, 1).

b) Present Studies

Examination of numerous thin sections has revealed that the Foot Bay Gneiss has an inequigranular mylonitic or porphyroclastic-porphyroblastic texture generally due to repeated metamorphism, re-mylonitization and multiple brecciation (Plate II, 2; Plate VI, 5, 6). This type of texture is due to perfectly rounded megacrysts ranging from 0.1 mm to 8-10 cm in diameter. In places they are ovoidal and are composed of red-stained plagioclase, microcline and white quartz. All these minerals also form medium to large grains which generally occur in large bands alternating with more mafic layers composed of chlorite, rarely biotite and hornblende. The augen are quite abundant usually surrounded by large bent porphyroblasts of mica, locally broken and altered to chlorite. Large grains composed of several minerals show sutured margins or are locally cemented by a mylonitic matrix. The megacrysts or augen-shaped porphyroclasts show irregular or fringed edges surrounded by fine aggregates of polycrystalline quartz in bands or thin ribbons with good flow structures. Some grains display partial rotations up to 90°. In several thin sections, at least two generations of feldspar were noted. Plagioclases are generally large; they show bent twinning lamellae, locally crushed or offset and recemented by secondary calcite or by a mylonitic matrix. Quartz is clear to whitish with strained appearance; it presents undulatory extinction and interlocking edges. It also occurs as platy or rolled-out grains (Plate VI, 5). Locally it is rounded or subrounded as inclusions in plagioclase and microcline or in hornblende. Occasionally myrmekitic intergrowths are visible indicating the polymetamorphic nature of the rock (Burwash and Krupička, 1969). Hornblende occurs in dispersed large corroded and deformed crystals, in places poikiloblastic, intensely pleochroic from deep green to brown. It is always found in protected areas between large augen or porphyroclasts surrounded by a mortar texture. In several thin sections hornblende presents a kelyphitic rim of epidote or it is enclosed by chlorite. In one instance cummingtonite was noticed with hornblende (O'Nions, 1967). Both micas are often present and are seen to fill the interstices between the grains surrounding crushed and altered crystals of garnets. Biotite may also be bleached or is characterized by pleochroic haloes due to zircon inclusions. Epidote is abundant and is associated with penninite. In places chessboard albite, string and patchy perthite are also visible. Pyrite, hematite, magnetite, leucoxene, allanite, calcite and pseudo-grains or clumps of anhydrite constitute the varietal minerals. Apatite, sphene and zircon of different generations are the accessory minerals. Commonly two periods of mylonitization were observed (Plate VII, 10). In one thin section (Plate VI, 6) it is possible to distinguish two directions of movement intersecting at $\sim 45^{\circ}$. It is noteworthy that several samples collected on the 25th Level (Fay Mine sector) were characterized by intense deformation. Several kakirites (Watanabe, 1965) and cryptobreccias passing laterally to cataclasites were recognized in a zone situated at the contact between the Foot Bay Gneiss and the Donaldson Lake Gneiss. Trigg (1964), in an internal report written for Eldorado Mining and Refining Ltd., concluded that they were 'pseudo-tachylites' (Moorhouse, 1959).

The Foot Bay Gneiss is not always homogeneous in composition; it may include lenses of well crystallized amphibolite, zones of chloritic gouge and breccias, bodies richer in chlorite, amphibole, epidote and pyrite-rich quartzitic lenses conformable with the layering. In other places, especially at the contact with the Donaldson Lake Gneiss, it may be intermixed with hornblende quartzo-feldspathic gneisses, generally fine grained and porphyroclastic. Froese (1955) studying several specimens of amphibolite outcropping E of Verna shaft stated that a typical amphibolite contains 70% hornblende, 20% oligoclase, 7% clinozoisite, 3% chlorite. In places, as in the hanging wall of the St. Louis Fault (Verna sector), the contact with the Donaldson Lake Gneiss is sharp and faulted and is always marked by a thick clay gouge of chloritic or amphibolitic material. This contact, which can be traced from the 19th Level downwards, (Verna Mine and Fay-Winze) may be due to the presence of a steeply dipping fault, most probably the

Basca Fault, which also (on the surface in some locations) divides the Foot Bay Gneiss from the Donaldson Lake Gneiss before joining from the SE the plane of the St. Louis Fault. At this point it is important to recall that the presence of the Foot Bay Gneiss (S of the St. Louis Fault) was also recognized by Tremblay (1957) in the preliminary maps published in 1957 but was subsequently discarded in the maps published in 1968 (see area around the N shore of Fookes Lake, Tremblay's map unit 1, 1957).

In the foot wall of the St. Louis Fault, at the mine coordinate 40 +00 W - 15 +00 S (Fig. 13), it is possible to see that the Foot Bay Gneiss is cut by fresh undeformed reddish-brown quartz-porphyry dykes, 20 to 40 feet thick, which offset slightly fractured diabase dykes (Plate III, 6; Plate V, 6). Apparently the quartz-porphyry dykes were intruded along weak zones situated along the contact between the Foot Bay Gneiss and the Donaldson Lake Gneiss. Quartz-porphyry dykes were also encountered by D.D. holes drilled NW in the extreme foot wall of the Fay Mine sector (D.D.H. No. 27-1). In the hanging wall of the St. Louis Fault, the Foot Bay Gneiss is discordantly cut by red to red-orange pegmatite dykes (Plate I, 3) which in some places are offset by small fresh, slightly fractured diabase dykes.

Composition of the Foot Bay Gneiss

The average mineral composition, obtained by point counting eight stained thin sections of Foot Bay Gneiss samples, collected in the Fay Mine

Table 1 - Modal Analyses of the Foot Bay Gneiss (Fay Mine)

Thin Section No.	F-25-002	F-25-092	F-25-097	F-25-099	F-25-101	F-25-102	F-22-021	F-22-023	Average
Quartz	34.5	27.3	26.1	22.2	33.5	23.6	27.6	34.1	28.6
Microcline	28.9	19.3	27.0	32.2	18.4	33.1	21.1	22.5	25.3
Plagioclase	24.4	33.7	31.3	27.4	28.7	25.3	38.1	25.6	29.3
Biotite	9.4	6.8	3.3	4.4	4.3	4.6	2.6	4.2	4.9
Amphibole	0.2	3.2	4.1	1.1	0.5	4.2	0.9	4.3	2.3
Chlorite	1.6	2.0	2.0	2.8	5.6	2.5	4.0	1.0	2.7
Calcite	0.1	0.3	0.4	Tr.	0.2	0.4	0.2	0.4	0.3
Garnet	Tr.	0.2	0.4	0.6	0.1	0.2	0.1	0.3	0.2
Epidote	0.6	1.2	0.9	2.1	2.7	2.7	1.4	1.7	1.7
Apatite	0.1	0.6	0.4	1.2	0.6	0.6	0.5	0.7	0.6
Sphene	0.1	0.2	0.3	1.2	0.6	0.8	0.5	0.5	0.5
Zircon	Tr.	0.2	0.5	0.4	0.3	0.5	0.3	0.4	0.3
Anhydrite	-	0.2	0.2	0.1	-	-	-	0.1	0.1
Sulfides	0.1	1.4	1.0	1.7	2.1	0.4	1.5	1.6	1.2
Oxides	Tr.	3.1	2.0	2.6	2.3	1.0	1.2	2.5	1.8
Accessories	-	-	0.1	-	0.1	0.1	-	0.1	
No. of Points	1234	1212	1226	1223	1233	1209	1237	1224	1224

Table 2 – Average Modes of the Foot Bay Gneiss Compared with the Values Reported by Tremblay, Beck, Burwash & Krupička and Godfrey & Watanabe

	Fay Mine	Tremblay, 1968 (Beaverlodge Area)	Beck, 1966 (Beaverlodge Area)	Burwash & Krupička 1969 (Athabasca Zone)	Godfrey & Watanabe, 1963 (NE Corner of Alberta)		
Quartz	28.6	20 (13-31)	26 (14-40)	28.49	29.59	24.41	28.49
K-Feldspar	25.3	27 (10-40)	15 (3-36)	29.19	28.72	16.40	36.60
Plagioclase	29.3	33 (14-45)	48 (3-67)	25.33	29.61	41.27	29.10
Biotite	4.9	18 mafics	5 (3-22)	6.13	6.35	14.37	2.99
Hornblende	2.3		1	1.68	2.50	1.09	0.05
Pyroxene				0.10	0.12		
Muscovite				2.01	0.49	0.01	1.01
Chlorite	2.7		(2-16)	3.72	1.15	0.89	1.09
Epidote	1.7			1.66	0.70	0.92	0.10
Garnet	0.2			0.35	0.04		
Sillimanite				0.12			
Kyanite				0.02			
Cordierite				0.05			
Sphene	0.5		(1- 2)	0.11			
Carbonate	0.3		(1- 3)	0.06			
Sulfides	1.2		opaques(1- 2)	0.02			
Oxides	1.8			0.79			
Accessories	1.2			0.17	0.77	0.73	0.35
	Foot Bay Gneiss	Foot Bay Gneiss	Type 'O' Granite	Deformed Gneisses	Granite Gneisses	Porphyrocl. Granite	Biot-Musc-Granite

and thought to represent the typical rock-type as defined by Tremblay (1968) is presented in Table 1. As may be seen the Foot Bay Gneiss is characterized by microcline and plagioclase, both in almost equal proportions, and by a lesser amount of quartz. Thus the rock approaches a melanocratic adamellite. The dark minerals of the Foot Bay Gneiss include hornblende, garnets and epidote. Accordingly, the rock may best be termed a mylonitic and brecciated biotite ± garnet ± hornblende microcline-plagioclase gneiss. Comparison of the average values of Table 1 with those published by Tremblay, Beck, Godfrey and Watanabe and by Burwash and Krupička (see Table 2) indicates that they approach those published for the deformed basement gneisses belonging to the Athabasca mobile zone (Burwash and Krupička, 1969) or they agree with those reported by Godfrey and Watanabe (1963) for some granitic gneisses of the NE corner of Alberta.

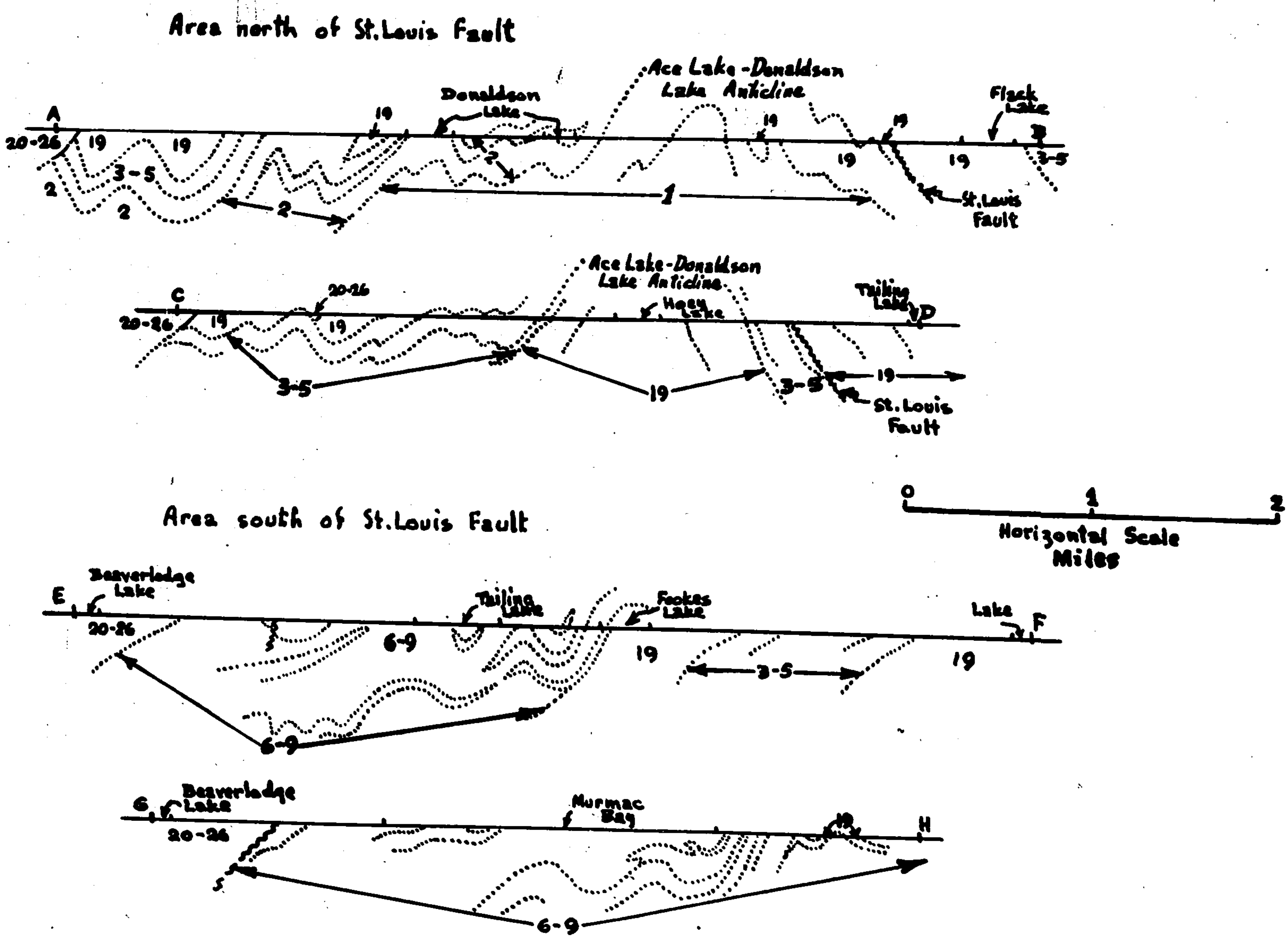
2. Middle Tazin Group (The Donaldson Lake Gneiss)

a) Previous Studies

Stratigraphically above the Foot Bay Gneiss and structurally intimately associated with it is a younger stratigraphic unit called by Tremblay (1968) 'Donaldson Lake Gneiss' (Plate I, 2). This puzzling and controversial unit, well exposed between the Donaldson Lake and Mickey Lake (along the HAB road), was first described by Tremblay in 1968 and was thought to form the W flank of the Donaldson Lake antiform. It was never recognized on the eastern flank around Hoey Lake or along the foot wall of the St. Louis Fault where it was generally mapped as a younger unit called 'metasomatic granite' (map unit 19, Tremblay, 1968), (Fig. 11). According to Tremblay (1968, p. 155) this unit outcrops in several areas both N and S of the St. Louis Fault and was thought to be composed of several different types of granites all derived by granitization of pre-existing rocks. Quartzo-feldspathic gneisses and quartzitic rocks, containing up to 15% mafic minerals and banded gneisses, locally massive and generally white to greenish grey, were also described by Tremblay in the preliminary maps published in 1954 and 1955. These rocks were found to occur in several areas around the St. Louis Fault, S and W of Fish Lake, N of Fookes Lake and W of Yahyah Lake. Similar rocks, mainly 'metasomatic granite' (map unit 5, Tremblay, 1954 and 1955), generally red, massive and cut by few pegmatite dykes and sills, were also mapped by Tremblay between Collier Lake and Flack Lake. To further complicate the picture, the terms 'alaskite' and 'leucocratic gneiss' were applied to certain quartzo-feldspathic gneisses, mylonite gneisses and associated rocks by several geologists working for Eldorado Nuclear Ltd. during the years 1950-1960.

Edie (1951) preferred the term 'alaskite' for cataclastic salmon-pink granitoid rocks containing less than 2 per cent ferromagnesian minerals outcropping on the Eagle-Ato-Mic claims. Campbell (1957) used the term 'alaskitic gneiss' for fine to coarse crystalline aggregates of red oligoclase

Fig. 11. Geological cross sections showing the Donaldson Lake antiform, after Tremblay (1968). The numbers shown correspond to those map-units described in Tremblay's memoir.


Area north of St. Louis Fault
A
B
20-26
19
3-5
2
1
14
Donaldson Lake
Ace Lake-Donaldson Lake Anticline
Flack Lake
St. Louis Fault
C
D
Hoey Lake
Tailing Lake
Area south of St. Louis Fault
E
F
Beaverlodge Lake
Tailing Lake
Fookes Lake
Lake
6-9
G
H
Murmac Bay
0
Horizontal Scale
Miles

and white quartz with minor ferromagnesian minerals. Trigg (1964) included under the term 'mylonite gneiss' a group of predominantly quartzo-feldspathic rocks characterized by mylonitic fabrics. He also stated that the mylonite gneisses occurring in the Verna Mine did not fulfill the fourth requirement of Spurr's original definition of 'alaskite' (1900, p. 230) since they were deficient in silica and richer in lime than the average of Spurr's analyses. He also stated that the majority of the gneisses occurring in the Verna Mine were granitic rather than alaskitic in composition. Finally 'leucocratic gneisses' containing less than 15 per cent mafic minerals and showing crude foliation were recognized by Burwash (1965) between Yahyah Lake and Rags Lake. According to Tremblay's definition (1968) the 'Donaldson Lake Gneiss' is white to rusty-brown, generally coarse grained, locally layered; it is made up of two distinct rock types corresponding to a white granite gneiss and to a rusty quartzo-feldspathic biotite gneiss. Of the two rocks the layered, coarse-grained and granitoid rock of quartz-monzonitic composition is the most abundant. The rusty-brown granoblastic gneiss was considered to be hypidiomorphic-granular, made up of anhedral to euhedral plagioclases scattered in a mass of irregular grains of interstitial quartz and microcline. The distribution of plagioclases also suggested to Tremblay that they formed earlier than microcline and quartz.

b) Present Studies

On the basis of field studies done in the Fay and Verna Mines and on surface, and in the light of petrographic evidence, it is the author's opinion that the rocks outcropping in the foot wall and hanging wall of the St. Louis Fault (Plate I, 2) around Hoey Lake, NE of Eldorado campsite, N and W of Ace Lake, E and NE of Emar Lake, between Collier Lake and Flack Lake and in the area N of the Basca Fault and W of Yahyah Lake, are the cataclastic equivalents of the Donaldson Lake Gneiss (Fig. 8). Thus the gneissic rocks outcropping on the crest of the Donaldson Lake antiform (around Hoey Lake) are thought to submerge towards SE until they reach the foot wall of the St. Louis Fault (in the Fay Mine sector) where they form part of the intensely deformed southeastern flank of the Donaldson Lake antiform. The Donaldson Lake Gneiss (although not recognized as such by the geologists working for Eldorado Nuclear Ltd.) was first encountered in the 8th Level (Fay Mine) and is well exposed in the Fay shaft where it was found to be in contact with the Foot Bay Gneiss (Fig. 13). On section 22 + 00 W (Fig. 14), the Donaldson Lake Gneiss, previously termed 'mylonite gneiss', 'quartz-feldspar gneiss' or 'banded chloritic-feldspar gneiss', reaches a minimum depth of about 4000 feet. The Donaldson Lake Gneiss occurs also in the hanging wall of the Verna orebodies, that is, in the foot wall of the Basca Fault where it is in contact with the upper metasedimentary sequence outcropping E of the Verna Lake. It is also present in the hanging wall of the Fay Mine, where it underlies a sequence of metasedimentary rocks called by Tremblay 'Murmac Bay Formation' (Tremblay's map units 6 to 9, 1968).

In the Fay Mine sector, the Donaldson Lake Gneiss is generally white to greenish-black or light greenish grey, granitic looking, generally roughly layered or locally massive, medium to coarse grained, interbedded with irregular and elongated masses of amphibolites generally parallel to the foliation (Plate II, 3). It is also composed of a reddish brown to red orange granitic gneiss which displays alternating bands or layers of quartz, feldspar and mafic materials. As noted by Tremblay (1968) this rock is more finely gneissic than the preceding one.

According to present work, the Donaldson Lake Gneiss has a general granoblastic texture becoming slightly porphyroclastic or porphyroblastic towards the St. Louis Fault (Plate VI, 2). This texture is due to anhedral to subhedral grains of albite or albite-oligoclase and rare microcline, scattered in a mass of smaller irregular grains of interstitial quartz, crushed plagioclases and micaceous minerals. The grains range in size from fractions of a millimeter to 4 - 6 mm in diameter; they are usually rounded or elongated with irregular and sutured edges. Plagioclases have bent and deformed twinning lamellae; locally some red stained grains show good poikiloblastic textures with quartz and biotite inclusions. Generally the amount of microcline is low and in some thin sections is absent. Where it is present it develops at the expense of more altered feldspars. Quartz is generally interstitial to other minerals or groups along bands or ribbons surrounding the plagioclase grains. In some instances it is rolled out or completely granulated. Biotite is well developed and occurs in the form of lepidoblastic flakes generally bent or broken. It is altered to penninite. Muscovite is found in protected areas where it develops in large flakes. In some areas biotite has broken down to sphene and opaques. Chlorite is well developed at the expense of the micas and is found associated with sphene, hematite and pyrite. Magnetite, zircon and apatite are also present. Calcite and anhydrite and rarely fluorite veinlets cut the rock in all directions. In some thin sections, newly crystallized panidiomorphic microlites of plagioclase (albite) scattered in a quartz-feldspar hematitic matrix were noticed. In places myrmekitic textures are visible.

It is important to recall that Trigg (1964), describing in detail the petrographic characteristics of several 'porphyroclastic mylonite gneisses' collected in the Verna Mine, stated that K-feldspar is present in only minor amounts and is usually perthitic (string or rod type) (Table 3).

As suggested by Tremblay (1968) the Donaldson Lake Gneiss is not necessarily homogeneous in character: it may be interlayered with thick, irregular lenses or bodies of well crystallized amphibolite or chlorite-amphibole gneisses. According to Edie (1952) the plagioclase amphibolite present in the Eagle-Ato-Mic Claims was completely crushed and recrystallized. On the other hand similar rocks dark-green in color, with hornblende, sericite epidote, calcite and minor amounts of K-feldspar, chlorite, sphene, apatite and leucoxene showed a complete lack of deformation. He also stated that the contacts between the amphibolites and the 'porphyroclastic mylonite gneisses' were sharp, conformable, often faulted and healed by calcite. At the contact narrow lenses of granitic material were lying parallel to the foliation or were cutting the rock at steep angles.

According to the present investigation the amphibolitic lenses or irregular bodies contained within the Donaldson Lake Gneiss are granoblastic or lepidoblastic in texture due to large and elongated prismatic crystals of hornblende set in a highly altered, fine grained quartzo-feldspathic matrix. Hornblende is usually poikilitic with large inclusions of quartz and altered biotite. Plagioclase is strongly sericitized and in certain instances may show undulatory extinction. It does not show twinning lamellae: only in one instance was it possible to recognize polysynthetic lamellae strongly masked by alteration. Biotite is apparently optically oriented and is undergoing 'bleaching processes'. Large rods of apatite, grains of epidote, hematite and calcite are also present. They usually occur in veinlets or patches filling the interstices between the grains. According to Tremblay (1968) the amphibolitic bodies occur preferentially at the nose of tight folds or in zones of intense deformation, in which case they develop a strong gneissic texture. The amphibolites are not the only rock-type associated with the Donaldson Lake Gneiss: commonly it is possible to note thin red-brown, medium grained conformable 'endemic' pegmatitic sills (Plate I, 2) which are older than the red to red-orange coarse grained pegmatite dykes found to cut discordantly both the Foot Bay and the Donaldson Lake Gneisses (Plate I, 4), (Fay-Winze shaft, 23rd, 24th and 25th Levels). In the Fay Mine sector these pegmatites, although not seen to cut the upper units of the Fay Mine Complex, represent the latest granitoid rocks to have crystallized, thus they will be described separately.

Composition of the Donaldson Lake Gneiss

The average mineral composition of the Donaldson Lake Gneiss derived from seven thin sections is presented in Table 3.

The data reported indicate that the Donaldson Lake Gneiss has a large amount of plagioclase and quartz and a lesser amount of microcline. The rock lacks hornblende and garnet but is rich in muscovite (this mineral cannot be considered diagnostic as it occurs in samples of Foot Bay Gneiss). The rock approaches a granodiorite, not a quartz monzonite as stated by Tremblay (1968). The averages reported are similar to those found by Trigg for some 'porphyroclastic mylonitic gneisses' collected S of the Verna Mine and to those of Edie for samples of 'albite alaskite' and 'gneissic granodiorite' collected in the Ace Mine and on Emar Lake. The average values agree with those reported by Froese (1955) for some 'oligoclase gneisses' outcropping around Moran Lake (41% oligoclase and

Table 3 - Modal Analyses of the Donaldson Lake Gneiss (Fay Mine)

Thin Section No.	FW-23-1	FW-23-2	SU-1	SU-3	F-25-014	F-25-016	F-25-019	Average
Quartz	38.6	39.3	35.4	34.3	39.2	38.7	35.5	37.3
Microcline	3.4	3.6	5.1	4.3	11.6	12.3	0.9	5.9
Plagioclase	40.4	43.8	47.2	44.2	34.1	40.9	47.3	42.5
Biotite	4.1	4.9	5.2	1.0	3.2	2.2	4.0	3.5
Muscovite	0.4	0.6	1.5	6.3	6.2	-	0.4	2.2
Chlorite	3.7	1.5	1.0	3.6	0.8	1.9	4.9	2.5
Calcite	0.4	0.7	-	0.1	0.2	-	1.5	0.4
Epidote	2.1	0.9	1.0	0.9	0.7	0.8	0.9	1.0
Apatite	0.4	0.3	0.4	0.6	0.4	0.3	0.8	0.5
Sphene	1.3	0.6	0.4	1.1	0.6	0.7	0.7	0.7
Zircon	0.6	0.7	0.5	0.6	0.5	0.5	0.5	0.6
Anhydrite	1.8	1.3	-	-	0.4	-	-	0.5
Sulfides	2.1	0.6	1.0	0.8	0.9	0.5	0.9	1.0
Oxides	0.7	1.2	1.3	2.2	1.1	1.2	1.7	1.3
No. of Points	1206	1216	1218	1214	1223	1236	1215	1218

Table 4 - Average Mode of the Donaldson Lake Gneiss Compared with the Values Reported by Tremblay, Edie, Trigg and Burwash & Krupička

	Fay Mine	Tremblay, 1968 (Beaverlodge Area)	Edie, 1952 (Ace Mine)	Edie, 1952 (Emar Claims)	Trigg, 1963 (S of Verna Mine)	Trigg, 1963 (Collier Lake)	Burwash & Krupička 1969 (Athabasca Zone)
Quartz	37.3	34 (20-54)	30.4	36.8	34.7	30.9	23.38
K-Feldspar	5.9	32 (18-44)			about 5%	about 5%	11.91
Plagioclase	42.5	27 (19-48)	57.6	32.9*	47.6**	36.8**	32.21
Biotite	3.5	7 others	11.9 others	16.9			11.83
Hornblende							12.62
Pyroxene							0.16
Muscovite	2.2						2.69
Chlorite	2.5			6.1	10.3	17.6	1.65
Epidote	1.0			4.2			0.36
Garnet							0.27
Sillimanite							0.22
Kyanite							
Cordierite							0.88
Sphene	0.7						0.48
Carbonate	0.4				1.7	0.9	0.47
Sulfides	1.0				0.6 opaqu.	2.7 opaqu.	0.23
Oxides	1.3			1.6		0.8	0.57
Accessories	1.7			1.6			0.07
	Donaldson Lake Gneiss	Donaldson Lake Gneiss	Albite Alaskite (in Tremblay)	Gneissic Granodiorite	Porphyroclastic Mylonite Gneiss	Porphyroclastic Mylonite Gneiss	Undeformed Gneisses

* The value reported is the sum of albite and sericite

** The value reported is the sum of plagioclase and sericite less 5% of K-feldspar sericite, 10% microcline, 30% quartz, 8% biotite, 6% chlorite, 5% calcite and some zircon, apatite, sphene and pyrite). It is therefore the author's opinion that the Donaldson Lake Gneiss collected in the Fay Mine is best described as a cataclastic biotite ± muscovite ± plagioclase gneiss.

3. Upper Tazin Group (The Fay Mine Complex)

Introduction

In the original studies regarding the Beaverlodge area, the meta-sedimentary sequence named by the author 'Fay Mine Complex', was either not recognized as such or was mapped as an undifferentiated part of the Tazin Group.

This complex which acts as host for the uraniferous mineralization of the Ace-Fay Mines is well exposed in the Verna Mine (Trigg, 1964), between the S shore of Ace Lake and the Eldorado campsite or between Tom Lake and Eagle Lake (Edie, 1952). It also corresponds to Tremblay's map unit 3-5 and 19b and has strong similarities with the 'Murmac Bay Formation (Tremblay's map unit 6-9, 1968) outcropping between Ace Creek and Fulton Lake.

In the investigated area, the Fay Mine Complex consists of strongly deformed albite paraschists and paragneisses, calc-silicate rocks, phyllonitic and epidote-amphibolite, metavolcanics and metasedimentary rocks, which occupy the upper part of the Tazin stratigraphy since they appear to rest (unconformably?) on the Donaldson Lake Gneiss. Field evidence, based on underground workings (Fay Mine) demonstrate that the Fay Mine Complex may be divided into four major mappable units:

UNIT IV .	Granitic Gneiss (Youngest)
UNIT III .	Albite Paragneisses and Paraschists and Minor Quartzite
UNIT II .	Schistose Epidote and Phyllonitic Amphibolite
UNIT I .	Calc-silicate Rocks, Quartzite and Conglomerate (Oldest)

UNIT I . <u>Calc-silicate Rocks, Quartzite and Conglomerate (Oldest)</u>

a) Previous Studies

Tyrrell (1895) describing some rocks outcropping between Lake Athabasca and Thluicho Lake, reported brown thinly foliated ferruginous chlorite schists associated with coarse conglomerate displaying rounded pebbles and sparse chloritic matrix. Camsell (1916), mapping the Thekulthili Lake area, encountered a squeezed and almost schistose conglomerate containing flattened quartz pebbles. He also noted along the shore of Hill Island Lake bluish limestones interbedded with calcareous 'slates' and 'phyllites'. Occasionally they were intermixed with narrow bands of ferruginous mica schists. Alcock (1936) describing the 'Beaverlodge Series' reported quartzites characterized at the base by conglomerate. Along the NW side of the ridge situated NE of the head of Elliot Bay, the conglomerate was thought to rest unconformably on a complex of ellipsoidal greenstones and was seen to pass laterally into white and reddish quartzite. Immediately above, the rocks were well bedded. Alcock also stated that unconformable relationships between quartzite and Tazin gneisses could be observed at two places: about a mile SW of the camp of Consolidated Mining and Smelting Company of Canada Ltd. and E of the mouth of Fish Hook Bay. Here he noted red and bluish quartzitic beds containing hematite in such considerable amounts that the rocks were thought to be 'iron formations'. At Langley Bay Alcock found white quartzite intruded by amphibolite; above the quartzite he reported a zone of reddish arkose thought to belong to the 'Athabasca Series'. Christie (1953) grouping Alcock's Tazin Group with the 'Beaverlodge Series', stated that no mappable unconformity was present although he admitted that some conglomeratic layers could be seen within the Tazin Group. He also stated that until an indisputable unconformity was located in the area, the Tazin metamorphics should be regarded as a conformable series. Describing the quartzites, Christie (1953) noted that they were very common near the Goldfields region and around Milliken Lake. In such areas the rocks were seen to grade laterally to arkosic quartzite and 'greywacke'. Massive quartzite with minor amounts of dolomitic material or 'chlorite schists, biotite schists and amphibolites' were also present. Describing the 'ferruginous quartzites', Christie (1953) noted that they were brecciated and recemented by quartz and hematite. In the Fish Hook area, the ferruginous members were found to be interbedded with 'normal quartzite, dolomite rocks and schists'.

Dudar (1960) studying the Tazin rocks occurring in the Verna environs, reported quartzite and metaconglomeratic layers conformable with cherty quartzite. They were cut by pegmatite and aplite dykes.

Trigg (1964) named 'siliceous mylonite' a group of rocks outcropping near the Radiore Fault (E of Verna Lake) and displaying sharp contacts with the so-called 'phyllonitic amphibolite'. Tremblay (1968), describing map unit 3, stated that it is composed by two rock-types (quartzite and chlorite schist) which overlie and closely follow the upper contact of the Donaldson Lake Gneiss. North of the St. Louis Fault, Tremblay's map unit 3 is represented by thinly bedded quartzite and schists (Ace shaft) and by thick masses of quartzitic rocks and 'granitized schists' outcropping NW of Verna Lake or W of Flack Lake. South of the fault map unit 3 was thought to be represented by a wide belt of quartzitic rocks interbedded with hornblende schists and 'argillites' (E of Verna Lake and Flack Lake). Describing the Murmac Bay Formation exposed S of the Yahyah Fault, Tremblay stated that it overlies conformably the succession outcropping N of the St. Louis Fault (map unit 3-5) and is characterized by such rock-types as white quartzite, 'limestones', 'massive garnetiferous quartz-biotite schists and hornblende-bearing rocks'. According to his studies the rocks of this formation were not heavily granitized since they were seen to pass laterally to 'greywacke' and to rusty-brown quartz-biotite schists. In one location, on the S shore of Murmac Bay, a quartz-pebble conglomerate, interbedded with quartzite and narrow lenses of chlorite schist was reported. Describing map unit 15a, Tremblay (1968) reported the presence of an 'uncommon bluish-white, glassy quartzite, thinly bedded or massive' which was thought to grade into white granitoid layers belonging to the Donaldson Lake Gneiss unit.

b) Present Studies

Field evidence indicates that white and bluish quartzites are exposed in the Fay and Verna Mines where they constitute the lower part of the Fay Mine Complex (Plate II, 6). The quartzite forms irregular layers which are stratigraphically above the Donaldson Lake Gneiss. They are followed upwards by the upper units of the Fay Mine Complex and are characterized at the base by an irregular horizon (several feet thick) of basal quartz-pebble conglomerate or by ferruginous quartzite and breccia in which large angular fragments and pebbles are seen to be cemented by an hematitic matrix (Plate II, 4). This horizon, encountered in several D.D. holes drilled in the foot wall of the St. Louis Fault, apparently is in sharp contact with strongly deformed and folded gneisses and amphibolites belonging to the Donaldson Lake Gneiss unit (Plate II, 5). It grades upwards towards thinly bedded bluish or yellowish quartzites. Quartzite intermixed with diopside and tremolite calc-silicate rocks or interfingering with lenses of schistose epidote amphibolite and metavolcanics, occurs also along the foot wall of the St. Louis Fault (sections 40 +00 W and 22 +00 W). Close examinations of sections 40 +00 E and 48 +00 E (Fig. 15 and 16) also indicate that an irregular folded belt of quartzitic rocks forms the crest and southwestern limb of a major fold (Trigg's Verna anticline, 1964). The same layer of quartzite also occurs in the foot wall of the Verna orebodies where it constitutes the northeastern limb of the same structure.

In thin section the quartzites are cataclastic and locally granoblastic due to the presence of fine to medium grained quartz and feldspar grains, which are usually stained by a fine hematitic dust. They show interlocking and sutured edges and mortar texture. In places the rock is mylonitized with strained quartz grains showing undulatory extinction. Larger grains of microcline, chessboard albite, perthite and quartz are elliptical or subrounded with edges rimmed by small microlites of chlorite and epidote grains. Secondary albite may be present as irregular veinlets cutting the bedding at various angles. Secondary quartz fringes or encloses feldspar grains which are in places stretched out, elongated or sheared. Plagioclases when present, show strong deformation of the twinning lamellae. Commonly some rotation of the grains is discernible. The rock may be very feldspathic or transitional to a quartzo-feldspathic gneiss. It may be interbedded with calc-silicate rocks. In general this transition occurs more frequently in the hanging wall of the Verna orebodies, where thin layers of the so-called 'carbonate rocks' are seen to occur at the nose of the antiform or along its southwestern limb (Fig. 16). It is noteworthy that quartzites exposed in the Fay Mine are intersected by small red to pink pegmatite dykes which may correspond to those dykes seen by Tremblay to cut quartzitic rocks belonging to the Murmac Bay Formation or to those pegmatites found by Dudar to cut impure cherty quartzite of the Eagle area.

In conclusion, it is apparent that the typical quartzites outcropping N of the St. Louis Fault have numerous affinities with those belonging to the Murmac Bay Formation. The only difference is probably due to the different degree of deformation and granitization. The tendency of both rock-types to grade upwards towards similar lithologies cannot be considered purely accidental: the similarities between the basal part of the Murmac Bay Formation and the lower unit of the Fay Mine Complex are too strong to be ignored, thus it is the author's opinion that the Murmac Bay Formation and the Fay Mine Complex are the lateral equivalent of one another. This conclusion is substantiated by new underground exploratory work in the Fay Mine, where long D.D. holes have encountered typical quartzites, ferruginous quartzites and ferruginous quartz-pebble conglomerates in zones where Tremblay found rocks belonging to the Murmac Bay Formation (his map unit 6). Since these rocks, outcropping in the foot wall of the Ace Creek Fault, can be traced underground where they underlie schistose units and deformed granitic gneisses (Units III and IV of the Fay Mine Complex) before being covered unconformably by the sediments of the Martin Formation (Fig. 8 and section 64 +00 W, Fay Mine), it is the author's opinion that they provide the necessary link which permits the correlation between the quartzites of the Murmac Bay Formation and the more deformed quartzites situated at the base of the Fay Mine Complex. The present author also believes that the irregular layers of ferruginous conglomerates and breccias, which are conformable with the Donaldson Lake Gneiss, do not necessarily exclude the former existence of a minor unconformity in the Tazin Group; on the contrary it is very probable that the unconformity was obscured by the strong deformation which rendered all the Tazin rocks almost conformable to one another.

UNIT II .. Schistose Epidote-and Phyllonitic-Amphibolite

a) Previous Studies

Stratigraphically above Unit I, but locally alternating with younger units of the Fay Mine Complex, is Unit II. It is mainly composed of schistose epidote amphibolite, phyllonitic amphibolite and metavolcanic rocks. The unit may include schistose rocks which have been described as 'argillites' or 'slates' (Tremblay, 1968).

Unit II, well exposed in the Fay and Verna Mines, W and E of the

Verna shaft, S of Flack Lake, in the Nesbitt synform, around Eagle Lake and Mickey Lake, constitutes one of the best marker horizons of the area examined.

Smith (1952), studying some outcrops around Tam Lake, reported fine grained epidote-chlorite schists overlying conformably flat-lying quartzites and 'slates'. Edie (1952), working on the Eagle-Ato-Mic Claims reported large outcrops of 'slates'. Dudar (1960) stated that the chloritic rocks occurring in the Verna Mine preserved sedimentary structures and bedding since the degree of metamorphism did not exceed the greenschist facies. Trigg (1964), describing the rocks exposed within the wedge-shaped area created by the Radiore and St. Louis Faults and by the S shore of Collier Lake, reported that they are generally 'phyllonitic' and locally intercalated with 'siliceous mylonites' almost conformable with the foliation. In places he found layers of the so-called 'mylonitic mica schist' passing to 'phyllonitic amphibolite' over a distance of a few feet. Speculating on the origin of the metavolcanic rocks outcropping in the Verna Mine sector he postulated that they were probably derived from tholeiitic basalts. He also considered the fabrics found in thin section as the result of mechanical degradation whilst the pseudo-beddings noted in certain rocks were thought to be the result of regional metamorphism.

Tremblay (1968), describing his map unit 4, recognized that 'slate and argillites' were locally related to rock-types belonging to his map unit 3. According to him, these rocks occur most abundantly between Mickey Lake and the ABC Fault, along the St. Louis Fault, between the Ace Lake and the

Eldorado campsite and E of Verna Lake. In particular his map unit 4 was thought to form a large arch on both sides of the axial trace of the Donaldson Lake antiform. In the area S of the St. Louis Fault, this unit was represented by large masses and bodies of hornblende schist (SW of Collier Lake and S of Flack Lake).

South of Fish Lake unit 4 was not recognized by the writer; in this locality, well crystallized amphibolites were associated with hornblende-microcline gneisses belonging to the Foot Bay Gneiss unit (Fig. 8). According to Burwash (1965), the so-called 'greenschists' posed certain problems in mapping as they were of variable mineralogy and texture and apparently of different origin. All of them were thought to be the product of retrogressive metamorphism of mafic-rich rocks. They were also thought to be spatially related to faults.

b) Present Studies

In the Fay Mine, dark-green to pistachio-green epidotic rocks termed 'schistose epidote amphibolite and phyllonitic amphibolite' constitute a distinctive marker horizon characterized by its color, appearance and intimate association with younger units of the Fay Mine Complex. The stratigraphic position of these rocks is unequivocal as they lie above the quartzites of Unit I. In the Fay Mine, these epidotic rocks have been mapped separately from the more massive and well crystallized amphibolites belonging to the Donaldson Lake and Foot Bay Gneisses. It was felt that although both rocks may have similar composition, they are definitely situated in different stratigraphical horizons and thus should be mapped separately (Fig. 8). In the field, rocks belonging to Unit II are intersected by a strong network of veinlets of white calcite, pink feldspar and quartz. Epidote occurs as fracture fillings cross-cutting the rock; locally it is very abundant. Chlorite, hematite and euhedral crystals of pyrite occur preferentially along fractures. In places granitic lenses, up to 10 feet in length, lie conformably with the foliation. Unit II occurs both in the hanging wall and foot wall of the St. Louis Fault where it is the host for the uraniferous mineralization. In general pitchblende veinlets parallel the foliation or they occur at the contact between schistose epidote amphibolite and quartzite. Locally uraniferous veinlets may intersect the rocks belonging to Unit II but they do not show great lateral extent or even pinch-out over a distance of a few feet. The grade of the ore is generally low. Commonly the epidote amphibolite grades upwards or is intermixed with albite para-gneisses and paraschists belonging to Unit III.

Field evidence corroborated by numerous D.D. holes drilled in the hanging wall of the St. Louis Fault indicate that the schistose epidote amphibolite and phyllonitic amphibolite unit is quite thick in the hanging wall of the Verna orebodies but seems to be stretched along the northwestern limb of the Verna folded structure (Figs. 15 and 16). In thin section the rock shows perfect lamination (Plate VII, 8). It is composed of dark to light alternating bands of submicroscopic sericitic grains by miniporphyroclasts-porphyroblasts of feldspar and by crushed and altered garnets. Miniblasts (Plate VI, 3) of chlorite are scattered in the darker bands. In other thin sections the appearance of the rock is cataclastic with strong affinities to deformed basic metavolcanic rocks and metatuffites. In several locations the rock passes laterally into mylonitic chlorite-muscovite gneisses or to mylonitic feldspar-rich chlorite-muscovite paraschists. Petrographic and field evidence also indicate that, in the Fay Mine, Unit II may occur interbedded with bands (up to 20-30 feet thick) of whitish and locally hematite-stained, fractured or massive quartzites, or with grey to dark-grey, fine grained and weakly foliated hornblende-plagioclase schists. In some locations it grades upwards to chlorite muscovite paraschists and feldspathic paragneisses which occasionally display lenses or ribbons of quartzitic material that resemble stretched-out pebbles. It is noteworthy that in certain locations, small lenses of calc-silicate rocks occur intermixed with Unit II. These layers are usually rich in uranium minerals and most frequently occur at the noses of tightly folded structures (Figs. 15 and 16).

UNIT III . Albite Paragneisses and Paraschists and Minor Quartzite

a) Previous Studies

Chlorite and muscovite albite paraschists and paragneisses locally intensely mylonitized, are the most common rock-types of Unit III. This unit belongs to the Fay Mine Complex and is stratigraphically located above

Unit II. The albite paraschists and paragneisses of the Fay Mine are of considerable economic importance for it is within them or at the contacts with upper and lower units of the Fay Mine Complex that the main uraniferous mineralization occurs.

Typical chlorite sericite schists composed of 30% chlorite, 30% sericite, 20% oligoclase and 10% quartz were found by Christie (1953) around Beaverlodge Lake. Another variety of these schists was composed of 45% chlorite, 35% sericitized oligoclase and lesser amounts of quartz and epidote. Since the schist was rich in andalusite, cordierite and garnet, Christie concluded that it probably was of sedimentary origin. Edie (1952) reported chlorite-sericite schists and garnet-muscovite schists in several localities of the Eagle-Ato-Mic area. According to him, microscopic studies demonstrated that these rocks were chiefly composed of chlorite, white mica and minor amounts of albite, quartz and epidote. Trigg (1964) noted 'mylonitic mica schists' in the core of the 'Verna anticline'. Speculating on the origin of the rock, he noted that the composition of the 'mylonitic mica schist' was comparable to an average greywacke rich in alumina. Several varieties of biotite schists and gneisses were seen to occur in numerous localities by Dudar (1960); they were rich in sillimanite, cordierite and andalusite.

Fine grained 'argillites' with 40% sericite, 30% chlorite, 10% quartz, 10% plagioclase and 10% clinozoisite were also found by Chamberlain (1958) in the Ace-Fay Mine. Tremblay (1968), describing his map unit 8 (Murmac

Bay Formation), stated that rocks such as 'argillites' and 'greywackes' usually occur interbedded with impure quartzites, hornblende schists and amphibolite. According to him the schists are locally bedded or layered and are rich in garnet, andalusite, cordierite, biotite and quartz. An 'argillite' very similar to that mapped as unit 4a, was seen to be interbedded with quartzitic rocks S of Ace Creek. Dirty-grey to light yellowish-green schists, interbedded with quartzites, were also reported by Tremblay (1968) in the region N and W of Mickey Lake. In thin section the foliation was thought to be indicated by zones of different mineral composition, by the alignment of the larger grains, and by the flakes of mica and chlorite. In many instances the larger grains had the appearance of fragments of clastic origin, deformed and partly recrystallized. Buff quartzite (Tremblay's map unit 5) and light-brown quartzite were also thought to be stratigraphically located above map unit 4 and locally directly above map unit 3. Some of the quartzitic lenses outcropping E of Fredette Lake were thought to be remnants of the original rocks after incomplete granitization. Lastly, he reported that relics of massive and brecciated quartzites outcropping in the 'red granitic region' SE of the Tazin Martin unconformity, had gradational contacts with the granite or they graded into it over a distance of a few feet and locally a few inches.

b) <u>Present Studies</u>

In the Fay Mine, field evidence supported by mineralogical and petrographical studies indicate that porphyroclastic-porphyroblastic biotite-chlorite-muscovite albite paragneisses and paraschists (Plate III, 1) or hematite-rich mylonitic garnet-chlorite-muscovite-albite paraschists transitional to quartzites occur in the foot wall of the St. Louis Fault where they reach a minimum depth of 4000 feet. These rocks, which constitute the main host-rock for the uranium mineralization, are also present in the Verna Mine, in the HAB Mine and in the region E of Eagle Lake. Stratigraphically they belong to the Fay Mine Complex (Unit III) and are seen to conformably overlie the schistose epidote amphibolites of Unit II. They may pass laterally or grade upwards to quartzitic layers or lenses which in turn are in contact with the intensely deformed granitic gneisses belonging to Unit IV. In the Verna Mine, Unit III constitutes the core of Trigg's 'Verna anticline' since it is in contact (above and below) with rocks belonging to Unit II (Figs. 15 and 16). Similar rocks, probably richer in 'metaquartz lenses' occur also in the foot wall of the St. Louis Fault (Verna sector) where they occupy the same stratigraphic position above Unit II. In one location (Fig. 13, section 40 +00 W, 19th and 21st Levels), Unit III is in sharp contact with Unit IV, being separated by a chloritic gouge zone (one foot thick) paralleling the plane of the St. Louis Fault.

In thin section the rock is mylonitic or blastomylonitic, with large red-stained porphyroclasts-porphyroblasts (4-5 mm in length) composed of albite or albite-oligoclase and minor K-feldspar that are surrounded by small quartz grains showing strong undulatory extinction. Generally the porphyroclasts of albite are replaced by fine grained quartz or they are intensely sericitized. Early feldspar grains show poikilitic textures or original twinning lamellae deformed by stress. They are crushed and recemented by a mylonitic matrix or by calcite (Plate VI, 1). In most cases micaceous alteration has developed along twinning planes. String, rod and patchy perthite and locally myrmekitic textures and chessboard albite are well developed. In some thin sections hematite veinlets or microfractures cut idioblasts of albite. Fresh subhedral flakes of muscovite, biotite and chlorite are disposed in ribbons or rim early feldspar grains. Locally the micas are bent, broken and offset. Locally biotite is bleached and rimmed by iron oxides. Chlorite usually fills microfractures cutting the foliation at 45°. In several instances fibrolite needles in semiradiating acicular aggregates are found offset by microfaults or occur as pseudo-nodules in a micaceous matrix. Thin section studies also indicated that the 'metaquartz lenses' found in schists exposed in the Verna Mine may have a sedimentary origin (Plate VII, 12). Commonly these quartz lenses showed thin alternating bands of quartz and red-stained feldspar perpendicular to the schistose and micaceous matrix surrounding them. In other locations the lamination of the quartz grain is strongly discordant with that of the schistose matrix (Plate V, 1). Pyrite, small grains of magnetite and iron oxides may also be present. Sphene, garnet and zircon constitute the accessory minerals. It is noteworthy that the paraschists and paragneisses belonging to Unit III may be conglomeratic since they contain ellipsoidal or 'egg-shaped' boulders (several feet in length) of red granitic gneisses or bluish quartzites, which belong to lower stratigraphic units (i.e. Donaldson Lake Gneiss and Unit I, Fay Mine Complex).

The upper contact of Unit III is generally characterized by elongated lenses of whitish and buff quartzites (not more than 40 feet thick) which may display sharp contacts with Unit IV. In other locations the contact is indicated by a decrease in muscovite and concomitant increase in quartz, in which case it is almost indistinguishable and so appears to be gradational. As mentioned before this unit has a notable economic importance since it carries most of the uranium ore found in the '09' zone (Fay Mine) for a lateral distance of ~800 feet to a depth of at least 4000 feet. It produces the richest ore mined in the Eldorado property.

UNIT IV . Granitic Gneisses (Youngest)

a) Previous Studies

Stratigraphically above Unit III, and occasionally separated by small lenses of white to buff quartzites, is a mylonitized red-orange to salmon-pink rock known as 'feldspar rock' or as 'orange porphyroclastic mylonite' to the geologists employed by Eldorado Nuclear Ltd. (Plate III, 2). This unit, which occupies the upper part of the Fay Mine Complex, is usually overlain unconformably by the basal conglomerate belonging to the Martin Formation. The rock was first described by Alcock (1936) as a mixture of gneisses which were thought to represent altered equivalents of the Tazin metamorphics. Red to pink, well foliated or almost massive granitic gneisses containing variable amounts of fragments of older rocks were found by Christie (1953) around the Goldfields-Martin Lake area. In particular Christie noted the presence of two types of granites: an older type, commonly gneissic with some ferromagnesian minerals, was distinguished from a younger albite granite associated with a pegmatitic phase. Smith (1952) recognized that in the Ace-Fay Mine the granite was intensely mylonitized and brecciated. An 'albite-alaskite' containing irregular bodies of milky quartzite and an 'uniform alaskite', locally passing to granitic gneiss and showing relict bedding, was noted by Edie (1952) in the Eagle-Ato-Mic area. Comparing the chemical analyses and the mineralogical composition of three samples collected in the Ace-Fay Mine, Eagle area and Ace Creek with those from Johannsen (1932), he found that the values were similar except of the percentage of Na and K.

Tremblay (1968), describing his map unit 19 (metasomatic granite), stated that at least five types of granite may be found in the field: 'normal granite, gneissic and foliated granite, impure hybrid granite, brecciated granite and carbonatized granite'. The 'normal granite' was thought to be the most common type; the 'gneissic and foliated granite' was thought to be abundant NW of the Black Bay Fault whilst large areas of 'carbonatized granite' were found in areas N of the St. Louis Fault. All these granites were believed to be derived by granitization of pre-existing rocks. In general the nature of the latter could be determined: for example, the granite outcropping around Eagle shaft was considered to be derived from the 'buff quartzite' (Tremblay's map unit 5) while the granite situated at the nose of the Donaldson Lake antiform, was thought to be developed from the quartzite-chlorite schists (Tremblay's map unit 3-5) outcropping near the Eldorado campsite. Describing the 'carbonatized granite', Tremblay mentioned that it was related to the 'normal granite' and to the 'brecciated granite' and was made up of red feldspar and calcite and minor amounts of chlorite and quartz. Regarding the 'brecciated granite', he stated that the rock was derived from all the other granites except the 'carbonatized granite'. In the Eagle shaft area he noted that the granite was in sharp contact with 'amphibolite, hornblende schist, chlorite schist and argillite'. Some contacts were thought to be fault planes. In particular the contact between the granite and hornblende schist occurring along the Power line to Eldorado, E of Tam Lake, was found to be sharp and dipping 65°SW. Here the granite was believed to overlie the 'argillite' and the 'hornblende schist' (Tremblay's map unit 4), the latter apparently having moved southwards down and underneath the granite. Describing the rock outcropping near the Eldorado campsite and N of the main road E of Padget Bay (Beaverlodge Lake), Tremblay (1968) noted that the rock was thinly layered and faintly gneissic, dense, cherty and probably represented a mylonite. He also mentioned that most of the granite mapped as unit 19b was brecciated and mylonitized. The rock contained many remnants of country rock, such as quartzite, amphibolite, chlorite schist and hornblende schist. In conclusion Tremblay (1968) stated:

> '....because of the gradations in composition, because of the mixtures, and because of the incipient granitization, particularly in rocks such as quartzite, it is believed that most of this granite area was once a normal sedimentary succession that has been differentially and selectively granitized ......
>
> In other words, rocks in this area, are almost the end product of the granitization of a sedimentary succession, the degree of granitization reached having varied with the nature of the original rock and probably also, to a certain extent, with the intensity of metasomatism and ease of circulation through the rock.'

b) Present Studies

Field evidence indicates that pinkish to red-orange deformed granitic gneisses are exposed on the surface in the immediate vicinity of the Ace shaft, NE of the Verna shaft and W of Flack Lake. Red-orange mylonitic granitic gneisses associated with uranium mineralization were mined underground in the upper levels of the Ace Mine. The same rock-type, fine to medium grained, well foliated and intensely mylonitized occur in the foot wall of the St. Louis Fault from section 100 + 00 W (Fay sector) to at least section 120 +00 E (Verna sector). In all these locations, the rocks belonging to Unit IV are stratigraphically above the albite paraschists and paragneisses of Unit III, and constitute the youngest unit of the Fay Mine

Complex. In general the mylonitic granitic gneiss form a discontinuous but persistent unit, spatially related with the '01' zone, which submerges along the plane of the St. Louis Fault to a minimum depth of 4000 feet. Occasionally the granitic gneiss is separated from the plane of the fault by the presence of large bodies (up to 300 feet thick) of basal conglomerate and conglomeratic arkose belonging to the Martin Formation (Plate III, 3 and 4). Underground, the contacts between the granitic gneisses and Unit III are either gradational, abrupt or fault-controlled in which case they are bordered by one foot of chloritic gouge (Figs. 13 and 14, 19th and 21st Levels, Fay Mine). Locally a thick chaotic zone of regolithic material set in a chloritic and amphibolitic matrix marks the contact (Plate IV, 6). In two places the writer observed gradational contacts but generally the relationships between the two rock-types are obscured by high-grade mineralization. Discontinuous bands of red-orange to salmon-pink, well foliated mylonitic gneiss, locally interbedded with fine grained quartzites, are exposed in the hanging wall of the St. Louis Fault, where they are in tectonic contact with rocks belonging to the Donaldson Lake Gneiss unit. Towards NW, Unit IV parallels a large lens (several hundred feet thick) of basal conglomerate interbedded with arkosic layers belonging to the Martin Formation (Figs. 15 and 16, 17th, 18th and 19th Levels). Medium grained porphyroclastic granitic gneisses were also encountered in D.D. holes drilled SE into the hanging wall of the St. Louis Fault from the upper levels of the Verna Mine (Figs. 15 and 16, Main Drift

No. 7 and Drift No. 9-32), in which case the granitic gneissic rocks parallel a long body of basal conglomerate with interbedded sills and flows of Martin amygdaloidal basalt. Towards the NW Unit IV is conformable with Unit II.

Mylonitic and brecciated granitic gneisses are also present in the hanging wall of the St. Louis Fault (Fay Mine sector) where they underlie those Martin rocks outcropping on the surface SW of the Fay Mine shaft (section 60 + 00 W). Unit IV is also well exposed on the 13th Level of the Fay Mine, about mine coordinate 80 +00 W.

Close to this location, a chaotic zone, developed between the St. Louis Fault and the extreme foot wall, trends west as the ABC Fault whilst the St. Louis Fault itself continues southwestwards through the Beaverlodge Lake. It is the author's opinion that it may represent the junction area of the ABC and the St. Louis Fault. If this assumption is correct, the ABC Fault is older than the St. Louis Fault since it was cut and offset by the latter (see 13th Level, Fay Mine).

Microscopic examination indicates that the granitic gneiss has a mylonitic texture, locally cataclastic or brecciated. Abundant pale pink fine to medium grained porphyroclasts of plagioclase (albite or albite-oligoclase) show strongly deformed twinning lamellae. They are usually surrounded by ribbons or threads of rolled-out quartz, locally intensely crushed and re-crystallized. In places myrmekitic textures are common and chessboard albite is also visible. Microcline, when present, shows good grid twinning, it is porphyroclastic and usually occurs in egg-shaped clasts generally larger than the plagioclases. Chlorite fills the interstices between grains; it has anomalous interference colors from deep blue to purple (penninite). Generally brownish to clear, rounded, elongated and well crystallized zircon is scattered with subangular apatite crystals. Garnet, pyrite, specularite, sericite and leucoxene constitute secondary minerals. Accessory iron oxides may locally be important. In general the rock is cut by hematite-healed fractures and abundant chalcedonic quartz and pink calcite veins. A network of veinlets of newly formed albite is also seen in thin sections. From the economic point of view this unit has a notable importance since it constitutes the so-called '01' zone which produced considerable tonnage of low grade uranium ore.

Discordant Pegmatite Dykes

a) Previous Studies

Sharp-walled pegmatites, mostly 5 feet wide and 200 feet long, were reported by Beck (1966) in the Beaverlodge district. According to him the pegmatites were seen to intrude all the granites of the area except the albite-rich variety.

Coarse grained pegmatites were found by Burwash (1965) cutting tabular bodies of amphibolite near Yahyah Lake.

Tremblay (1968) observed numerous pegmatite dykes and coarse grained granites around Yahyah Lake and E of Murmac Bay. He thought them to be younger than the so-called 'metasomatic granite' as they were cutting large areas of granitized rocks. These pegmatite dykes were thus considered to be the latest granitoid rocks to have crystallized in the area. Red pegmatites were reported by Trigg (1964), in the Verna area, and by several other workers in the region around Beatrice Lake, Inspiration Lake, N of the Edie Fault and NW of Beth Lake.

b) Present Studies

In the Fay and Verna Mines, white to red-orange or salmon-pink pegmatite dykes occur in the hanging wall of the St. Louis Fault about the position of the new internal Fay-Winze shaft at mine coordinate 2 + 00W -39 + 00 S or at mine coordinate 5 + 00E - 45 + 00 S on the 25th Level. They can be traced upwards to the 23rd Level (Plate I, 4).

Field evidence suggests that two types of pegmatites are present in the mine: the first, probably the oldest one, is always found to be conformable with the foliation of the related gneissic rocks. It is medium grained, containing large fractured and strained microcline grains, stained by hematite and veined by chlorite and calcite. It occurs as small conformable sills or lenses, fractured and brecciated, in the Foot Bay Gneiss, but is better developed in the Donaldson Lake Gneiss, where it assumes the characteristic appearance of pegmatites sweated-out during metamorphism (Plate I, 2). The second type, occurring as dykes 2 to 5 feet wide, locally up to 8 feet, coarse grained, sharp-walled, discordant to the foliation, may be considered the last granitoid to have crystallized in the area. In the hanging wall (25th Level, Fay-Verna Mines sector) the discordant pegmatite dykes metamorphosed rocks of the Foot Bay and the Donaldson Lake Gneisses. These pegmatites have not been observed to cut the upper units of the Fay Mine Complex or the Martin Formation. However, they do cut the quartzites belonging to Unit I (Plate II, 6) (25th Level, Fay Mine). The second type of pegmatites are strained to cataclastic and either hypidiomorphic or granoblastic due to large crystals of plagioclase set in a coarse grained aggregate of quartz and feldspar (Plate V, 4). The plagioclase shows bent twinning lamellae fractured and cemented by a slightly mylonitic matrix. It is albitic or oligoclasic in composition with exceptionally good chessboard textures. Microcline and perthite are also present and seem to be fresh and develop at the expense of the plagioclase. Muscovite is bent and biotite, when present, completely chloritized. Euhedral pyrite, large apatite, sphene and hematite constitute the accessory minerals. The contact with the country rock is generally sharp and marked by a thin metamorphosed rim of wall rock, half a foot wide, rich in poikiloblastic feldspar, recrystallized muscovite and wall rock fragments not completely assimilated. Field evidence suggests that these pegmatites are fracture fillings, locally rich in carbonate. They occur in faulted zones and are cut by major fractures. As already mentioned, the discordant pegmatite dykes are cut by younger, dark-green, slightly fractured diabase dykes and these, in turn, are offset by fresh, red-brown quartz-porphyry dykes.

B. THE MARTIN FORMATION

Introduction

This section is devoted to the general description, petrographic character and field relationships of the Martin rocks found underground in the Fay and Verna Mines. It is noteworthy to recall that only a reduced portion of the Martin sequence (as defined by Tremblay, 1968), is apparently present underground, thus if the reader is interested in the description of all the Martin rocks, he should consult Tremblay (1968).

The petrographic description of a few representative samples is presented in Appendix B.

Brief Summary of Past Literature

The name Martin Formation was first introduced by Fahrig (1961) for Christie's steeply dipping rocks outcropping on the W shore of Beaverlodge Lake and Martin Lake. The name 'Martin' was adopted becuase it had already been used by Gussow (1957, 1959) for the more deformed Athabasca rocks outcropping N of Lake Athabasca.

recognizes the following mappable units constituting the lower Martin Formation.

UNIT III . Amygdaloidal Basalt Sill

UNIT II . Conglomeratic Arkose and Siltstone

UNIT I . Basal Conglomerate and Breccia

UNIT I . <u>Basal Conglomerate and Breccia</u>

Tremblay (1968) reported that the basal conglomerate of the Martin Lake area is separated from the Tazin metamorphics by a major angular unconformity; however, in several places the two units appear to be gradational.

A pronounced unconformity between the Martin and the Tazin rocks was also recognized by Smith (1952), Trigg (1964) and by almost all the geologists working in the area. On surface, around the Fay Mine, the basal conglomerate occurs mainly in the hanging wall of the St. Louis Fault, SW of the Eldorado Mill. Underground, in the Fay sector, the basal conglomerate is in sharp contact with the deformed granitic gneiss belonging to Unit IV. In particular the contact is usually non-conformable ranging from a distinct break, marked by regolithic material set in a chloritic and amphibolitic matrix (Fraser et al., 1970), to an indistinct, locally brecciated and hematized transition zone which may be obscured by mineralization. Basal conglomerate grading into a breccia with chalcedonic quartz matrix or to a conglomeratic arkose rich in large red granitic fragments, is also found on the S shore of Ace

Lake and S of the Ace Creek Fault (Plate IV, 3). Furthermore, red to brown conglomeratic material intermixed with breccia and layers of brown arkose and siltstone is also found in the foot wall of the St. Louis Fault, behind the elementary school of the Eldorado campsite and the manager's house (Plate IV, 1,2).

Basal conglomerate also occurs underground in the foot wall of the St. Louis Fault, where apparently it lies in irregular lenses conformable with all the units belonging to the Fay Mine Complex (Plate I , 5; Figs. 13 and 14) (sections 40 +00W, 22 + 00W). In addition, it is found in several levels of the Verna-Winze Mine where it constitutes a large lens, several hundred feet wide, situated about mine coordinate 30 + 00E. In this location, easily accessible from the 18th and 19th Levels of the Verna-Winze shaft, the basal conglomerate passes laterally, into a conglomeratic arkose with trough type cross-bedding structures (Plate III, 5). At sections 40 + 00E and 48 + 00E the basal conglomerate occurs either in the foot wall or in the hanging wall of the St. Louis Fault in direct contact with the deformed granitic gneiss belonging to the upper unit of the Fay Mine Complex. It is interbedded either with conformable layers of red-brown arkose or with an amygdaloidal basaltic sill extending almost from the 4th Level to the 9th Level (Fig. 15, section 40 + 00E, 401 Drift, 501 Drift, 639 Drift, 7 Main Drift, 932 Drift, foot wall, Verna Mine).

In general the basal conglomerate is characterized by angular to sub-angular and rounded fragments of variable size, set in a fine grained chloritic, hematitic quartzo feldspathic matrix. The clasts are irregular in shape and are composed of different rock types derived directly from rocks of the Tazin Group. Large- to medium-sized fragments of the following rock-types were recognized: paragneisses and paraschists, ferruginous and feldspathic quartzite, Donaldson Lake Gneiss, Foot Bay Gneiss, red pegmatites, schistose-epidote amphibolite, phyllonitic amphibolite and amphibolite. The fragments are embedded in a matrix that is related to the rocks situated directly below the unconformity; in places the fragments are set in a penninite-rich and hematite-rich slightly epidotic arkosic matrix. Apatite, calcite, zircon, specularite, pyrite and sphene are visible in thin section. In general the basal conglomerate may also contain fragments of basement rocks with abraded to rounded corners, and large pebbles or boulders several feet in diameter. At one locality, on the 2-55 stope (Fay Mine), a 60-foot block composed of red granitic gneiss was found to be surrounded by pitchblende mineralization. In general, the basal conglomerate is weakly mineralized; it usually constitutes the so-called '55' zone or forms part of the '01' zone. In the Verna Mine (hanging wall) the conglomerate is poorly mineralized and thus was mined only in the upper levels (about 20 + 00 E, 9th and 11th Levels, Verna-Winze).

UNIT II. Conglomeratic Arkose and Siltstone

Chocolate-brown, fine-grained, hematized siltstone was mapped by Tremblay E of the Ace shaft, in the foot wall of the St. Louis Fault

(Plate IV, 4) (Tremblay's map-unit 21a, 1968). Arkose belonging to map-unit 22a, was also mapped by Tremblay on the S shore of Emar Lake, but was not recognized by the author. Thin layers of siltstone, interbedded with basal conglomerate and breccia are present in the foot wall of the St. Louis Fault behind the elementary school of the Eldorado campsite (Plate IV, 1 and 2).

Much of the arkose present in the Fay Mine and Verna Mine is either interbedded with siltstone or changes laterally to a conglomeratic arkose and finally to a well consolidated conglomerate. Generally the arkose is intimately associated with the basal conglomerate although stratigraphically it may occur above it.

It is present underground along the foot wall of the St. Louis Fault, where it constitutes an irregular band 10-20 feet wide, generally conformable with the units belonging to the Fay Mine Complex. The arkose occurs also in lenses interbedded with basal conglomerate, about mine coordinate 40 +00 E, where it extends approximately from the 17th to the 19th Levels (hanging wall, Verna Mine).

Thin section studies performed on samples collected in the foot wall of the fault, about mine coordinate 30 + 00 E (Verna-Winze), indicate that the texture of the rock is clastic due to the presence of detrital, sub-angular to sub-rounded grains of feldspar, plagioclase, perthite, microcline, chessboard albite and quartz set in a quartz feldspar matrix (Plate V, 5). Occasional lithic fragments, mainly composed of rocks belonging to the Tazin Group, were noted in thin section.

The arkose is composed of well sorted and closely packed grains showing interlocking or sutured margins generally surrounded by thin rims of hematite, chlorite or calcite. Epidote occurs as detrital grains. A variety of feldspar grains are present: both altered and fresh plagioclase and perthite. Rare volcanic feldspar was also noted. Quartz grains are usually cloudy and elongated or they constitute composite grains with sutured edges. Zircon, garnet, apatite, sphene, magnetite, rutile, specularite and pyrite are the accessory minerals.

Cross-bedding of trough type was noted and sampled (Plate III, 5) in the conglomeratic arkose occurring at mine coordinate 30 +00E (18th and 19th Level, Verna-Winze, foot wall).

UNIT III . <u>Amygdaloidal Basalt</u>

An amygdaloidal basaltic sill, extending from the 4th Level to approximately the 9th Level, was encountered in the foot wall (Fig. 15, section 40 +00E) during the early development of the upper levels of the Verna orebodies. The same sill was also encountered in several D.D. holes drilled SE through the plane of the St. Louis Fault, from the 501, 7, and 932 Drifts. The sill was apparently interbedded with basal Martin conglomerate and roughly paralleled the plane of the fault. It appeared to be cut by the fault, indicating that volcanic activity in the Martin area pre-dated the last movement on the St. Louis Fault. The rock was described as brown to reddish-brown, massive, fine to medium grained, commonly amygdaloidal and porphyritic. Another amygdaloidal basalt sill, dark brown to maroon with spotted pink and white feldspar laths in a fine grained matrix, showing medium to large amygdules of white to pink calcite, was also mapped 10 feet E of station 6048 (6394 Drift E, Verna Mine) and was sampled as specimen No. 84 by geologists working in the Verna Mine. The location being inaccessible for lack of ventilation, it was impossible for the author to obtain a sample of rock.

Diabase Dykes and Sills

As mentioned before, a swarm of slightly fractured, dark-green, fine grained and massive, diabase dykes and sills with sharp chilled margins cutting the Tazin metamorphics occur throughout the foot wall and the hanging wall of the St. Louis Fault. These rocks intersect most of the rocks belonging to the Tazin Group but apparently, in the Fay and Verna Mine, do not cut rocks of the Martin Formation. According to Tremblay (1968), they are very abundant in the area between the Boom Lake Fault and the Black Bay Fault. They are up to 150 feet wide but most of them are less than 10 feet thick, averaging about 6 feet. Apparently in the field they are distributed in an 'en echelon' pattern and generally dip vertically. In the Donaldson Lake region the dykes and sills trend southeasterly. They are diabases generally porphyritic and ophitic or sub-ophitic with medium to large laths of plagioclase embedded in a very fine grained matrix composed of chlorite locally pseudomorphic after pyroxene, feldspar, plagioclase and quartz (Plate V, 6). There is a clear bimodal size distribution of plagioclase laths and also two distinct generations of crystals: an older type that appears intensely saussuritized and a fresher, zoned with good Carlsbad twins. In rare cases it was possible to measure the extinction angles of some large crystals, generally indicating labradorite. The clinopyroxene is intensely altered to uralite and may be rimmed by hornblende or chlorite, probably due to deuteric or hydrothermal alteration (Tremblay, 1968). The plagioclase and the pyroxene occur both as phenocrysts and as groundmass minerals. The opaques occur as scattered crystals on the borders of larger minerals. Some larger crystals of pyroxene are poikilitic and twinned. The rock does not exhibit any deformation except for small micro-fractures and micro-joints that are filled with chlorite, iron oxides and locally epidote. Ilmenite and zircon are the accessory minerals.

In some other thin sections the optics of rounded smaller grains of plagioclase, with good Carlsbad twins indicate more sodic compositions probably due to a xenolithic origin or to late changes in the composition of the magma. Locally myrmekitic intergrowths are visible and they may be due to late reactions or contamination. It is the author's opinion that these dykes represent an intrusive phase at the end of or after the Hudsonian orogeny.

Quartz Porphyry Dykes

Greyish red to dusky red, undeformed, fine to medium grained, massive quartz porphyry dykes with wide chilled brown margins and cutting the diabase dykes were encountered in the foot wall of the St. Louis Fault about mine coordinate 40 +00W - 15 +00 S, almost at the contact between the Foot Bay Gneiss and the Donaldson Lake Gneiss.

In thin section they show a porphyritic texture with small phenocrysts of sanidine and oligoclase or albite-oligoclase embedded in a red-stained cryptocrystalline matrix. They are fine to medium grained with the phenocrysts ranging up to 8 mm in length; the grains are usually surrounded by iron oxides and locally by ilmenite or are grouped in clusters. In one thin section early plagioclase crystals are embedded in newly formed phenocrysts suggesting two periods of crystallization of the magma. Sanidine occurs in larger phenocrysts usually altered to sericite; quartz is rare and shows corroded margins lined by small chloritic flakes. Biotite is present in rare flakes and is altered to chlorite or to iron oxides. A faint spherulitic structure is apparent in places. Zircon, apatite, ilmenite and epidote are accessory minerals

Clearly these rocks represent the latest intrusion in the area - thus they may be considered post-orogenic.

CHAPTER 4 - MULTIPLE DEFORMATION OF THE TAZIN CRYSTALLINE ROCKS OCCURRING IN THE FAY MINE ENVIRONS

Introduction

Several geologists have commented on the metamorphism and the grade attained by the rocks present in the Beaverlodge area, and many of them studied the metamorphism of the rocks outcropping along the St. Louis Fault.

Christie (1953) suggested that regional metamorphism, in the area, reached the amphibolite facies although certain chloritic rocks, of lower metamorphic grade, were interpreted either as zones of retrograde metamorphism or as downfolded remnants of low grade rocks outcropping in a surrounding higher terrane. Trigg (1964) believed that the Verna chloritic- and phyllonitic-rocks once attained the amphibolite facies and have, since then, undergone retrogressive metamorphism. O'Nions (1967), in an internal report written for Eldorado Nuclear Ltd., on the rocks of the Beatrice Lake area, reported the following mineral assemblages:

(i) GARNET-SILLIMANITE-BIOTITE-QUARTZ-FELDSPAR, paragenesis believed to be diagnostic of the SILLIMANITE-ORTHOCLASE-ALMANDINE subfacies of the Almandine-

Amphibolite facies (Winkler, 1965)

(ii) CUMMINGTONITE-HORNBLENDE-ANDESINE, paragenesis believed to be diagnostic of the upper AMPHIBOLITE facies

(iii) CHLORITE-MUSCOVITE-ALBITE-BIOTITE, paragenesis believed to be diagnostic of the QUARTZ-EPIDOTE-BIOTITE subfacies of the Greenschist Facies.

O'Nions thought that two metamorphic episodes occurred prior to the deposition of the Martin Formation: the first producing the upper amphibolite facies assemblages, the second producing the retrograde metamorphism.

Burwash (1965), in a report prepared for Eldorado Nuclear Ltd., on the geology of the Prince Lake area, recognized that the rocks of the Beaverlodge area were affected by regional metamorphism of medium to high grade. He also believed that 'synkinematic metamorphism and intrusion' occurred before an 'early paracrystalline (syncrystalline) deformational phase' which was followed by 'late kinematic intrusions'. 'Late paracrystalline (syncrystalline) deformation' and 'post-crystalline deformation' completed the cycle.

Tremblay (1968) stated that all the rocks of the Tazin Group have been regionally metamorphosed and granitized, that is, they had been subjected to deep-seated processes involving recrystallization. Subsequently some of the rocks suffered strong repeated retrogressive metamorphism. They were thought porphyroclasts)

Degree 4 = ultramylonitic rocks (crushing of all minerals to a very fine-grained powder, common development of pseudotachylitic textures (Moorhouse, 1959, p. 413); both extremes of orientation; massive or with fluidal lamination, frequently exhibiting excellent mechanical mineral separation).

On the basis of this classification the average degree of deformation in the individual units of the stratigraphic sequence is as follows:

pegmatites: 1.7

granitic gneiss: 2.6

paraschists and paragneisses: 2.6

quartzite: 2

Donaldson Lake gneiss: 1.7

Foot Bay gneiss: 3

kakirites of the Foot Bay gneiss: 3.7

The highest average degree of deformation is thus in the lowermost unit, the Foot Bay gneiss. In the brecciated ultramylonites of this unit, the kakirites, the degree attains the extreme value of 3.7. Not a single grain of the original rock has remained unaffected.

The average intensity of dynamic deformation in the upper parts of the Tazin, although still high, is somewhat lower than in the Foot Bay gneiss.

But in each unit of the sequence (except the pegmatites) it is possible to note very strong to extreme deformation. Ultramylonites are found even in the uppermost member of the Fay Mine Complex. Amphibolites are generally less deformed because of their boudinage and shielding by the less competent gneissic environment which took the brunt of the movement, and also because of their higher capability for recrystallization. Watanabe (1965, p. 103) states that hornblende gneiss in the cataclasites of northeastern Alberta is markedly less deformed than the biotite gneiss.

The cross-cutting pegmatites, considered to be the youngest member of the crystalline rocks, are strained (deg. 1) and cataclastic (deg. 2). They are less deformed than the other rocks. They have been affected only by the later stages of deformation and, moreover, their relatively coarse grain made them more resistant to penetrative differential movement.

The grain size is a good indicator of the intensity of destructive deformation. Fine and ultrafine (0.01-0.001 mm) grain is characteristic of the crystalline rocks of the Tazin Group, except the pegmatites and some portions of the granitic gneiss (Unit IV).

The Foot Bay gneiss shows a three-size grouping of the constituents. It cannot be called genuinely hiatal for there are transitional sizes; nevertheless, the grouping is distinct: 0.1-0.3 mm for the fragmented matrix (partly re-crystallized quartz, some feldspar), 0.01-0.05 mm for the crushed, mylonitized matrix (plagioclase, mica, chlorite, epidote, Ti-minerals), 0.5-5 mm for the porphyroclasts (plagioclase). The grain size is dominated in many specimens by syndeformational microcline porphyroblasts-porphyroclasts measuring as much as 10 mm across. These megacrysts developed as blasts in the later stages of deformation, and were themselves later deformed at least partly into clasts (Plate VI, 5). Many are surrounded by fine-grained plagioclase mortar, indicating their younger age. The same phenomenon was observed in the basement rocks under the platform sediments of western Canada by Burwash and Krupička (1969, p. 1384).

In the kakirites (brecciated and ultramylonitized mylonites) the grains are pulverized down to 0.001 mm. The pseudotachylitic matrix contains scattered miniporphyroclasts (feldspar) 0.02-0.2 mm in size (Plate VII, 10).

The Donaldson Lake gneiss, with the lower average degree of deformation (1.7), has a large proportion of grains within the range of 0.1-1 mm; the porphyroclasts of feldspar attain up to 5 mm, those of hornblende up to 3 mm, the mylonitic material ranges from 0.01 to 0.05 mm.

In the quartzites forming the base of the Fay Mine Complex deformational effects are very commonly partly masked by recrystallization of quartz. Of the original minerals, quartz has the highest capability of recrystallization. The three size groups are 0.2-0.3 mm (corresponding at least partly to the sedimentary clastic grain size), 0.01-0.1 mm for the granulated quartz and up to 8 mm for the recrystallized quartz. Some of the last group may represent original pebbles.

The upper units of the Fay Mine Complex show a large proportion of extremely fine grain sizes, with the grain in the ultramylonitic portions as low as 0.001 mm. In the granitic gneiss the range is 0.002–3 mm. The pegmatites are characterized by large grains (2–6 mm) fringed or traversed by crush zones with grain size between 0.02 and 0.1 mm.

Types and Phases of Deformation

Practically every type of (postcrystalline and syncrystalline) dynamic deformation is found in the crystalline rocks of the Fay Mine. The style is closely related to the degree of deformation, but it also reflects the mechanical nature of the rock and the structural level at which the deformation took place.

Both penetrative and shattering (fracturing) deformation are encountered. In many rocks both types occur together; they belong, however, mostly to different time phases. The penetrative deformation is characterized by a quasiplastic change of texture due to granulation of a large part of the rock and a thorough penetrative differential movement. This happens if the deforming forces are strong and operate for a longer time, if the rock has enough platy minerals (micas, chlorite) or minerals easily pulverized (quartz) to lubricate the movement, and generally if it occurs at deeper structural levels. On the other hand, the rock yields to the strain by breaking and moving along narrower slip and shear zones if the stress is rather short-lived and more impact-like, if the rock has not enough minerals enabling quasi-plastic movement, and generally if the deformation occurs at higher structural levels. The Foot Bay gneiss is the oldest and most intensely deformed unit of the Fay Mine area.

There is no undeformed rock among the samples of the Foot Bay gneiss. All underwent very strong penetrative deformation (mylonitization) followed in many cases by a very strong shattering deformation to form brecciated mylonites-kakirites; some brecciation is present in all samples of this unit.

Both the penetrative and the shattering deformation affected fully crystalline rocks. The intensity of the deformation makes it difficult to establish with certainty the original nature of the rocks. The paragneissic and amphibolitic nature of the better preserved portions of the Foot Bay gneiss indicates that, before the deformation, most of the complex was the product of high-grade progressive metamorphism of supracrustal rocks, mostly greywacke and shale with basic to intermediate volcanics.

The first phase of the deformation led to a thorough mylonitization (degree 3 of deformation); only locally do we find cataclastic rocks (deg. 2). The differential movement proceeded at depths where the temperature allowed part of the biotite and hornblende to persist in spite of severe crushing effects. The movement was lubricated by micas, chlorite and granulated quartz, and some granulated epidote. The resulting texture is porphyroclastic (Plate VI, 4), conspicuously fluidal around many feldspar and garnet porphyroclasts. Quartz is rolled out into narrow bands and stringers (Plate VI, 5), commonly with incipient recrystallization. The fine-grained crush constituting the matrix proper consists of plagioclase, biotite, chlorite, hornblende, epidote-zoisite and tiny Ti-minerals. In spite of the intensity of deformation of feldspars only a little muscovite developed.

Microcline has a special position in the evolution of the rocks. At least part of it developed at a rather late stage of the first phase of deformation. Some K-metasomatism has thus to be postulated, especially for microcline megacrysts in hornblende-rich rocks of more basic composition (cf. Burwash and Krupička, 1969, p. 1385). The microcline megacrysts (up to 10 mm) are the largest minerals in the Foot Bay gneiss and are both porphyroblasts and porphyroclasts. Many large microcline grains are fringed by or enclose very fine-grained crush of older plagioclase. The history of the Foot Bay gneiss is thus an example of strong dynamic deformation accompanied by microclinization. The same phenomenon seems to be typical for large areas of the Precambrian basement of western Canada (Burwash and Krupička, 1969 and 1970). The soda metasomatism mentioned by Tremblay (1968, p. 235) and Christie (1953) is later than the potassium metasomatism; in the Foot Bay gneiss it is less common than in the higher units.

The second main deformation phase, brecciation accompanied by ultramylonitization (Plate VII, 7), reaches its maximum in the kakirites of the Foot Bay gneiss. In these rocks the first phase mylonite plays the role of the original 'predeformational' rock with respect to the violent shattering of the second phase. The mylonite is crushed yet further, down to a grain size of the order of 0.001 mm, along a generally chaotic network of shear zones, and angular fragments of the older dynamically derived bands and zones have been moved, rotated and scattered throughout the superfine (0.01 mm) ultramylonitic matrix (Plate VII, 10 and 11).

In the kakirites the ultramylonitic crush constitutes from one quarter to more than three quarters of the whole rock. In most cases it is massive, non-foliated and even in the finest-grained portions is composed of crystalline constituents. So far as could be established it is composed predominantly of feldspar, epidote, chlorite, with some sericite and Ti-minerals. It has either uniform, ultrafine grain, or carries its own miniporphyroclasts (0.05-0.3 mm). These are partly the old mylonite porphyroclasts worn down still further and partly preserved grains of the old mylonite matrix which survived the ultramylonitization.

The former microcline megacrysts of the mylonite phase have disappeared in the ultramylonitic crush. No new K-feldspar porphyroblasts formed during the second deformation. This, taken with the fact that the mylonite behaved as a mature, older rock during the ultramylonitic phase, indicates a considerable time gap between the first and the second phase of deformation.

The deformational history of the gneiss does not end with the ultramylonitic brecciation. Later deformation phases were, however, less intense. Narrow, discordant shear zones cut the old mylonitic foliation (Plate IV, 6) at high angles and traverse and offset the later ultramylonitic portions. The older of these shear zones frequently contain veins of younger epidote, calcite, or anhydrite or gibbsite (Plate V, 3). Chlorite and microcline are the main constituents in somewhat younger veinlets (Plate V, 2) which, in their turn, are cut by yet younger narrow shear zones that shift both them and the epidote-bearing shear zones. Microcline of this vein type is much younger than the microcline of the mylonite phase. Chlorite, and to a lesser degree quartz, form the youngest observed veinlets. Associated with these is the main period of pyritization.

The Donaldson Lake gneiss is a more felsic, plagioclase gneiss. It is on the average distinctly less deformed than the Foot Bay gneiss; its average degree of deformation is cataclastic. It contains both moderately strained rocks (Plate VI, 2) and mylonites, but even in the less deformed portions two main phases are evident, as in the Foot Bay gneiss. Parallel slippage zones of the older phase, marked by concentration of mica and chlorite, are cut discordantly by younger shear zones made up of a very fine-grained crush of feldspars, quartz and chlorite. And these again may be cut and offset by veinlets of albite-oligoclase in which new fresh plagioclase crystals grew in optical continuity with strongly altered oligoclase-andesine crystals of the wall (cf. Christie, 1953, p. 68).

Porphyroblasts-porphyroclasts of muscovite are much more common than in the Foot Bay gneiss. Their history seems to be similar to that of microcline in the Foot Bay gneiss. They belong to the first deformation phase, have been affected by its later stages, and later broken and offset by discordant shear zones of the brecciation phase.

The overlying quartzite also has a polydeformational history. The average degree of deformation is cataclastic, but stronger degrees are quite common. In these too, zones of foliated quartz mylonite are cut by narrow zones of quartz ultramylonite, indicating two distinctly separated phases of deformation. The ultramylonite zones themselves may be transected by chlorite-calcite veins.

In the upper units of the Fay Mine Complex, consisting of schistose rocks, phyllonitic amphibolites, epidote amphibolites, quartzites and granitic gneisses dynamic deformation is again more intense. Mylonites and ultramylonites (Plate VI, 3; Plate VII, 12) are common. Again we find two main deformation phases, the penetrative and the shattering, and two or three less intense phases. But in contrast to the other units, some rocks here contain even, concordant, layers and perfectly parallel laminae of an extremely fine-grained (down to 0.001 mm) ultramylonitic material (Plate VII, 8) which seems to belong to the first phase. Some laminae are sharply broken, offset and shifted on later shear zones carrying material of ultrafine grain. No doubt these rocks were developed under very strong dynamic metamorphism, probably of volcanic rocks; they may show a kinematically reworked foliation of original metatuffs and metatuffites.

A typical example of this type consists of perfectly parallel light-coloured quartz layers with grain size 0.005–0.01 mm, ultrafine-grained dark epidote (zoisite)-chlorite layers with 0.001 mm grain size and pure sericite layers with an average grain size of approximately 0.005 mm (Plate VII, 8). The optical orientation of the sericite is perfect, length slow, and the whole layer extinguishes and reacts with the compensator as one long crystal. In contrast, the grains of quartz, in the quartz layers, have random optic orientation. The optic orientation of the grains in the darkest layers is again almost perfect, due to perfect alignment of ultrafine chlorite flakes. Mini-porphyroclasts (0.02–0.07 mm) of feldspar and garnet are found only in the dark bands. Pyrite in euhedral crystals (up to 1.5 mm) is common, either scattered or concentrated along cross-cutting chlorite veinlets.

The most conspicuous marker horizons in the brecciated schists and granitic gneisses of the Fay Mine Complex are the pre-brecciation layers of quartz crush. They are cut, offset and shifted (cf. Tremblay, 1968, p. 246) in fragments by later deformation (Plate VII, 9), with usually straight and sharp discordant boundaries against the second-phase ultramylonitic crush. Trigg (1964) also found lenses of siliceous mylonite abruptly terminated on faults. Both the original bands and the fragments show great diversity in the optical orientation of their parallel platy quartz grainlets.

The banded ultramylonites commonly show extreme mechanical separation of mineral constituents. Such rocks in sheared and retrograded regions all over the world have frequently been mistaken for unmetamorphosed tuffs and argillites or for slightly metamorphosed slates. They resemble argillites so strongly that it led to some contradictory statements even in the excellent G.S.C. Memoir by Tremblay (1968). On page 235 he expressly states that all rocks of the Tazin Group have been metamorphosed and granitized, on page 236 he stresses that the area lies entirely within the amphibolite facies, yet on page 239 he speaks of argillites and slates retrograded to chlorite-sericite schists. On page 150, however, he considers the argillite-like looking rocks as mylonites. Chamberlain states (1958, p. 16) that close to the faults it is common to find well-bedded 'argillites' that show no evidence of crushing.

The rocks of the Fay Mine Complex contain abundant dark minerals, mostly chlorite, epidote and green biotite. Many show intense microfolding either of the concordant chlorite-mica slip surfaces or of the narrow bands of quartz crush. Many small feldspar porphyroclasts are flattened into ellipsoids. This form is generally not developed in feldspars which yielded to strain by breaking or by rounding; and it supports the concept of long-term continuous strain in the first deformation phase.

The uppermost member of the Fay Mine Complex, the granitic gneiss (Tremblay's 'metasomatic granite' - map unit 19, 1968; and Tremblay, 1970) contains rocks as strongly deformed as those in the lower members. Beside strained and cataclastic rocks there are mylonites and even ultramylonites in this unit. Some are brecciated to the same degree as the kakirites of the Foot Bay gneiss. In these rocks, commonly quartz-rich, the phenomenon of variable optic orientation of the deformed quartz, found in all Tazin rocks of the area, is very marked. In the layers of mylonitized quartz the flattened, platy quartz grains may be: a) length-slow, with ω parallel to the elongation of the grain and the trend of the layer, or b) length-fast, with ε parallel to the grain elongation and the trend of the layer, or c) the ω or ε may be parallel to the elongation of the grain but inclined to the trend of the layer because the platy grains are discordantly oriented to the trend of the layer, or d) the optic orientation of the grains may be discordant both to the elongation of the grain and to the trend of the layer. In an example of d) ω and ε are inclined at 45° to the very pronounced elongation of the quartz grains, and the long axis of the grains makes an angle of approximately 23° with the margins of the band.

Finally, effects of deformation are readily apparent even in the cross-cutting pegmatites. The degree of deformation varies between 1 and 2 in these rocks. Broken plagioclase, commonly in different stages of microclinization, strongly bent muscovite, and crushed quartz are common features.

Evidently the deformation has outlasted crystallization in the whole of the Tazin Group.

Metamorphic Grade

The mylonitization and brecciation of the Tazin affected fully crystalline rocks. They were higher-grade metamorphic rocks of the amphibolite facies: gneisses, amphibolites, quartzites and calc-silicates (cf. Tremblay, 1968, p. 235, 236, and Geology of Canada, 1970, p. 92, 167). Originally plutonic igneous rocks were less abundant. Not one example among the samples analyzed can properly be interpreted as a sheared unmetamorphosed or weakly metamorphosed sediment. All the specimens resembling argillites, meta-argillites, slates and tuffs are, in reality, strongly to extremely deformed feldspar-rich gneissic rocks, predominantly paragneisses, interlayered with metavolcanics.

Texturally the kinematic metamorphism manifests itself in the textures described above. Mineralogically it causes a degradation of the original mineral assemblage (chloritization and epidotization of the dark minerals, sericitization and zoisitization of the feldspars). The retrograde metamorphism, however, is certainly not a simple function of the intensity of deformation or of the relative age of the rock. Many completely mylonitized rocks of the oldest unit, the Foot Bay gneiss, still retain biotite even in the ultrafine crush and carry non-chloritized hornblende porphyroclasts, even though some less deformed, cataclastic or only strained samples of the Donaldson Lake gneiss contain chlorite as the only dark mineral. Edie (1951, p. 25) states that even in strongly crushed amphibolites some hornblende reamins as a mass of tiny fragments. Even within the space of one thin section biotite zones and chlorite zones may alternate, with the biotite zone more intensely crushed than the chlorite zone. A partial but definitely not complete explanation for the preservation of biotite even under extreme shearing may be found in the fact that it is most commonly observed in rocks (Foot Bay gneiss) undergoing syndeformational microclinization, in other words, probably K-import.

Similarly, plagioclase commonly remains unaltered in very fine crush in the Foot Bay gneiss, whereas abundant muscovite develops at its expense in the less sheared Donaldson Lake gneiss.

In general, the retrogressive metamorphism was stronger in the brecciation and ultramylonitization phase because of the higher crustal level in which the brecciation took place. The overall result of the strong, repeated deformation of the Tazin Group is the co-existence of a non-equilibrium association of mineral assemblages belonging to the amphibolite, epidote-amphibolite and greenschist facies.

Conclusion

The rocks of the Tazin Group at the Fay Mine in the Beaverlodge area are a first-class example of polydeformation of crystalline rocks. A of retrogressive kinematic metamorphism:

1) The progressive metamorphism of the whole Tazin Group is Archean (Kenoran). The Hudsonian orogeny consisted essentially in a large-scale brittle deformation of the pre-existing crystalline complex. Geology of Canada, 1970, p. 93, states about the Beaverlodge area: "The main expression of the Hudsonian orogeny may be faulting."

2) Part of the Tazin (the Foot Bay Gneiss) is Kenoran, part is Aphebian. The earlier stages of the Hudsonian orogeny have produced the progressive metamorphism of the Aphebian supracrustal rocks, the later stages have brought about the kinematic metamorphism of both the Kenoran basement and the metamorphosed Aphebian cover.

3) The term "Hudsonian" comprises two distinct orogenic events. Burwash (1969, p. 364) says with respect to what is generally called the Hudsonian orogeny: "Within the North American craton, however, the total range of values is great enough to suggest that two sequential orogenies occurred...." If this is the case then the progressive metamorphism of the Aphebian part of the Tazin Group belongs in the first, the kinematic metamorphism of the whole group belongs in the second of the Hudsonian orogenies.

The higher average degree of kinematic metamorphism in the Foot Bay gneiss suggests that part of the deformation may have been Kenoran in age. But it cannot have been the principal one because all the main phases of deformation also appear, even if generally in a somewhat weaker form, in the younger units. The different intensity of kinematic metamorphism within these higher units is not a result of differences in age but of differences in the mechanical properties of the rocks. The time of the great crushing, kneading, shearing and shattering of all the rocks of the Tazin Group came in the Hudsonian.

CHAPTER 5 - STRUCTURAL GEOLOGY OF THE INVESTIGATED AREA

Introduction

Several authors have in the past discussed the structural geology of the Beaverlodge district, with the hope of revealing favourable, structurally controlled, exploration targets. Most of these have concluded that the controls of uranium mineralization in the area are complex and can only in part be related to regional tectonic features. It has also been concluded that the mineralization of the district is a function of the existence of pre-metamorphic 'donator' lithologies and of limited tectonic-hydrothermal events which have affected repeated remobilization of the ore components over the last 1950 m.y. (Koeppel, 1968; Tremblay, 1968).

The objective of this chapter is to elucidate the structure and tectonic history of the Eldorado Fay Mine.

A considerable volume of literature, both published and in the form of internal company reports, has dealt with various aspects of the structural geology of Eldorado Nuclear's Fay, Ace and Verna Mines. However, it is regrettable that no up-to-date synthesis of this information exists for the student of the Beaverlodge district.

The first cursory descriptions of the structural environment of the orebodies adjacent to the St. Louis Fault were those by MacDonald (1954) MacDonald and Kermeen (1956), Campbell (1957) and Dudar (1960). Their work was summarized and augmented by that of Chamberlain (1958, 1959) who concluded that the St. Louis Fault and the ABC Fault (Fig. 8) were syntectonic and constituted part of a single fracture initiated after the deposition of the Precambrian Martin Formation.

Trigg (1964) stated that the folds in the Verna Mine trended S70°W (an azimuth differing by 56° from the S14°W trend of the structures in the immediately surrounding area). It was therefore suggested that WSW-ENE structures had been superimposed upon earlier ~N-S trending folds during a phase syntectonic with the late stages of mylonitization in the area.

Tremblay (1968), contesting Chamberlain's conclusions, suggested that the Tazin metamorphics had suffered two periods of folding and two periods of faulting; the older faults being represented by extensive zones of mylonite and breccia, whilst the younger faults were characterized by 'clean-cut' fractures filled with gouge and exhibiting various degrees of hydrothermal alteration of their wall-rocks.

On the basis of noticeable axial curvature in minor folds, S of the St. Louis Fault and ABC Fault, Tremblay postulated that the St. Louis Fault had undergone both normal and lateral (probably sinistral) movement. The last phase of movement of the St. Louis Fault was determined to be of normal character, since the Martin Formation is preserved on the south side of the fault.

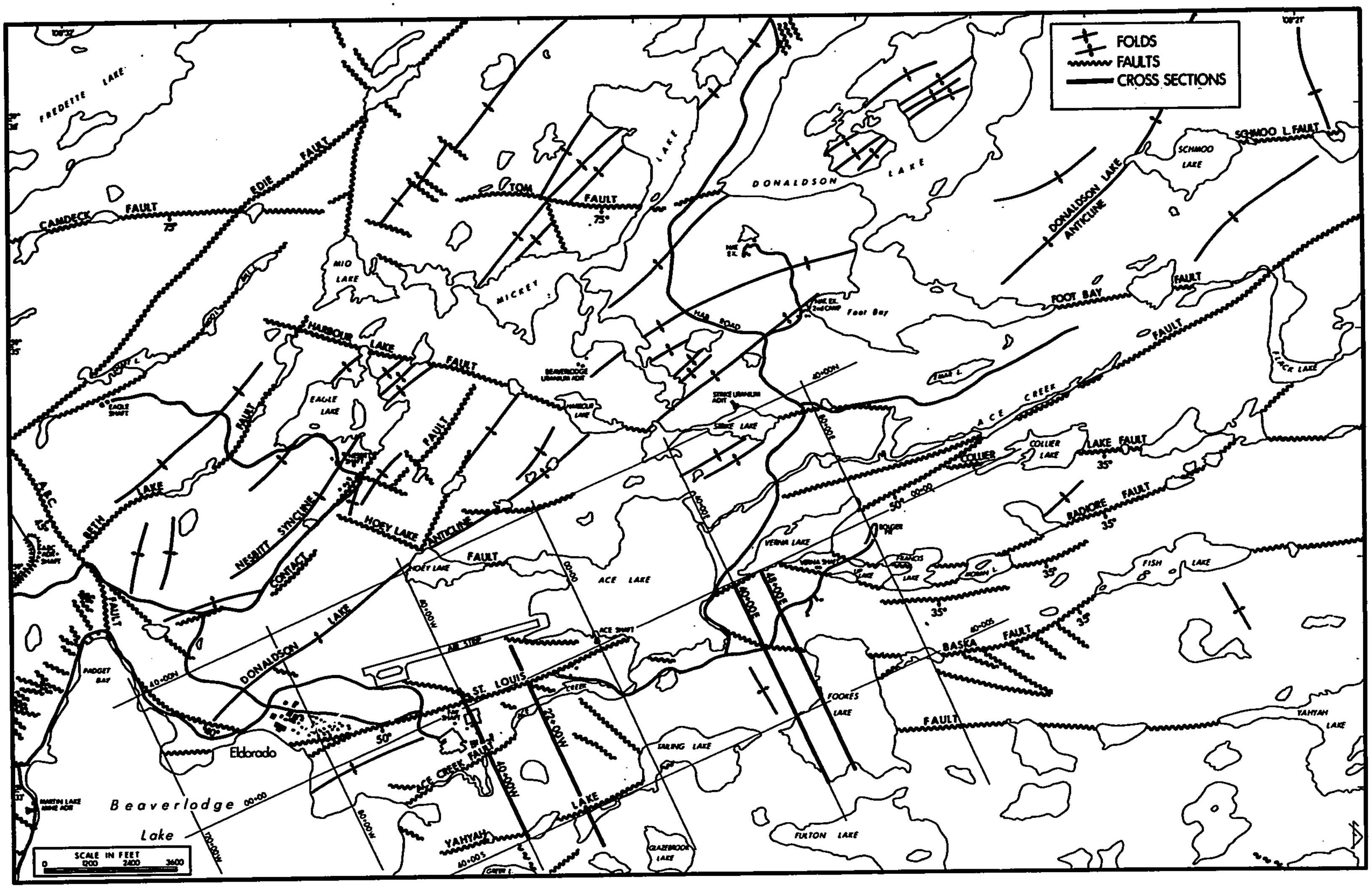
Beecham (1970) provided details of the structural interrelationships between the St. Louis Fault and the ABC Fault and postulated that the ABC Fault is a normal, left-handed oblique fault, with a net slip of 3.9×10^3 m; the direction of movement being parallel to the intersection between the ABC Fault and the Black Bay Fault (a vector which plunges 35° towards an azimuth of 202°). The ABC Fault was, in Beecham's opinion, a younger structure than the St. Louis Fault, but it had suffered subsequent contemporaneous, secondary movement, together with the St. Louis Fault itself.

Finally Beck (1970), reviewing the past literature, concluded that the Tazin lithologies contrasted strongly in structural style with those of the overlying Martin Formation, the former being characterized by tight, almost isoclinal, NE trending folds, whilst the latter were folded into broad, open structures whose axial traces roughly parallel those of the folds in the Tazin basement. Beck also recognized, as he had done earlier (Beck, 1964, 1966), two differing deformational environments within the Tazin Complex, namely the heavily faulted 'Linear Belts' and the less fractured 'Stable Blocks'.

Folds

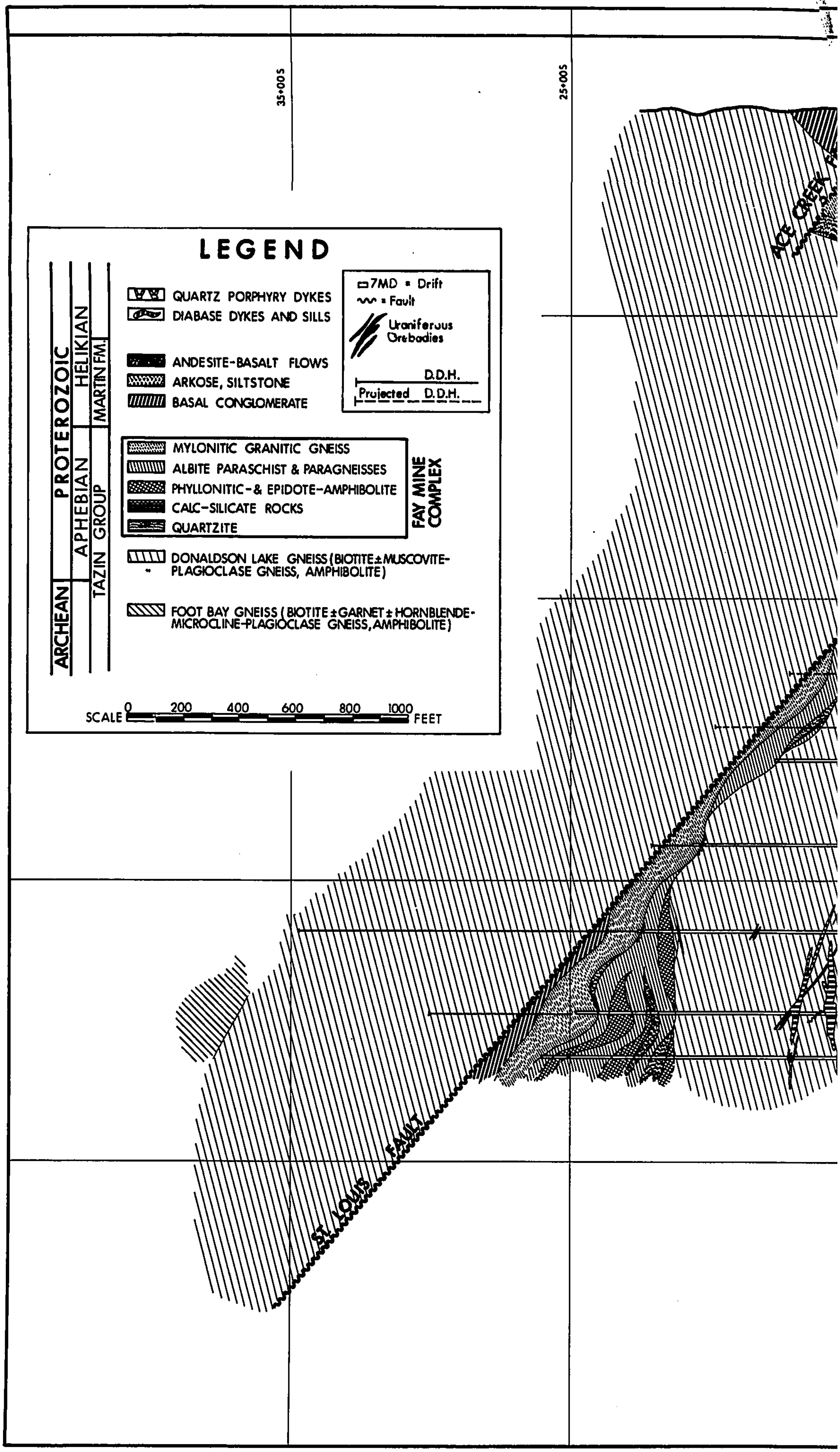
The principal structural features of the Fay Mine environs are illustrated in Fig. 12. This figure shows that the region is characterised by a dominant series of folds whose axial traces trend NE-SW and a relatively poorly-developed set of folds whose axes trend NW-SE. The latter folds are best represented in the sector SE of the St. Louis Fault but are occasionally

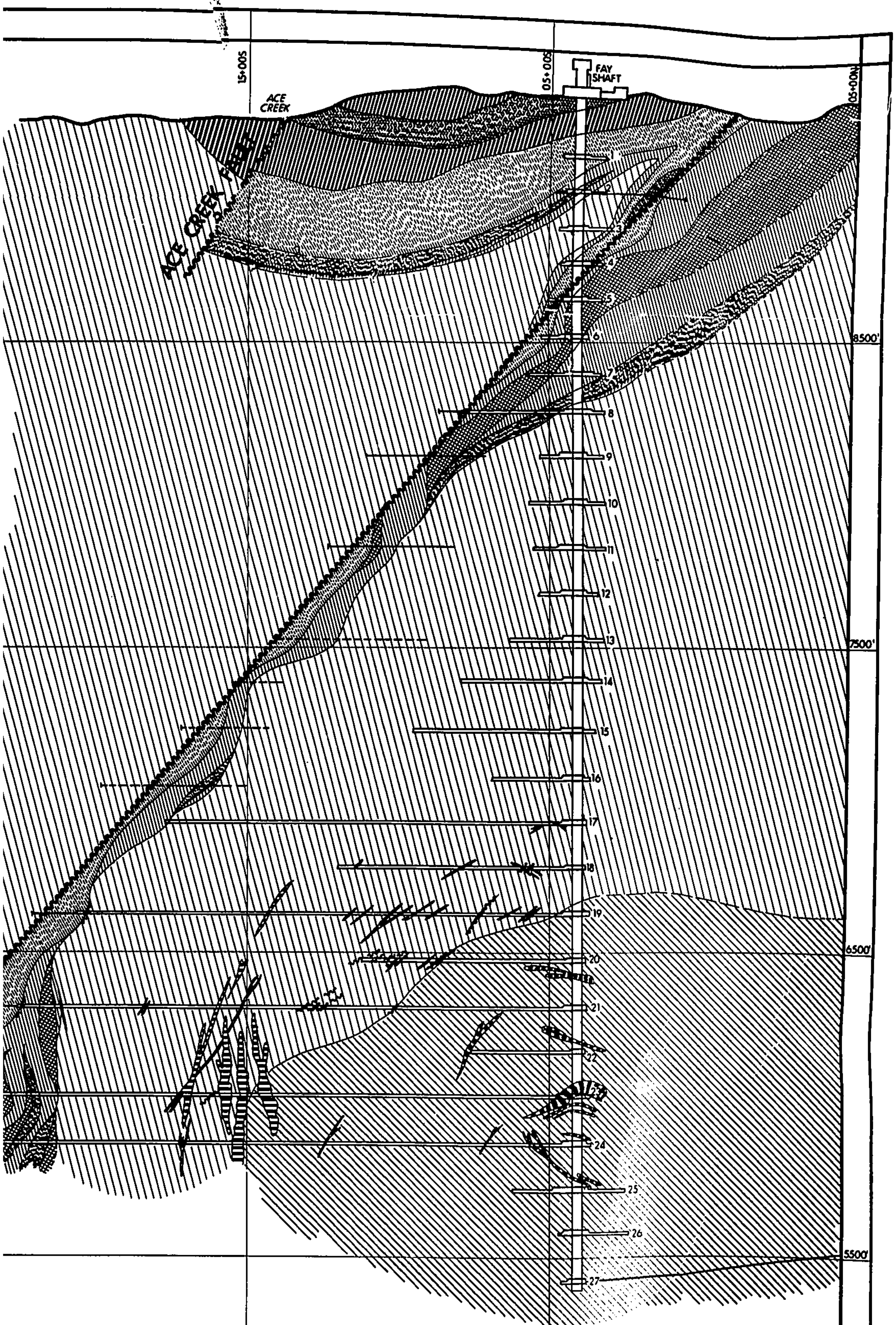
Fig. 12. Principal folds and faults in part of the Beaverlodge District, NW Saskatchewan (after G.P. Sassano, 1971).



PRINCIPAL FAULTS AND FOLDS OF THE AREA AROUND THE FAY MINE.
NORTHWEST SASKATCHEWAN.

Fig. 13. Geological cross-section 40 +00 W, Fay Mine, NW Saskatchewan (after G.P. Sassano, 1971).


35+00S
25+00S
LEGEND
PROTEROZOIC
ARCHEAN
APHEBIAN
HELIKIAN
TAZIN GROUP
MARTIN FM.
QUARTZ PORPHYRY DYKES
DIABASE DYKES AND SILLS
ANDESITE-BASALT FLOWS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC-& EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COMPLEX
DONALDSON LAKE GNEISS (BIOTITE ± MUSCOVITE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE ± GARNET ± HORNBLENDE-MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
7MD = Drift
= Fault
Uraniferous Orebodies
D.D.H.
Projected D.D.H.
SCALE 0 200 400 600 800 1000 FEET
ACE CREEK
ST. LOUIS FAULT



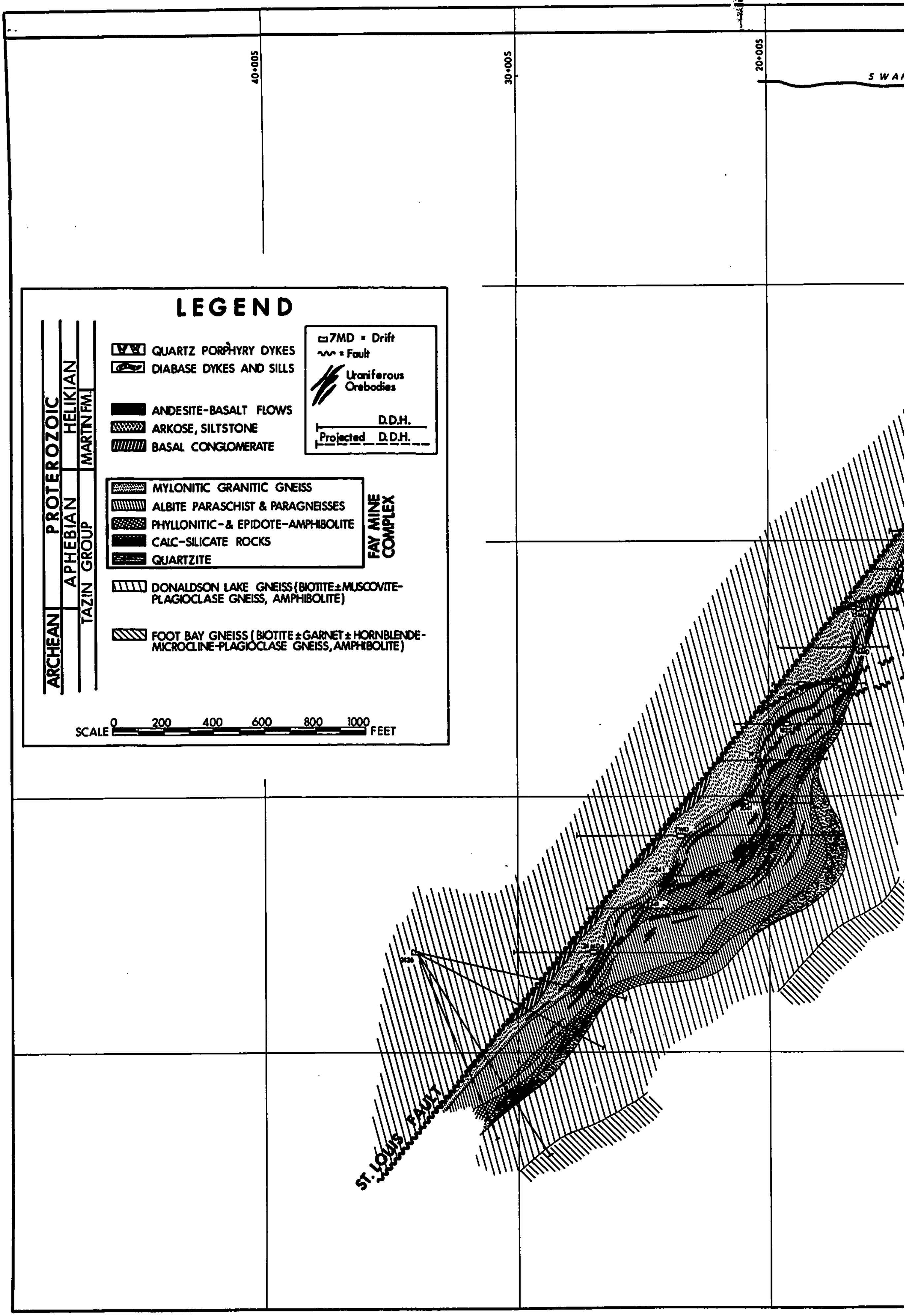
FAY MINE, NW. SASKATCHEWAN

GEOLOGICAL CROSS-SECTION

40+00 W

ELDORADO NUCLEAR LTD
Geological interpretation by
G. P. SASSANO - 1971

Fig. 14. Geological cross-section 22 + 00 W, Fay Mine, NW Saskatchewan (after G.P. Sassano, 1971).


40+00S
30+00S
20+00S
SWA
LEGEND
PROTEROZOIC
ARCHEAN
APHEBIAN
HELIKIAN
TAZIN GROUP
MARTIN FM.
QUARTZ PORPHYRY DYKES
DIABASE DYKES AND SILLS
ANDESITE-BASALT FLOWS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC-& EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COMPLEX
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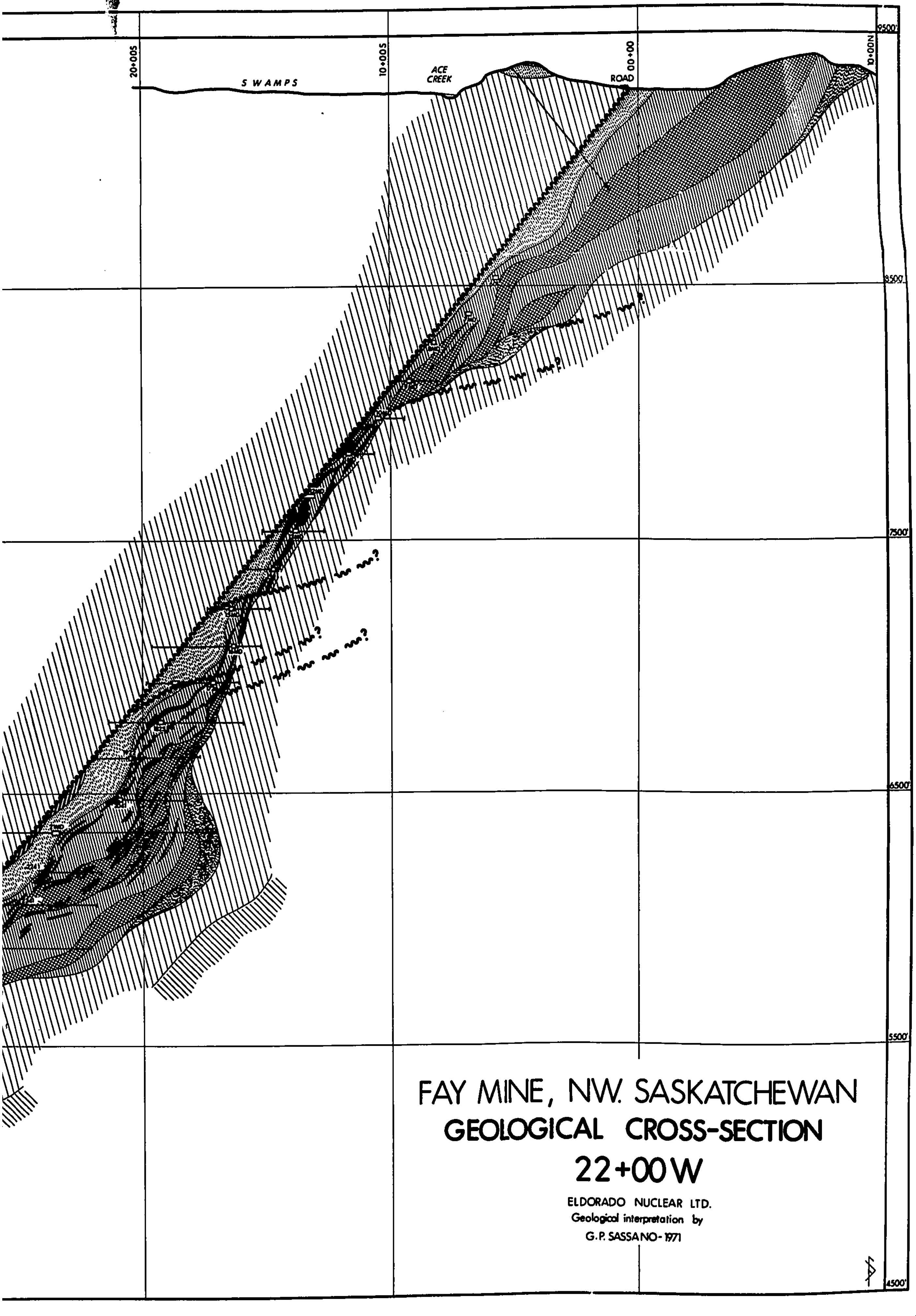
FOOT BAY GNEISS (BIOTITE±GARNET±HORNBLENDE-MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
7MD = Drift
= Fault
Uraniferous Orebodies
D.D.H.
Projected D.D.H.
SCALE 0 200 400 600 800 1000 FEET
ST. LOUIS FAULT



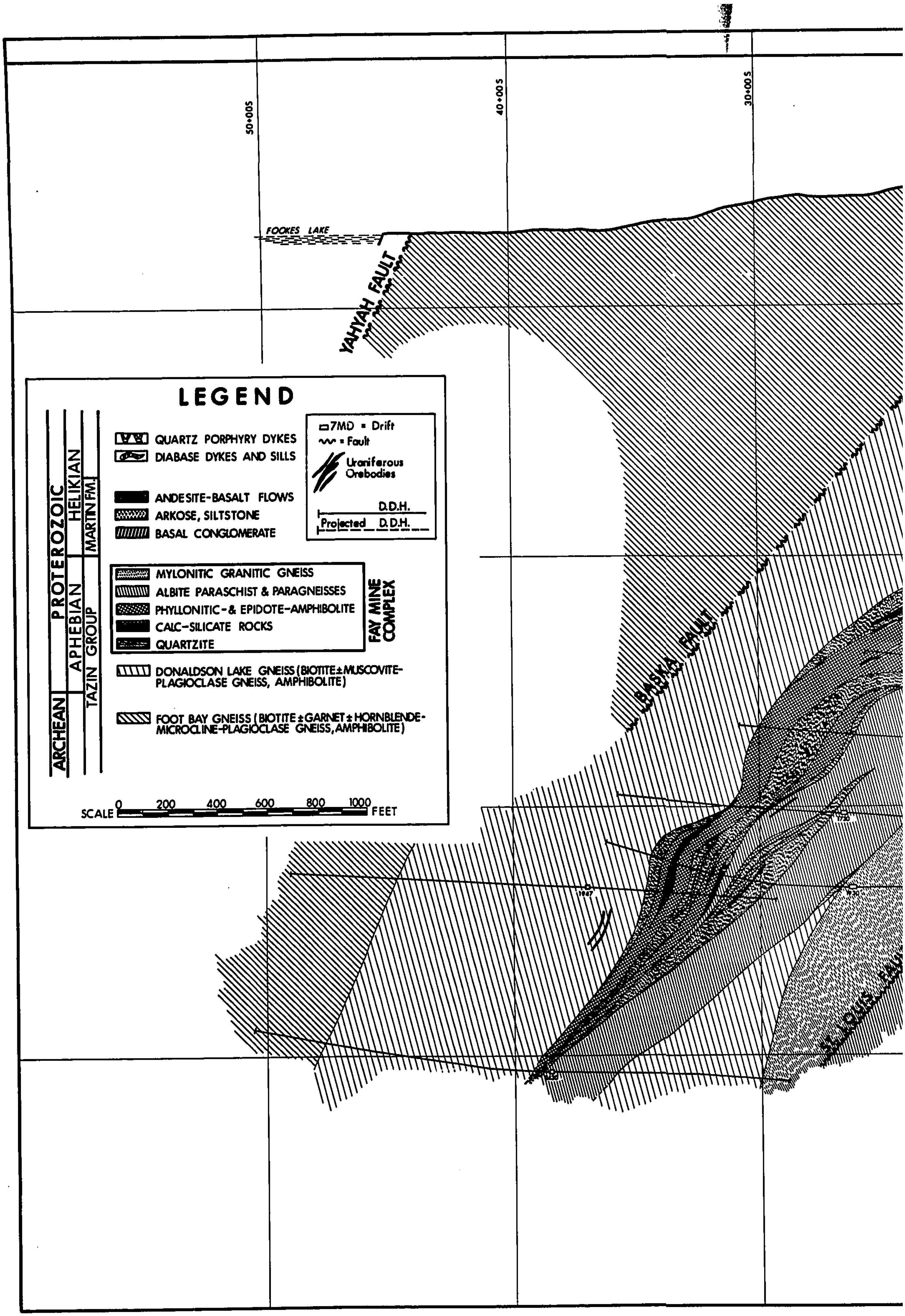
FAY MINE, NW. SASKATCHEWAN

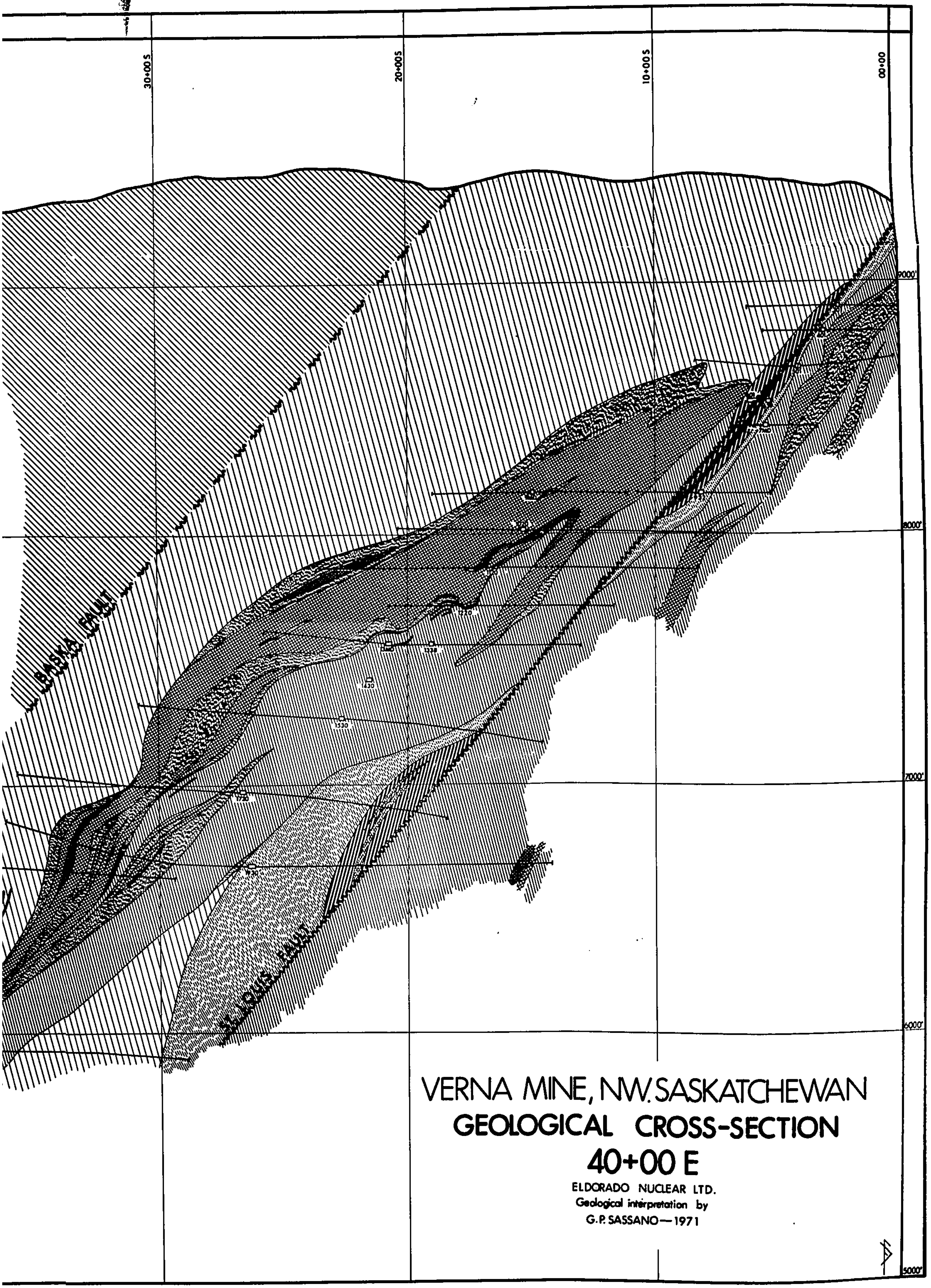
GEOLOGICAL CROSS-SECTION

22+00W

ELDORADO NUCLEAR LTD.
Geological interpretation by
G.P. SASSANO-1971

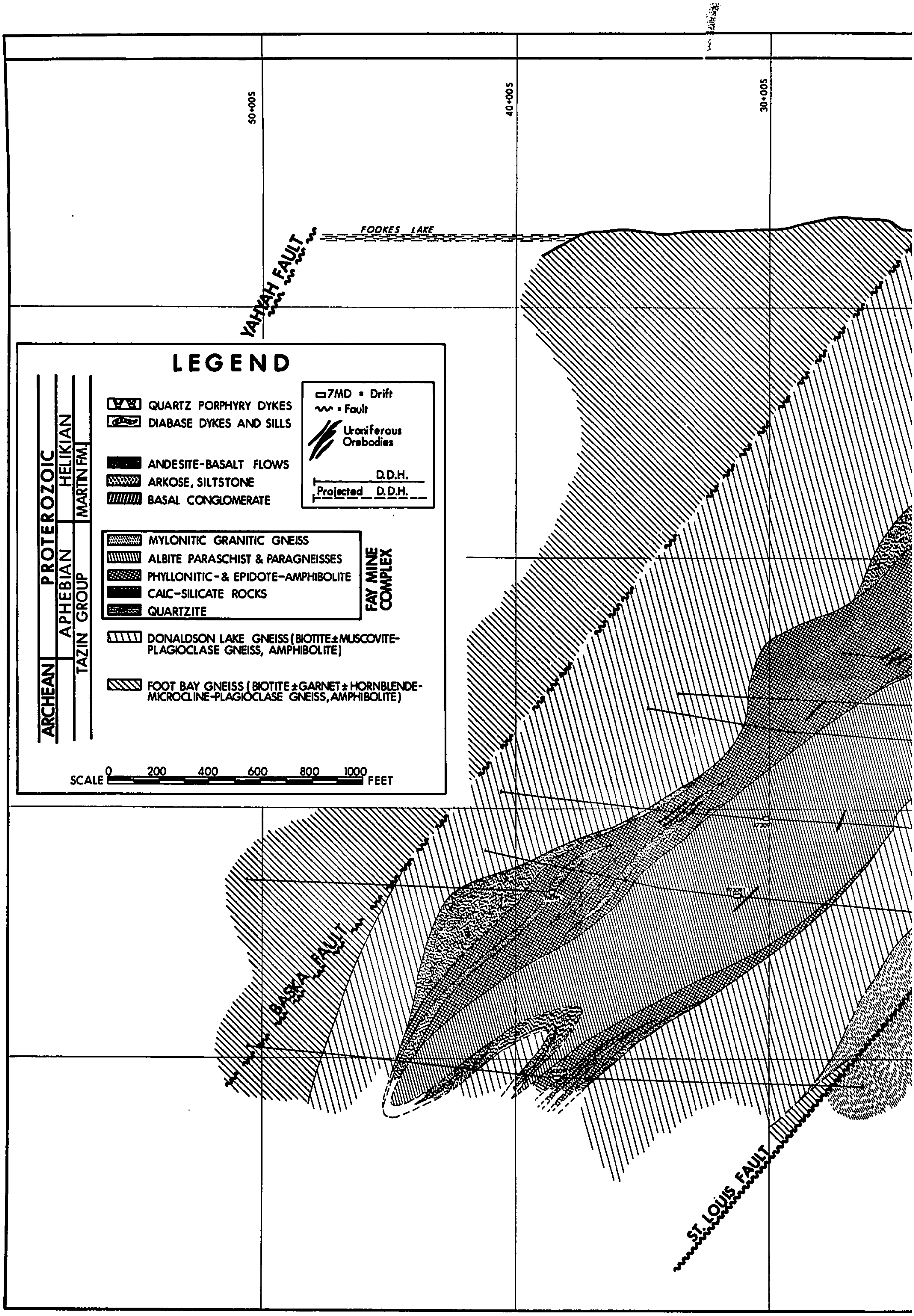
Fig. 15. Geological cross-section 40 + 00 E, Verna Mine, NW Saskatchewan (after G.P. Sassano, 1971).

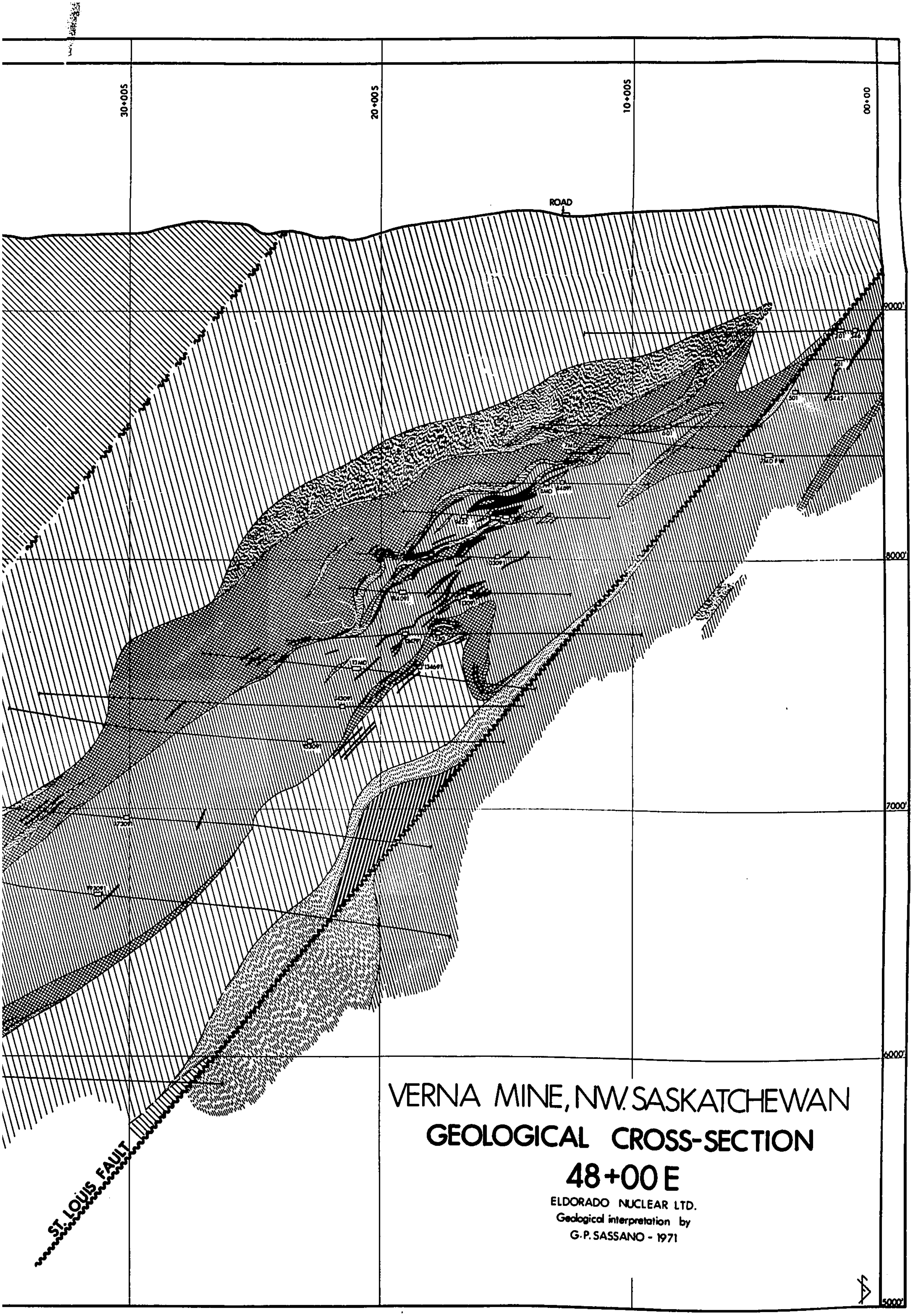

50+00S
40+00S
30+00S
FOOKES LAKE
YAHYAH FAULT
BASKA FAULT
ST. LOUIS FAULT
LEGEND
QUARTZ PORPHYRY DYKES
DIABASE DYKES AND SILLS
ANDESITE-BASALT FLOWS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC-& EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COMPLEX
DONALDSON LAKE GNEISS (BIOTITE±MUSCOVITE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE±GARNET±HORNBLENDE-MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
PROTEROZOIC
HELIKIAN
MARTIN FM.
APHEBIAN
TAZIN GROUP
ARCHEAN
7MD = Drift
= Fault
Uraniferous Orebodies
D.D.H.
Projected D.D.H.
SCALE 0 200 400 600 800 1000 FEET



VERNA MINE, N.W. SASKATCHEWAN
GEOLOGICAL CROSS-SECTION
40+00 E
ELDORADO NUCLEAR LTD.
Geological interpretation by
G.P. SASSANO—1971

Fig. 16. Geological cross-section 48 +00E, Verna Mine, NW Saskatchewan (after G.P. Sassano, 1971).


50+00S
40+00S
30+00S
FOOKES LAKE
YAHYAH FAULT
BASKA FAULT
ST. LOUIS FAULT
LEGEND
QUARTZ PORPHYRY DYKES
DIABASE DYKES AND SILLS
ANDESITE-BASALT FLOWS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC- & EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COMPLEX
DONALDSON LAKE GNEISS (BIOTITE±MUSCOVITE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE±GARNET±HORNBLENDE-MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
PROTEROZOIC
HELIKIAN
MARTIN FM.
APHEBIAN
TAZIN GROUP
ARCHEAN
7MD = Drift
= Fault
Uraniferous Orebodies
D.D.H.
Projected D.D.H.
SCALE 0 200 400 600 800 1000 FEET



30+00S
20+00S
10+00S
00+00
ROAD
9000'
8000'
7000'
6000'
5000'
ST. LOUIS FAULT
VERNA MINE, NW. SASKATCHEWAN
GEOLOGICAL CROSS-SECTION
48+00E
ELDORADO NUCLEAR LTD.
Geological interpretation by
G.P. SASSANO - 1971

seen north of this dislocation (e.g. NE of Schmoo Lake). It is noteworthy that the predominant NE-SW trending folds exhibit curvilinear axial trends (e.g. the Donaldson Lake Antiform).

The Fay, Verna and Bolger mining operations are located adjacent to the ENE-WSW striking St. Louis Fault. The Fay Mine is situated on the gently folded southern limb of the Donaldson Lake antiform which occurs in the SE dipping foot wall of the St. Louis Fault (Figs. 13, 14). The Verna Mine and the Bolger open pit are situated on the crest of a SW plunging anticlinal structure whose axial plane dips steeply southwards. This antiform described in detail by Trigg (1964) constitutes a major isoclinal overturned synform which has been recognized at depth in the hanging wall sector of the Verna Mine (see sections 40 +00E and 48 +00E, Verna Mine, Figs. 15, 16). SW of the Verna Lake and SE of Fish Lake respectively, two minor fold structures trend northwesterly. These structures, which are both noticeably confined to lithologies belonging to the Foot Bay Gneiss, are apparently truncated by two major faults trending almost E-W; the Baska Fault and the Yahyah Fault. In the northern part of the area the majority of folds trend NE-SW but a few synclinal structures are seen to display a N-S or N15°W orientation (e.g. the synform occurring NE of Schmoo Lake).

The dominant fold structure of the region, N of the St. Louis Fault, is the so-called 'Donaldson Lake antiform' (Tremblay, 1968), trending NE-SW. It extends from Padget Bay, on Beaverlodge Lake (where it is truncated by the

ABC Fault), to the W shore of Schmoo Lake in the NE portion of the area. The axial trace of this major antiform is discontinuous and offset several times by a set of E-W and NW-SE trending faults, such as the Harbour Lake Fault, the Foot Bay Fault, and possibly the Schmoo Lake and Hoey Lake Faults. The Donaldson Lake antiform is believed, by most workers (Tremblay, 1968) to plunge 40° to 60° southwesterly. The SE limb of this structure exhibits drag-folding on a large scale (Tremblay, 1968) whereas the NW limb is less deformed and apparently passes northwestwards into a sector in which the folding is less complex and more open in character (Tremblay, 1968).

Another important structural feature of the area is the NE-SW trending Nesbitt synform, extending from Padget Bay to the N shore of Eagle Lake, where it is cut by the Tom Fault. 1200 feet NE of Padget Bay this structure is partly truncated by the so-called Tom Lake Fault. The Nesbitt synform is flanked on the NW by an open synclinal structure termed the HAB synform (SE of the Edie Fault).

Faults

The investigated area is characterized by three sets of faults. The major dislocations, such as the St. Louis Fault and the Edie Fault, strike NE-SW and offset a second E-W striking set of faults such as the Collier Lake, the Radiore, Yahyah Lake, Baska and Foot Bay Faults. A third set of faults, striking NW-SE appears to be truncated by the E-W trending faults and rarely, in turn, offsets occasional NE-SW trending faults. Occasionally the NW-SE trending faults are seen to turn into a N-S orientation. All three sets of faults cut the NE-SW trending fold structures whilst the E-W trending faults are sometimes seen to cut the NW-SE trending folds.

The predominant dislocations of the Fay Mine area are the St. Louis Fault, the ABC Fault and a number of NW-SE striking faults which parallel the ABC Fault.

The St. Louis Fault has been explored to a depth of 4000 feet and is proved to be a clean-cut fracture filled by 1 to 11 feet of clay gouge (av. 1 - 2 feet) usually paralleled in the hanging wall by a set of gouge-filled minor fractures. In the Fay Mine the fault plane has a constant dip of 49° and exhibits a slightly convexity to the SE. As stated by Tremblay (1968) the last movement of the St. Louis Fault was of normal character. However, interpretation of underground fold data, in the Verna Mine, suggest that the movement, at some stage, was probably of both lateral and reverse nature. This fault has undoubtedly undergone considerable variation in its sense of dislocation direction during a number of rejuvenation phases.

The ABC Fault, and the approximately parallel set of faults striking NW-SE or WNW-ESE, dip $\sim 45^{\circ}$ southwestwards or southwards and is observed underground in the Fay Mine to be offset by the St. Louis Fault (13th Level, at about mine coordinate 80 +00W, Fay Mine). The concomitant set of WNW-ESE striking faults, in the hanging wall, dipping approximately

45° southwestwards, is also truncated by the St. Louis Fault (13th Level, at about mine coordinate 10 +00 E, Fay-Verna Mine). The problem of the relations between the NE-SW fault set and the ABC Fault set, however, remains an enigma, for whilst Christie (1952) clearly showed the Edie Fault to cut the ABC Fault N of the ABC Adit, Beecham (1970) states that the ABC Fault has apparently displaced at least seven of the NE-SW striking faults NW of the Eldorado campsite.

Data Collection and Treatment

Approximately 5500 structural readings (dip and dip direction) were collected by the writer on the 16th, 22nd, 23rd, 24th and 25th Levels of the Fay Mine in order to ascertain a number of attitudes of structural planes which could be processed to obtain equal-area stereographic projections of point density. For this purpose a Fortran IV program, originally developed by Muecke and Charlesworth (1966) and recently modified by Ramsden (1970) was adopted by the writer.

The program determines point density by counting axes or poles to planes directly on the reference hemisphere, since the axis of a circular cone whose apex is at the centre of the hemisphere, is placed successively through each of 333 counting locations. The number of observations falling within the cone, at each location, is recorded as a percentage of the total. This cone defines a circle on the surface of the hemisphere whose area is the same fraction of the total surface area of the hemisphere. The program also uses the computer's line printer to produce a 10 inches radius, equal-area projection of the counting locations, each location being represented by their appropriate point density value. To give a simple line-printer format the counting locations were chosen so that their projections formed a rectangular grid with a spacing of one tenth the radius of the reference hemisphere. The contoured diagram represents a 'density surface', the elevation of which at any point shows the percentage of axes falling within a 'per cent counting circle' centered at that point. It is taken as an estimate of the probability that an axis selected randomly will fall within a 'per cent counting circle' centered at that point. Since the method counts points directly on the reference hemisphere using a circular cone, all the inaccuracies are eliminated. Use of the computer also eliminates plotting and counting errors and allows diagrams to be prepared in a small fraction of time. The resultant contoured stereographic plots pertinent to the present discussion are shown in Figs. 17 to 19.

Interpretation of the Fay Mine Structural Data

1. Foliation and Schistosity Data

Fig. 17 includes all data obtained on foliation and schistosity planes present in the Tazin sequence of the Fay Mine, together with a stereographic plot of data from the uraniferous ore-veins, for comparative purposes. The data for foliation, schistosity and gneissosity are plotted separately as they represent respectively the S-plane components of three discrete lithological members of the foot wall metamorphic sequence; namely, the 'foliated mylonitic granitic gneiss', the 'paraschists' and the 'Foot Bay Gneiss'. Fig. 17A represents a compilation of all data on schistosity within the Fay Mine Complex and demonstrates that the S-planes dip generally S24°E at 1° to 80°, but the majority of them have a dip of S24°E at 35°. In contrast, Fig. 17B represents the foliation of the 'mylonitic granitic gneiss' situated within 300 feet of the plane of the St. Louis Fault. This plot exhibits both a distinct maximum of data representing S-planes dipping S24°E at a steeper angle of 50° and a somewhat greater scatter of orientation. Such features are easily explained as being due to a simple rotational re-orientation of pre-existing foliation planes in the gneisses to an attitude which approximately parallels the plane of the St. Louis Fault.

Fig. 17C represents data on the schistosity of the paraschists lying 300-600 feet away from the plane of the St. Louis Fault and clearly shows the relatively unrotated orientation of the schistosity at this location. In this case the data show a maximum representing planes dipping S24°E at 35°.

In total contrast to all other lithologies the Foot Bay Gneiss whose gneissosity data is represented in Fig. 17D, exhibits a unique structural aspect. The data plot in a much more scattered manner but have two maxima:

Fig. 17. Data concerning foliation, schistosity planes and uraniferous ore-veins present in the Tazin sequence of the Fay Mine.

A Schistosity in all levels examined.

B Foliation in 'mylonitic granitic gneiss' (Fay Mine Complex) within 300 feet (~ 91 m) of the St. Louis Fault.

C Schistosity in 'paraschists' (Fay Mine Complex) within 600 feet (~ 183 m) of the St. Louis Fault.

D Gneissosity in the Foot Bay Gneiss.

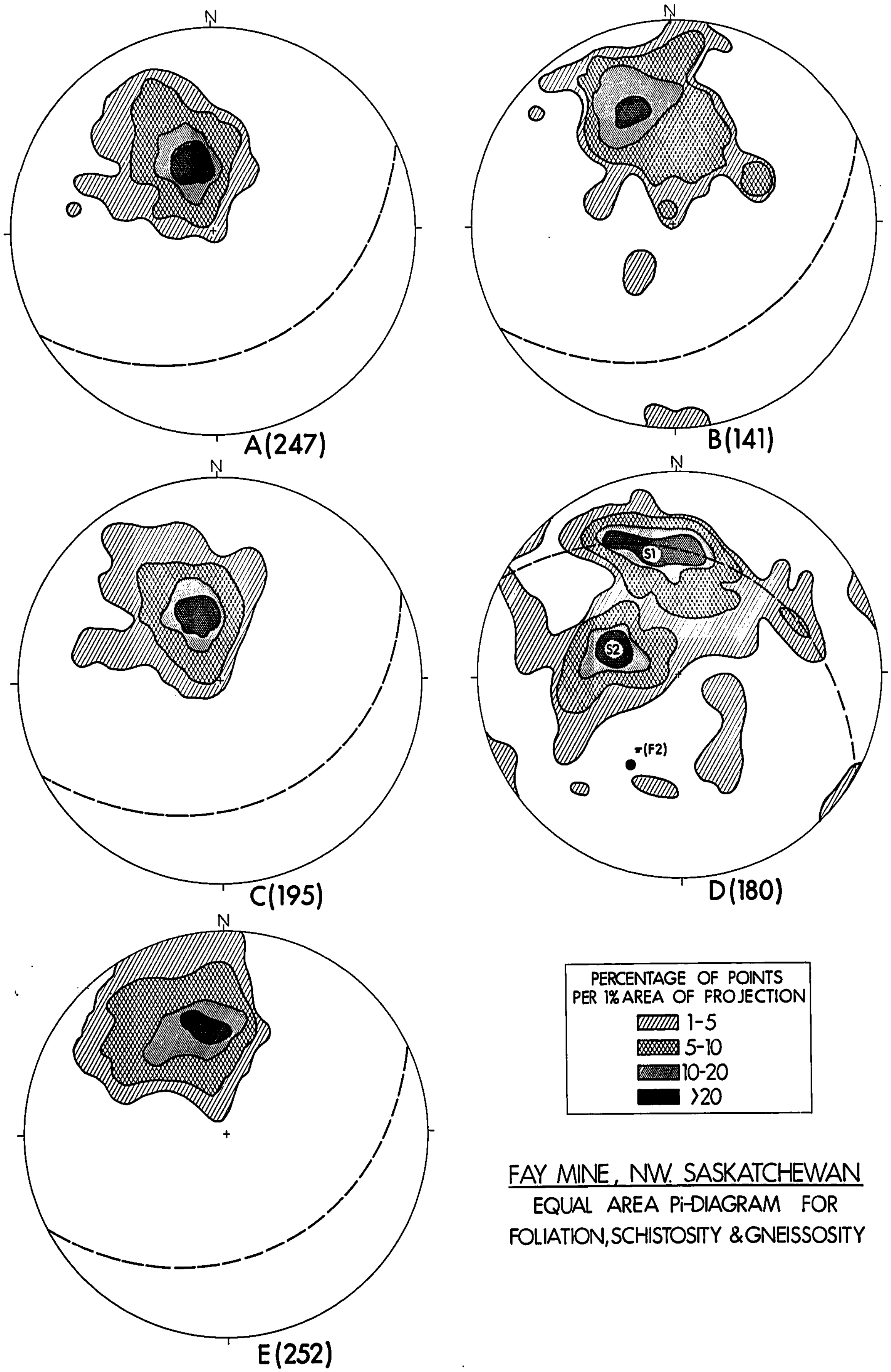
E Ore-veins in all levels examined.

Note:

* The numbers in brackets refer to the number of observations.

** The great circle of Figs. A, B, C and E represents the St. Louis Fault.

*** The great circle of Fig. D represents planes dipping S20°W to S10°W at 55° to 75° . It is due to the superimposition of a younger foliation (S 2) upon an older foliation (S 1) the latter having suffered deformation by folds (of a F 2 generation) whose axes plunge ~S30°W at about 50°.



FAY MINE, NW. SASKATCHEWAN
EQUAL AREA Pi-DIAGRAM FOR FOLIATION, SCHISTOSITY & GNEISSOSITY

Fig. 18. Data concerning recognizable faults within the Tazin sequence of the Fay Mine.

A Faults in all levels examined.

B 'Medium and large faults' in all levels examined.

C 'Minor faults' in 'mylonitic granitic gneiss' within 300 feet ($\sim$ 91 m) of the St. Louis Fault.

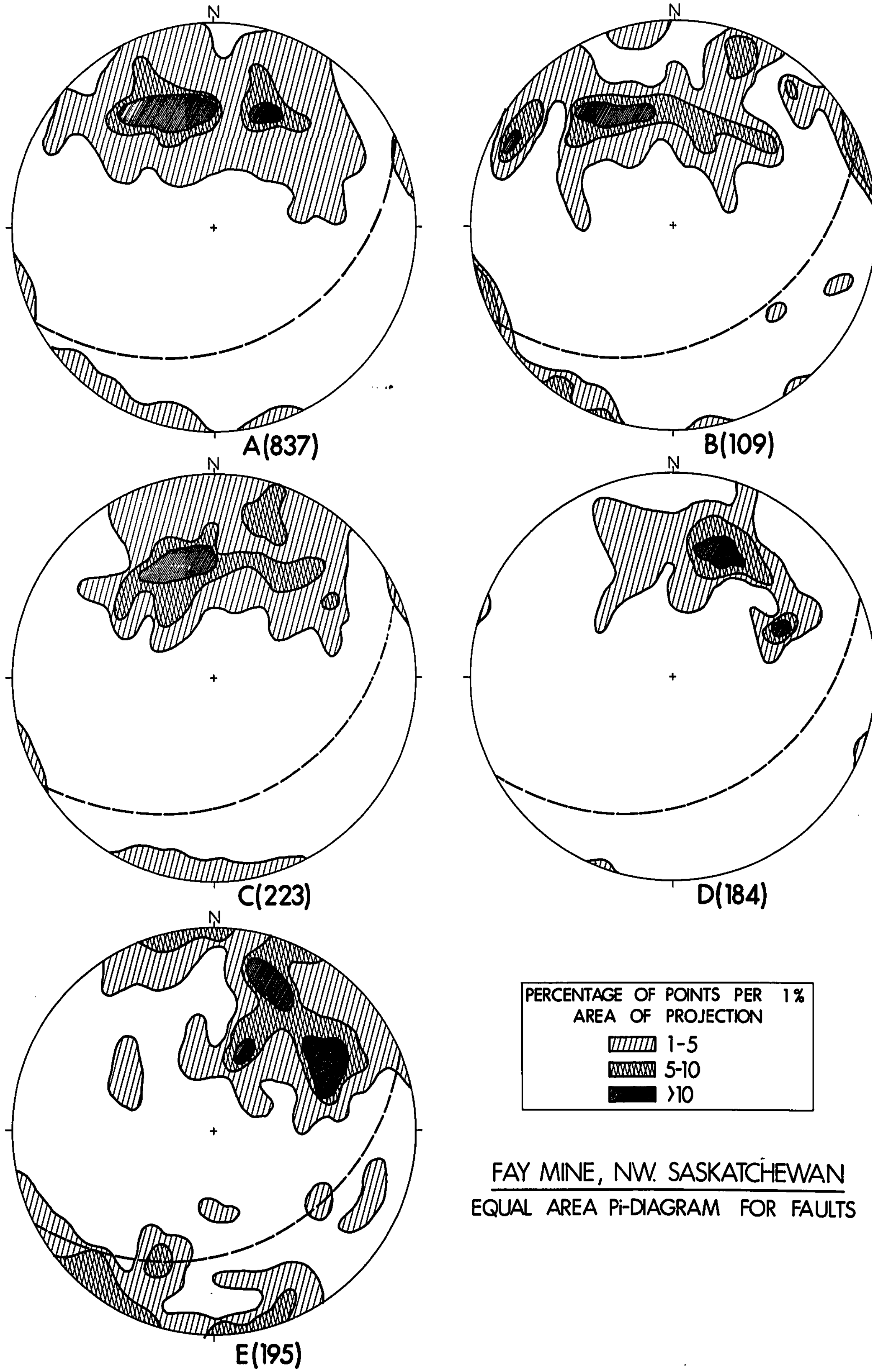
D 'Minor faults' in Donaldson Lake Gneiss about 1200 feet ($\sim$ 366 m) away from the St. Louis Fault.

E 'Minor faults' in the Foot Bay Gneiss.

Note:

* The numbers in brackets refer to the number of observations.

** The great circle of Figs. A, B, C, D, and E represents the St. Louis Fault.



FAY MINE, NW. SASKATCHEWAN

EQUAL AREA Pi-DIAGRAM FOR FAULTS

Fig. 19. Data concerning all joints measured in the Fay Mine.

A Joints in all levels examined.

B Joints in 'mylonitic granitic gneiss' within 300 feet (~91 m) of the St. Louis Fault.

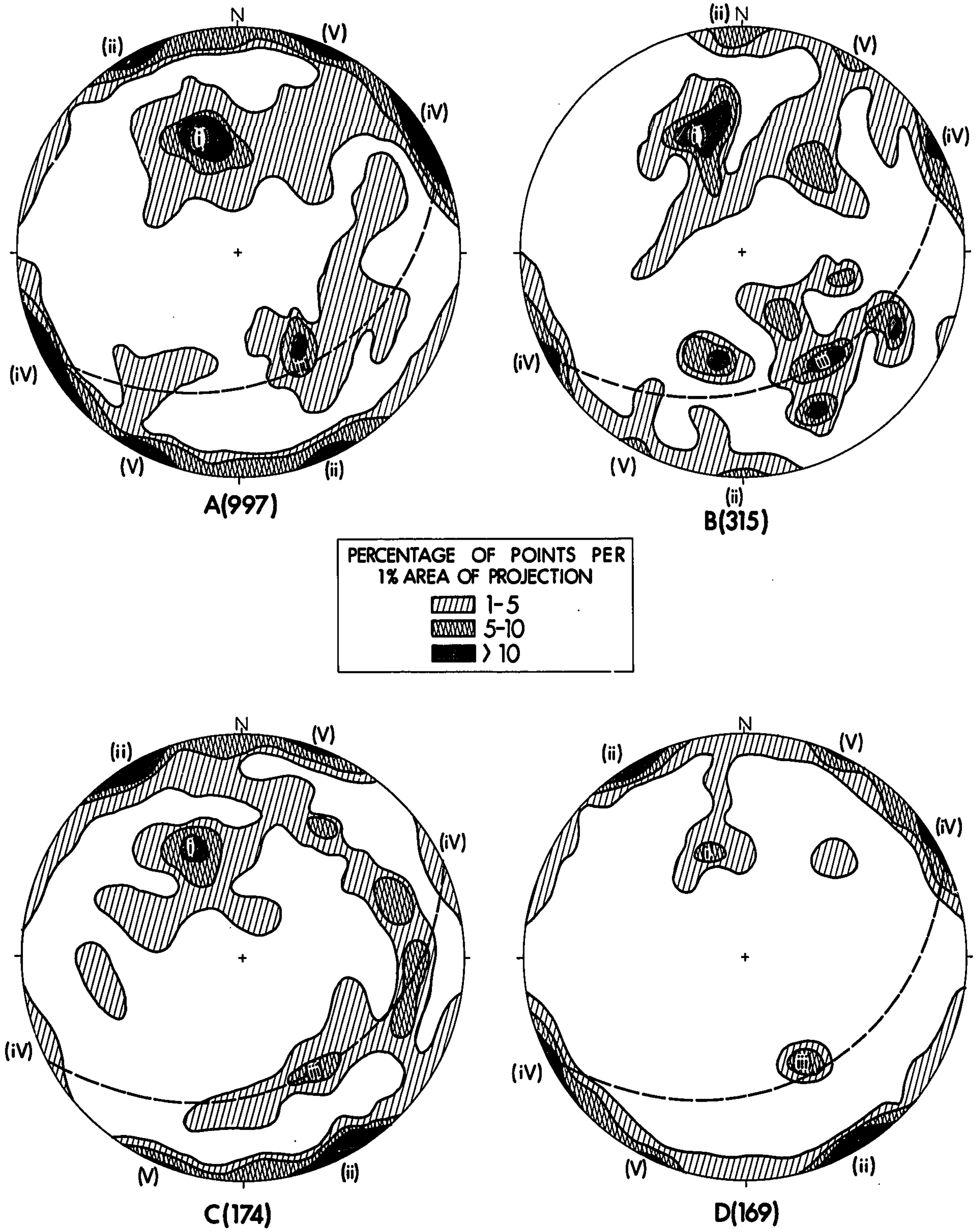
C Joints in Donaldson Lake Gneiss about 1200 feet (~366 m) away from the St. Louis Fault.

D Joints in the Foot Bay Gneiss.

Note:

* The numbers in brackets refer to the number of observations.

** The great circle of Figs. A, B, C and D represents the St. Louis Fault.



FAY MINE, NW. SASKATCHEWAN
EQUAL AREA Pi-DIAGRAMS FOR JOINTS

one representing planes dipping S70°E at 35° and the other (arcuate form) which represents planes dipping S20°W to S10°W at 55° to 75°. Such a data is interpreted as being due to the superimposition of a younger foliation (S 2) upon an older foliation (S 1) the latter having suffered deformation by folds (of an F 2 generation) whose axes plunge S30°W at about 50°. This conclusion is based upon the great circular arcuate distribution of the S 1 foliation poles, which infer an F 2 pole, as shown in Figure 17D. The retention of the S 1 foliation in the Foot Bay Gneiss is compatible with the fact that this member of the sequence is situated farthest away from the St. Louis Fault and with the data presented in Chapter 4. It is also noteworthy that the plunge of the F 2 folds inferred by the π pole of Fig. 17D is in good agreement with the folding around the Verna Mine (plunging at 41° towards S14°W) mentioned by Trigg (1964).

At this juncture it is interesting to consider the data derived from the uraniferous ore-veins of the Fay Mine represented in Fig. 17E. It can be seen that the veins dip generally S or SE with dips varying from 5° to 90°. However, the majority of the veins appear to have a dip of 45°S to SSE. This data plot is the result of the fact that the ore-veins occur almost parallel to the schistosity in the paraschists, and to the foliation in the mylonitic granitic gneiss near the St. Louis Fault. Consequently the net maximum of the data simply represents an approximately intermediate value between that for the foliation and the schistosity shown in Fig. 17A and B.

2. Fault Data

Fig. 18 includes all data obtained concerning recognizable faults within the sequence of the Fay Mine. Fig. 18A constitutes a total compilation of data for all faults measured within the mine and it can be clearly seen that the stereographic plot contains two maxima. A principal maximum representing faults striking N60°-70°E and dipping SE at ~50° is undoubtedly representative of all dislocations which parallel the major St. Louis Fault. The second maximum of Fig. 18A represents a common group of faults which strike S65°E and dip WSW at ~55°. This second fault set is considered to represent complimentary faults which belong to the set characterized by the ABC Fault. These faults are possibly bent off an originally more NW-SE strike by lateral movement of the St. Louis Fault system. This feature is well illustrated by exposures in the 13th Level of the Fay Mine.

In contrast to the stereographic plot of Fig. 18A, that of Fig. 18B represents selectively filtered data which characterize only those faults of sufficient magnitude to be classified under the arbitrary title of 'medium and large faults' during the mine survey. The information revealed by this plot is quite distinct since it demonstrates the presence of other fault sets. Once again the 'St. Louis type faults' are clearly dominant amongst these larger dislocations. The existence of the 'ABC type faults' is indisputable but these are obviously of minor importance. Three other maxima, not so well represented in Fig. 18A, are noteworthy. Two of these represent almost vertical faults striking N25°W whilst the third represents a concentration of faults striking N25°E and dipping ESE at 80°-85°. The orientation of these latter faults strongly suggests that they might represent a complimentary set of second-order shears (intersecting at ~50°) associated with a sinistral-strike-slip phase of movement on the St. Louis Fault system (c.f. Tremblay (1968) who postulated such sinistral movement on the St. Louis dislocation).

The data of Fig. 18A were further filtered in an attempt to demonstrate clearly the dependence of ' minor fault orientations' within the Fay Mine upon proximity of the St. Louis Fault. Fig. 18C presents 'minor-faults' data for the foliated mylonitic granitic gneiss within 300 feet of the St. Louis Fault plane and shows clearly that there is an overwhelming predominance of minor faults approximately parallel to the St. Louis Fault, striking N75°E and dipping at 50°-55°SE. Faults of the 'ABC type faults' are also evident.

In total contrast, the stereographic plot of Fig. 18D, which represents only those data on 'minor faults' within the Donaldson Lake Gneiss, situated about 1200 feet away from the St. Louis Fault plane, in the foot wall sequence of the Fay Mine, shows a marked paucity of faults parallel to the St. Louis Fault but a strong predominance of faults triking S70°-65°E and dipping 55°-50°SW (i.e. what have herein been considered as 'complimentary faults of the ABC system').

Finally the lowest degree of structural influence by the St. Louis Fault is demonstrated by those data obtained from 'minor faults' developed within the Foot Bay Gneiss, which occurs the furthest away from the fault plane in the Fay Mine (Fig. 18E). Here there is an almost total absence of orientation parallel to the St. Louis Fault and the stereographic plot shows considerable scatter. Noteworthy are a few vertical faults striking N70°E which might represent fractures related to the St. Louis system but which will be discussed later (see jointing). Also present within the plot there is a dual maximum sector which appears to represent clearly the presence of 'ABC type faults' (striking S35°E and dipping SW at 55°-60°) and of the complimentary 'ABC type faults' dislocations which strike S65°E and dip either N or S at 70°. Thus one can observe, in the lowest member of the Fay Mine's metamorphic sequence, the retention of older palimpsest complimentary fault sets related to the same system as the ABC Fault; a feature which positively augments the observations of preserved S 1 foliations within this unit described in the previous sections of this chapter.

3. Joint Data

Before considering the data appertaining to the joints observed within the Fay Mine metamorphic rocks, the reader is reminded that the data and the information considered so far have revealed at least two phases of folding with discrete associated foliations, and at least three directions of fault orientation with possible associated complimentary second-order shear sets. Thus the joint data will be discussed in the light of these observations with the objective of relating the principal joint sets to a net major deformational pattern.

Fig. 19A is a net compilation of data on all joints measured in the Fay Mine. Five distinct sets are evident from the stereographic plot, namely:

(i) A set of joints striking N75°E and dipping mainly at 50°SE. These parallel the St. Louis Fault and in part the schistosity in the metamorphics.

(ii) A vertical set, striking N65°-75°E, and paralleling the 'minor faults' described in the Foot Bay Gneiss, having the same strike at the St. Louis Fault, but obviously a steeper dip.

(iii) A set striking ~N65°-75°E (i.e. paralleling the previous set) but dipping at ~45°N. This set is thus approximately normal to the plane of the St. Louis Fault. It is noteworthy that these joints are always barren of ore in the Fay Mine.

(iv) A vertical set striking N30°-40°W.

(v) A vertical set striking N65°W.

Before considering the origins and inter-relationships of these five joint sets it is pertinent to examine Fig. 19B, C and D which represent selective data groups from locations in the Fay Mine at increasing distances from the St. Louis Fault respectively. Fig. 19B, representing joint data from the mylonitic granitic gneiss adjacent to the St. Louis Fault, exhibits all joint sets seen in the stereographic plot of Fig. 19A with the marked exception of distinction that the vertical sets appear to strike in a more E-W direction. On this basis it is concluded that this latter joint set has locally been rotated.

In contrast, Fig. 19C illustrates data from the Donaldson Lake Gneiss, farther away from the St. Louis Fault plane. This stereographic plot exhibits a very similar statistical distribution to that of the composite plot shown in Fig. 19A, and consequently it is possible to say that at this location all joint sets are developed. But the stereogram clearly indicates a predominance of the N65°-75°E striking vertical set (ii).

Finally a completely unique joint pattern is evident within the Foot Bay Gneiss, the unit farthest away from the St. Louis Fault (Fig. 19D). Here there is a marked paucity of joints paralleling or normal to the St. Louis Fault. The locality is thus characterized by vertical joints striking N65°-75°E, N40°W and N65°W. On the basis of these joint data the three latter sets must be related to folding phenomena and not to the St. Louis Fault. In the light of the predominance of NE-SW trending F 2 folds in the Fay Mine area, together with the presence of a strong S 2 schistosity in the Foot Bay Gneiss, it is logical to consider the relationship of the joints in this unit to the F 2 structures and their causative stress field. On this basis the vertical joints could simply represent NW and WNW striking F 2 complimentary shear joints and the complimentary ENE striking F 2 tension joint set. The F 2 shear set too agrees exactly with the orientation of what were termed in the previous section 'ABC type faults' and 'complimentary ABC type faults'. It is therefore concluded that these faults were generated along the F 2 joint anisotropies.

The conclusions of the joint studies in the Fay Mine are diagrammatically summarized with relation to certain other structural features in Fig. 20.

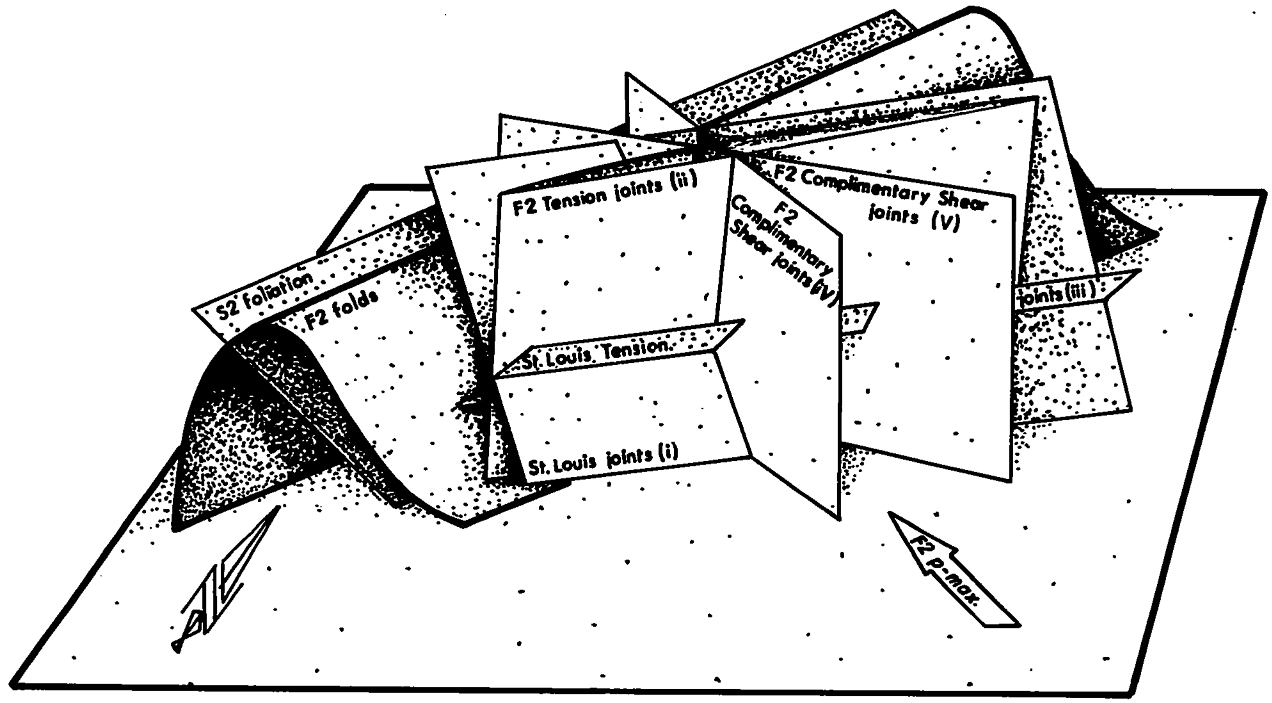
4. Statistical Relationships between Structures and Mineralization Type

In an attempt to document, for paragenetic purposes the relationship between mineralization of various types and certain structures within the Fay Mine, the aforementioned 5500 data sets were again filtered. Plots of the statistical orientation of structures bearing veins of epidote (var. pistacite), calcite, quartz, pyrite, and hematite were produced. The following observations were made from the resultant stereograms of Figs. 21 to 23.

(a) Epidote is mainly found in non-uraniferous veins occupying minor faults of the ABC-type and to some extent in all joint sets. There is a marked predominance of epidote veins in the joints F 2 shear set. Likewise, a marked absence of epidote in the ore-veins was noted; (Fig. 21A and B).

(b) Chlorite (the data for which is presented in Fig. 21C, D and E) was found to be abundant in all fault zones of the St. Louis and ABC systems. This mineral was, however, rarely seen in the joints paralleling the St. Louis Fault, whereas it was particularly abundant in joints of the St. Louis tension fracture set (such fractures being obviously more dilatant and open to hydrothermal fluids effecting chloritization of wall rocks). Fig. 21D clearly illustrates

Fig. 20. Approximate relationship between joints and F 2 structures, in the Fay Mine, NW Saskatchewan.



APPROXIMATE RELATIONSHIP BETWEEN JOINTS AND F2 STRUCTURES.
FAY MINE , NW. SASKATCHEWAN.

Fig. 21. Data concerning structures bearing veins of epidote and chlorite.

A 'Minor faults' with epidote.

B Joints with epidote.

C Joints with chlorite.

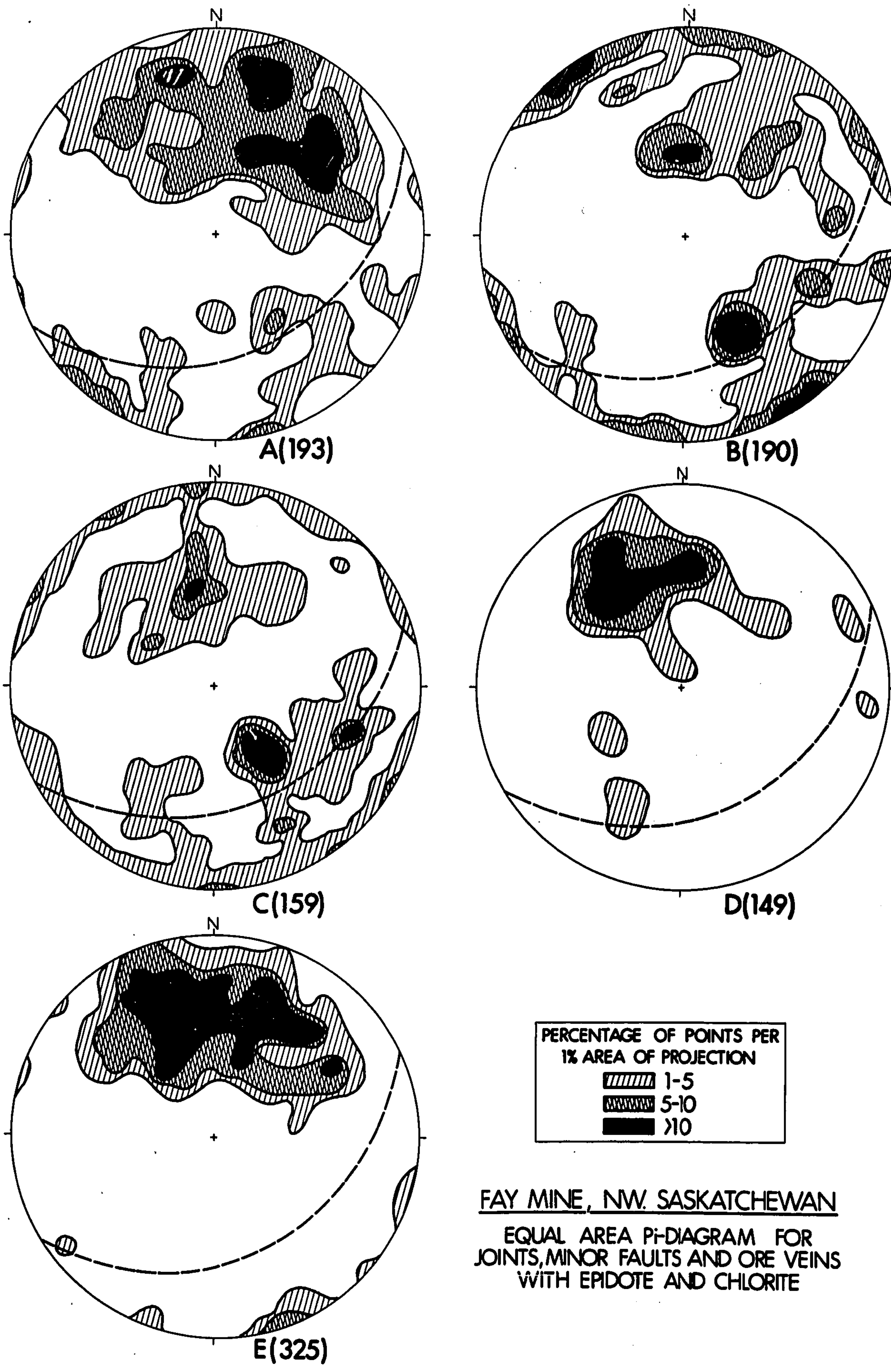
D Ore-veins with chlorite.

E 'Minor faults' with chlorite.

Note:

* The numbers in brackets refer to the number of observations.

** The great circle of Figs. A, B, C, D and E represents the St. Louis Fault.



FAY MINE, NW. SASKATCHEWAN

EQUAL AREA Pi-DIAGRAM FOR JOINTS, MINOR FAULTS AND ORE VEINS WITH EPIDOTE AND CHLORITE

Fig. 22. Data concerning structures bearing veins of calcite and pyrite.

A Ore-veins with calcite.

B Fractures with calcite.

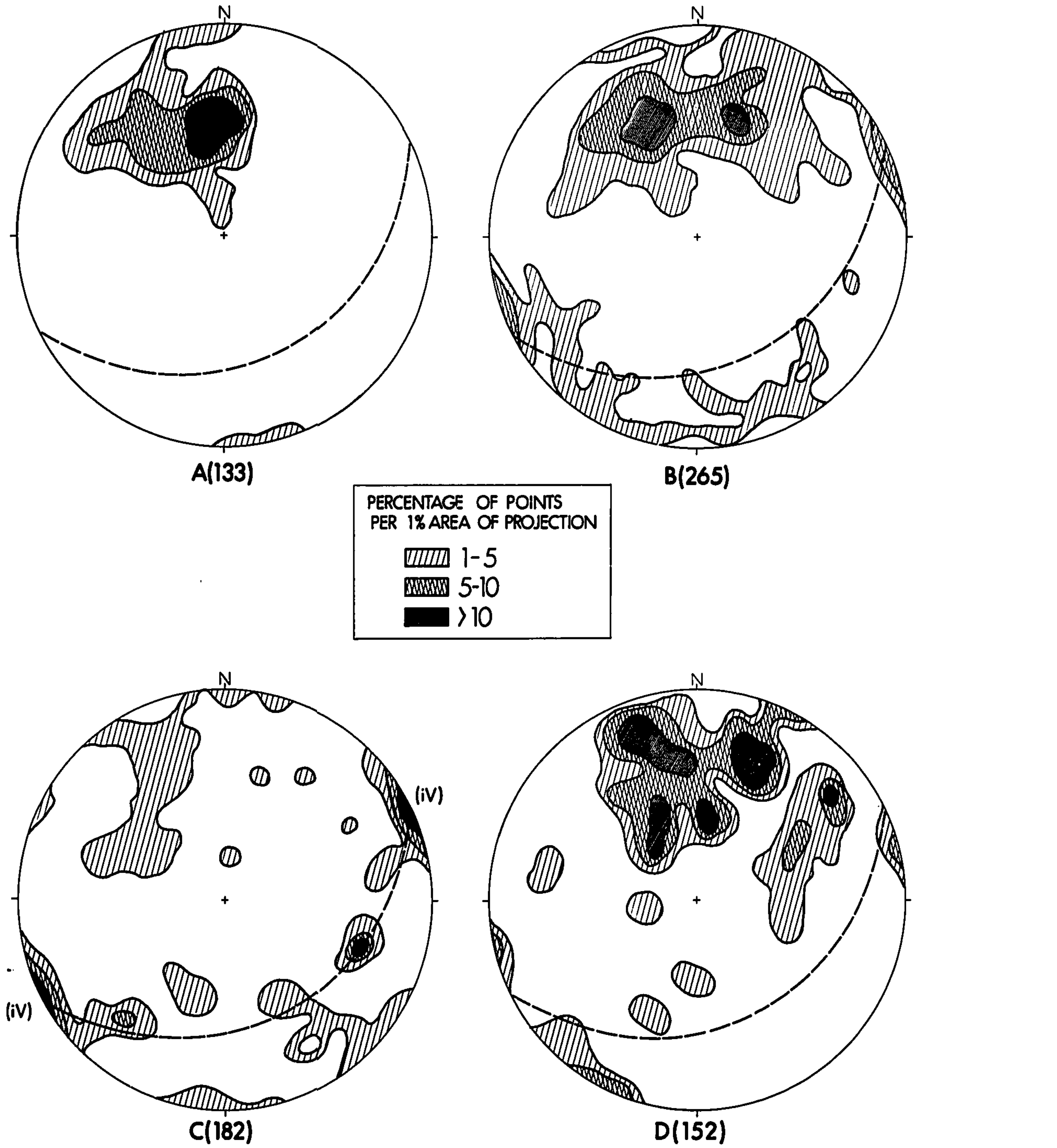
C Joints with calcite.

D 'Minor faults' with pyrite.

Note:

* The numbers in brackets refer to the number of observations.

** The great circle of Figs. A, B, C and D represents the St. Louis Fault.



FAY MINE, NW. SASKATCHEWAN.

EQUAL AREA Pi-DIAGRAMS FOR ORE VEINS, FRACTURES, JOINTS AND MINOR FAULTS WITH CALCITE AND PYRITE.

Fig. 23. Data concerning structures bearing veins of hematite and quartz.

A Ore-veins with hematite.

B 'Minor faults' with hematite.

C Joints with hematite.

D Ore-veins with quartz.

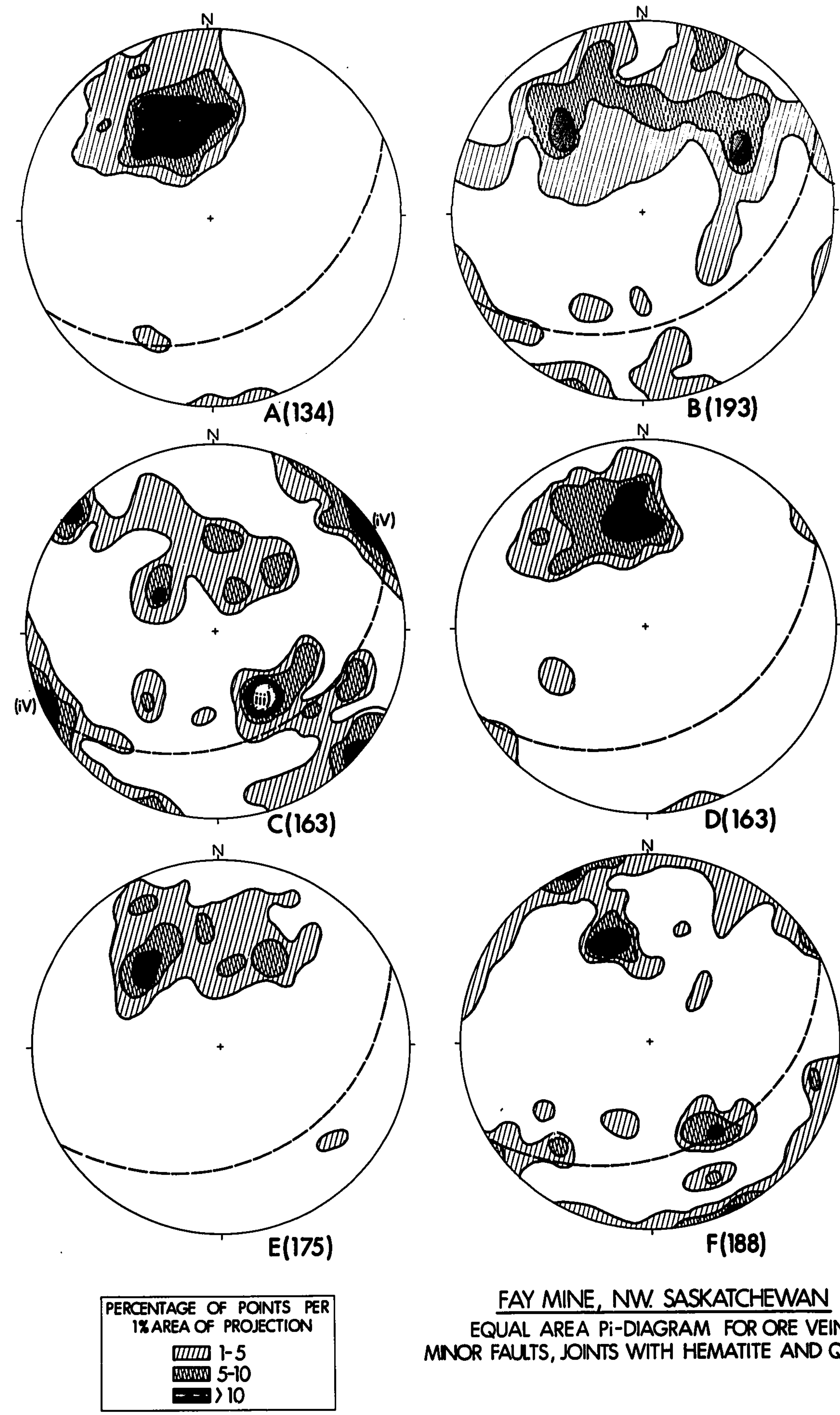
E 'Minor faults' with quartz.

F Joints with quartz.

Note:

* The numbers in brackets refer to the number of observations.

** The great circle of Figs. A, B, C, D, E and F represents the St. Louis Fault.



FAY MINE, NW. SASKATCHEWAN

EQUAL AREA Pi-DIAGRAM FOR ORE VEINS, MINOR FAULTS, JOINTS WITH HEMATITE AND QUARTZ the fact that chlorite commonly accompanies pitchblende in the Fay Mine ore veins.

(c) Calcite appears to be ubiquitous within all sets of the 'major fractures' particularly in the St. Louis Fault types (Fig. 22B) and accompanies the pitchblende and chlorite in the ore veins (Fig. 22A). Fig. 22C shows that this carbonate appears to be present in all joint sets, but it is notably predominant in the NW-SE striking components of the complimentary F 2 shear set.

(d) Pyrite exhibits a certain predominance within the veins associated with the 'complimentary ABC type faults' of the mine (Fig. 22D).

(e) Hematite is associated with all the minor fault types and with all the joint sets (Fig. 23A, B and C). It is noticeable, however, that Fig. 23C illustrates a distinct predominance of hematite veins in the St. Louis tension fractures (iii) and in the same NW striking F 2 shear joints (iv) which were characterized by common calcite infillings. Fig. 23A also demonstrates the ubiquity of hematite developed in the uraniferous ore veins.

(f) Quartz, whose data appear in Fig. 23D, E and F accompanies uraninite within the veins parallel to the schistosity (Fig. 23D). This mineral is also present as veins in all faults and joint sets of the Fay Mine (Fig. 24E and F).

Finally, it is particularly noteworthy that, during the statistical studies, almost 100% of the observed occurrences of pitchblende were noted in the foliated schistose members of the Fay Mine Complex. Only rare occurrences of uranium mineralization were noted in the Donaldson Lake Gneiss and Foot Bay Gneiss.

The Tectonic Development of the Fay Mine Area

The following scheme for the development of the tectonic structures and certain geologic features in the Fay Mine is proposed on the basis of the data presented herein:

(1) The Foot Bay Gneiss situated at the base of the sequence present in the Fay Mine was first folded during the Kenoran orogeny along a series of folds (F 1) which trend NW-SE or N-S, and parallel the main trend characterizing the Slave structural province.

(2) Subsequent to the deposition of a sequence of sediments and volcanics now represented by the Donaldson Lake Gneiss and the Fay Mine Complex, a second series of folds (Hudsonian) was then generated and superimposed upon the old Kenoran structures. This second phase of folding (F 2) was characterized by NE-SW trending fold axes and by a foliation which dipped southeastwards. During the later stages of the F 2 tectonic phase, extensive horizons of folded mylonites probably developed by 'bed over bed' type sliding and consequent cataclasis. This F 2 phase was also accompanied by the generation of three well-developed joint sets, one NE-SW set of a tensional nature and two complimentary shear sets striking NW and WNW

respectively.

It is felt that the latter stages of this F 2 phase were accompanied by the localized taphrogeosynclinal deposition of a sequence of sediments (the Martin Formation) on top of the evolving Tazin basement; (Fraser et al., 1970). Thus the newly deposited Martin sediments were soon involved in the late-stage F 2 tectonic cycle, becoming folded into broad, open NE-SW structures and extensively faulted.

The development of the F 2 cycle was characterized in its latter stages by the generation of major tear faults along sites determined by the original F 2 shear sets. These faults are now typified by the ABC Fault and the Baska Fault.

(3) Subsequent to the development of the basic F 1 - F 2 tectonic framework and the associated structural anisotropies, repeated movement of variable character took place along the established faults and joints. Thus the St. Louis Fault, originally initiated as a probable F 2 tension joint system, exhibits evidence of both normal and sinistral lateral movements (Tremblay, 1968) whereas many of the faults, such as the ABC Fault, are characterized by arcuate traces which are a result of the amalgamation of the F 2 shear joint set.

These conclusions are in excellent agreement with the observations of previous workers such as Tremblay (1968), Trigg (1964) and Beck (1970). The existence of F 1 and F 2 structures, their orientation and their interrelationships are also fully compatible with the results of Koster (1970) on the Tazin metamorphics of the Tazin Lake region.

Structural Control of the Uranium Mineralization

The study has clearly shown that, in the Fay Mine, the uranium mineralization is confined only to the Fay Mine Complex and was obviously emplaced during or subsequent to the development of the schistosity (S 2) associated with the NE-SW trending younger (F 2) folds. Examination of the 40 +00 E and 48 + 00 E sections from the Verna Mine (Figs. 15 and 16) also demonstrates that the main ore bodies are encountered in dilatant zones occupying the crests, troughs and limbs of the F 2 folds, wherever these folds exhibit minimal plunge.

It is also striking that the uranium mineralization is neither encountered in the F 1 foliation structures, nor in any of the mineralized F 2 joints. Also the St. Louis Fault activity, which was obviously accompanied by hydrothermal events, has effected only local rotational reorientation and brecciation of the ore veins.

Such conclusions place rather strict confines upon the age of the initiation of the epigenetic uranium mineralization in the Fay Mine and have obvious bearing upon future exploration programs.

CHAPTER 6 - GEOCHRONOLOGY, WHOLE-ROCK Rb-Sr STUDIES

Introduction

The whole rock method of Rb-Sr dating is a powerful tool currently available to geochronologists, since it seems that medium-sized specimens of rocks may remain closed systems with respect to Rb and Sr, even when subjected to high grade metamorphism. On the other hand, analyses of cogenetic whole-rock samples with different Rb-Sr ratios are capable of providing a test for closed system behaviour (Compston, 1961).

Whole-rock Rb-Sr studies have been undertaken in order to examine the scale on which closed-system whole-rock behaviour was maintained under conditions of very strong kinematic metamorphism and mineralization. It was also intended to provide additional information concerning the age of the Foot Bay Gneiss, Donaldson Lake Gneiss and the discordant pegmatite dykes of the surrounding Beaverlodge area.

Previous Literature

Several authors have determined radiometric ages for rocks and vein materials of the Churchill province, but few whole-rock Rb-Sr age determinations are presently available for the Beaverlodge area. Radiometric ages for the Tazin metamorphics have been proposed by Collins, Farquhar and Russell (1954), Wasserburg and Hayden (1955), Eckelmann and Kulp (1956), Aldrich and Wetherill (1956), Russell and Ahrens (1957), Fahrig (1961), Lowdon (1961), Lowdon et al. (1963), Burwash et al. (1962), Koster (1962), Wanless et al. (1965, 1966, 1967, 1968) and Beck (1966).

U-Pb ages for samples of uraninite collected in the Fay Mine were reported by Koeppel (1968), whilst whole-rock Rb-Sr ages for the Tazin metamorphics and basement gneisses, granites and pegmatites were presented by van Breeman (1966), Baadsgaard and Godfrey (1967) and Sinha (1970).

Samples

The samples selected for Rb-Sr measurements are representative of three stratigraphically associated rock types in the Tazin Group, namely: the Foot Bay Gneiss, the Donaldson Lake Gneiss and discordant pegmatite dykes. Unfortunately most of the rock samples collected in the mine environs are cataclastic to mylonitic (see Appendix for petrographic description of samples) and are generally situated near areas of extensive secondary mineralization. It is therefore highly unlikely that these underground and surface whole-rock samples have behaved as closed chemical systems and consequently they fail to meet one of the most fundamental requirements of geochronology (Baadsgaard, 1965). In addition, the Foot Bay and Donaldson Lake Gneisses are largely meta-sedimentary in nature and the problematic questions of the homogeneity and degree of weathering of the original sediments

Table 5 - Rb/Sr Analytical Data, Foot Bay Gneiss

Sample	Rb, ppm	Sr^N, ppm	Rb^{87}/Sr^{86}, atomic ratio	Sr^{87}/Sr^{86}, atomic ratio
F-25-001	134.5	142.2	2.735	0.8029
F-25-002	136.6	140.2	2.819	0.8328
F-25-092	2.77	129.9	0.062	0.7191
F-25-097	100.8	334.4	0.872	0.7357
F-25-101	138.1	417.9	0.956	0.7394
F-25-102	122.1	324.0	1.090	0.7494
F-22-023	123.4	336.1	1.062	0.7469

Note: The estimated maximum analytical error for individual analyses was $\pm$ 2% for Rb^{87}/Sr^{86}. The maximum measurement error for Sr^{87}/Sr^{86} was $\pm$ 0.001.

are added to the interpretation of Rb-Sr data.

Notwithstanding these drawbacks to simple geochronological interpretation, Rb-Sr data may be used to test the open-system behaviour of these different rock types under the conditions of metamorphism, cataclasis and mineralization which have prevailed. Furthermore, if one attempts to correlate the age of the Foot Bay and Donaldson Lake Gneisses with ages in other parts of the Athabasca region, the extent and timing of the effects of open-system metamorphism may in part be outlined.

Analytical

Whole-rock samples of ~25 kg were crushed by conventional methods. Each sample was repeatedly quartered and coned to a final weight of approximately 15 grams. Samples with favourable Rb-Sr ratios were selected by X-ray fluorescence spectrometry. Isotope analyses were performed on a 6 inch, 60^{o} sector, single-filament, mass spectrometer designed and built by Dr. G.L. Cumming of the Department of Physics, the University of Alberta. Samples used for concentration determinations were spiked with enriched Sr^{84} and Rb^{87} tracers before dissolution. Rb and Sr were separated and purified by cation exchange procedures.

The constants employed in this work were:

Sr^{86}/Sr^{88} (atomic) = 0.1194 (all Sr data being normalized to this value)

Rb^{85}/Rb^{87} (atomic) = 2.60

$\lambda = 1.39 \times 10^{-11}$/years

Table 6 - Rb/Sr Analytical Data, Donaldson Lake Gneiss

Sample	Rb, ppm	Sr^N, ppm	Rb^{87}/Sr^{86} atomic ratio	Sr^{87}/Sr^{86}, atomic ratio
SU-1	113.8	219.0	1.503	0.7580
SU-3	57.6	398.5	0.418	0.7228
SU-5	10.48	66.0	0.459	0.7434
F-25-010	52.5	96.7	1.571	0.7709
F-25-014	79.7	107.8	2.139	0.7850
F-25-016	86.0	73.1	3.467	0.8178
F-25-018	10.03	327.6	0.089	0.7215
F-25-019	6.58	100.2	0.190	0.7313

Note: The estimated maximum analytical error for individual analyses was $\pm$ 2% for Rb^{87}/Sr^{86}. The maximum measurement error for Sr^{87}/Sr^{86} was $\pm$ 0.001.

Table 7 - Rb/Sr Analytical Data, Discordant Pegmatite Dykes

Sample	Rb, ppm	Sr^N, ppm	Rb^{87}/Sr^{86}, atomic ratio	Sr^{87}/Sr^{86}, atomic ratio
F-25-004	167.1	24.61	19.67	1.2761
F-25-006	841.3	50.34	48.43	2.0934
F-25-011	6.17	78.72	0.227	0.7386
F-25-012	283.6	52.93	15.53	1.0503
F-25-021	255.7	62.93	11.77	1.0509
F-25-024	233.6	85.43	7.92	0.9413

Note: The estimated maximum analytical error for individual analyses was $\pm$ 2% for Rb^{87}/Sr^{86}. The maximum measurement error for Sr^{87}/Sr^{86} was $\pm$ 0.001.

The measured blanks were less than 1 part per 1000 of sample Sr and were therefore considered as negligible. The estimated maximum analytical error for individual analyses was $\pm$ 2% for Rb^{87}/Sr^{86}. The maximum measurement error for Sr^{87}/Sr^{86} was $\pm$ 0.001.

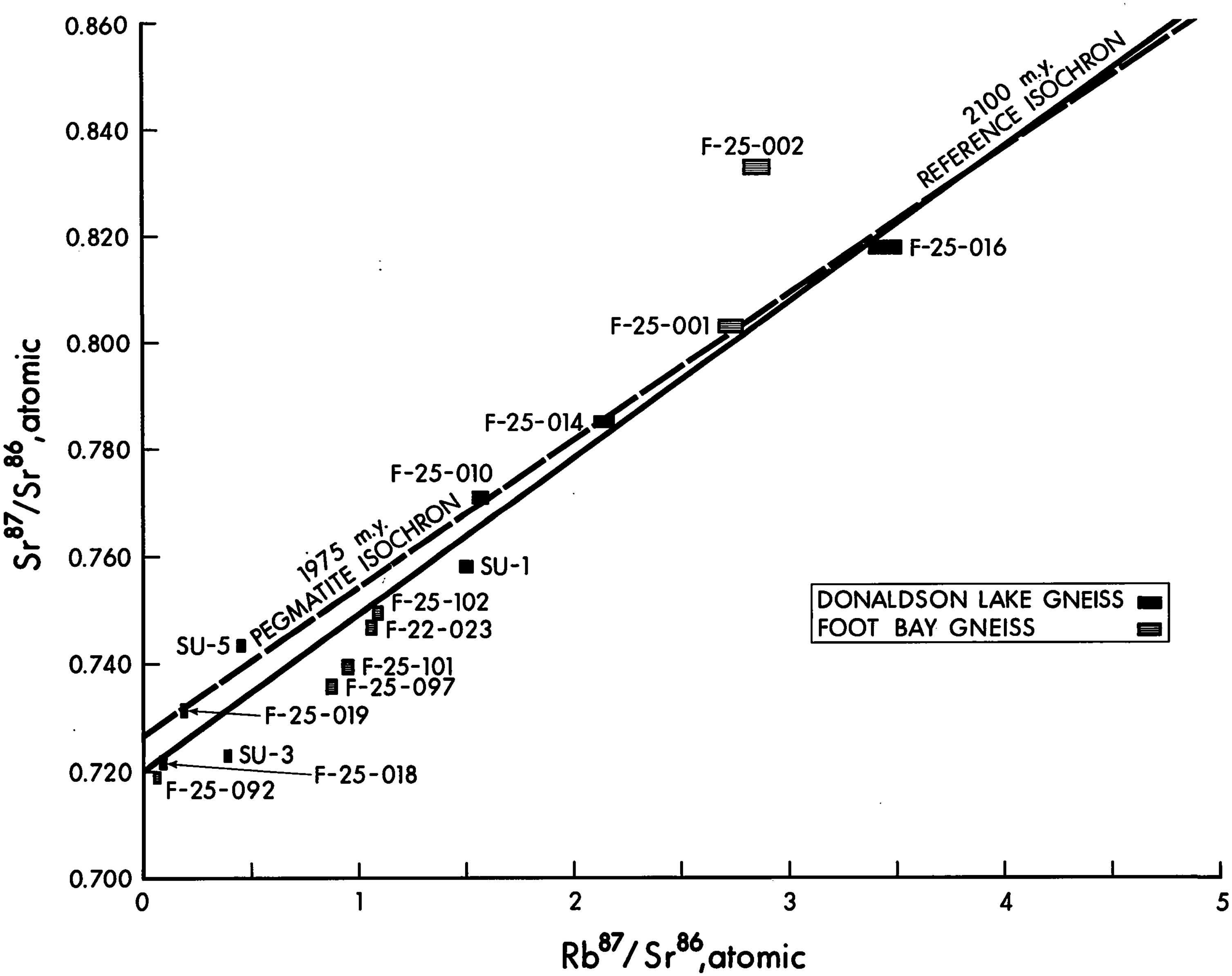
Several Sr^{87}/Sr^{86} determinations analyses were carried out on the Eimer and Amend Sr standard. The mean of 9 determinations performed in the Geochemical Laboratory of the University of Alberta is 0.7081 $\pm$ 0.0006 (2σ). Where feasible, isochron ages were obtained using an APL computer program (RBSRISOCHRON) written by H.B. and based upon the method of least squares regression for a straight line (York, 1966; McIntyre et al., 1966) which allows for non-uniform variance in the Rb^{87}/Sr^{86} ratios and incorporates prior estimates of the precision for both coordinates.

Results

Analytical results for samples of the Foot Bay Gneiss, Donaldson Lake Gneiss and discordant pegmatite dykes are presented in Tables 5, 6 and 7. Nicolaysen Rb-Sr isochron plots are shown in Fig. 24 for the Foot Bay and Donaldson Lake Gneisses and in Fig. 25 for the discordant pegmatite dykes.

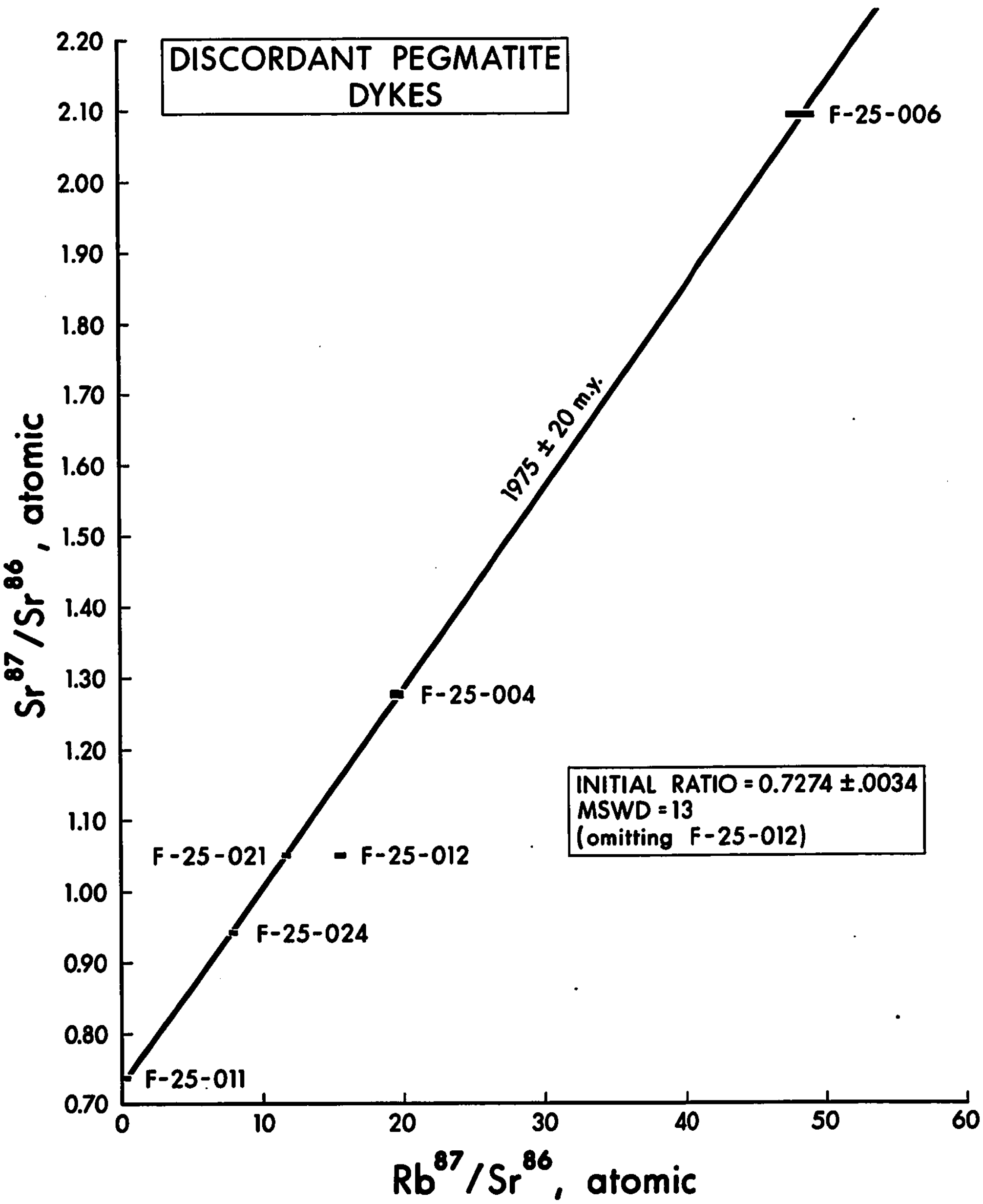
As seen in Fig. 24 the plotted Rb-Sr whole-rock points scatter badly and no reasonable isochron may be computed. A reference isochron at ~2100 m.y. (omitting sample F-25-002) indicates that the gneisses are at least 2100 m.y. old, but probably considerably older, taking into account

Fig. 24. Nicolaysen Rb-Sr isochron plot for the Foot Bay Gneiss and Donaldson Lake Gneiss.



0.860
0.840
0.820
0.800
0.780
0.760
0.740
0.720
0.700
0
1
2
3
4
5
Sr87/Sr86,atomic
Rb87/Sr86,atomic
2100 m.y. REFERENCE ISOCHRON
1975 m.y. PEGMATITE ISOCHRON
F-25-002
F-25-016
F-25-001
F-25-014
F-25-010
SU-1
F-25-102
F-22-023
SU-5
F-25-101
F-25-097
F-25-019
SU-3
F-25-018
F-25-092
DONALDSON LAKE GNEISS
FOOT BAY GNEISS

Fig. 25. Nicolaysen Rb-Sr isochron plot for the discordant pegmatite dykes.



DISCORDANT PEGMATITE DYKES
1975 ± 20 m.y.
F-25-006
F-25-004
F-25-021
F-25-012
F-25-024
F-25-011
INITIAL RATIO = 0.7274 ±.0034
MSWD = 13
(omitting F-25-012)
Sr87/Sr86, atomic
Rb87/Sr86, atomic

the high apparent values for the Sr^{87}/Sr^{86} initial ratio. A combined isochron for the Foot Bay and Donaldson Lake Gneisses, which would take into consideration sample F-25-002, would give an age of ~2300 m.y. which is in good agreement with the 'survival' ages reported by Aldrich and Wetherill (1956), by Burwash et al. (1962) and by Beck (1966) for the basement gneisses of the Athabasca region.

If the clastic material which ultimately formed the Foot Bay and Donaldson Lake Gneisses was derived from rocks with an initial Sr^{87}/Sr^{86} of 0.700, then from 400 to 800 m.y. could have elapsed until these rocks were partly homogenized at a later time. This 'later time' was most probably the Hudsonian orogeny, peaking at around 1900 m.y.

The discordant pegmatite dykes' isochron plot of Fig. 25 gives, however, a fair isochron at 1975 $\pm$ 20 m.y., omitting sample F-25-012, but yields a very high initial ratio of ~0.727. This date is in agreement with the Rb-Sr ages reported by Davis et al. (1956) and Aldrich et al. (1958) for pegmatite samples collected at Viking Lake. The discordant pegmatite dykes collected in the Fay Mine have been affected by only slight cataclasis, thus they are probably preserved as 'closed systems'. In this event, the pegmatite dykes may have been intruded close to 1975 m.y. ago (sample F-25-006 must be close to this date), but have been contaminated or derived (by local remelting ?) from older supracrustal materials at depth. Since five of the points are reasonably closely co-linear, the latter probability is favoured.

If the materials of the Foot Bay and Donaldson Lake Gneisses are roughly equivalent in age to the Nolan Granodiorite (2370 m.y. by K-Ar) or to the 'migmatitic-gneissic basement' complex in NE Alberta (2300 - 2600 m.y.), then they have been incompletely, but strongly, rehomogenized by the Hudsonian orogeny.

If melting at depth produced the pegmatites they could represent the alkali-rich (and Sr^{87}-rich) phase of the gneissic system and thus the high apparent initial ratio, seen in Fig. 25, can be accounted for. The melting at depth may be loosely correlated with the formation of granites in the Hudsonian along the Alberta-Saskatchewan border. These granites, the so-called Colin Lake Granodiorite series date at ~1900 m. y. by the whole-rock Rb-Sr method (Baadsgaard and Godfrey, pers. comm.).

Discussion

Stratigraphic evidence, augmented by structural and petrographic data, indicate that the Foot Bay Gneiss is relatively older than the Donaldson Lake Gneiss, and therefore the reference isochron plotted in Fig. 24 merely reflects an average 'minimum' age for the two basement units.

The apparent isochron of ~3200 m.y. which one could draw through the five data points belonging to the Foot Bay Gneiss (omitting samples F-25-092 and F-25-001) in Fig. 24, although probably meaningless, may suggest the possibility of the existence of palimpsest Kata-Archean remnants in parts of the Canadian Shield which are not so intensely disturbed as the Beaverlodge area.

Two hypothetical models might be employed to explain the observed sequence of events in the Fay Mine environs:

1. Part of the Tazin Group (the Foot Bay Gneiss) is an Archean rock up-dated by the Kenoran and the Hudsonian orogenies, part is Aphebian (the Donaldson Lake Gneiss and the Fay Mine Complex), whilst the discordant pegmatite dykes are of Hudsonian age.

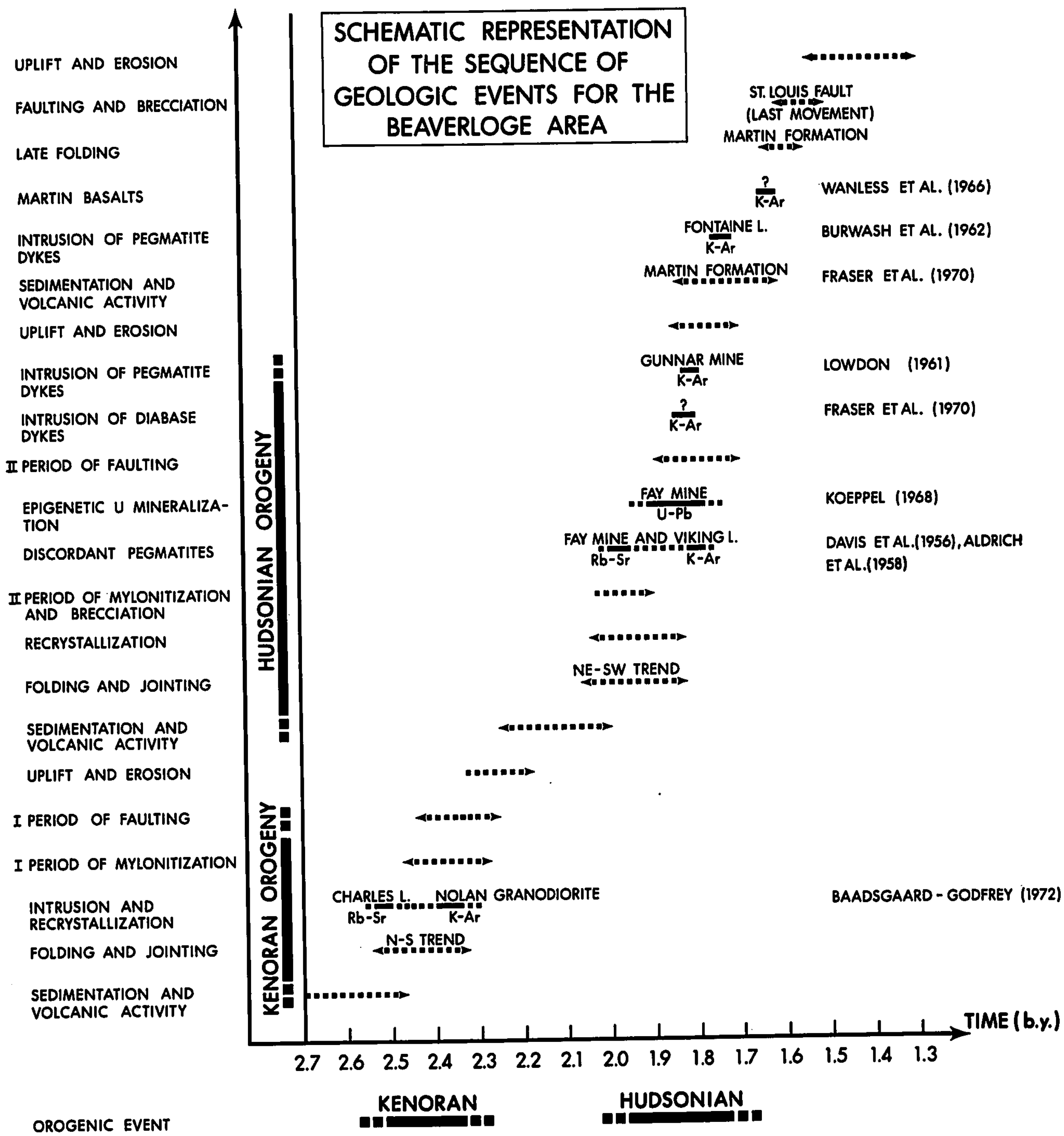
2. Part of the Tazin Group (the Foot Bay Gneiss) is a Kata-Archean remnant up-dated by the Kenoran and the Hudsonian orogenies, part is Archean (the Donaldson Lake Gneiss) and part is Aphebian (the Fay Mine Complex); the discordant pegmatite dykes being of Hudsonian age.

The author believes that model (1) provides a better explanation than model (2) for the geochronologic data from the Tazin Group. On this basis a postulated sequence of events for the Beaverlodge area is schematically represented in Fig. 26 and may be summarized as follows:

1) A sequence of sedimentary and volcanic rocks was probably deposited on an older basement about 2700-2500 m.y. ago.

2) A tectonic cycle (Kenoran orogeny) metamorphosed these supracrustal rocks (Foot Bay Gneiss) and developed N-S trending folds. Mobilization and intrusion were probably followed by a postcrystalline dynamic phase.

Fig. 26. Schematic representation of the sequence of geologic events for the Beaverlodge area.



SCHEMATIC REPRESENTATION OF THE SEQUENCE OF GEOLOGIC EVENTS FOR THE BEAVERLOGE AREA
UPLIFT AND EROSION
FAULTING AND BRECCIATION
LATE FOLDING
MARTIN BASALTS
INTRUSION OF PEGMATITE DYKES
SEDIMENTATION AND VOLCANIC ACTIVITY
UPLIFT AND EROSION
INTRUSION OF PEGMATITE DYKES
INTRUSION OF DIABASE DYKES
II PERIOD OF FAULTING
EPIGENETIC U MINERALIZA-TION
DISCORDANT PEGMATITES
II PERIOD OF MYLONITIZATION AND BRECCIATION
RECRYSTALLIZATION
FOLDING AND JOINTING
SEDIMENTATION AND VOLCANIC ACTIVITY
UPLIFT AND EROSION
I PERIOD OF FAULTING
I PERIOD OF MYLONITIZATION
INTRUSION AND RECRYSTALLIZATION
FOLDING AND JOINTING
SEDIMENTATION AND VOLCANIC ACTIVITY
HUDSONIAN OROGENY
KENORAN OROGENY
ST. LOUIS FAULT
(LAST MOVEMENT)
MARTIN FORMATION
?
K-Ar
WANLESS ET AL. (1966)
FONTAINE L.
K-Ar
BURWASH ET AL. (1962)
MARTIN FORMATION
FRASER ET AL. (1970)
GUNNAR MINE
K-Ar
LOWDON (1961)
?
K-Ar
FRASER ET AL. (1970)
FAY MINE
U-Pb
KOEPPEL (1968)
FAY MINE AND VIKING L.
Rb-Sr
K-Ar
DAVIS ET AL.(1956), ALDRICH ET AL.(1958)
NE-SW TREND
CHARLES L.
NOLAN GRANODIORITE
Rb-Sr
K-Ar
BAADSGAARD - GODFREY (1972)
N-S TREND
TIME (b.y.)
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
KENORAN
HUDSONIAN
OROGENIC EVENT

3) The Kenoran cycle was followed by uplift and erosion and by the deposition of Aphebian sediments and volcanics (Donaldson Lake Gneiss and Fay Mine Complex precursors). Some of these sediments are thought to have been uraniferous.

4) Polymetamorphism during the Hudsonian tectonic cycle (a) transformed these Aphebian sediments into paragneisses and paraschist and (b) remetamorphosed the Kenoran rocks. Refolding of the Kenoran structures was also accompanied by folding of the Aphebian sequence on a NE-SW trending pattern. Mylonitization and remylonitization of the crystalline rocks accompanied the main period of the Hudsonian orogeny, whilst the final orogenic phase was marked by the emplacement of late-kinematic discordant pegmatite dykes and the intrusion of granites and granodiorites (e.g. NE corner of Alberta).

5) Fault movements favoured the rapid deposition, in taphrogeosynclinal basins (Fraser et al., 1970), of the Martin Formation which itself was affected by the last stage of the Hudsonian orogeny and developed the same NE-SW fold pattern as the underlying Tazin metamorphics.

6) A set of faults, active at the very end of the tectonic cycle, produced normal and lateral sinistral dislocation. These faults offset the whole sequence and also some of the post-orogenic diabase dykes intruded in the area.

7) Discontinuous intrusion of porphyry dykes was followed by some block faulting in the basement.

Conclusions

The data reported in Fig. 24 do not supply a meaningful age for the Foot Bay Gneiss and the Donaldson Lake Gneiss, although they provide an estimate of the nature of the isotopic redistribution and of the degree of homogenization attained by the system. Previous work has demonstrated that a linear array on an isochron diagram can only be produced by complete chemical equilibration and 'closed system' evolution (Lanphere et al., 1964). In this case the strong deviation (beyond experimental error) from the reference isochron of most of the points plotted in Fig. 24, indicates a significant degree of 'open system behaviour' which might be easily explained if one considers the intense deformation, the extensive secondary mineralization and possibly the K and Rb metasomatism which affected the Fay Mine environs (Burwash and Krupička, 1969, 1970). In the case of the Foot Bay Gneiss and Donaldson Lake Gneiss, partial homogenization of different portions of the rock at different times, or local variation in the degrees of cataclasis and mylonitization (and ultimately the incomplete recrystallization of two different rock types of possible different initial ages) have to be seriously considered to explain the scattering points in the Rb-Sr isochron diagrams.

Although recent work (Abbott, 1972) has demonstrated that rather complete homogenization may occur in zones of intense strain and recrystallization along shear zones, it is the author's opinion that further studies are needed to determine the variable degree of Rb and Sr mobilization attained in mylonitic zones.

CHAPTER 7 - MINERALOGY OF THE URANIFEROUS ORES

Introduction

This chapter describes the metallic and non-metallic constituents of the uraniferous ores present in the Fay and Verna Mines and in the Bolger open pit, and their textural relationship in the paragenetic sequence as found during the microscopic examination of 52 polished sections. The chapter also describes the data on the temperature of deposition, obtained through studies of fluid inclusions found in the gangue minerals, which have been utilized in the elucidation of the cooling history of the orebodies.

It should be noted that the abundance of calcite in all phases of mineralization indicates that carbonate-rich solutions probably constituted active transporting agents for several minerals (Trigg, 1964). It is therefore important to know the isotopic composition of the carbonate minerals and of the fluids involved in the deposition of the ores and compare them with the isotopic values found in waters presently circulating within the orebodies.

Previous Literature

Considerable data concerning the mineralogy and the paragenetic relationships of the minerals present in the vein deposits of the Beaverlodge area are available. Only a brief resumé of the salient features characterizing the deposition of the ores in the Fay and Verna Mines and Bolger open pit is presented here, since it was found that the general scheme published by the previous authors was essentially in agreement with the present author's evidence. Certain differences were recorded in the paragenesis of the gangue minerals and in particular in the order of deposition of the carbonates.

According to Robinson (1955a) the sequence of deposition was highly complex and involved several generations of hematite, calcite, chlorite, pitchblende and pyrite. Two generations of quartz and bornite and one generation of chalcopyrite and galena are present, but numerous exceptions were noted as many phases are apparently overlapping and transitional. Smith (1952) pointed out that the mineralization at the Martin Lake Mine could be divided into two rather indistinct periods of deposition; the first being characterized by the introduction of pitchblende, carbonate and hematite, and the second by the introduction of sulphides and selenides of copper and lead. Dudar (1960) noted that massive pitchblende occurred in the Verna orebody, as cavity fillings, in fissures and fracture zones and that it was preceded by an 'early' pyrite. Dudar also noted hematite along cleavage planes of calcite, indicating an early carbonate mineralization preceding the deposition of hematite. He pointed out that the white veinlets of calcite occurring in the Verna orebodies are post-ore in age as they include small fragments of red-stained calcite. Such conclusions, which are corroborated by the findings of the present investigation, support the concept of multiple generations of carbonate occurring with pitchblende in the orebodies of the Fay and Verna Mines.

a younger rim of pyrite which is cemented by pitchblende and gangue minerals (Dudar, 1960) (Table 8, stage 1). The first generation seems to precede the major deposition of pitchblende whilst the second seems to accompany it. Locally the second generation of pyrite may occur as large fractured and crushed subhedral grains (Dudar's 'exploded bomb' texture, 1960) mantled by hematite and cemented by pitchblende. In one locality (sample F-1809-96, Fay Mine) pyrite occurs as rims bordering large angular and fractured pitchblende fragments which include rounded grains of pyrite replaced in turn by carbonate minerals (i.e. pseudomorphic after pyrite). The fragments are cemented by calcite (Table 8, stage 4) and by a newly formed pitchblende which is also noted to occur as veinlets cutting the carbonate gangue. The latter was disseminated with microscopic grains of chalcopyrite (Table 8, stage 4) and was intersected by veinlets of specularite. The third generation of pyrite occurs as perfect euhedral crystals concentrated along cross-cutting chlorite veins. It is noteworthy that, in general, pyrite is not zoned when examined utilizing the Nomarsky's phase interference contrast test.

c) <u>Pitchblende</u>

Robinson (1955a) reported the following textures for pitchblende veins occurring in the Beaverlodge area: dusty or sooty, massive, colloform and euhedral. Smith (1952) noted spheres, pellets, rims and botryoidal aggregates displaying syneresis cracks. In general early pitchblende occurs

Metallic Minerals

A small variety of metallic minerals occurs in the Fay and Verna Mines and Bolger open pit. According to Robinson (1955a) the estimated order of abundance is: hematite, pyrite, pitchblende, chalcopyrite, galena, clausthalite, bornite, nolanite, ilmenite, marcasite and sphalerite.

According to Koeppel (1968) the uraniferous veins contain thucholite and brannerite but they are of minor importance. The present study revealed that metauranocircite, leibigite and bequerelite are also present as alteration products after pitchblende.

a) Hematite

At least three generations of hematite are found in the uraniferous veins of the Fay and Verna Mines and Bolger open pit. The first generation occurs as a dusty variety impregnating a red colored calcite displaying bent twinning lamellae (Table 8, stage 2). The second generation is usually massive, it accompanies pink calcite and apparently follows the main deposition of pitchblende (Table 8, stage 4). The third generation occurs in the form of well crystallized specularite coating yellow calcite in the final stages of the paragenetic sequence (Table 8, stage 7).

b) Pyrite

At least three generations of pyrite are found in the uraniferous veins of the Fay Mine. The first generation occurs as rounded grains overgrown by as fragments including rounded crystals of pyrite, as disseminated grains cemented by gangue minerals or as veinlets cutting wall-rock. It may be massive, partly replaced by carbonate and other gangue minerals or euhedral. Late pitchblende is found as rounded pellets rimmed by pink calcite, as botryoidal aggregates displaying syneresis cracks or as rims banding wall-rock fragments. Syneresis cracks, when present are filled with sulphides, hematite and gangue minerals. Locally colloform pitchblende is sharply cut by younger clausthalite veins.

d) Chalcopyrite

Apparently only one generation of chalcopyrite is present in the vein material of the Fay Mine. It occurs as small discrete grains disseminated in pitchblende, pyrite and bornite or as exolution lamellae in bornite.
It may be present in the gangue minerals or in the wall-rock (Table 8, stage 4).

e) Galena

Galena replaces all the metallic minerals found in the vein material of the Fay Mine with the exception of specularite, clausthalite and the alteration products after pitchblende (Table 8, stage 6). In one locality was found to occur as isolated euhedral crystals set in a carbonate matrix. It may contain finely disseminated chalcopyrite and bornite grains.

f) Clausthalite

Clausthalite occurs in rare veinlets cutting pitchblende veins (Table 8, stage 7). Robinson (1955a) reported that, in some peripheral veins, clausthalite is associated with bornite.

g) Bornite

Bornite is always associated with chalcopyrite; locally it is found as minute grains in pyrite (Table 8, stage 5).

h) Nolanite

Although studied by several authors, nolanite was not found during the present study. Apparently it is more abundant in the Verna orebodies.

i) Ilmenite

Robinson reported a vein of ilmenite occurring in the foot wall of the Ace-Fay Mine. In this study ilmenite was found to be very abundant as an accessory mineral but was never noted in the vein material studied.

j) Marcasite

Robinson reported the presence of marcasite as sheaves of acicular crystals in calcite and pitchblende. No marcasite was found during this study.

k) Sphalerite

Robinson recognized the presence of minor quantities of sphalerite as minute grains in quartz gangue. No sphalerite was found during this study.

l) Arsenopyrite

Dudar reported the presence of fine grained lamellar crystals of arsenopyrite curling around pyrite. No arsenopyrite was found during this study.

Non-Metallic Minerals

According to Robinson (1955a) the estimated order of abundance of the non-metallic minerals is: calcite, chlorite, quartz and traces of apatite and anatase.

a) Carbonates and quartz

The present study revealed at least five generations of carbonates and at least two generations of quartz. Some of these are easily distinguishable in the field, whilst others (especially the carbonates) can be distinguished only by differences in their isotopic composition.

The first and most common type of carbonate, (Type A), is a dense, brown to brick-red or pink calcite, with a high concentration of hematite particles. This type is usually coarsely crystalline or massive, exhibits strong deformation, bent twin lamellae and wavy extinction (Plate VIII,6).No primary fluid inclusions were found in samples belonging to this group, but numerous secondary inclusions were noted. This type of calcite appears to have been deposited before the pitchblende and accompanied or slightly preceded the deposition of hematite. There is also abundant evidence that this type of calcite followed the deposition of the 'early' pyrite mentioned above. Type A could be the late phase of an early generation of white calcite (Type a_o), rarely found in the mine, but distinguishable through isotopic studies. (Samples F-41, F-42 and B-11; Fay Mine and Bolger open pit).

Type A calcite was followed by a dense, grey to light-grey or light bluish-grey dolomite (Type B), which is coarsely crystalline, moderately fractured, exhibiting strong undulose extinction. This type usually replaces the red, coarse-grained Type A calcite and it is cut by a younger generation of pink calcite (Type C). The Type B dolomite commonly occurs in the Fay Mine coating coarse, angular fragments of brecciated wall rock. It is characterized by its content of disseminated, fine-grained pellets or spherules of pitchblende coated by fine rims of calcite, or by colloform pitchblende coated by younger pinkish calcite (Type C). In the ore veins the dolomite is occasionally accompanied by very small amounts of ankerite and siderite. It is noteworthy that primary fluid inclusions were not observed in the samples of Type B dolomite, owing to their opacity. The present study indicates that the Type B dolomite was probably deposited during and/or shortly after a major deformational event which effected repeated fracturing and brecciation in the orebodies. It is important to mention that two samples of dolomite (Samples F-6, and F-7; Fay Mine) gave somewhat different values, for these carbonates presumably belong to a distinct phase of mineralization.

A third variety of carbonate (Type C) is a clear, pinkish, less-deformed calcite, displaying slightly undulose extinction. This variety is always present in small veinlets cutting the red-stained, coarsely crystalline Type A calcite and the grey, Type B dolomite in which it effects dedolomitization (Plate VIII,5), or it occurs as fine rims coating the red-stained calcite (Type A). The Type C carbonate, which can only be separated from Type A by petrographic studies, seems to represent the beginning of the fracture-filling stage.

A fourth type of carbonate (Type D) is a whitish-grey or slightly pinkish calcite with no signs of deformation, which occurs either as scalenohedra or rhombohedra, 1-2 centimeters in length, coating the walls of open vugs in large fractures. This variety apparently followed the deposition of euhedral quartz (second generation of Robinson, 1955a) and late pitchblende. This Type D carbonate also occurs with specularite or encrusted by thin layers of a late-stage, yellow to moderate-brown calcite (Type E).

The Type D calcite may have been contemporaneous with the deposition of the selenides (Robinson, 1955a). Well developed primary and secondary fluid inclusions were found in several samples of this type of calcite.

A fifth type of carbonate present in the Fay Mine and Bolger open pit is a translucent yellow to greyish-yellow or moderate-brown calcite (Type E), which often coats euhedral crystals of Type D calcite. This carbonate also occurs as small aggregates or lenses in the centre of open vugs associated with specularite and several alteration products after pitchblende (i.e. metauranocircite, leibigite and becquerelite). This type of calcite undoubtedly represents the last period of carbonate deposition associated with the uranium mineralization. Several primary and secondary fluid inclusions were found in samples belonging to this group.

No carbonate phase later than the Type E calcite has to date been observed in the Fay Mine and Bolger pit.

b) Chlorite

Chlorite is commonly associated with pitchblende in the vein material of the Fay Mine. Hugson and Kaiman (1967) noted small particles of anatase and brannerite associated with notable amounts of chlorite.

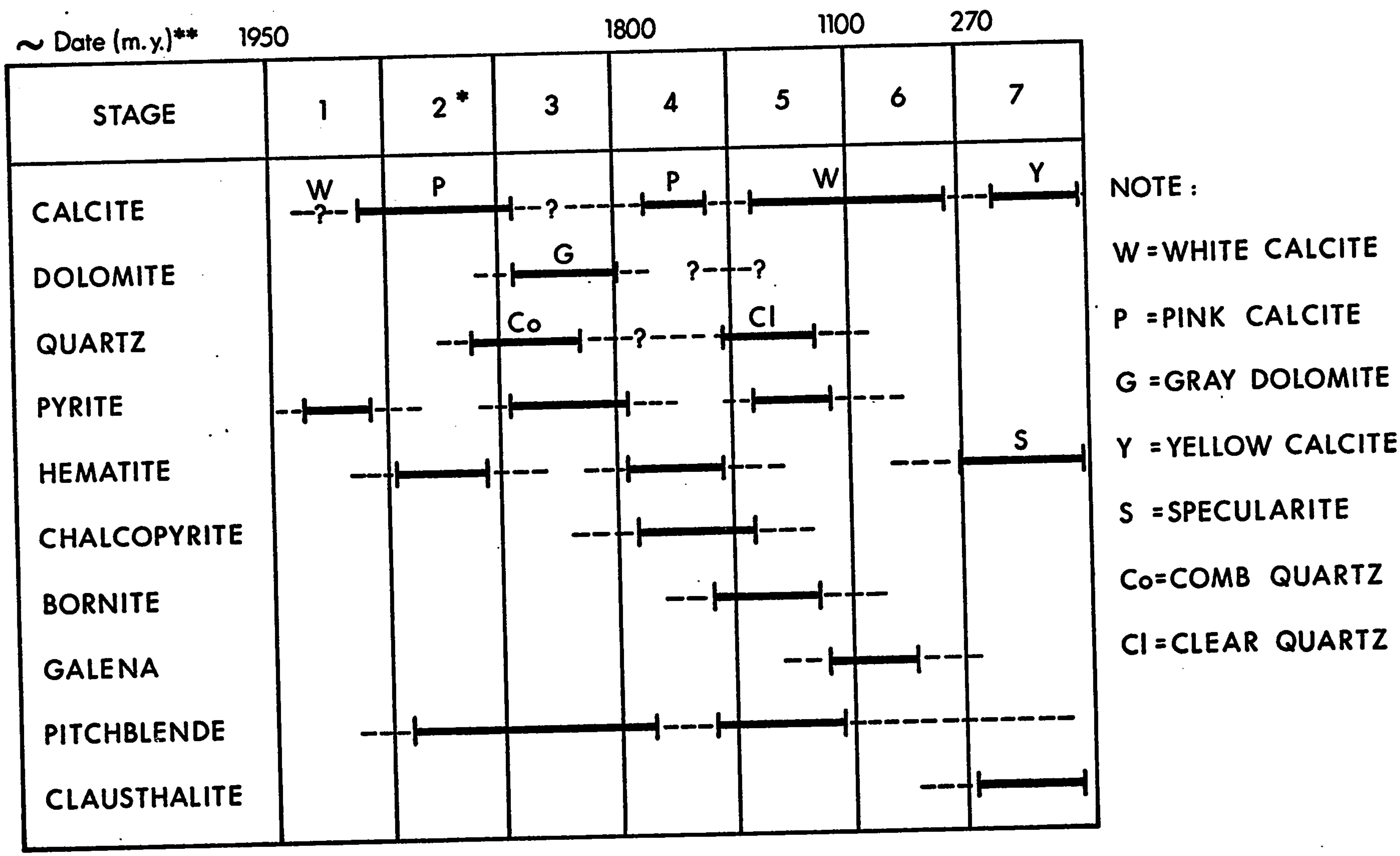
c) Anatase

Anatase was not found during this study.

Conclusions

In conclusion it is interesting to compare the paragenetic sequence revealed during the present study with that set up by previous authors and ordered geochronologically by Koeppel (1968). Table 8 includes a tentative geochronologic scale which is based upon a comparison with Koeppel's data and upon the following limited observations:

Table 8. Paragenetic sequence of the more common minerals, modified after Robinson, 1955a.



* STAGE No.2 CORRESPONDS TO A MAJOR BRECCIATION EVENT

** DATA FROM KOEPPEL (1968)

(1) The phase 2 and 3 pitchblende (in Table 8) is pre-Martin in age and is syn- or post-tectonic with the brecciation and ultramylonitization phase concluded to be of Hudsonian age.

(2) The second generation of pitchblende which is in part replaced by galena (itself apparently post-dated by clausthalite) is believed to be the product of Koeppel's 'first reworking phase' which occurred at around 1100 m.y. ago.

(3) The youngest generations of pitchblende, which are accompanied by galena and hematite, are correlated with Koeppel's 'second reworking phase' dated at 270 m.y. ago.

Fluid Inclusion Studies

More than fifty samples were examined during this study, but only eleven were found to be suitable for optical studies. The heating experiments were conducted on a E. Leitz Model-350 Heating Stage. A chrome-alumel thermocouple and a digital thermometer were utilized to measure the temperature directly adjacent to the sample chamber. The thermocouple thermometer was calibrated against the melting points of lead and bismuth. The homogenization temperatures were determined with an apparent precision of $\pm 2^{\circ}C$.

Results

Several types of fluid inclusion were noted in the samples examined.

PLATE VIII

1. Primary fluid inclusion characterized by a gas and liquid phase, (Sample B-26, quartz, Bolger open pit; transmitted light). Small secondary fluid inclusions are visible in the background along a healed fracture.

2. Primary fluid inclusion contained in a partial negative crystal exhibiting a vapour and liquid phase and a salt crystal (Sample B-24, calcite, Bolger open pit; transmitted light).

3. Various primary fluid inclusions characterized by 2 and 3 phases contained in negative crystals (Sample B-22, calcite, Bolger open pit; transmitted light).

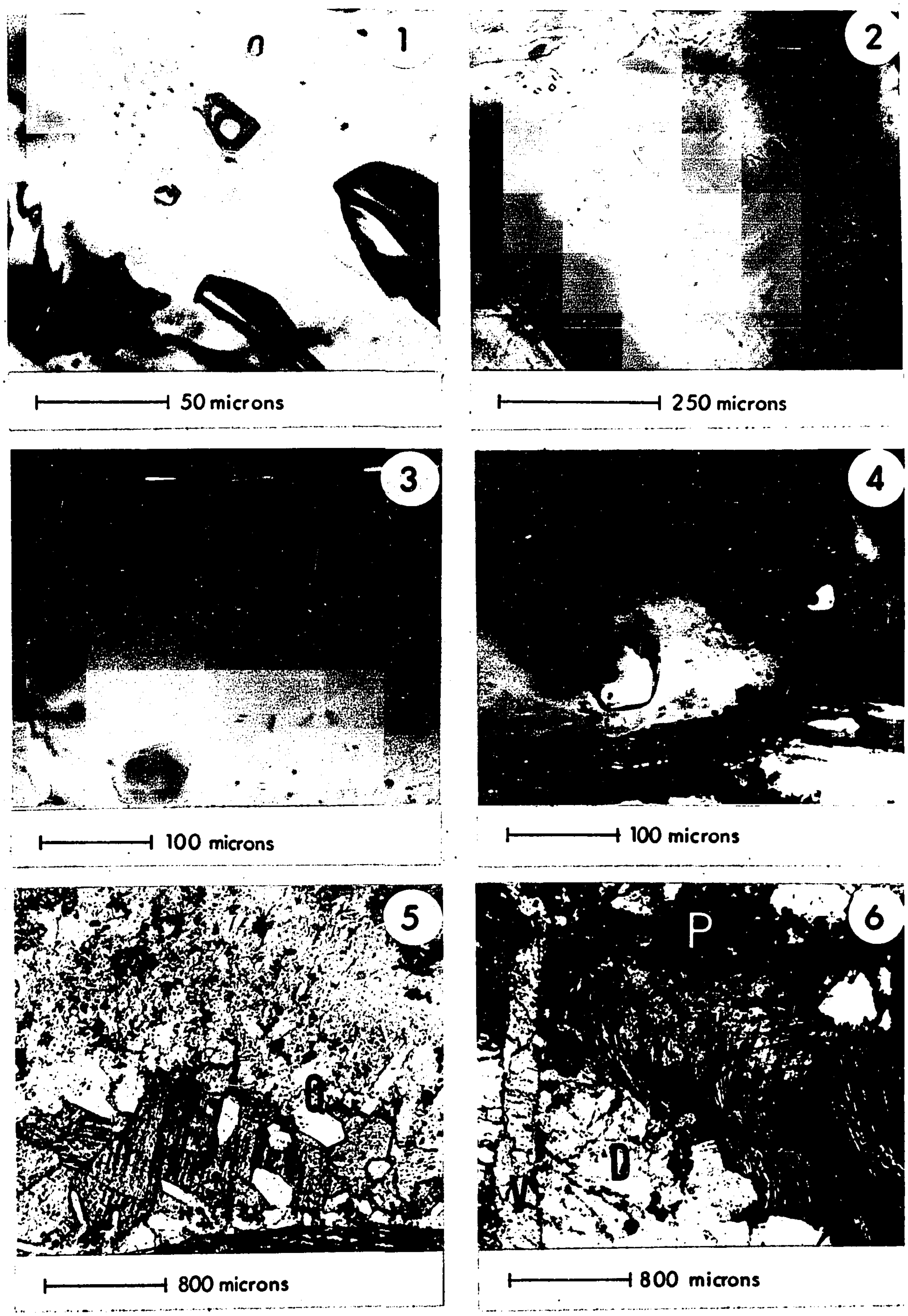
4. Primary fluid inclusions characterized by 2 and 3 phases contained in negative crystals (Sample B-25, calcite, Bolger open pit; transmitted light).

5. Clear prismatic quartz crystals (Q) encrusting the walls of a small veinlet filled with white calcite (C) (Type D) (Sample B-26, wall rock, Bolger open pit; partly polarized light).

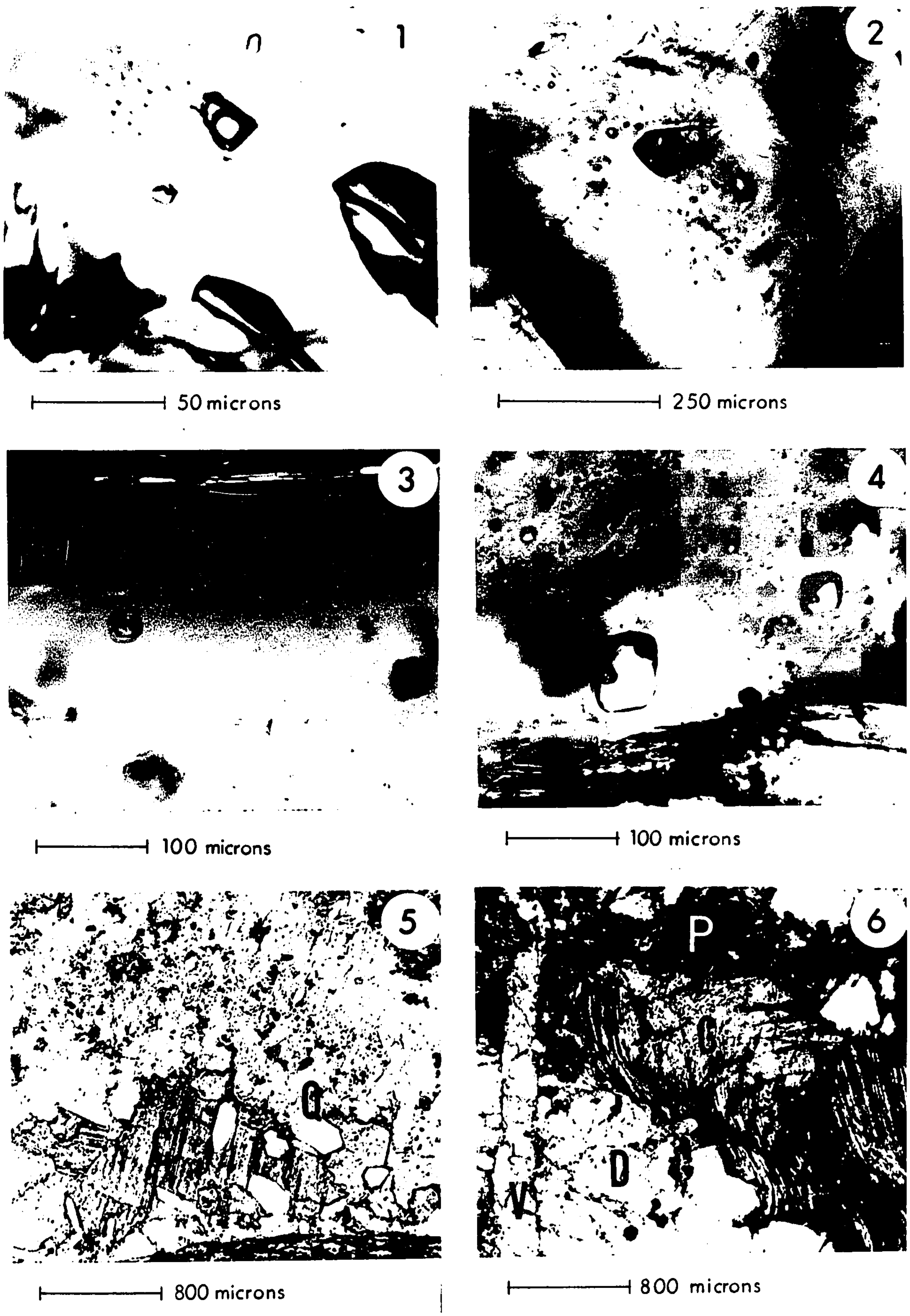
6. Thick rim of pitchblende (P) on older fragments of red-stained calcite (C), (Type A) displaying bent twin lamellae, partly replaced by gray dolomite (D), (Type B), in which spherules of pitchblende occur rimmed by a younger generation of calcite (extreme lower centre). Both carbonates are cut by a younger vein of pinkish calcite (V), (Type C), which has effected partial dedolomitization (Sample F-17, wall rock, Fay Mine; partly polarized light).

The criteria employed for the distinction between primary and secondary inclusions were those proposed by Roedder (1967). The first type was observed in the euhedral crystals of clear quartz in open vugs and associated with scalenohedra of Type D calcite. (Sample B-26, quartz; Bolger open pit). These fluid inclusions are primary, irregular or elongate in shape, very often 'necked', displaying a gas phase and a liquid phase (Plates VIII and IX). Their dimensions are usually less than 250 microns in length and the volume of the gas phase is 25 to 35 per cent of the total volume at room temperature. This type of fluid inclusion was accompanied by abundant small secondary inclusions, usually situated along healed fractures (Plate IX).

Another type of primary fluid inclusion was found in the Type D calcites, contained within negative crystals less than 100 microns in length and containing a gas phase constituting 25 to 35 per cent of the total volume at room temperature (Samples B-26, quartz and calcite; B-25, calcite; B-22, calcite; B-24, calcite; Bolger open pit). Other samples displayed fluid inclusions containing a gas phase which upon heating filled the cavity completely (Plate IX). Because both types of fluid inclusions appear to be primary, and homogenized at the same temperature, it was concluded that this effect was due to boiling phenomena (Roedder, 1967). The presence of boiling hydrothermal fluids in the orebodies would thus indicate that at the time of deposition of these calcites the pressure was not higher than 0.3 Kbars, i.e. equivalent to a depth of approximately 3600 feet (Roedder, 1967; Ohmoto


1
50 microns
2
250 microns
3
100 microns
4
100 microns
5
800 microns
6
P
D
800 microns

PLATE


1
2
50 microns
250 microns
3
4
100 microns
100 microns
5
6
P
D
800 microns
800 microns

PLATE

PLATE IX

1. Primary fluid inclusions contained in negative calcite crystals displaying a vapour bubble, liquid phase and salt crystal (Sample B-24, calcite, Bolger open pit; transmitted light). The photographs illustrate how, upon heating, the vapour phase is the first to disappear, while the salt crystal is still visible at 80°C (temperatures of 47°C, 65°C, 75°C and 80°C respectively).

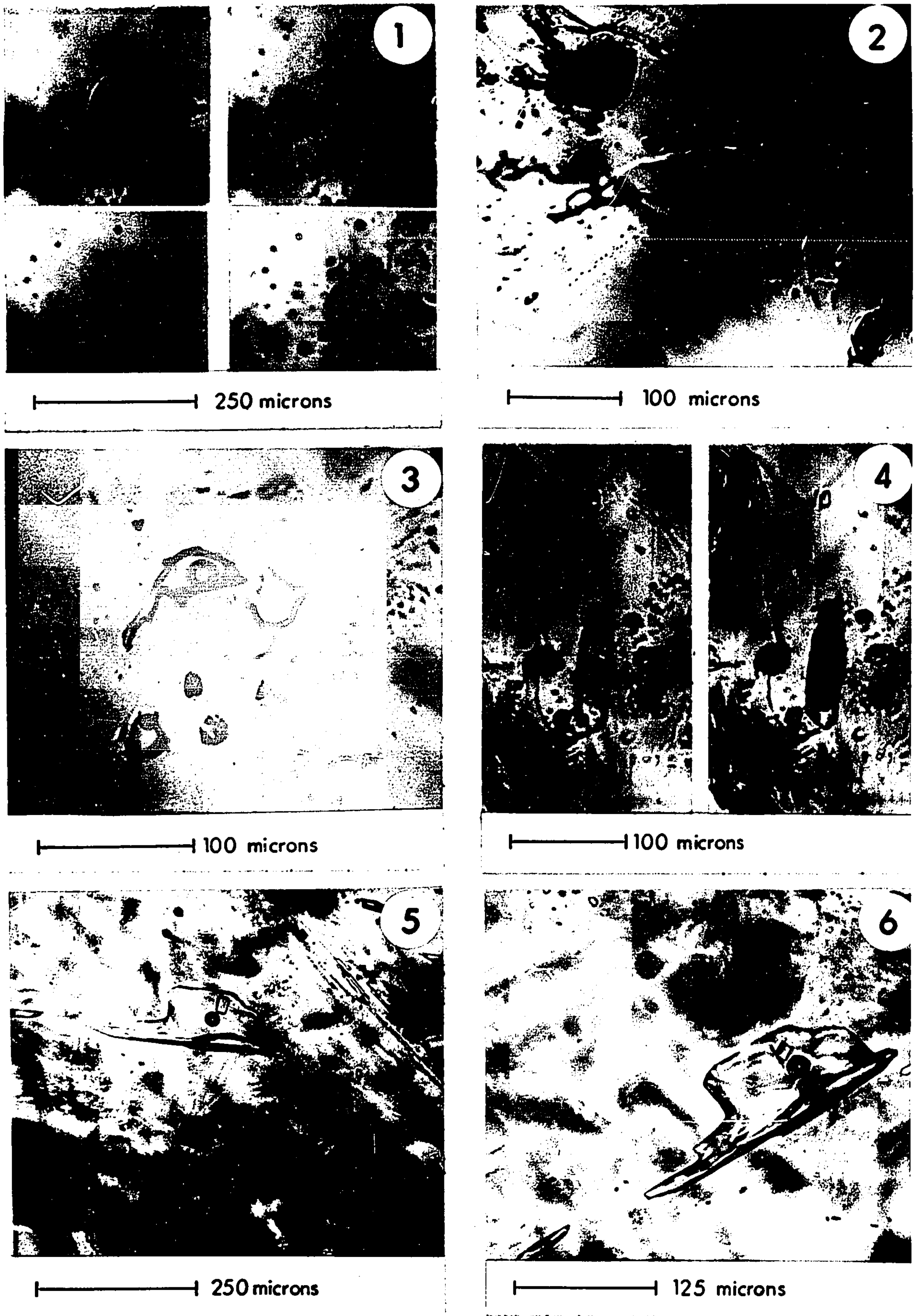
2. Partially 'necked' primary fluid inclusion in quartz characterized by two gas bubbles (left and right side) (Sample B-26, quartz, Bolger open pit; transmitted light). Upon heating, the gas phase homogenized at 385°C-395°C. Typical small secondary fluid inclusions are also visible in the background.

3. Two types of primary fluid inclusions in quartz: the lower one was characterized by a vapour phase which, upon heating, filled the cavity completely, while the upper one homogenized at about the same temperature (Sample B-26, quartz, Bolger open pit; transmitted light).

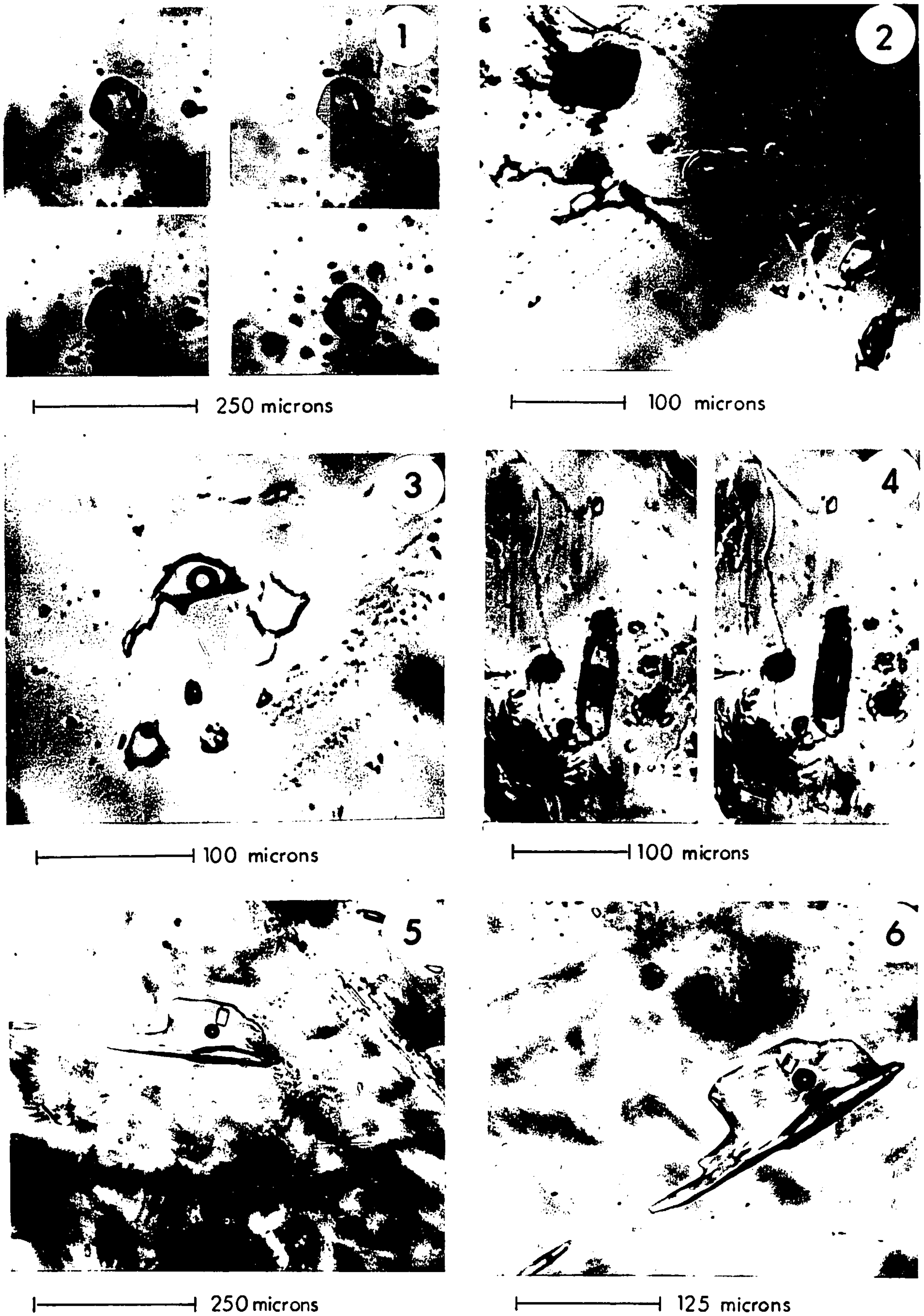
4. Primary fluid inclusion in quartz characterized by a vapour phase which upon heating filled the cavity completely (Sample B-26, quartz, Bolger open pit; transmitted light). The two pictures were taken at temperatures of 105°C and 165°C respectively.

5. Primary fluid inclusion in calcite, displaying a vapour bubble, liquid phase and a salt crystal, surrounded by several pseudo-primary fluid inclusions and by a secondary fluid inclusion situated along a healed fracture (Sample B-26, calcite, Bolger open pit; transmitted light).

6. Same fluid inclusion as Fig. 5. Upon heating the salt crystal has started to melt and moved from the original position. The picture was taken at 65°C. Upon heating the gas phase homogenized at 72°-85°C.


1
250 microns
2
100 microns
3
100 microns
4
100 microns
5
250 microns
6
125 microns

PLATE


1
2
250 microns
100 microns
3
4
100 microns
100 microns
5
6
250 microns
125 microns

PLATE

and Rye, 1970; Beck, 1970).

Finally fluid inclusions characterized by a gas phase, liquid phase and salt crystal were observed in Type D calcite, contained within negative crystals less than 100 microns in length (Samples B-22, B-24, B-25, B-26, B-27, B-28; Bolger open pit).

Filling Temperature Measurements

Robinson (1955a) reports that Haycock tested several samples of calcite and quartz, collected in the Beaverlodge district, employing the decrepitation method described by Scott in 1948. Samples collected in the Ace-Fay Mine gave temperatures of 335°-350°C, whereas samples collected in the Martin Lake, Eagle and Nesbit-Labine Mines produced relatively lower temperature data, in the order of 300°C. Robinson also reported that temperatures obtained from gangue minerals associated with pitchblende ores were all higher than those obtained from minerals collected in barren veins.

During the present study the only fluid inclusions which gave dependable results were those in the gangue minerals (calcite and quartz) belonging to the late stages of the paragenetic sequence (Table 8, phase 5 and 6). No primary fluid inclusions were found in Type A, B or C carbonates; only secondary fluid inclusions were noted in two samples belonging to Type A calcite (Samples F-13 and F-41; Fay Mine).

The highest temperatures (380°C to 410°C) were obtained in primary fluid inclusions of samples B-26 (quartz and calcite), B-24 (calcite, B-22 (calcite) and B-25 (calcite) from the Bolger open pit (Table 9). These were the fluid inclusions which apparently displayed boiling effects, although this phenomenon was also observed in fluid inclusions which homogenized at around 300°C, 250°C and 190°C respectively. Temperatures of about 155°C were noted in primary fluid inclusions located in the very late stage Type D calcites (Table 8, phase 6).

All those fluid inclusions which exhibited three phases (gas, liquid and solid) homogenized at relatively low temperatures. Upon heating, the salt crystals were the last phases to disappear at a temperature of circa 100°C for the calcite samples B-26, B-22, B-25 and B-24, and at temperatures of circa 135°C for the calcite samples B-28 and B-27 (Bolger open pit) (Plate IX). As one may assume that at these temperatures the solution contained in the fluid inclusions is saturated with sodium chloride, the amount of salt present in the solution may be computed using diagrams published by Keevil (1942). In such a case, water saturated with sodium chloride at 100°C and 135°C contains approximately 26 wt.% NaCl and 28 wt.% NaCl respectively (i.e. an average of a 5 molar solution of equivalent NaCl).

Finally very low homogenization temperatures (~60°C to 70°C) were observed in the yellow, Type E calcites.

Table 9 – Homogenization Temperatures Observed in Quartz and Calcite

Code No.	Type of Carbonate	Locality	Temperatures in °C (no pressure corrections were applied to the values reported)						
F-41	a_0	Fay Mine				180°-187°	150°-157°		
F-13	A	Fay Mine				185°-195°	145°-150°		
B-26, quartz	d_1	Bolger	380°-410°			177°-195°	145°-152°		
B-26, calcite	d_1	Bolger	380°-405°	305°-312°		185°-190°		97°-102°*	75°-82°
B-25	d_1	Bolger	382°-410°	305°-312°	247°-253°	172°-177°		99°-102°*	70°-75°
B-22	d_1	Bolger	385°-410°	300°-307°	247°-255°		150°-157°	99°-103°*	72°-80°
B-24	d_1	Bolger	378°-407°	297°-305°	247°-252°		143°-152°	100°-107°*	68°-80°
B-27	d_2	Bolger					145°-152°	130°-135°*	72°-80°
B-28	d_2	Bolger					150°-157°	130°-133°*	70°-77°
B-33	E	Bolger							60°-72°

Note: * indicates temperature of the disappearance of salt crystals
Undisputable primary fluid inclusions are underlined

Pressure Corrections of the Filling Temperatures

In fluid inclusion thermometry, pressure corrections are essential, for the temperatures measured are only minimum values and do not represent the actual temperatures of the fluid circulating in the orebodies. By employing the diagrammatic correction plots prepared by several authors (Lemmlein and Kletsov, 1961; Ohmoto and Rye, 1970) temperature corrections were computed for the aforementioned calcites studied. The results of these calculations range from +10°C to a maximum of +30°C at an average estimated pressure of about 0.3 Kbars. (Note that the known vertical extent of the Ace-Fay orebody is approximately 4000 feet; the lithostatic pressure at such a depth would be approximately 330 atmospheres). The average minimum and maximum corrected temperatures obtained in this study would thus be 85°C ± 10°C and 440°C ± 30°C respectively. None of these estimates appears unrealistic or contrary to those values previously reported by Robinson and by Beck. Furthermore, since the estimated depositional temperatures mainly relate to the Type D calcites, it is felt that Robinson (1955a) was essentially correct in stating that the initial temperatures of deposition in the hydrothermal veins were probably high, possibly of the order of 500°C.

Oxygen and Carbon Isotope Studies

All samples analyzed for oxygen and carbon isotope studies were separated from the host-rock and ground to a powder of <200 mesh. Pure calcite and pure dolomite samples were directly reacted at 25°C with 100% phosphoric acid (McCrea, 1950). Dolomite associated with calcite was purified by treating with dilute HCl (1/15), thoroughly washed with demineralized water and dried. Since no physical separation of calcite and dolomite was possible, the entire sample was then reacted for one hour, and the gas produced assumed to be derived from the calcite alone. With dolomite samples the usual reaction time was approximately 15 days and for pure calcite, 1 day (Epstein et al., 1964; Fritz, 1967).

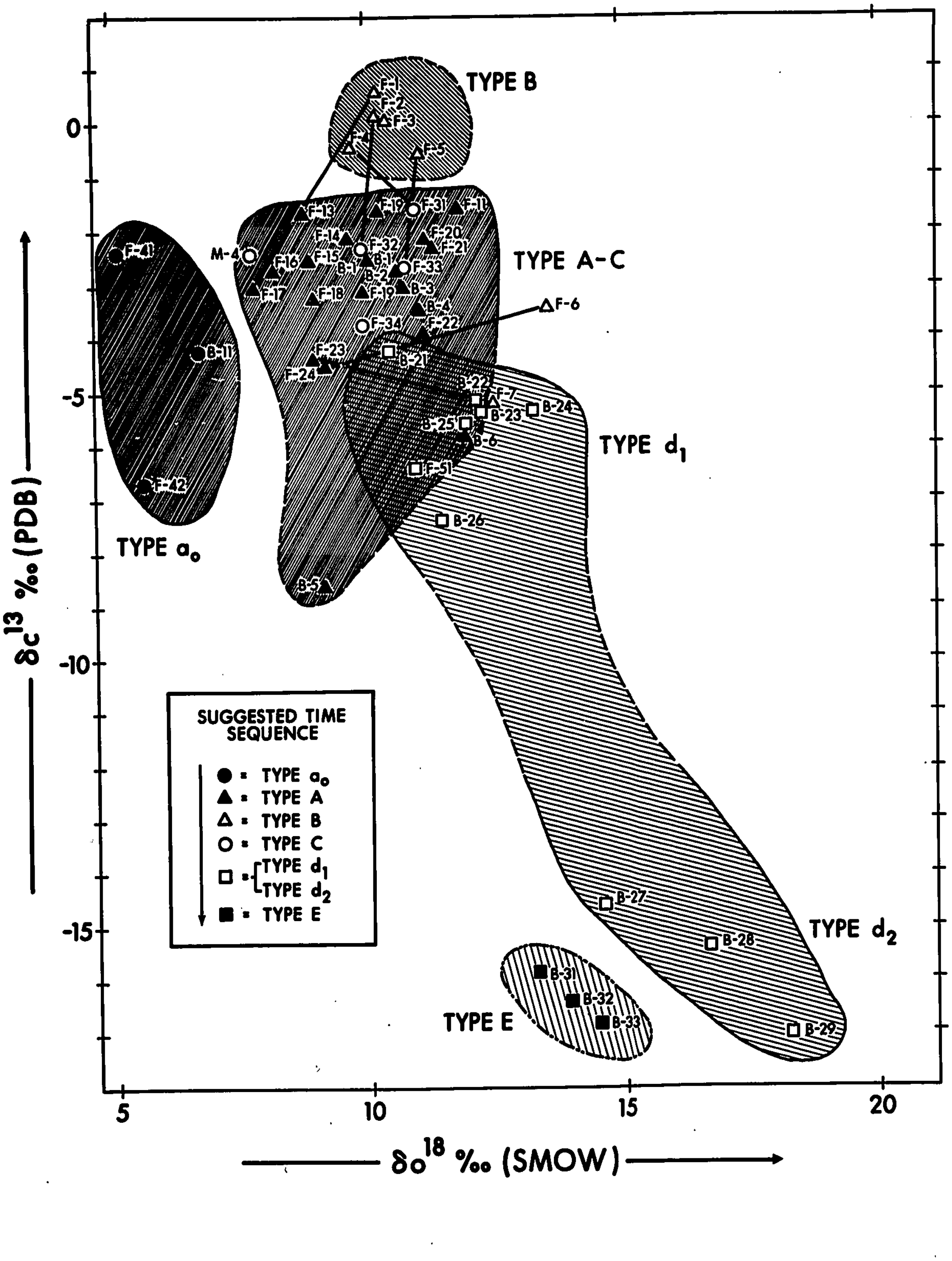
The CO_2 obtained from the acid reaction was analyzed on a 12", 90°, Magnetic Analyser Mass Spectrometer built by Dr. H.R. Krouse, in the Physics Department of the University of Alberta.

Corrections were applied to the data, using the method of Craig (1957). The carbonate analyses were also corrected for residual oxygen not extracted during the acid treatment (Sharma and Clayton, 1965). The corrected results are reported in Fig. 27 against the PDB standard for δC^{13} and against the SMOW standard for δO^{18} values. (Note: the corrected results reported in the Appendix are against the PDB Standard only). The overall error for calcite and dolomite samples was less than $\pm 0.2\%$.

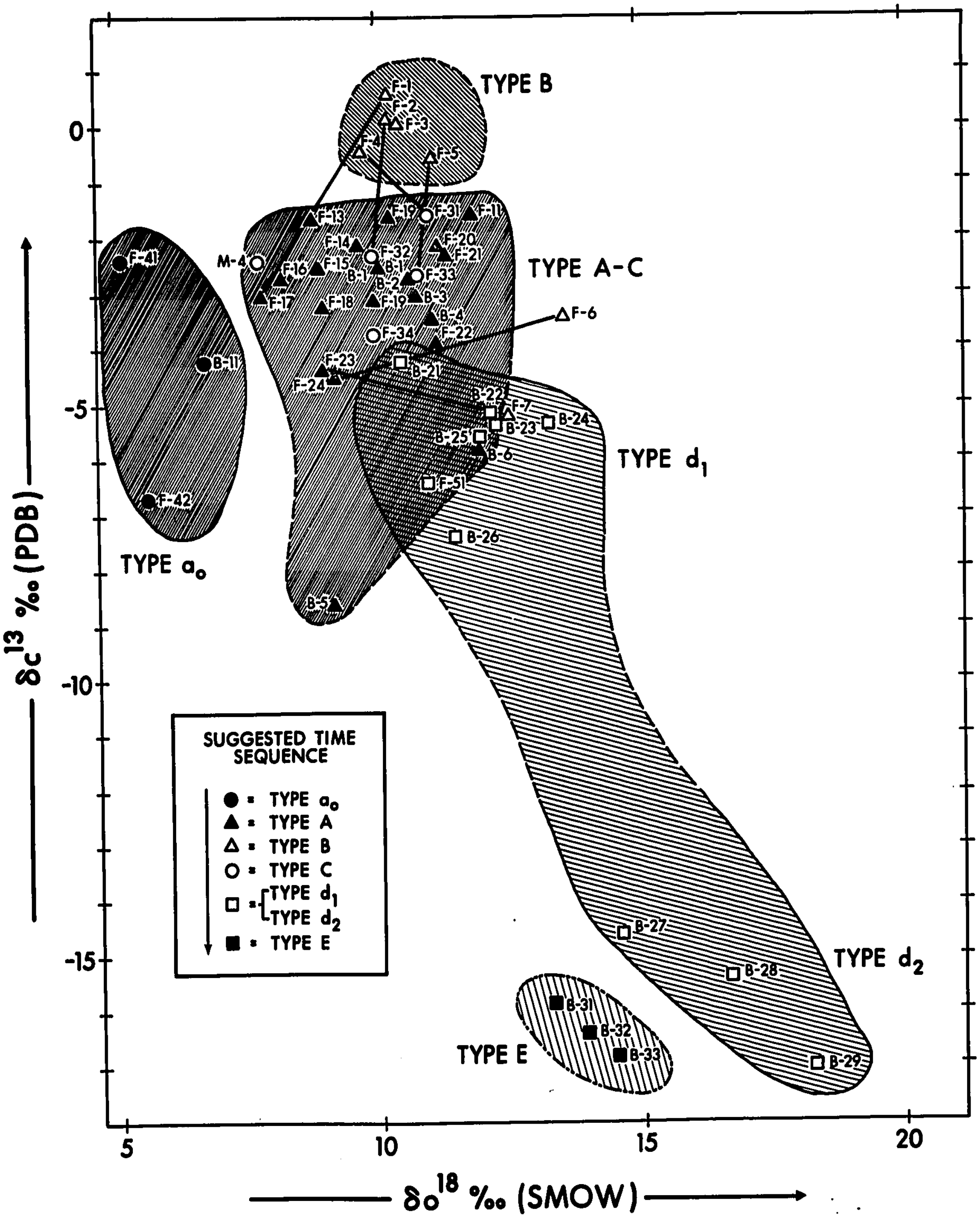
Results

From Fig. 27 it appears that, although some of the isotopic results obtained are similar and overlapping, it is possible to distinguish at least five

Fig. 27. δO^{18} values vs. δC^{13} values plot for the carbonates present in the Fay Mine and Bolger open pit.



TYPE B
TYPE A-C
TYPE a_o
TYPE d_1
TYPE d_2
TYPE E
F-1
F-2
F-3
F-4
F-5
F-6
F-7
F-11
F-13
F-14
F-15
F-16
F-17
F-18
F-19
F-20
F-21
F-22
F-23
F-24
F-31
F-32
F-33
F-34
F-41
F-42
F-51
M-4
B-1
B-2
B-3
B-4
B-5
B-6
B-11
B-21
B-22
B-23
B-24
B-25
B-26
B-27
B-28
B-29
B-31
B-32
B-33
0
-5
-10
-15
5
10
15
20
δC^{13} ‰ (PDB)
δO^{18} ‰ (SMOW)
SUGGESTED TIME SEQUENCE
● = TYPE a_o
▲ = TYPE A
△ = TYPE B
○ = TYPE C
□ = TYPE d_1, TYPE d_2
■ = TYPE E



TYPE B
TYPE A-C
TYPE a₀
TYPE d₁
TYPE d₂
TYPE E
SUGGESTED TIME SEQUENCE
● = TYPE a₀
▲ = TYPE A
△ = TYPE B
○ = TYPE C
□ = TYPE d₁, TYPE d₂
■ = TYPE E
δC¹³ ‰ (PDB)
δO¹⁸ ‰ (SMOW)

generations of calcites displaying discrete isotopic values. Fig. 27 shows that δO^{18} values of the Type A and C calcites exhibit a range of about 7 per mil (~+5 to +12‰) limited by a range of δC^{13} values of about 8 per mil (~-1 to -9‰). This range includes three samples that apparently belong to an earlier generation of white calcite (Table 8, stage 1) which is distinguished as a_o, and probably preceded the deposition of the pink Type A calcite. These samples have lower δO^{18} values (~+5 to +7‰) and almost the same δC^{13} values as those found in Type A calcite.

Type B dolomites present relatively constant isotopic values (δO^{18}~ +9.5 to +11‰, δC^{13}~ -0.6 to +0.55‰).

Type D calcites, which apparently seem to be composed of two distinct generations, subdivided here into types d_1 and d_2, display a wider range of δO^{18} and δC^{13} values. As one can see, the d_1 type presents values that are relatively similar to the values reported for Type C calcites (δO^{18}~ + 10.5 to + 14‰, δC^{13}~ -4 to -8‰) while the d_2 type strongly differs with respect to the δC^{13} values (~ -14 to -17‰) but approaches the value reported for the Type E calcite (δO^{18}~ +13‰ to +14.5‰, δC^{13}~ -15‰ to -16.8‰) which represents the final stage of deposition in the system.

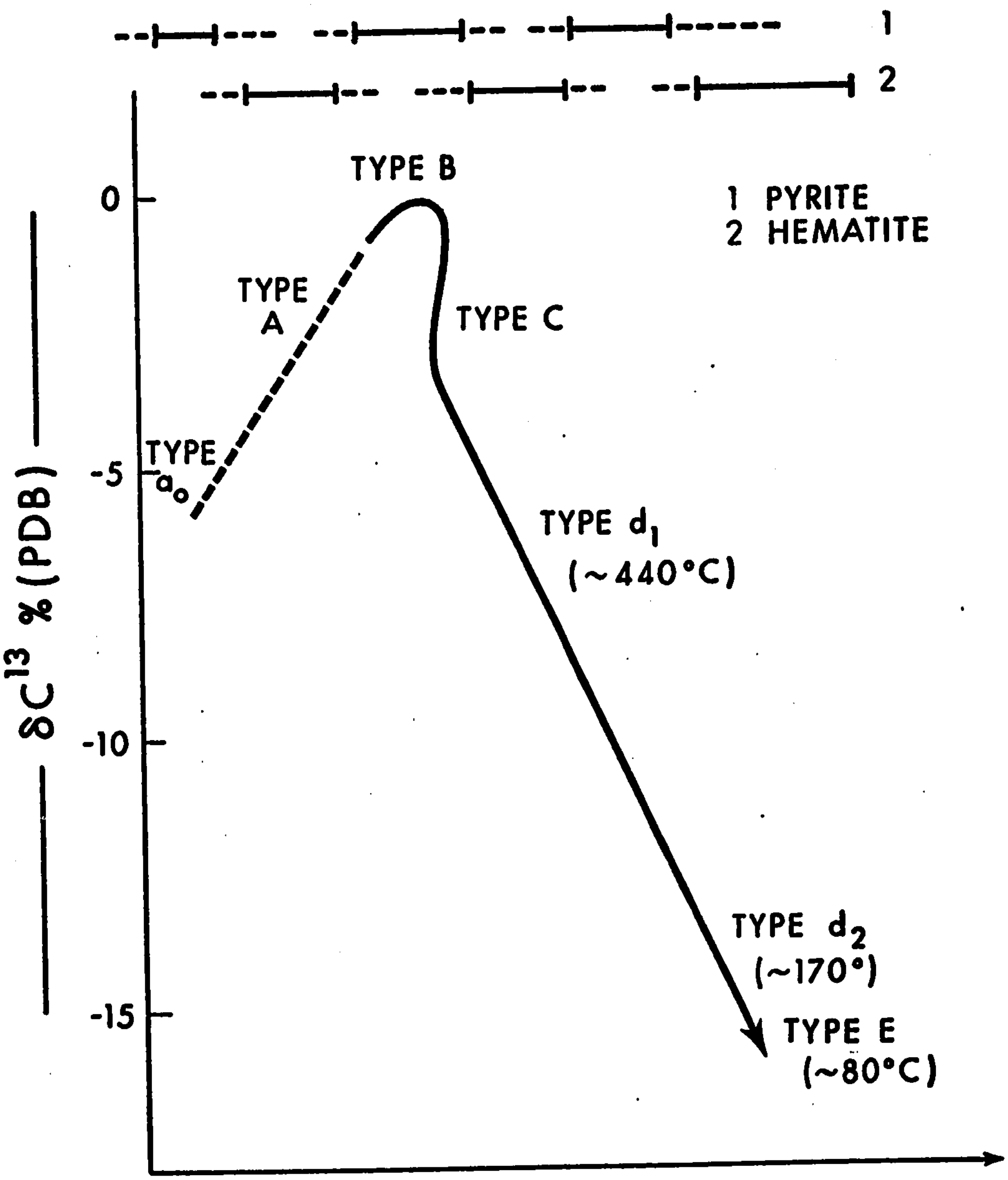
Little can be said about the preservation of the original isotopic composition of the calcites collected in the Fay Mine and Bolger open pit. It should be recalled that d_1 calcites revealed the highest homogenization temperatures, while Type A calcites had apparently lost their primary fluid inclusions during a major period of brecciation. It is also possible that Type D calcites continued to grow during a considerable time interval, since a large variety of fluid inclusions, characterized by decreasing temperatures, were encountered. It is thus quite possible that the isotopic composition of some of these calcites revealed during this study reflects merely the average composition of calcites deposited over a long time interval.

Discussion

The oldest calcites (Types A and a) encountered in the Fay Mine and Bolger open pit do not possess any primary fluid inclusions. This fact, together with their physical appearance, indicates that they were subjected to major post-depositional deformation and recrystallization which might have caused a distinct change in their primary isotopic composition. In the depositional sequence these calcites are followed by a generation of dolomite (Type B) with which they are closely associated. Since dolomite does not easily recrystallize and secondary alteration often causes dedolomitization, such as that observed during these studies, it was concluded that the dolomites have probably preserved their original isotopic composition. Unfortunately no fluid inclusions were observed in these samples and their temperature of formation is thus unknown. However, their position in the paragenetic sequence suggests that they may have formed at rather high temperatures. This assumption is possibly confirmed by the changing O^{18} contents of the various carbonate generations, where a continuous increase in O^{18} is observed in all generations younger than the Type B dolomites. Since the fluid inclusion data demonstrate decreasing temperatures for all carbonates younger than the d_1 calcites, paralleled by an increase in O^{18}, it is possible to project this trend backwards and to postulate that there was at least, post the deposition of the Type B dolomites, a decrease in temperature. However, since the isotopic composition of carbonates is not only controlled by their temperature of formation but also by the isotopic composition of the hydrothermal fluids, it is possible to obtain, from the carbonates, some information about the isotopic characteristics of the mineralizing fluids and the carbonate species dissolved in it. This discussion is presented in the next section.

Fluid inclusion data have clearly demonstrated that the d_1 and d_2 calcites were deposited over a wide range of temperatures. It is thus interesting to note that the salt crystals contained in the inclusions of these younger d_2 calcites disappear, during heating, at higher temperatures than these in the d_1 generation; a fact which indicates an increasing fluid salinity during the terminal stages of mineralization. The carbon isotopic composition of these carbonates varied considerably with time and a clear trend appears to have been established after the deposition of the Type B dolomites so that progressively lower δC^{13} values can be observed. Unfortunately insufficient cogenetic minerals were found, which might permit the construction of stability diagrams and the consequent determination of the oxygen fugacity within the hydrothermal system at various times. The existence or nonexistence of minerals in this system appears to have been not only a function of their stability, but also of the geochemical characteristics of the hydrothermal fluids which apparently were subject to changes during their evolution. However, the distribution of hematite and pyrite and a comparison with the observed δC^{13} values proved to be of considerable value: Fig. 28 is a comprehensive plot of some parameters controlling the composition of the carbonate gangue. It shows clearly that the low δC^{13} values parallel the occurrence of hematite and that the highest values are found in dolomites cogenetic with some pyrite. This could indicate a direct relationship between the C^{13} of the carbonate species, the carbon dioxide in solution and the oxygen fugacity of the system. Since without doubt CH_4 was present and under such isotopic equilibration conditions, methane is considerably depleted in C^{13} with respect to CO_2, its oxidation could produce a C^{13}-rich carbon dioxide and thus precipitate carbonate with relative low δC^{13} values. This appears to be the simplest explanation of the observed trend but it should also be mentioned that bacteriogenic CO_2 could give rise to similar C^{13}-rich carbonates. However, the high salinity of the final stage hydrothermal fluids makes such biological activity in the system seem somewhat unlikely.

Fig. 28. Comprehensive plot of some parameters controlling the composition of the carbonate gangue.



1. DECREASING TEMPERATURE WITH TIME →
2. INCREASING O^{18} VALUES OF CARBONATE →
3. INCREASING SALINITY OF HYDROTHERMAL FLUIDS →

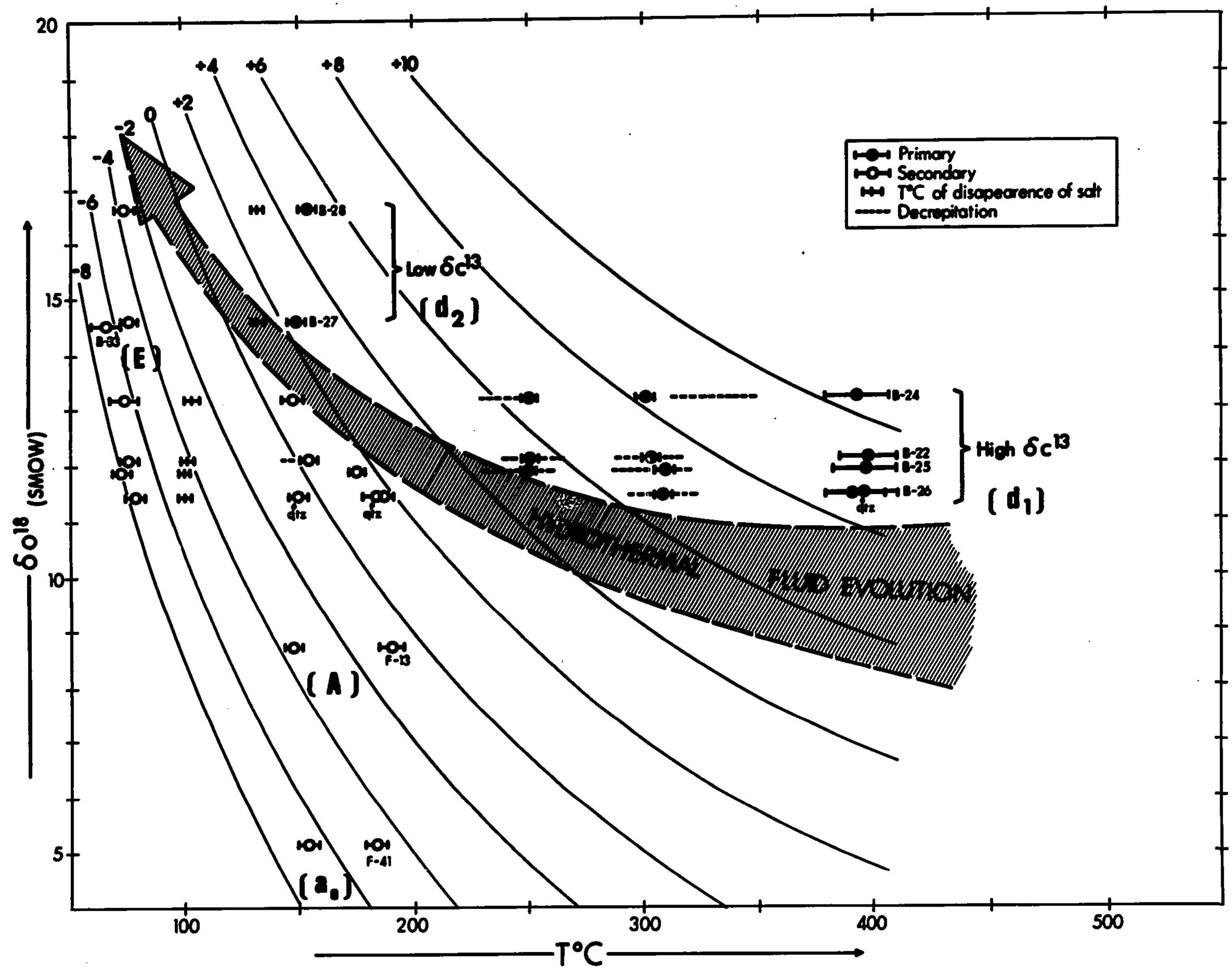
The Evolution of the Hydrothermal Fluids

In an effort to determine the isotopic composition of the hydrothermal fluids circulating in the orebodies the δO^{18} values of the water which equilibrated with the calcium carbonates were calculated utilizing the equation presented by J.R. O'Neil (O'Neil et al., 1969). The iso- δO^{18}-lines thus obtained are plotted in Fig. 29 superimposed on a δO^{18} vs. temperature plot of the samples analyzed for fluid inclusions.

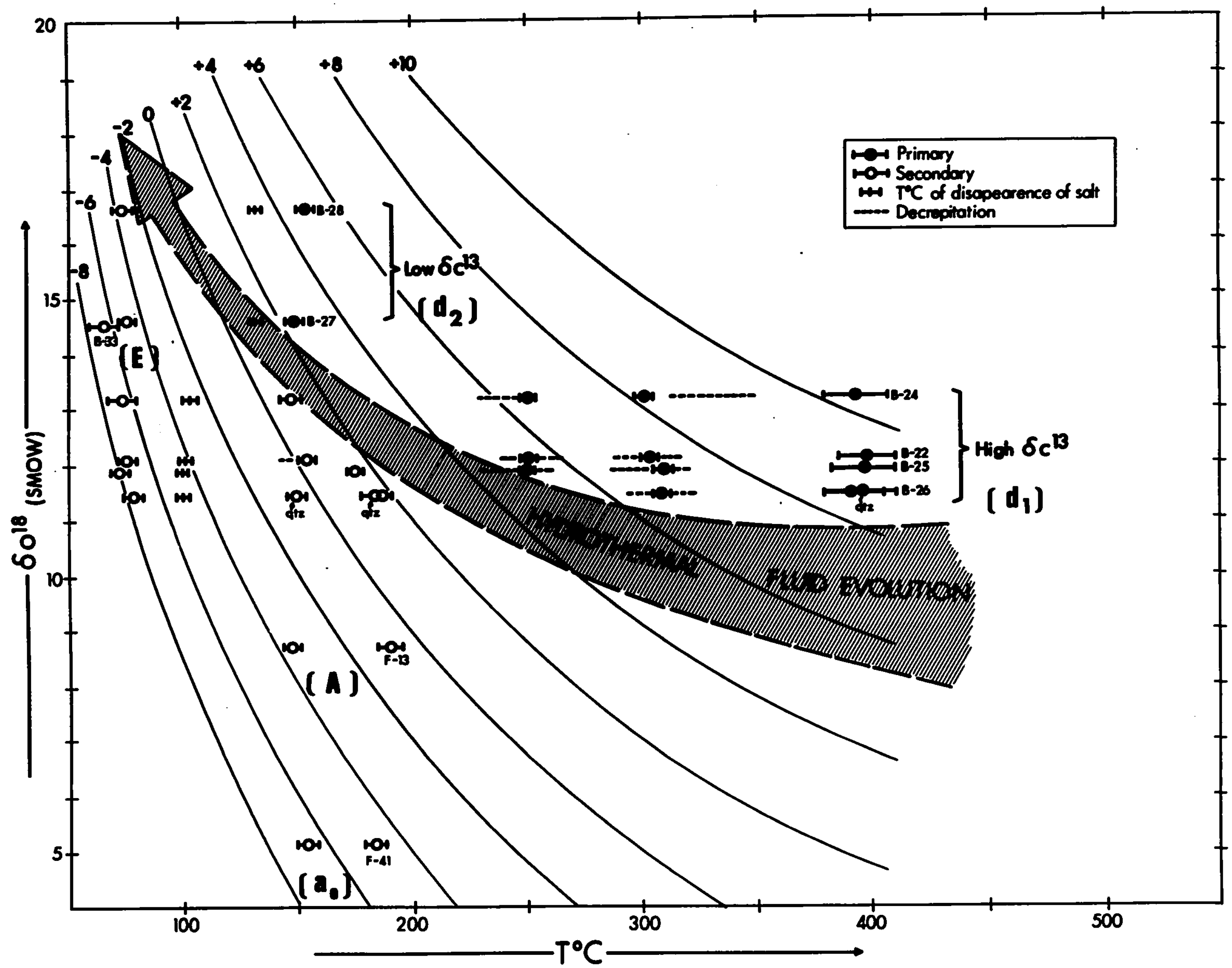
The highest homogenization temperatures observed were found in calcites of Type d_1 which, however, apparently continued to grow and 'heal' until the termination of the deposition of hydrothermal minerals in the system. The isotopic values of these carbonates thus probably represent average values and it can be assumed that if the final carbonates corresponded isotopically to Types d_2 and E calcite the original bulk composition was probably lower than the average. If this assumption is correct, and if these calcites closely preserved their original composition, the hydrothermal fluids had, during the deposition of the Type d_1 calcites, a δO^{18} of +6 to +8‰.

Since the Type B dolomites most probably formed at temperatures similar to, or somewhat higher than, those existing during the initial deposition of the Type d_1 calcites, the O^{18} contents of the dolomites indicate that the mineralizing fluids had possessed this composition at least since the time of dolomite formation. These relatively high δO^{18} values can best be explained by isotope exchange reactions with the host rock at elevated temperatures

Fig. 29. δO^{18} values vs. temperature plot for samples containing fluid inclusions. Note the δO^{18} values of water in the hydrothermal fluids which equilibrate with the carbonates at a given temperature of deposition. Note also the possible hydrothermal fluid evolution.



Primary
Secondary
T°C of disapearence of salt
Decrepitation
Low δc13
(d2)
High δc13
(d1)
HYDROTHERMAL
FLUID EVOLUTION
(E)
(A)
(a0)
B-24
B-22
B-25
B-26
B-27
B-28
B-33
F-13
F-41
qtz
-8
-6
-4
-2
0
+2
+4
+6
+8
+10
δO18 (SMOW)
T°C
20
15
10
5
100
200
300
400
500



Primary
Secondary
T°C of disapearence of salt
Decrepitation
Low δc13
(d2)
High δc13
(d1)
HYDROTHERMAL
FLUID EVOLUTION
(E)
(A)
(a0)
B-24
B-22
B-25
B-26
B-27
B-28
B-33
F-13
F-41
qtz
δo18 (SMOW)
T°C

since it is unlikely that magmatic fluids participated in the deposition of these orebodies for no igneous intrusion has been observed adjacent to the sector studied which might have contributed to the fluid regime.

As indicated in Fig. 29 the fluids gradually lost their high O^{18} contents and reached δO^{18} values of -2‰ or less during the deposition of the later Type E calcites. A similar decrease in O^{18} has also been observed in various other deposits and in general can be explained by an influx of isotopically lighter surface waters into the system (Fritz, 1969; Ohmoto and Rye, 1970), such an influx of meteoric water would cause a decrease in salinity of the mineralizing fluids. This effect was not observed in the hydrothermal system discussed here, but rather a strong increase in salinity towards the end of the mineralization was noted. It is therefore proposed that this system was relatively 'closed' and the fluids present (pore fluids etc.) continuously exchanged O^{18} with the host rock leading to decreasing δO^{18} values in the fluid with decreasing temperature. As no 'flushing' of the system occurred, the salinity gradually increased until it attained the highest values observed within the fluid inclusions of the late-stage carbonates.

It is interesting to note that during the drilling for the internal Fay Mine shaft pockets of water with exceptionally high salinity (2 mol % NaCl; 69,000 to 171,000 mg/1 total solids) were encountered. This water was under relatively high pressure (flowage from the collar) and δO^{18} values of about -16‰ were observed. It is not known to what extent the water samples collected were contaminated by local surface water, but it appears possible that they represent the present day, continually evolving, hydrothermal fluids described above.

The deuterium content of the fluids found in fluid inclusions should confirm the model outlined above. If the fluids evolved through continuous exchange reactions with the host rocks their D/H ratio should remain constant throughout the time of ore deposition and the only change would occur with the influx of isotopically lighter surface water.

At this point it should be mentioned that there might be a possibility that highly saline brines (" formation water") with relative lower O^{18} contents entered the system rather than salt free surface water. However, the occurrence of highly saline waters in closed pockets makes this explanation somewhat unlikely. Again, deuterium analyses could probably provide a final answer.

Conclusions

The data reported in this chapter provide evidence concerning the cooling history of the uraniferous orebodies present in the Fay Mine and Bolger open pit.

The deposition of pitchblende apparently occurred over a long period of time and was accompanied by the sequential deposition of several varieties of carbonate each characterized by discrete isotopic composition. During the early stages of mineralization, the fluid temperature was probably in the order of 500°C and gradually decreased to 80°C. The mineralizing fluids responsible for the deposition of the ore and gangue minerals were probably present as pore fluids before diagenesis and metamorphism changed their isotopic and chemical characteristics. Exchange reactions between these fluids and the host rocks at temperatures near 500°C determined their δO^{18} values which during the initial stages of mineralization were close to or higher than + 6‰. It is felt that this system was essentially 'closed' and no major fluid movements or flushing occurred which would permit a continuous re-equilibration of the mineralizing fluids with the host rock and lead to their progressive depletion in O^{18} with decreasing temperature of the system. We cannot speculate on the size of this system, but such a model could demand that the deposition of the ore minerals was due simply to the redistribution of elements originally present in the host rock whereby deposition took place in dilatant zones or veins, in and towards which, a limited circulation of fluids might have been possible.

It is possible that future isotopic studies on the minerals of the deposits might reveal the effects of changes in salinity and O^{18} concentration of the fluids upon the isotopic constitution, chemistry and mineralogy of the uranium minerals, sulfides and selenides. In this respect, it is noteworthy that the Bolger pit, where fluid inclusions in calcite contained the most saline fluids of all studies, was characterized by a predominance of secondary uranium minerals (e.g. leibigite, becquerelite and meta-uranocircite) over pitchblende.

It is also suggested that the Fay Mine Complex might be thought of as the original uraniferous 'donator' sequence which provided the components of the ore veins. In other words the uranium mineralization of the Fay Mine was originated during the Hudsonian orogeny by exchange reactions between metamorphic fluids and their uraniferous Aphebian host rocks at high temperatures (Tremblay, 1968; Beck, 1970). In such a case the Fay and Verna orebodies may be tentatively reclassified as 'mobilized stratabound deposits'.

CHAPTER 8 - REFLECTANCE AND MICRO-INDENTATION HARDNESS VS. CHEMICAL COMPOSITION IN URANINITES

Introduction

The mineralogy and crystal chemistry of uraninite (syn. pitchblende), the natural mineral in the series UO_2-UO_3, has been extensively documented by such authors as Berman (1957), Frondel (1956, 1958), Sobolewa and Pudovkina (1957) and Lima de Faria (1964). Ramdohr (1969) has provided the only comprehensive summary of the relationship between the physical properties of uraninites and their chemical composition and concludes that 'uraninite has been relatively little studied under the ore microscope'.

Uraninites possess isometric symmetry and have unit cell dimensions (a_o) ranging from ~5.56Å to ~5.34Å (Frondel, 1958; Beck, 1966). This range in unit cell size has been attributed both to the U^{4+}:U^{6+} ratio (Wasserstein, 1951; Brooker and Nuffield, 1952; Frondel, 1958; Kašpar and Hejl, 1971) and to oxygen order-disorder relationships which were considered to be a function of the R.E.:ThO_2 ratio (Berman, 1957). The uraninites usually contain Th and Rare Earths, together with Pb of 'contaminant' or radiogenic origin; the former elements being particularly enriched in the uraninites of pegmatitic occurrences. Other elements such as Al, Fe, Mn, Ca, Na, Ba, Bi, Cu, Zr, As, P, and Te, although often reported as being present in trace amounts after bulk wet-chemical analyses, have never been conclusively proven to be present in the uraninite lattice other than as inclusions of foreign material (Palache et al., 1944). H_2O too, occasionally reported as occurring in small amounts, is probably not an essential component of the uraninite lattice, but represents some secondary hydrated phase generated during alteration.

The reflectance of uraninite (and pitchblende) are reported by Uytenbogaardt and Burke (1971) to be 17.1% @ 515 nm and 'about 10-15%' respectively; the reflectance of pitchblende is thought to decrease with increasing UO_3 content. The same authors give a range of VHN of 314-803 for pitchblende and of $VHN_{50-100\ gm}$ of 625-929 for uraninite. Beck (1966) reported $VHN_{100\ gm}$ of 588-1033 for uraninites from the Beaverlodge district of NW Saskatchewan.

In view of the desire of the IMA-Commission on Ore Microscopy to document the quantitative microscopic characteristics of analyzed materials, the present study was undertaken at the University of Alberta. Those uraninites chosen were simply those Canadian specimens at hand in the University of Alberta collections which, under the electron microprobe, proved to contain sufficiently homogeneous domains which could be analyzed prior to reflectance and micro-indentation hardness determination. Two of the specimens are from Hudsonian veins in the Fay Mine of Eldorado Nuclear Ltd., in the Beaverlodge area of N Saskatchewan, whilst three others are from a nearby pegmatite and younger stockworks. The other specimens analyzed came from Hudsonian veins in the old Eldorado Mine at Port Radium on Great Bear Lake in the NW

Table 10 - Unit Cell Parameters of the Analyzed Uraninites

Sample No.	Locality	Type of Occurrence	a_o(Å) ± 0.004	UO_m*	Inferred Oxygen wt %, ± 0.04%
F-1309-23	Fay Mine	Vein	5.345	$UO_{2.96}$	16.6
F-1709-18	Fay Mine	Vein	5.345	$UO_{2.96}$	16.6
UA-1869	Fission U Mines	Pegmatite	5.398	$UO_{2.68}$	15.2
UA-1820	Port Radium Mine	Vein	5.430	$UO_{2.51}$	14.4
F-255-5	Fay Mine	Stockwork	5.430	$UO_{2.30}$	13.4
UA-2218	Martin Lake Adit	Stockwork	5.435	$UO_{2.26}$	13.2
SU-6	Emar Lake	Pegmatite	5.462	$UO_{2.68}$	15.2

* Values of the oxidation state of uranium extrapolated from Kašpar and Hejl's diagram (1970) after correction for Th where necessary according to Frondel (1958).

Territories (Ruzicka, 1971) and from a Grenvillian pegmatite at Fission Uranium Mines, Wilberforce, Ontario (Lang et al., 1962).

Unit Cell Dimensions

Powder diffraction patterns of the uraninites were produced on a 229.2 mm diameter, Nonius Guinier-DeWolff camera, using quartz-monochromatized CuK_{α} radiation and a silicon internal standard. Final refinements of the cell parameters were obtained employing the extrapolation function of Nelson and Riley (1945) and an APL language computer program for least squares regression. The maximum error in these determinations was ± 0.004Å. The results of the determinations of cell size appear in Table 10. This table also contains data concerning the 'inferred oxidation states' of the uraninites which were computed from an extrapolated version of Kašpar and Hejl's (1971) diagram, after correction of the a_0 value for Th content according to the data of Frondel (1958).

Electron Probe Analyses

Polished samples, vacuum-coated with carbon, were analyzed on an ARL-EMX electron probe using an operating voltage of 15 Kv (except for Pb and U analyses, where samples were run at 25 Kv), a beam current of 0.1 to 1.0 microampere and a beam spot size of ~1 micron. Employing an integration time of 50 seconds on the scaler , pulse height discrimination was used for all elements; a minimum of 10 counts per element being performed. Where a noticeable degree of inhomogeneity was detected, two separate areas (designated 'A' and 'B' in Table 11) approximately 200 microns apart were analyzed in the same specimen. During all the analyses, the specimen was moved automatically beneath the beam at a rate of 96 μm min in order to minimize sample damage by the beam and the build-up of contamination. The X-ray line intensities obtained for U, Pb, Ca, Ce, Si, Th, Y, and Fe were corrected for background, atomic number, mass absorption and fluorescence effects utilizing the APL language computer program of Smith and Tomlinson (1970). The X-ray line intensities for the trace elements Mn, Al, Ti, Mg, Na, S, Ba, and Zr were corrected for background only. 99.99% pure metal standards were used in the analyses for U, Th, Y, and Zr, whereas for the remaining elements laboratory standards of analyzed galena, barite, fluorapatite, albite, orthoclase and amphibole were utilized. All quantitative analyses were preceded by qualitative analytical scans.

The results of the electron probe partial analyses are presented in Table 11. It should be noted that the computation of these data was based upon an 'inferred oxidation state' as shown in Table 10.

Results

The following observations may be made concerning the analytical results:

Table 11 - Partial electron microprobe analyses (in wt %) of Canadian uraninites. (Analyst: G.P. Sassano, U. of A.)

Specimen No.	F-1309-23	F-1709-18		UA-1869		UA-1820		F-255-5	UA-2218		SU-6
Element	wt %	wt %		wt %		wt %		wt %	wt %		wt %
U	66.10	69.79	71.58	64.48	64.32	68.81	68.82	73.16	66.79	68.87	56.29
Th	n.d.	n.d.	n.d.	11.45	12.06	n.d.	n.d.	n.d.	n.d.	n.d.	10.21
Pb	9.55	4.98	7.84	10.85	10.69	16.20	16.21	9.65	13.93	11.57	18.07
Y	n.d.	n.d.	n.d.	0.61	0.61	0.31	0.38	n.d.	n.d.	n.d.	0.36
Ce	n.d.	0.04	0.08	0.45	0.06	0.18	0.19	0.60	0.01	0.60	0.18
Ca	2.36	4.07	3.69	0.68	0.45	0.91	0.88	2.01	2.91	3.48	0.40
Fe	1.44	1.39	1.57	0.07	0.04	0.12	0.17	0.35	0.01	0.08	0.06
Mn	0.49	0.14	0.15	0.07	0.05	0.26	0.25	0.53	0.38	0.51	0.04
Ti	0.42	0.16	0.09	0.05	0.04	0.05	0.06	0.23	0.04	0.06	0.04
Si	1.07	0.61	0.64	0.08	0.06	0.06	0.06	0.16	0.14	0.15	0.21
Al	0.31	0.06	0.07	0.01	0.01	0.04	0.02	0.02	0.03	0.01	0.03
Na	0.14	0.15	0.15	0.02	0.02	0.08	0.07	0.11	0.12	0.12	0.02
Mg	0.05	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.03	0.02
Ba	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01
Zr	0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S	0.60	0.33	0.47	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.05
Partial Total	82.59	81.74	86.35	88.86	88.84	87.05	87.15	86.86	84.39	85.49	85.99

Footnote: La, Nb, Re, In, Ta, HF, Te, Cu and As were sought during preliminary qualitative scans, but were below the detection limits.

(1) The only uraninites with detectable concentrations of Th are those of pegmatitic affinity; a point which agrees with the observations of previous authors (c.f. Ramdohr, 1969).

(2) The Pb content of the uraninites varies, even markedly within single specimens over distances of <200 microns. In each case, computation on the basis of the mineral's known approximate radiometric age reveals clearly that the bulk of the Pb present is of a radiogenic nature.

(3) All the samples analyzed contained Ca which appears to exhibit a generally antipathetic relationship towards Pb throughout the suite of samples. There is little doubt that this Ca is proxying for U in the uraninite structure as is evidenced by the electron beam scanning photographs of Plates X, XI and XII.

(4) Elements such as Fe and Si (which were notably abundant in the samples from the Fay Mine) obviously occurred as microscopic (< 1μ) inclusions of hematite (and/or siderite) and silicates respectively; (see Plates X, XI and XII), although the Fe in the uraninites is probably in part substituting in the uranium oxide lattice.

(5) Other elements such as Cu and S, wherever present occurred as microscopic inclusions of sulfides (e.g. bornite, covellite and pyrite) and other gangue minerals; see Plate XII.

PLATE X

Sample F-1709-18, 'A', Fay Mine

S.C. : Sample current photograph of uraninite (white) with veinlets, patches and microscopic inclusions of quartz (QTZ).

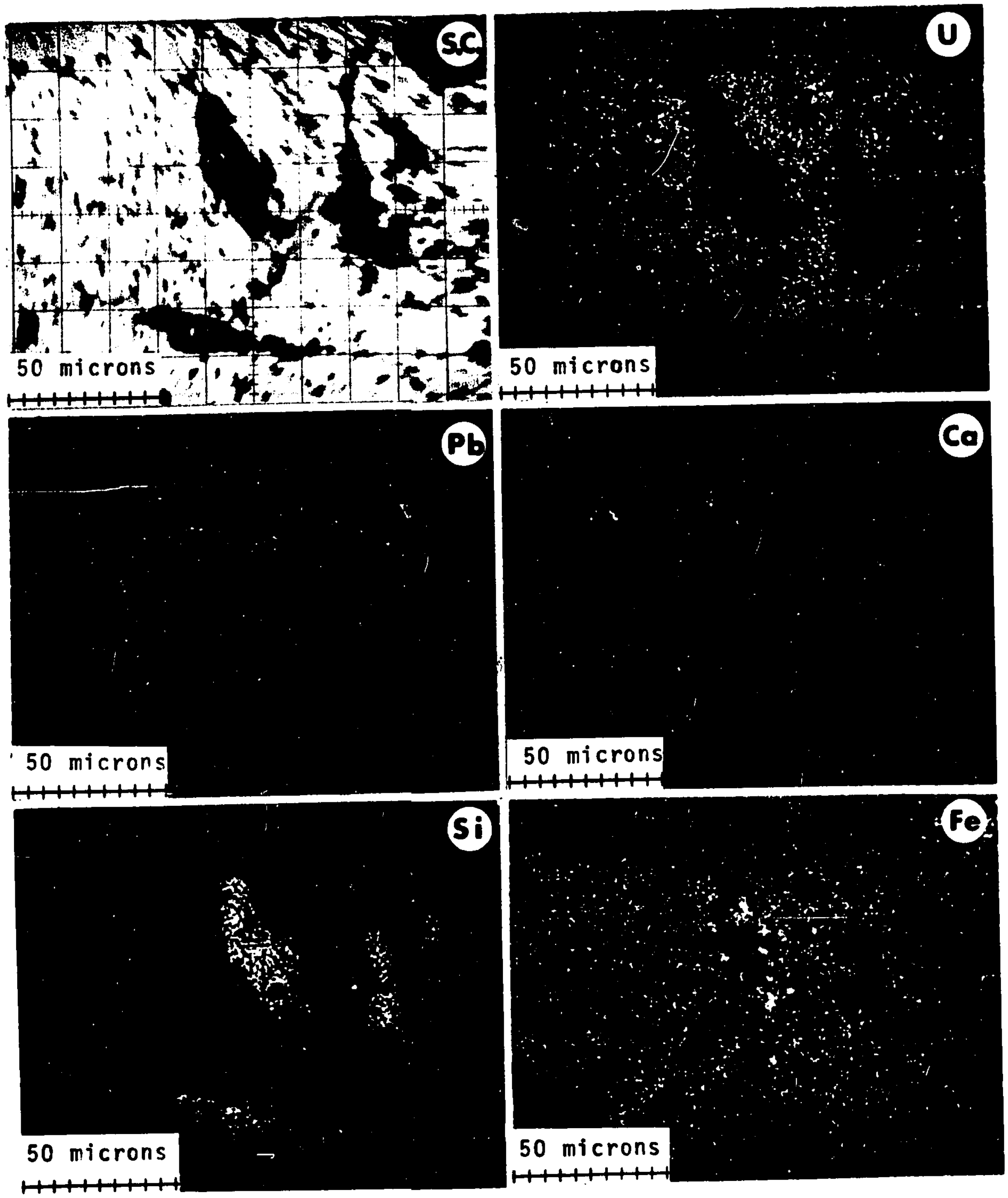
U : $U_{M\alpha 1,2}$ X-ray emission photograph.

Pb : $Pb_{L\alpha_1}$ X-ray emission photograph.

Ca : $Ca_{K\alpha 1,2}$ X-ray emission photograph. Note that Ca occurs throughout the uraninite and in gangue minerals (carbonates).

Si : $Si_{K\alpha 1,2}$ X-ray emission photograph. Si occurs in gangue minerals only (quartz and feldspar).

Fe : $Fe_{K\alpha 1,2}$ X-ray emission photograph. Fe occurs throughout the uraninite and as disseminated hematite microcrystals.


S.C.
50 microns
U
50 microns
Pb
50 microns
Ca
50 microns
Si
50 microns
Fe
50 microns

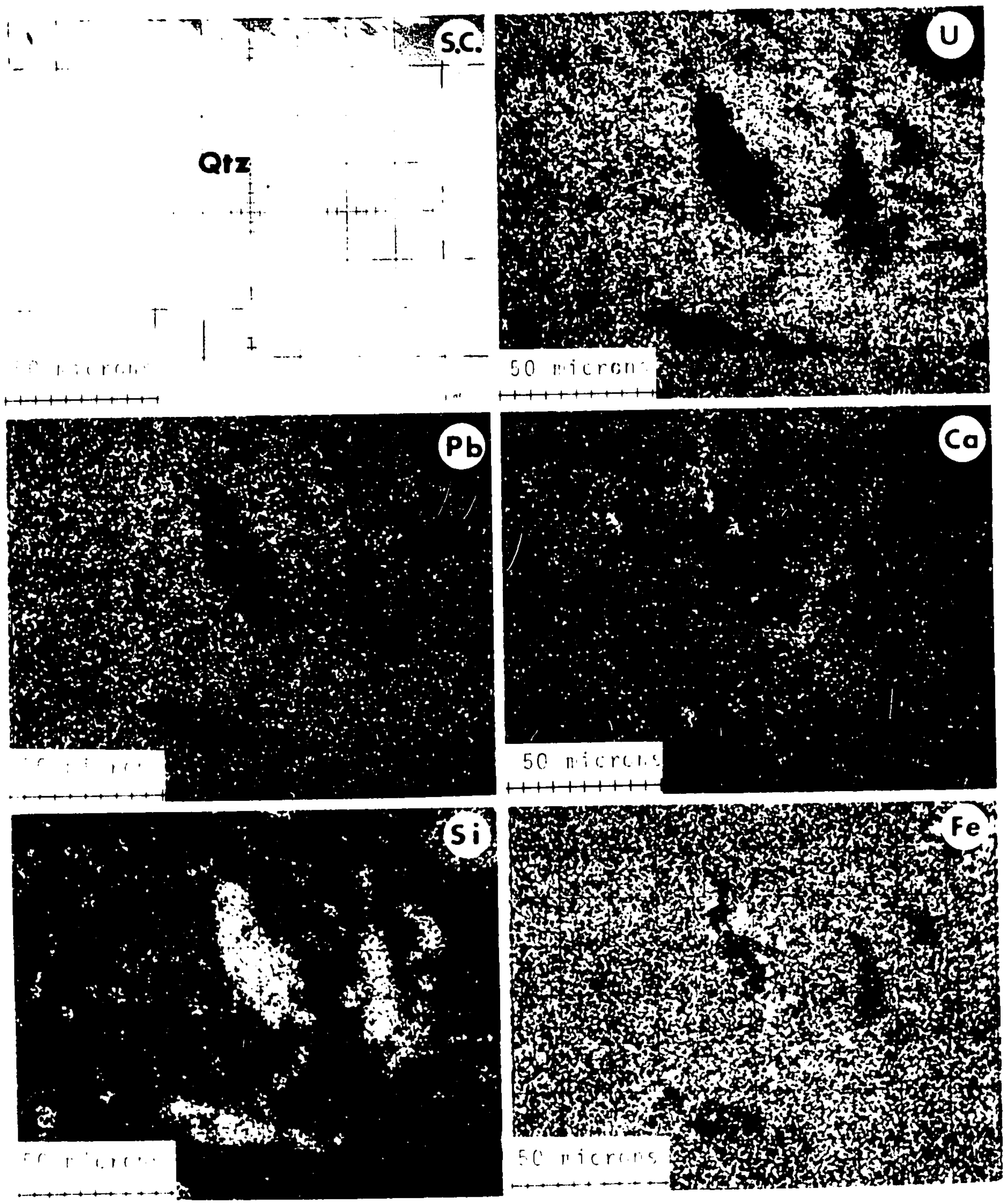

S.C.
Qtz
U
50 microns
Pb
Ca
50 microns
Si
Fe
50 microns

PLATE XI

Sample UA-2218, 'A', Martin Lake Mine Adit

S.C. : Sample current photograph of botryoidal uraninite (white) in massive calcite gangue (CAL).

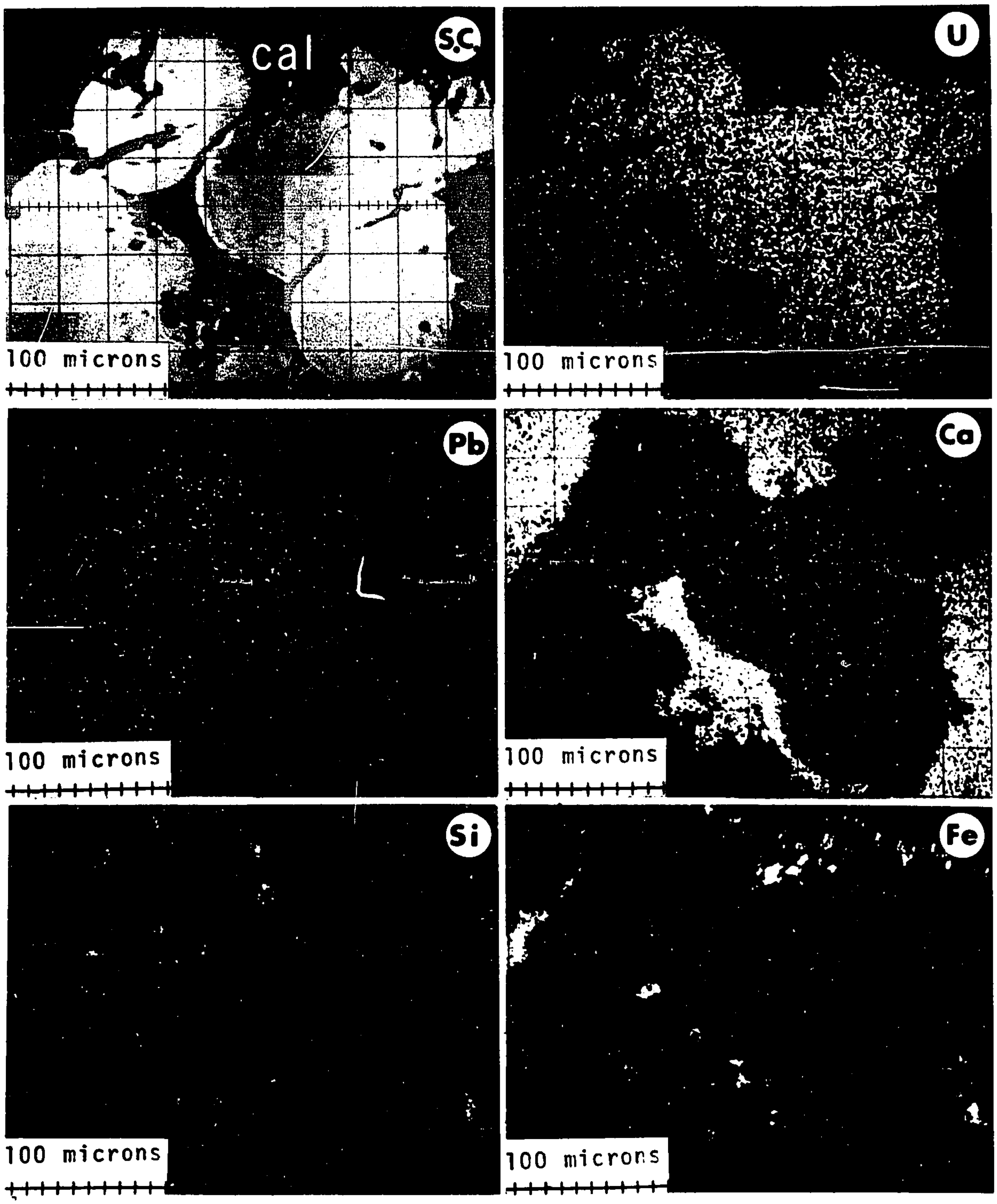
U : $U_{M\alpha 1,2}$ X-ray emission photograph.

Pb : $Pb_{L\alpha 1}$ X-ray emission photograph.

Ca : $Ca_{K\alpha 1,2}$ X-ray emission photograph. Ca occurs throughout the uraninite and in gangue minerals (carbonates).

Si : $Si_{K\alpha 1,2}$ X-ray emission photograph. Si occurs in gangue minerals (quartz and feldspar) bordering uraninite.

Fe : $Fe_{K\alpha 1,2}$ X-ray emission photograph. Fe occurs throughout uraninite and as disseminated hematite dust or sulfide micro-inclusions.


S.C.
cal
100 microns
U
100 microns
Pb
100 microns
Ca
100 microns
Si
100 microns
Fe
100 microns

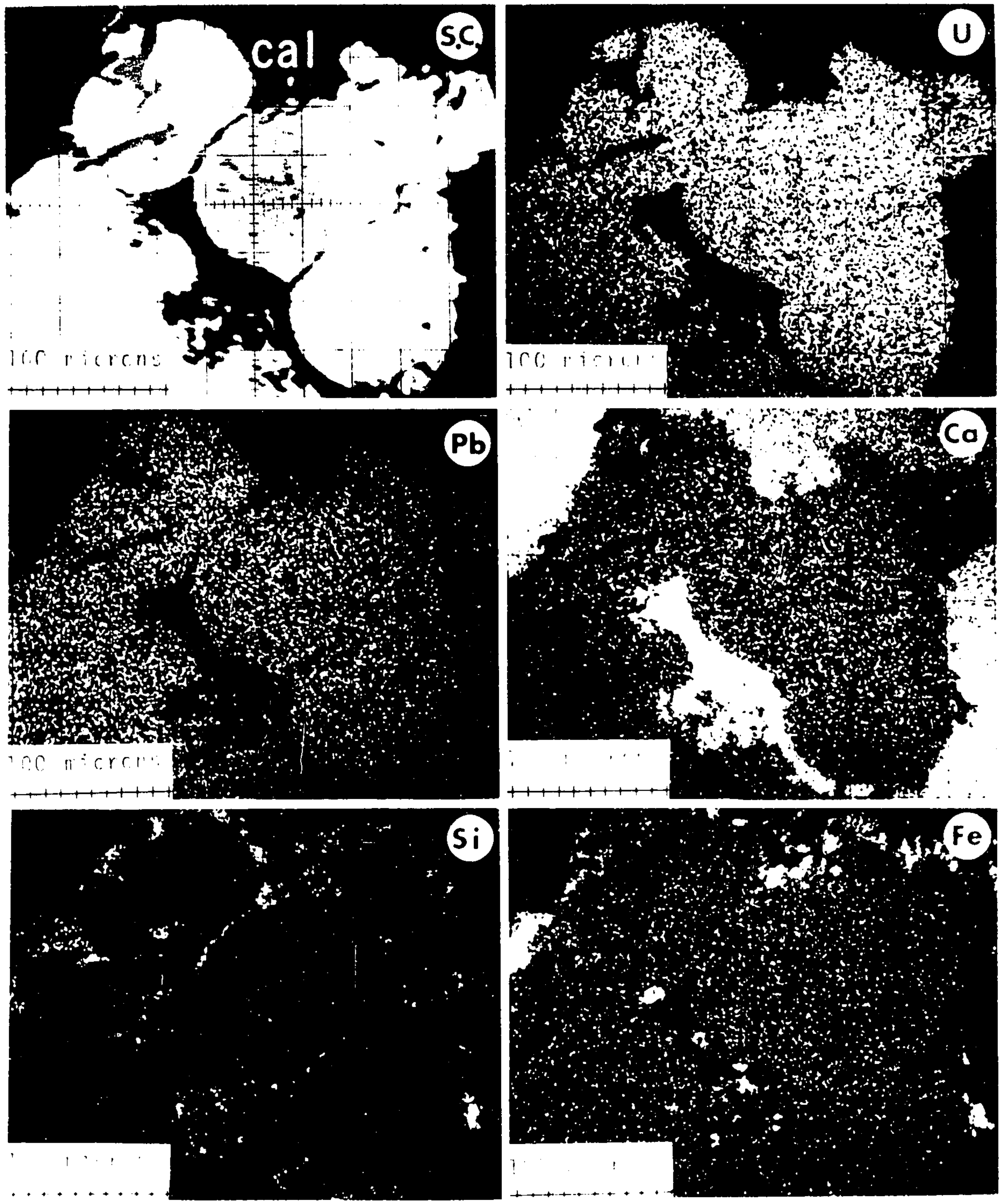

S.C.
cal
100 microns
U
Pb
100 microns
Ca
Si
Fe

PLATE XII

Sample UA-2218, 'B', Martin Lake Mine Adit

S.C. : Sample current photograph of botryoidal uraninite (white) in massive calcite gangue (CAL).

U : $U_{M\alpha 1,2}$ X-ray emission photograph.

Pb : $Pb_{L\alpha 1}$ X-ray emission photograph.

Ca : $Ca_{K\alpha 1,2}$ X-ray emission photograph. Ca occurs throughout the uraninite and in gangue minerals (carbonates).

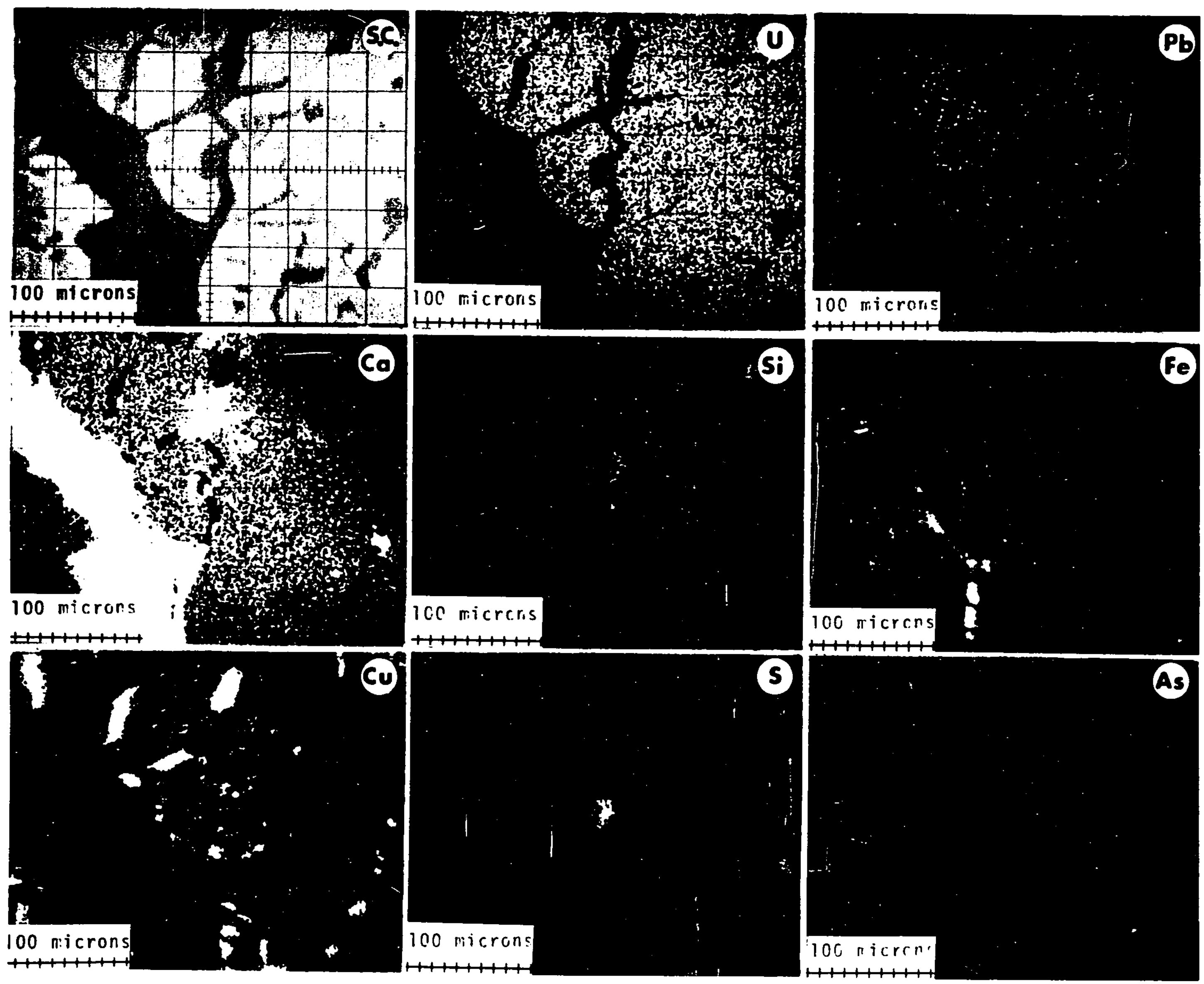
Si : $Si_{K\alpha 1,2}$ X-ray emission photograph. Si occurs in cracks filled by gangue minerals (quartz or feldspar).

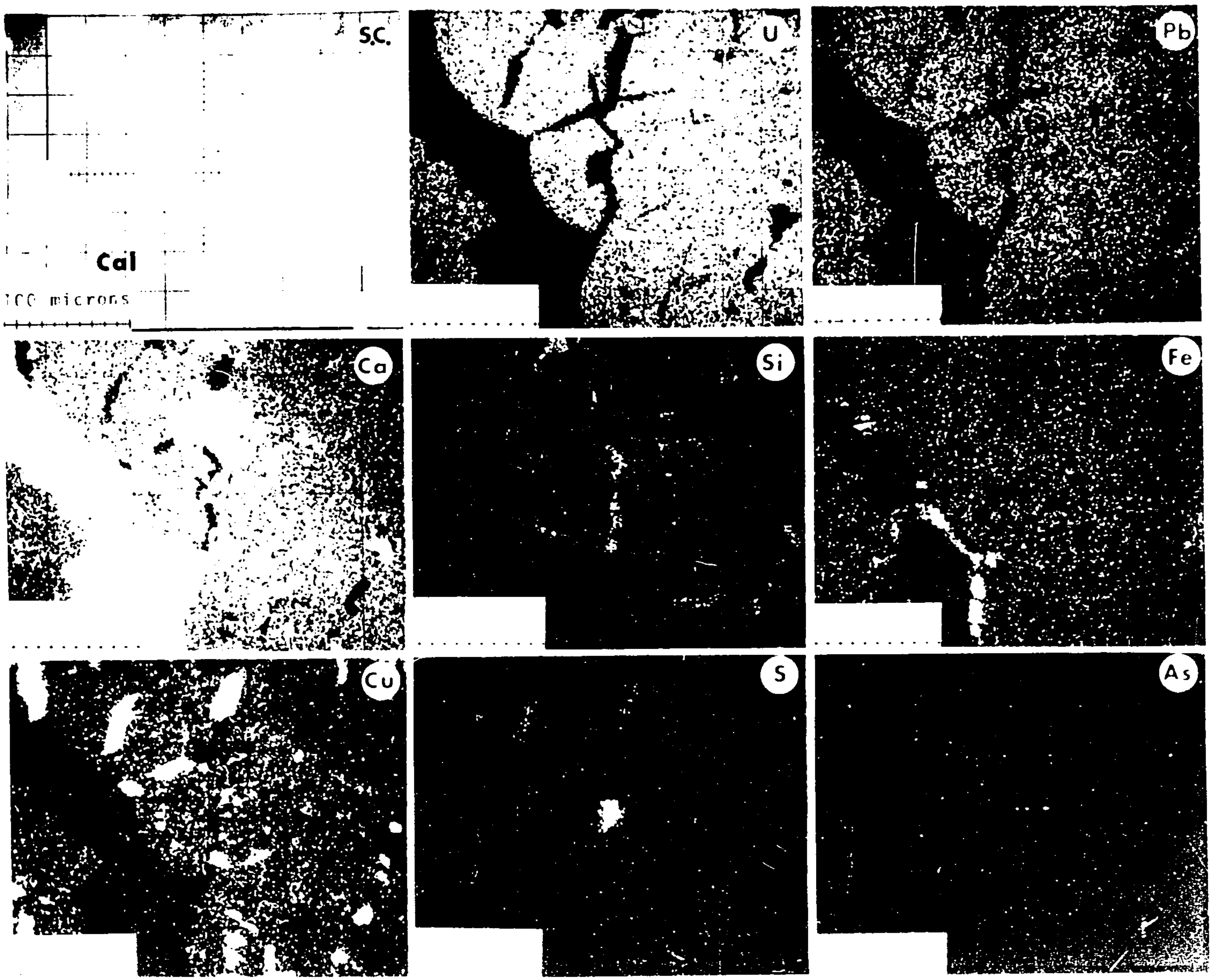
Fe : $Fe_{K\alpha 1,2}$ X-ray emission photograph. Fe occurs throughout uraninite and as disseminated hematite dust or micro-crystals.

Cu : $Cu_{K\alpha 1,2}$ X-ray emission photograph. Cu occurs in bornite and covellite.

S : $S_{K\alpha 1,2}$ X-ray emission photograph. S occurs in gangue minerals only.

As : $As_{K\alpha 1,2}$ X-ray emission photograph. As not detected.


SC
100 microns
U
100 microns
Pb
100 microns
Ca
100 microns
Si
100 microns
Fe
100 microns
Cu
100 microns
S
100 microns
As


S.C.
Cal
100 microns
U
Pb
Ca
Si
Fe
Cu
S
As

Reflectance and Micro-indentation Hardness

The reflectance measurements were performed using a Vickers' M74 polarizing microscope with a stabilized, 12v - 100 w, quartz-halogen, filament lamp, a running interference-filter monochromator and an EEL (165) digital microphotometer. The standard used in each determination was a Carl Zeiss and Co. SiC slice (#474281 - No. 080) whose R% @ 546 nm in air was 21.0%.

Micro-indentation hardnesses (Vickers Hardness Numbers) were determined employing an hydraulically impelled Vickers 136 diamond indenter. All indentations were performed at standard loads of 100 gm. In every case the indentations proved to be almost perfect and slightly concave.

The results of the micro-indentation hardness and reflectance (air) measurements are presented in Table 12.

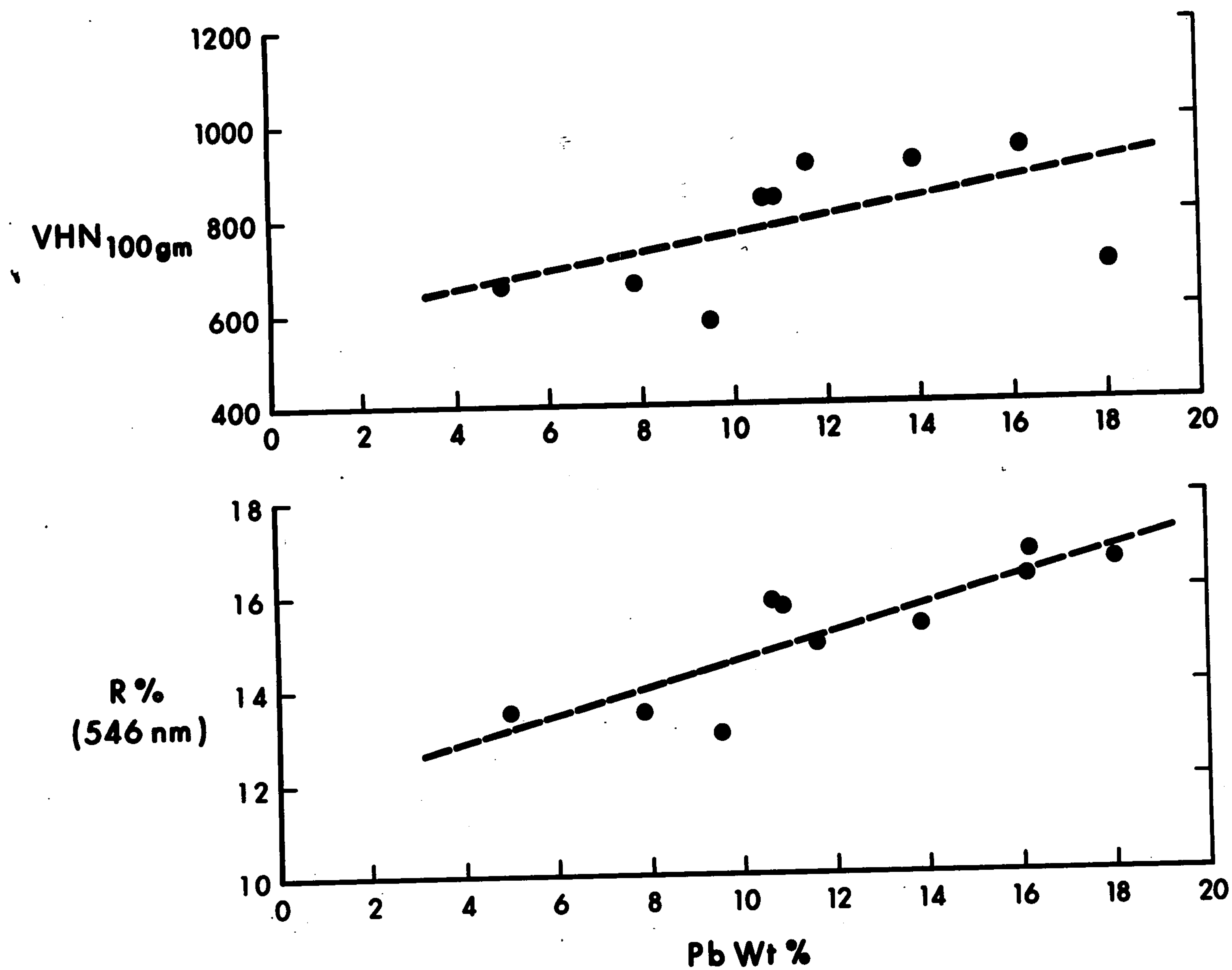
Relationships between Chemistry, VHN and Reflectance

The variations in $VHN_{100\ gm}$ and R% @ 546 nm (air) in the uraninites studied cannot be directly related to the oxidation state of the oxide computed on the basis of the unit cell dimensions. However, there appears to be a distinct relationship between VHN and R% and the amount of Pb present in the structure. Generally, as is evidenced by Figure 30, an increase in R% at 546 nm (air) and $VHN_{100\ gm}$ accompanies an increase in the Pb content; although one sample (SU-6) appears to be somewhat anomalous.

Table 12 – Reflectance and Micro-indentation Hardness Values for Uraninite

Sample No.		$VHN_{100\ gm}$	Reflectance % @ 546 nm (air)
F-1309-23		579	13.0
F-1709-18	A	656	13.5
	B	660	13.5
UA-1869	A	839	15.7
	B	840	15.8
UA-1820	A	941	16.3
	B	940	16.8
UA-2218	A	908	15.3
	B	910	14.9
SU-6		690	16.6

Fig. 30. Micro-indentation hardness (100 gm) and reflectance (air) vs. Pb wt. % diagram.



VHN100gm
1200
1000
800
600
400
0
2
4
6
8
10
12
14
16
18
20
R %
(546 nm)
18
16
14
12
10
Pb Wt %

SUMMARY AND CONCLUSIONS

This study has revealed that the main epigenetic uraniferous mineralization of the Fay Mine is confined to the mylonitized albite paraschists and paragneisses belonging to the Fay Mine Complex. The lower members of the metamorphic Tazin Group, the Donaldson Lake and the Foot Bay Gneisses, are usually barren and only occasionally bear minor erratic syngenetic (pegmatitic) uranium mineralization of low grade character. The ore controls of the Fay Mine are of structural and lithological nature: uranium oxides $\pm$ quartz $\pm$ carbonates $\pm$ hematite $\pm$ chlorite veins occur sub-parallel to the foliation planes, in crests, troughs and limbs of folds formed during the Hudsonian orogeny. Such veins are thought to have been generated during the retrogressive phase of the regional metamorphism by mobilization of uranium-rich fractions from uraniferous precursors of the Fay Mine Complex. The Fay Mine orebodies are therefore re-classified as 'mobilized stratabound deposits'. Fluid inclusion data, augmented by stable isotope and petrographic studies, have also revealed a cooling history from the initial phase of mineralization at $440^{\circ} \pm 30^{\circ}C$ (i.e. the greenschist facies of retrogression) down to final stages of crystallization at around $80^{\circ} \pm 10^{\circ}C$. Later movements of such structures as the St. Louis Fault have apparently effected only local deformation and re-brecciation of the uraniferous veins.

From the economic point of view, stratigraphic and structural evidence indicates that the Verna deposit should not extend below the 26th Level of that mine. The Fay orebodies however, could reach and extend below the 32nd Level, although it is possible that the Foot Bay Gneiss, seen in section to advance gradually towards the St. Louis Fault (towards the SW) may pinch-out the Fay Mine sequence and consequently cut off the foot wall orebodies. For those areas not within the immediate vicinity of the Fay Mine, similar stratigraphy, rock types and structures should be prospected. In particular, the Milliken Lake antiform, which in many ways resembles the Donaldson Lake antiform, should be explored in detail. Other areas N and NW of the Black Bay Fault and the Tazin Lake region should also be considered as favourable explorations targets.

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APPENDIX A

Petrographic Description of Analyzed Samples

FOOT BAY GNEISS

F-25-001 (Location: 254191 Drift E, Fay Mine):

CATACLASTIC-MYLONITIC CHLORITE-BIOTITE MICROCLINE-PLAGIOCLASE GNEISS

This rock is cataclastic to mylonitic in texture, partly porphyroclastic due to a rough alternation of quartz and feldspar-rich bands or ribbons. Red-stained microcline (29%), plagioclase (25%) and quartz (35%) are set in a mylonitic matrix. The megacrysts are usually surrounded by rare muscovite flakes or by biotite (9%) porphyroblasts altered to chlorite. Quartz is rolled-out and elongated, sometimes displaying sutured margins, cemented by a fine-grained mylonitic matrix. Very well oriented chlorite occurs in bands. Calcite fills grain interstices. Pyrite and sphene constitute the varietal minerals whilst zircons of multiple origin and generations and hematite constitute the accessories.

F-25-002 (Location: 254191 Drift E, Fay Mine):

MYLONITIC CHLORITE-BIOTITE-MICROCLINE-PLAGIOCLASE GNEISS

Petrography as for F-25-001, with slight modal differences.

F-25-092 (Location: 254191 Drift E, Fay Mine):

CATACLASTIC-MYLONITIC CHLORITE-HORNBLENDE-BIOTITE MICROCLINE-PLAGIOCLASE GNEISS

The rock is cataclastic to mylonitic, characterized by medium to large porphyroclasts and porphyroblasts of microcline (19%), plagioclase (34%) and quartz (27%) set in a fine-grained, polycrystalline aggregate of quartz, feldspars and micas. The grains are rounded to ellipsoidal, fractured and recemented by a mylonitic matrix. The feldspars are quite altered and red-stained, and are surrounded by bands or ribbons of rolled-out quartz. Flakes of biotite (7%) occur in the interstices between grains. Some relics of hornblende (3%) are also visible. Hematite and pyrite are the varietal minerals whilst sphene, zircon and apatite constitute the accessory fraction.

F-25-097 (Location: 254191 Drift E, Fay Mine):

MYLONITIC GARNET-CHLORITE-BIOTITE-HORNBLENDE MICROCLINE-PLAGIOCLASE GNEISS

The rock is mylonitic porphyroclastic to porphyroblastic, locally cataclastic, fine- to medium-grained, with well rounded porphyroclasts of microcline (27%) and plagioclase (31%) set in a chloritized quartz-feldspar matrix. The plagioclases are intensely altered, broken or crushed, usually with irregular edges, sometimes overgrown by recrystallized quartz. They are also locally surrounded by chlorite (var. penninite) or by small relics of hornblende (4%). Quartz (26%) is strongly deformed and rolled-out. When present, albitization appears to postdate microclinization, since albite occurs in veinlets. Biotite (3%) is broken or bent. Hematite, pyrite and ilmenite are the varietal minerals, whilst apatite, sphene, zircon, epidote and anhydrite constitute the accessories.

F-25-101 (Location: 254191 Drift E, Fay Mine)

MYLONITIC GARNET-HORNBLENDE-BIOTITE-CHLORITE MICROCLINE-PLAGIOCLASE GNEISS

The rock is mylonitic fluidal, porphyroclastic, and characterized by megacrysts (up to 5 cm in diameter) of plagioclase (28%) and porphyroblasts of microcline (18%) set in a fine aggregate of quartz, feldspar, biotite and chlorite. The megacrysts are ellipsoidal or rounded with fractured and fringed edges, they are also surrounded by ribbons of fine granulated quartz or by a mylonitic matrix. Hornblende (0.5 to 4%) occurs as large subrounded crystals, which are slightly poikiloblastic and intensely pleochroic (deep green to brown). Biotite (4%) is also present as small contorted flakes surrounding the megacrysts or filling the interstices between grains. Quartz (34%) occurs in bands, and trends of rolled-out clasts or in ribbons formed by an aggregate of fully recrystallized grains. Hematite is the varietal mineral whilst apatite, sphene, epidote and zircon are accessories.

F-25-102 (Location: 254191 Drift E, Fay Mine):

MYLONITIC GARNET-CHLORITE-HORNBLENDE-BIOTITE MICROCLINE-PLAGIOCLASE GNEISS

Petrography as for F-25-101, with some modal differences.

F-22-023 (Location: 224091 Drift E, Fay Mine):

MYLONITIC GARNET-CHLORITE-EPIDOTE-BIOTITE-HORNBLENDE MICROCLINE-PLAGIOCLASE GNEISS

The rock exhibits a porphyroclastic mylonitic fluidal texture due to perfectly rounded or ellipsoidal megacrysts (up to 6 cm in diameter) of plagioclase (25%) and porphyroblasts of microcline (22%) alternating with bands or ribbons of recrystallized quartz (34%) and ultracrush. The clasts are irregularly fractured or broken and have serrated margins which are overgrown by a fine aggregate of polycrystalline quartz. Locally broken and fractured crystals of hornblende (4%) are seen to have undergone biotitization. Abundant small flakes of biotite (4%), altered to chlorite, form layers which alternate with rolled-out quartz or surround major clasts. The feldspars are quite altered, usually fractured, locally brecciated or recemented by a mylonitic matrix. In some places fresh microcline is seen to have developed at the expense of older red-stained feldspars. Pyrite, hematite, graphite are the varietal minerals, whilst zircon apatite, epidote and calcite are the accessories.

DONALDSON LAKE GNEISS

SU-1 (Location: HAB Road, between Mickey Lake and Donaldson Lake):
STRAINED EPIDOTE-CHLORITE-MUSCOVITE-BIOTITE PLAGIOCLASE GNEISS

The rock has a porphyroclastic, locally grano-lepidoblastic texture. It is composed of anhedral grains of Na plagioclase (47%) scattered in a fine-grained quartz and mica matrix. Some of the large grains are perfectly rounded and locally these are broken and display poorly developed twin-lamellae due to strong alteration. Microcline is fresh and not very abundant (5%). Quartz (35%) is usually interstitial to other minerals forming thin ribbons surrounding the plagioclase grains. Biotite (5%) is present as bent flakes which are usually associated with fine-grained opaques; it is also seen altered to chlorite. Some of the biotite flakes are full of zircon inclusions displaying pleochroic haloes. Hematite and opaques constitute the varietal minerals whilst zircon and apatite are the accessories.

SU-3 (Location: EMAR Lake Road, S of Foot Bay):
MYLONITIC EPIDOTE-BIOTITE-CHLORITE-MUSCOVITE PLAGIOCLASE GNEISS

The rock has a mylonitic texture with large megacrysts (up to 3 cm in diameter) of plagioclase (44%) and minor microcline (4%) set in fluidal aggregate of quartz and feldspar crush. The grains are quite broken and fractured, being subrounded and locally recemented by a mylonitic matrix.

Highly deformed porphyroclasts of muscovite (6%), intensely altered to chlorite, are visible along the edges of the clasts, which are usually sutured and irregular, and marked by notable amounts of sphene, opaques and hematite. Several ultramylonitic zones are seen to cut the contorted bands of quartz at about 85 . In these zones the clasts are very fine-grained and pulverized. Quartz (34%) is finely crushed or rolled-out. Biotite is usually very altered and has broken down to form sphene and opaques. Hematite, pyrite and sphene are the varietal minerals whilst calcite is the accessory.

SU-5 (Location: EMAR Lake Trenches):

CATACLASTIC HEMATITE-CHLORITE-MUSCOVITE PLAGIOCLASE GNEISS

The rock has a cataclastic to mylonitic texture with large megacrysts of plagioclase (42%) and minor microcline (3%) set in a quartz, feldspar, chloritic, calcitic matrix. The clasts are quite broken, fractured and recemented by a mylonitic matrix. Plagioclases show intense deformation with microfractures or microfaults filled by iron oxides, or by calcite. Quartz occurs as crush aggregate in bands or is rolled-out forming elongated trains surrounding the plagioclases. In some locations it is possible to find fresh, recrystallized panidiomorphic microlites of albite scattered in the quartz feldspar hematitic matrix. Some older grains show myrmekitic textures. Hematite, pyrite, and sphene are the varietal minerals whilst zircon, calcite, anhydrite and epidote constitute the accessory fraction.

F-25-010 (Location: 254191 Drift E, Fay Mine):

CATACLASTIC CHLORITE-BIOTITE-MUSCOVITE PLAGIOCLASE GNEISS

The rock is cataclastic porphyroclastic-porphyroblastic, and locally granonematoblastic with medium-grained subangular plagioclase grains (34%) and microcline (11%) set in a very fine-grained quartz-feldspar-mica matrix. The plagioclases exhibit strong deformation of their twin lamellae and are locally poikiloblastic. Quartz (39%) is partly recrystallized, 'dusty' and red-stained. The interstices between grains are in part the loci of nematoblastic, broken muscovite which is intensely bent and chloritized. Pyrite, hematite and opaques are the varietal minerals whilst zircon, sphene, apatite, calcite and anhydrite are the accessories. Very evident is the cutting-off of slip zones by younger very fine-grained crush zones.

F-25-014 (Location: 254191 Drift E, Fay Mine):

CATACLASTIC CHLORITE-BIOTITE-MUSCOVITE PLAGIOCLASE GNEISS

Petrography as for F-25-010, with slight modal differences.

F-25-016 (Location: 254191 Drift E, Fay Mine):

STRAINED EPIDOTE-CHLORITE-BIOTITE PLAGIOCLASE GNEISS

The rock is strained to cataclastic, locally granoblastic with medium- to fine-grained subrounded acid plagioclases (41%) and rolled-out quartz (39%) set in a fine-grained interlocking aggregate of quartz, feldspar, chlorite and opaques. The plagioclases are quite altered, although in some places relic twinning is visible. Microcline (12%) is usually developed at the expense of the plagioclases, or it is fresh and interstitial. Trains of interlocking quartz grains surround larger grains of feldspar. Chlorite (2%) is pseudomorphic after biotite (2%) or occurs in rims along the quarta and feldspar bands or porphyroclasts, thin veinlets of albite intersect the rock at various angles. Again in this thin section the breakdown of biotite to chlorite, opaques and sphene was observed. Apatite, pyrite and opaques constitute the varietal mineral; zircon and sphene form the accessory fraction.

F-25-018 (Location: 254191 Drift E, Fay Mine):

CATACLASTIC EPIDOTE-CHLORITE-BIOTITE PLAGIOCLASE GNEISS

Petrography as for F-25-016, with slight modal differences.

F-25-019 (Location: 154191 Drift E, Fay Mine):

CATACLASTIC MUSCOVITE-CHLORITE-BIOTITE PLAGIOCLASE GNEISS

Petrography as for F-25-010, with slight modal differences.

PEGMATITE DYKES

F-25-004 (Location: 254191 Drift E, Fay Mine):

STRAINED MUSCOVITE PEGMATITE

The rock is strained, holocrystalline, hypidiomorphic, slightly granoblastic, locally cataclastic with large euhedral crystals of plagioclase (50%) and microcline (16%) set in a medium- to fine-grained quartz feldspar matrix. The plagioclases show deformation of the twinning lamellae and along their margins they are locally cemented by a mylonitic matrix. The microcline is fresh and occurs in strongly altered plagioclases, locally exhibiting myrmekitic textures. Quartz (25%) shows saturated edges, strong undulose extinction and usually forms a rim at the contact with the country-rocks. Muscovite (10%) is present in the interstices between grains or as large books along the contacts; the flakes are strongly bent and deformed. Exceptionally large apatites are present as accessories.

F-25-006 (Location: 254191 Drift E, Fay Mine):

STRAINED MUSCOVITE PEGMATITE

Petrography as for F-25-004, with slight modal differences.

F-25-011 (Location: 254191 Drift E, Fay Mine):

STRAINED MUSCOVITE PEGMATITE

Petrography as for F-25-004, with slight modal differences.

F-25-012 (Location: 254191 Drift E, Fay Mine):

STRAINED MUSCOVITE PEGMATITE

Petrography as for F-24-004, with slight modal differences.

F-25-021 (Location: 254191 Drift E, Fay Mine):

CATACLASTIC CHLORITE-MUSCOVITE PEGMATITE

The rock is strained, holocrystalline, hypidiomorphic, granoblastic and locally cataclastic with large deformed plagioclases (45%) set in a quartz-feldspar matrix. Microcline (20%) seems to be quite fresh and develops at the expense of altered and red-stained plagioclases. Quartz (23%) presents sutured and crushed grains which are cemented by a fine-grained quartz feldspar matrix. Muscovite (8%) occurs in large books showing strong deformation. Hematite, calcite, apatite, chlorite and sphene constitute the accessory minerals.

F-25-024 (Location: 254191 Drift E, Fay Mine):

STRAINED-CATACLASTIC CHLORITE-MUSCOVITE PEGMATITE

Petrography as for F-25-021, with slight modal differences.

APPENDIX B

Location of the Most Representative Samples Studied*

Sample No.	Location	Stratigraphic Unit	Rock Name
F-22-023	224091	Foot Bay Gneiss	Mylonitic garnet-chl.-epidote-biot.-horn. microcline-plagioclase gneiss
F-24-166-1	D.D.H. 24-166 245' from Collar	Foot Bay Gneiss	Mylonitic porphyroclastic garnet-biot. microcline-plagioclase gneiss
F-25-001	254191 Dr. East	Foot Bay Gneiss	Cataclastic mylonitic chl.-biot. microcline-plagioclase gneiss
F-25-092	254191 Dr. East	Foot Bay Gneiss	Cataclastic mylonitic chl.-horn.-biot. microcline-plagioclase gneiss
F-25-102	254191 Dr.	Foot Bay Gneiss	Mylonitic garnet-chl.-horn.-biot. microcline-plagioclase gneiss
F-25-2-1	D.D.H. 25-2 161' from Collar	Foot Bay Gneiss	Mylonitic porphyroclastic muscov.-chl. microcline-plagioclase gneiss
F-25-2-2	D.D.H. 25-2 313' from Collar	Foot Bay Gneiss	Mylonitic porphyroclastic epidote-chl. plagioclase gneiss

* Underground samples were collected within a space bounded by mine coordinates 80 + 00W and 100 + 00E (distance of approximately 22000 feet), down from the 2nd to the 27th level (approximately 3700' vertical distance); the sampled horizonatal drill holes stretched up to 1500' both NE and SE of the St. Louis Fault. The sample intervals were 40'-50' in the drifts, 150'-300' in the drill holes.

F-25-2-3	D.D.H. 25-2 396' from Collar	Foot Bay Gneiss	Brecciated gneissic chl.-epidote mylonite-kakirite
F-25-2-4	D.D.H. 25-2 420' from Collar	Foot Bay Gneiss	Brecciated chl.-epidote microcline-plagioclase kakirite
F-25-2-5	D.D.H. 25-2 444' from Collar	Foot Bay Gneiss	Ultramylonite
F-25-2-6	D.D.H. 25-2, 531' from Collar	Foot Bay Gneiss	Brecciated gneissic chl.-epidote mylonite-kakirite
F-27-1-1	D.D.H. 27-1 282' from Collar	Foot Bay Gneiss	Mylonitic porphyroclastic chl. microcline-plagioclase gneiss
F-27-1-2	D.D.H. 27-1 1041' from Collar	Foot Bay Gneiss	Cataclastic mylonitic biot.-chl. plagioclase gneiss
SU-1	HAB Road, East of Donaldson Lake	Donaldson Lake Gneiss	Strained epidote-chl.-muscov.-biot. plagioclase gneiss
SU-3	EMAR Lake Road South of Foot Bay	Donaldson Lake Gneiss	Mylonitic epidote-biot.chl.-muscov. plagioclase gneiss
SU-5	EMAR Lake trenches	Donaldson Lake Gneiss	Cataclastic hematite-chl.-muscov. plagioclase gneiss
F-25-010	254191 Dr. East	Donaldson Lake Gneiss	Cataclastic chl.-biot.-muscov. plagioclase gneiss
F-25-013	254191 Dr. East	Donaldson Lake Gneiss	Strained chl.-muscov. plagioclase gneiss

F-25-014	154191 Dr. East	Donaldson Lake Gneiss	Cataclastic chl.-biot.-muscov. plagioclase gneiss
F-25-016	254191 Dr. East	Donaldson Lake Gneiss	Strained epidote-chl.-biot. plagioclase gneiss
F-25-018	254191 Dr. East	Donaldson Lake Gneiss	Cataclastic epidote-chl.-biot. plagioclase gneiss
F-25-019	254191 Dr. East	Donaldson Lake Gneiss	Cataclastic muscov.-chl.-biot. plagioclase gneiss
FW-23-1	234191 Dr. East	Donaldson Lake Gneiss	Cataclastic chl. plagioclase gneiss
A-1	Ace Creek, South of Eldorado Mill	Fay Mine Complex	Cataclastic biot.-muscov.-chl.-magnetite meta-quartz conglomerate
F-13-478-1	D.D.H. 13-478 1063' from Collar	Fay Mine Complex	Strained muscov.-hematite-meta-quartz conglomerate
F-25-060	254191 Dr. East	Fay Mine Complex	Mylonitic calcareous quartzite
F-25-072	254191 Dr. East	Fay Mine Complex	Cataclastic sericite quartzite
F-25-073	254191 Dr. East	Fay Mine Complex	Mylonitic quartzite
F-25-104	254191 Dr. East	Fay Mine Complex	Cataclastic calcareous chlorite quartzite
BO-11	Bolger pit, 6th Bench	Fay Mine Complex	Laminated garnet-chl.-sericite ultramylonite
F-22-005	224191 Dr. East	Fay Mine Complex	Chl.-muscov. feldspar-rich mylonite
F-22-006	224191 Dr. East	Fay Mine Complex	Chl.-calcite-epidote mylonite

F-22-007	224191 Dr. East	Fay Mine Complex	Cataclastic chl. paragneiss
F-22-015	224191 Dr. East	Fay Mine Complex	Cataclastic meta-tuffite
F-22-036	254191 Dr. East	Fay Mine Complex	Cataclastic basic meta-tuffite
F-25-037	254191 Dr. East	Fay Mine Complex	Brecciated mylonite
F-25-065	254191 Dr. East	Fay Mine Complex	Mylonitic chl. paragneiss
F-25-069	254191 Dr. East	Fay Mine Complex	Cataclastic chl.-muscov. plagioclase gneiss
F-25-075	254191 Dr. East	Fay Mine Complex	Cataclastic quartz-rich plagioclase gneiss
F-25-085	254191 Dr. East	Fay Mine Complex	Mylonitic chl.-muscov. feldspar-rich gneiss
F-25-086	254191 Dr. East	Fay Mine Complex	Cataclastic chl.-muscov. paragneiss
F-25-039	254191 Dr. East	Fay Mine Complex	Ultramylonitic gneissic breccia
F-25-043	254191 Dr. East	Fay Mine Complex	Mylonitic porphyroclastic felsic plagioclase gneiss
F-25-066	254191 Dr. East	Fay Mine Complex	Cataclastic calcite-muscov. plagioclase gneiss
F-25-004	254191 Dr. East	Tazin Group	Strained to cataclastic muscov. pegmatite
F-25-006	254191 Dr. East	Tazin Group	Strained muscovite pegmatite
F-25-021	254191 Dr. East	Tazin Group	Cataclastic chl.-muscov. pegmatite

F-25-024	254191 Dr. East	Tazin Group	Strained to cataclastic chl.-muscov. pegmatite
FW-18-1	18th Level close to Fay-Winze Station	Martin Formation	Conglomeratic arkose
FW-18-2	18th Level close to Fay-Winze Station	Martin Formation	Arkose
FW-19-1	19th Level close to Fay-Winze Station	Martin Formation	Conglomerate

APPENDIX C

The Isotopic Composition of Calcites and Dolomites from the Fay Mine and Bolger Open Pit, Eldorado, Sask.

Sample Number Locality	Code No.	Description	$\delta\ O^{18}$PDB%	$\delta\ C^{13}$PDB%
F-255-4, 2nd L. Fay Mine	F-20	Pink calcite, massive, in Martin conglomerate, with ore	-18.66	- 2.20
F-255-5, 2nd L. Fay Mine	F-21	Pinkish brown calcite, massive, in Martin conglomerate, with ore	-18.56	- 2.32
BO-2 A, Bolger P. 3rd Bench	B-24	White calcite, rhombohedra, covered by yellow calcite, with ore	-16.69	- 5.37
BO-2 B, Bolger P. 3rd Bench	B-33	Yellow calcite	-15.48	-16.82
BO-2 C, Bolger P. 3rd Bench	B-22	White calcite, small rhombohedra covered by yellow calcite	-17.73	- 5.17
BO-2 D, Bolger P. 3rd Bench	B-23	White calcite, large rhombohedra covered by yellow calcite	-17.60	- 5.41
BO-2 E, Bolger P. 3rd Bench	B-32	Yellow crust covering large white rhombohedron of calcite	-16.1	-16.42
BO-5 A, Bolger P. 4th Bench	B-29	Large composite rhombohedra of white calcite covered by brown crust	-11.75	-17.04
BO-5 B, Bolger P. 4th Bench	B-28	Large composite crystals of white calcite	-13.37	-15.43
BO-5 C, Bolger P. 4th Bench	B-27	Rhombohedra of white calcite covered by a rusty brown crust	-15.34	-14.63

Sample Number Locality	Code No.	Description	δO^{18}PDB%	δC^{13}PDB%
BO-6, Bolger P. 5th Bench	B-1	Brown calcite, massive	-19.79	- 2.57
BO-7, Bolger P. 5th Bench	B-6	Brown calcite, massive	-17.95	- 5.84
BO-9, Bolger P. 5th Bench	B-25	White calcite veins, associated with minute crystals of quartz	-17.90	- 5.63
BO-9, Bolger P. 5th Bench	B-31	Gray to yellowish gray calcite crystals in open vugs	-16.61	-15.88
BO-13 A, Bolger P. 6th Bench	B-4	Brown calcite, massive	-18.74	- 3.52
BO-13 B, Bolger P. 6th Bench	B-3	Brown calcite, massive	-19.08	- 3.10
BO-13 C, Bolger P. 6th Bench	B-2	Brown calcite, massive	-19.17	- 2.74
BO-15, Bolger P. 6th Bench	B-21	White calcite in veins cutting host rock	-19.34	- 4.28
BO-16, Bolger P. 6th Bench	B-11	Whitish pink (?) calcite in veins cutting host rock	-23.00	- 4.23
BO-21, Bolger P. 6th Bench	B-5	Brown calcite, coarse grained, massive	-20.67	- 8.67
BO-24, Bolger P. 6th Bench	B-26	Scalenohedra of white calcite covered by a yellow-orange crust and associated with clear quartz crystals	-18.40	- 7.42
F-170918, 17th L. Fay Mine	F-31	Pinkish calcite co-existing with gray dolomite, with pitch-blende	-18.83	- 1.62

Sample Number Locality	Code No.	Description	δ 0^{18}PDB%	δC^{13}PDB%
F-170918 A, 17th L. Fay Mine	F-4	Gray dolomite, massive, with pitch-blende	-20.06	- 0.49
F-170930, 17th L. Fay Mine	F-33	Whitish calcite with gray dolomite	-19.03	- 2.71
F-170930 A, 17th L. Fay Mine	F-5	Gray dolomite, massive, with pitch-blende	-18.78	- 0.60
F-170931, 17th L. Fay Mine	F-13	Large brecciated fragments of pink calcite in pitchblende matrix	-21.03	- 1.68
F-180925, 18th L. Fay Mine	F-17	Large brecciated fragments of pink calcite with gray colomite and pitch-blende	-21.92	- 3.07
F-180925 A, 18th L. Fay Mine	F-1	Gray dolomite coating wall-rock fragments, pink calcite and pitch-blende	-19.53	+ 0.55
F-201391, 21st L. Fay Mine	F-3	Gray dolomite, massive, with pitch-blende	-19.40	+ 0.04
F-210923, 21st L. Fay Mine	F-32	White calcite with gray dolomite and pitchblende	-19.84	- 2.35
F-210923 A, 21st L. Fay Mine	F-2	Gray dolomite, massive with pitch-blende	-19.56	+ 0.15
F-210934 A, 21st L. Fay Mine	F-11	Pink calcite with massive gray dolomite	-18.03	- 1.60
F-210934 B, 21st L. Fay Mine	F-51	Small whitish to gray scalenohedra of calcite covered by rusty crust	-18.90	- 6.47
F-25-017, 25th L. Fay Mine	F-42	Whitish calcite in veins cutting amphibolite bands	-24.08	- 6.73

Sample Number Locality	Code No.	Description	δO^{18}PDB%	δC^{13}PDB%
F-25-027, 25th L. Fay Mine	F-16	Pink calcite in veins, massive	-21.56	- 2.76
F-25-030, 25th L. Fay Mine	F-23	Pink calcite, massive, with gray dolomite (in breccia)	-20.81	- 4.42
F-25-030 A, 25th L. Fay Mine	F-7	Gray dolomite coating wall-rock fragments (in breccia)	-17.40	- 5.25
F-25-031, 25th L. Fay Mine	F-24	Pink calcite in breccia with gray dolomite	-19.59	- 4.58
F-25-031 A, 25th L. Fay Mine	F-6	Gray dolomite coating wall-rock fragments	-16.36	- 3.44
F-25-032, 25th L. Fay Mine	F-22	Well crystallized pink calcite, in veins	-18.72	- 3.91
F-25-038, 25th L. Fay Mine	F-18	Pink calcite, massive, in veins	-20.80	- 3.28
F-25-040, 25th L. Fay Mine	F-19	Network of pink calcite (in breccia)	-19.80	- 3.17
F-25-041, 25th L. Fay Mine	F-34	Probably two generations of white and pink calcite	-19.82	- 3.77
F-25-063, 25th L. Fay Mine	F-12	Pinkish calcite, in veins	-19.53	- 1.62
F-25-064, 25th L. Fay Mine	F-41	White calcite, massive, in veins	-24.58	- 2.45
F-25-081, 25th L. Fay Mine	F-15	Pink calcite in veins	-20.88	- 2.56
SU-5, NE of Imar Lake, surface	F-14	Pink calcite, massive, in veins with ore	-20.16	- 2.18

The isotopic composition of mine waters from the Fay Mine, Eldorado, Saskatchewan

Sample No. Locality	Description	$\delta^{18}O$ (SMOW)
F-1278, Pilot H. Fay Mine	Water	-16.2
F-1279, Pilot H. Fay Mine	Water	-16.0

APPENDIX D

Description of Uraninite Specimens Studied

F-1309-23: Brecciated uraninite in quartz - hematite - carbonate gangue. Microscopic inclusions of sulfides and other minerals visible. 13th Level, '09' zone, Fay Mine, Saskatchewan.

F-1709-18: Brecciated uraninite with poorly developed parting // to (100), in quartz - hematite - carbonate gangue. Microscopic inclusions of sulfides and other minerals are visible. From 17th Level, '09' zone, Fay Mine, Saskatchewan.

UA-1869: Uraninite as veinlets or massive clumps associated with zoned, complex pegmatite dykes. Richardson property, Wilberforce, Cardiff Twp., Haliburton, Ontario.

UA-1820: Coarsely brecciated, botrioidal uraninite with sineresis cracks filled by quartz, carbonate and sulfides. No. 2 Vein, 1233 stope, Port Radium, Eldorado, Great Bear Lake, N.W. Territories.

F-255-5: Fractured, botrioidal uraninite in carbonate gangue. 2nd Level, '55' zone, Fay Mine, Saskatchewan.

UA-2218: Clusters of uraninite spheres in massive carbonate gangues; locally botrioidal or banded with sineresis cracks filled by sulfides. Martin Lake Mine adit, Saskatchewan.

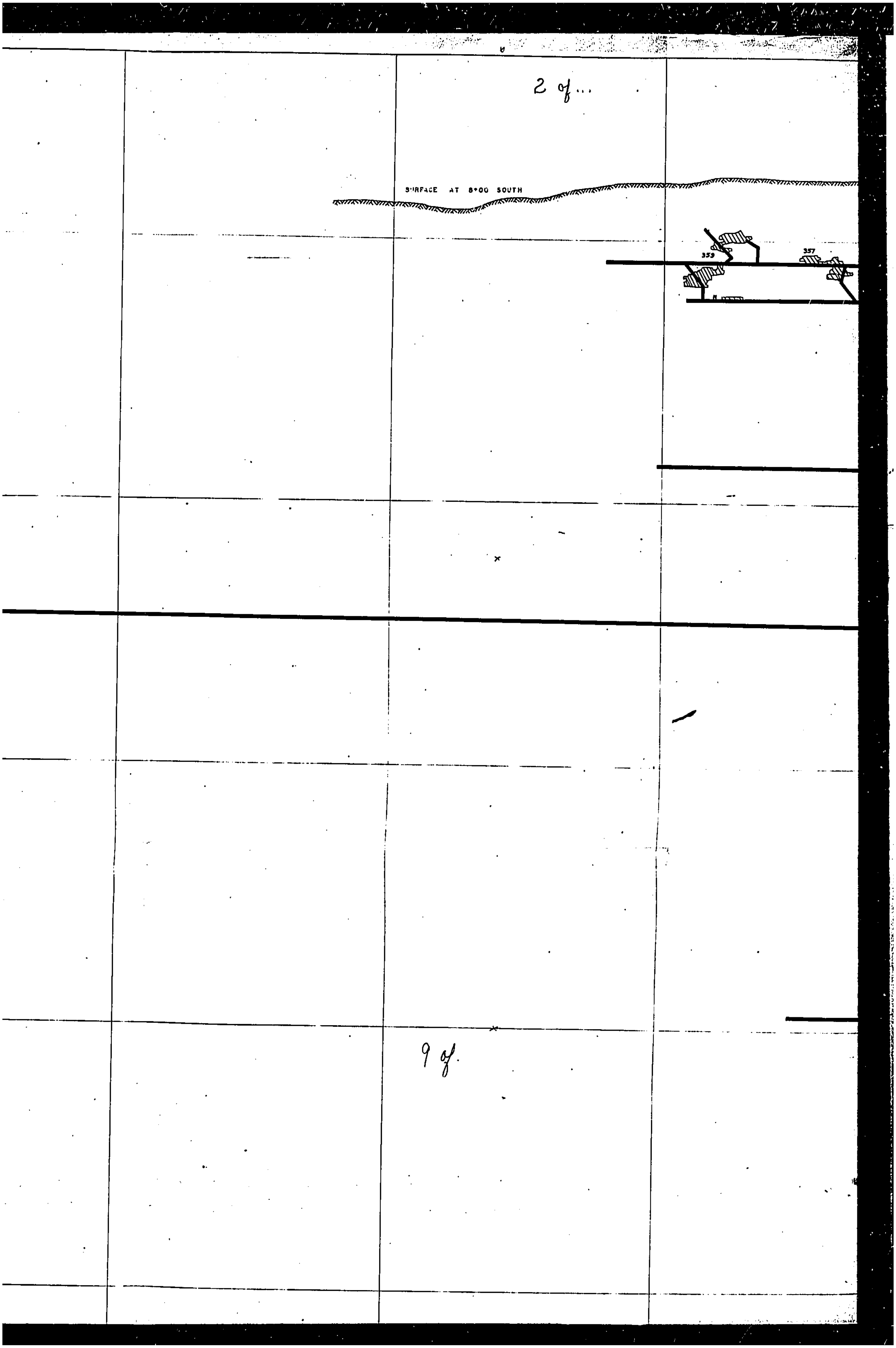
SU-6: Corroded crystal of uraninite associated with mafic pegmatite in carbonate gangue. Emar Lake trenches, Eldorado, Saskatchewan.

VOLUME II.

TABLE OF CONTENTS: In Volume I

APPENDIX E. Original geological map, plans and sections of the Fay and Verna Mines.

WEST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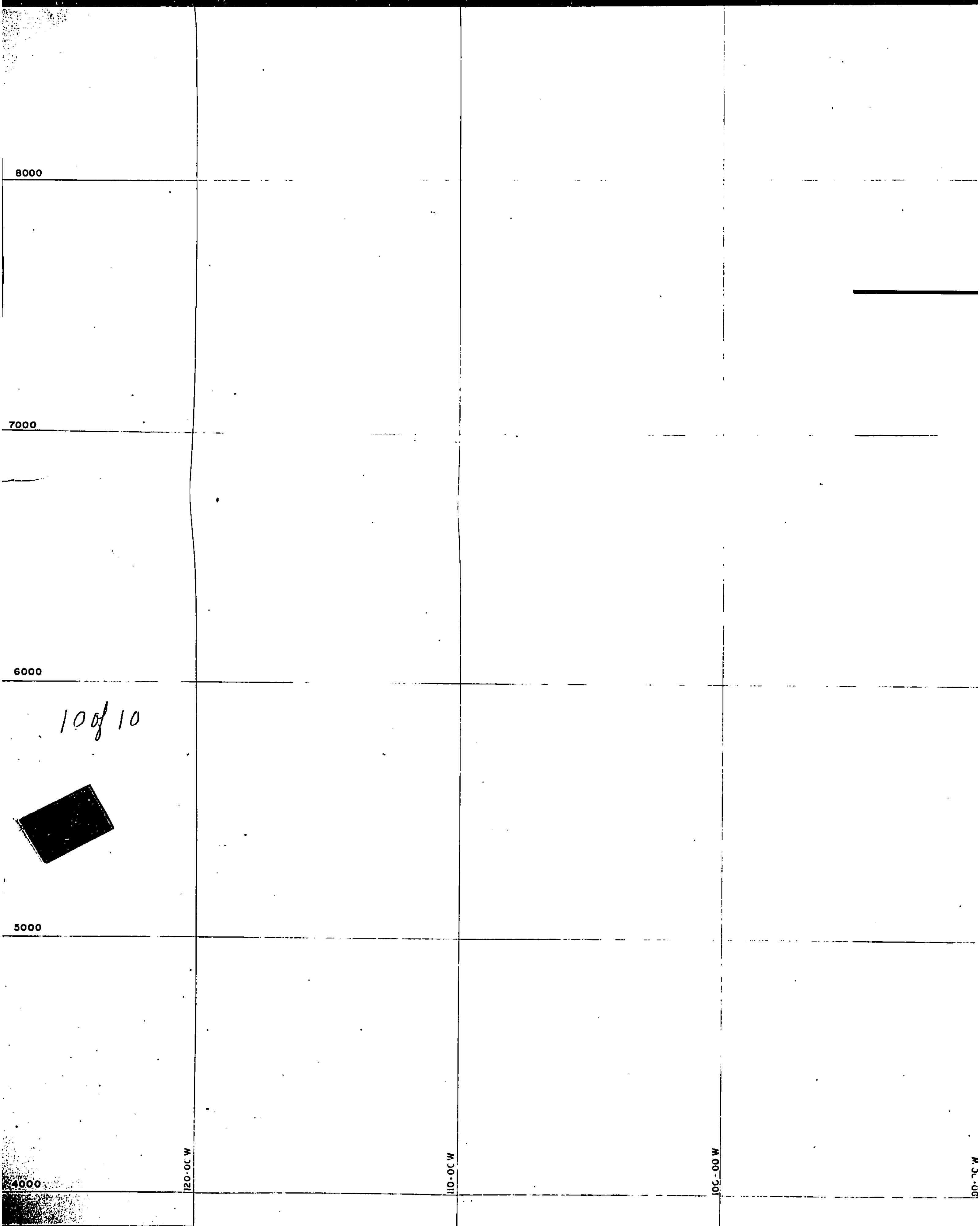
10 of 10



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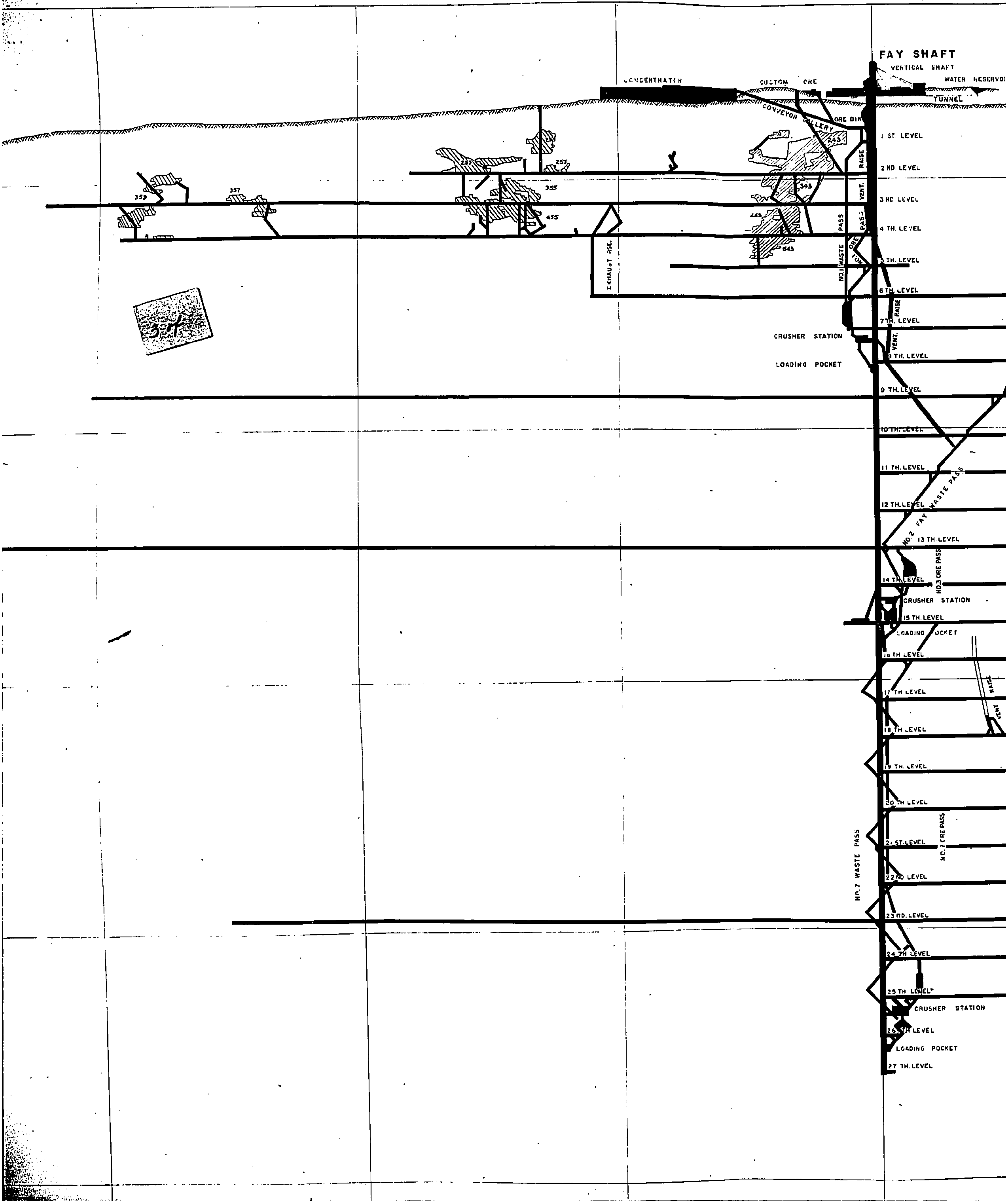
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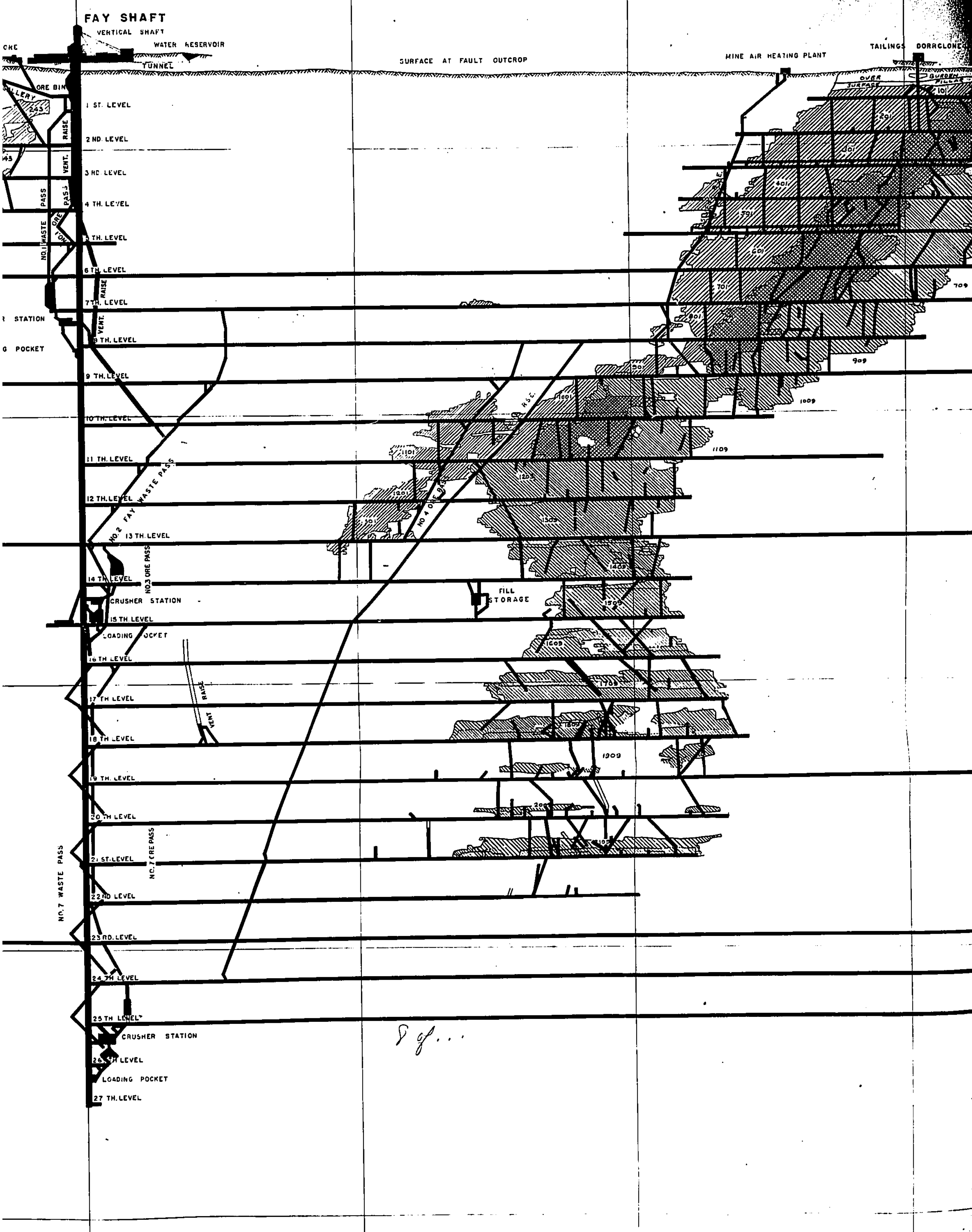
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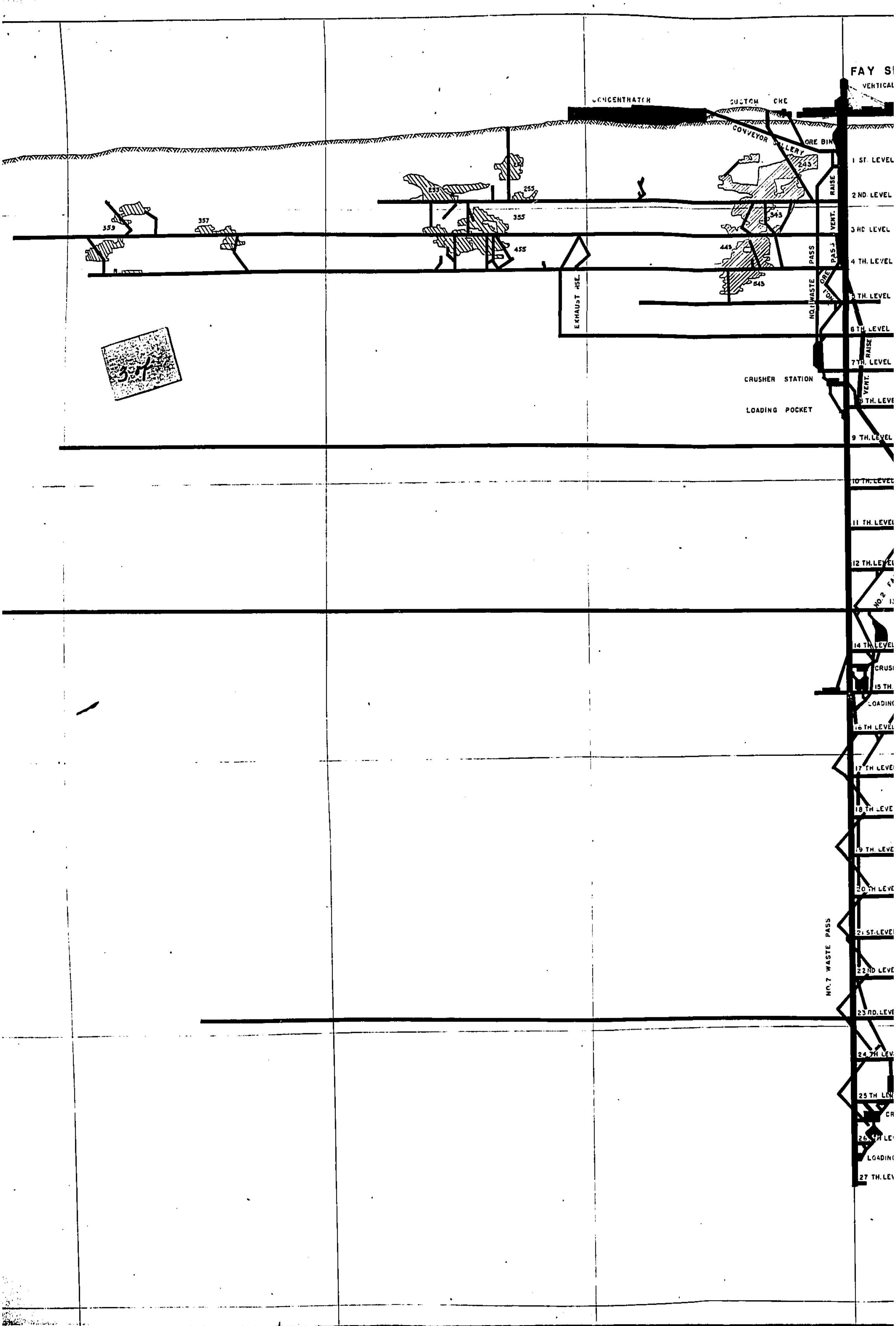

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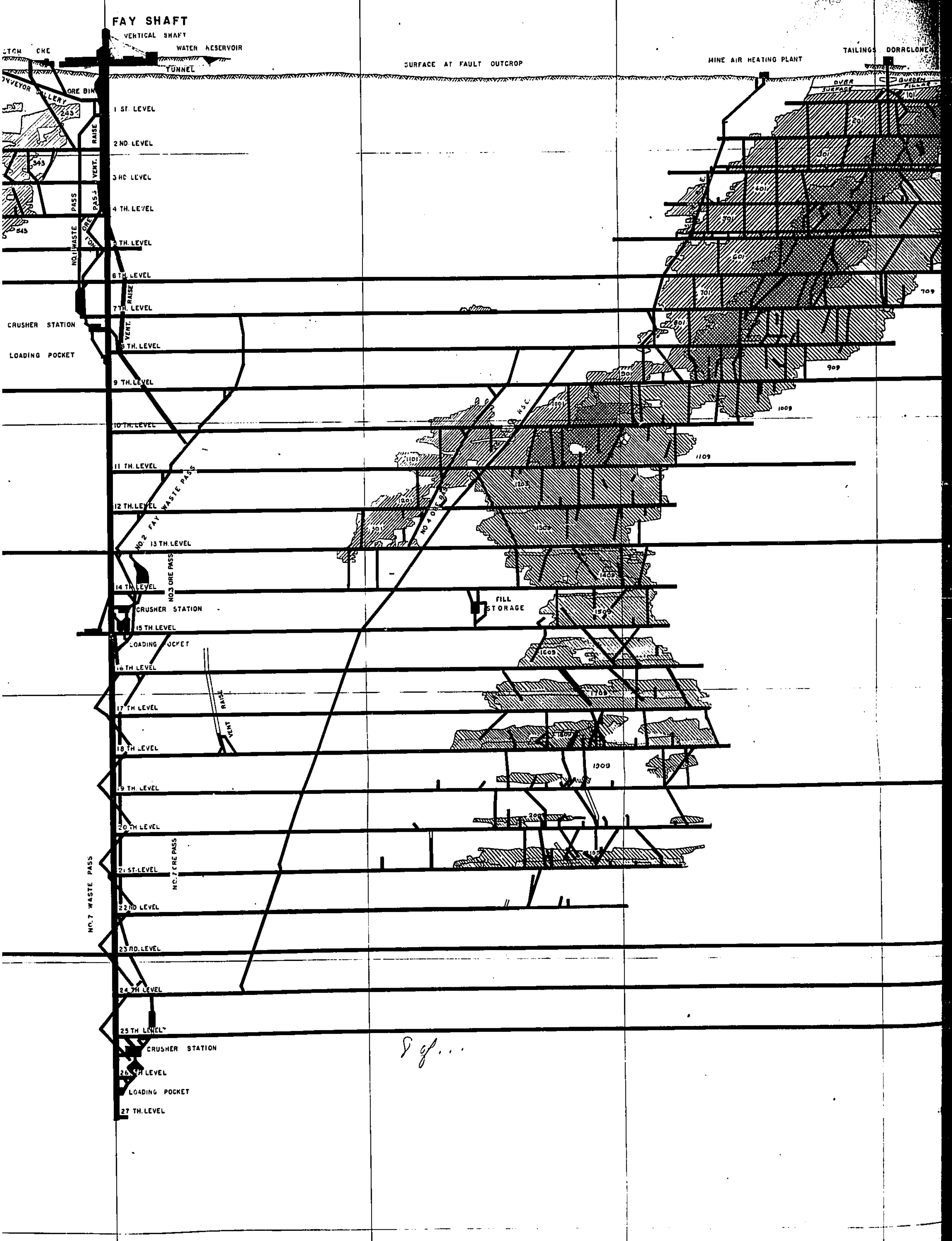
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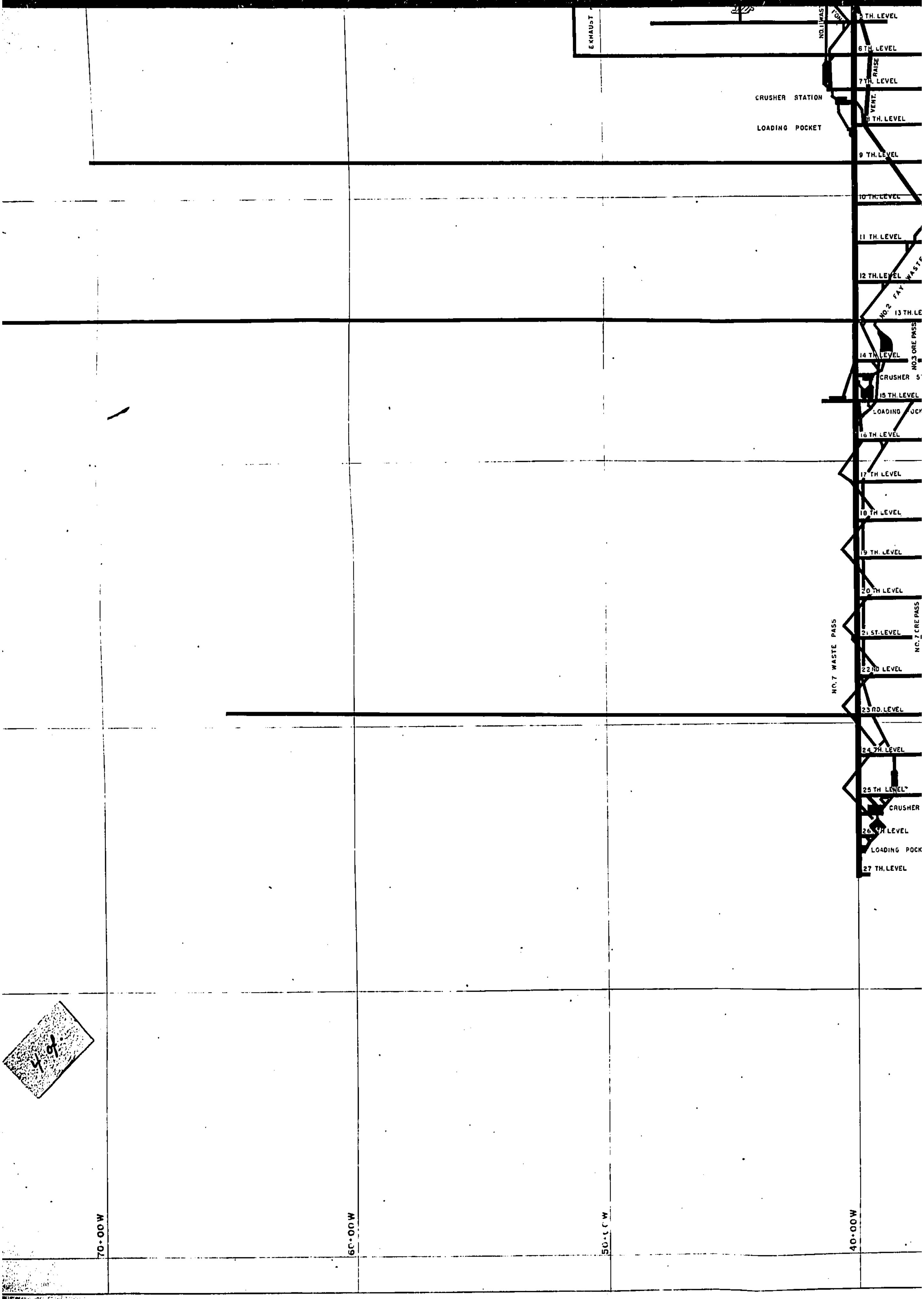

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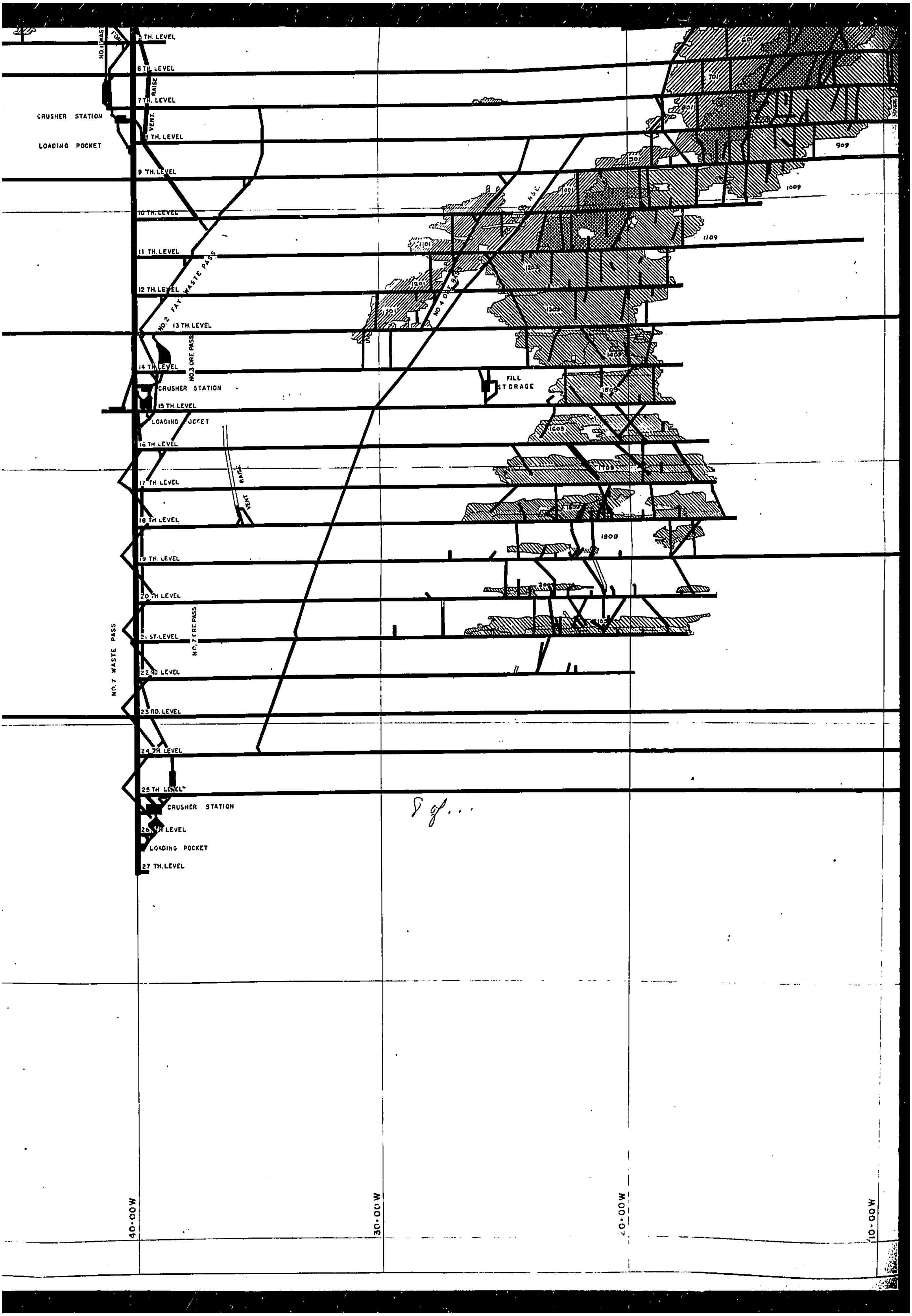

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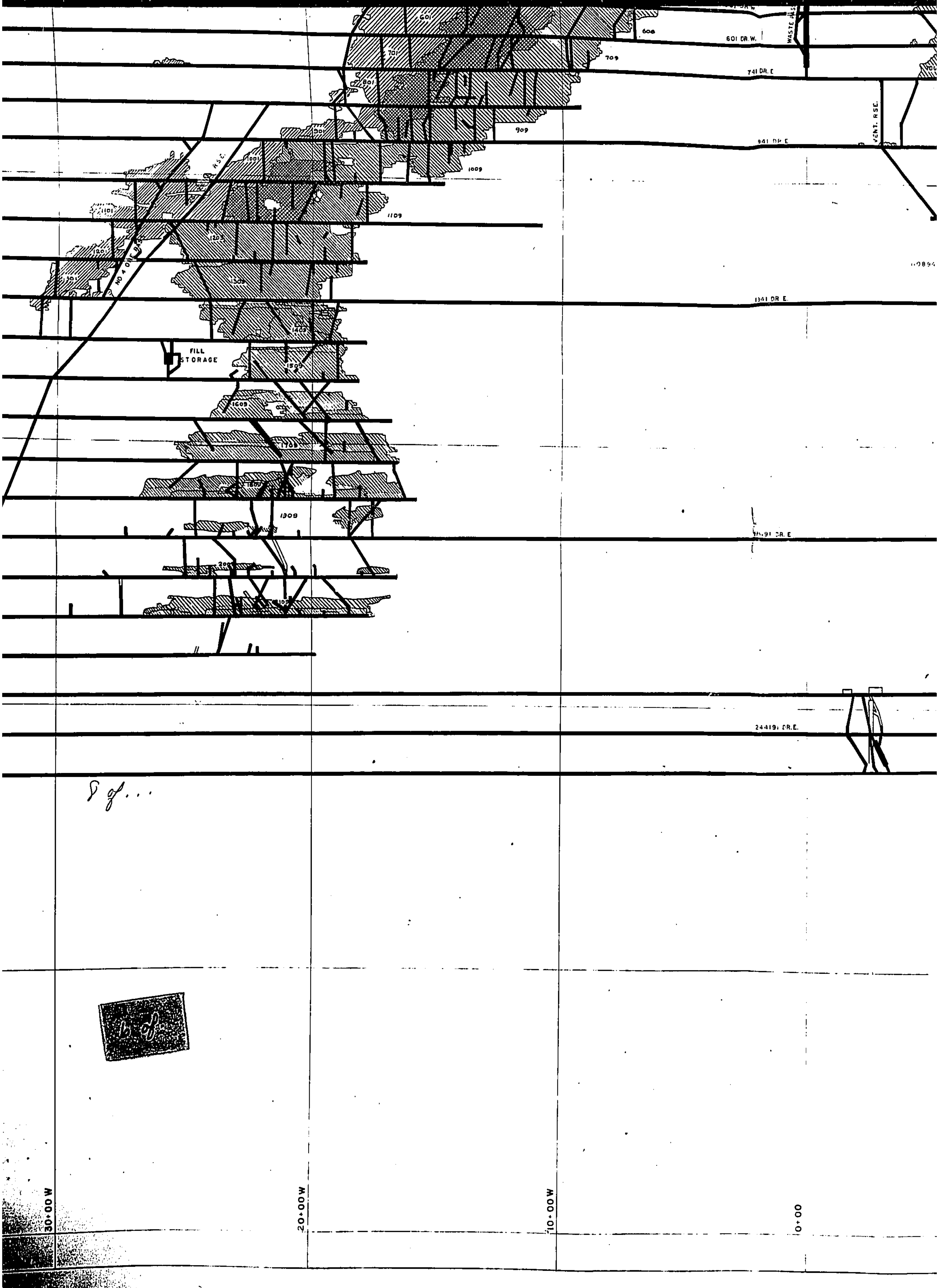
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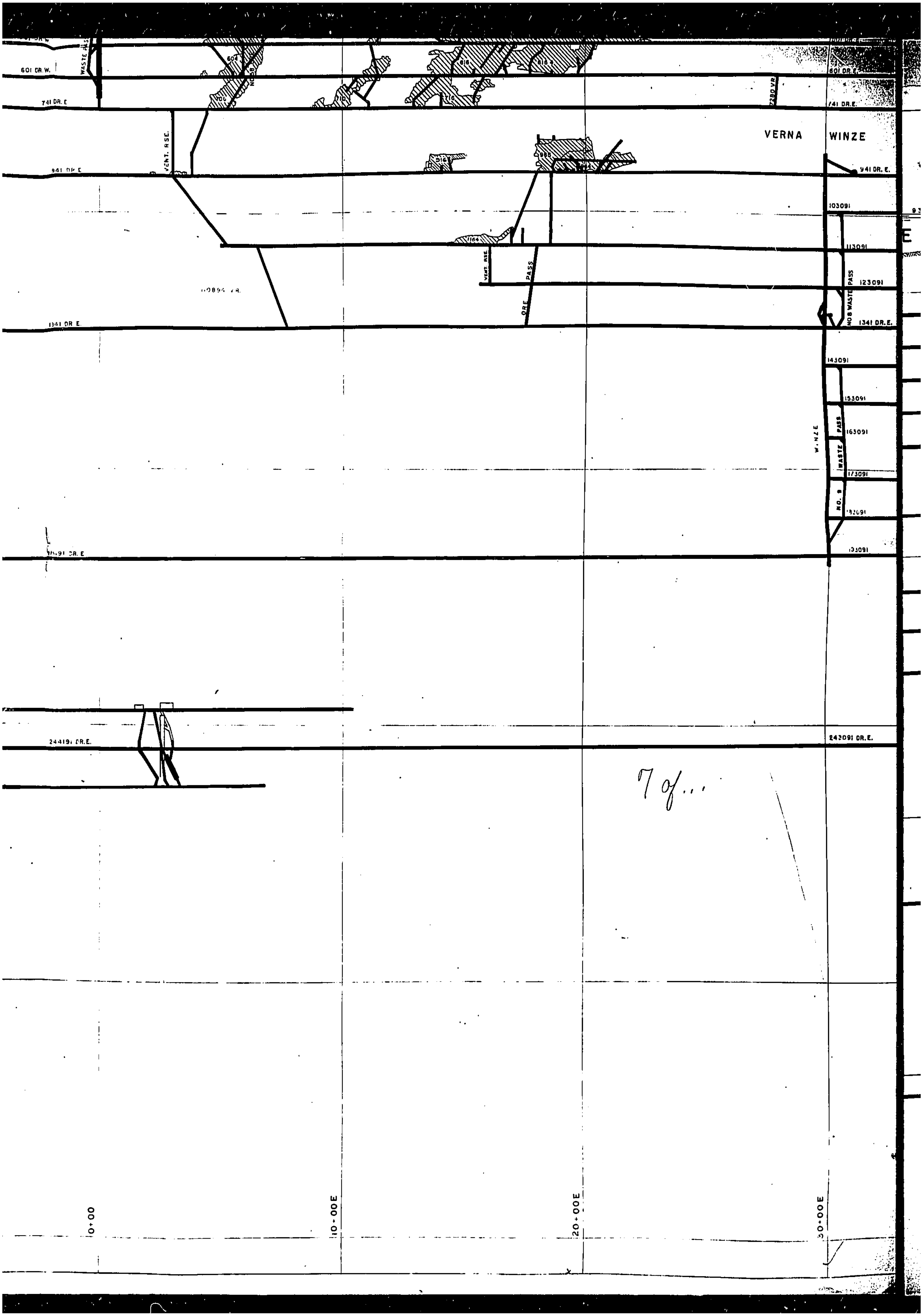
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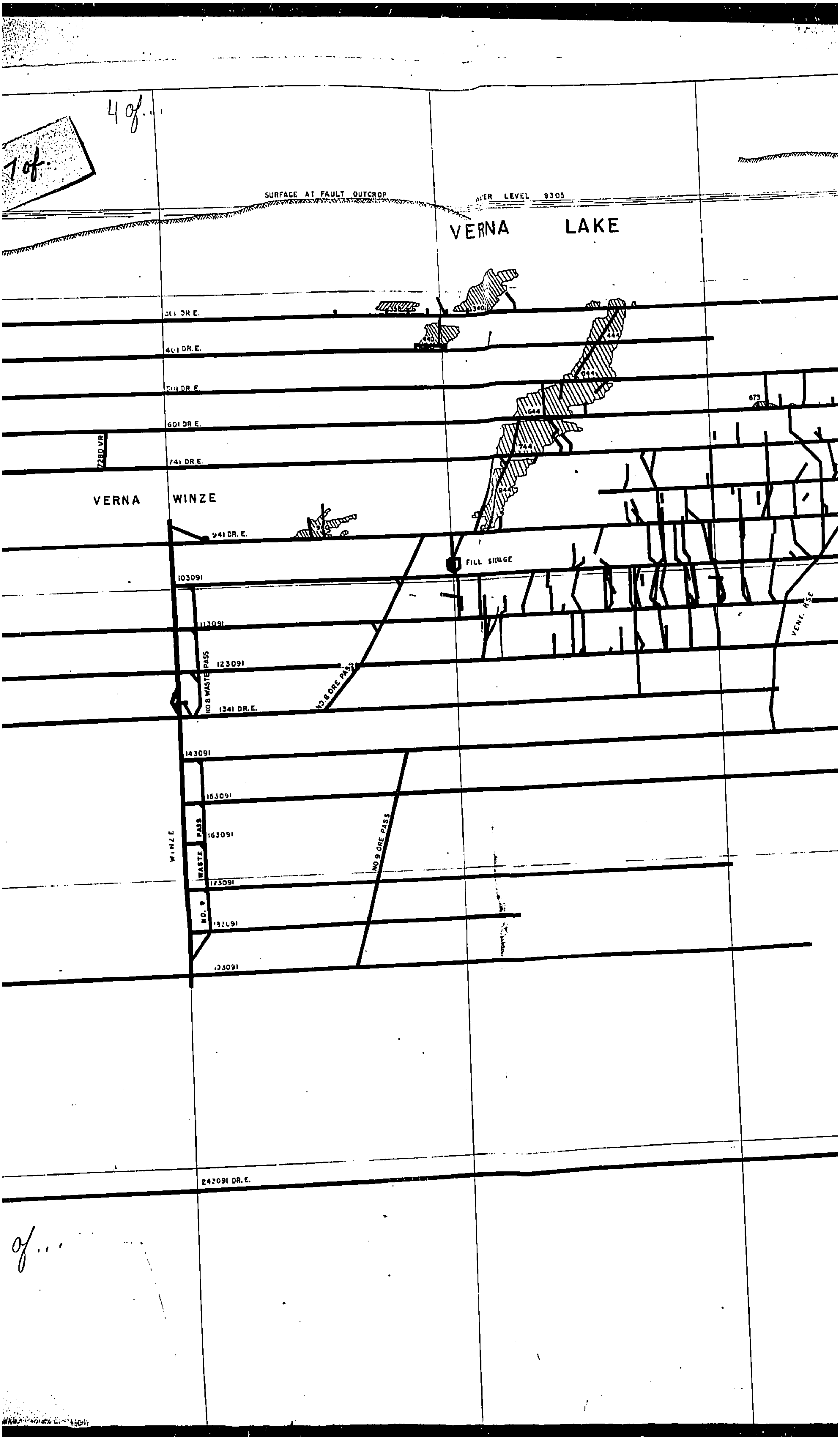
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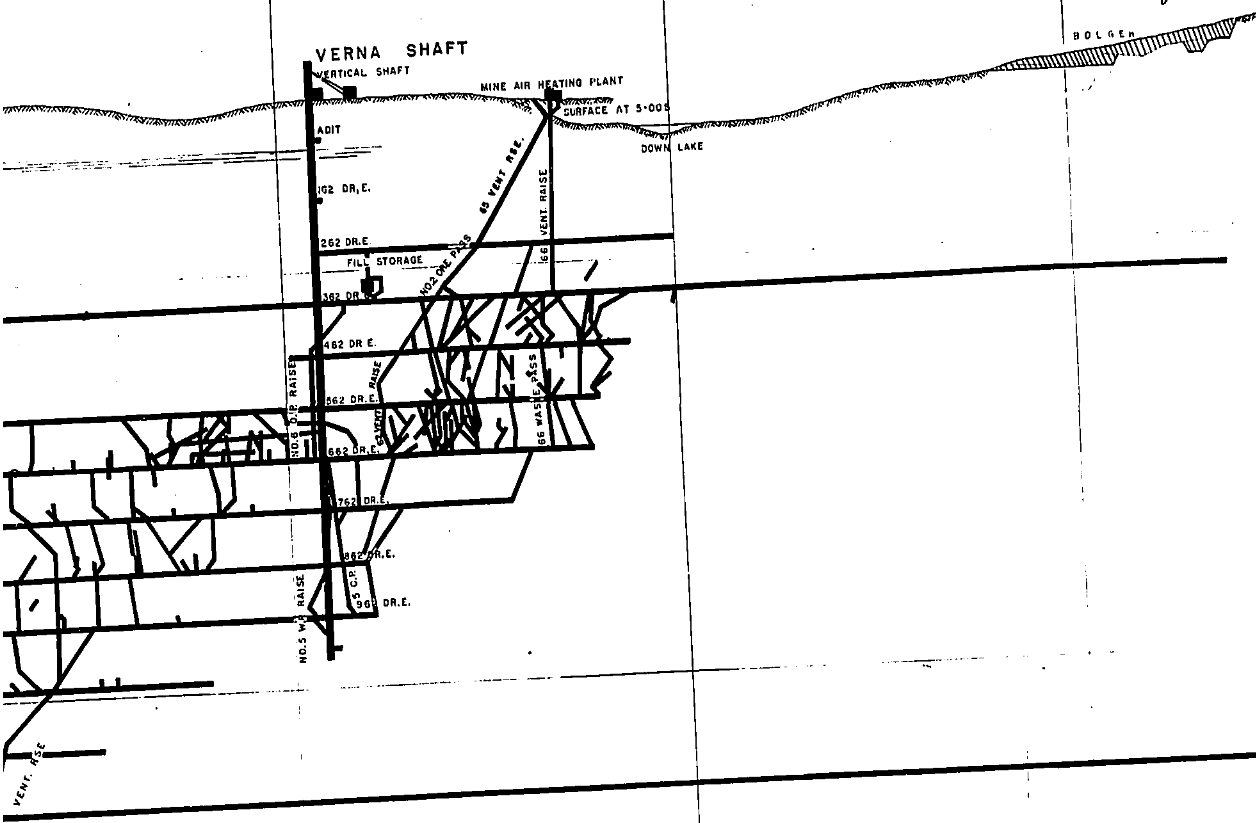
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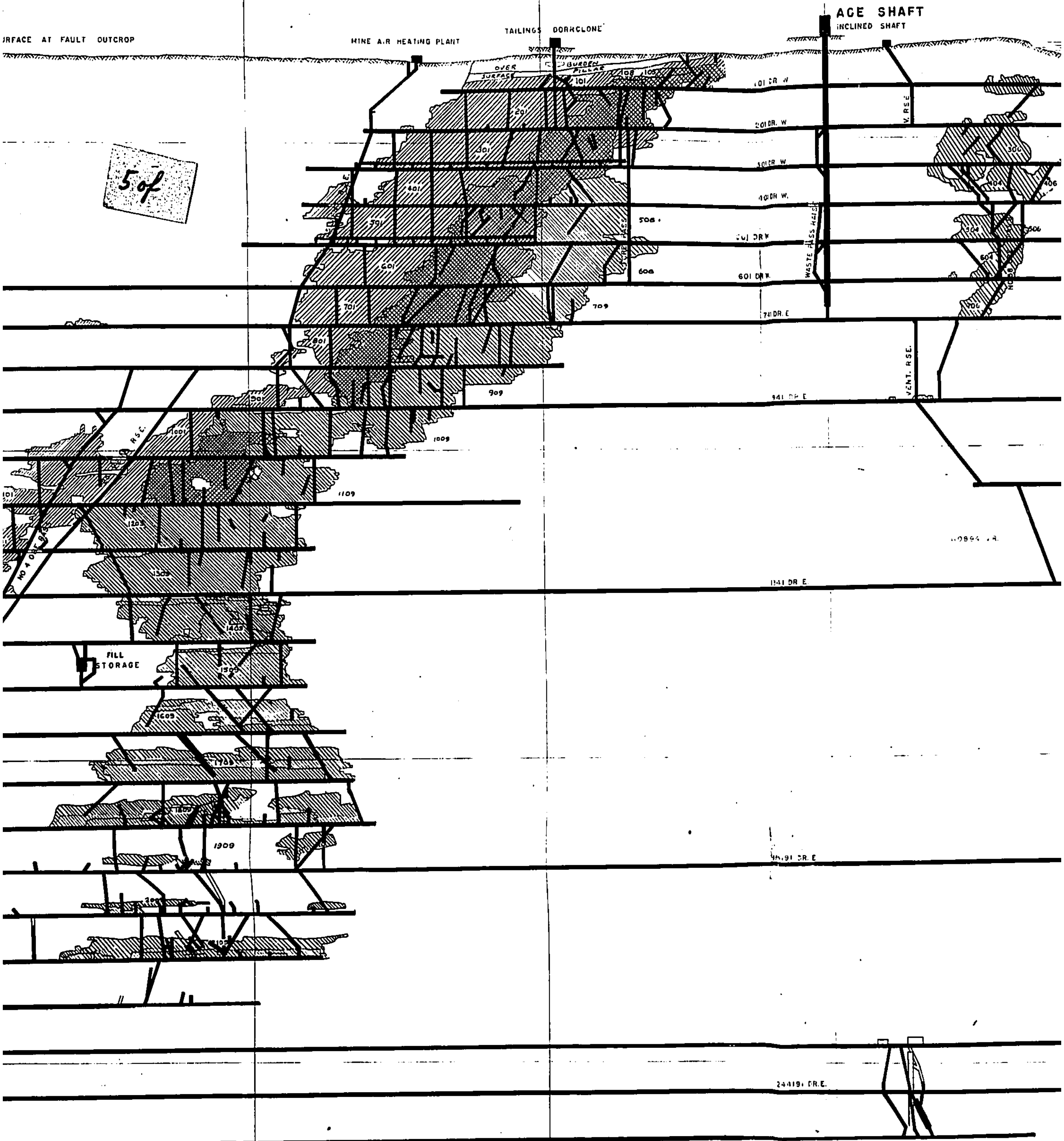

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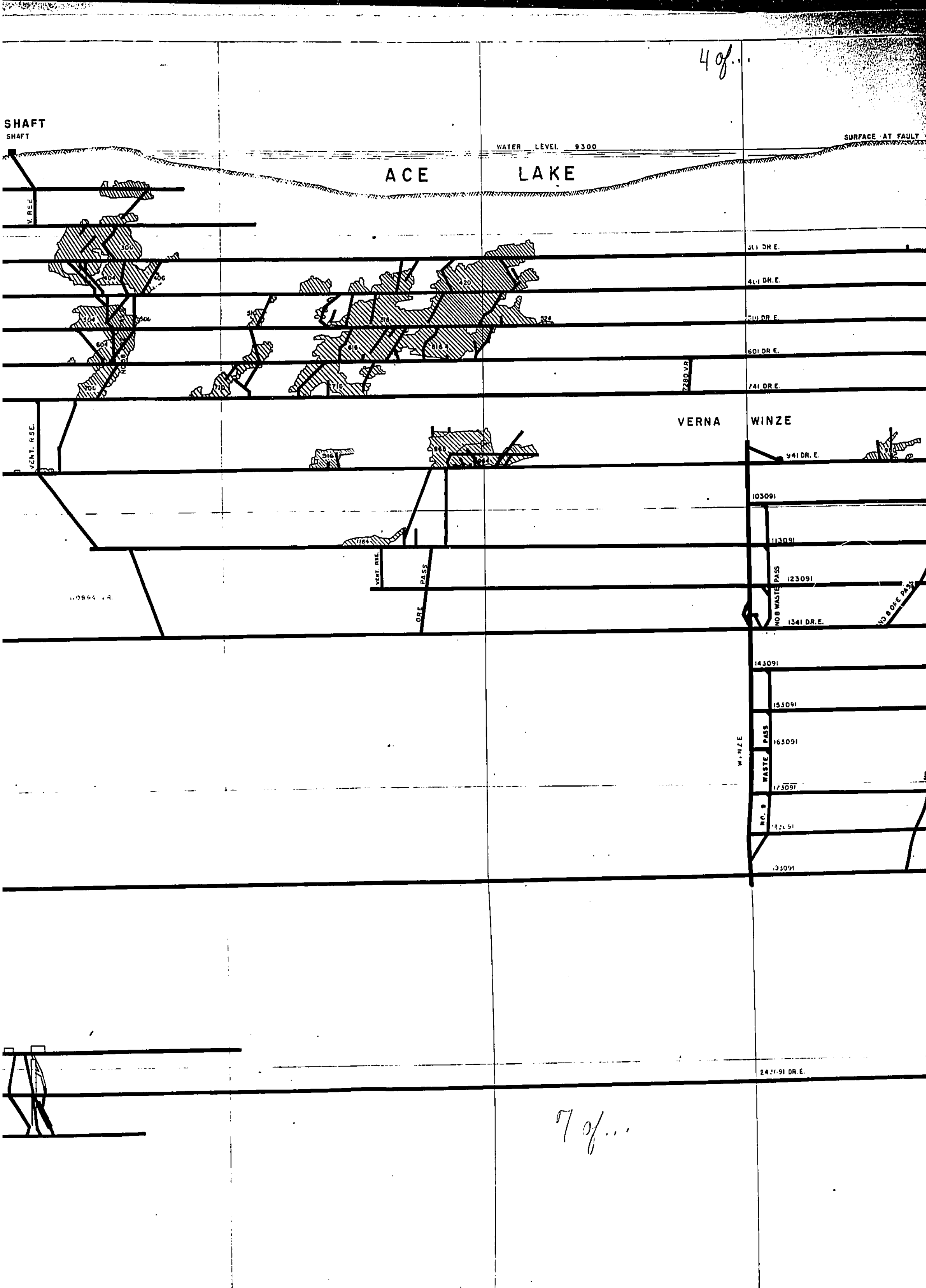
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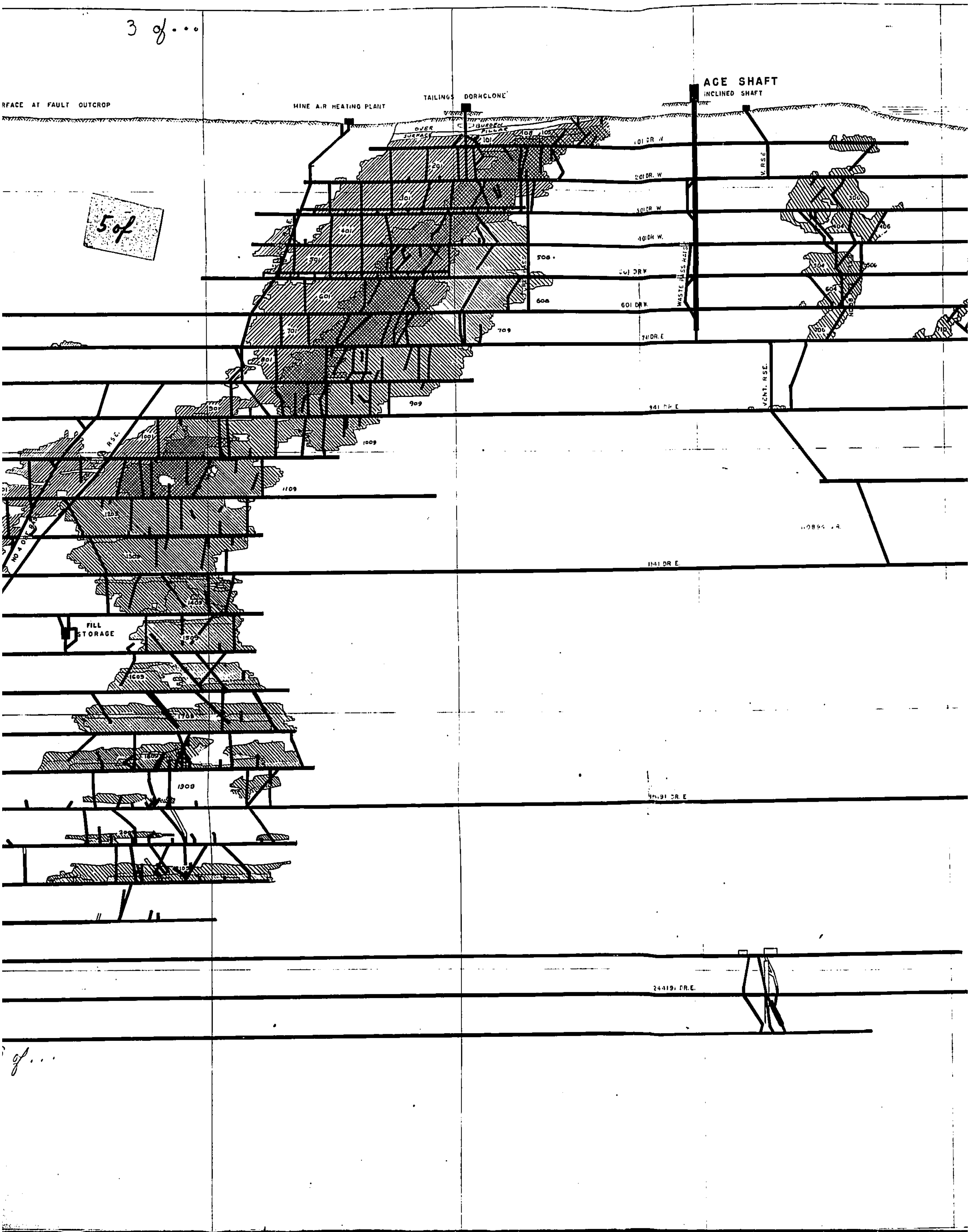

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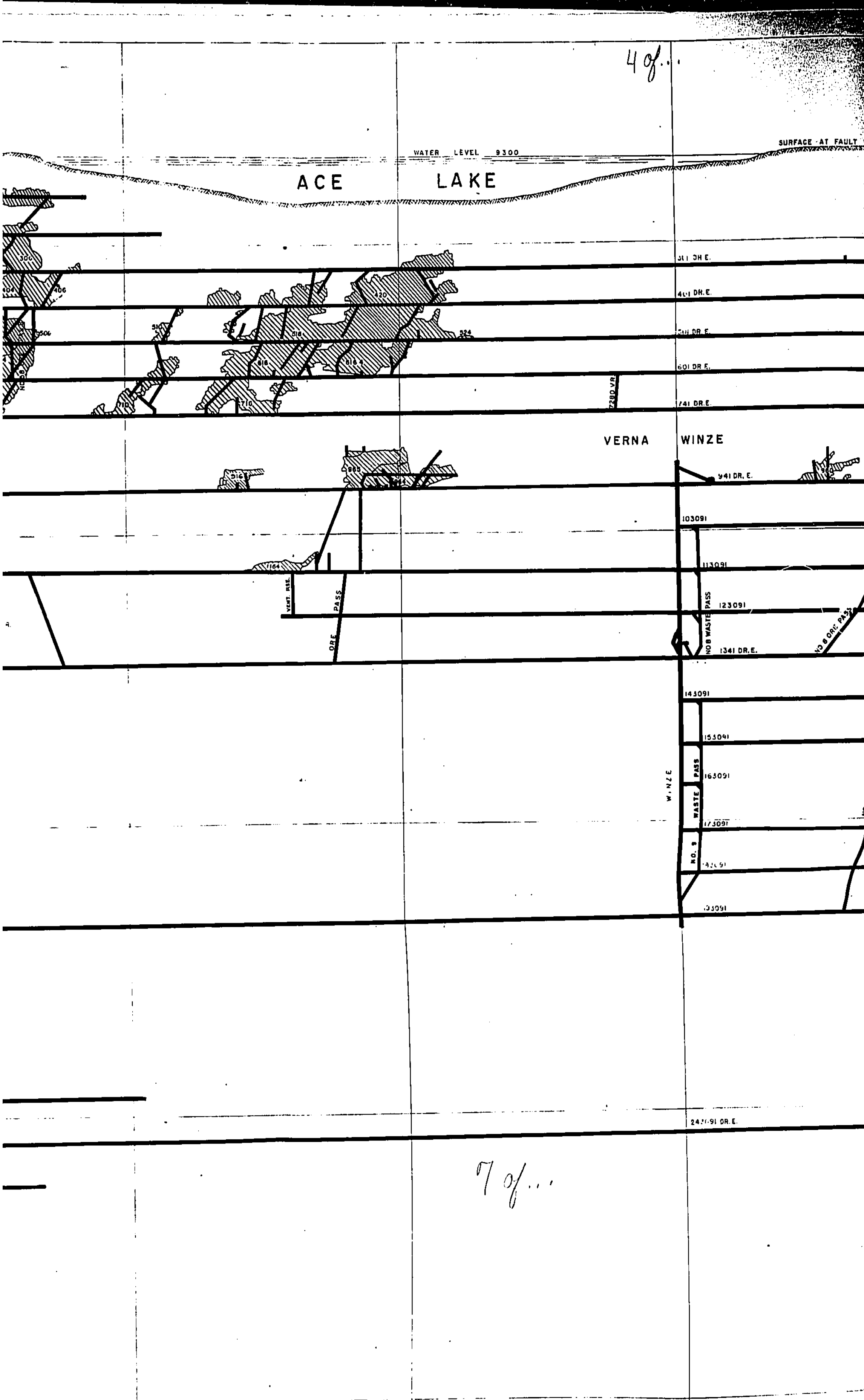
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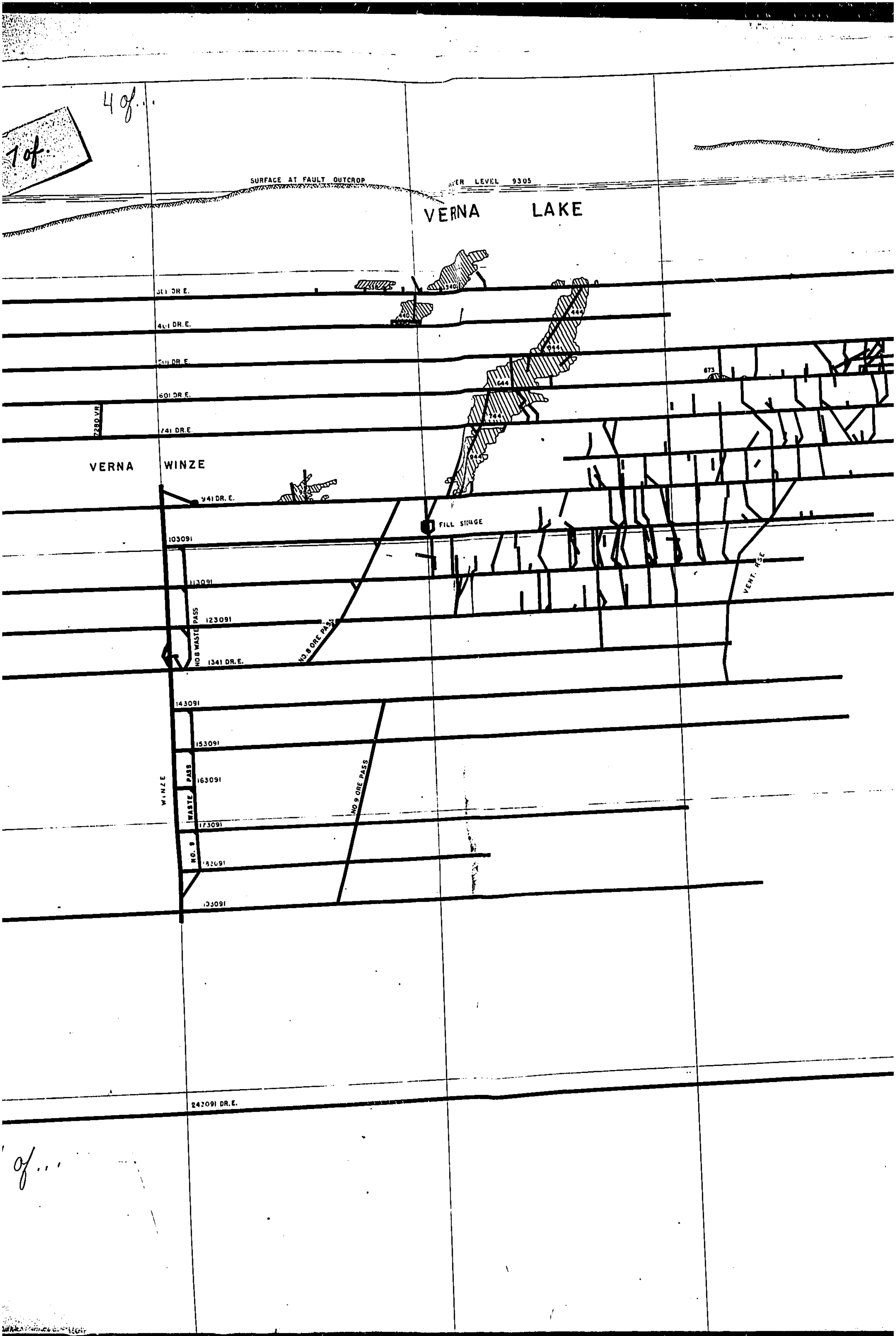

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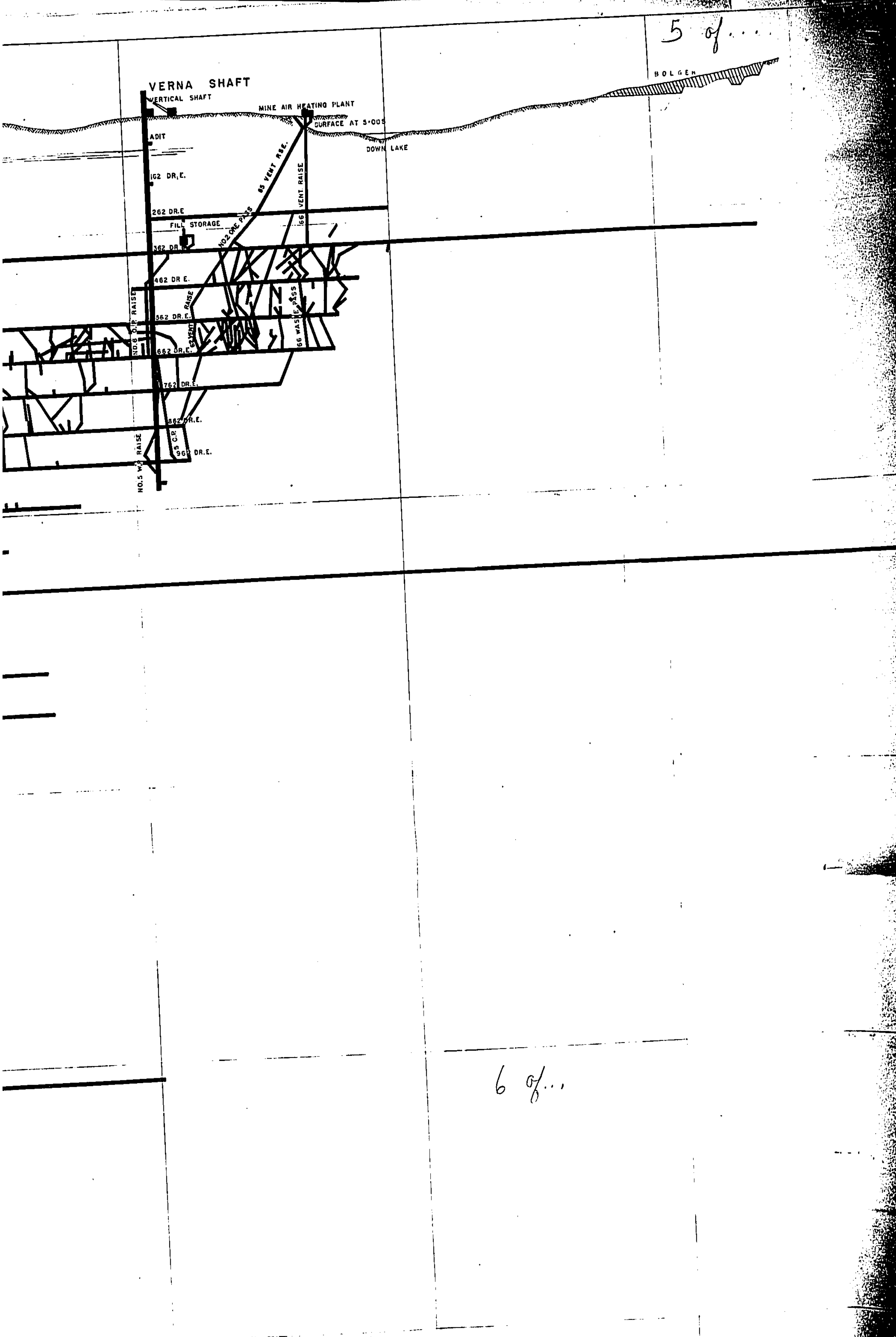

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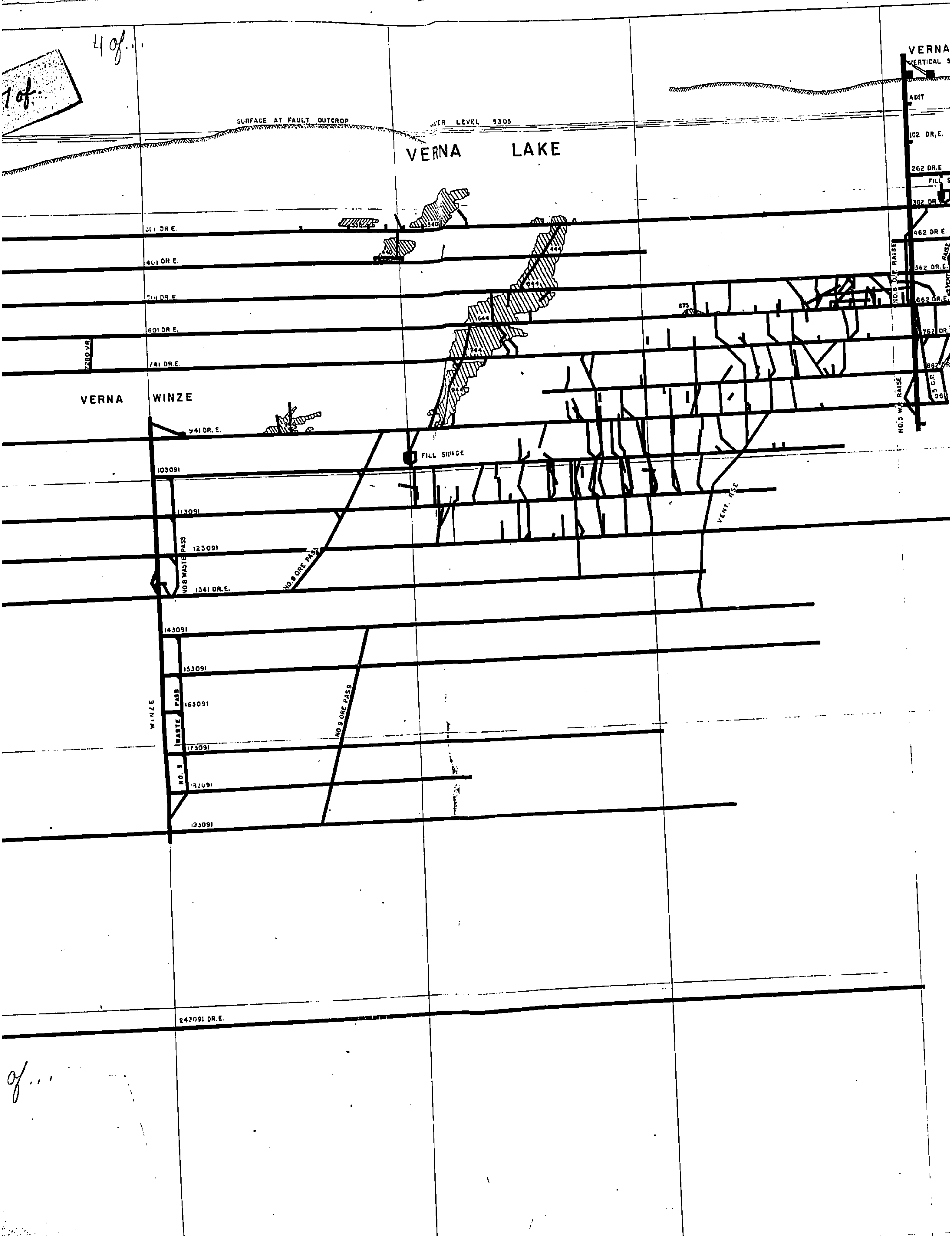
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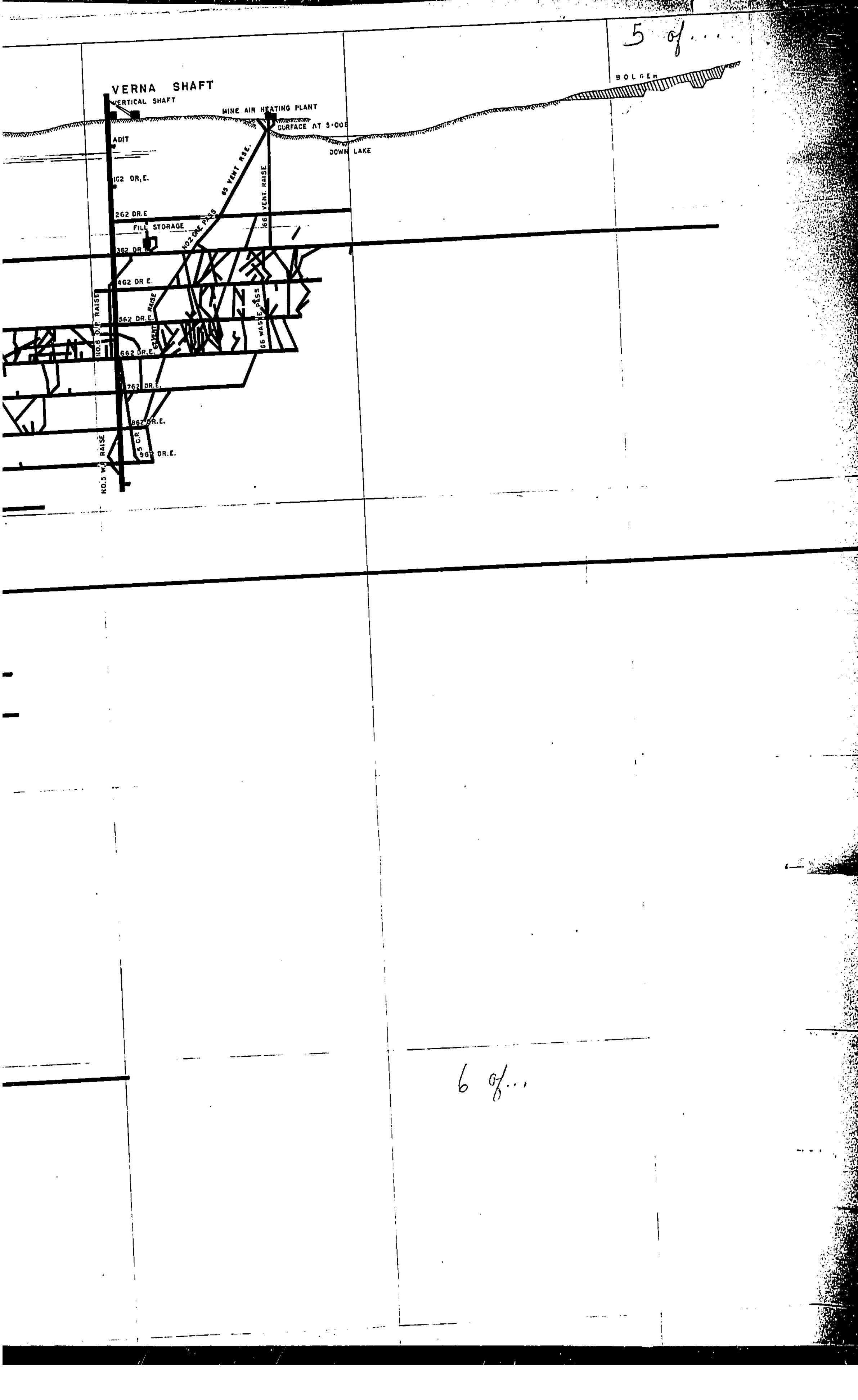
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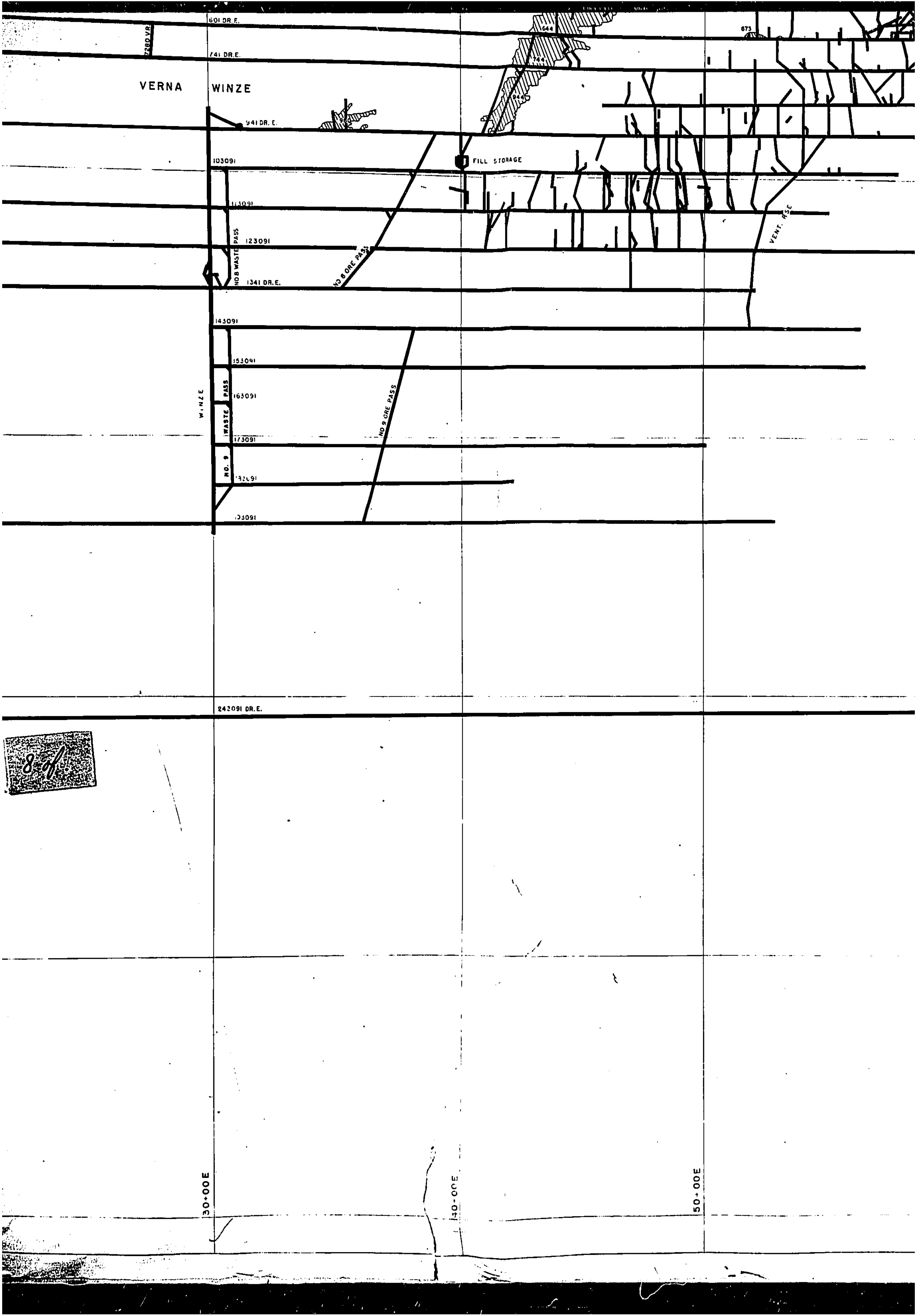
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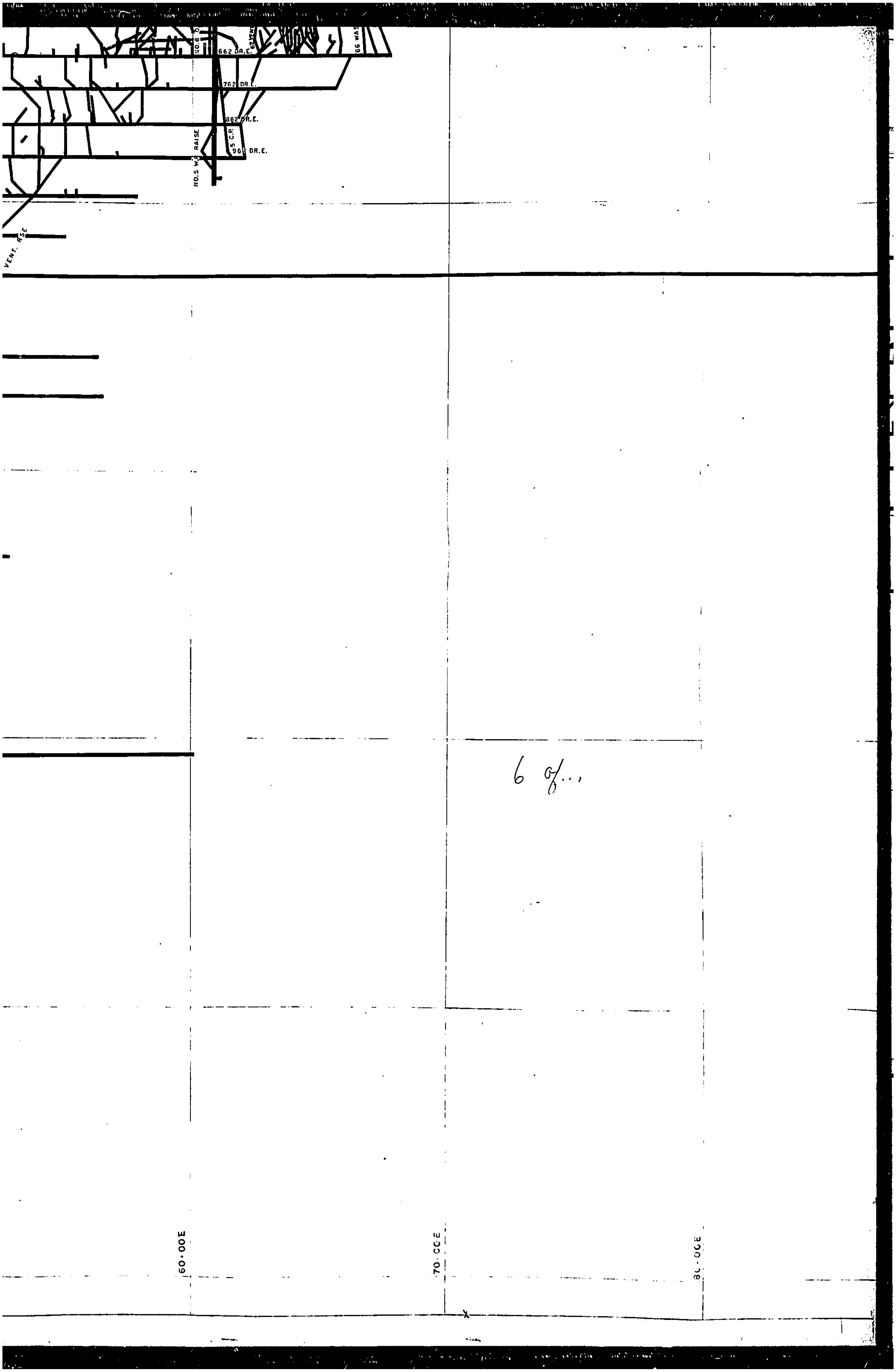

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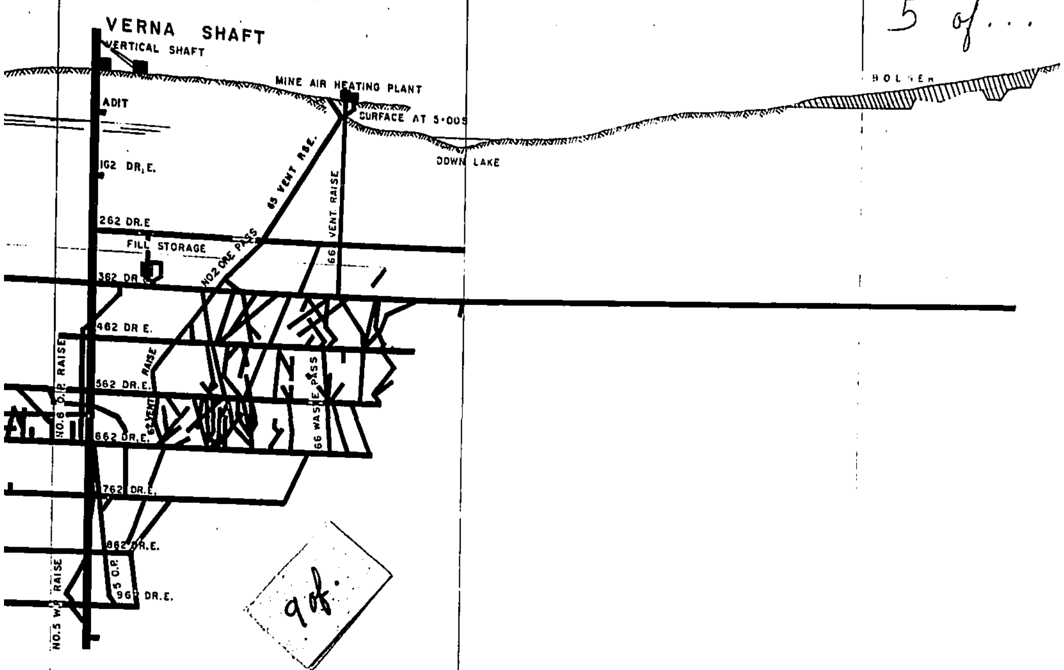
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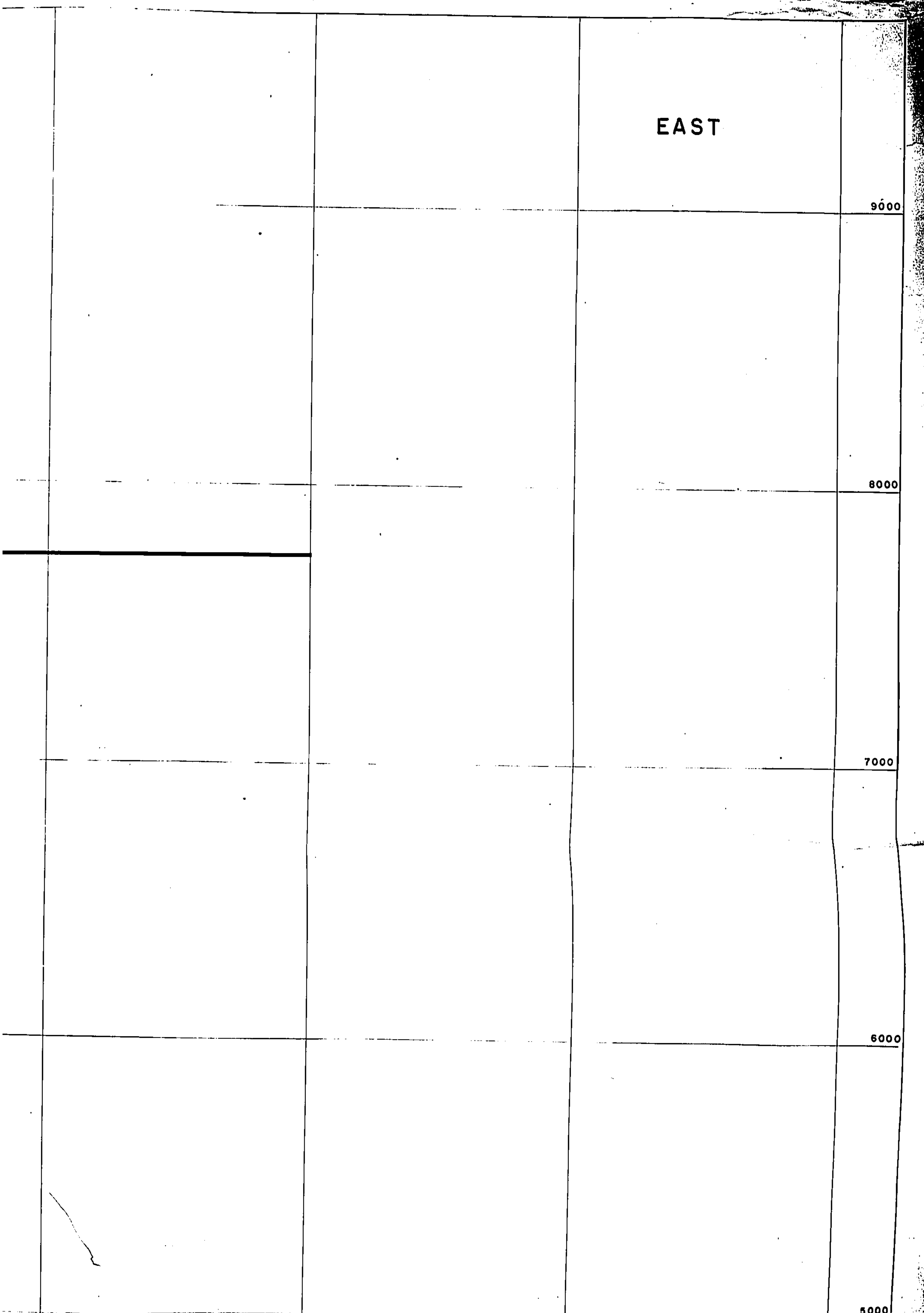
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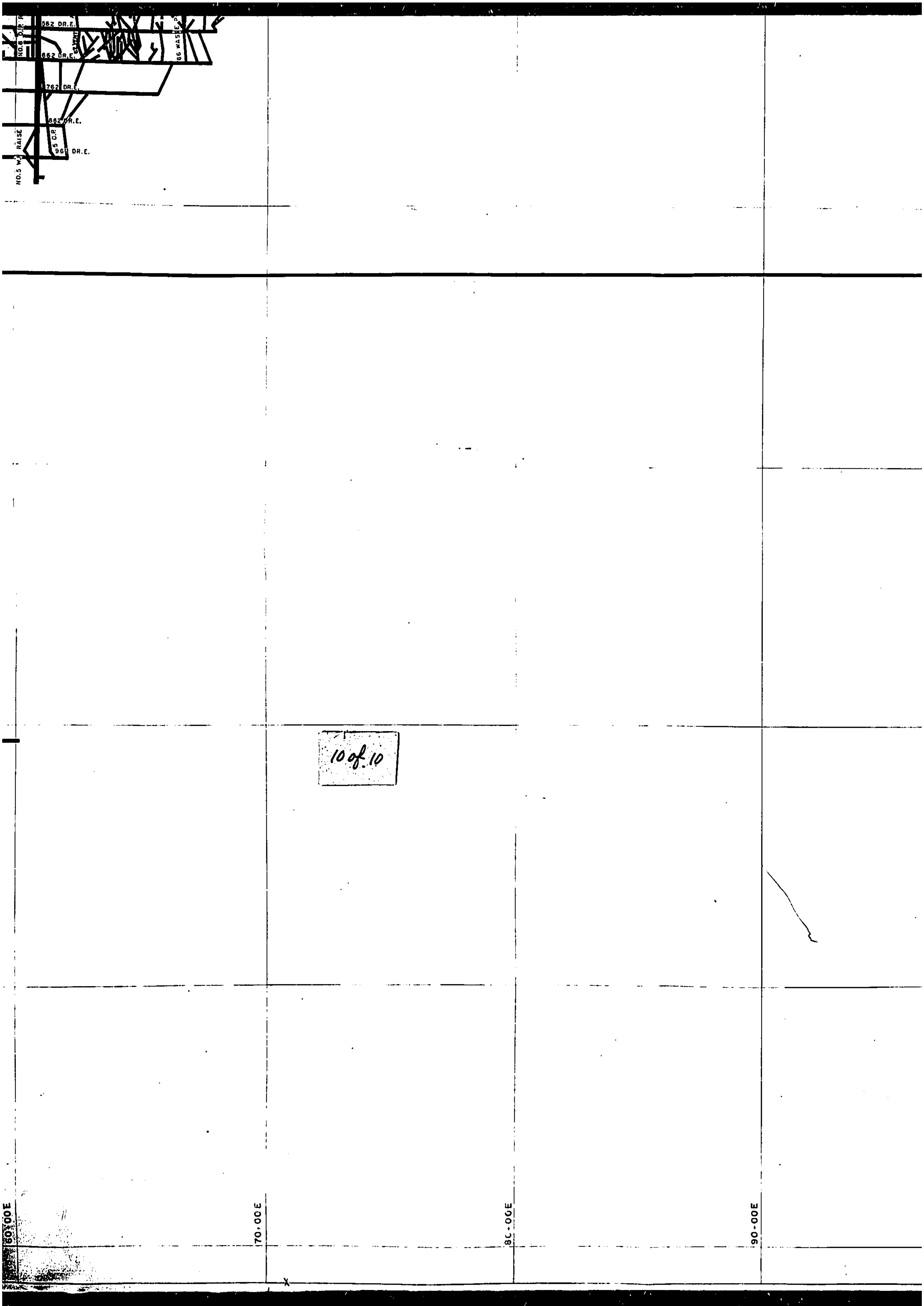

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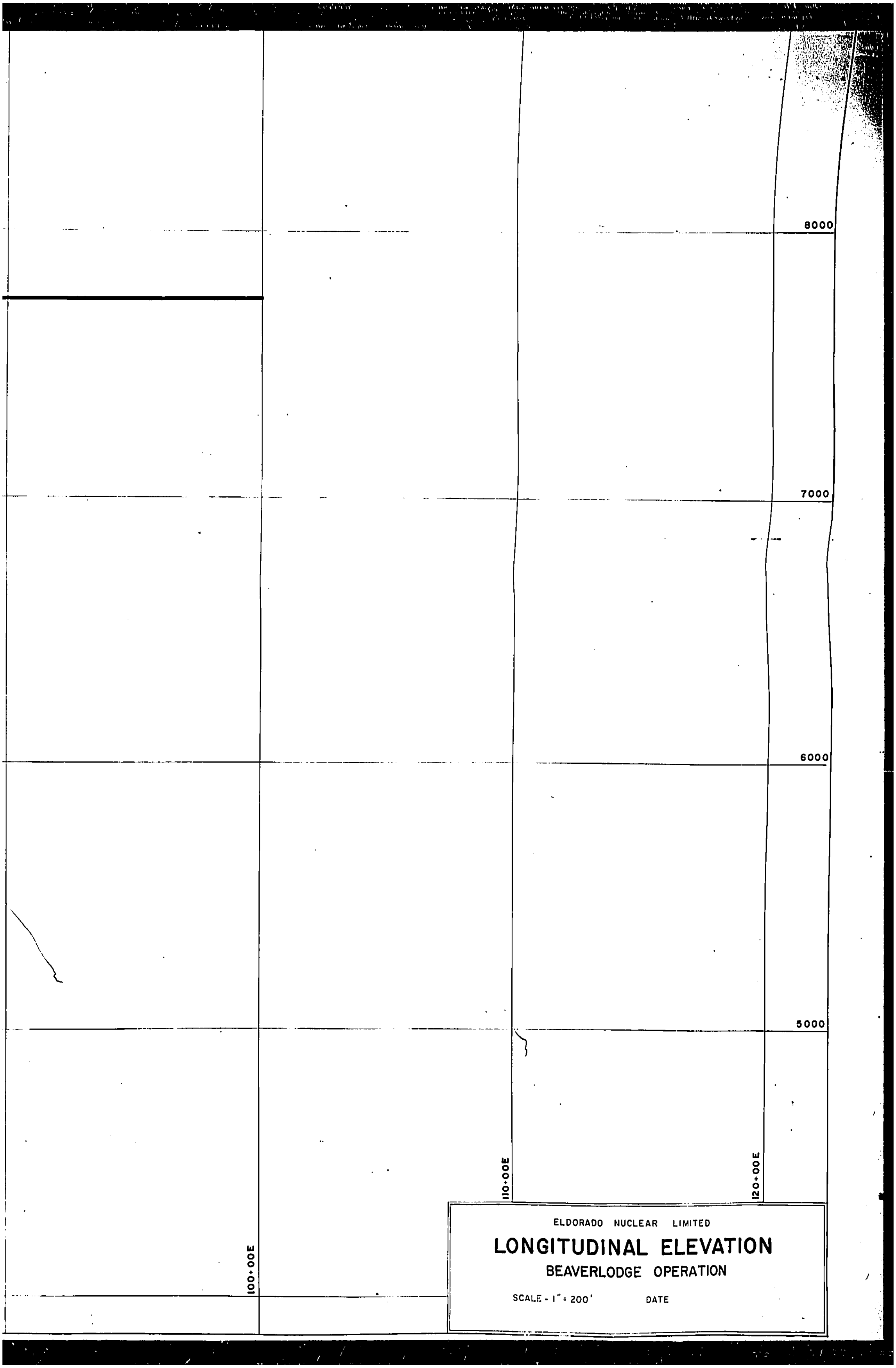
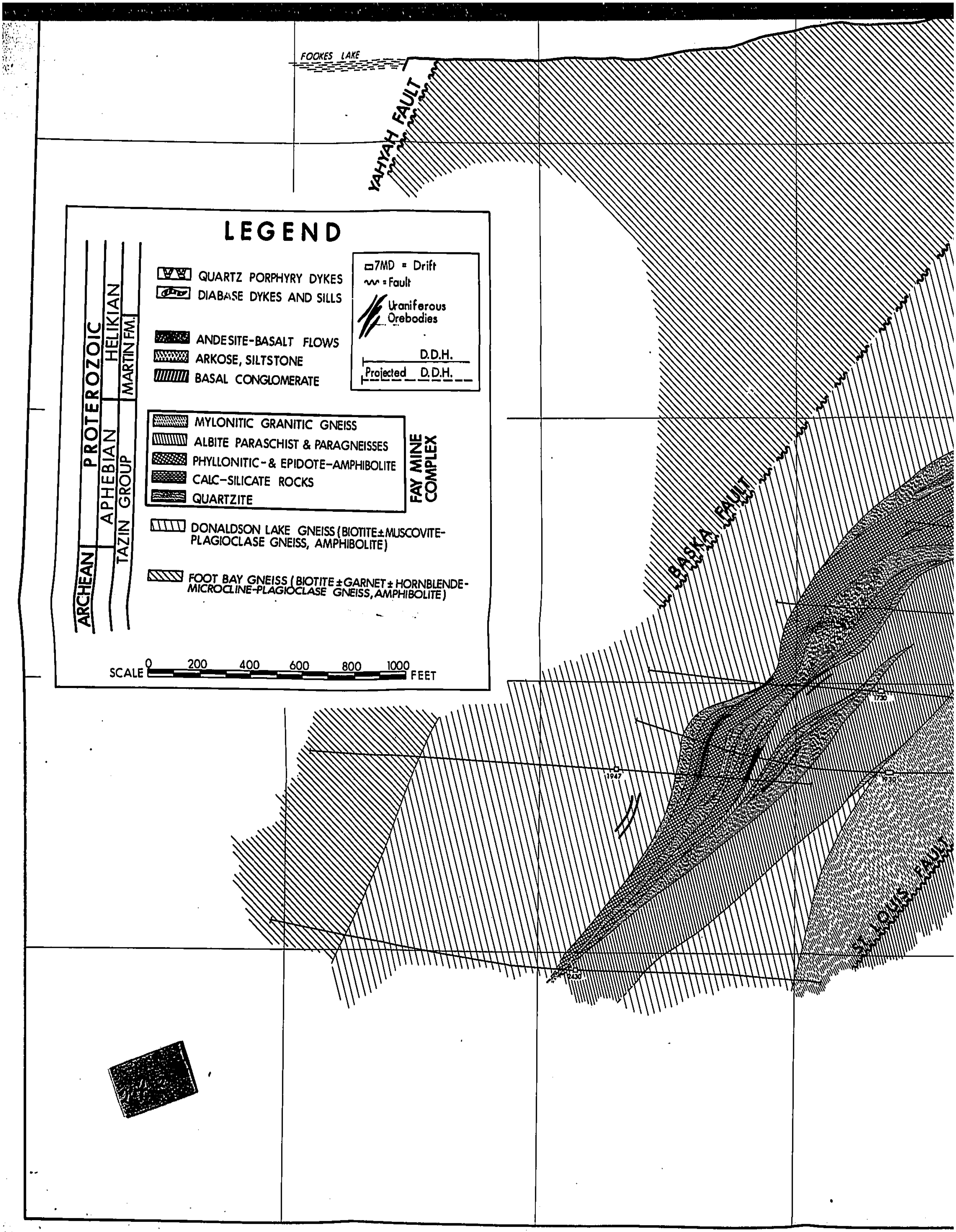


ELDORADO NUCLEAR LIMITED

LONGITUDINAL ELEVATION

BEAVERLODGE OPERATION

SCALE - 1" = 200'   DATE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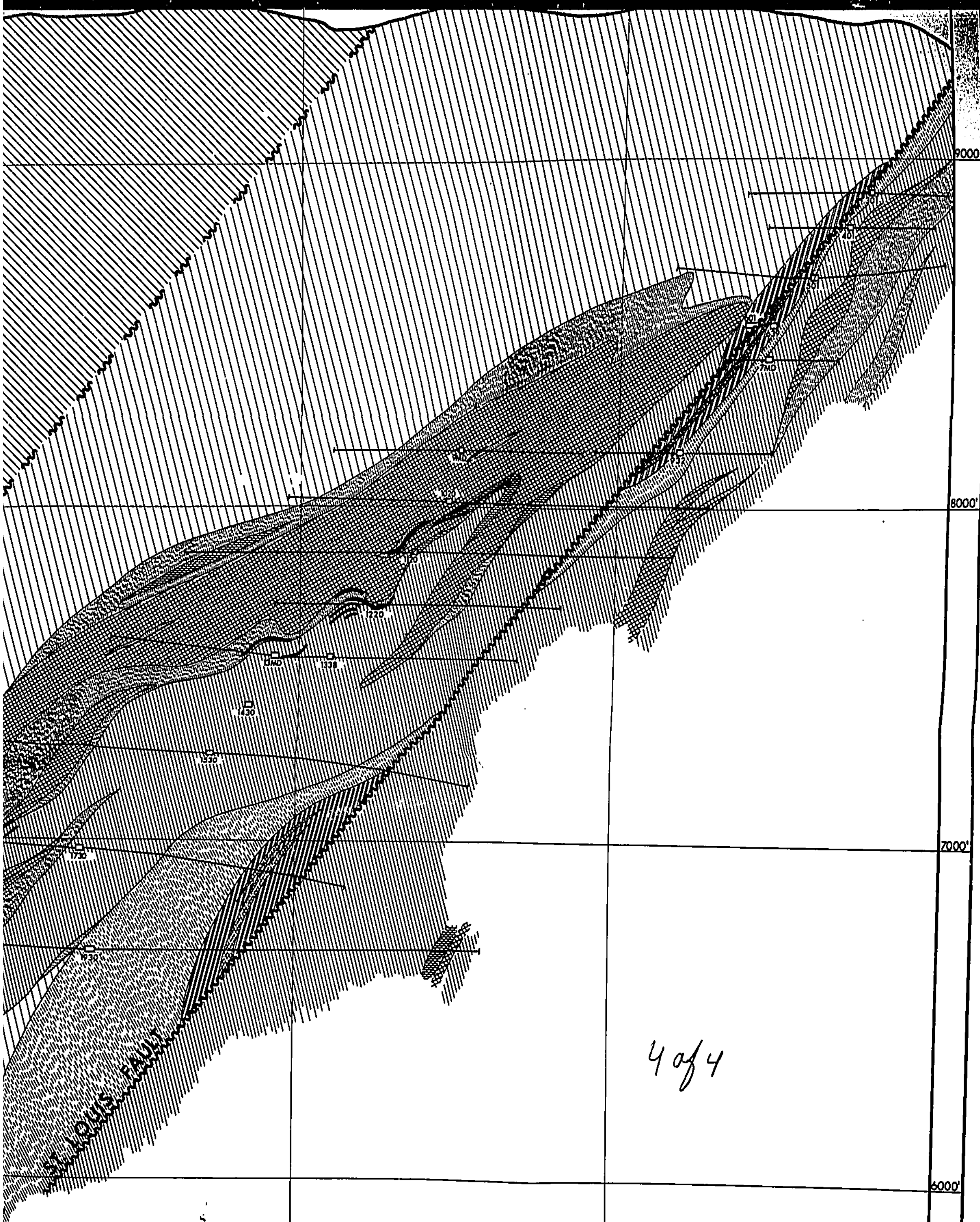
QUARTZ PORPHYRY DYKES
DIABASE DYKES AND SILLS
ANDESITE-BASALT FLOWS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC-& EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COMPLEX
DONALDSON LAKE GNEISS (BIOTITE±MUSCOVITE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE±GARNET±HORNBLENDE-MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
7MD = Drift
= Fault
Uraniferous Orebodies
D.D.H.
Projected D.D.H.
SCALE 0 200 400 600 800 1000 FEET

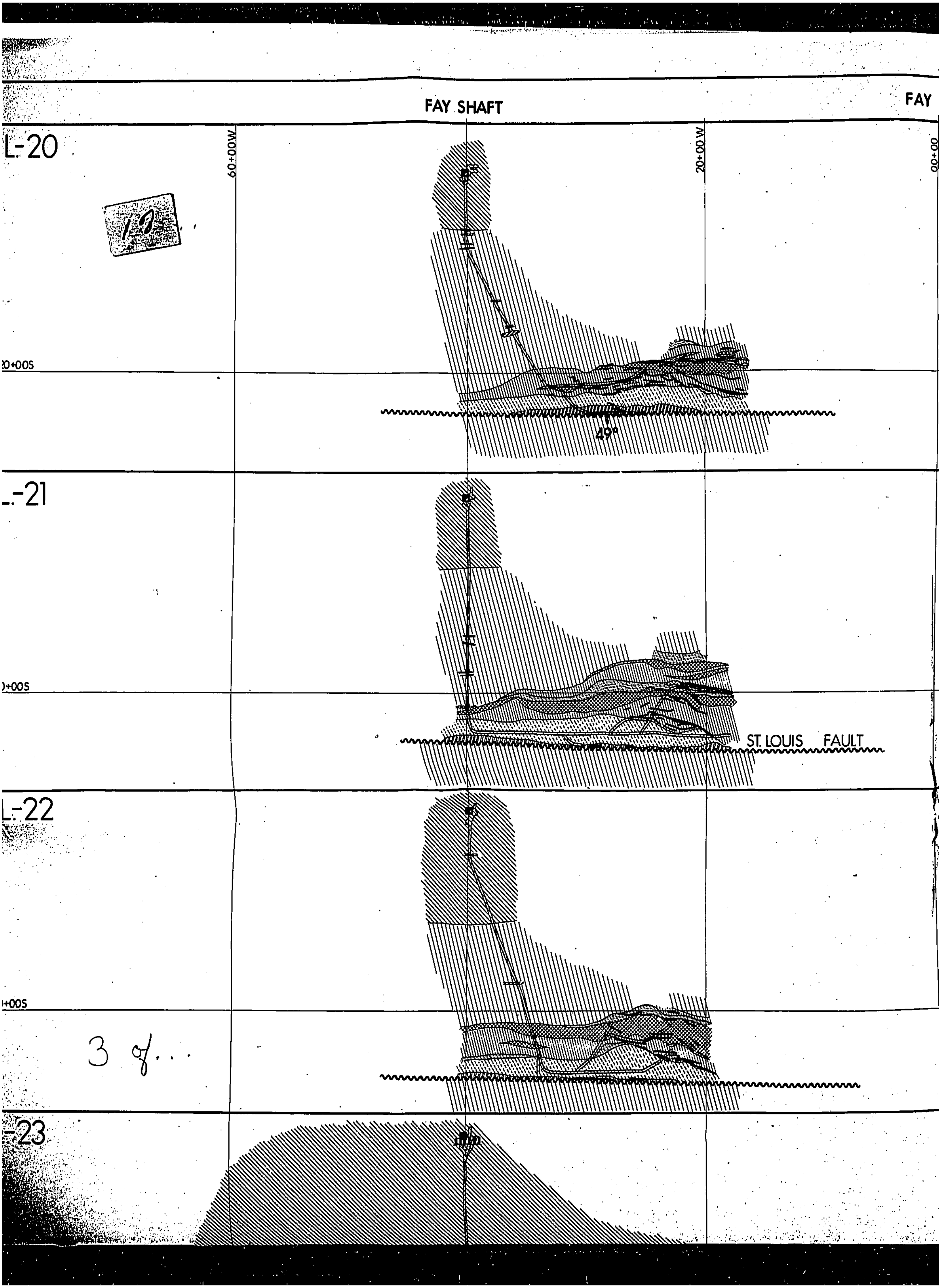


4 of 4

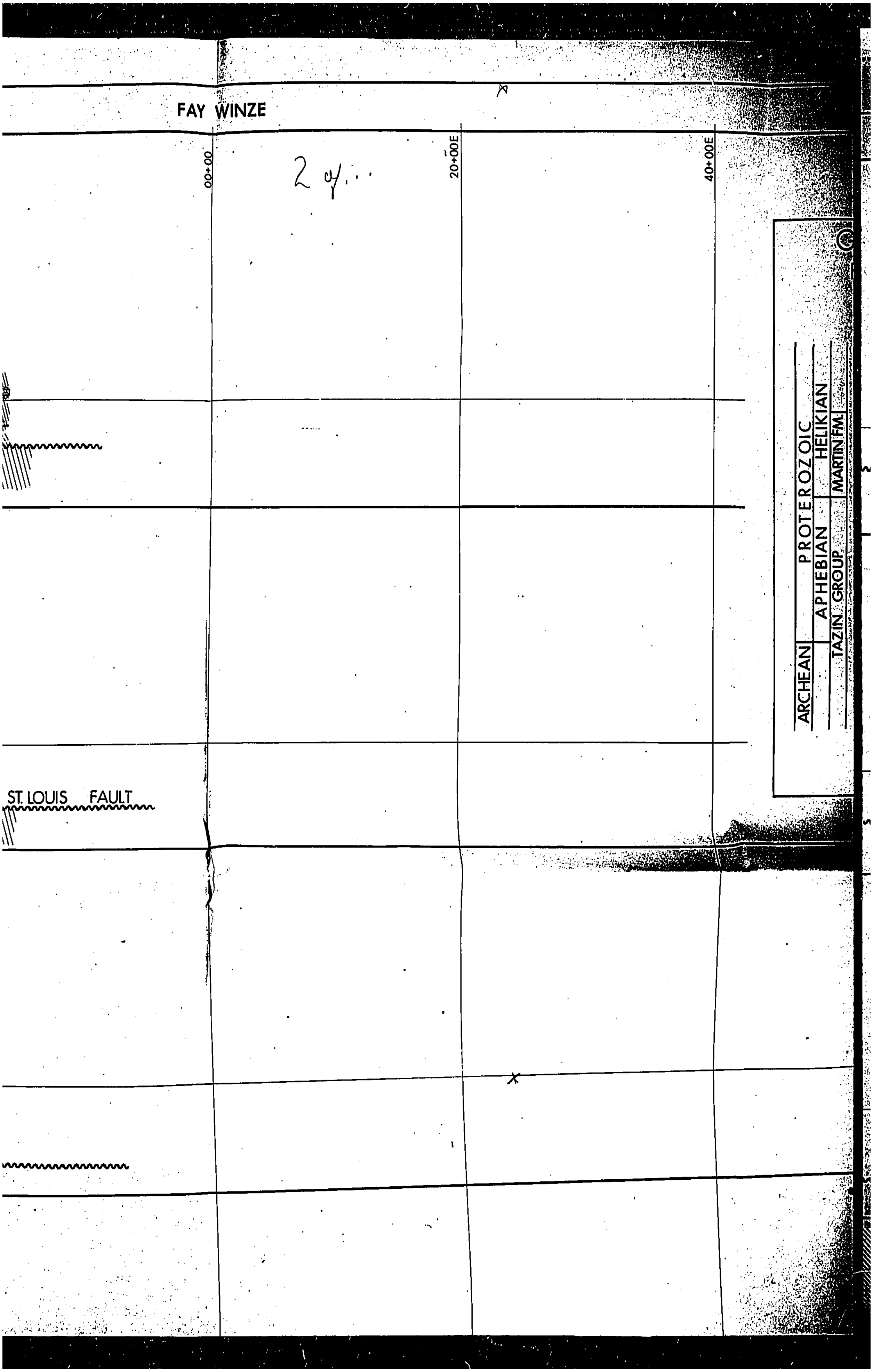
VERNA MINE, NW. SASKATCHEWAN
GEOLOGICAL CROSS-SECTION
40+00 E

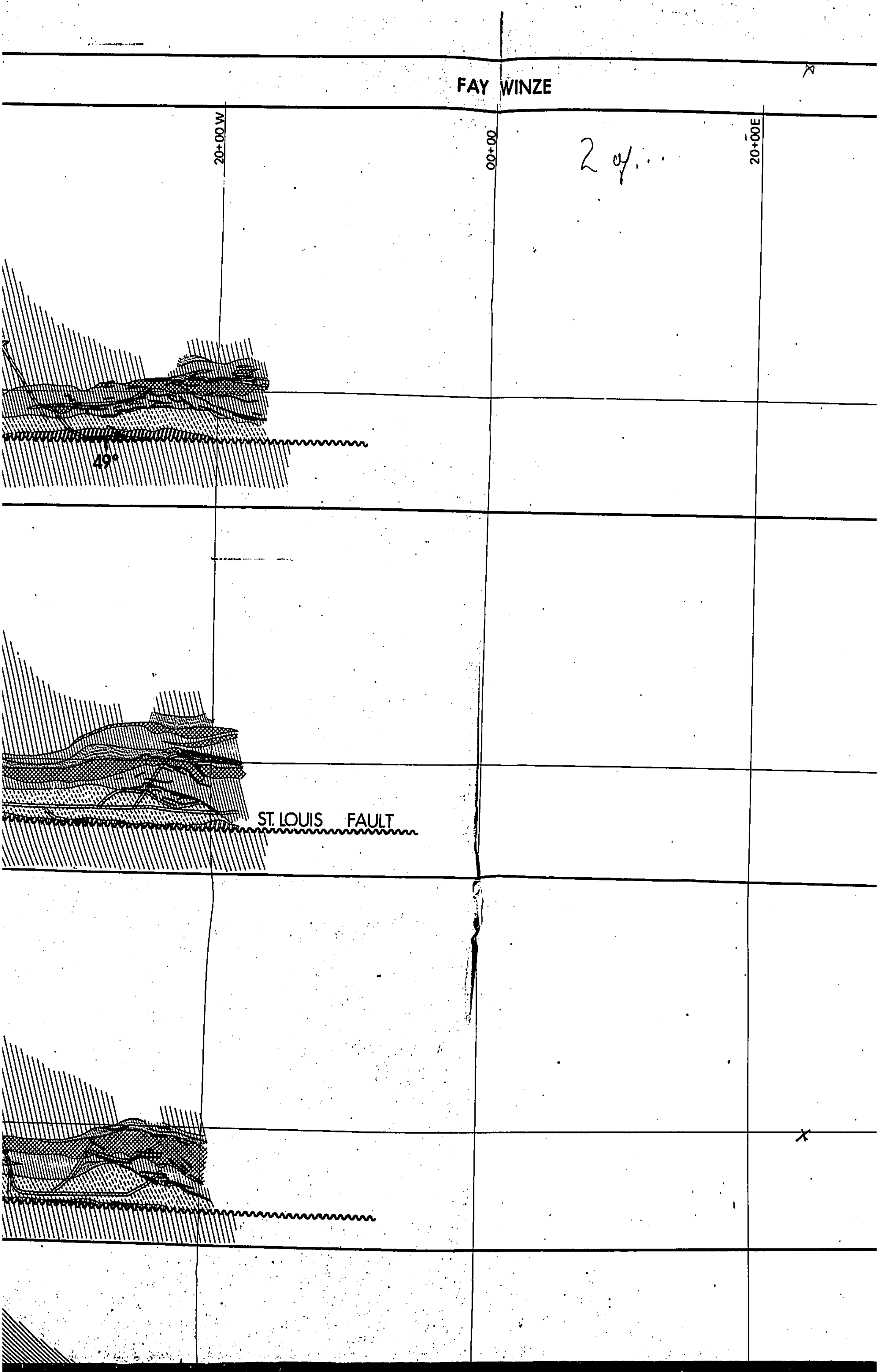
ELDORADO NUCLEAR LTD.
Geological interpretation by
G.P. SASSANO—1971

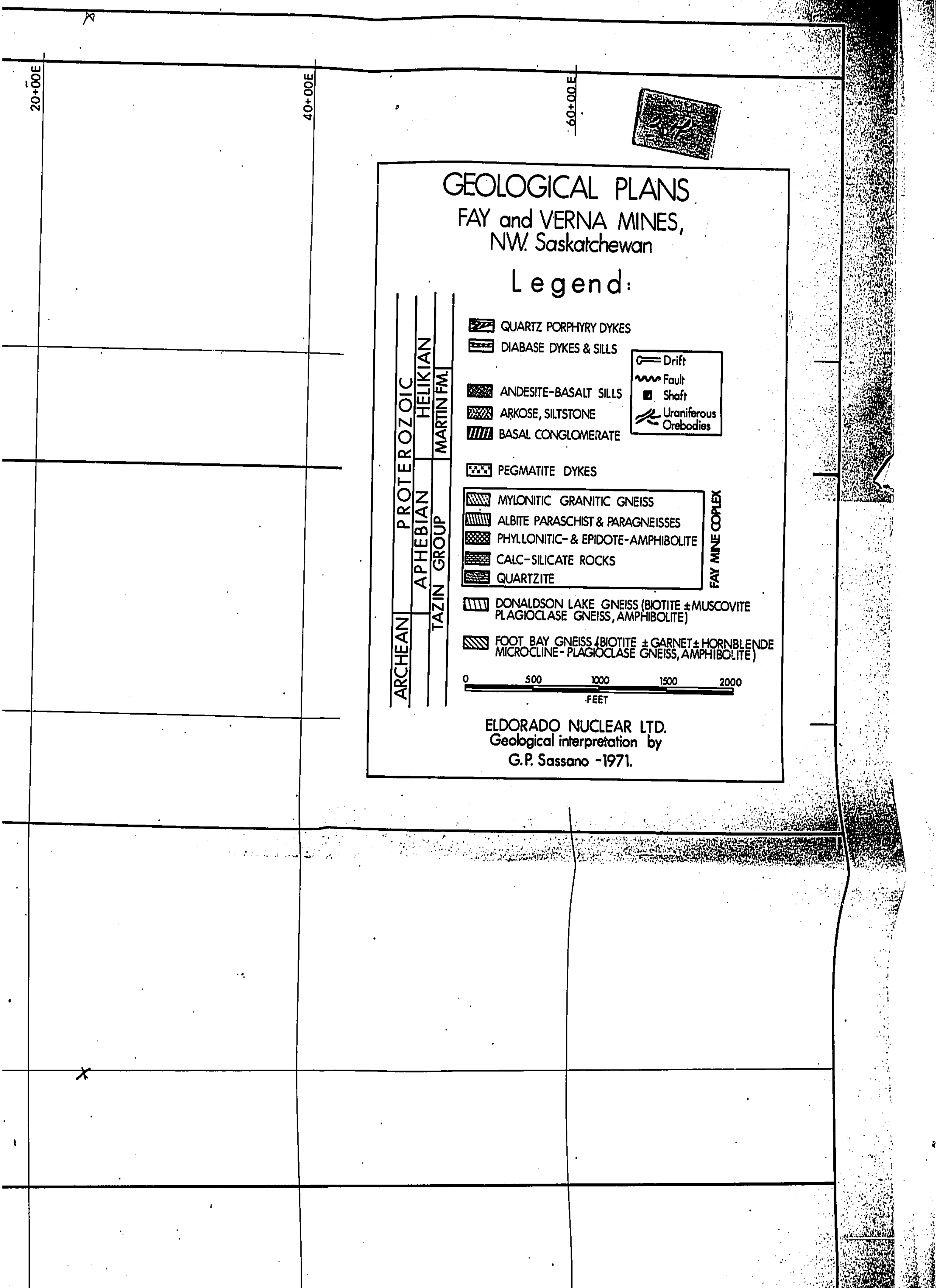
5000'

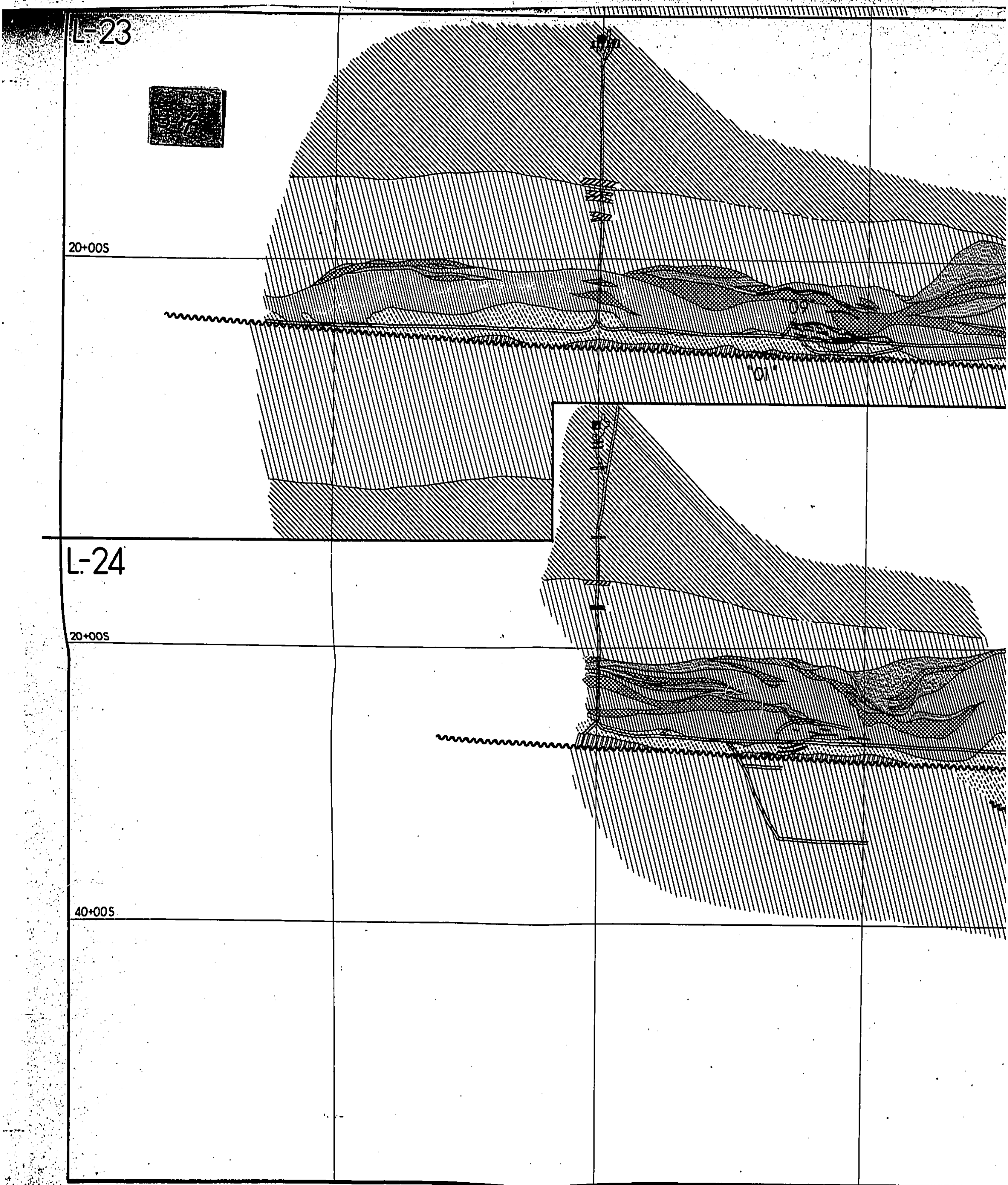


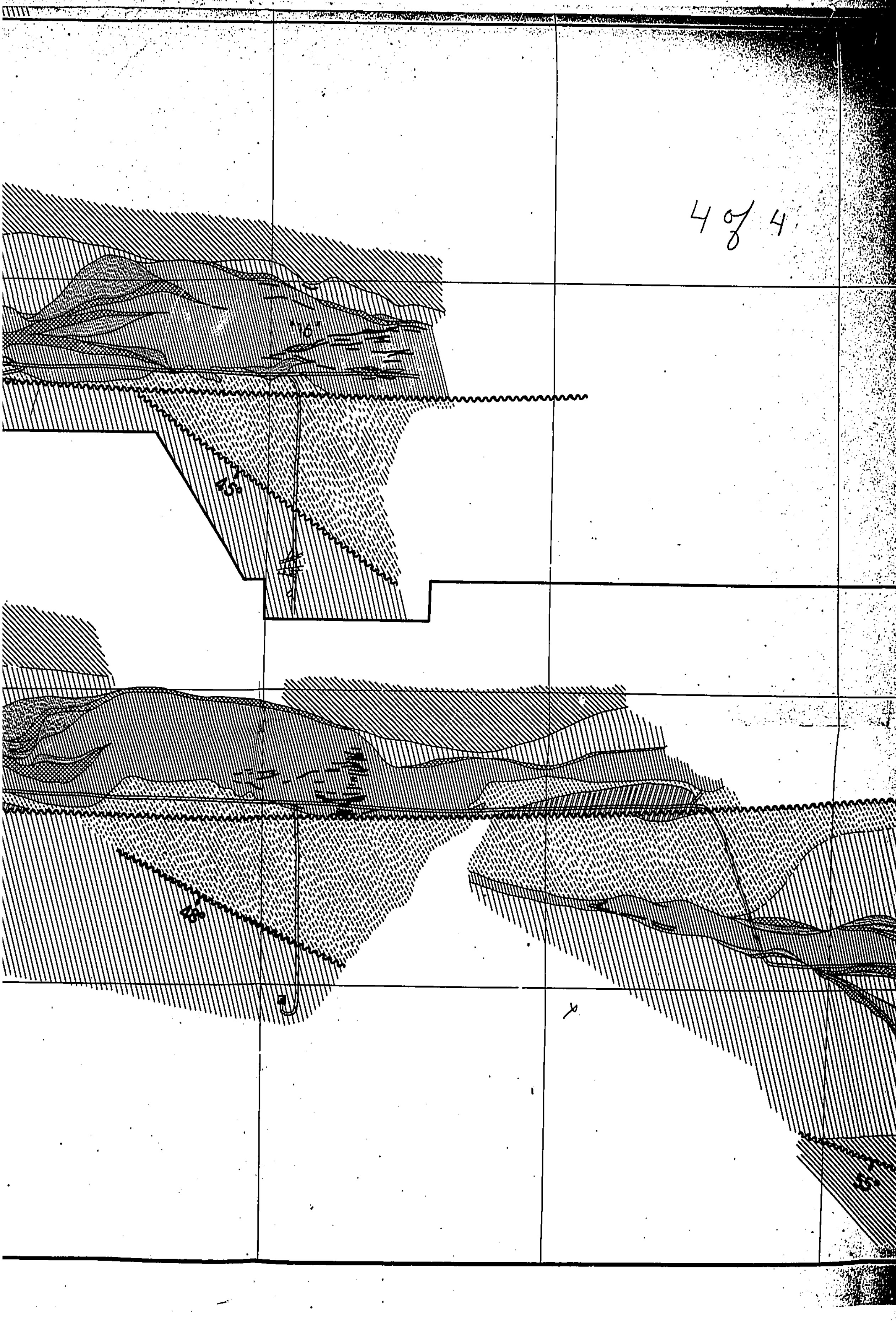
FAY SHAFT
FAY
L-20
60+00W
20+00 W
00+00
20+00S
49°
L-21
0+00S
ST. LOUIS FAULT
L-22
0+00S
3 of...
-23

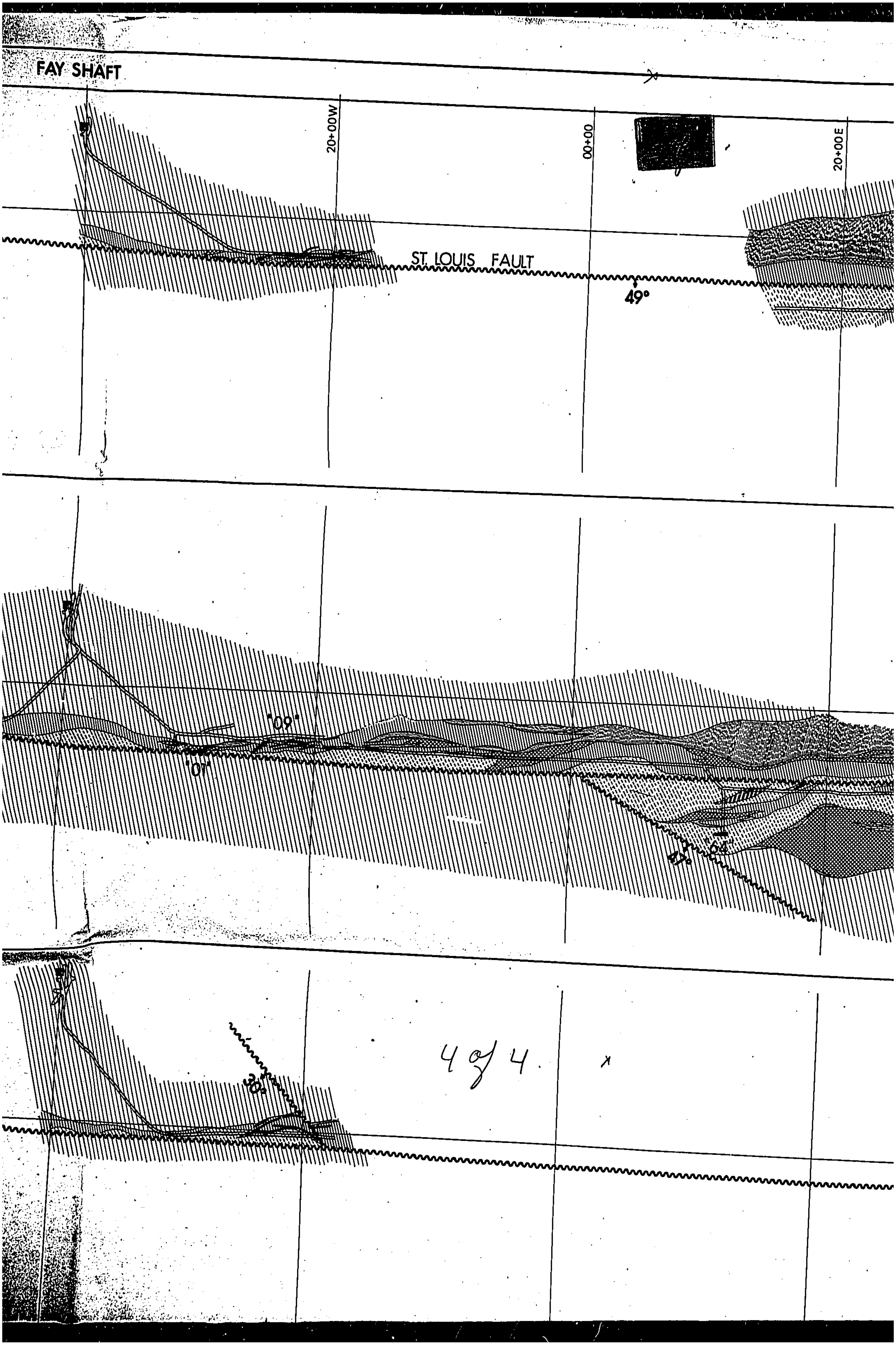

FAY WINZE
00+00
20+00E
40+00E
ST. LOUIS FAULT
ARCHEAN
PROTEROZOIC
APHEBIAN
HELIKIAN
TAZIN GROUP
MARTIN FM.

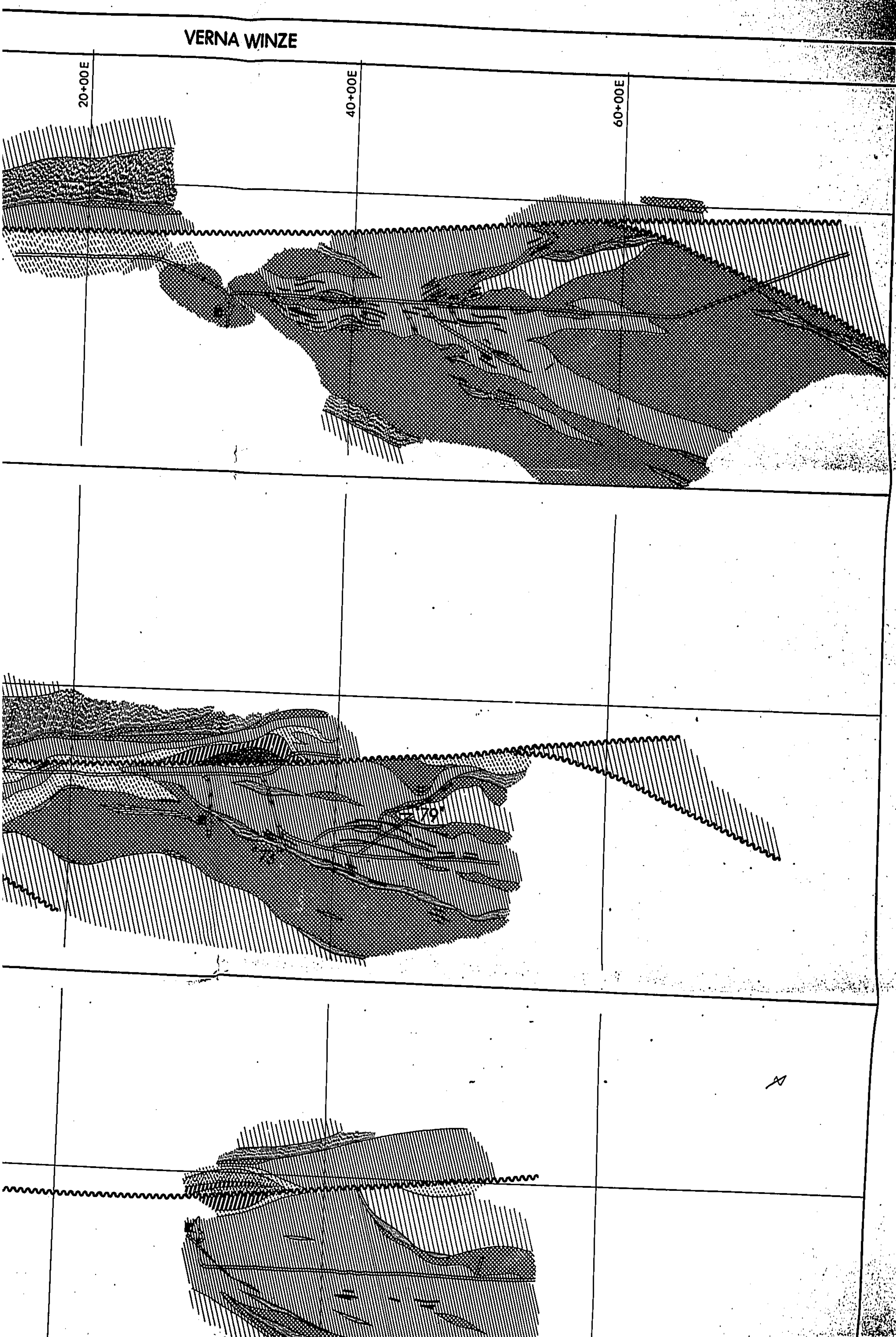

FAY WINZE
20+00 W
00+00
20+00E
49°
ST. LOUIS FAULT

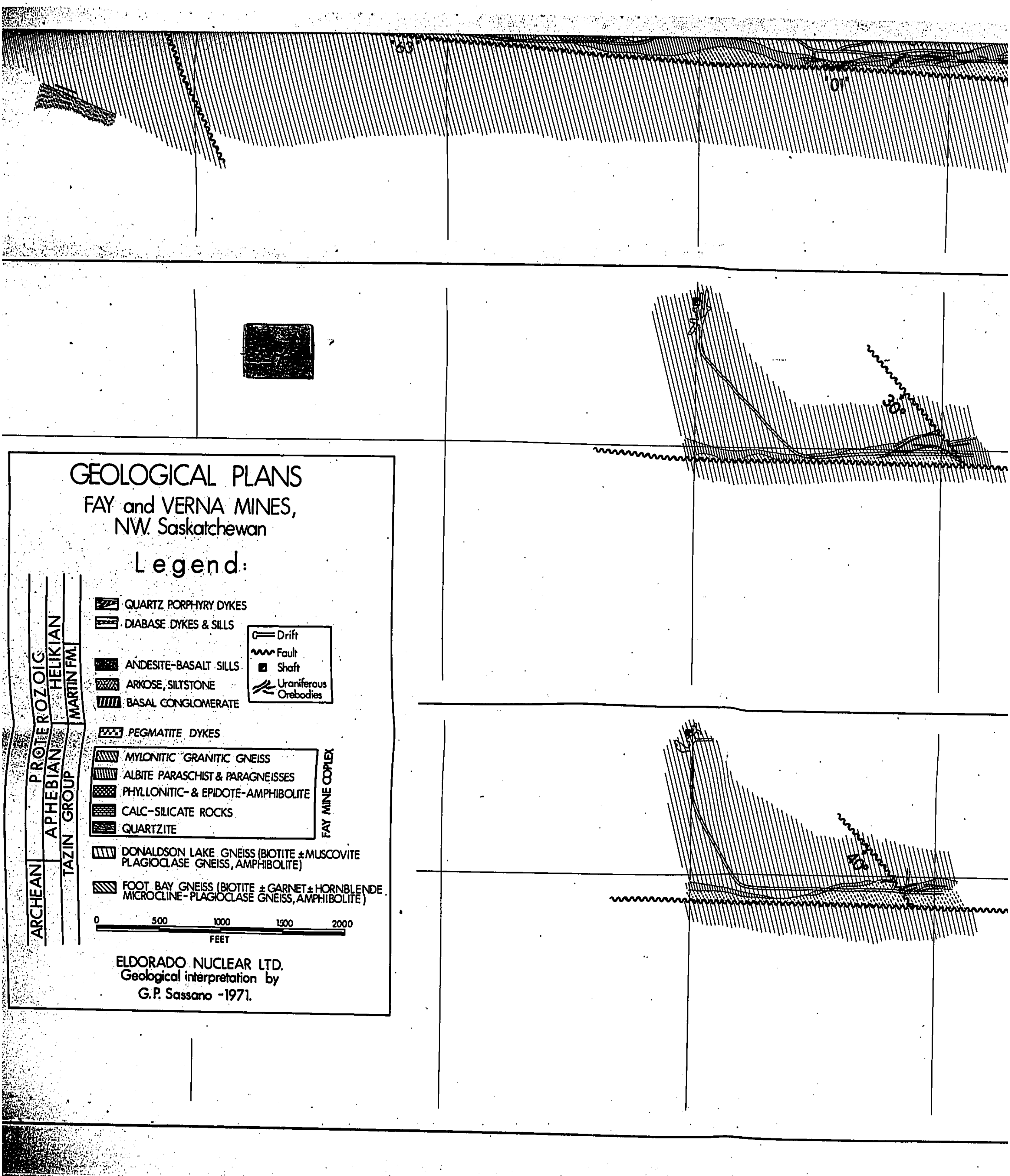

20+00E
40+00E
60+00E
GEOLOGICAL PLANS
FAY and VERNA MINES,
NW. Saskatchewan
Legend:
QUARTZ PORPHYRY DYKES
DIABASE DYKES & SILLS
ANDESITE-BASALT SILLS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
PEGMATITE DYKES
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC- & EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COPLEX
DONALDSON LAKE GNEISS (BIOTITE ±MUSCOVITE PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE ± GARNET± HORNBLENDE MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
Drift
Fault
Shaft
Uraniferous Orebodies
PROTEROZOIC
HELIKIAN
MARTIN FM.
APHEBIAN
TAZIN GROUP
ARCHEAN
0
500
1000
1500
2000
FEET
ELDORADO NUCLEAR LTD.
Geological interpretation by
G.P. Sassano -1971.

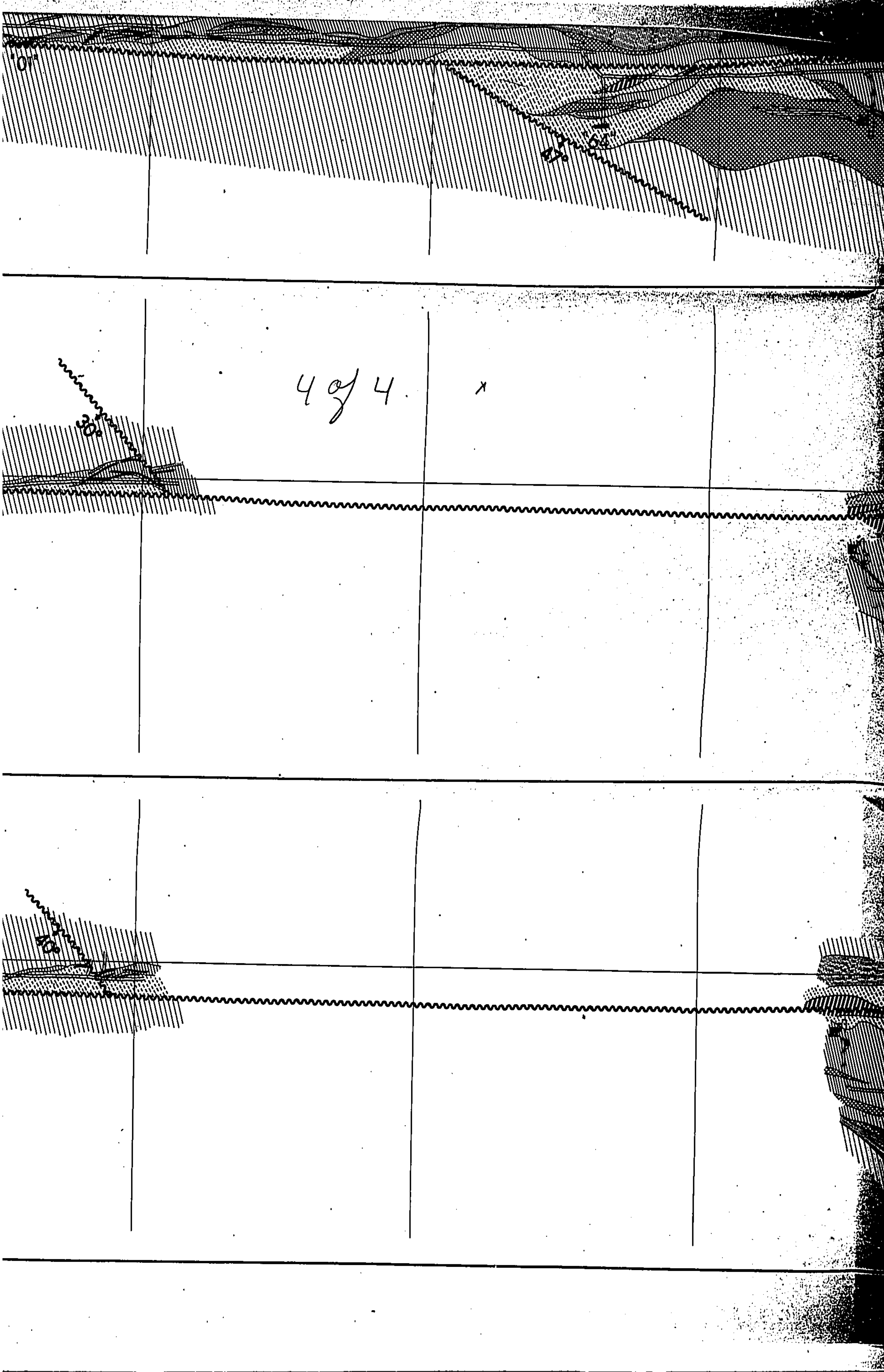

L-23
20+00S
L-24
20+00S
40+00S


"16"
45°
48°
55°

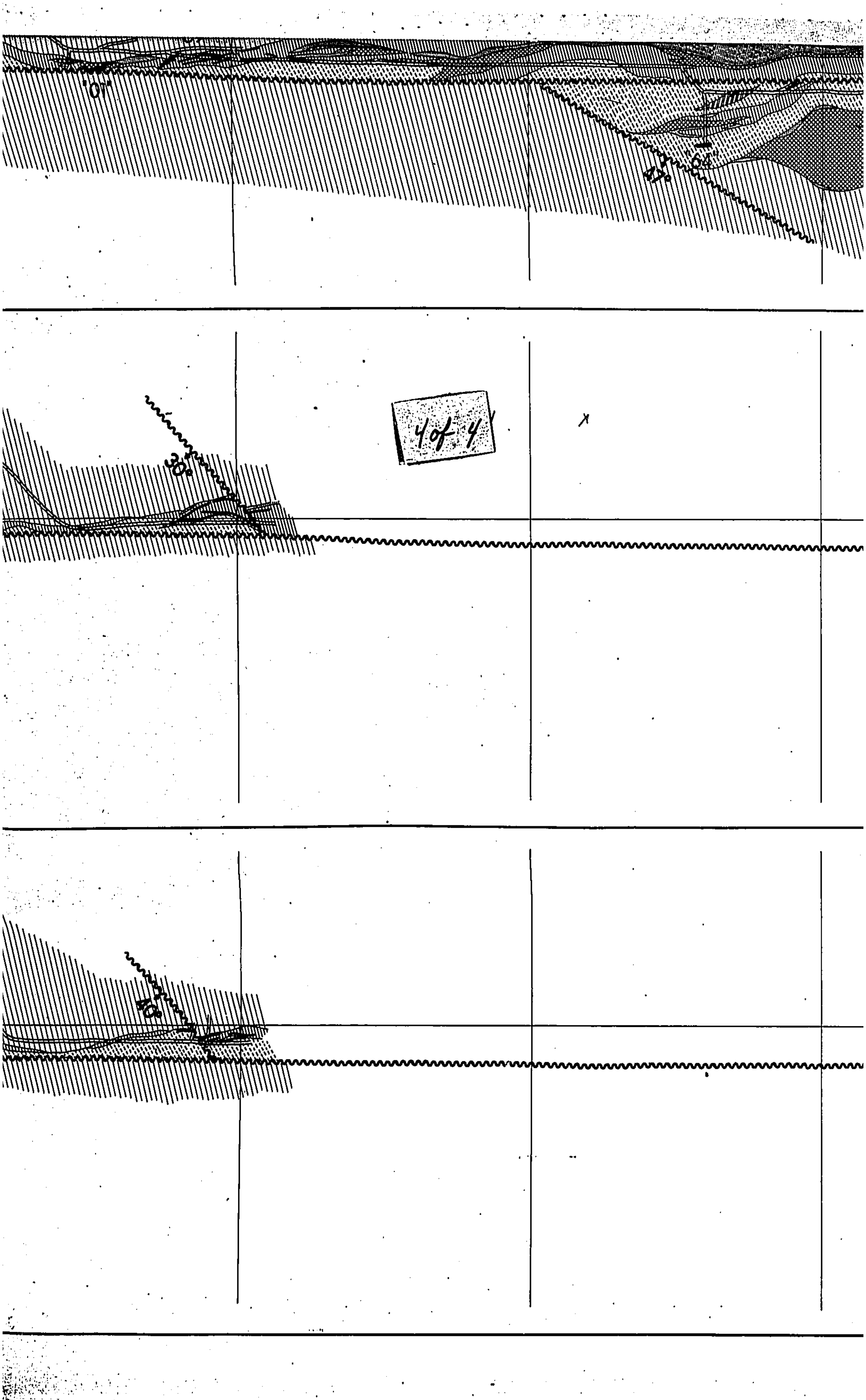

FAY SHAFT
20+00W
00+00
20+00E
ST. LOUIS FAULT
49°
"09"
"01"
47°
30°
4 of 4

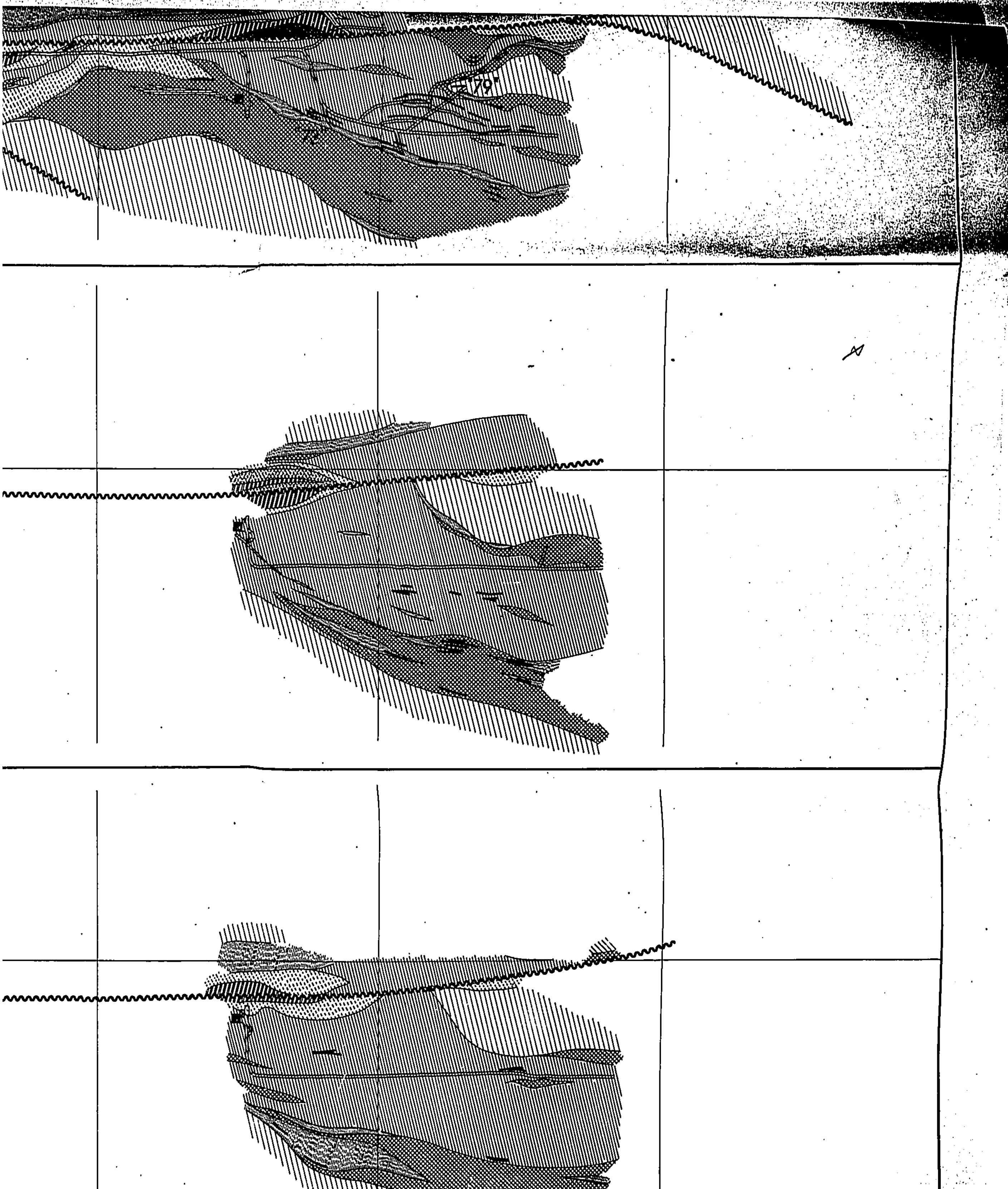

VERNA WINZE
20+00E
40+00E
60+00E
79°

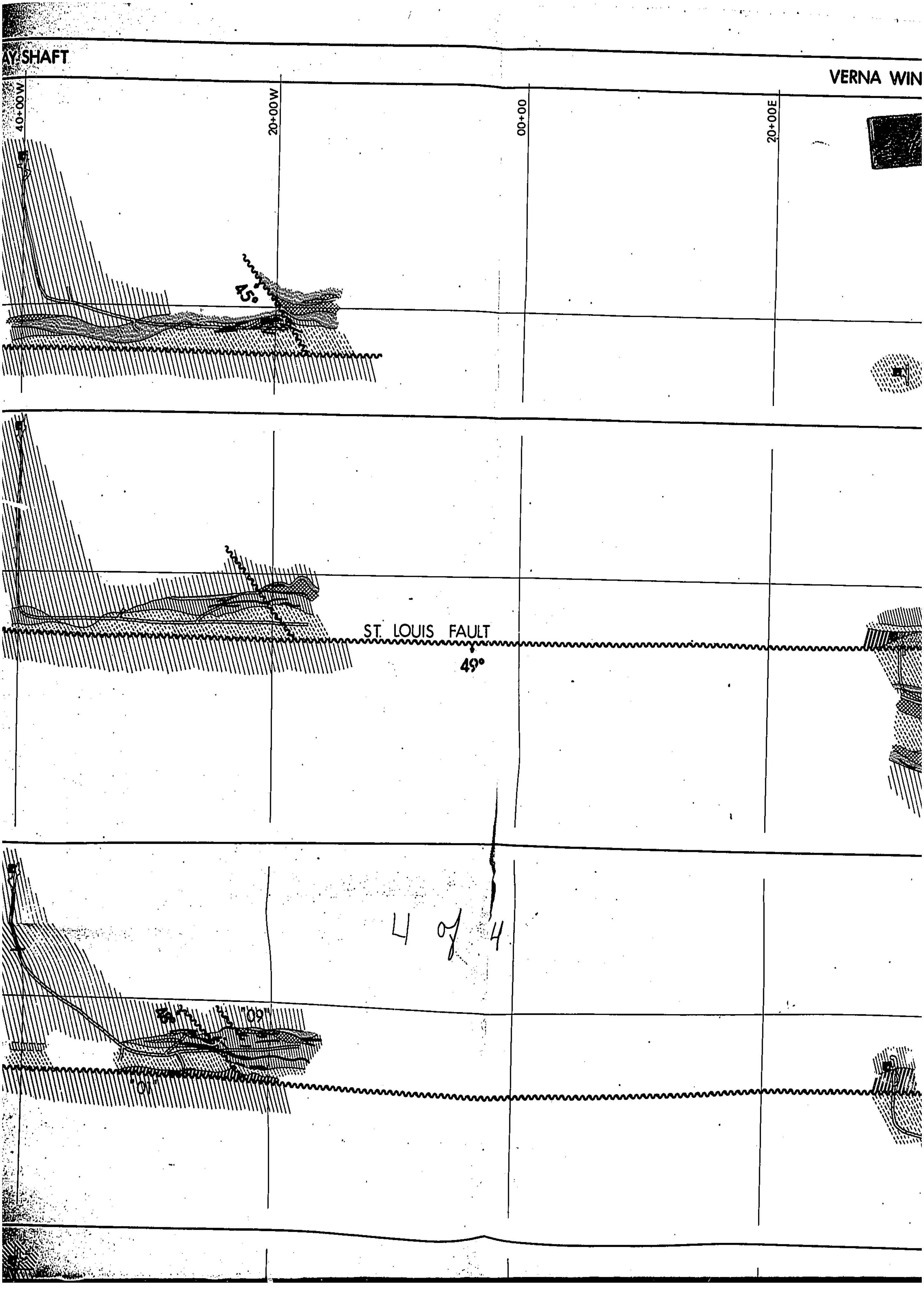

63°
01°
30°
40°
GEOLOGICAL PLANS
FAY and VERNA MINES,
NW. Saskatchewan
Legend:
ARCHEAN
PROTEROZOIC
APHEBIAN
HELIKIAN
TAZIN GROUP
MARTIN FM.
QUARTZ PORPHYRY DYKES
DIABASE DYKES & SILLS
ANDESITE-BASALT SILLS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
PEGMATITE DYKES
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC- & EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COPLEX
DONALDSON LAKE GNEISS (BIOTITE ±MUSCOVITE PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE ± GARNET ± HORNBLENDE MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
Drift
Fault
Shaft
Uraniferous Orebodies
0 500 1000 1500 2000
FEET
ELDORADO NUCLEAR LTD.
Geological interpretation by
G.P. Sassano -1971.



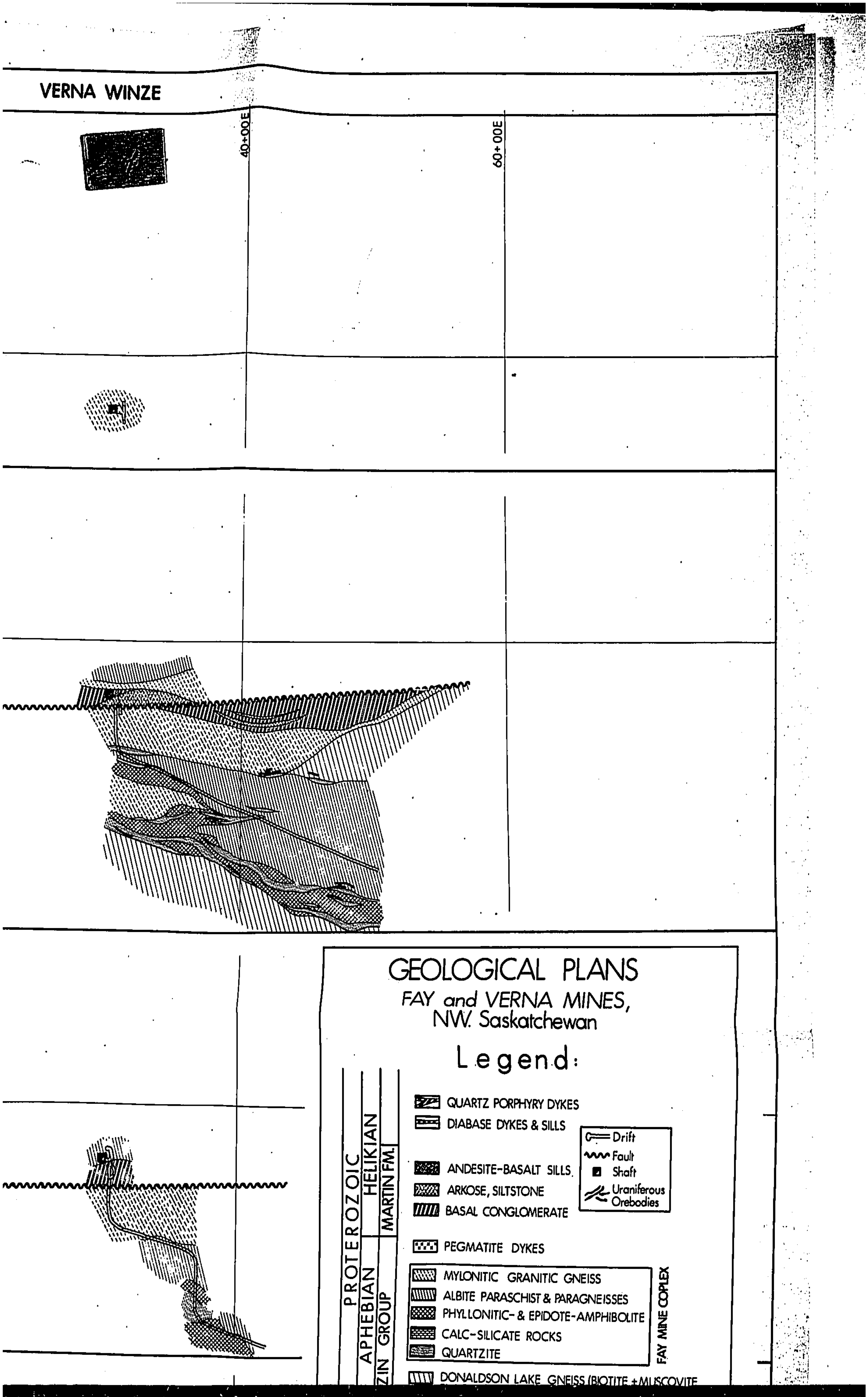
47°
4 of 4
30°
40°

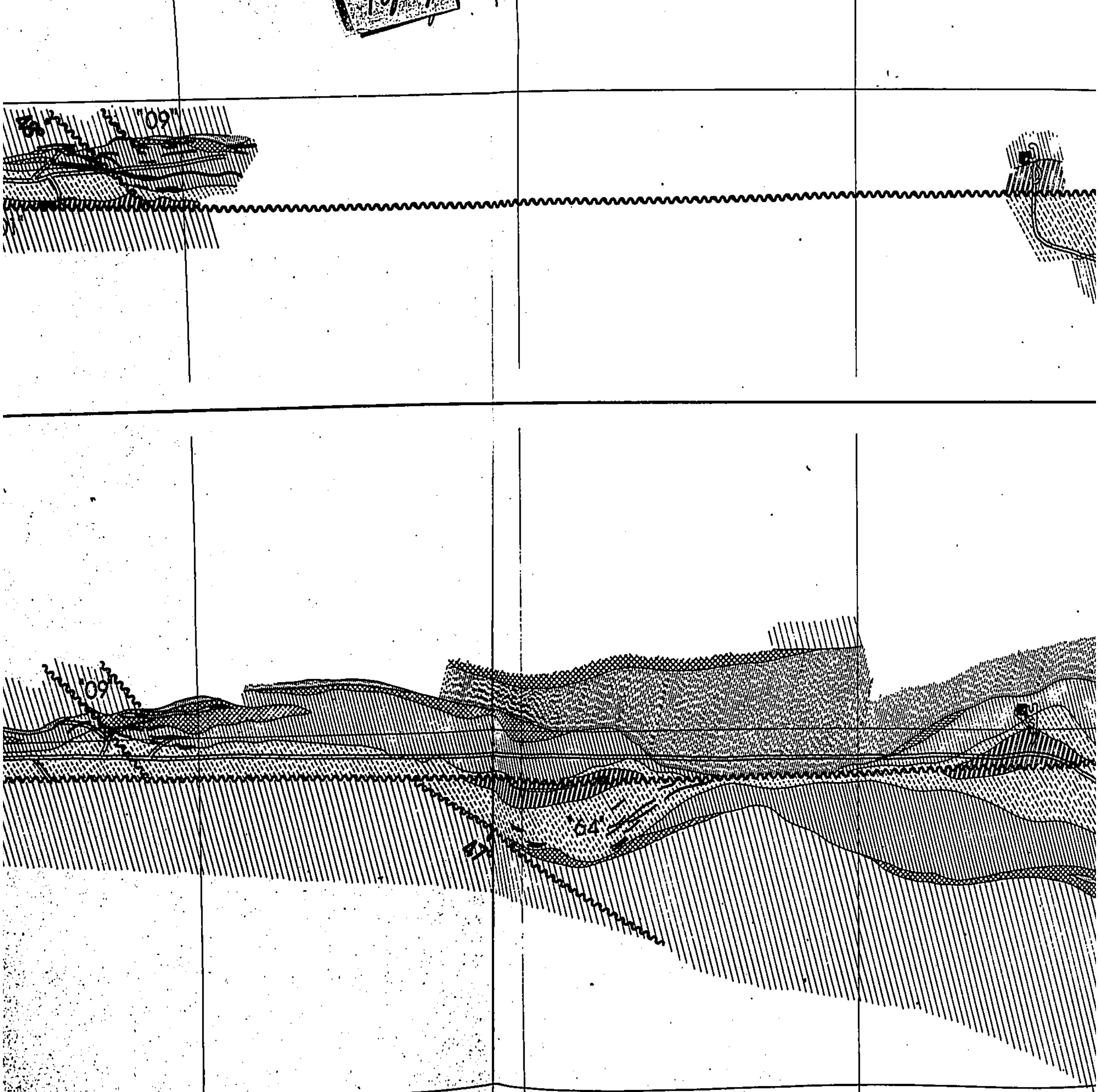

"01"
"64"
47°
4 of 4
30°
40°

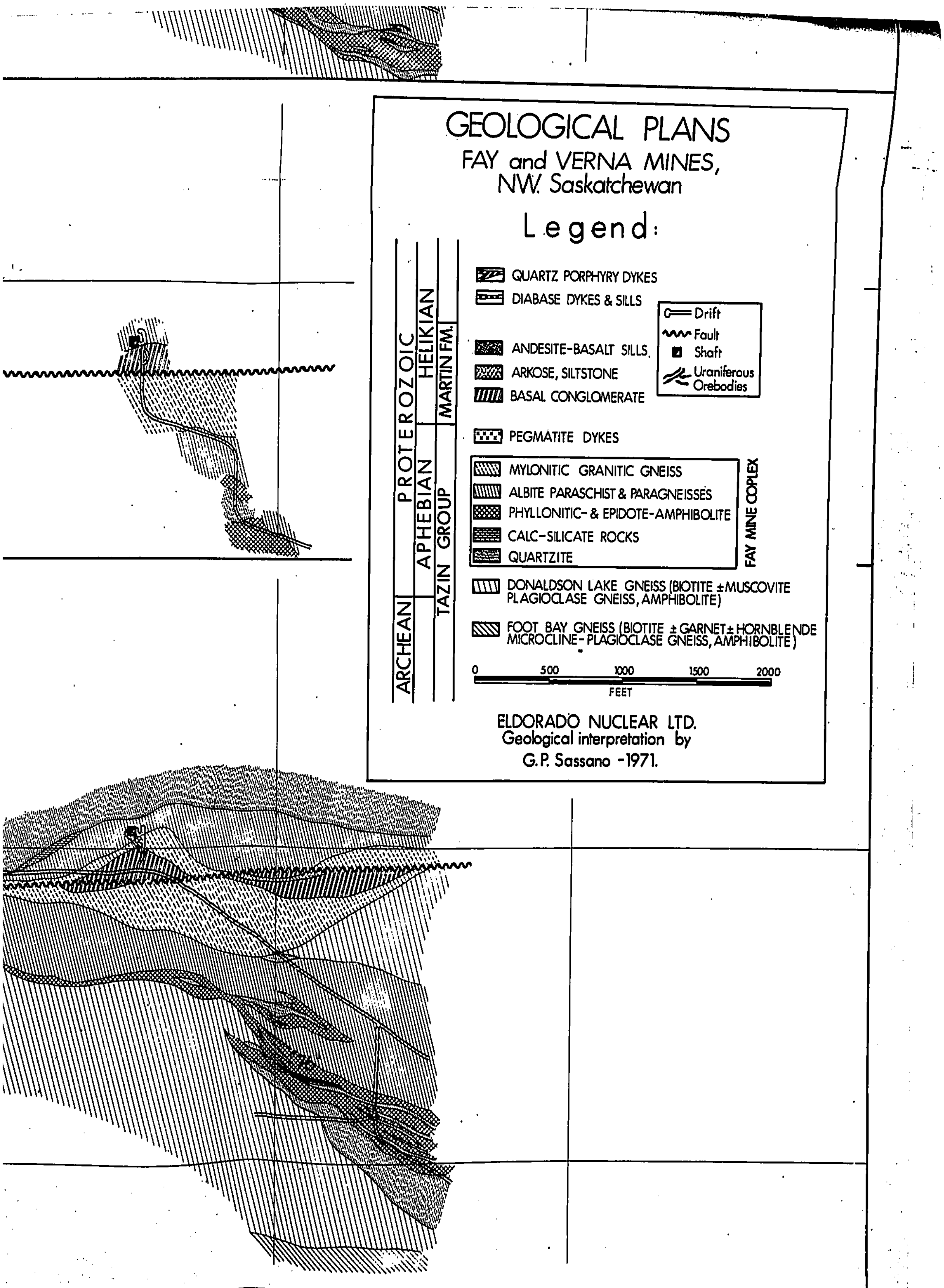

79°



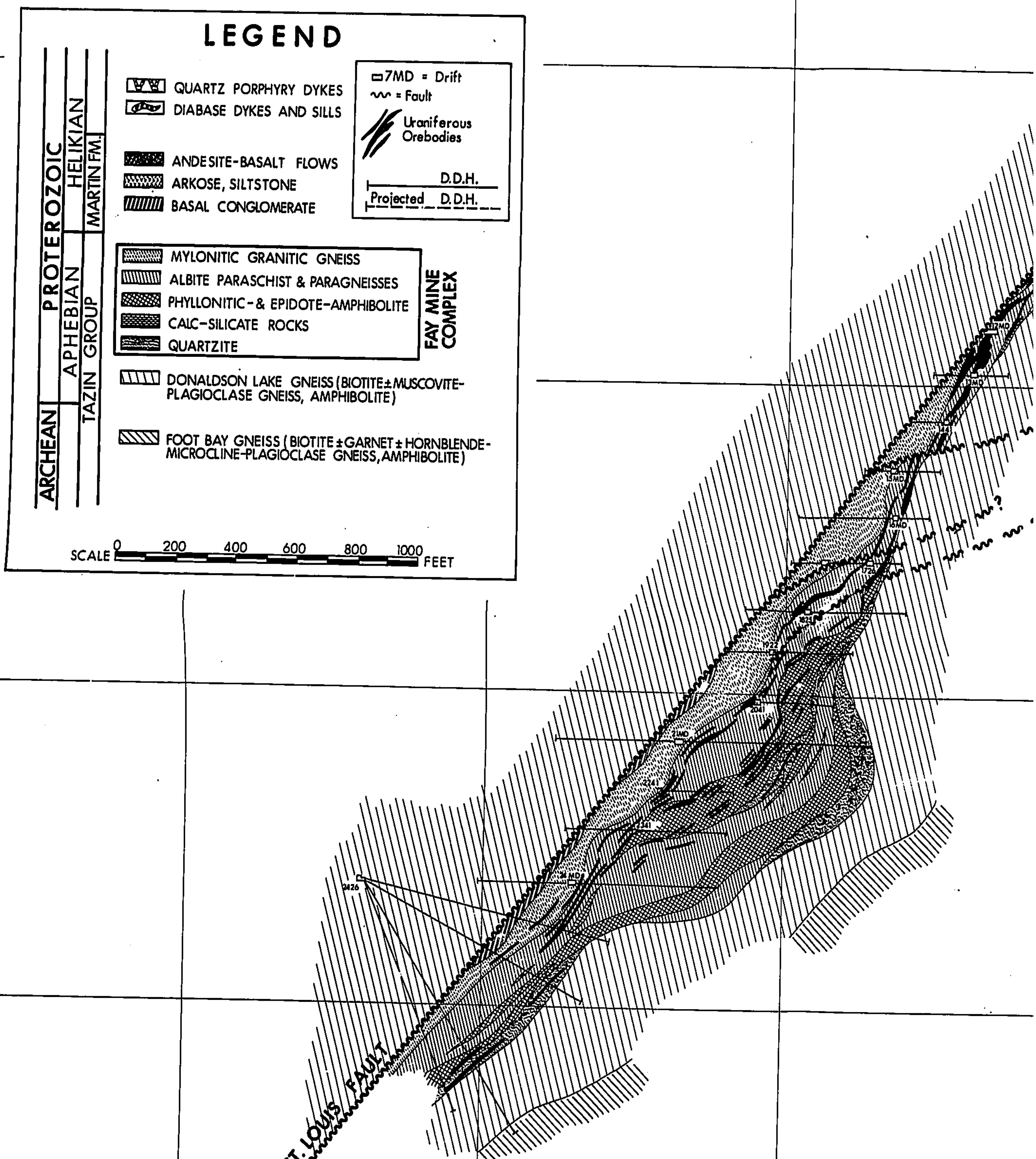
AY SHAFT
VERNA WIN
40+00W
20+00W
00+00
20+00E
45°
ST. LOUIS FAULT
49°
"09"
"01"
4 of 4


VERNA WINZE
40+00E
60+00E
GEOLOGICAL PLANS
FAY and VERNA MINES,
NW. Saskatchewan
Legend:
QUARTZ PORPHYRY DYKES
DIABASE DYKES & SILLS
ANDESITE-BASALT SILLS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
PEGMATITE DYKES
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC- & EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
DONALDSON LAKE GNEISS (BIOTITE +MUSCOVITE
FAY MINE COPLEX
PROTEROZOIC
HELIKIAN
MARTIN FM.
APHEBIAN
ZIN GROUP
Drift
Fault
Shaft
Uraniferous Orebodies

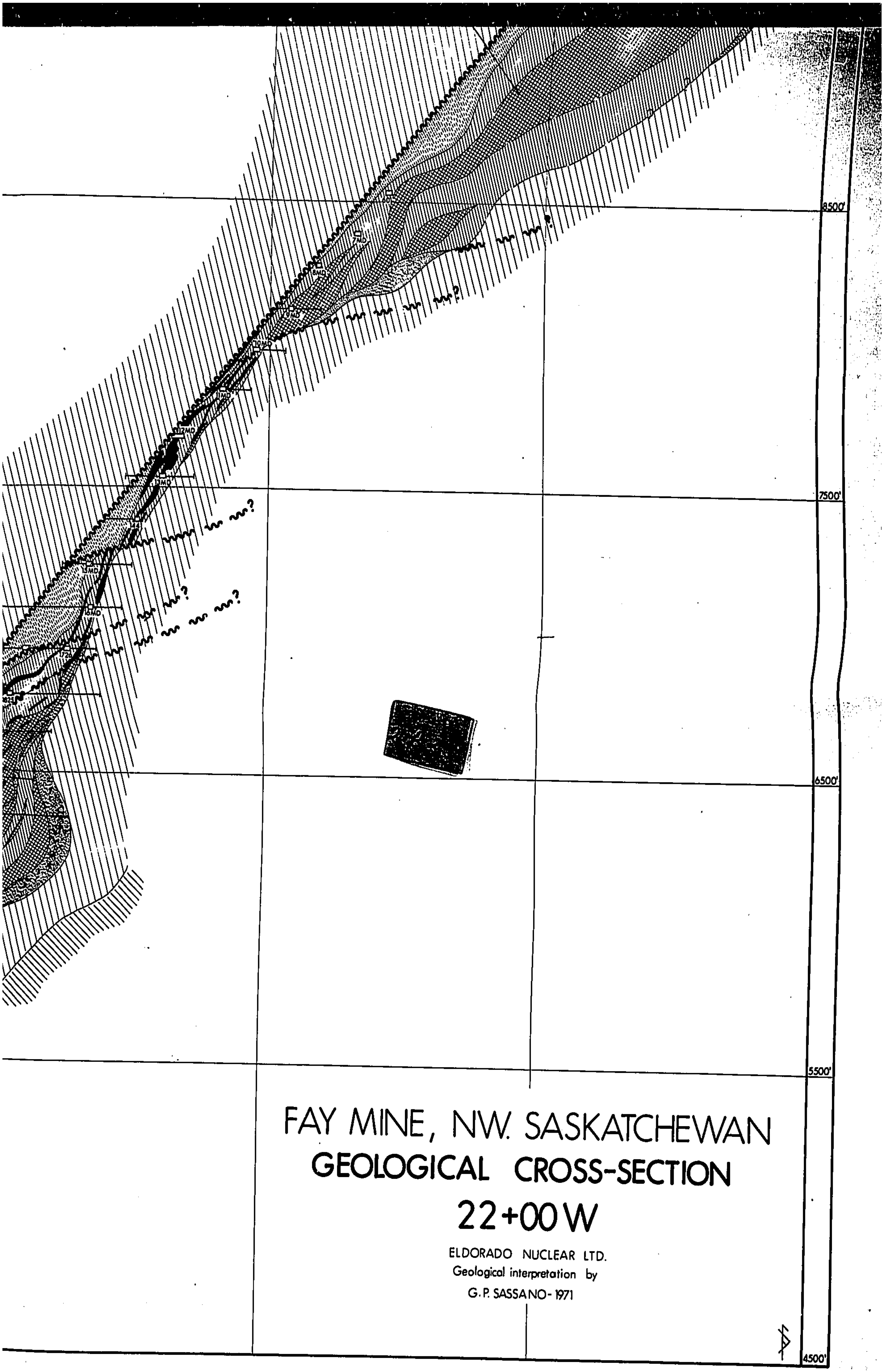

"09"


GEOLOGICAL PLANS
FAY and VERNA MINES,
NW. Saskatchewan
Legend:
PROTEROZOIC
HELIKIAN
MARTIN FM.
QUARTZ PORPHYRY DYKES
DIABASE DYKES & SILLS
ANDESITE-BASALT SILLS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
Drift
Fault
Shaft
Uraniferous Orebodies
APHEBIAN
TAZIN GROUP
PEGMATITE DYKES
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC- & EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COPLEX
ARCHEAN
DONALDSON LAKE GNEISS (BIOTITE ±MUSCOVITE PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE ± GARNET ± HORNBLENDE MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
0
500
1000
1500
2000
FEET
ELDORADO NUCLEAR LTD.
Geological interpretation by
G.P. Sassano -1971.

One of...


LEGEND
QUARTZ PORPHYRY DYKES
DIABASE DYKES AND SILLS
ANDESITE-BASALT FLOWS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC-& EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COMPLEX
DONALDSON LAKE GNEISS (BIOTITE±MUSCOVITE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE±GARNET±HORNBLENDE-MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
PROTEROZOIC
HELIKIAN
MARTIN FM.
APHEBIAN
TAZIN GROUP
ARCHEAN
7MD = Drift
= Fault
Uraniferous Orebodies
D.D.H.
Projected D.D.H.
SCALE 0 200 400 600 800 1000 FEET
ST. LOUIS FAULT

3 of...



FAY MINE, NW. SASKATCHEWAN

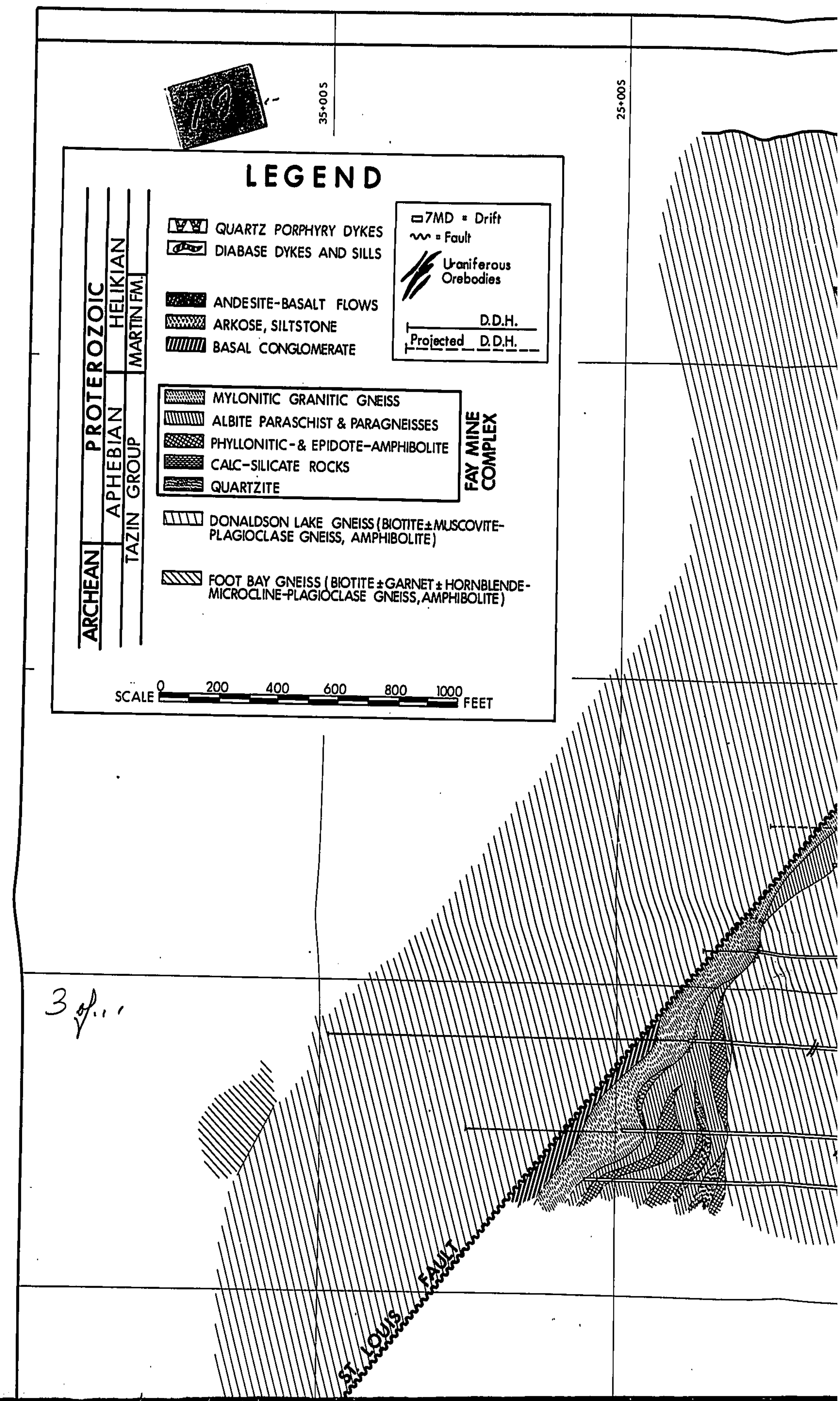
GEOLOGICAL CROSS-SECTION

22+00W

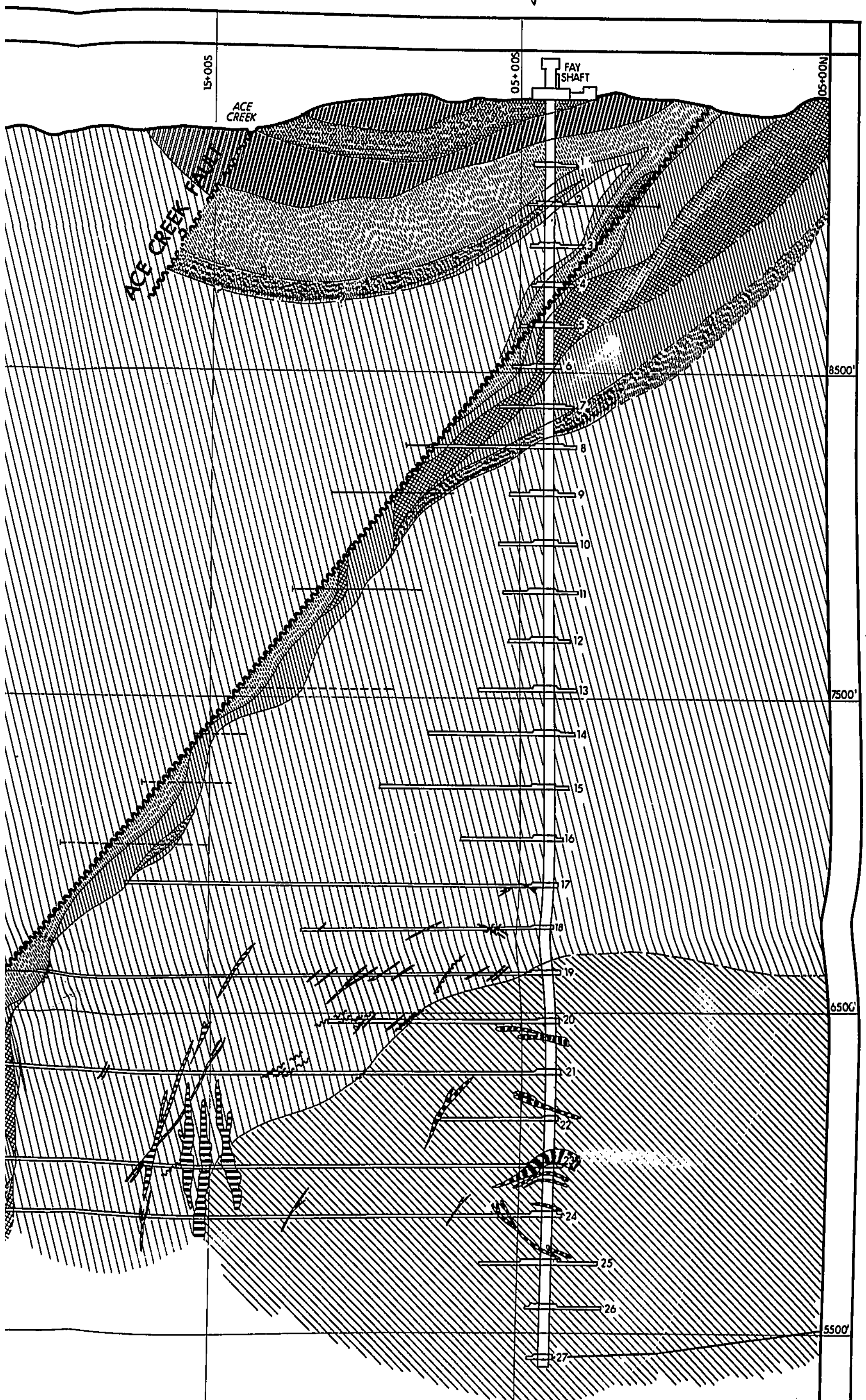
ELDORADO NUCLEAR LTD.

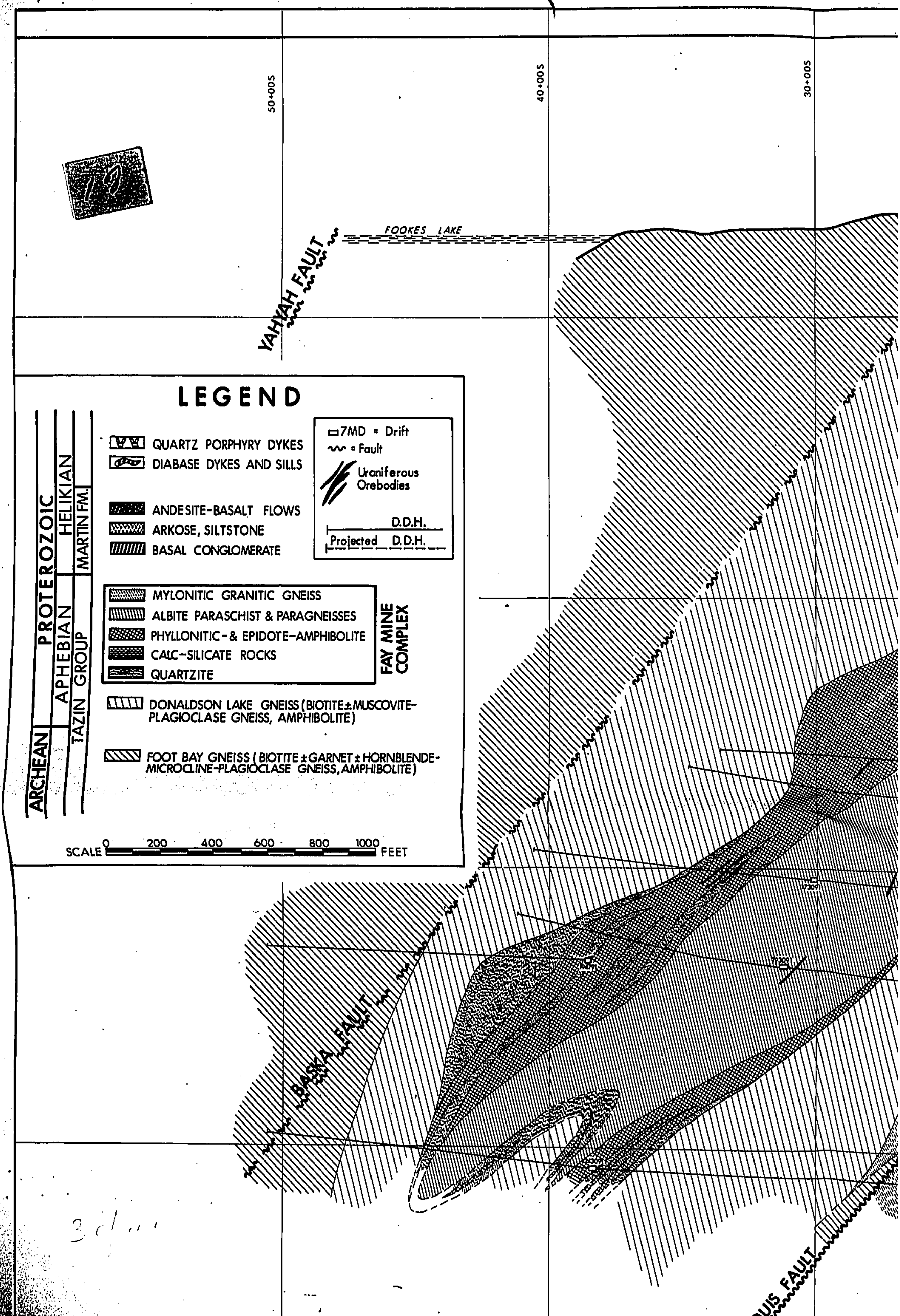
Geological interpretation by

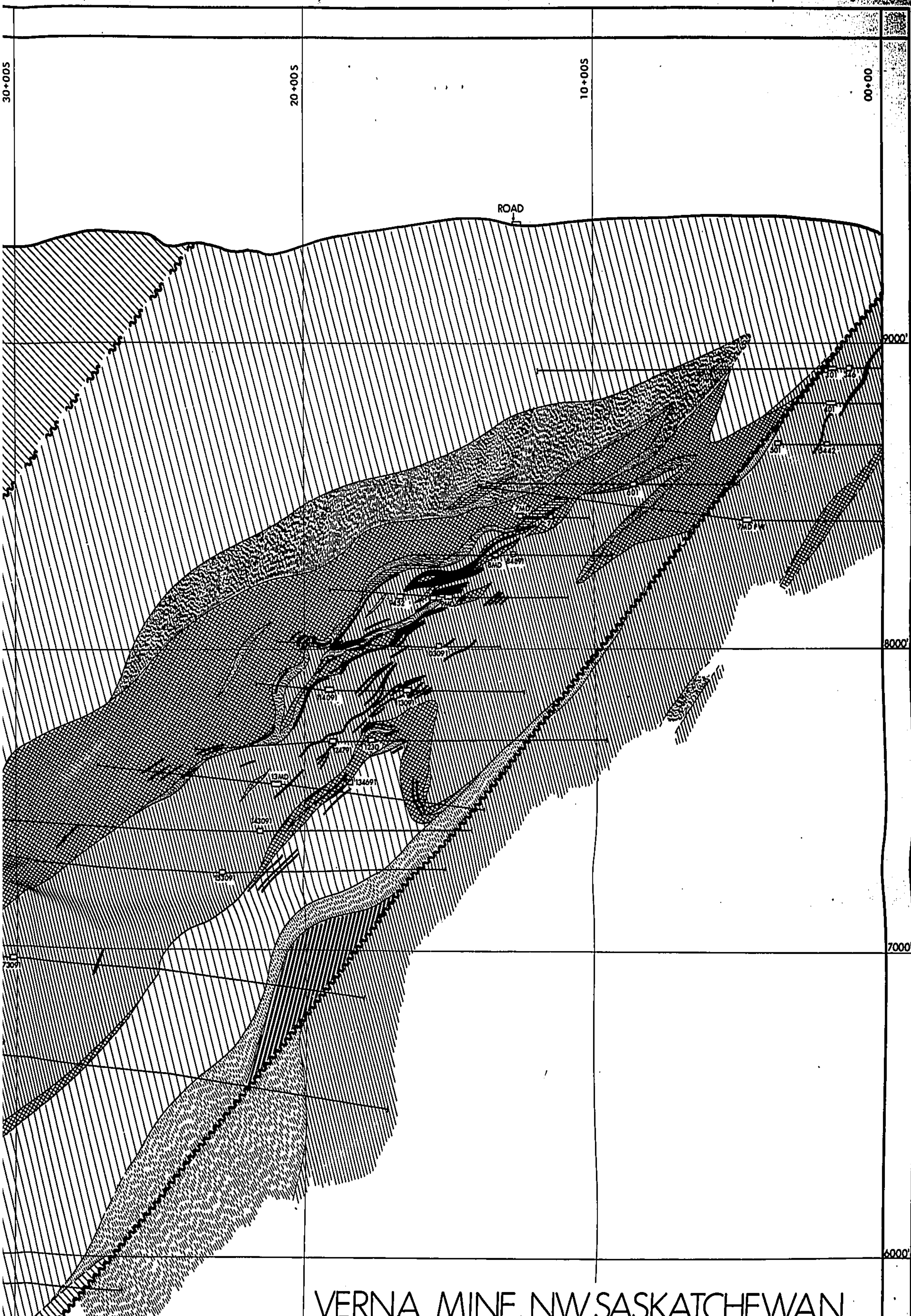
G. P. SASSANO - 1971



35+00S
25+00S
LEGEND
PROTEROZOIC
HELIKIAN
MARTIN FM.
APHEBIAN
TAZIN GROUP
ARCHEAN
QUARTZ PORPHYRY DYKES
DIABASE DYKES AND SILLS
ANDESITE-BASALT FLOWS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC-& EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COMPLEX
DONALDSON LAKE GNEISS (BIOTITE±MUSCOVITE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE±GARNET±HORNBLENDE-MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
7MD = Drift
= Fault
Uraniferous Orebodies
D.D.H.
Projected D.D.H.
SCALE 0 200 400 600 800 1000 FEET
3 of..
ST. LOUIS FAULT


15+00S
05+00S
05+00N
FAY
SHAFT
ACE
CREEK
ACE CREEK FAULT
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
8500'
7500'
6500'
5500'


50+00S
40+00S
30+00S
FOOKES LAKE
YAHYAH FAULT
LEGEND
QUARTZ PORPHYRY DYKES
DIABASE DYKES AND SILLS
ANDESITE-BASALT FLOWS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC-& EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COMPLEX
DONALDSON LAKE GNEISS (BIOTITE±MUSCOVITE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE±GARNET±HORNBLENDE-MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
PROTEROZOIC
HELIKIAN
MARTIN FM.
APHEBIAN
TAZIN GROUP
ARCHEAN
7MD = Drift
= Fault
Uraniferous Orebodies
D.D.H.
Projected D.D.H.
SCALE 0 200 400 600 800 1000 FEET
BASKA FAULT
...OUIS FAULT

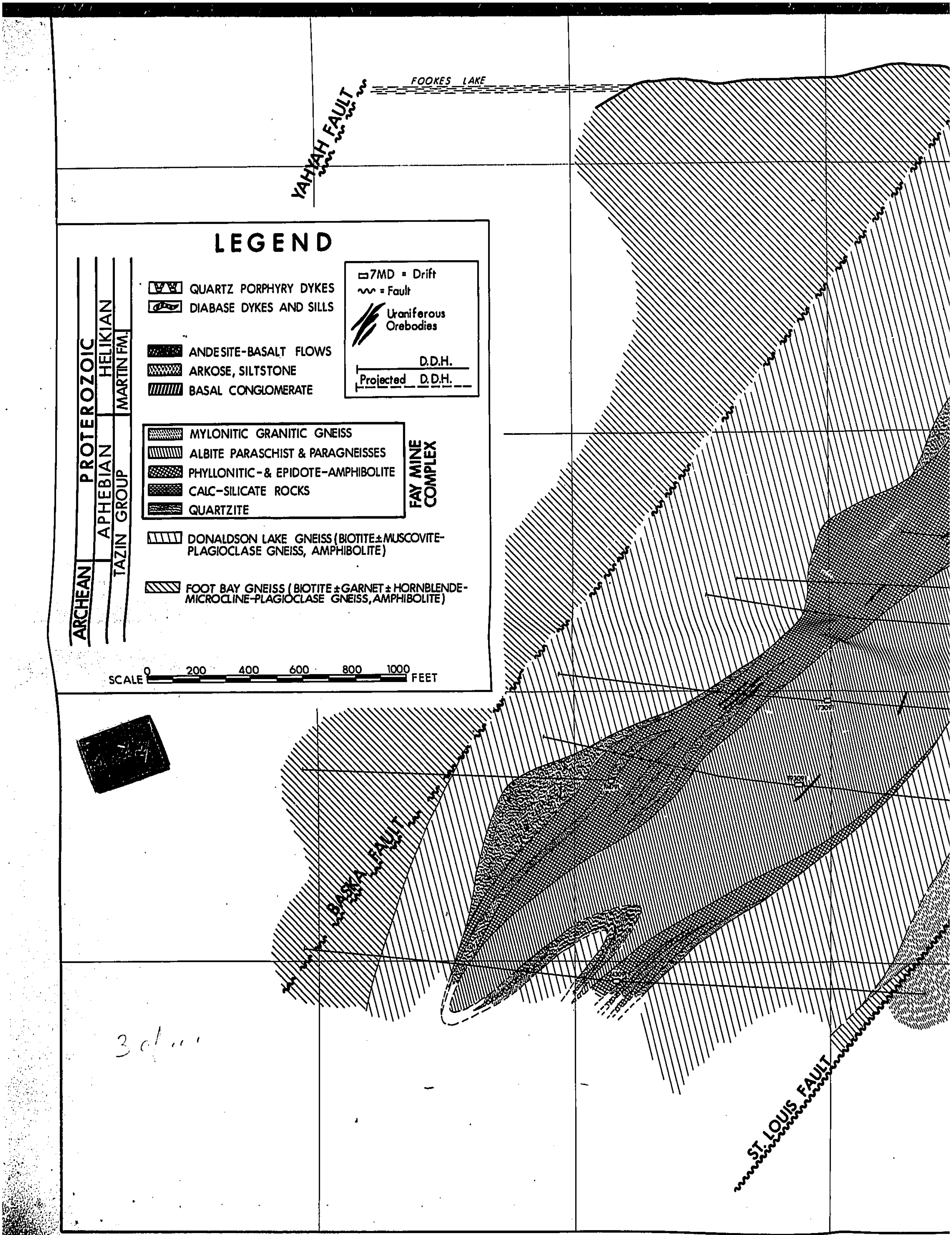


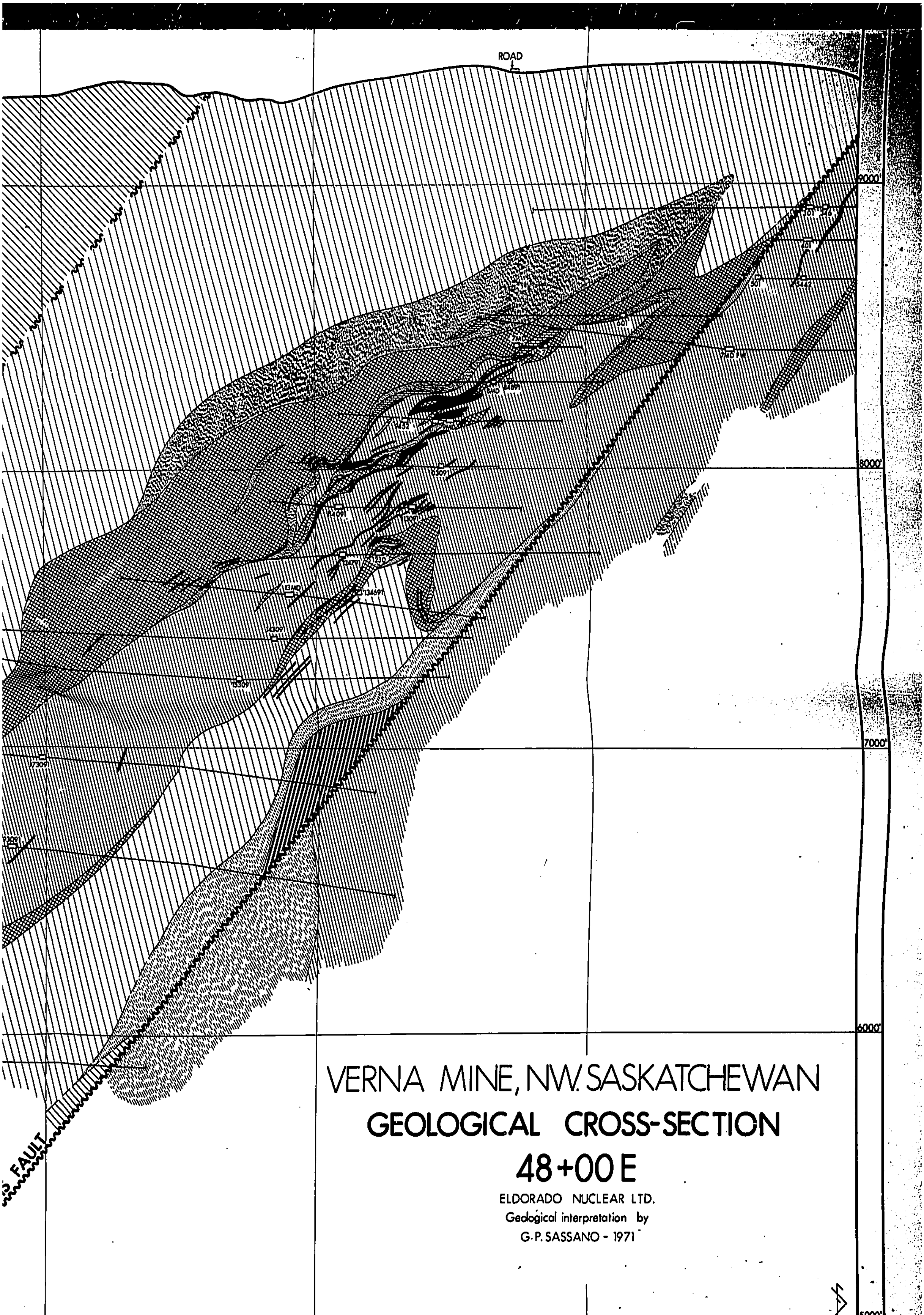
VERNA MINE, NW. SASKATCHEWAN

GEOLOGICAL CROSS-SECTION

48+00E

ELDORADO NUCLEAR LTD.


FOOKES LAKE
YAHYAH FAULT
LEGEND
PROTEROZOIC
HELIKIAN
MARTIN FM.
APHEBIAN
TAZIN GROUP
ARCHEAN
QUARTZ PORPHYRY DYKES
DIABASE DYKES AND SILLS
ANDESITE-BASALT FLOWS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC-& EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COMPLEX
DONALDSON LAKE GNEISS (BIOTITE± MUSCOVITE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE ± GARNET ± HORNBLENDE-MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
7MD = Drift
= Fault
Uraniferous Orebodies
D.D.H.
Projected D.D.H.
SCALE 0 200 400 600 800 1000 FEET
BASKA FAULT
ST. LOUIS FAULT



VERNA MINE, NW. SASKATCHEWAN

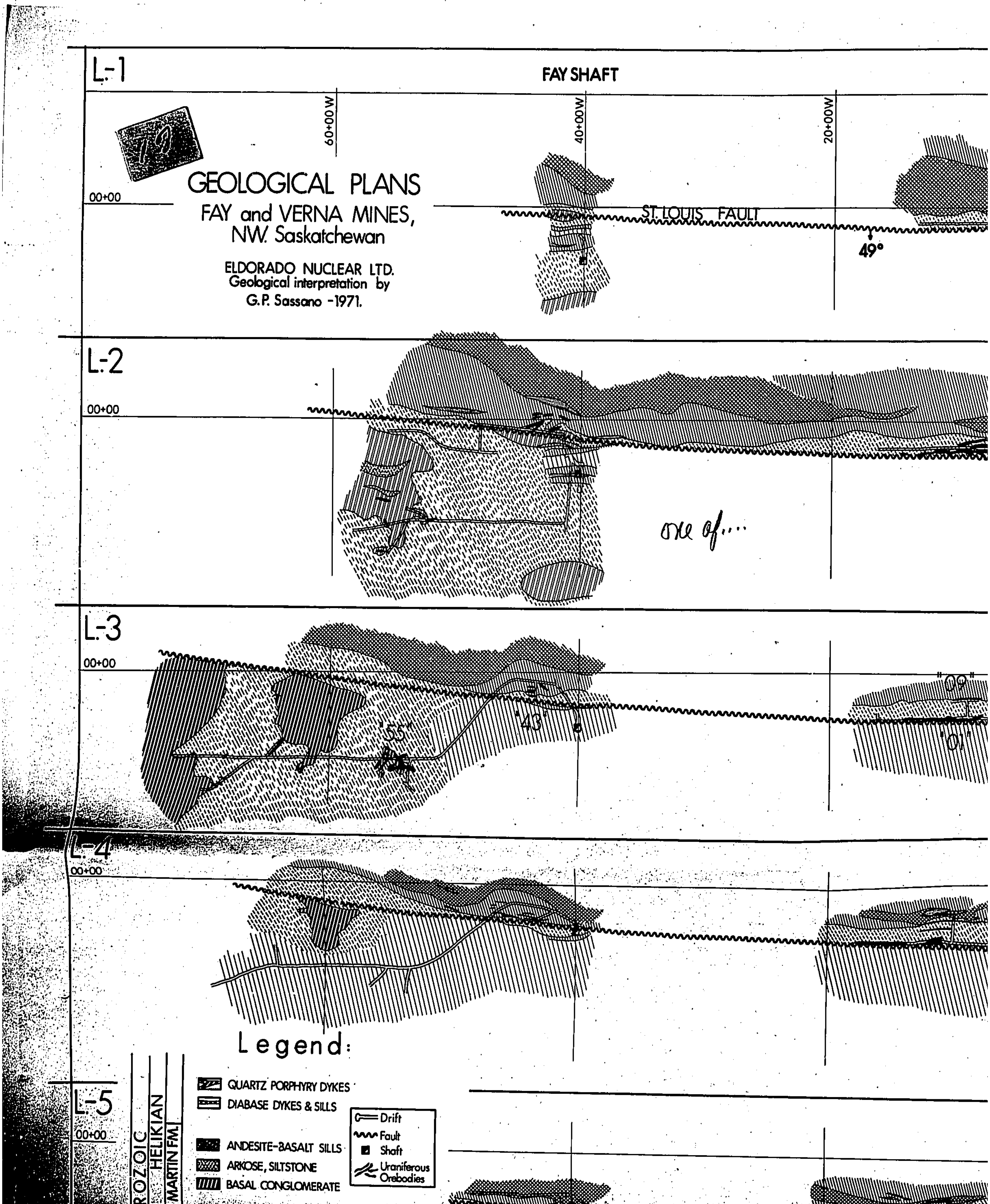
GEOLOGICAL CROSS-SECTION

48+00 E

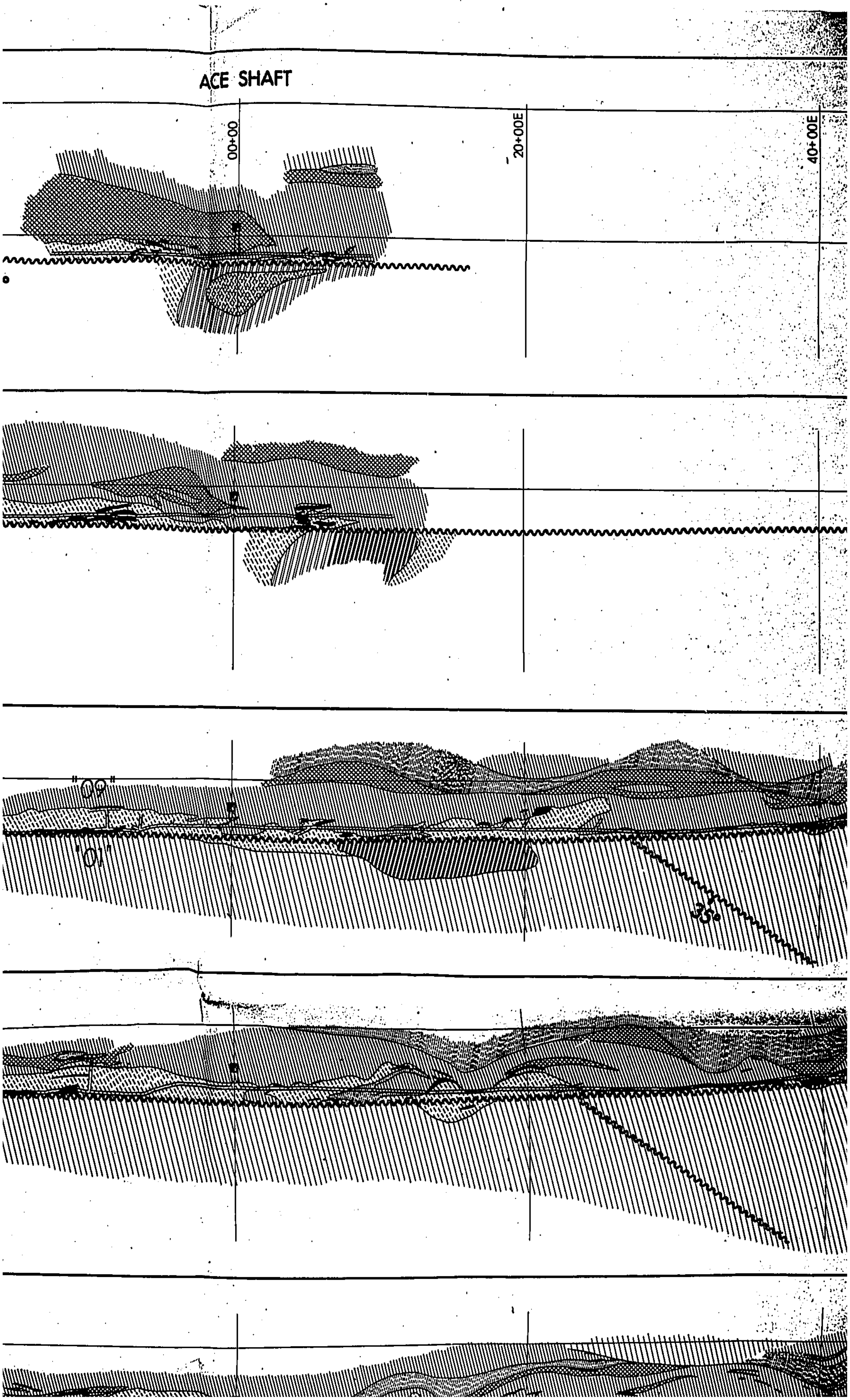
ELDORADO NUCLEAR LTD.

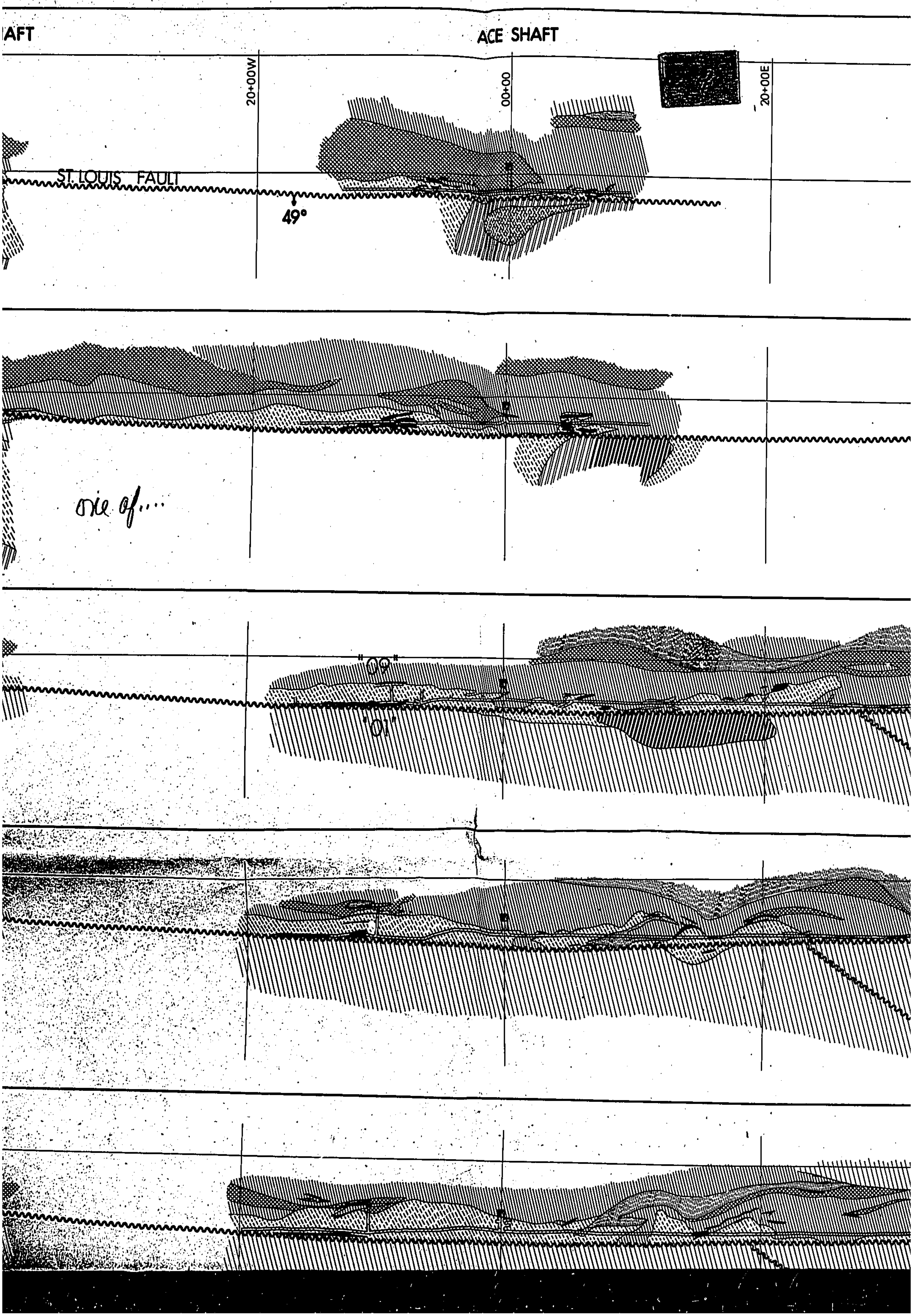
Geological interpretation by

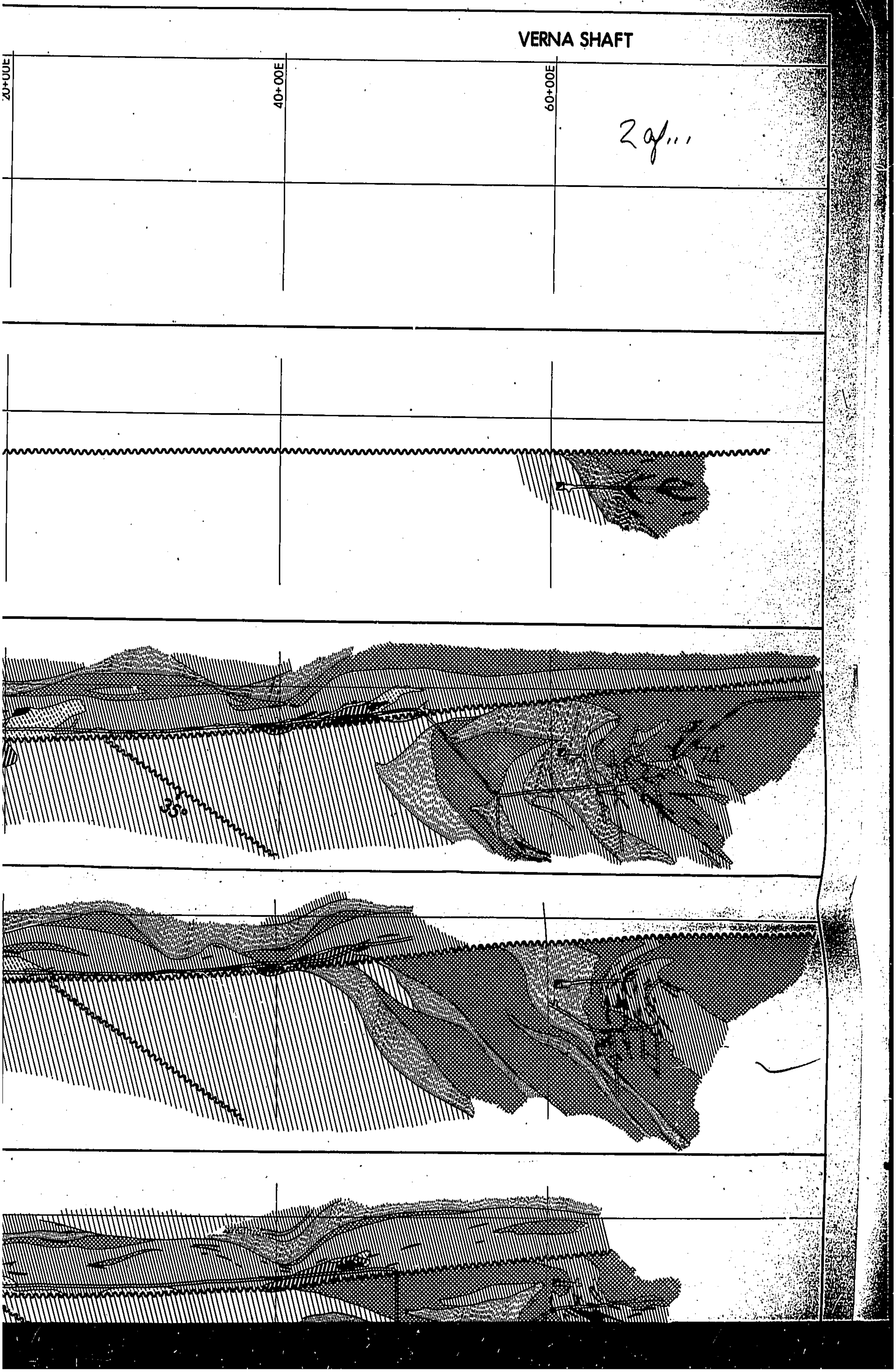
G.P. SASSANO - 1971

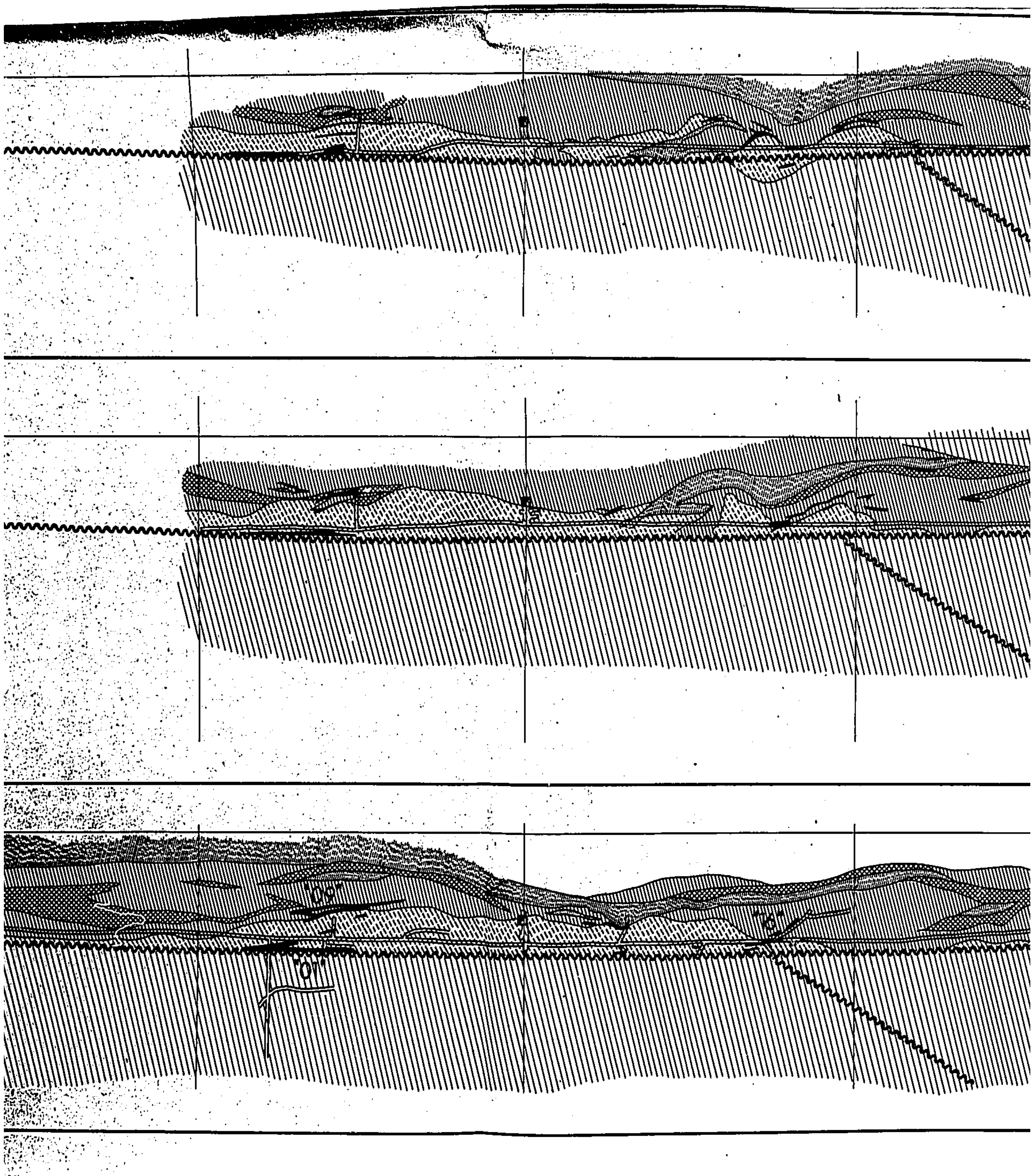


L-1
FAY SHAFT
60+00W
40+00W
20+00W
00+00
GEOLOGICAL PLANS
FAY and VERNA MINES,
NW. Saskatchewan
ELDORADO NUCLEAR LTD.
Geological interpretation by
G.P. Sassano -1971.
ST. LOUIS FAULT
49°
L-2
00+00
one of....
L-3
00+00
55°
43°
"09"
"01"
L-4
00+00
Legend:
L-5
00+00
ROZOIC
HELIKIAN
MARTIN FM.
QUARTZ PORPHYRY DYKES
DIABASE DYKES & SILLS
ANDESITE-BASALT SILLS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
Drift
Fault
Shaft
Uraniferous Orebodies

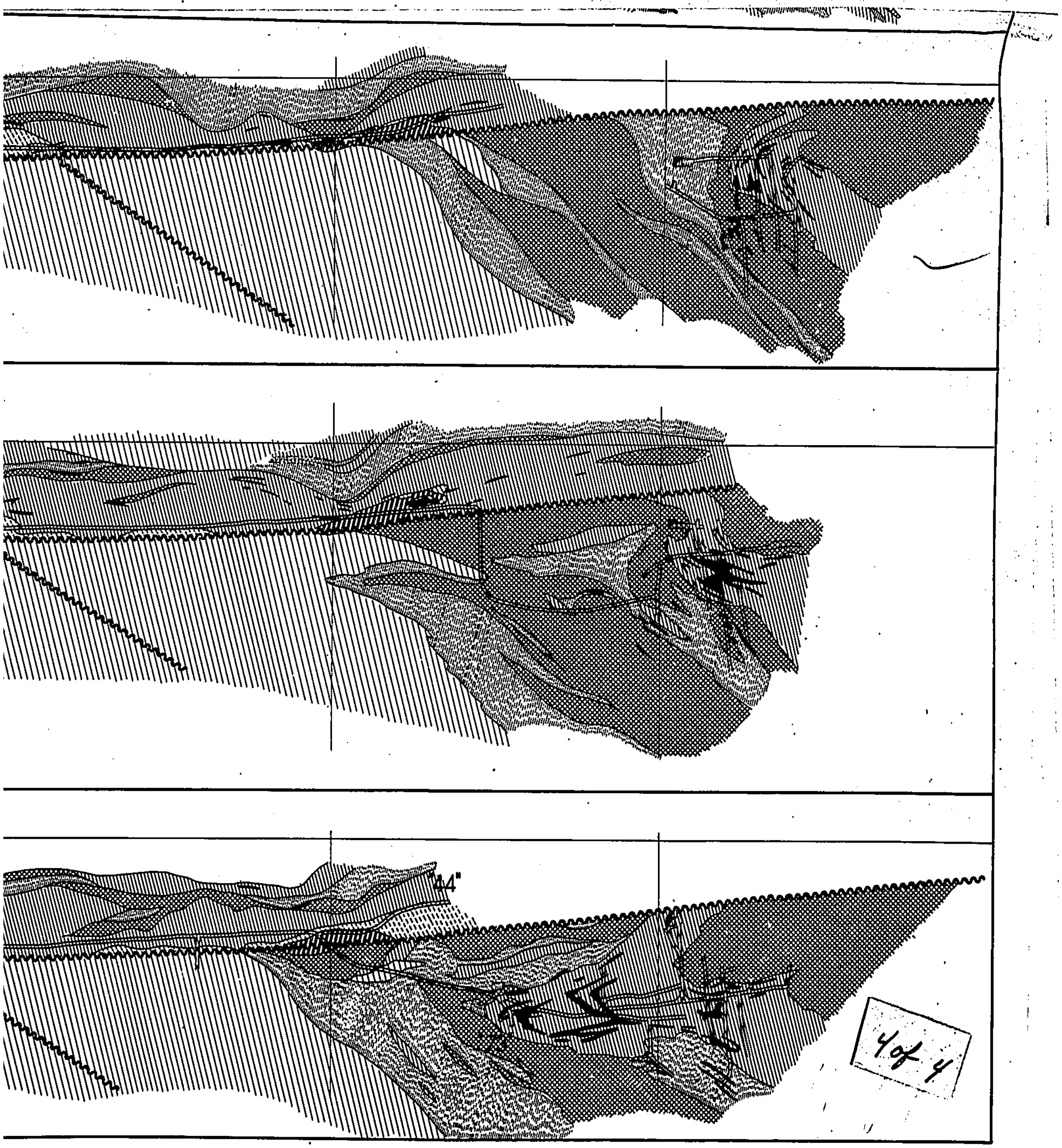

ACE SHAFT
00+00
20+00E
40+00E
"09"
"01"
35°

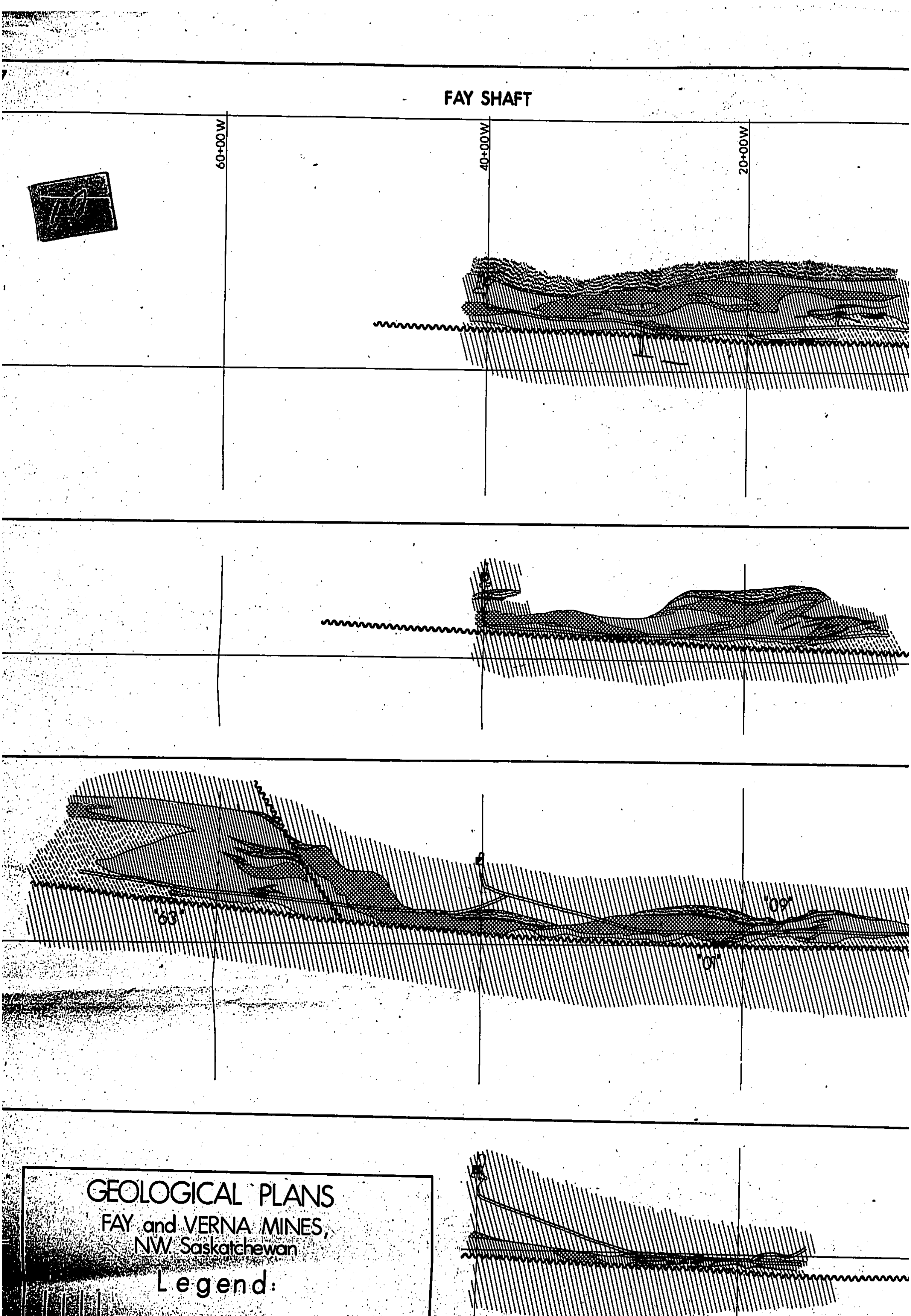

AFT
ACE SHAFT
[redacted]
20+00W
00+00
20+00E
ST. LOUIS FAULT
49°
one of....
"09"
"01"

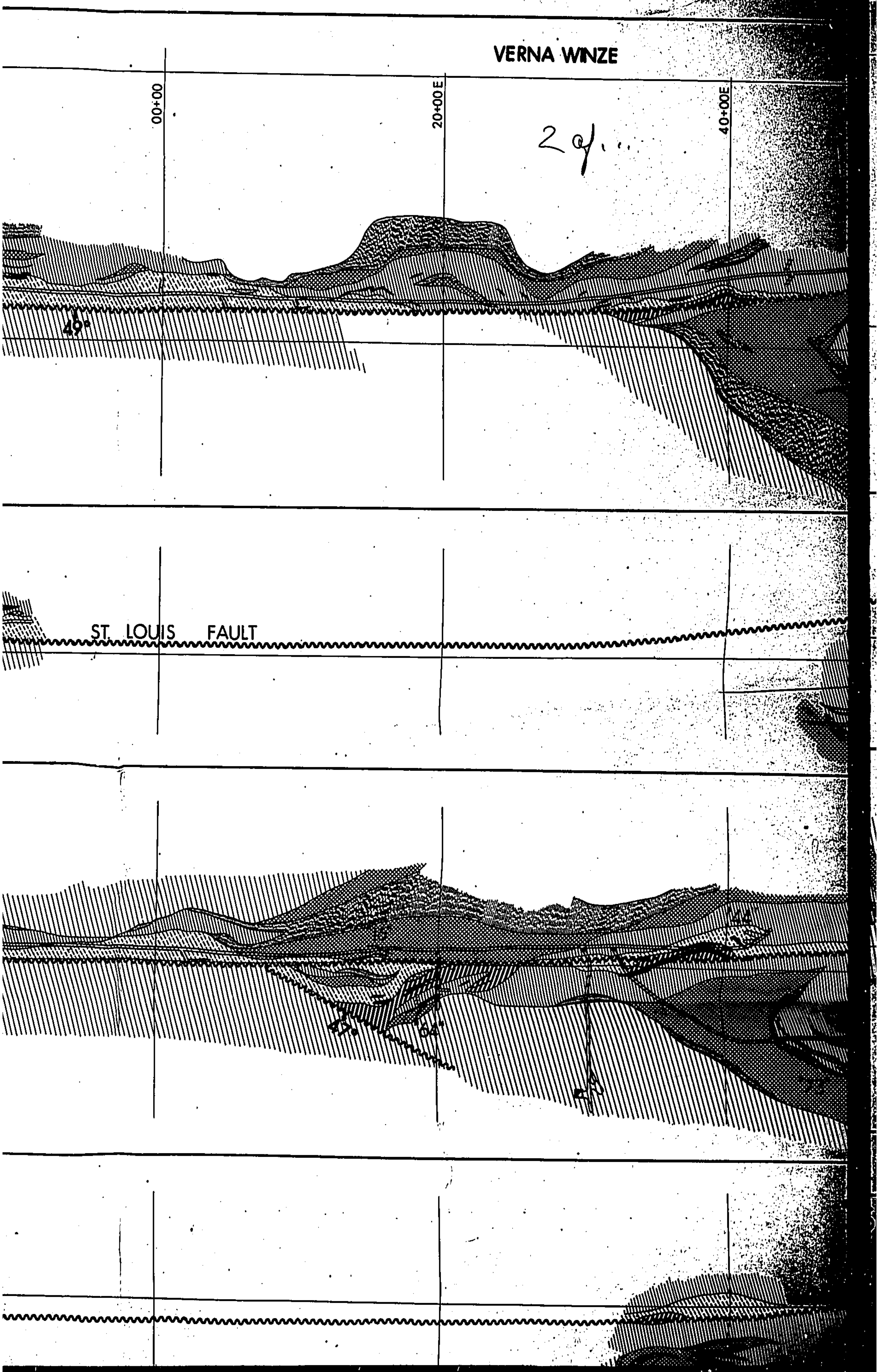

VERNA SHAFT
20+00E
40+00E
60+00E
2 of...
35°

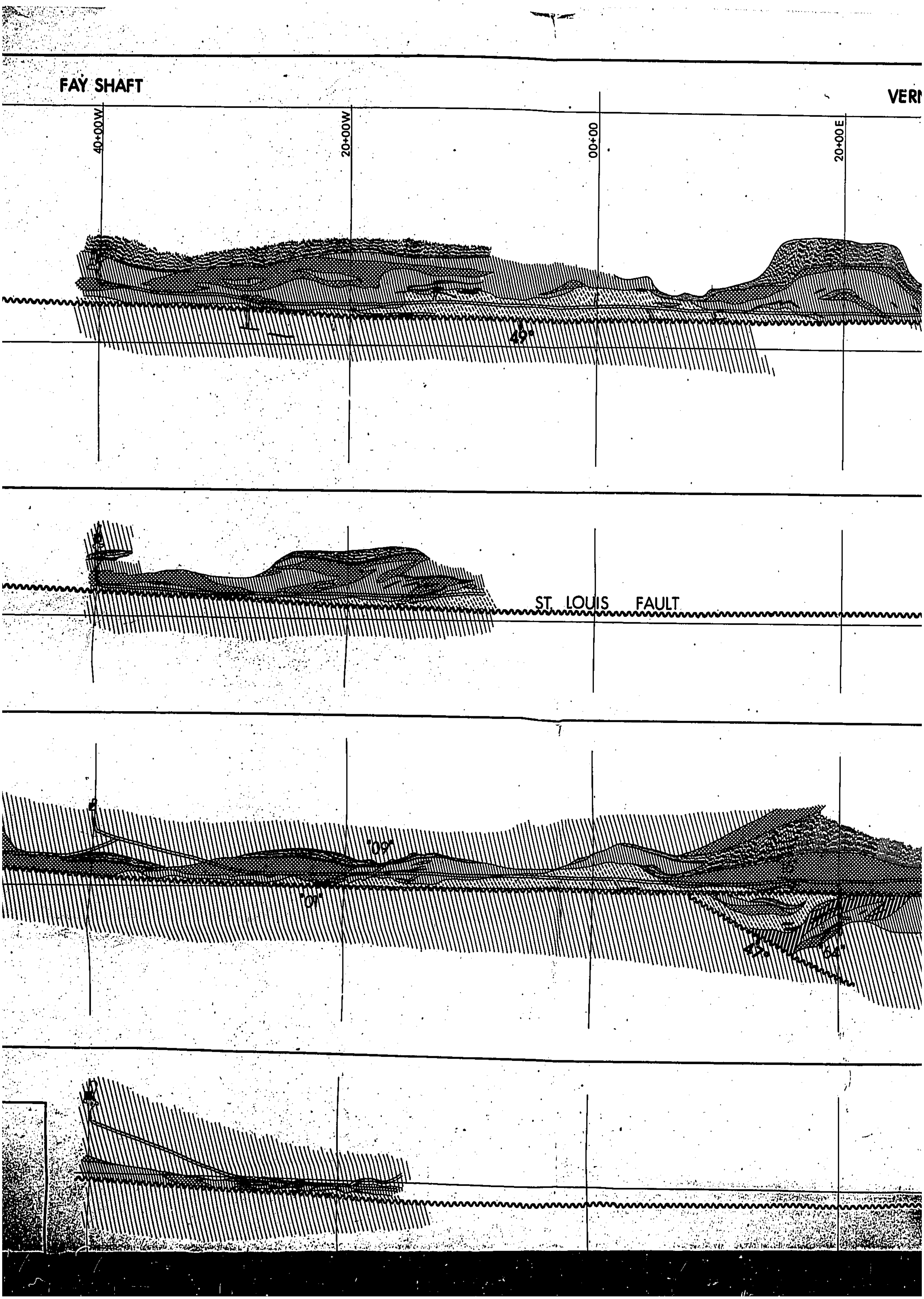


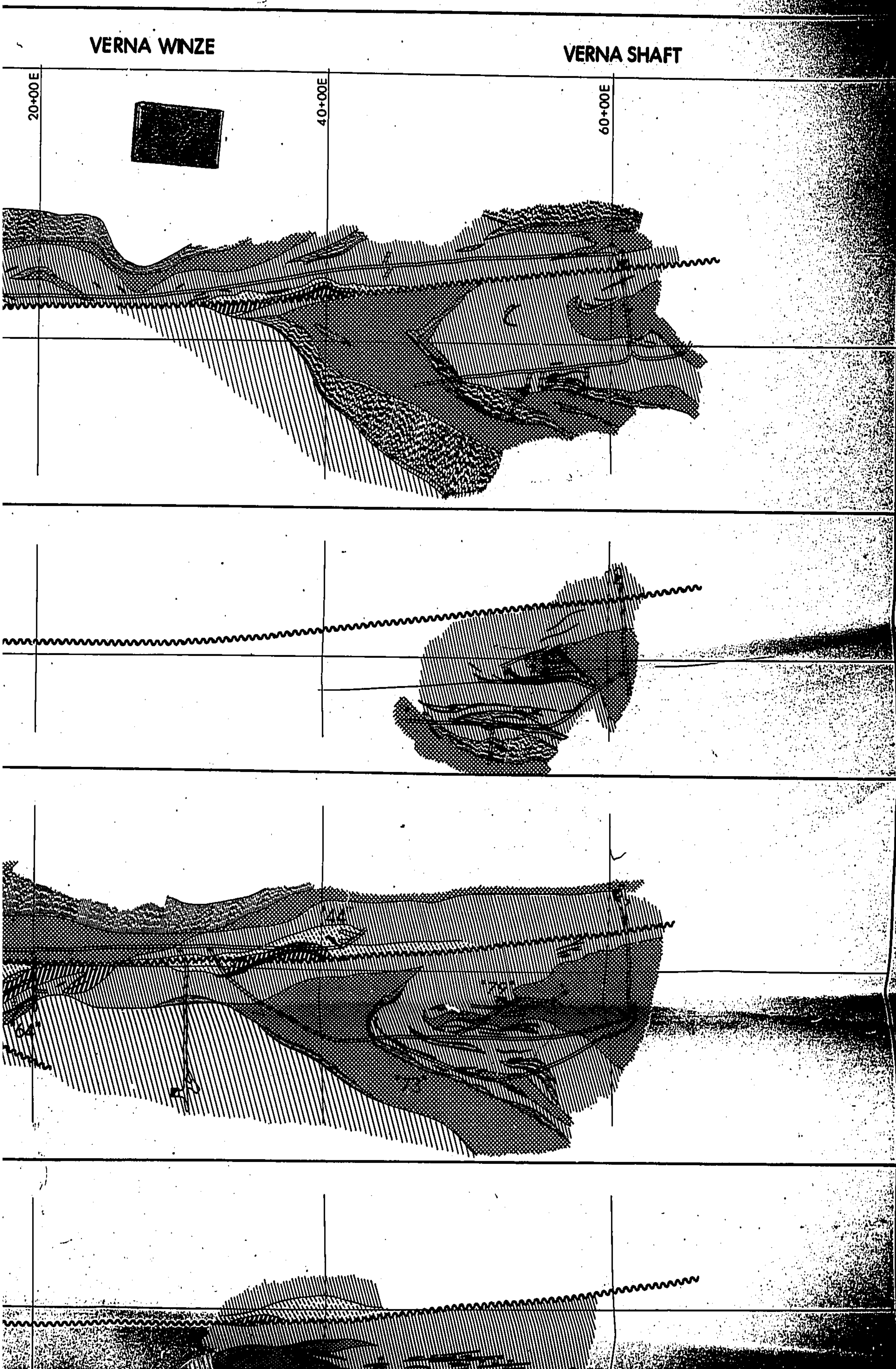
"09"
"01"

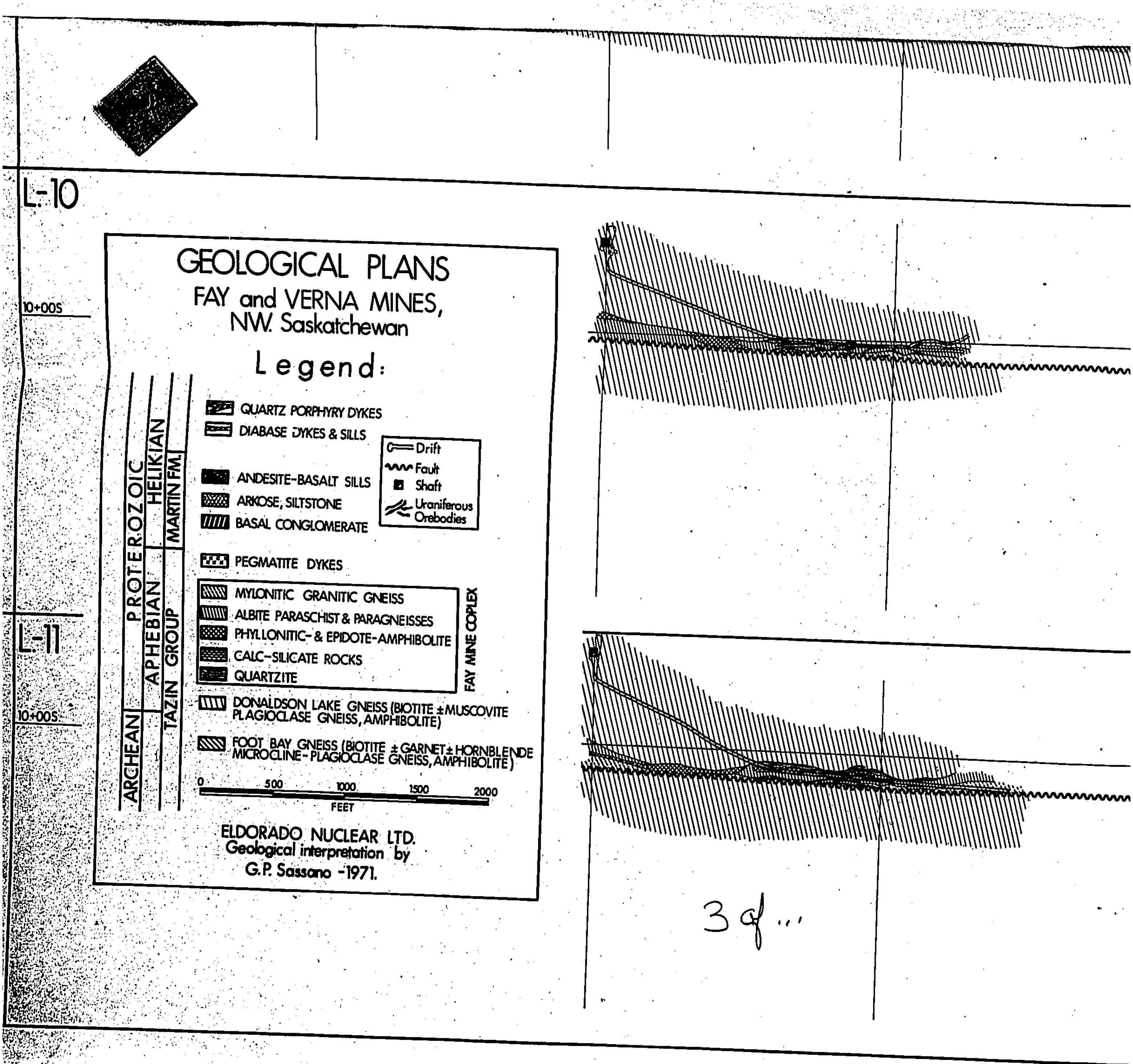

44"
4 of 4

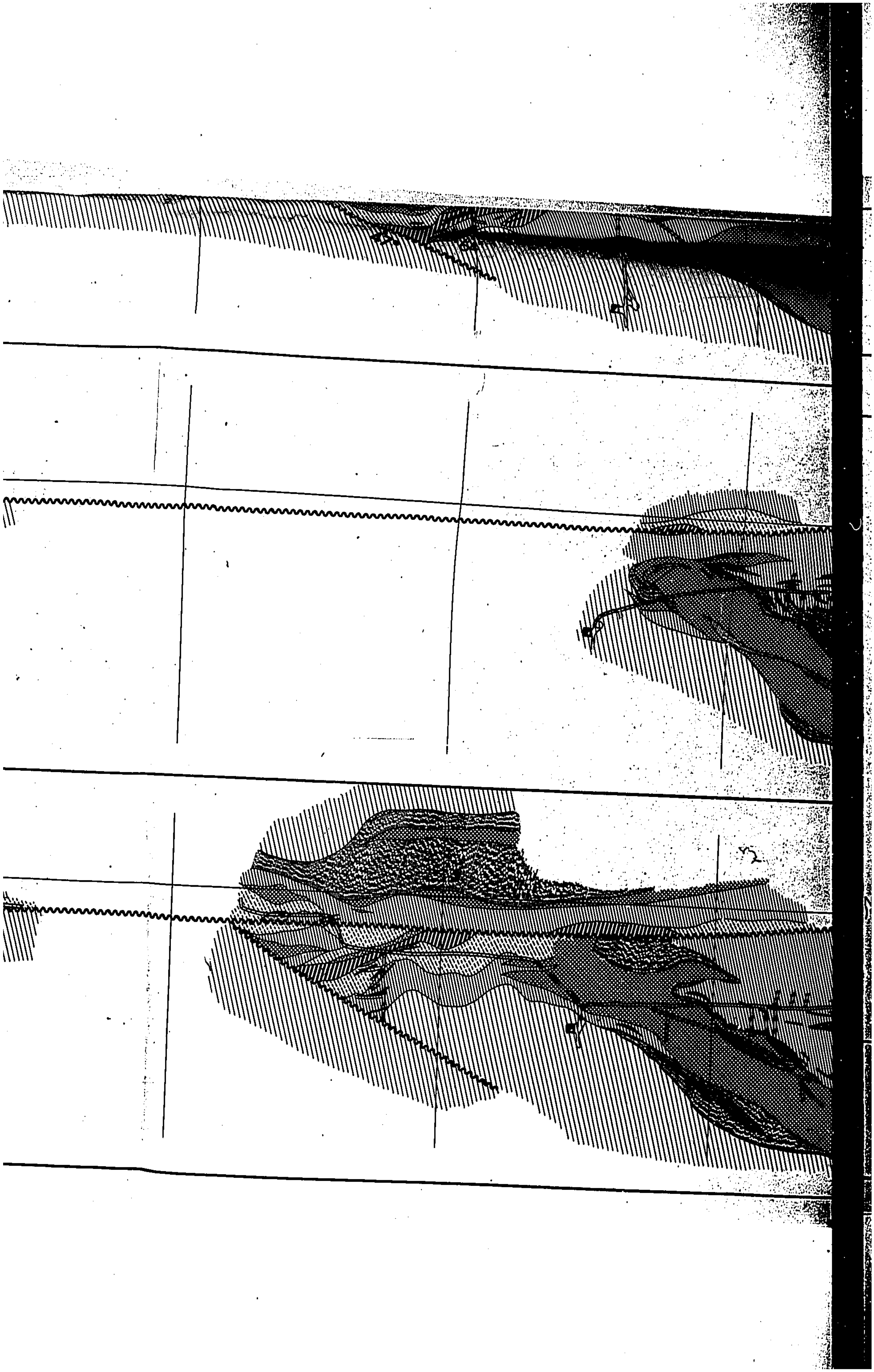

FAY SHAFT
60+00W
40+00W
20+00W
"63"
"09"
"01"
GEOLOGICAL PLANS
FAY and VERNA MINES,
N.W. Saskatchewan
Legend:

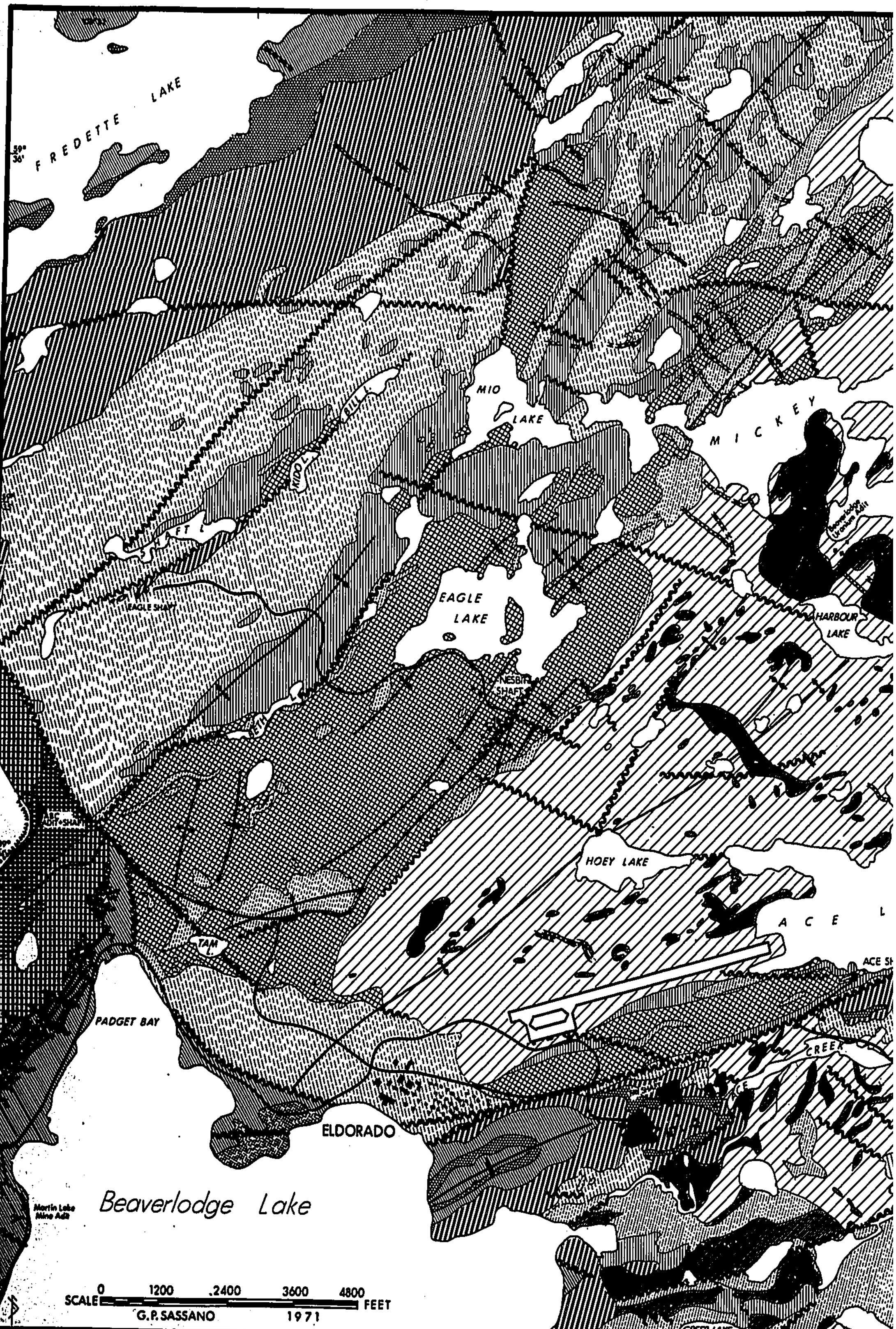

VERNA WINZE
00+00
20+00 E
40+00E
49°
ST. LOUIS FAULT
47°
64°


FAY SHAFT
VERN
40+00W
20+00W
00+00
20+00 E
49°
ST. LOUIS FAULT
"09"
"07"
47°
64°


VERNA WINZE
VERNA SHAFT
20+00E
40+00E
60+00E

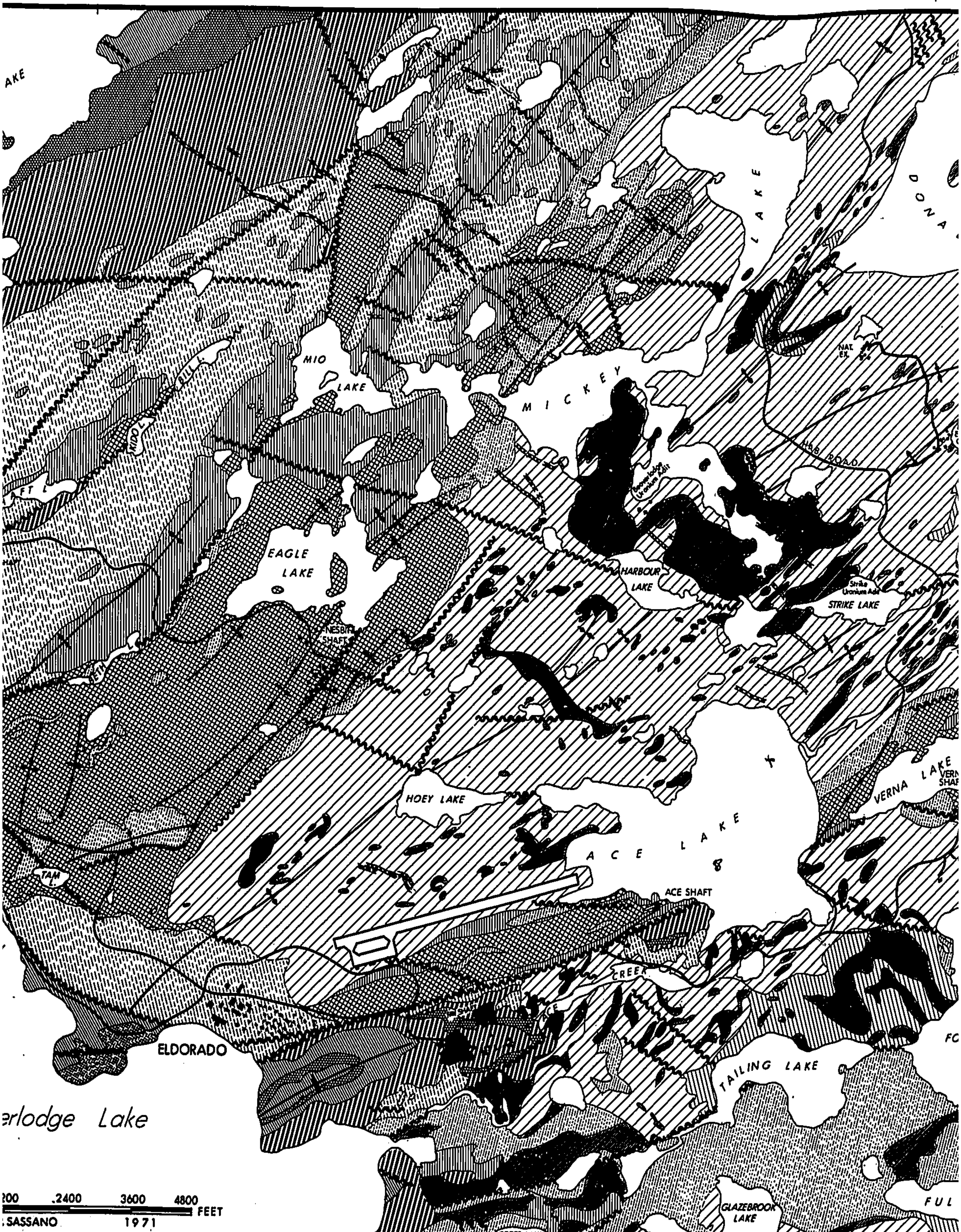

L-10
L-11
10+00S
10+00S
GEOLOGICAL PLANS
FAY and VERNA MINES,
NW. Saskatchewan
Legend:
QUARTZ PORPHYRY DYKES
DIABASE DYKES & SILLS
ANDESITE-BASALT SILLS
ARKOSE, SILTSTONE
BASAL CONGLOMERATE
PEGMATITE DYKES
MYLONITIC GRANITIC GNEISS
ALBITE PARASCHIST & PARAGNEISSES
PHYLLONITIC- & EPIDOTE-AMPHIBOLITE
CALC-SILICATE ROCKS
QUARTZITE
FAY MINE COPLEX
DONALDSON LAKE GNEISS (BIOTITE ±MUSCOVITE PLAGIOCLASE GNEISS, AMPHIBOLITE)
FOOT BAY GNEISS (BIOTITE ± GARNET ± HORNBLENDE MICROCLINE-PLAGIOCLASE GNEISS, AMPHIBOLITE)
PROTEROZOIC
HELIKIAN
MARTIN FM.
APHEBIAN
TAZIN GROUP
ARCHEAN
Drift
Fault
Shaft
Uraniferous Orebodies
0
500
1000
1500
2000
FEET
ELDORADO NUCLEAR LTD.
Geological interpretation by
G.P. Sassano -1971.
3 of...





FREDETTE LAKE
MIO LAKE
MICKEY
EAGLE LAKE
EAGLE SHAFT
NESBITT SHAFT
HARBOUR LAKE
HOEY LAKE
ACE
TAM L.
PADGET BAY
ELDORADO
Beaverlodge Lake
Martin Lake Mine Adit
GREER LAKE
SCALE 0 1200 2400 3600 4800 FEET
G.P. SASSANO 1971


DONALDSON LAKE
LAKE
NAT. EX.
NAT. EX. 2nd CAMP
Foot Bay
HAB ROAD
HARBOUR LAKE
Strike Uranium Adit
STRIKE LAKE
EMAR LAKE
ACE CREEK
COLLIEI
BOLGER PIT
VERNA LAKE
VERNA SHAFT
FRANCIS L.
MORAN L.
ACE LAKE
ACE SHAFT
CREEK
FOOKES LAKE
TAILING LAKE
FULTON LAKE
GLAZEBROOK LAKE


AKE
MIO LAKE
MICKEY
LAKE
EAGLE LAKE
HARBOUR LAKE
STRIKE LAKE
NESBITT SHAFT
HOEY LAKE
ACE LAKE
ACE SHAFT
VERNA LAKE
TAM L.
CREEK
ELDORADO
TAILING LAKE
erlodge Lake
GLAZEBROOK LAKE
GREER LAKE
FUL
200 2400 3600 4800 FEET
SASSANO 1971


DONALDSON LAKE
SCHMOO LAKE
Foot Bay
NAT. EX. 2nd CAMP
FLACK LAKE
EMAR LAKE
CREEK
Strike Uranium Adit
COLLIER L.
VERNA LAKE
VERNA SHAFT
BOLGER PIT
FRANCIS L.
MORAN L.
FISH LAKE
FOOKES LAKE
YAHYAH LAKE
FULTON LAKE