JOINT PATTERNS IN RELATION TO REGIONAL AND LOCAL STRUCTURE IN THE CENTRAL FOOTHILLS BELT OF THE ROCKY MOUNTAINS OF ALBERTA

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by

Ronald G. Schmidt

A.B. Columbia College 1953
M.A. Columbia University 1955

UNIVERSITY OF CINCINNATI

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I hereby recommend that the thesis prepared under my supervision by Ronald G. Schmidt

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be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

Approved by:

William F. Jenks

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ABSTRACT

A study of jointing in the rocks of the Central Foothills Belt of Alberta was undertaken in order to determine the relationships of joint patterns to regional and local structure. The writer used a different approach to the problem than that used by many previous investigators in this field. No attempt was made to relate joint directions found to fractures produced experimentally by earlier workers under controlled stress conditions. Interpretation is based solely upon demonstrable relationships between individual joint patterns and known structure.

The Central Foothills Belt is a portion of a continuous linear zone, bounded on the east by the easternmost extent of thrust faulting and on the west by the First Range of the Eastern Rocky Mountains of Canada. The area studied is the portion of this belt which lies between latitudes 52°15' and 53°15'. Here, low angle thrusts of Laramide Age, folded together with the rocks they cut, outcrop at the surface as steep to vertical reverse faults with, in some cases, total displacements of over six miles.

Data were gathered on over 9000 joint surfaces at 144 different locations within the area studied. Each location was carefully chosen for its known structural position. Variable factors of lithology, sampling selectivity and time of deformation were recognized and taken into account while data were gathered and compiled. These orientation data were plotted on nets of equal-area projection and the resulting poles were contoured according to standard practice. Joint patterns thus derived, when examined in the light of both regional and local structural settings lead the writer to conclude that:

1. A regional fracture pattern exists within this area. It is composed of two trends which are approximately perpendicular to each other and to bedding, regardless of the attitude of the beds.
2. Two subsidiary trends are present at some locations especially in rocks which have experienced more intense deformation than those which possess only the regional joint pattern. These trends do not have a regular relationship to each other or to bedding, but usually intersect nearly equal angles on either side of one of the regional trends.
3. In some cases rotation of joint trends has taken place together with rotation of the strata.
4. Later trends of both the regional and subsidiary patterns have been developed in some areas.
5. The main trends of the individual patterns developed very early in the deformational history of the area when the strata were essentially flat-lying and therefore before the principle Laramide diastrophism.
6. The specific conditions which produced the early joint trends appear to have continued sporadically through the deformational history of the rocks. While the original trends were rotated with the bedding during deformation, joint trends were produced which are similar to the original trends of those formed earlier.
7. Shale lithologies which commonly lack joints or have joints with irregular or curvilinear surfaces probably possessed jointing similar in trend to that of the more competent horizons. Flowage of these rocks in response to tectonic stresses built up during the Laramide

orogeny may account for the distortion or obliteration of these joint surfaces.

INTRODUCTION

History of the Project

During the summers of 1953 and 1954 the writer served as Technical Officer on a field mapping party for the Geological Survey of Canada in the Central Foothills Belt of Alberta. In 1953 structural and joint data were gathered on two prominent tear fault zones in the Central Foothills (Schmidt, 1955), in order to determine similarity or dissimilarity in the origin of the faults. Structural data, analyzed independently from the joints, indicated that movement on one fault zone was primarily transcurrent or strike slip while the other had experienced largely vertical or normal displacement. Joint trends in the direct vicinity of one of these fault zones differed from those near the other zone. In each case there is a direct relationship between certain joint directions and direction of the faults.

As conceived, the major problem was to study the nature, local variation, and relationship of fracture patterns to both regional and local structure. The writer approached this problem with the following aims:

1. The determination, through the use of objective techniques, of representative joint patterns at not less than 100 locations. Each was to be situated with known relationship to structure and based upon sufficient measurements to insure statistical validity.
2. To analyze these data empirically, rather than genetically, i.e., with the aim of interpreting joint patterns from field observations alone employing strict control of variable factors[1] <u>without</u>

1. See section on "Control" p. 24.

reference to preconceived principles of rock fracture as determined by experimental work or mathematical deduction. The writer feels that many previous observers have failed to reach conclusive results for one or more of the following reasons:

a. Insufficient or inaccurate structural data were used[1],

b. the method was applied to highly complex structure as a means of acquiring further data where conventional investigation methods proved insufficient[2],

c. the worker attempted to extrapolate genetic relationships from experimental data[3], which may not be a valid procedure. Although the latter case is an ultimate goal of every investigation of joint patterns its fulfillment must come after the basic principles of rock fracture have been established in the field.

In the present study it was hoped that the establishment of relationships of joints to structure through empirical methods in relatively simple and well investigated areas would eventually lead to the determination of the fundamental relationships which govern the formation of joints and joint patterns on a regional scale. Knowledge of these relationships might then allow joint techniques to become an important tool in the solution of structure and tectonic history in more complex or uninvestigated areas.

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1. Wilson, 1934; Melton, 1931.
2. Wilson, 1934
3. Bucher, 1920; Kupsch, 1955.

Location of the Area

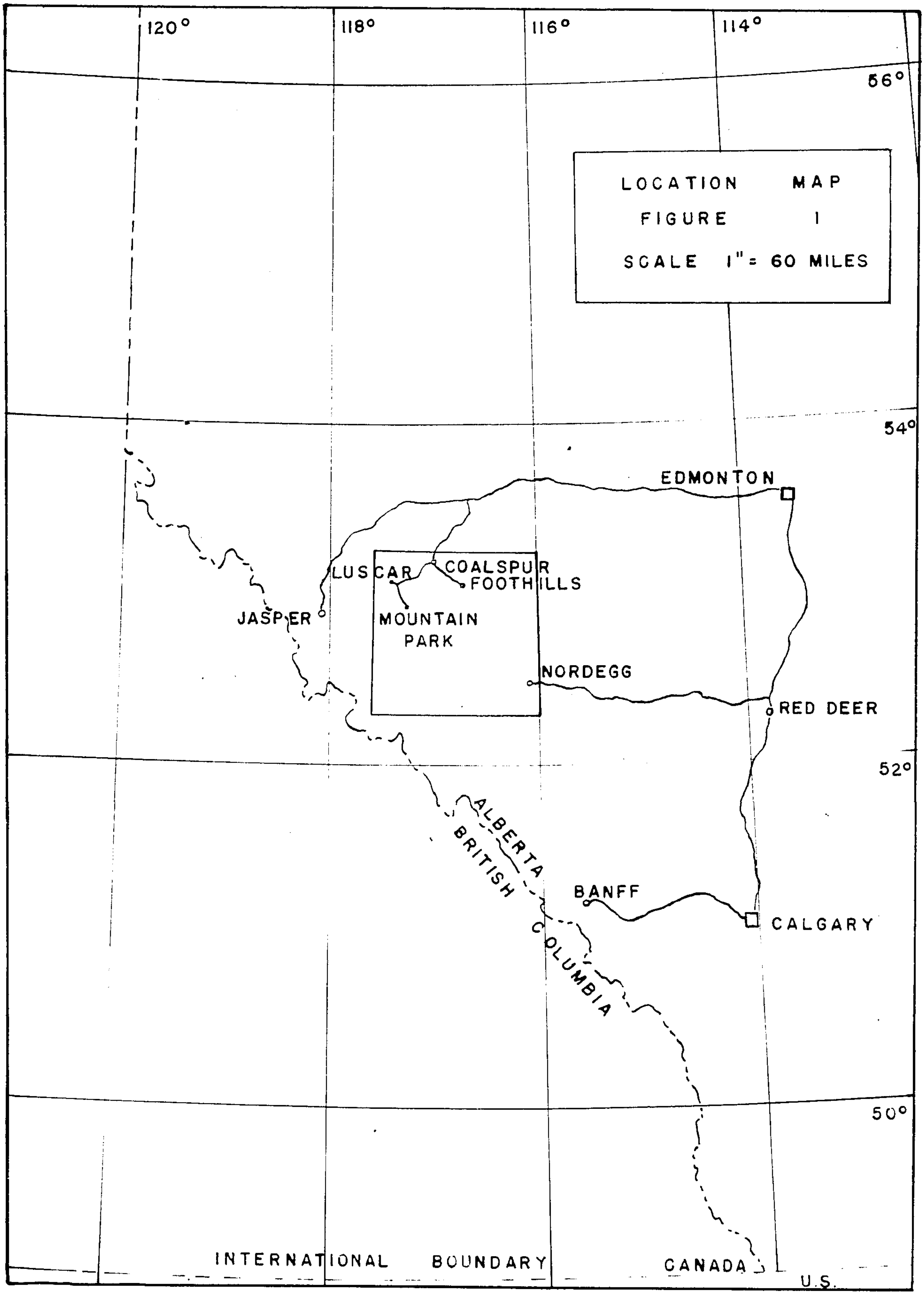
The area investigated covers approximately 2400 square miles. It extends in a north-northwesterly direction along the structural trend from Latitude 52°15', Longitude 116°00' to Latitude 53°15', Longitude 117°30' and covers the major portion of twelve 15 minute map areas (see maps, Figures 1 and 2).

It is the major portion of what has been termed the Foothills Belt of Central Alberta (McKay 1943), and is bounded on the east by the easternmost limit of thrust faulting and on the west by the ramparts of the Front Range of the Rocky Mountains. Northwest and southeast, well beyond the confines of the area, the Central Foothill ranges gradually diminish to be replaced by other ranges in the Southern and Northern Foothills. Within the area three foothill ranges, the Brazeau, Bighorn, and Nikanassin rise to elevations of nearly 9,000 feet, but the majority of the land surface is composed of gently rolling ridge and valley topography with about 1500 feet maximum relief.

Access to the area is provided on the north and south by Forestry Service roads, but the greatest portion had to be investigated by horseback and on foot.

Acknowledgements

The writer is greatly indebted to Dr. R.J.W. Douglas, whose unpublished manuscript maps have been used freely, and for his enthusiastic encouragement and guidance in the field; to field assistants Don Rose, Ralph Thrall, Ray Burke, Jack Arthur, Robin Dawson and Julian Hawryszko; and to Dr. W.F. Jenks for advice on the preparation of this report. The writer also wishes to thank Messrs. John Pope and John Tappe and Mrs.


120°
118°
116°
114°
56°
54°
52°
50°
LOCATION MAP
FIGURE 1
SCALE 1" = 60 MILES
EDMONTON
LUSCAR
COALSPUR
FOOTHILLS
JASPER
MOUNTAIN PARK
NORDEGG
RED DEER
ALBERTA
BRITISH COLUMBIA
BANFF
CALGARY
INTERNATIONAL BOUNDARY
CANADA
U.S.

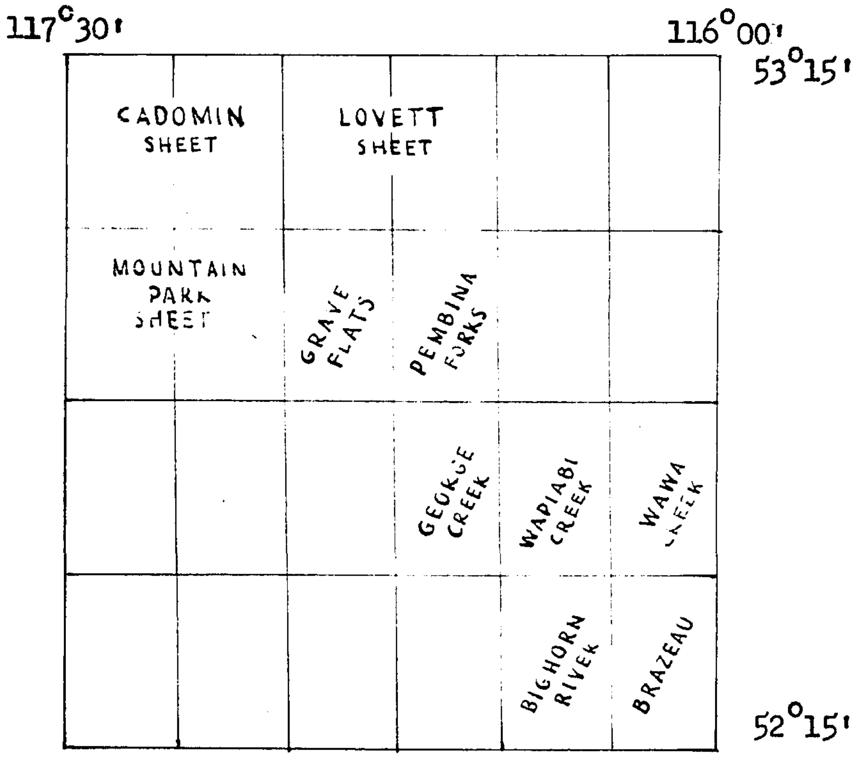


FIGURE 2

MAP AREAS WITHIN THE AREA OF INVESTIGATION

Elizabeth Dalve for their technical advice and assistance in preparation of illustrations, and my wife for her helping hand and moral support.

HISTORY OF THE STUDY OF ROCK FRACTURE

The study of rock fractures precedes the oft-quoted works of Daubree. Bakewell (1833) discussed "seams" in his published lectures given at Yale. Hopkins (1835) was the first man to attribute the "regularity of joints in rocks to the mechanical action of an elevating force", thus linking rock fracture to deformation on a regional scale. Most early workers viewed joints as "tensional" phenomena which came about through contraction either by the loss of water, or by cooling. A series of articles appearing in the American Journal of Science from 1882 to 1884 well illustrates the differing opinions of the day with respect to the origin of joints. Le Conte (1882) and Kinahan (1882) presented the view that joints result from contraction due to drying and Gilbert (1882a,b; 1884) felt that, since the joints which he had observed fell into a rectangular pattern rather than a polygonal one, there must be an explanation other than shrinkage.

The monumental work of Daubree in 1878 and later, was the foundation upon which virtually all subsequent fracture investigations have been based. He was the first to integrate experimental work with field observations of joints or "diaclases" as he called them, and to recognize the potentialities of experimentation in this field as a possible key to natural processes. Because his experiments and observations have been treated in some detail by many writers, they will not be described here.

In the period 1883 to 1893, W.O. Crosby published a series of articles in which he advanced the theory of rock fracture in response to the suddenly applied stress of earthquake waves. A growing quantity of unrelated joint observation (Shaler 1887,88,89, Buckley, 1898, and

Cushing, 1901) formed a framework for the work of Hobbs (1901, 1904, 1905, 1911) who repeatedly called attention to the regularity and systematics of rock fractures and their apparent relations to other structures. He recognized and expressed well the empirical relationships he observed:

> "... in regions which since their formation have been little disturbed, the joint planes stand near the vertical, and in their network two dominating series are generally found to be approximately normal to each other." (Hobbs, 1904)

Hobbs had little to say about detailed relationships, and preferred to discuss joints in terms of the broader structural features of the earth's crust.

> "The significant fact is that wherever a relatively simple and orderly system has been discovered, the dominant structural and relief directions represent one or more of the elements within the quadruple set [of joints] which has been above described." (Hobbs, 1911)

Although Hobbs' work suffers a great deal from sweeping and often misinformed generalizations and a lack of adequate specific information, the impact of his work was felt through the stimulus which it provided for other workers to investigate the origins of rock fracture. (Harder, 1906; Sheldon, 1912).

In 1920 W.H. Bucher published his critical work on "The Mechanical Interpretation of Joints". Using more modern analytical technique (stereographic projection) he was able to demonstrate in several instances the applicability of joint pattern analysis to structural interpretation. Like the work of Hobbs, that of Bucher gave a new impetus to fracture research. (Swanson, 1927; Bucher, 1928; Lovering, 1928). In 1929 Melton published the first of a series of articles on regional fracture patterns of the Ouachita Mountains and the Interior Plains of Oklahoma. Melton's work represents the first effort to use detailed joint observations in regional tectonic interpretation. Although based on much more factual data than Hobbs' work, Melton still maintained an approach of broad generalization. In a later abstract (1931) to a paper which was apparently never published, he drew regional patterns in the southwestern United States from the Mississippi River to New Mexico, based on scattered local patterns. At this same time , Wager (1931) published his work on "Jointing in the Great Scar Limestone of Craven", England, in which he related the jointing to the tectonics of the area. In 1933 what was perhaps the first aerial-photo study of fractures was published by Barton on an area in southern Texas. Studies of joint patterns and their particular relations to igneous intrusion and ore emplacement were made in 1934 by Johnston and Cloos and in 1935 by Cloos.

Wilson's study in 1934 of jointing in the Five Springs Creek Area, Wyoming brought to light some new techniques for the use of data on joints in deciphering the tectonic history of an area in which igneous intrusions are important features. Unfortunately the presentation of his material is not entirely clear. Since his conclusions are, to say the least, somewhat hypothetical[1], the strength of the work suffers. Nevertheless, it serves as a valuable springboard for speculation.

In 1942 Parker published his work "Regional Systematic Jointing in Slightly Deformed Sedimentary Rocks", a study which was perhaps the most important analysis until that date. The joints he studied are in

1. Wilson, p. 518.

essentially flat-lying strata in New York and Pennsylvania so that he was able to show joint patterns quite clearly by plotting the strike of individual joints on a rosette diagram. This procedure not only lent itself to simpler mechanical and statistical treatment of data, but also allows a clearer visual understanding on the part of the reader. By closely linking his joint data with both regional and local structure, Parker was able to show a distinct correlation. At about the same time Ver Steeg (1942) undertook the compilation of joint data in Ohio from various sources. He, like Parker, found that there is a close correlation between structural trends and the direction of joint planes. Although the work lacks statistical validity the generalizations drawn are believed to be significant in the light of Parker's study.

From 1946 to the present a wealth of information on joints has appeared in the literature. Although only a few studies have been concerned with the investigation of joint patterns alone on either a local or regional scale, many workers have tried to use the analysis of fracture patterns as a means of acquiring supplementary information. (Higgins, 1947; Gram, 1947; Harrison, 1953). In 1950, Shainen published an important analysis of the nature of en echelon tension fractures which he found to be aligned along conjugate shear directions. This study, along with others by Duschatko (1953), Gilkey (1953), and Bucher and Gilkey (1953) have done a great deal to throw light on the fundamental properties of joint patterns in their natural framework.

Laboratory or experimental study of rock fracture was concurrent with the development of techniques of study of the field relations of joints or fractures. Bucher (1920) published an excellent summary of early work (largely foreign) in this field, for the most part pertaining to flow and fracture in stressed metals. Daubree (1879, 1880) performed what were perhaps the earliest actual experiments on the strain behavior of stressed materials. Using clay blocks and crude apparatus he succeeded in demonstrating that fracture patterns analagous to those found in nature could be produced experimentally. In the United States, Case (1895) performed significant experiments involving flow and fracture of moving ice, but it wasn't until the work of Adams (Adams, 1901, 1918; and Adams and Coker, 1905) that experimentation was carried on upon specimens of indurated rock.

Listed below are a number of articles which, although by no means a comprehensive assemblage, offer significant contribution to the knowledge of experimental deformation of earth materials. Those marked with an asterisk (*) are felt to be most useful.

Karman (1911)
Wright (1920)
Becke (1924)
Withy & Aston (1925)
* Nadai (1931, 1950)
Rettger (1935)
Birch & Dow (1936)
* Hubbert (1937)
* Griggs (1940)
Goranson (1940)
Hughes & Jones (1950)
* Griggs, Turner, Mitler, Handin & Ch'ih (1951)
Parker & McDowell (1951)
* Griggs, Turner, Borg, & Sosoka (1951, 1953)
Borg & Turner (1953)
* Handin & Fairbairn (1953, 1955)
* Higgs & Handin (1954)
* Turner, Griggs, Heard (1954)
* Robertson (1955)
* Cloos (1955)

In very recent years, the application of statistical methods to joint data has become increasingly important. Chayes (1949, Lowe (1946) and more notably Pincus (1951, 1952, and 1953) have discussed this phase in great detail, but not without criticism. (Rodgers, 1952).

Previous Fracture Studies in the Central Foothills Belt

In 1950, the Geological Survey of Canada published the report of O. A. Erdman covering the Alexo and Saunders Map Areas (360 square miles). These map areas adjoin the area of the present study on the south. Together with the mapping and general geology, Erdman conducted a limited investigation of the joint patterns. He recorded data on 600 individual joint surfaces at 300 stations. He then tabulated major directions and compiled the results, together with the major structural trends, on a reduced map of the area (Fig. 3, p. 39 of his report). He concluded that:

1. "A joint system composed of two, intersecting, steeply dipping sets is present throughout the map-areas, and in places a third set is apparent. One set, referred to as 'strike joints', is parallel with the general strike of the beds; the other set, the 'dip joints' is approximately at right angles to the general strike."

2. "The strike and dip joints are generally equally persistent and regular in attitude. The quality of joints in rocks of the same formation and of similar lithology varies throughout the map-areas."

3. "The dips of strike joints appear more variable than those of the dip joints, although each set may range from steep to vertical. Strike joints appear to dip approximately normal to the dip of the associated beds. The dip of the dip joints at the crest of a fold may be nearly normal to the plunge of the fold. In other words, the data indicate that both strike and dip joints are approximately perpendicular to the bedding plane."

4. "Field evidence from a few places indicates that the joints were formed previous to the faults or during fault movements."

Purpose of Studying Joints

As stated, the writer's purpose does not differ markedly from that of other workers. Most have sought to relate joint patterns to structure. However, geologists have used a number of different approaches to the study of joints and their structural relationships. On a fundamental level, however, these may be reduced to three, which are here termed observational, experimental and mathematical. The first might be also termed an empirical approach in that conclusions are based upon only the data which appear through observation of the attitudes and relations of joint planes as they are found in the field. The second two might be grouped as the genetic approach in that they seek to employ the concepts of genesis of joint planes derived by experimental means in the laboratory or by mathematical deduction as an explanation of the patterns found in the field.[1] The validity of this procedure has never been demonstrated. It is a basic assumption which must be accepted if one is to accept the resultsof studies involving this technique. Inconclusive results[2] of such studies lead the author to believe that the fault lies not in the technique or reasoning of the worker, but in the assumption which must be made. The writer has approached the problem from the empirical point of view as did Hobbs (1904, 1911), Melton (1929) and Parker (1942), but with the purpose of applying strict control of the many variable factors.[3]

In this way, it was felt that the field relationships of joint planes and structure, once demonstrated by using carefully controlled techniques in the light of known tectonics, might be used as a tool in areas of

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1. e.g. Cloos (1955)
2. Wilson, 1934; Gilkey, 1953.
3. This latter aspect will be discussed under "Control" - Section 5

unknown structure. When and if sufficient controlled field data are available, it may be possible to relate natural fractures to those produced in the laboratory.

FIELD TECHNIQUE

Orientations of joints were taken at 144 locations. 33, 50, 67 or 100[1] individual joint surfaces were measured at each location depending on factors discussed below. In all cases determinations of strike and dip were made by Brunton compass within $\pm 1^{\circ}$ on the instrument, and probably within $\pm 2^{\circ}$ of the true orientation of the joint surface where measured. It is well known that individual joint surfaces display variability within several degrees of an average direction and the writer does not intend that the figure $\pm 2^{\circ}$ be construed as the limit of that variation, but merely as the average error found by re-measuring the same group of joint surfaces.[2] In addition to strike and dip, features of each joint surface were recorded at every location.

Once it was determined that there were sufficient joints within the area of outcrop for adequate treatment, orientations were determined for every joint in a straight line along the outcrop. Thus the writer was forced to record every joint regardless of its orientation. The foregoing procedure was followed in all instances except that of curved joints. Since strikes and dips are impossible to determine, these joints must be omitted. On the few occasions where regularly curved surfaces broke into planar joints at either or both ends, the orientations of the planar segments were recorded with the notation "goes into". These planar segments of the surfaces were plotted separately. Joints which possess a wavy or irregular surface, but which otherwise have a consistent bearing, were used, and the inconsistencies noted. In all cases, compass readings were made with the use of a note-book placed on the surface so that

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1. Convenient number-groups for contouring purposes.
2. See page 30.

readings would represent, as nearly as possible, the true orientation of the surface where measured and would not be influenced by minor surface irregularities. (See photograph No. 1).

Corrections were made for compass declination which varied within the area by adjusting the declination periodically as the work progressed from one map area to the next. As an additional precaution the declination setting on the instrument was checked daily.

In a few cases, later compilation showed the number of joints recorded at each location to be insufficient for accurate determination of the location of preferred orientations[1], but the majority were satisfactory. Early in the study 100 joints were taken, at every locality, but contouring in groups of ten[2] showed that the number might well be reduced with little loss in accuracy, thus assuring greater coverage of the area within the available time.

At least one photograph and hand specimen was taken at every location, the first for later identification of the location, the second to provide material for examination and comparison. Individual locations were accurately located and recorded on the aerial photographs being used for mapping. These locations were later transferred to copies of the completed maps. At least three bedding readings were recorded at each location and the results averaged and plotted on the equal-area nets at the same time the joints were plotted. Whenever there was wide

1. See section on Local Joint Patterns and Local Structure.
2. The writer determines the minimum sample size necessary for adequate treatment in a new area by splitting the entire sample of orientation data into smaller groups and plotting and contouring each group cumulatively. When the addition of each new group of data no longer changes the position of established highs or produces new ones, the sample number may be considered an adequate one.

deviation of bedding each reading was plotted separately.

An arbitrary system for estimating extent of joint surfaces was used in recording the magnitude of each joint. Since there is no way in which the true magnitude of a joint surface may be determined, unless it is terminated in all directions within the exposure of the outcrop, the writer used the following estimate dictated by visible joint extent.

Designation	Area
S (small)	10 square inches or less
M (medium)	10 to 64 square inches
L (large)	64 square inches to 4 square feet
VL (very large)	over 4 square feet

In addition to the notations described above, detailed notes were taken on the structural setting in the immediate vicinity of the joint location, and on pertinent features concerning each joint surface or group of surfaces, e.g. open joint 1/8", calcite-filled, slickensides (with directions), displacement, planar, irregular surface, wavy surface, curved surface, "goes into", etc.

COMPILATION

Polar coordinates of the recorded orientation of joints were plotted on an upper hemisphere of the Schmidt Equal Area Net (standard 10 cm. radius) by means of a plotting device similar to that described by Duschatko (1955). The Polar Coordinate overlay was then transferred to a grid and the polar plots were contoured on a second overlay using the method described by Billings (1954).

The collection of joint orientation data in sample groups of 33,50 67 and 100 facilitated contouring of the plotted poles for the following reason. Use of the standard 1 % counting circle is based upon a sample group (N) of 100 joints, the value assigned to each joint being 1 %. If the same 1 % counting circle is applied to a sample group of 50 joints, the resulting value for each will be 2 %. In the same manner, a value of 1 and 1/2 % for each point (N equals 67), and 3 % for each point (N equals 33) may be derived. Contours were drawn using these values, on an interval which seemed to best suit the requirements of each individual location. In cases where the polar plots showed high concentration in 1 or 2 local areas, a larger interval was used for purposes of clarity. In other cases, where dispersion was large and greater definition was necessary, smaller intervals were used. On the whole, however, it was desired to keep the interval as uniform as possible. For this reason the intervals of 3 % (N equals 33), 4 % (N equals 50), 3 % (N equals 67) and 2 % (N equals 100) were usually used. Contour diagrams reproduced in Appendix A were all drawn using these intervals (See contour key - front of Appendix A).

In order to preserve the observed relationship of joint planes to bedding, the nets were not rotated to a position in which the bedding is horizontal. It was felt that the direct relationship to structure would be obscured by such a procedure. The pattern shown at any one location may be related to other locations, merely by mentally rotating the net in accordance with the bedding plots which are shown on each contour diagram.

In addition, rotation of the nets would result in de-emphasis of 2nd and 3rd generation patterns which appear to be related to present strike and dip of the beds. Rotation of the net itself makes necessary the assumption that regional dip of the beds was negligible when the joints were formed; an unwarranted assumption. Although non-rotation of the contoured nets sacrifices some clarity and requires mental re-orientation as each net is examined, the additional information thus gained compensates for the minor inconvenience.

Relationship Between Magnitude and Direction of Joints

In order to determine the relationships between magnitude and joint direction, the writer plotted joints from nine locations on multiple overlays. "Small, "Medium" and "Large" joints were each plotted on separate sheets and were contoured individually. Locations were randomly selected one from each of the formations in which most of the joint orientation data were taken and on 3 representative structures. The results showed no correlation between magnitude and direction. In most cases the dispersion was similar to that of the completely plotted net.

Either the method of joint magnitude classification used here is inconclusive due to lack of exposure of joint-surface terminations, or if relative magnitudes recorded are valid, there is no correlation between relative magnitude of joint surfaces and their orientation in space.

CONTROL

Stratigraphy

The rocks exposed in the Central Foothills Belt range in age from Cambrian to Paleocene and consist of the following:

Age	Formation	Lithology	Thickness
Tertiary	Paskapoo	Non-marine shale and limestone	Unknown
Upper Cretaceous	Brazeau	Non-Marine shale and limestone	2000'±
	Wapiabi	Marine shale	1600-1800'
	Bighorn	Marine sandstone, conglomerate and shale	220-400'
	Blackstone	Marine shale, silt and grit	1000-1400'
		Disconformity?	
Lower Cretaceous	Mountain Park	Non-marine shale and sandstone	300-1000'
	Luscar	Non-marine shale, sandstone and coal	910-2400'
	Cadomin	Conglomerate (non-marine?)	15-30'
	Nikanassin	Shale and sandstone (non-marine)	200-1200'
Jurassic	Fernie	Marine shale, sandstone and carbonate	400-500'
		Disconformity?	
Triassic	Spray River	Marine siltstone and dolomite	0-500'
		Disconformity?	
Pennsylvanian?	Rocky Mountain	Marine sandy dolomite and chert	0-42'
Mississippian	Rundle	Marine dolomite, limestone and shale	534-1188'
	Banff	Marine limestone and shale	500-837'

Age	Formation	Lithology	Thickness
Devonian	Exshaw	Marine shale	3-26'
	Palliser	Marine limestone and dolomite	724-828'
	Alexo	Marine sandstone, dolomite	240-333'
	Fairholme	Marine dolomite, limestone, shale	1100' ±
Cambrian or later	Ghost River(?)	Marine dolomite	198-250'
Upper Cambrian	Formation C	Marine shale and dolomite	310-600'
Middle Cambrian	Formation B	Marine dolomite and limestone	270'
	Formation A	Marine limestone and shale	1200'

For more detailed stratigraphic descriptions of these rocks the reader is referred to Douglas (1956).

Joint orientation data were taken in the Paskapoo formation, Brazeau formation, Bighorn formation, Mountain Park formation, Luscar formation, Cadomin formation, Nikanassin formation and Spray River formation. For experimental purposes one location was made in the Wapiabi formation, and two in the Paleozoic rocks.

Joint investigations were confined to the more competent beds within Mesozoic formations for two reasons:

1. Since local, and perhaps regional disconformity has been recognized at the base of the Triassic strata and within the Mississippian (Rundle) it is possible that regional warping of unknown cause and extent has taken place at those times. The absence of Permian rocks and limited thickness of Pennsylvanian rocks (?) (20 to 40') lends further weight to this

possibility. It was felt that by confining the investigation to the rocks which, as far as could be determined, had only been affected by a single orogenic cycle, the resulting joint patterns would reflect a single system of stress directions. Also, provided the premise as outlined is valid, this variable factor for determining relationship between joint patterns and regional structure could be adequately controlled. In order to test the premise, two locations were established in Paleozoic rocks (Patterns BB - 1 and PGR - 1) and the resulting patterns appear to bear out the premise (see discussion p. 67).

2. Flow of incompetent rocks in response to minor deformational stress is well known[1]. Joints were not measured in rocks of this lithology since it was felt that if joints are fractures formed in response to deformational stress, then the joint surfaces present would reflect local stress conditions rather than regional ones, and hence would yield little information concerning the regional pattern. In any case it was impossible to determine joint planes in these rocks due to the curved and irregular nature of the joint surfaces. One location was made in what was felt to be a representative horizon of this type (the Wapiabi formation - see pattern WA - 1).

Rocks from each joint location were examined in the field and in the laboratory. Thin-sections were cut from a few representative specimens from three formations and compared under the petrographic microscope. Examination of both the hand specimens and the thin sections gave

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1. Lovering, 1928.

indication of very little variation in grain size, mineral composition or cement of rocks of the same formation. Where slight variation did exist, it apparently had no effect in variation of the joint pattern[1]. Of the formations in which joint orientation data were taken, the Paskapoo, Brazeau and Mountain Park were those which exhibited greatest variation and Bighorn, Cadomin, Nikanassin and Spray River, the least. In the case of the former, the overall nature of the rock through which entire joint surfaces were traced was remarkably uniform, although variation was great within a few square inches of the outcrop area. In one particular case sub-planar joints were observed to extend continuously through 30 feet or more of poorly sorted, cross-bedded, heterogeneous arkosic conglomerate with little variation in strike or dip (see photographs No. 2 and No. 3).

Conversely, outcrops with marked vertical variation in lithology tend to exhibit joint surfaces which are distinct only within each lithologic type. Discrete surfaces end at the interface of two lithologies. (see photograph No. 4). This is particularly evident in the case of interbedded sandstones and shales where the sandstones are commonly well jointed and the shales show irregular and heterogeneous joint development. In the same outcrop, successive sandstone layers generally possess essentially the same fracture pattern. The writer feels that the extreme mobility of the shales under minor stresses is responsible for this condition. They appear to adjust to space requirements of the more competent beds by flow while the more competent layers themselves yield through discrete fracture.

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1. See Conclusions, page 76

Photograph No. 5 is a view of a minor antithetic reverse fault above a larger thrust. The 6 inch sandstone layer in the upper left is displaced downward to the right along a series of parallel fractures which displace only the bed itself and do not continue into the shale. The trace of the fault is parallel to the hammer handle and is located at the point of the hammer head. Total displacement is 7'6", right side down. Photograph No. 6 is a view of the same fault from a distance of about 100 feet.

Table I is a description of lithologies in which joints were measured.

Sampling

Unless a predetermined approach is used in gathering data for a statistical study there is a tendency on the part of the observer to be selective in the gathering process. In choosing joint orientation data this factor is particularly important since certain trends are often oriented in such a position as to be more noticeable than others. If the observer has previously formed opinions concerning major or minor trends the tendency toward selectivity is even more pronounced and every effort must be made to eliminate or compensate for it if the study is to have sampling validity. For this reason, control was executed continually while data were being collected. Outcrops were selected for study on the basis of two factors: structural position, and sufficient joint surfaces to provide an adequate sample. Once these two requirements were fulfilled every joint along a straight line was measured and recorded, with the exception of curved joint surfaces, which were omitted for reasons already discussed.

TABLE I

Paskapoo formation - coarse to medium-grained, angular arkosic silicarenite with abundant rock fragments. Grain size highly variable from silt to conglomerate. Poorly cemented.

Brazeau formation - lithologically the Brazeau formation and Paskapoo formation are indistinguishable.

Bighorn formation - well bedded to massive, medium to fine-grained, silica-cemented silicarenite.

Mountain Park Formation - coarse to medium-grained, angular, arkosic, silicarenite. Locally, it varies from conglomeratic to silty.

Luscar formation - fine to medium-grained, evenly bedded, argillaceous, silicarenite and fine to coarse-grained, angular arkosic, silicarenite.

Cadomin formation - conglomerate composed of rounded pebbles of chert and quartzite up to 3 inches in diameter. It is locally sandy, but everywhere well cemented by silica.

Nikanassin formation - massive to thinly bedded, fine to medium grained silicarenites and silicasiltites. It is poorly cemented and friable.

Spray River formation - thinly bedded, finely and evenly laminated, silicasiltites and fine-grained silicarenites.

In order to test the reproducability of a series of readings at one locality (DD - III) the writer chalked numbers on each surface as measurements were made. At the end of the traverse, and without reference to the previous notes, measurements were made of the same joint surfaces working in the opposite direction. The two series of notes were compared by number and differences in both strike and dip were added and the mean variation was found to be less than $\pm 2^{o}$ for both strike and dip.

Another possible source of sampling bias was recognized but could not be adequately dealt with in many cases. Joints whose surfaces are parallel to a cliff face are often neglected due to their lack of outcrop on the face of the cliff. Where many measurements must be made along such outcrops samples reflect the absence or reduced density of joints with trends parallel to the cliff face. In an area where cliff face outcrops have a random orientation this factor has a tendency to be eliminated in the regional picture, but in the Central Foothills Belt where outcrops are often located along the water courses and hence have a tendency to be parallel to one another, the reduced frequency of certain directions is not compensated and the regional patterns will reflect this fact. However, since cliff face outcrops are seldom perfectly planar, joints parallel to the face are exposed wherever irregularities in the face occur. The writer included these with the other directions when they were encountered, but there seemed to be no way to insure definite compensation for this factor.

The Areal Density Factor

There are two important parameters which may be derived from a contoured net of joint poles. They are a measure of relative density and a measure of dispersion. Relative density may be defined as the number of poles falling within a unit counting circle (1 % of the total area of the net) divided by the total number of poles on the net. Thus:

$$\text{Relative density (D)} = \frac{\frac{n}{c}}{\frac{N}{100\,c} \times 100}$$ and is expressed in percent (%)

where: n equals number of poles
N equals total number of poles
c equals the area of the unit counting circle. (1% of the total area of the net)

Relative density then is a measure of the height of a high and, in general, it may be said that the higher the relative density the more likely is it that it represents a real[1] preferred orientation and not one which could have come about by chance alone.

In contouring polar plots, relative density intervals are used as contour intervals, e.g. the .1 - 4 % interval or the 4.1 - 8 % interval.

Of the many ways to measure dispersion, perhaps the easiest is to measure the area containing a given relative density. The smaller the area containing a given density, the more likely is the supposition that it is a unique preferred orientation. The greater the area, the more likely is the chance that it contains 2 or more highs.

For the purpose of convenience it is desired to combine these two measures into a single term which might then be used as a measure of the reliability of data being studied. For this reason the Areal Density

1. The writer uses this term to mean an actual preferred orientation rather than one which might result from chance or sampling error.

Factor (A.D.F.) is proposed and defined as the highest relative density of any apparent high on the net, divided by the area within the contour containing that density. Thus:

$$A.D.F. = \frac{D'}{A}$$ and is expressed in %/sq. in.

where D' equals highest relative density of a high in percent[1]

and A equals the area in square inches within the highest contour line containing that relative density.

Thus, a high of 20 percent covering an area of 1 sq. inch would yield an A.D.F. of 20 percent/sq. in. A high of the same relative density, covering an area of only 1/2 sq. in. would yield an A.D.F. of 40 percent/sq. in. Another with the same area but a relative density of 40 percent would yield an A.D.F. of 80 percent/sq. in.

The A.D.F. then forms a measure of the uniqueness and reality of a preferred orientation. The higher the A.D.F. the more reasonable is the assumption that it represents a single, real preferred orientation. It is apparent that the magnitude of the A.D.F. of any given high depends somewhat on the contour interval chosen. By contouring any preferred orientation using different intervals, larger or smaller areas and higher or lower densities will be derived. However, since the A.D.F. is a measure of reliability the generalization between magnitude of the A.D.F. and its uniqueness and reality is still valid. If, by using more closely spaced contours better definition of the form and height of the high is achieved, then the A.D.F. will be higher, while the use of more widely spaced contours will bring about a converse result. Since it is expressed

1. Since relative density is expressed on a contoured net in terms of an interval, D' then must be the average (or mid-point) of the highest interval,e.g.,if the highest interval is 12.1-16% then D' would be 14%.

as a ratio, an A.D.F. may be compared with those of other locations with a larger or smaller number of sample observations.

The writer hopes to analyze the A.D.F. with the aim of demonstrating the statistical validity of the factor and deriving a level of reliability for it. However, such treatment is beyond the scope of the present work and will be considered at a later date.

Tabulations of A.D.F's for preferred orientations on contour diagrams reproduced in Appendix A may be found in the Table, Appendix A, part 4.

REGIONAL STRUCTURE

Thrust faulting and, in some areas, concurrent folding are the major strain mechanisms through which regional stresses built up in the eastern portion of the Cordilleran Geosyncline were relieved in late Cretaceous and early Tertiary times.

The Central Foothills Belt is a portion of a continuous linear zone bounded on the east by the easternmost extent of thrust faulting and on the west by the high ramparts of the First Range of the Eastern Rocky Mountains of Canada. This zone extends from north central Montana northwesterly to beyond the 54th parallel, a distance of over 500 miles. Within the confines of this Foothills Belt, low angle thrusts, folded together with the rocks they cut, outcrop at the surface as steep to vertical reverse faults with, in some cases, total displacements of over 6 miles (Hake, Willis and Addison 1942). Stratigraphic, depositional and structural evidence together place the time of the orogeny which produced these features as post-Paleocene and probably Eocene. It is thus a phase of the widespread Laramide orogeny.

For the following discussion the reader is referred to Regional Map A, Appendix B (in pocket).

The Central Foothills Belt is approximately 20 miles wide and consists of seven linear, northwest trending, parallel elements listed below.

1. The outlying easternmost portion characterized by shallow, low-angle, widely separated thrust faults. This zone is highly deformed on the west where it is over ridden by the next element (2).

2. A complex narrow zone of thrust faults and folded faults which passes into the thrust-faulted anticline of the Brazeau Range to the south. (Brazeau Thrust Zone).

3. The easternmost of three broader synclines which preserve rocks of Uppermost Cretaceous Age.

4. A second, westerly, narrow zone of folded thrust faults which is here termed the Intermediate Folded Fault Zone.

5. A second, central syncline, this one narrower than the first, called the Black Mountain Syncline by Douglas (1956).

6. A zone of thrusting, exposing Lower Paleozoic rocks along the front of the Bighorn Range on the south and the Nikanassin Range on the north. (Bighorn Thrust Zone).

7. The westernmost of three synclines, overridden and overturned on the west by deep-seated thrust faults which bring Lowermost Paleozoic rocks to the surface along the front of the First Range of the Rocky Mountains.

Fundamentally, these elements may be resolved into two major thrust zones termed the Brazeau and Bighorn Thrust Sheets (Douglas, 1956) and a more complex, but shallower zone between.

To the south, along the front of the Brazeau Range, the Brazeau Thrust outcrops in a series of imbricate thrust faults which dip rather steeply. This imbricate zone involved rocks of Lower Mesozoic and Upper Paleozoic Age. The trace of the sole of the Brazeau Thrust lies to the east of this zone and brings Wapiabi and Brazeau rocks in contact with the Paskapoo formation. The northwest extension of this zone has undergone extensive contemporaneous faulting and folding and the resulting structure is that of a synclinally folded thrust zone lying beneath a synclinal structure in beds of the Alberta Group. This structure has been described in great detail by Hake, Willis and Addison (1942).

The Paleozoic rocks exposed in the Brazeau Range are folded into a doubly plunging anticline, the eastern flank of which is overturned and faulted at the base by the imbricate zone of the Brazeau Thrust as described above. The western flank dips more gently to the west and the Paleozoic strata disappear beneath the overlying Mesozoic rocks within about two miles of the crest of the fold.

Southwest of the first folded fault zone and the Brazeau Range, the Brazeau Thrust lies beneath Brazeau and older strata in an elongate synclinal structure which varies in width from two to six miles. Immediately west of this zone and in what is the Central part of the Brazeau Thrust Sheet, Luscar, Mountain Park and Blackstone formations are repeated in a series of steeply southwest dipping imbricate thrusts (zone 4). Thrusts within this zone, although not folded for the major length of their outcrop, are locally folded in the Wapiabi Creek map area (Douglas 1956) and in the Alexo Map Area (Erdman 1950).

The westernmost portion of the Brazeau Thrust Sheet is folded into an asymmetrical syncline in Upper Cretaceous rocks (zone 5) termed the Black Mountain Syncline. (Douglas, 1956). Its western flank is overturned, faulted and overridden by the Bighorn Thrust Sheet. To the north this syncline nas been crumpled and folded to compensate for increasing displacement on the thrust fault which brings to the surface Paleozoic rocks along the front of the Nikanassin Range. Here the faulted, asymmetrical anticlinal structure of the Nikanassin Range plunges south beneath the northern end of the Black Mountain Syncline. North of here, the structural position of the Syncline is occupied by the thrust block of the Nikanassin Range. Structurally equivalent to the Black Mountain Syncline a new syncline in Mesozoic rocks is developed in front of the Nikanassin range.

In the southern part of the area, the Black Mountain Syncline is overridden on the west by the front of the Bighorn Thrust Sheet, bringing to the surface west-dipping Lower Paleozoic rocks of the Bighorn Mountains. Along this zone (zone 6) displacement gradually decreases to the north until the Bighorn Thrust itself dies in the Blackstone formation on the southwest flank of the Nikanassin Range. Just north of the North Saskatchewan River, displacement on the Bighorn Thrust Sheet changes abruptly where a series of tear faults extend from the base of the thrust sheet at the Bighorn Range southwesterly to the base of the overriding First Range Thrust Sheet. These tears displace rocks of Paleozoic through Upper Cretaceous age and have a length of over 10 miles. South of this zone, Paleozoic rocks are not exposed along the front of the Bighorn thrust sheet within the area shown on the map.

Behind the Bighorn and Nikanassin Ranges, a third synclinal belt is evident (zone 7). It is longitudinally continuous from the southern boundary of the area to its northern terminus behind the Nikanassin Range, and is composed of gently westward dipping Mesozoic strata which have been strongly faulted and overturned along the western flank. The resulting structure is that of an asymmetrical syncline with a gently southwest dipping east flank and a west flank which is vertical to overturned. At its northern terminus it is cut off by anastomosing of the First Range and the Nikanassin Range. It plunges south from this point and attains a maximum width of four miles in its central portion. Further toward the south, immediately north of the North Saskatchewan River, it exhibits a sharp decrease in width and elevation along the tear-fault zone.

From a study of the maps and observation in the field it seems clear that the major thrust sheets within this area lie at a rather shallow depth. The frequent occurrence of local thrusts with small displacement and imbricate structures repeating Mesozoic strata leads one to suspect that they merge with depth with the main faults of the larger thrust sheets. Thus the underlying structure of the Central Foothills Belt may be viewed as two rather thin sheets which have been locally crinkled and folded both during and after thrust faulting. Local adjustments, even within the folds themselves, appear to have taken place in the more competent strata by fracture rather than rock flow. This is interpreted by the writer as a reflection of the shallow depth of burial at the time of deformation.

REGIONAL FRACTURE PATTERN

Examination of the contour diagrams (Plates 1 through 72) in Appendix A, part 2, should leave little doubt of the existence of a regional pattern of joint directions. This regional pattern possesses characteristic components which may be recognized in each individual contoured net. Generalized, the regional directions composing this pattern are two. The first (#1) strikes parallel to the structural trend and the strike of the beds (northwest-southeast), and dips within a few degrees of perpendicular to the dip of the beds at any locality. The second Trend (#2) runs across the strike of the beds (northeast-southwest) and is approximately perpendicular to trend # 1.[1] Its dip is generally within a few degrees of vertical. These directions may be seen generalized in Figure 3A and on the nets of Locations DD - II[2], DD- III, DG - I, DH - I, DH - II, DI - IV, DJ - I and DK - II which represent a few of the patterns of joints taken in the comparatively undeformed beds within two of the major synclines (zones 3 and 5).

Joint patterns in more highly disturbed areas tend to have the original regional pattern masked by joints developed in other directions. Although the relative density of the regional trends has a tendency to be reduced because of locally developed subsidiary directions, they still persist in most cases. (See nets DF - I, DH - III, DH - IV).

For the purposes of convenient reference the pattern just described is designated as pattern R (for regional) and will be termed such in

1. Arabic numbers appearing on the contoured nets are not trend numbers but are reference numbers for A.D.F. tabulations, Appendix A, part 4.
2. For meaning of locality numbers and their geographic location see Appendix A, part 3.

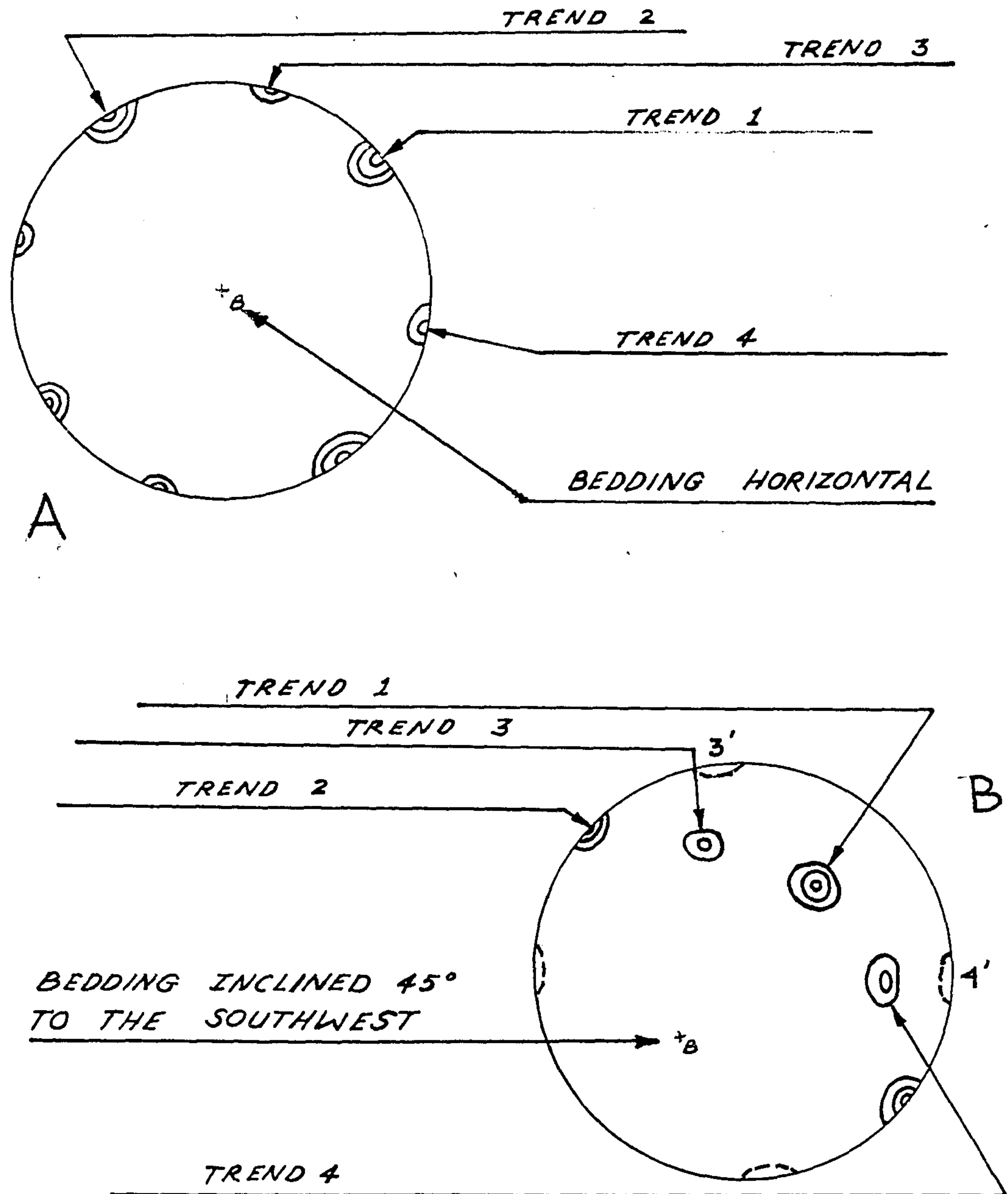

FIGURE 3

GENERALIZED ILLUSTRATION OF THE DEVELOPMENT OF JOINT TRENDS IN THE CENTRAL FOOTHILLS BELT later discussion.

Pattern R is essentially the same as that found by Erdman (1950) who designated the component directions as "S" and "D" for Strike joints and Dip joints (directions number 1 and 2 respectively). The writer has no particular objection to this terminology, but prefers to number the directions since directions other than R pattern components will also be discussed.

Almost without exception the joints of trends 1 and 2 have a attitude which is nearly perpendicular to bedding regardless of the attitude of the beds. This striking fact may be domonstrated by examining any of the contour diagrams[1]. Whenever the bedding is horizontal (or nearly so) the highs appear on the periphery of the net. When the bedding is inclined, the highs appear within the net and approximately 90° from the bedding (See Figure 3B).

Trends 3 and 4 of Figure 3A are common subsidiary directions in the Foothills Belt. In Figure 3B they are shown rotated along with Trends 1 and 2. They are often later, so that their polar highs fall near the circumference of the net (3' and 4') while Trends 1 and 2 are rotated as in 3B.

That the component trends of the R pattern developed early in the deformational history when the rocks were horizontal or very gently inclined is clear from the foregoing discussion and from other evidence. In some contour diagrams, there are secondarily developed new R patterns (R') which are oriented with respect to a present horizontal surface in the same way the original R pattern is related to the bedding (See

1. Bedding is shown by small crosses with the letter B. Subscript numbers refer to different bedding readings plotted individually while the letter B alone indicates an average of 3 or more bedding readings.

particularly nets DL - I, DN - V, DO - V, CM - I, CM - VI, CM - VIII, CR - II and CS - I. In this regard, it should be emphasized that the relative density of a high bears little relation to its direction. Locally any single direction may have a greater density than the others depending on genetic, as well as statistical conditions. Given a trend of a certain direction, it will decrease in relative density with the addition of each joint of another direction, so that locally any single trend may be represented by a high with the highest density. It is for this reason, in part, that in more highly deformed areas trends other than R pattern components often possess higher densities than the R component trends themselves.

LOCAL JOINT PATTERNS AND LOCAL STRUCTURE

Three terms are used by the writer to designate various characteristics of the preferred orientations or highs on a net. Developed refers to the density and hence "well developed" or "strong" would indicate a high density high. "Poorly developed" or "weak" indicates one of low density. Definition refers to the dispersion or scattering of the poles of the joint planes which make up the high. Thus "well defined" means a small area of scatter, and "poorly defined" means the converse. Regularity refers to the tendency to form a circle or an even curve; it gives some measure of the completeness of dispersion from the highest part of the high to the lowest. Outlines of highs which approach circularity are very regular. Those which have numerous extensions and reentrants without apparent system are termed irregular.

The arabic numbers on the nets are identification numbers of highs for which A.D.F.'s have been calculated and do not refer to trend numbers discussed below. See Appendix A, part 4.

AA - I Trends 1 and 2 of the R pattern are present, but 2 is very weak. E-W trend (3) is present. Local small thrust in overlying beds. Compare with location MA - I nearby, which does not have trend 3.

AB - I One of the few locations where the R pattern is nearly obscured by development of another direction (trend 4). This location is situated a short distance beneath a thrust fault.

AB - II The R pattern in this net is comparatively weak. Trends 3 and 4 are present in multiple highs. Joints were measured in beds immediately overlying a thrust.

AC - I R pattern is here present but again complicated by development of trends 3 and 4. Trend 1 is strong but trend 2 is weak and poorly defined. Location is 6 feet above a major thrust fault (The Bighorn Thrust).

AD - I R pattern present, trend 3 also present, trend 4 present and strong. Location is in rocks 300 feet above a thrust fault. Locations AD - I through AD - IV are shown on Map VII.

AD - II Shows strong R pattern; trend 1 is well-defined and regular; trend 2 is poorly defined and irregular. Location is in flat-lying beds with no local structure recorded.

AD - III This net again shows strong R pattern development, together with trend 4. Trend 3 is present but very weak. Although situated within the strongly folded, plunging, southwest limb of the Nikanassin Range, it is only indirectly associated with faulting. West-dipping thrusts of moderate displacement occur 1/4 mile upstream and downstream of the location.

AD - IV The R pattern is present as the 2 major highs on this net. There is apparent revolution of these highs with respect to the plane of projection. The location is on the west flank of a steeply plunging anticline.

AE - I R pattern present, but again confused by development of multiple subsidiary highs. Trend 2 strong, trend 1 weak and obscured. Trends 3 and 4 appear to be present as well as other indefinite trends. Situated 5 feet above a major thrust fault.

BB - I This net represents joints taken in the uppermost beds of the Paleozoic rocks (Mr. Head member of the Rundle formation - Mississippian in age). The location was made because only two oblique joint directions were apparent in the outcrop. The contoured net also shows only two. Location is on the western limb of the Brazeau Range Anticline.

CC - I The R.pattern on this net is well-defined and of high density in both trends. A subsidiary trend 4 appears, but is comparatively weak. No nearby local structures have been recorded.

CD - I A strong R pattern is also present here, however trend 2 has bifurcated appearing as a double high with a separation of about 15°. This location is on the axis of a synclinal structure overlying a folded thrust fault. CD - I is shown on Map II.

CE - I R pattern present with strong trend 1 and weaker trend 2. Trend 3 also present. Location is on the east flank of the synclinal structure overlying the same folded fault (as CD - I). CE - I is shown on Map II.

CF - I R pattern present with trend 1 weak and trend 2 strong. Trends 3 and 4 also present, but weak. Location is on the west limb of a syncline, 5 feet above cut-off of formation by folded thrust fault. CF - I is shown on Map II.

CG - I The R pattern is present, but both trends are weaker than 3 and 4. Beds are not highly disturbed, but Bighorn Thrust outcrops less than 1 mile upstream from this location.

CH - I All trends on this net have apparently been rotated. Since trends 3 and 4 as well as 1 and 2 are present and have been rotated, it is impossible to determine exact identification of the highs present with the trends they represent. Location is on the eastern flank of a doubly-plunging anticline beneath a folded thrust. Photograph no. 11 is a view of this location.

CH - II Net shows good development of R pattern with subsidiary trends 3 and 4 also present. All trends have been rotated. The location is between two west-dipping thrust faults.

CH - III The only clear trends present on this net are the R pattern components. Elongation of these highs in the usual positions of trends 3 and 4 might mean that they are present but distinctly subordinate to trends 1 and 2. This location is between two thrust faults of small displacement.

CI - I Trend 1 of the R pattern is strong and rotated on this net. Trend 2 is weak and poorly defined. Several subsidiary trends appear, but are of such low density and poor definition that their meaning is uncertain. This location is on the east limb of an anticline within a small fenster beneath a folded fault. Locations CI - I through CI - VI are shown on Map V.

CI - II The R pattern is present and well-defined on this net. There are no well-developed subsidiary trends, but four minor ones are present. The one in the eastern part of the net may either represent bedding plane separations rather than joints, or a joint trend at a very low angle to bedding. Location is on the east limb of an anticline beneath a folded fault.

CI - III This net shows trend 4 as well as both components of the R pattern. Minor trends of unknown significance also appear. As in CI - II, the high very close to the bedding pole may indicate separations along bedding planes. Location is on the west limb of the structure of CI - II.

CI - IV The R pattern is again well developed, as is trend 4. This location is on the western limb of a steeply plunging syncline between two west-dipping thrusts.

CI - V Trend 1 of the R pattern is strong and well defined. Trend 2 is represented by four separate highs perhaps indicating complication by trends 3 and 4. Location is on a thin slice of Bighorn formation in the trough of a syncline between two folded faults.

VI - VI This net exhibits both trends of the R pattern and trends 3 and 4 as well. Weaker subsidiary highs girdle the net. Structural position is similar to CI - V.

CJ - I Trends present are 1 and 2 of R pattern and subsidiary trend 4. See CI - II for explanation of remaining high. Joints taken in trough of synclinal structure beneath an anticlinally folded thrust fault. Locations CJ - I through CJ - IV are shown on Map VI.

CJ - II Trends 1, 2, 3 and 4 are all present here. Trend 3 has a dual high and, together with trend 4, is stronger than the R pattern components. Location is in steeply west-dipping rocks between two thrust faults.

CJ - III On this net trend 1 of the R pattern is absent. Interesting to note, however, is the development of a weak trend 1 which is normal to a horizontal plane. Trends 2 and 3 are present as well as a high which might represent bedding. Location is between two folded faults.

CJ - IV Trend 1 appears to be represented only by a rather weak tail on trend 3. Trend 3 itself is poorly defined, representing rather widely scattered poles. Structural position is immediately beneath an east-dipping folded thrust.

CK - I Rotation of all trends on this net has occurred. Trends 1, 2 3 and 4 are all present. Location is on the western limb of a plunging anticline developed above a west-dipping thrust . Locations CK - I through CK - V are shown on Map IV.

CK - II There is slight rotation of trend 1 on this net. Trend 4 is present and well defined; while 3 is perhaps represented by a tail on the trend 2 high. Location is near the culmination of a doubly plunging anticline 1/2 mile west of a west-dipping thrust.

CK - III Trends 1 and 2 are both weak and poorly defined here. Trends 3 and 4 are strong but irregular. Joints were taken in west-dipping rocks immediately beneath a west-dipping thrust. (see photograph no. 10).

CK - IV Trend 1 on this net is poorly defined. Trends 2, 3 and 4 are well defined and strong. Location is on the east limb of a synclinal structure within 25 feet of a west-dipping thrust.

CK - V Trends 1, 3 and 4 are all weak and poorly defined on this net. High dispersion of joints in the northwest quadrant indicates irregular joint development. This location is on the east limb of an anticline within 10 feet of a west-dipping thrust.

CL - I Trend 1 is weak and rotated slightly while trends 2 and 4 are strong and well defined. There appears to be rotation of the entire net in a counter-clockwise direction about 15 degrees, with what appears to be later development of very weak R pattern components in a position similar to those on other nets. Trend 3 is either absent or weakly represented by the tail on trend 4. Location is on gently west-dipping beds without nearby structural complications.

CL - II Trends 1, 2, 3 and 4 are all present on this net, together with a number of very weak, scattered trends whose meaning is uncertain.

Trend 4 appears as a triple high while trend 3 is very weak and poorly defined. Location is on the overturned western limb of a syncline a few hundred yards below a large thrust.

CL - III The only trends evident here are those of the R pattern, both of which have been rotated from their normal positions. The location is on the east limb of a plunging syncline.

CM - I Trends 1, and 2 of the R pattern are strong on this net. Trend 4 is also present but poorly defined and irregular in shape. Locality is on the west limb of an anticline developed above a large thrust fault. This location is shown on Map VII.

CM - II Both trends of the R pattern are present and well defined on this net. Trends 3 and 4 are either absent or represented by tails on the highs of trends 1 and 2. Location is immediately above a minor fault (Displacement 15 feet).

CM - III This net shows good development of both trends of the R pattern as well as subsidiary trend 4. Joints were measured below the fault in the same outcrop as CM - II.

CM - IV Trends 1, 2 and 4 are all well developed on this net. Location is situated on southwesterly dipping rocks between two west-dipping thrust faults.

CM - V On this net, trends 1, 2, 3 and 4 are all well developed and clearly defined. Joints were taken in steeply dipping beds above a large thrust.

CM - VI Both trends of the R pattern are exceptionally well developed here. The tandem high of trend 1 and the dispersion of trend 2 about the edge of the net both reflect the structure, since joints were taken over the crest of an anticline beneath a folded fault. The two bedding readings correspond to the dip of the beds on each flank of the structure and the double highs may be similarly correlated.

CM - VII Trends 1 and 2 are both present on this net together with trend 3 which, however, has a dual high. Location is on a syncline beneath a folded fault.

CM - VIII On this net rotation of all highs from normal position has taken place. Trends 1 and 2 are present and are well defined while trend 3 is probably representd by the tail on the trend 2 high. Structural position is similar to CM - III above.

CN - I Trends 1 and 2 are both present and well defined while trend 3 could be represented by a bulge in the contours connecting trends 1 and 2. Trend 4, if present, is represented by the secondary high near trend 2. Joints were taen in east-dipping beds approximately 300 feet above an east-dipping thrust.

CN - II Trends 1 and 2 are present as well as trend 4. All trends appear to have been rotated slightly. Another subsidiary trend is present, the meaning of which is uncertain. Location is on the overturned eastern limb of an anticline developed in front of a large thrust.

CN - III Trends 1, 2, 3 and 4 are all present. Location is situated on the east limb of a broad syncline which has been complicated by a minor thrust which outcrops 50 feet to the west. CN - III through CN - VI are shown on Map VI.

CN - IV Trends 1, 2 3 and perhaps 4 are all present here. 1 and 2 are both strong, 3 is weaker and 4 might be represented by the tail on 1. Slight rotation appears to have taken place. Location is immediately below a west-dipping folded fault.

CN - V Trends 1, 2, and 3 are all clearly defined with elongation of trend 2 high perhaps indicating the presence of trend 4. Slight rotation to the NW has also taken place. Location is on the west limb of a steeply, doubly plunging anticline 100 feet beneath a thrust fault.

CN - VI Trends 1, 2 and 3 are all present but poorly defined. Three subsidiary trends are present but their meaning is unknown. Location is immediately above the east-dipping limb of a folded fault.

CO - I On this net, trends 1, 2 3 and 4 are all present. Trend 1 however has a dual or tandem high. Trend 3 is very well developed and clearly defined. This location is situated on the west limb of a strongly folded syncline just east of the outcrop of an east-dipping folded fault.

CO - II Trends 1, 2 and 4 are present here, both 1 and 4 being of low density. Structural position is on the east limb of an anticline developed within an anticlinally folded fault.

CO - III Both trends of the R pattern are present here together with a poorly defined tandem high representing trend 3. Trend 4 is also present, merging with trend 2. Location is on the eastern limb of the broad syncline of zone 3 just west of the outcrop of a large thrust fault.

CP - I This net shows very good development of the R pattern trends. A few subsidiary highs are present, but none of these appear to correspond to trends 3 or 4. Trends 1 and 2 are both poorly defined and highly dispersed. Structural setting is near the axis of a syncline overlying a folded fault. Locations CP - I through CP - IV are shown on Map VIII.

CP - II Trends 1, 2 and 4 appear clearly on this net. 1 and 4 are weak, but 2 is strong and sell defined. Location is on overturned west-dipping rocks caught between two east-dipping folded faults.

CP - III As in CP - II trends 1, 2 and 4 are present and 3 is absent. Structural setting is similar to CP - II.

CP - IV Trends 1, 2 and 4 are present and have been rotated toward the southeast on this net. Location is on the overturned east limb of an anticline which lies beneath an anticlinally folded fault.

CQ - I Trends 1, 2, 3 and 4 are all present on this net. Trend 1 has a subsidiary high near the E-W margin of the net. Trends 2, 3 and 4 are all rather weak and irregular. Location is on the east limb of a plunging anticline beneath an anticlinally folded fault. Locations CQ - I through CQ - III are shown on Map VIII.

CQ - II Slight rotation of trends 1, 2, 3 and a very weak trend 4 has taken place here. Location is on the west limb of a south-easterly plunging syncline between folded faults.

CQ - III Trends 1, 2, 3 and 4 are all present here. Trend 2 is represented by the tail on the trend 3 high, but the others are strong and well defined. Joints were measured at this location in steeply south-west dipping beds above a large thrust fault.

CR - I On this net, trends 1, 2 and 4 are present. Trend 3 may be represented by the subsidiary high very close to trend 1. Trend 1 itself is very weak and appears on the net as a tail on trend 4. Joint development is irregular and poorly defined. Joints were measured at the trough of a very gently plunging syncline (zone 5) where the rocks have been locally faulted along east-west trending tears which are approximately parallel to trend 3 on the net.

CR - II Trends 1 and 2 are well developed but irregular. Trends 3 and 4 appear as tails on highs of trend 2. Trend 2 is represented by a dual or tandem high. Trend 1 shows marked elongation and a tendency to girdle. Same structural setting as CR - I.

CR - III Trends 1, 2 and 4 are present on this net. Trend 3 is apparently absent, but may be weakly represented by the bifurcation of trend 1, which is itself weak and poorly defined. Structural setting is again the same as CR - I.

CS - I Trends 1 and 2 are both present here, but have been rotated from their normal positions. Location is on the overturned western limb of a broad syncline (zone 5) thrust-faulted by the Nikanassin Thrust 1/2 mile to the west.

CS - II Trends 1, 2, 3 and 4 all of which are well developed have been rotated to the southeast. Location is on the east flank of zone 5 between two large thrust faults.

CS - III On this net the R pattern has been over shadowed by the strong development of trends 3 and 4. Trend 1 is represented by the bulge in the girdle between trends 3 and 4. Trend 2 appears as a similar bulge at the edge of the net. This location is on the east flank of zone 3, 1/2 mile southwest of a major thrust fault.

CT - I Trends 1, 2 and 4 appear on this net. 1 and 2 are well developed but 3 is weak. All are well defined. The structure at this locality is not clear. B.R. McKay has interpreted this small area as an imbricate structure in Bighorn formation rocks produced by 2 thrust faults. Later information from

Douglas indicates that these are 3 slices produced by a single folded fault.

CT - II Trends 1, 2, 3 and 4 are all present here. In addition there is a late development of trend 1 which is weak but in a normal position. For structure see CT - I above.

CT - III Trends 1 and 2 are clearly defined on this net. Low preferred orientations in the positions of trends 3 and 4 may indicate tendency toward development of these trends. Late development of a new trend 2 is also indicated here. For structure see CT - I above.

DD - I[1] This net shows good development of trends 1, 3 and 4 and weak development of trend 2. Location is at the axis of zone 3. Minor thrusts occur nearby.

DD - II Good development of trends 1 and 2 of the R pattern is indicated. Trends 3 and 4 are entirely absent. Joints were taken on the west flank of zone 3. No minor structures were recorded. DD - II is shown on Map II.

DD - III Excellent development of trends 1, 2, 3 and 4 is shown Trend 3 has a tandem high one part of which is connected to the trend 2 high. This location together with DD - IV is within a zone of minor thrusts only three of which are shown on the map. (Regional Maps A and B).

1. The patterns of the D series are for the most part representative of the broader, more flat-lying portions of the area. They represent joints taken in the Brazeau formation, which is seldom caught up in the more complicated structures. Except in those cases where this occurs discussion of local structure will be brief.

DD - IV The distribution of highs on this net is not clear. Trend 1 appears to be present, but other trends are irregular and poorly defined. The number of joints taken at this location is considered to be too small for adequate interpretation of the pattern.

DE - I Trends 1 and 2 are present here but are very weak while trends 3 and 4 are exceptionally well developed and regular in orientation. See DE - II for structural setting.

DE - II On this net, trends 3 and 4 dominate. Trend 1 is very weak and trend 2 appears to be absent. Both DE - I and this location are at the base of a large klippe of Brazeau and Wapiabi formations thrust over Brazeau.

DF - I Trends 1, 2 and 3 are present on this net. They are of approximately equal density and of slight irregularity in orientation. The location is on the western limb of zone 3 within 1/2 mile of an east-dipping thrust fault. DF - I is shown on Map IV.

DG - I Trends 1 and 2 of the R pattern are the only directions represented here. Location is on the west-dipping rocks of the Brazeau formation on the east flank of zone 7. The position of the location on the map is in doubt since this portion of the area was not mapped (see note - regional Map A)

DH - I Trends 1, 2 and 3 are all present here. Trend 1 has a tandem high, but 2 and 3 exhibit normal development. A subsidiary trend is present, the meaning of which is unknown. Location is on the east flank of zone 3. No local structures have been recorded.

DH - II Trend 2 is strong and regular while trends 1, 3 and 4 are present but weak on this net. Location is near the axis of zone 3. No minor structures have been recorded.

DH - III On this net trends 1, 2, 3 and perhaps 4 are present. 1, 2 and 3 are represented by distinct highs while 4 is represented by a tail on the trend 2 high. Structurally, this location is on the overturned west flank of zone 3. A major thrust passes 1/2 mile to the west. Photograph no. 9 shows this location.

DH - IV This net has trends 1, 2, 3 and 4 all well developed but irregular in form. Late development of a new R pattern is also evident. This location is on a slice of Brazeau formation which is part of an imbricate structure beneath 2 folded faults.

DI - I Rotation of trends 1, 2 and 3 has taken place. Trends 1 and 2 are strong and regular while trend 3 is weak. Structural position is on the western limb of the northwest plunging syncline of zone 5. No local structures have been recorded.

DI - II Trends 1, 2, 3 and 4 are all present on this net. Slight rotation has apparently taken place and trend 2 joints are inclined steeply to the southeast. Joints were taken at the axis of the syncline, zone 5.

DI - III Trends 1, 2 and 4 are present here. Trend 1 exhibits a tandem high but appears to be in a normal position. Trend 2 is rotated slightly as in DI - II. Location is on the east flank of zone 5 syncline.

DI - IV Trends 1 and 2 are present and some suggestion of zones 3 and 4 which are weak. Structural position of this location is on the east flank of zone 7.

DI - V Trends 1, 2 and 3 are present together with a weak suggestion of trend 4. Trends 1 and 2 are regular and well defined while trend 3 possesses rather broad dispersion. Same structural position as DI - IV, but farther to the west. Photograph no. 8 shows this location.

DJ - I Trends 1 and 2 are present, regular and well defined. Weak suggestions of trends 3 and 4 are apparent. Location is on the west flank of zone 3.

DJ - II Trends 1, 2 and 4 are present with a suggestion of 3. All trends except 4 are weak and poorly defined. Location is on the east flank of zone 3 with a minor thrust just to the east (See CN - III). Location DJ - II is shown on Map VI.

DJ - III On this net trends 1, 2 and 3 are present, together with a number of weak subsidiary directions. Location is above a shallowly dipping folded thrust, 1/2 mile from the outcrop of the fault plane. Beds are essentially flat-lying and little deformation has taken place.

DJ - IV Trends 1 and 2 are present and well defined together with weak suggestions of 3 and 4 and other subsidiary directions. Structural setting is the same as DJ - III, but closer to the fault plane outcrop.

DK - I Trends 1, 2, 3 and 4 are all present on this net together with another trend representing low-angle joints. This location is on a minor thrust fault.

DK - II Trends 1 and 2 are well developed on this net and trend 4 occurs as a weak high. Location is in flat-lying strata without recorded local structure.

DK - III Trends 1, 2, 3 and 4 appear to be represented here, however highs are so irregular that definition of some is in doubt. Trends 2, 3 and 4 are relatively strong and constant. Trend 1 is highly irregular and poorly defined. This location is on the crest of an anticline complicated by local dislocation of the beds.

DK - IV Southeastward rotation of trends 1 and 2, which are the only trends well developed here, has taken place. This location is on the east flank of a southeasterly plunging anticline between 2 major thrusts.

DK - V Trends 1, 2, 3 and 4 are all present here, although trend 3 is very weak, irregular and poorly defined. This location is immediately beneath a major folded thrust.

DK - VI On this net trends 1 and 2 have developed normal to the bedding while later trends 1 and 4 appear on the periphery of the net. Location is situated in the same structural position as DK - V .

DK - VII Trends 2 and 3 are well developed here, while trends 1 and 4 are weak. There appears to be slight rotation in dip of trend 2. Same structural position as DK - V and DK - VI.

DK - VIII Trends 1 and 2 of the R pattern are well developed. Trends 3 and 4 are very weak, but present. Location is on the west flank of an anticline (see DK - II). No local structure has been recorded here.

DL - I Trends 1 and 2 are well developed and trends 3 and 4 are present but weak. Location is on east flank of zone 3.

DN - I Trends 1, 2, 3 and 4 are all present. 1 and 4 are strong while the others are weak and poorly developed. Location is on the east flank of zone 3 at the narrowest point in the syncline. Note the steep dips of the beds at all locations DN - I to DN - V indicating marked constriction of the synclinal structure and consequent local deformation and dislocation. These locations are shown on Map VIII.

DN - II At this location trends 1, 2 and 3 are all present together with what appears to be late development of trend 3 joints. Location is on the west flank of zone 3, close to the axis.

DN - III Here trends 1, 2 and 3 are all strongly developed, regular, and well defined. Late appearance of trend 1 joints is also evident on the periphery of the net. Location is on the west flank of zone 3 within 1/4 mile of a major east-dipping thrust.

DN - IV Trends 1, 2 and 3 are well developed here together with weaker, more recent trends 3 and 4 which appear on the periphery of the net. Location is on the east flank of zone 3 near the axis.

DN - V Trends 1, 2 and 4 are present and well defined here. There is also late development of trend 1 joints as evidenced by the tail on early trend 1 high and a weak high at the periphery of the net. This location is on the east flank of zone 3 very close to the axis.

DO - I Trends 1, 2 and 4 are all well developed and well defined here. Location is on the west flank of zone 5. No local structures have been recorded.

DO - II Trend 1 and 2 are present and well developed. Trends 3 and 4, if present, are not in their normal positions. Structural position is on the east flank of zone 5. Local dislocations occur in this flank.

DO - III Trends 1, 2 and 4 are well developed and well defined. Trend 3 is perhaps represented by the irregular tail on trend 1. This location is on the west flank of zone 5 near the axis..

DO - IV On this net trends 1, 3 and 4 are strong and well defined. Trend 2 is represented by the weak tail on trend 4. Location is on the west flank of zone 3 with a large thrust exposed 1/2 mile to the west. Photograph no. 7 shows this location.

DO - V Trends 1 and 4 are present and well defined. Trend 2 appears to be absent here. Location is on the east flank of zone 3.

DO - VI Trends 1 and 2 are clearly defined on this net. Trend 3, if present, is displaced from its normal position. Trend 4 is present but weak. Structural setting of this location is on the west flank of a minor anticline developed in front of a major thrust. The thrust outcrops about 100 feet west of the location.

DO - VII Trends 1, 2, 3 and 4 are all present. Rotation to the southwest of all highs has taken place. A later development of trend 3 appears near the north pole of the net. Several minor thrusts have been recorded both above and below this location.

DO - VIII Only trend 3 is well developed on this net. Scattered, weak and irregular highs may represent other trends, but definition of such is uncertain. Same structural setting as DO - VII

Page 64 lacking. Filmed as received from the University of Cincinnati.

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DP - I Trends 1, 2, 3 and 4 are all present, but somewhat irregular. Location is 200 feet east of a major thrust.

DQ - I Trends 1, 2 and 3 are present but irregular and poorly defined. Location is between 2 folded tear faults. DQ - I is shown on Map VIII

DQ - II Trends 1, 2 and 4 are present and well developed. Elongation of trend 1 high indicates possible presence of weak trend 3. Structural position is similar to DQ - I.

DQ - III Trends 1 and 2 are well developed and well defined. Trend 3 is somewhat irregular. Location is on the west flank of an anticline developed in front of a major thrust.

EA - I This net and EA - II show excellent development of trends 1 and 2. No other subsidiary trends are present. Structural setting is in a tear-fault zone on the Bighorn Range. Locations EA - I through EA - II are shown on Map III.

EA - II The same trends are evident on this net as on EA - I. Same structural setting.

MA - I Trends 1 and 2 of the R pattern are present and well defined. Two weak, poorly defined highs are also present. Location is in flat-lying beds with no recorded local structure.

MB - I Trends 1 and 2 are present on this net, but weak trends 3 and 4 show an unusual development in that they are not in normal position relative to trends 1 and 2 and bedding. Location is on the east flank of a minor anticline developed behind a thrust fault. MB - I is shown on Map IV.

MC - I Trends 1, 2 and 3 are well defined and well developed here but have apparently experienced southeastward rotation. Late development of a second trend 1 high appears on the periphery of the net. One other well developed high is shown, but its meaning is unknown. Locations MC - I through MC - III are shown on Map VII.

MC - II Trends 1, 2 3 and 4 are all present and have all experienced rotation similar to that of MC - I. The location is on the west flank of a southeast plunging anticline 150 feet east of a thrust fault.

MC - III Trends 1, 2, 3 and 4 are also present here. Location is on the west flank of a broader, more gently plunging anticline than MC - II.

MD - I Trends 1 and 2 of the R pattern are the only trends present on this net. Trend 2 is well developed and strong but trend 1 is weak, poorly developed and irregular. Location is on a major tear fault in the Bighorn River tear fault zone. Locations MD - I through MD - IV are shown on Map I.

MD - II Trends 1, 2, 3 and 4 are all present here. Trend 2 is strong and well defined but the others are weaker. Location is on another tear fault in the same zone.

MD - III Trends 1, 2 and 4 are present on this net. 1 and 2 are poorly developed and irregular while 4 is strong and well defined. Location is similar to MD - II.

MD - IV Trends 1, 2 and 4 are present here as well. 1 and 2 are weak and poorly defined, but 4 is strong and well defined. Same structural setting as MD - II and MD - III.

NA - I On this net, trends 1, 2 and 4 are present, 2 and 4 being well defined and strong while 1 is weaker and dually developed. Slight rotation of trend 2 is evident. Location is on the southeasterly plunging southern end of the Nikanassin Anticline. This location is shown on Map VII.

NB - I Trend 2 is well developed but not well defined here, while trends 1 and 3 are present but weak. Structural setting is in the Bighorn Range tear fault zone. Locations NB - I through NB - III are shown on Map III.

NB - II Trends 1 and 2 are present, 2 being strong and well defined and 1 being weak and irregular. Location is similar to NB - I.

NB - III Trends 1 and 2 are the only directions present here. Slight rotation of trend 2 appears to have occurred. Setting is also similar to NB - I.

PGR - I This location is the only one taken in the Paleozoic limestones. In this case, trends 1, 2 and 3 are all present, but highs are weak, irregular and poorly defined. Location is within a massive thrust block of Lower Paleozoic, Ghost River formation in the First Range of the Rocky Mountains at Tarpien Rock, Brazeau River.

SA - I Trends 1 and 2 of the R pattern are both present and well developed. Trend 2, however, has a tandem high. Location is on the northwest plunging northern end of the Bighorn Range Anticline. This location is shown on Map IV.

SB - I Trends 1 and 2 are very well developed, regular and well defined. Location is on the west flank of the Nikanassin Range Anticline.

SC - I Trends 1, 2, 3 and 4 are present and well developed. All trends have undergone slight southeasterly rotation. Location is on the overturned east flank of the Nikanassin Range Anticline.

TA - I On this net, trends 1, 2 and 4 are present. Trends 1 and 2 are well developed and regular. Trend 4 is weak. Location is just below a major west dipping thrust. This location is shown on Map VI.

TA - II Rotation of trends 1, 2 and 4 is evident on this net. 1 and 2 are strong and regular. 4 is weak and poorly defined. Location is east of TA - I, away from the thrust. A minor thrust fault passes between these two locations.

TB - I Trends 1, 2 and 4 are present here. All are irregular, but well defined. Location is above a minor thrust in zone 1.

TC - I Trends 1, 2, 3 and 4 are present. Slight rotation in an easterly direction is apparent. All trends are irregular and poorly defined. Structural setting is in a zone of minor dislocations.

TC - II Trends 1, 2, 3 and 4 are also present here. Trend 1 is very weak, and the others are well developed but poorly defined. Secondary development of a new, later trend 3 is evident. Structure similar to TC - I.

TC - III Trends 1, 2, 3 and 4 are all present. Trends 3 and 4 are not in their normal position, but appear to have been rotated. Late development of a new trend 1 appears at the edge of the net. Location is in a minor fault zone.

TC - IV Trend 2 is the only distinguishable trend present here. Numerous weak and irregular highs appear but their development is too poor to allow interpretation.

TC - V There are no distinguishable trends on this net. All highs are poorly developed, poorly defined and irregular. Interpretation is not possible. Both TC - IV and TC - V are beneath an east-dipping thrust.

WA - I The development of joints at this location is typical of shale lithologies. The highs which appear apparently have no regional significance in terms of the other locations and are poorly developed, poorly defined and irregular. No interpretation can be made by the writer. This location is shown on Map VIII.

CONCLUSIONS

A number of generalizations may be drawn from the fore-going data.

A. The regional fracture pattern in the Central Foothills Belt is composed of two major trends which are approximately perpendicular to each other and to bedding regardless of the attitude of the beds. One of these trends commonly parallels the regional trend of the structure.

B. Since the trends of the regional pattern usually bear a relationship to the structural trend, they commonly have a similar relationship to bedding. However, in the near vicinity of plunging structures or thrust faults which have experienced change in displacement, the patterns show a definite rotation. In the former case, the orientation of joint planes of the component trends of the regional pattern are at present approximately normal to and parallel with the axis of the fold. In the latter case, rotated joint trends both follow and are normal to lines of equal displacement on the faults. As a result, rotation of the joint trends can be traced directly to similar rotation of beds wherever displacement increases or decreases laterally along the thrust plane outcrop. In a few cases rotation of one trend relative to the others is apparent. It is possible that such rotation has come about as a result of differential movement along intersecting joint planes thus forcing rotation and a change in the angle of intersection. Such changes in angle have been observed by others, but the writer has found no evidence of this mechanism within the area studied.

C. Secondary component trends of the regional pattern occur on some contour diagrams oriented with regard to a present horizontal plane in the same way that the original regional pattern trends are related to bedding. If the beds together with the normal joint trends were returned to the horizontal position while these secondary trends were held stationary, then these secondary directions would occupy the same positions as the normal regional trends. In a few cases, (see Location CR - II) certain highs show a distinct tendency to girdle, indicating joint development during folding.

D. From the foregoing it seems evident that:

1. The main trends of the individual patterns developed early in the deformational history of the area, when the strata were essentially flat-lying. In no other way can the writer account for the relationship between joint attitudes and the attitude of the bedding.

2. The conditions which produced the original patterns were also present sporadically both during folding and faulting and after the rocks had reached their present attitude. These conditions produced repetition of some early joint trends during deformation of the beds.

3. Conclusions 1 and 2 suggest a reason for the irregularity or absence of joint surfaces in the more incompetent rocks. Assuming that planar joints formed in the shales at the same time as in the more competent beds, subsequent deformation of the shales by flowage could easily have forced the joint planes themselves to be deformed and perhaps obliterated.

E. The relationship of joint trend directions to the structural trends and to the trend of the flexure bordering the Cordilleran Geosyncline makes interpretation of the genesis of these joint trends difficult.

1. The joints may have been formed in response to the earliest stresses produced during the Laramide Orogeny.
2. If tectonic movement progressed from west to east across the area, joints formed locally in response to the stresses thus produced could have successive origins as well.
3. Origin of the joints perhaps lies in the relationship between the joint directions and the trend of the eastern margin of the Cordilleran Geosyncline during Mesozoic time. (Eardley, 1951). This relationship might mean that the joints were formed in response to rather gentle warping about an axis of flexure, while deposition was still taking place.

Of the three suggested origins, the first or second is felt to offer the best explanation of the facts. Joint trends developed during the deformation are the same as those developed while the rocks were still essentially flat-lying. If joints which developed early are due to flexure of the surface of deposition, then those which developed later and are clearly related to the structure are similar in trend only through coincidence of structural and depositional trends.

F. Development of highs subsidiary to the component trends of the regional pattern is apparent on many of the contour diagrams. These trends, termed 3 and 4, are directly related to the degree of deformation at any particular location. They occur in the immediate vicinity of minor thrusts and tear faults. In the latter case one of the two trends is generally parallel to the trend of the fault plane. (See MD - 1 through MD - IV, and CR - I through CR - III). Both trends are especially well developed close to the larger thrust faults. Patterns of joints measured even at greater distances still show their presence. Areas which have been strongly folded also show these trends. Trends 3 and 4 have no definite relationship to the regional pattern trends or to each other, although they are also usually normal to the bedding. The angle between them varies from location to location being sometimes less than and sometimes greater than 90 degrees. Whatever the angle, however, the two trends, when present together, generally intersect equal angles on either side of trend 1 of the regional pattern. It is possible that these directions, because of the variability in their angle and their relationship to the more highly deformed parts of the area represent the conjugate shear planes discussed by Bucher (1920) and others.

G. On many nets a subsidiary high occurs close to the plotted pole of the bedding. Since the plotted attitude of the bedding is based on the average of only three individual readings in some cases it is likely that the bedding plot may be a few degrees in error. Because joints were measured without selectivity, undoubtedly in some cases bedding surfaces were measured and plotted as joints. Wherever a joint high occurs within a few degrees of the plotted bedding the writer feels that this high represents bedding plane poles rather than joints. In instances where there is an apparent division between the bedding plot and a contoured high the high is thought to represent joint planes which lie at a low angle to the bedding. In some cases these directions might represent shear planes or incipient thrusts developed at the same time as the thrust faults. However, not enough information is available on the attitude of thrust planes in the area to draw a distinct correlation.

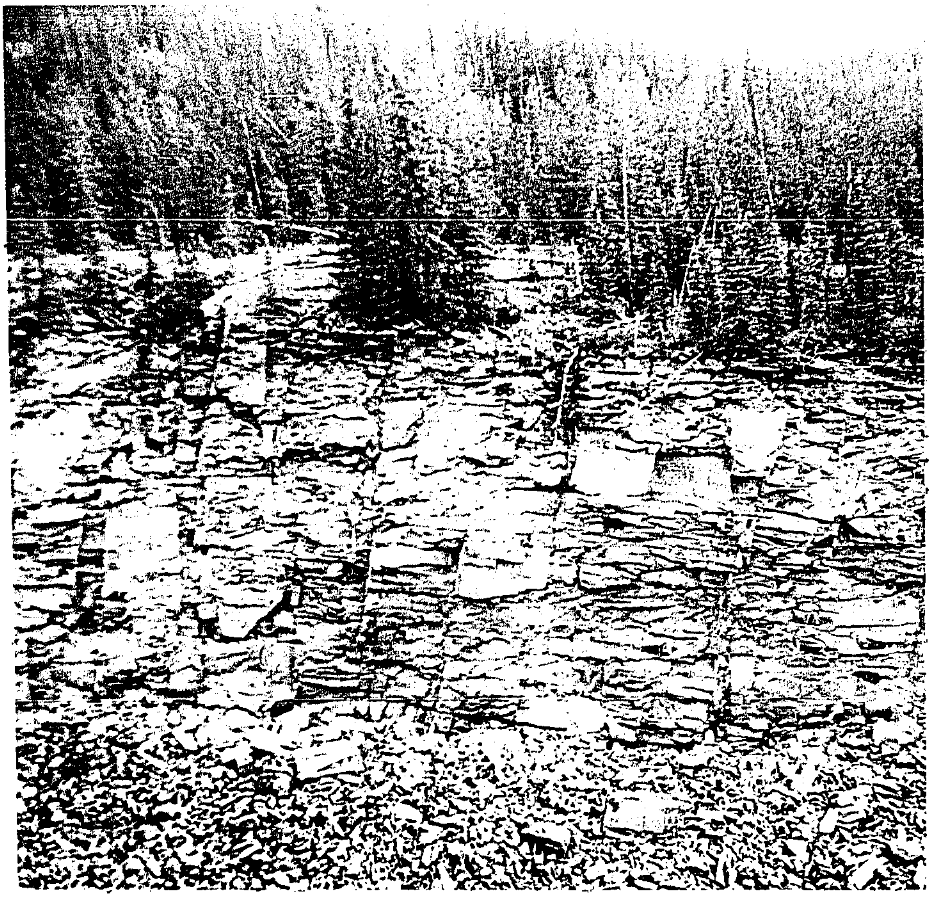
H. Regularity in outline of highs on individual nets is directly related to regularity of joint surfaces as described in the field. At those locations where joint surfaces were described as planar or regular the contoured nets have the same characteristic. Wherever the joints were termed irregular or wavy the contoured highs show the same feature. Irregularity of joint surfaces is characteristic of rocks in the more highly deformed belts of the area. (See D - 3 above). Poor development and poor definition are also characteristics of joint trends within highly deformed zones.

I. Contour diagrams DE - I and DE - II are excellent examples of the shift in relative density of one trend with the introduction of new trends or a decrease in sample number. In the case of DE - I where 100 joints were taken the regional pattern is clear, even in the presence of high density trends 3 and 4. AT DE - II where only 50 joints were taken, the regional trend has been almost completely subordinated. That the regional pattern exists at both localities seems a valid assumption to the writer since they both represent joints taken in the same stratigraphic horizon in the same structural position separated only by a distance of about 200 yards.

J. Within the range of lithologies of rocks in which joint measurements were made, the persistent presence of both the regional pattern and its modifications indicates that there is no observable relationship between lithology and joint pattern. Although the writer excluded joints in the shales from this study, this statement holds true for the various lithologies in which different series of joint locations were established, i.e., the lithologies of the Brazeau, Bighorn and Nikanassin formations are markedly different, but the regional patterns found in them are indistinguishable on the basis of lithologic type.

Photograph No. 1

Illustrating technique used in gathering joint orientation data. Brazeau River



Photograph No. 2

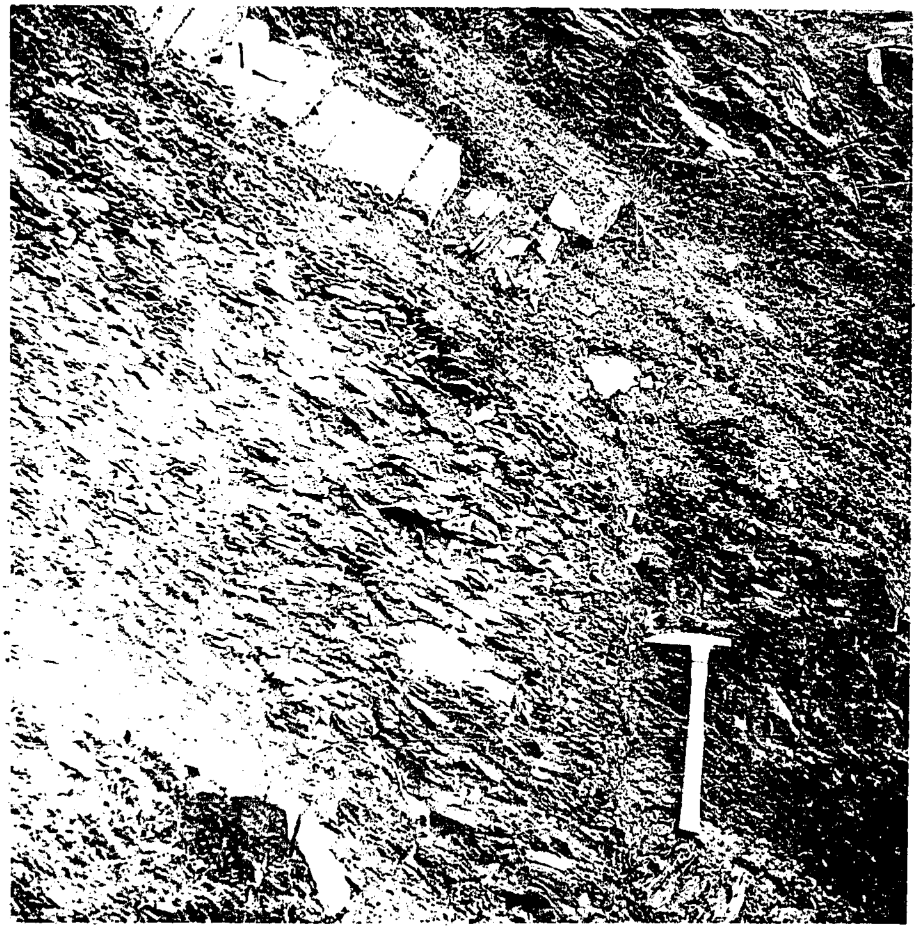
Discrete joint surfaces cutting through 30' of mixed sandstones and conglomerates. Southesk River.

Photograph No. 3

Typical outcrop of Brazeau sandstone with planar joints cutting through 25 foot bed of sandstone and conglomerate. Opaben Creek.

Photograph No. 4

Close view of typical joint development in Bighorn Sandstone. Note that discrete joint surfaces end at sand-shale interface. Cardinal River

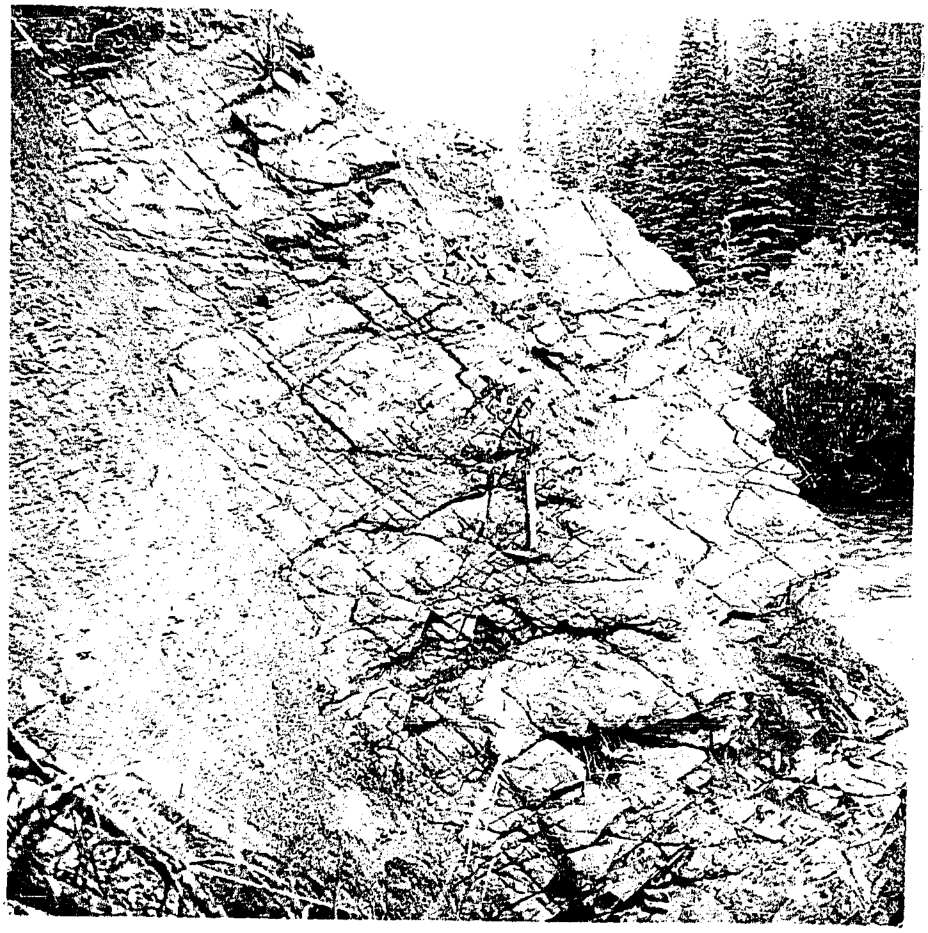


Photograph No. 5

Close view of minor antithetic reverse fault. Displacement is right hand side down 7 1/2 feet. Fault plane passes through point of hammer head and is parallel to handle. Cardinal River

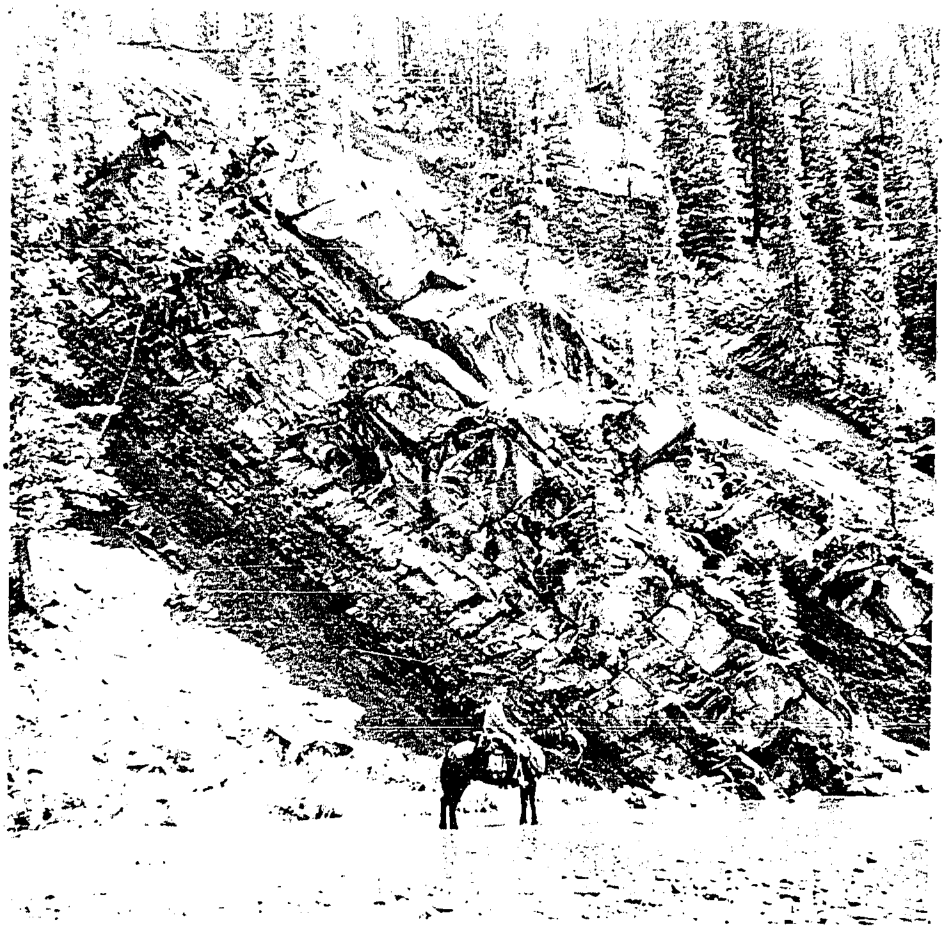
Photograph No. 6

Distant view (100 feet) of fault in Photograph No. 5
Cardinal River.



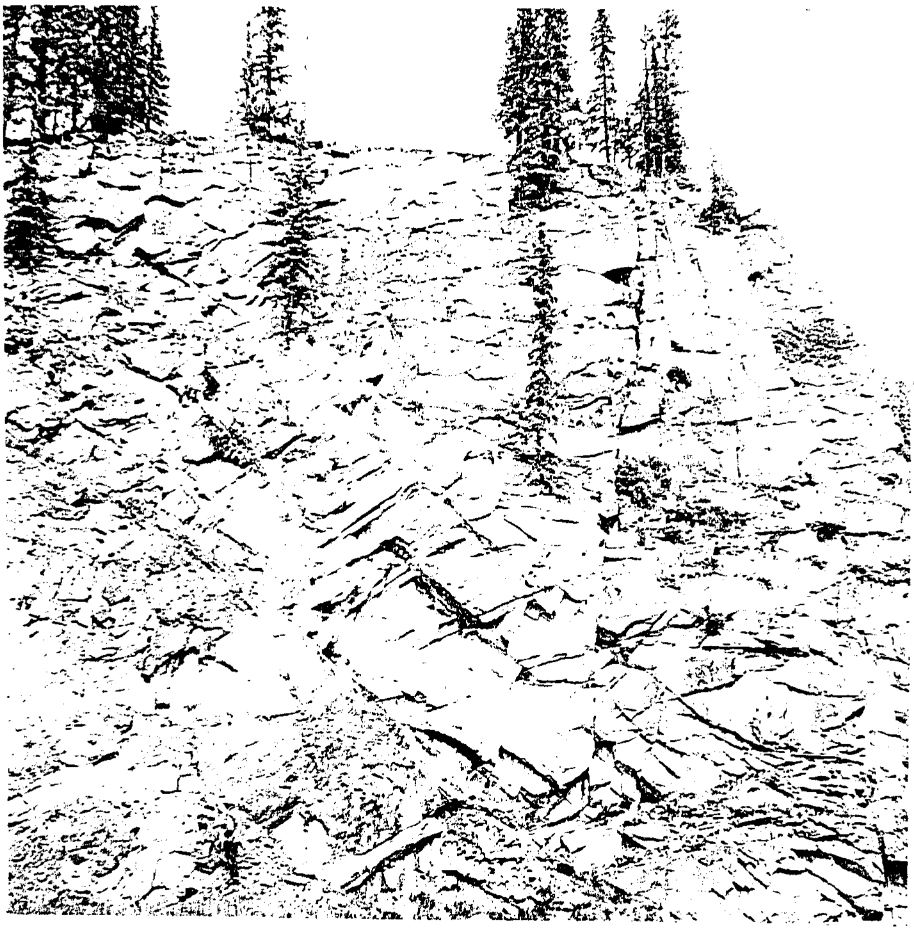
Photograph No. 7

Typical joint development in Brazeau formation sandstones. Joint Location DO - IV. Mackenzie Creek



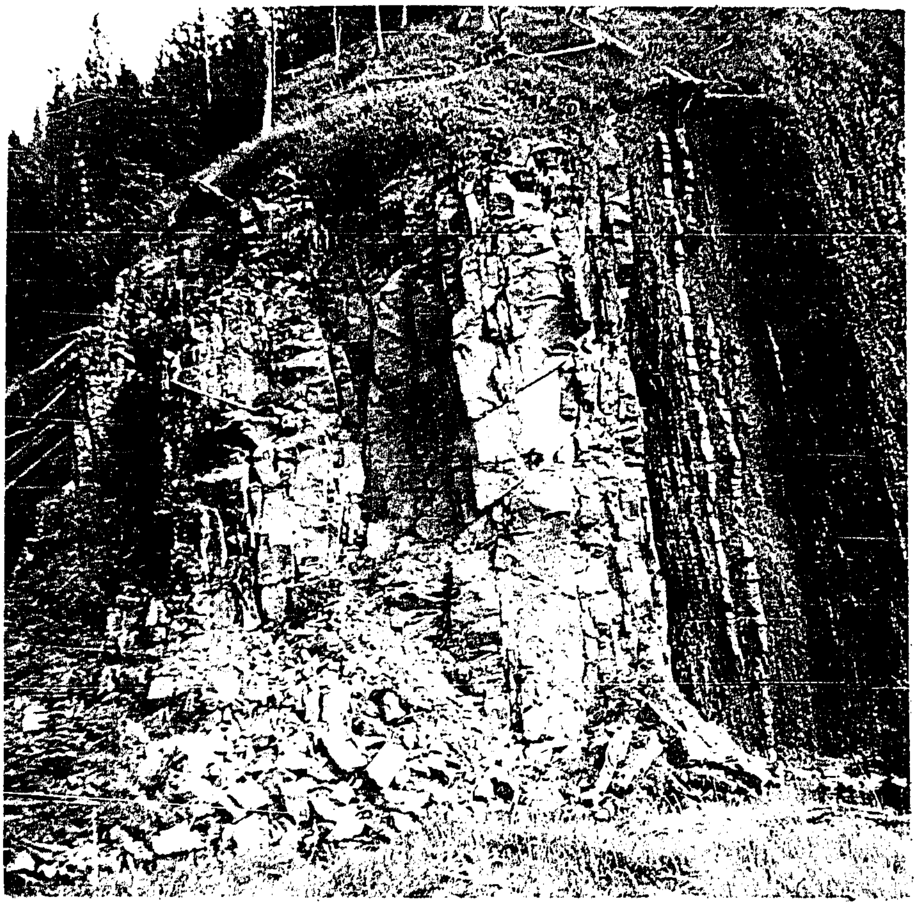
Photograph No. 8

Joints in the Brazeau formation Sandstones. Location DI - V. Thistle Creek.



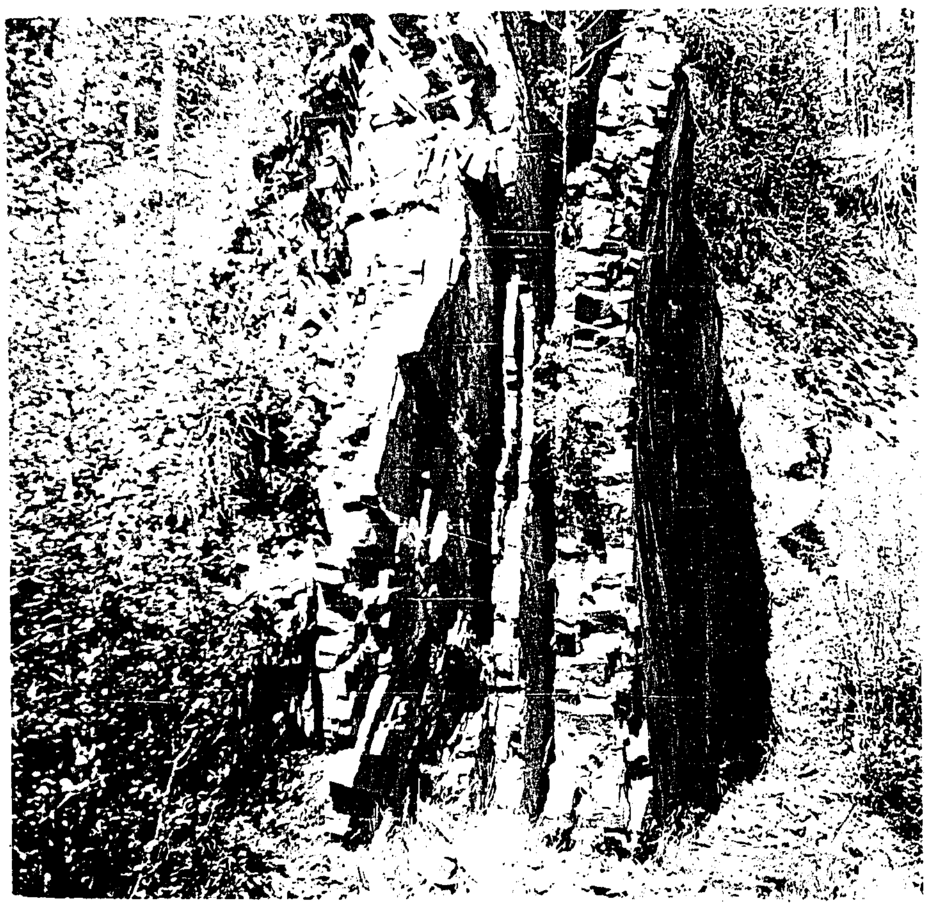
Photograph No. 9

Joint development in the Brazeau formation sandstones at Location DH - III. Upper Cardinal River.



Photograph No. 10

View of outcrop of Bighorn formation sandstone overturned with Blackstone formation transition beds on the right. Joint location CK - II. Upper Brown Creek.



Photograph No. 11

Typical joint development in Bighorn formation sandstones. Joint locality CH - I. Chungo Creek

APPENDIX A

Key for Symbols used on Coutour Diagrams

I. Formations in which joint orientation data were collected are indicated by the first letter of the location designation, e.g., AA - I.

A - Luscar formation

B - Mount Head member of the Rundle formation

C - Bighorn formation

D - Brazeau formation

E - Cadomin formation

M - Mountain Park formation

N - Nikanassin formation

P - Paleozoic rocks - Ghost River formation

S - Spray River formation

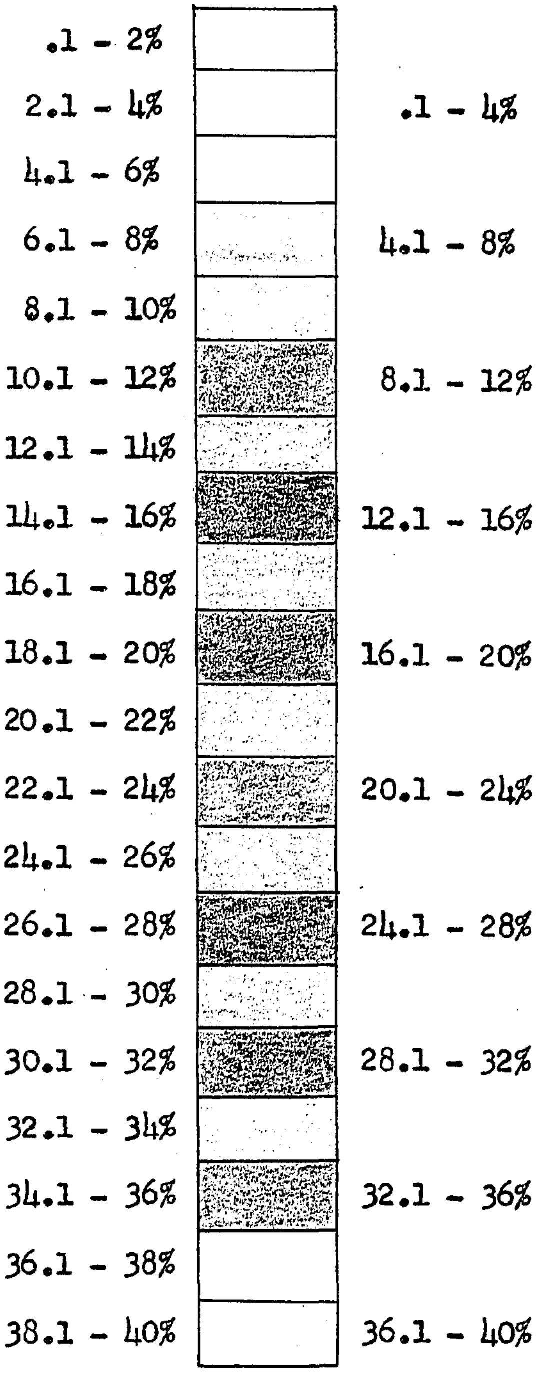
T - Tertiary - Paskapoo formation

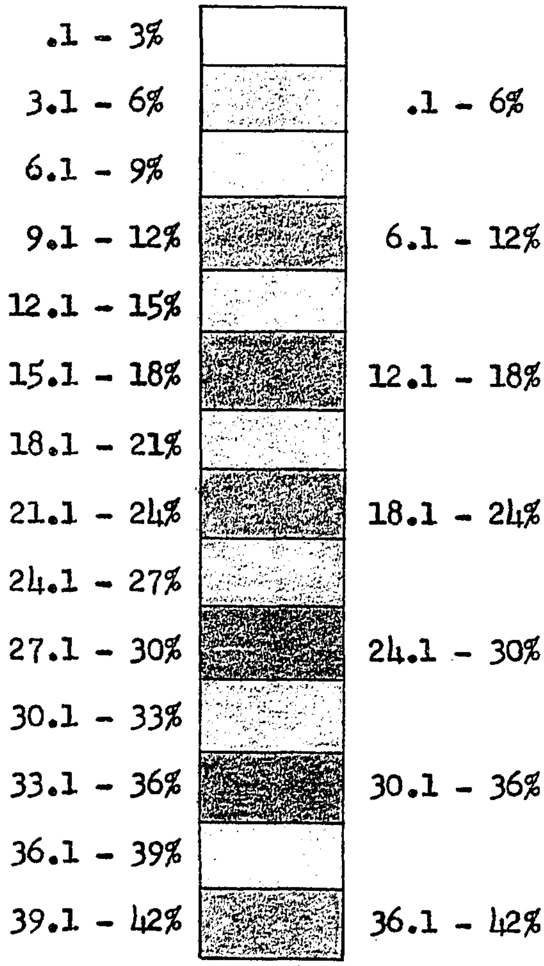
W - Wapiabi formation

II. Geographic location of joint locality is indicated by the second letter of the location designation. In general, all locations within a single formation and along the same stream have the same second letter, e.g., CN - I - all CN locations are along the Brazeau River. See Appendix A, part 3, for the location of each individual locality.

III. The Roman numeral which makes up the third component of the locality designation indicates the number of the locality within its group. Thus CN - I through CN - VI compose the entire group of localities of which CN - III is the third location established.

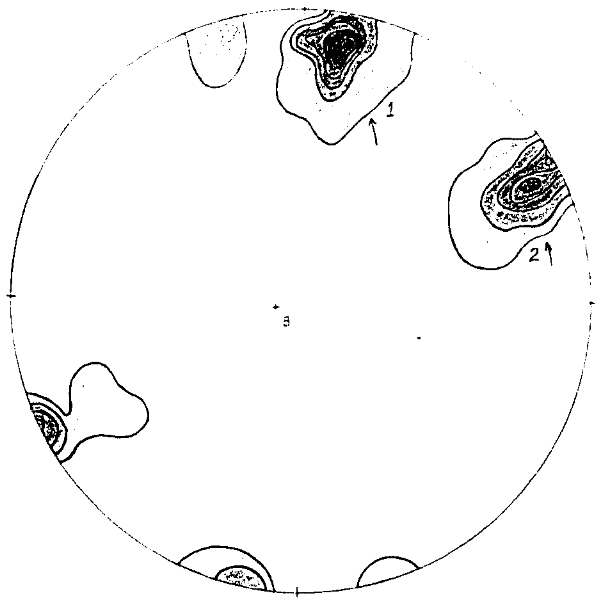
IV. The color key for contour intervals shown on Plates 1 through 72 is the following:





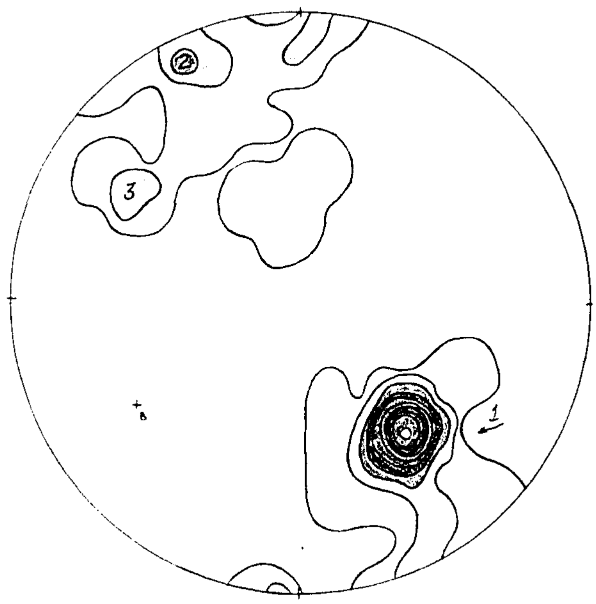
V. Arabic numerals on individual preferred orientations on the nets refer to the Areal Density Factor tabulations, not to designation of joint trends as discussed in part II, section 3.

PLATE I



AA - I

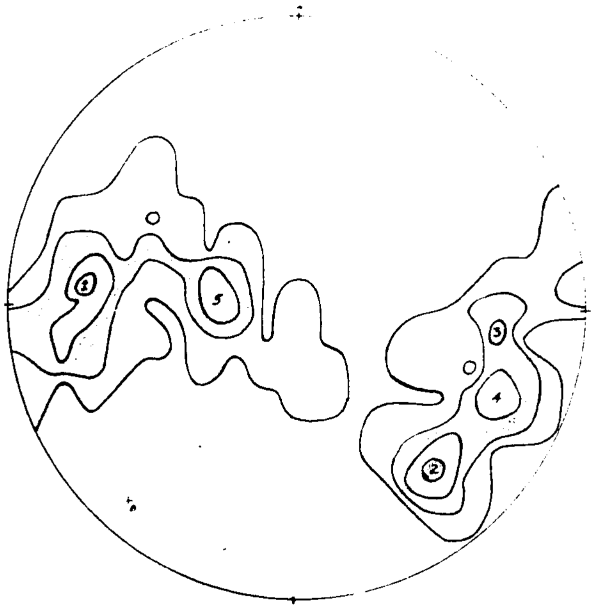
Strip Mine - Nordegg



AB - I

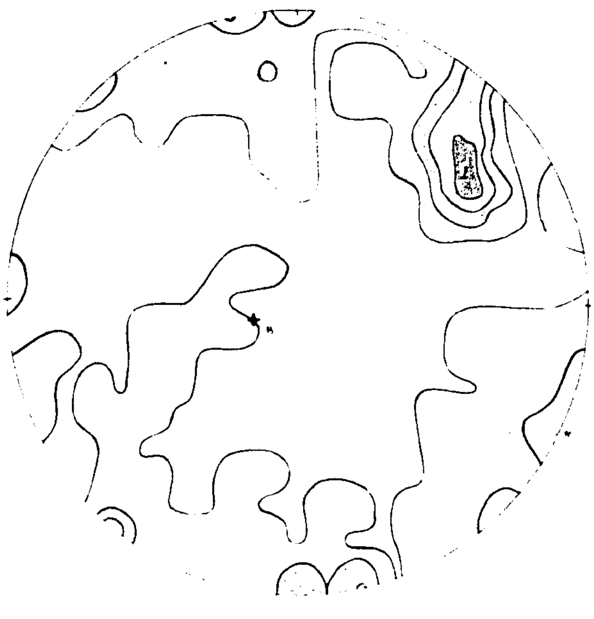
Nameless Creek

PLATE 2



AB-II

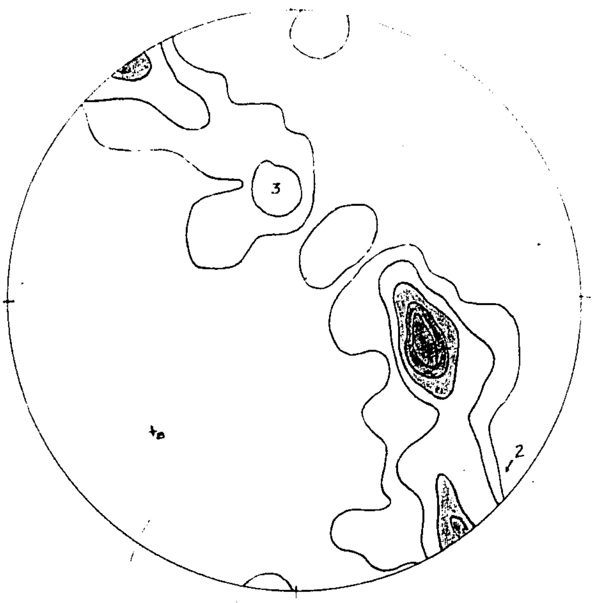
Nameless Creek



AC-I

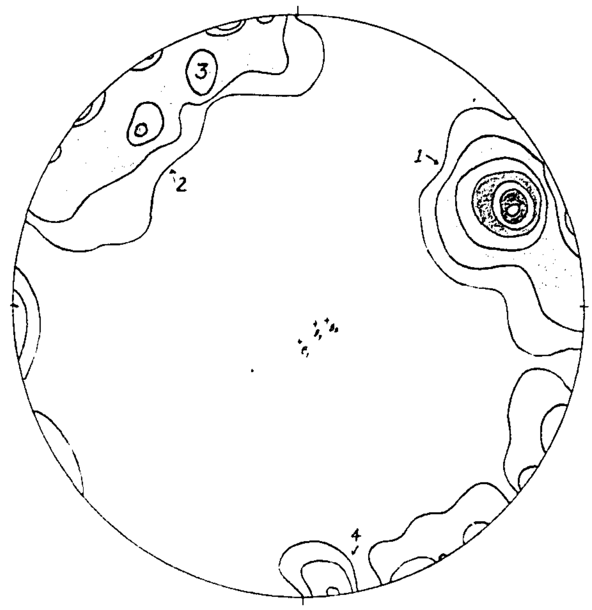
Smallpox Creek

PLATE 3



AD - I

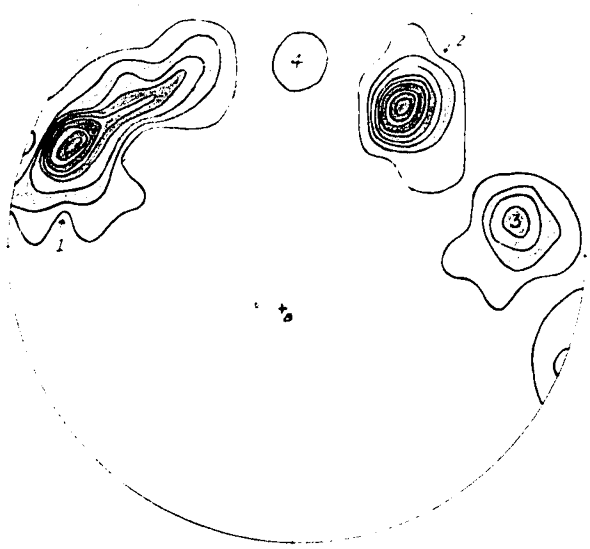
Cardinal River



AD - II

Cardinal River

PLATE 4



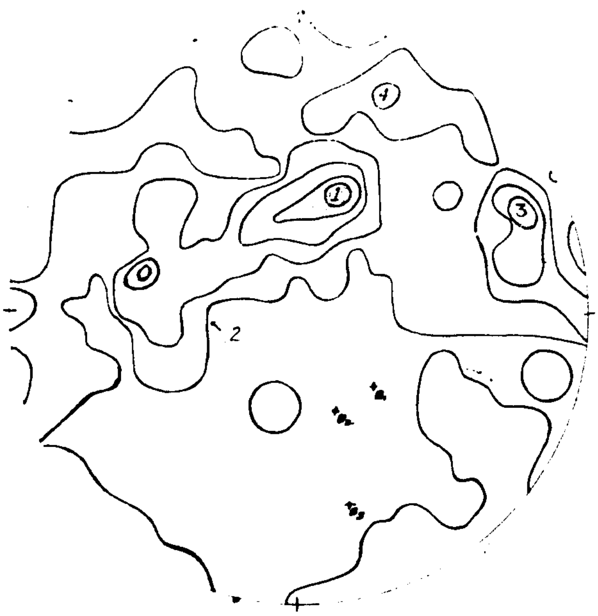
AD - III

Upper Cardinal River

AD - IV

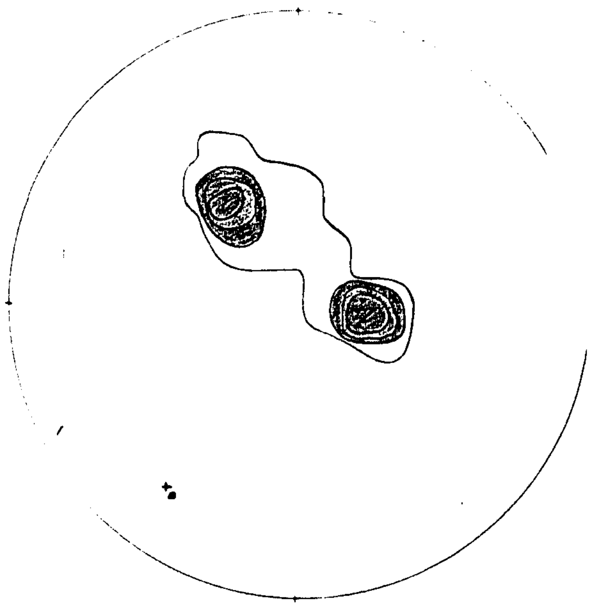
Ruby Creek

PLATE 5



AE - I

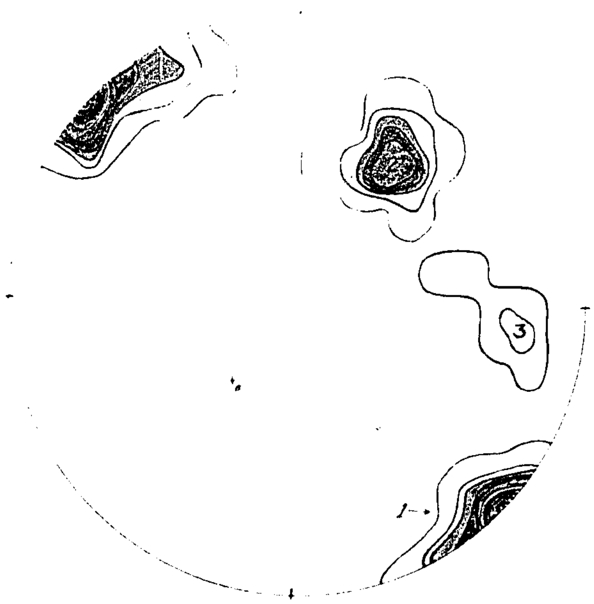
Brazeau River



BB - I

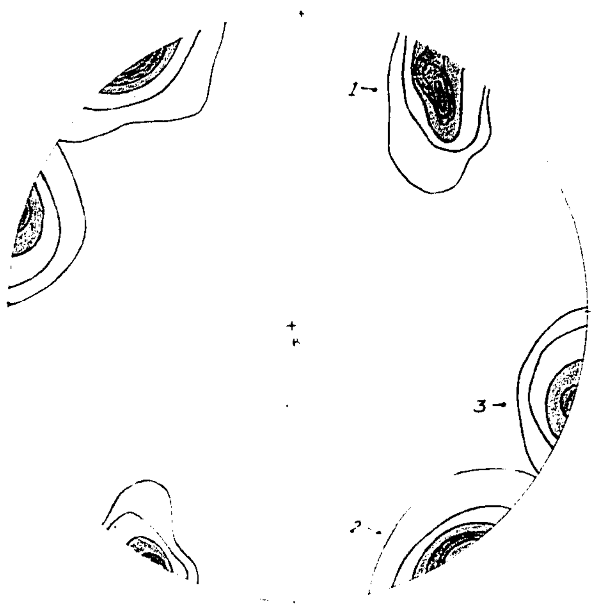
C.N.R. Trestle

PLATE 6



CC - I

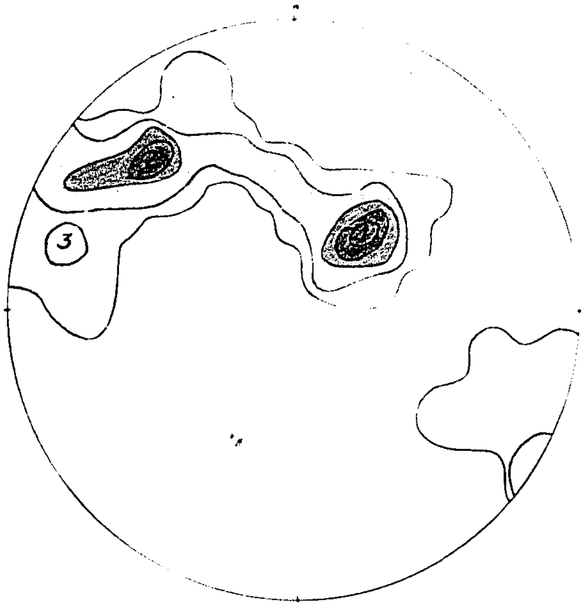
Smallpox Creek



CD - I

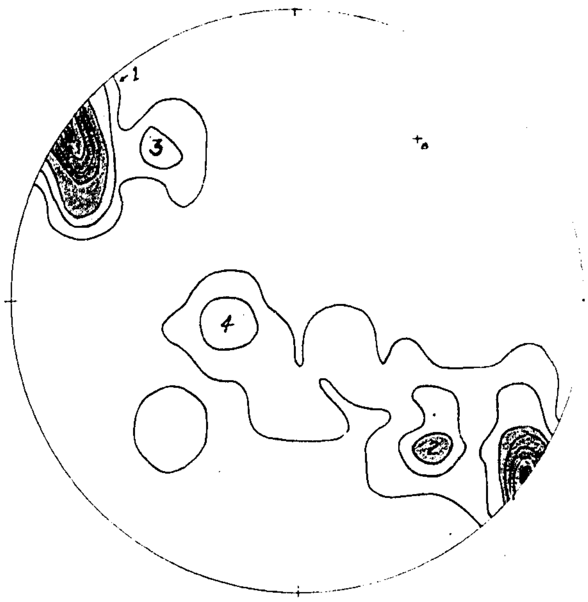
Wapiabi Creek

PLATE 7



CE - I

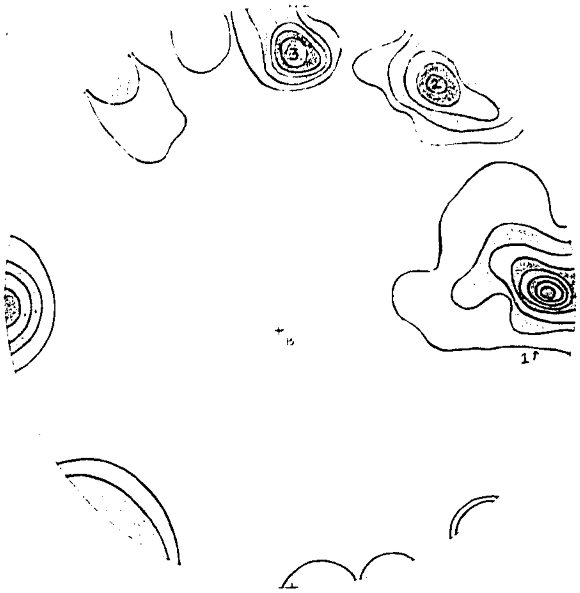
Wapiabi Creek



CF - I

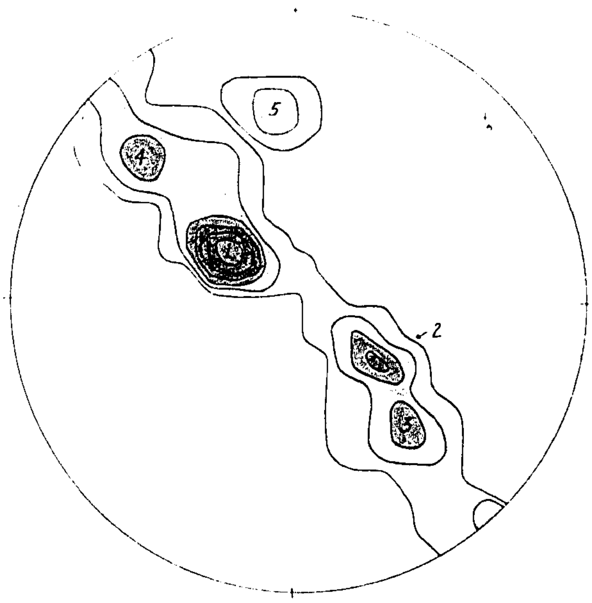
Sturrock Creek

PLATE 8



CG - I

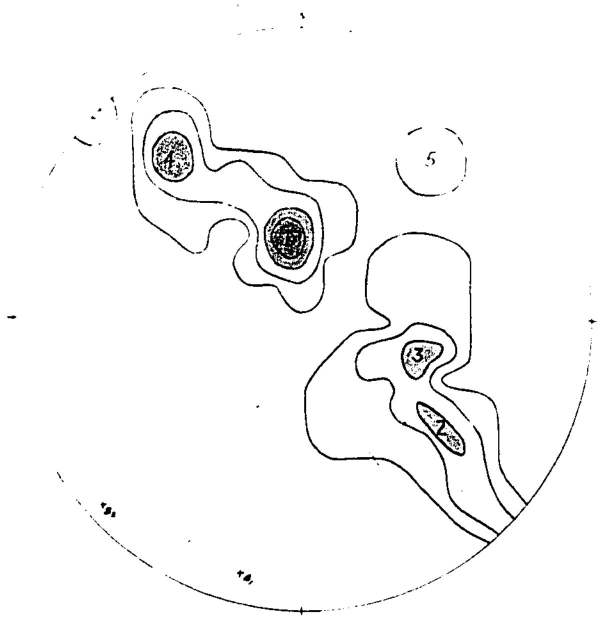
Wopiabi Creek



CH - I

Chungo Creek

PLATE 9



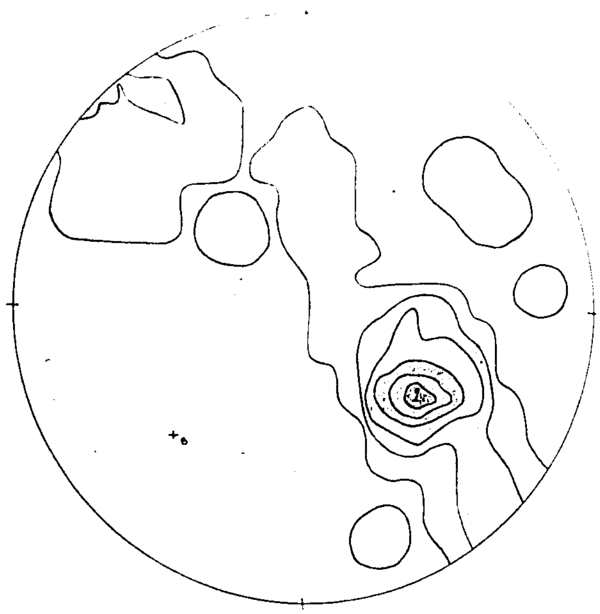
CH - II

Chungo Creek

CH - III

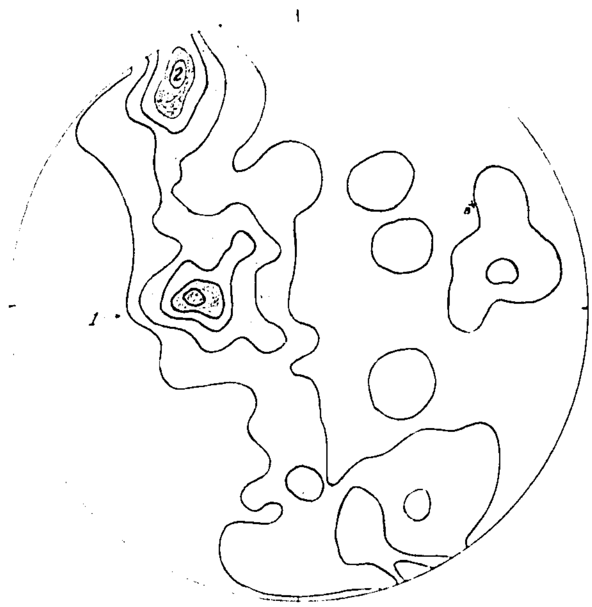
Chungo Creek

PLATE 10



CI - I

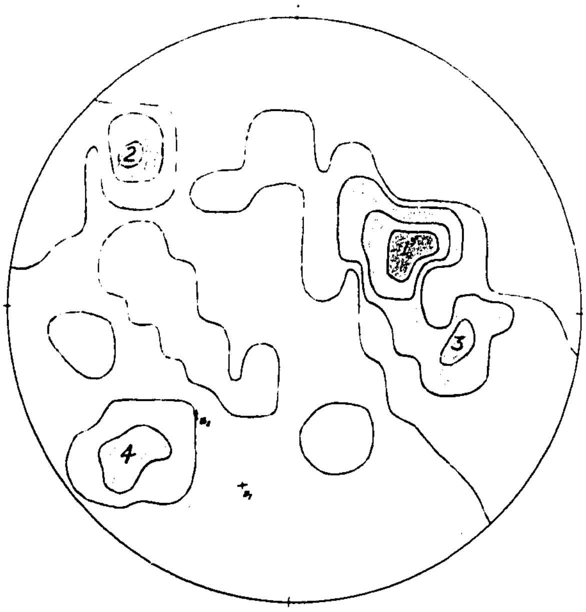
Brown Creek



CI - II

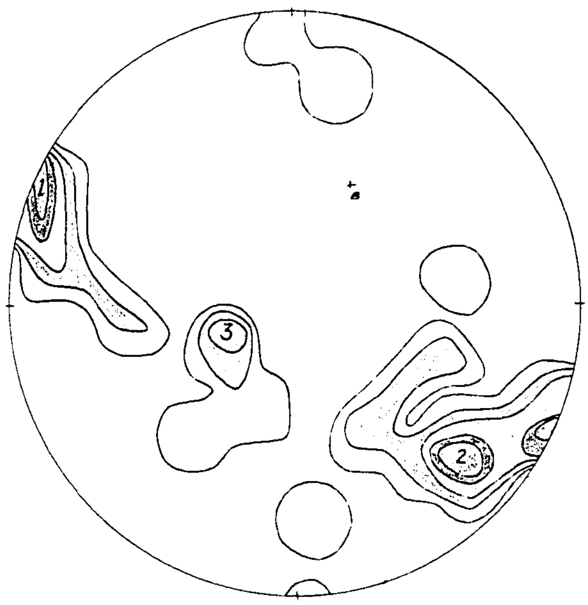
Brown Creek

PLATE 11



CI - III

Brown Creek



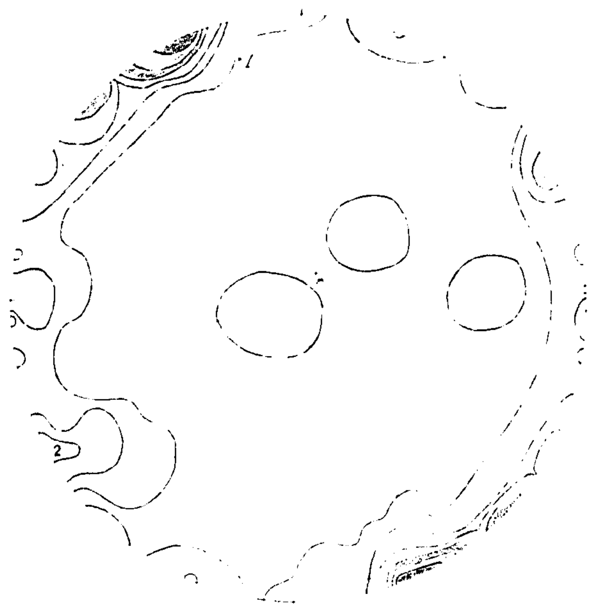
CI - IV

Brown Creek

PLATE 12

CI - V

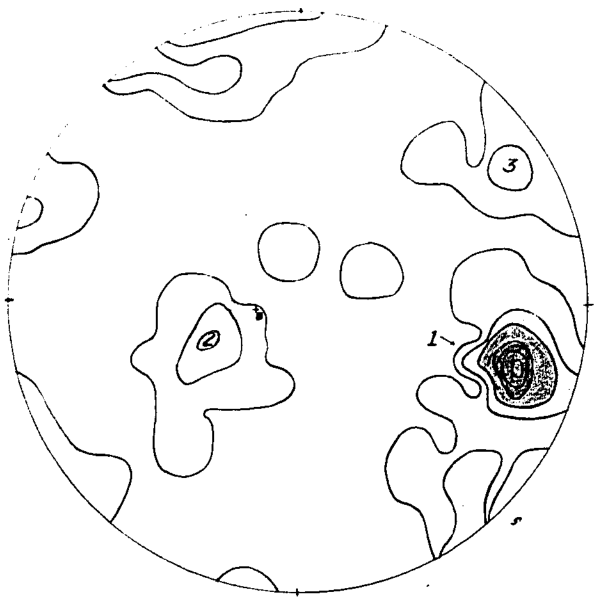
Brown Creek



CI - VI

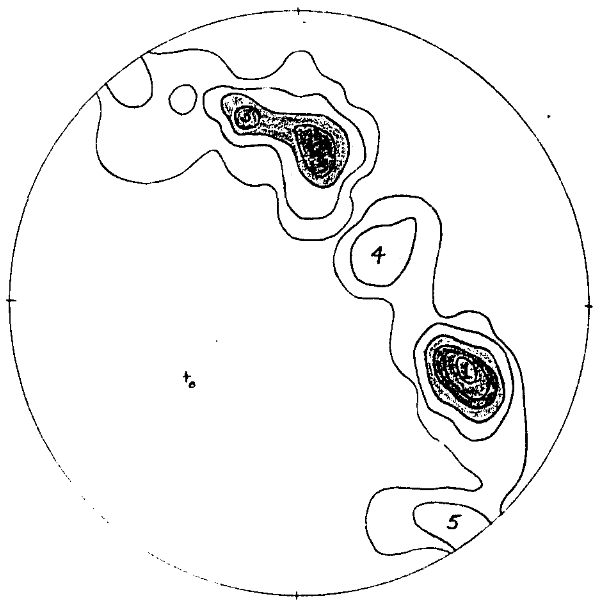
Brown Creek

PLATE 13



CJ - I

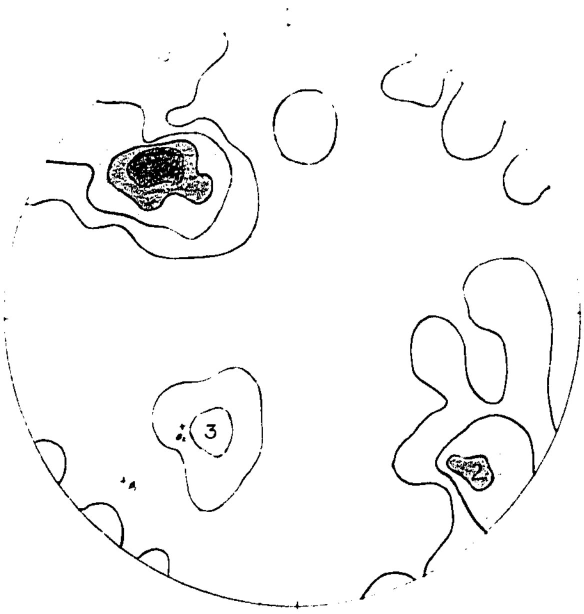
Canyon Creek



CJ - II

Canyon Creek

PLATE 14



CJ - III

Canyon Creek

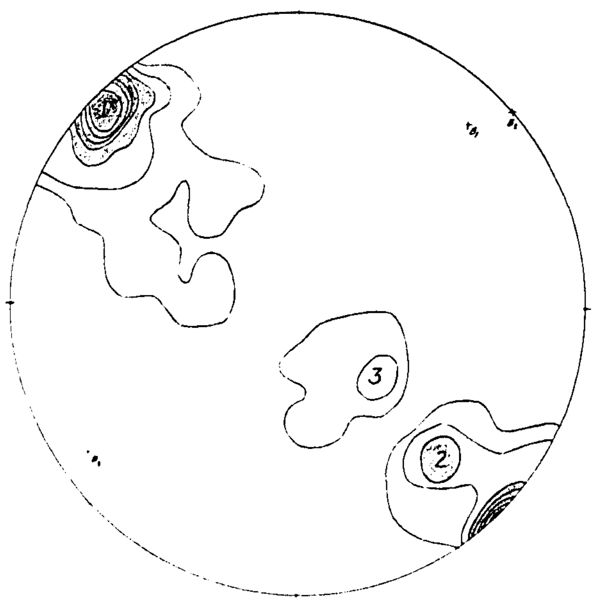
CJ - IV

Canyon Creek

PLATE 15

CK - I

Upper Brown Creek



CK - II

Upper Brown Creek

PLATE 16

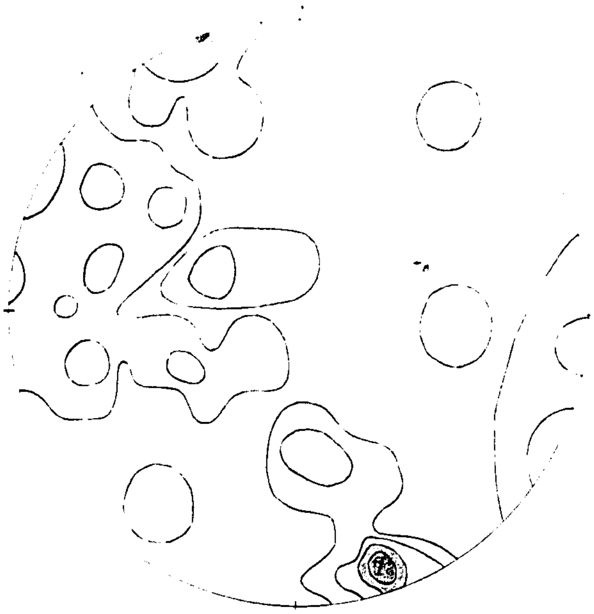
CK - III

Upper Brown Creek

CK - IV

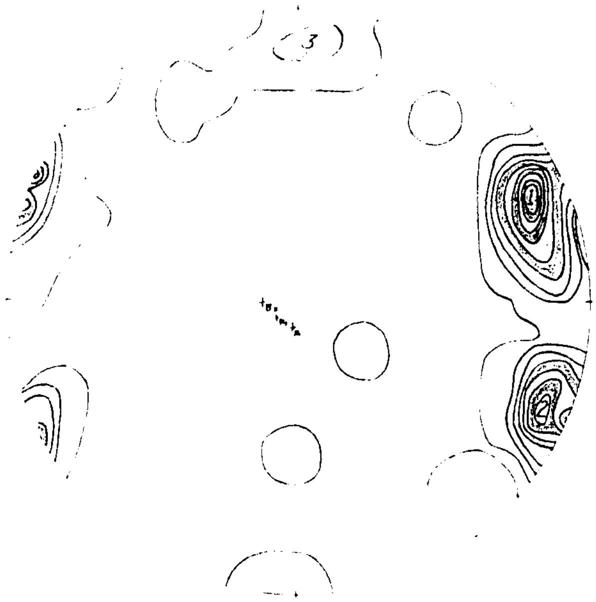
Upper Brown Creek

PLATE 17



CK - V

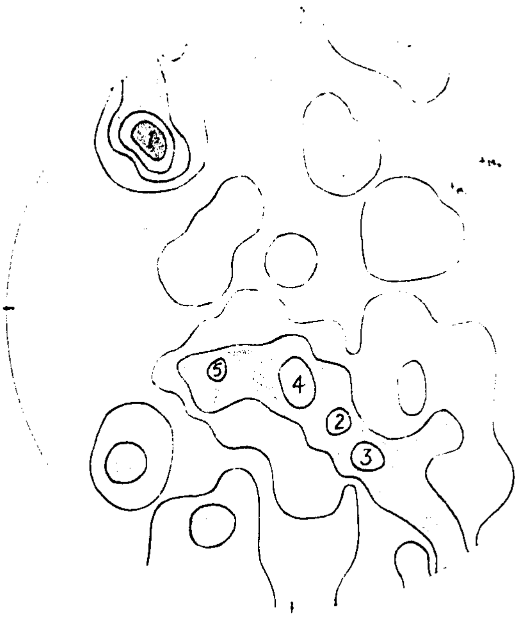
Upper Brown Creek



CL - I

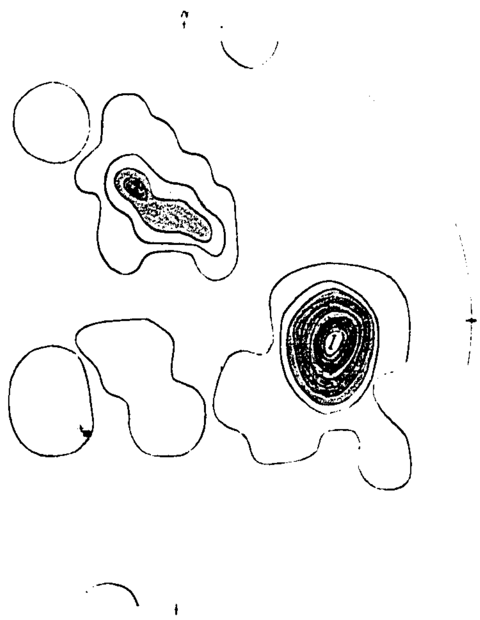
Thistle Creek

PLATE 18



CL - II

Thistle Creek



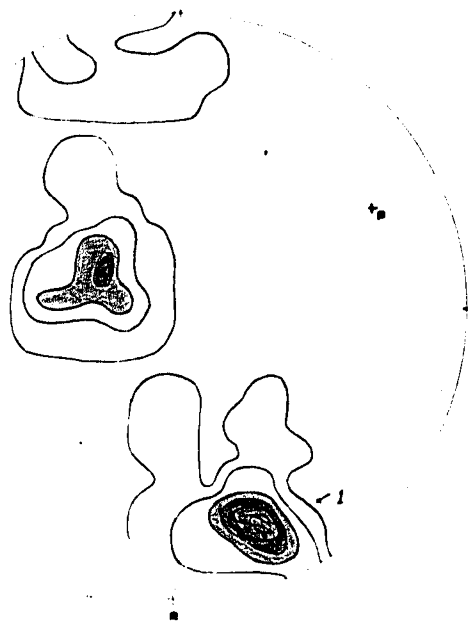
CL - III

Thistle Creek

PLATE 19

CM - I

Cardinal River



CM - II

Lower Cardinal River

PLATE 20

CM - III

Lower Cardinal River

CM - IV

Lower Cardinal River

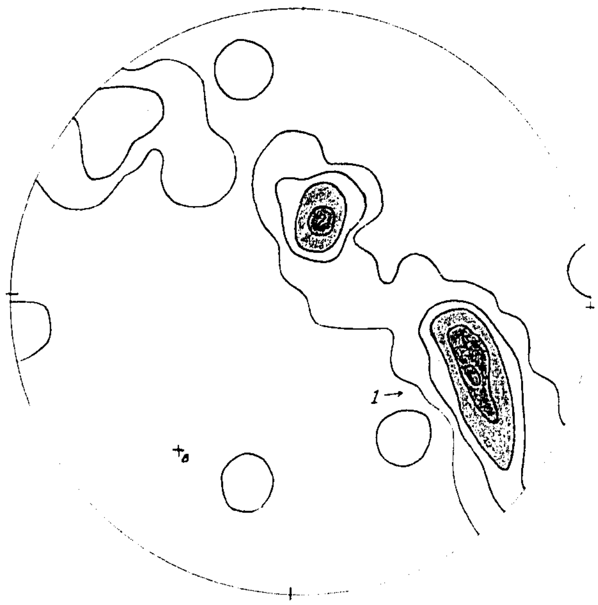
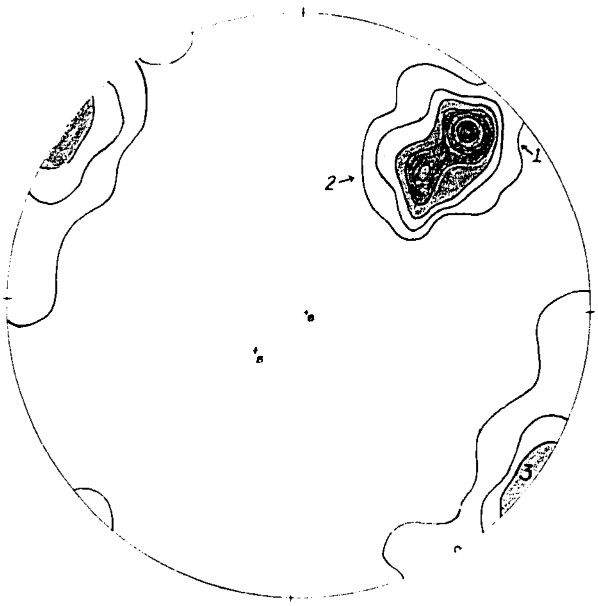


PLATE 21

CM - V

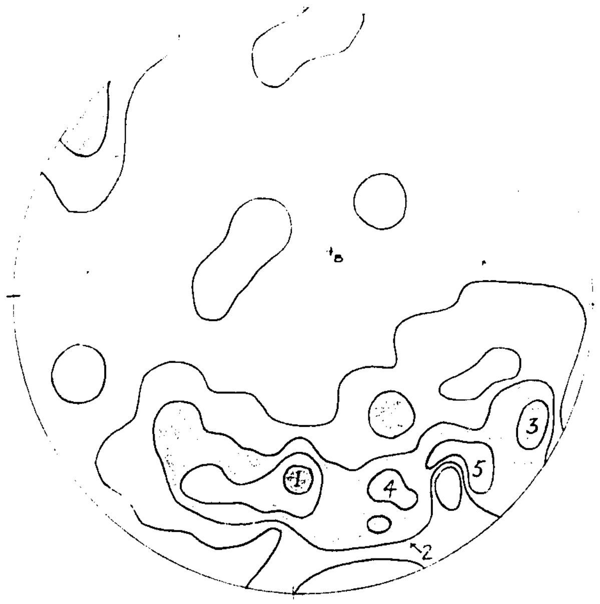
Middle Cardinal River



CM - VI

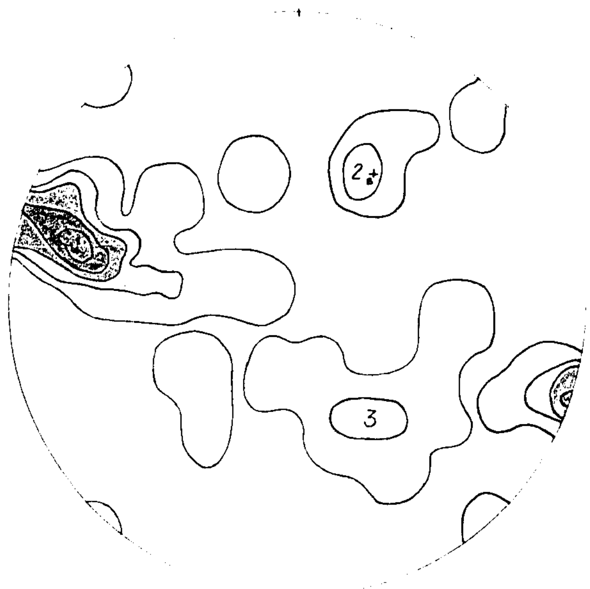
Cardinal River

PLATE 22



CM - VII

Cardinal River



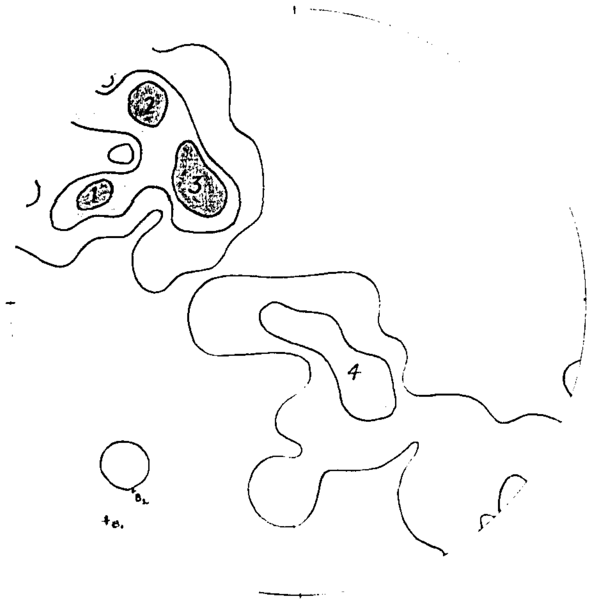
CM - VIII

Cardinal River

PLATE 23

CN - I

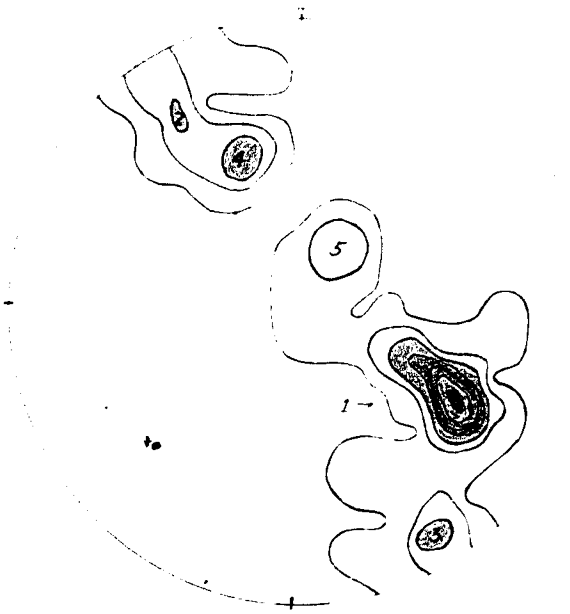
Brazeau River



CN - II

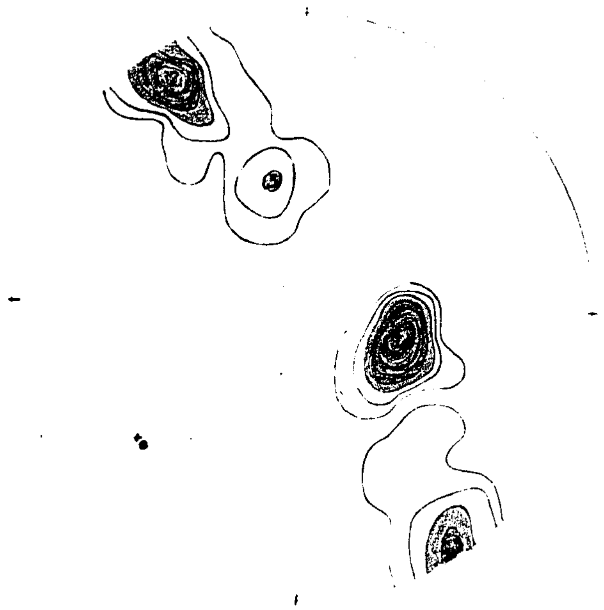
Brazeau River

PLATE 24



CN - III

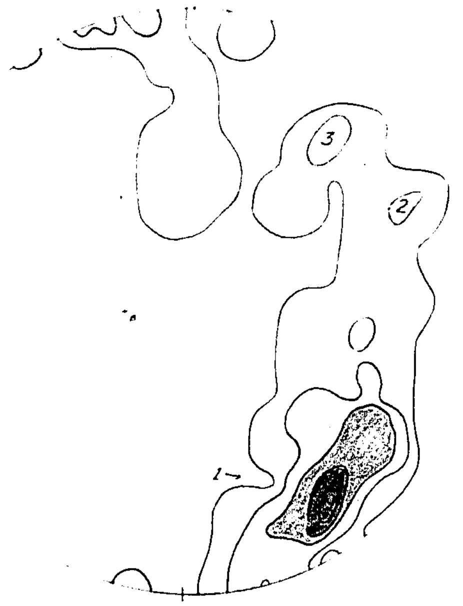
Brazeau River



CN - IV

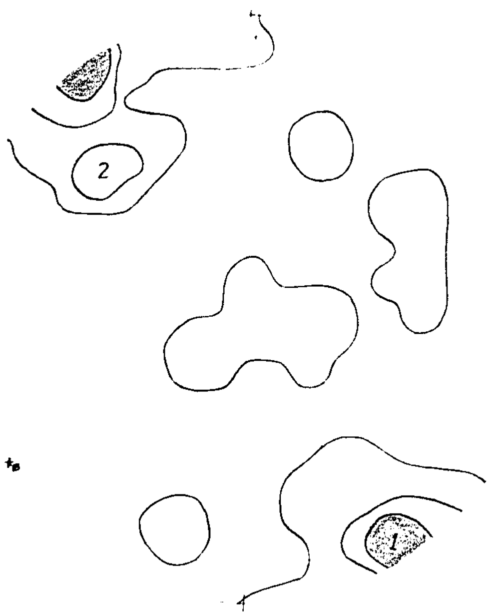
Brazeau River

PLATE 25



CN - V

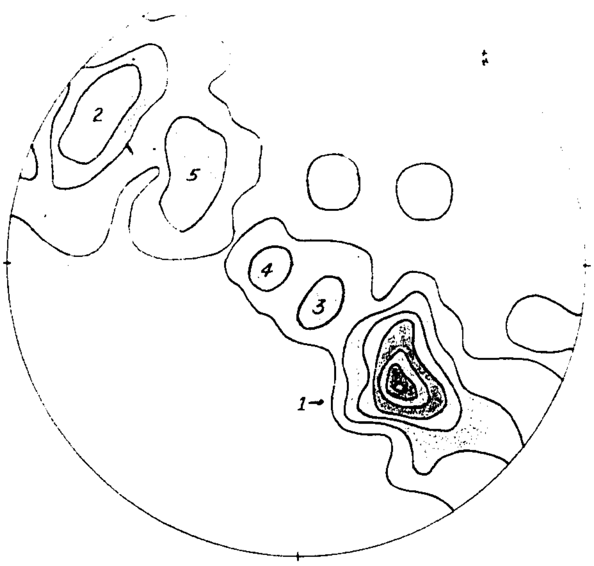
Brazeau River



CN - VI

Brazeau River

PLATE 26



CO - I

Hanson Creek

CO - II

Hanson Creek

PLATE 27

CO-III

Hanson Creek

CP-I

Rat Creek

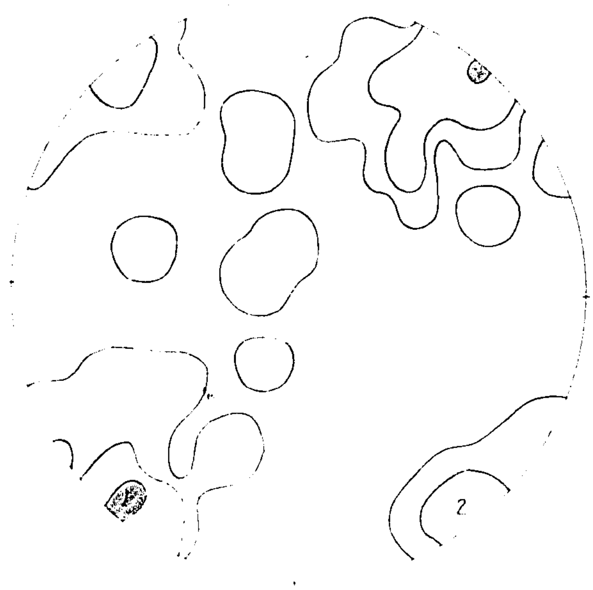


PLATE 28

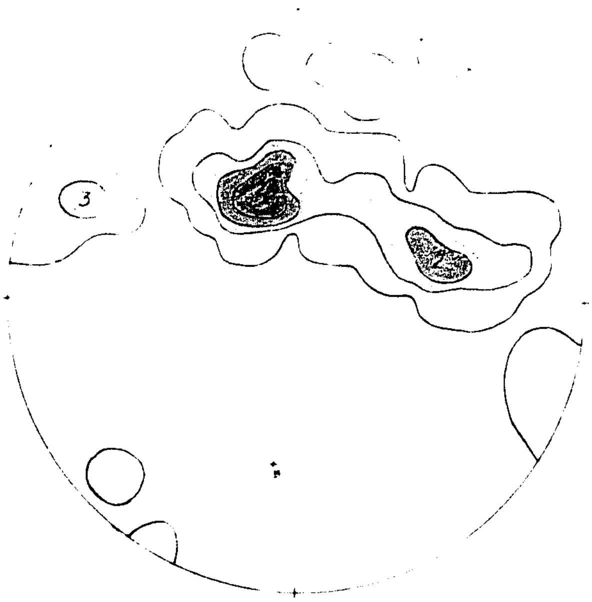
CP - II

Rat Creek

CP - III

Rat Creek

PLATE 29



CP - IV

Rat Creek

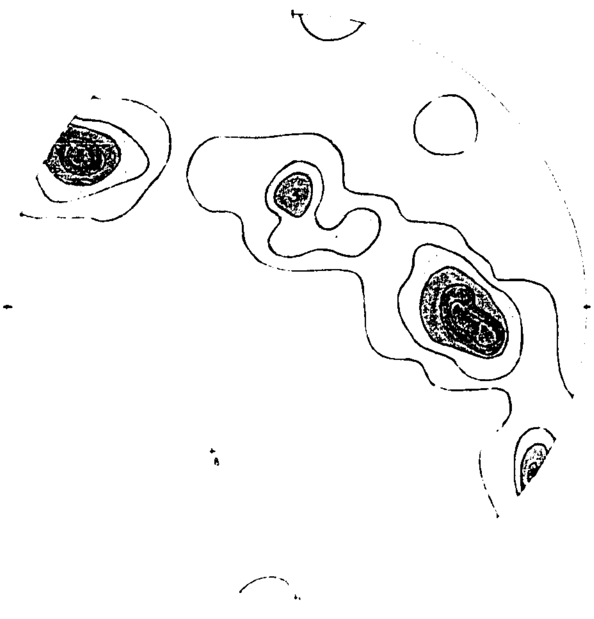
CQ - I

Pembina River

PLATE 30

CQ - II

Pembina River



CQ - III

Pembina River

PLATE 31

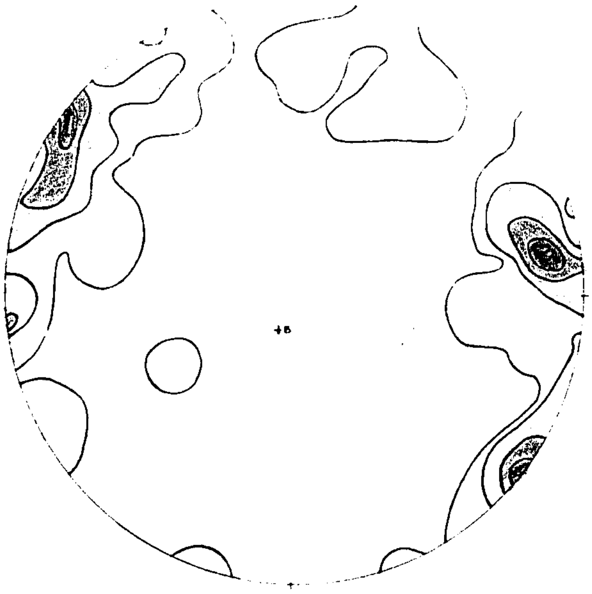
CR - I

Pembina River

CR - II

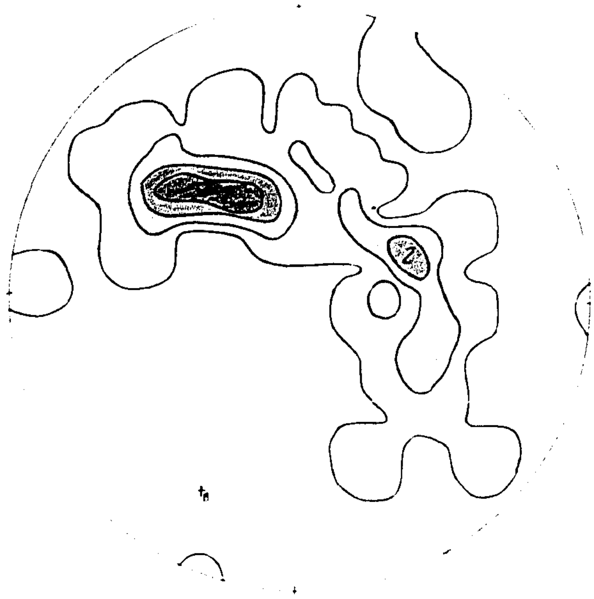
Pembina River

PLATE 32



CR - III

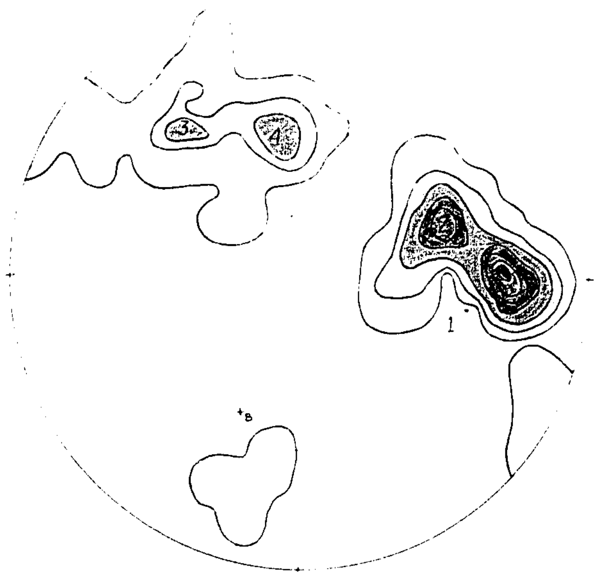
Pembina River



CS - I

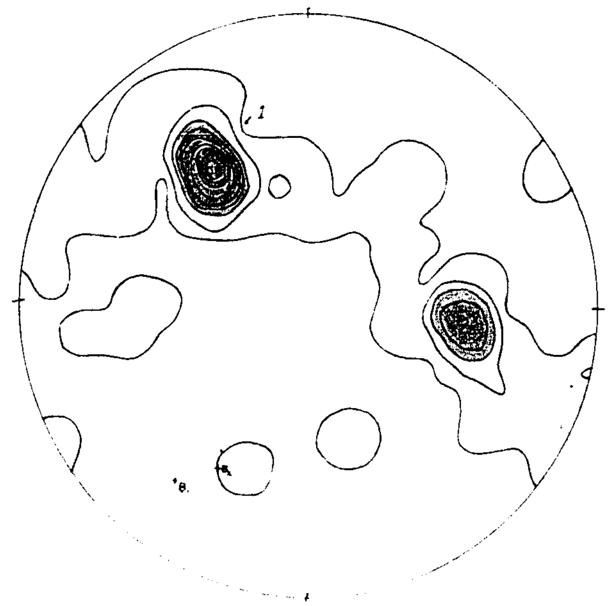
Mackenzie River

PLATE 33



CS - II

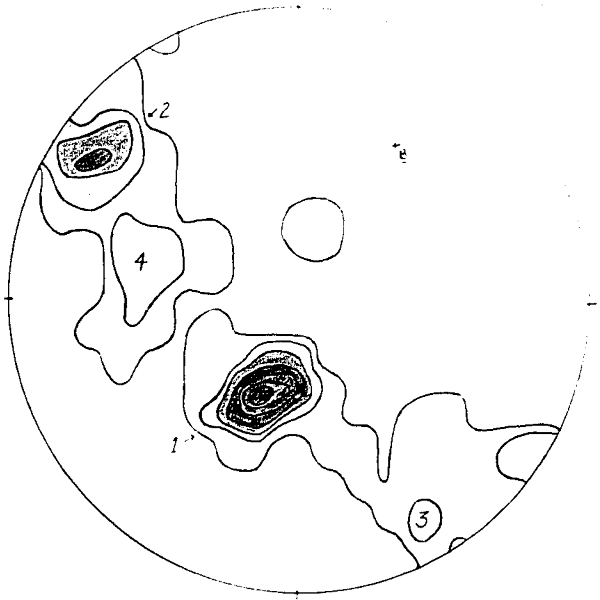
Mackenzie River



CS - III

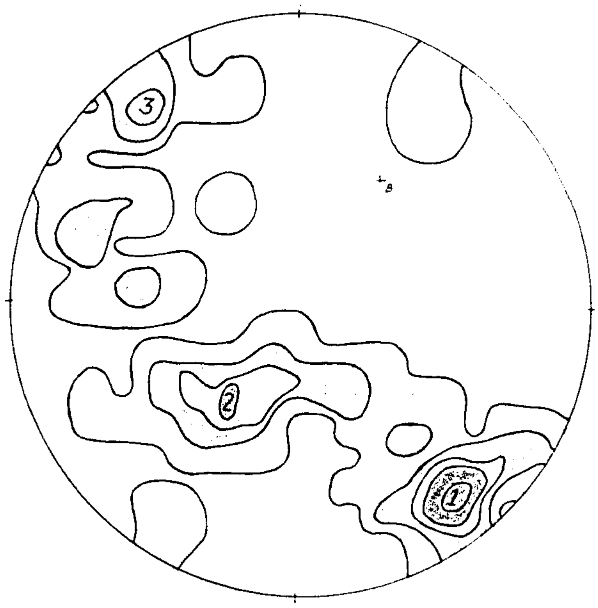
Mackenzie River

PLATE 34



CT - I

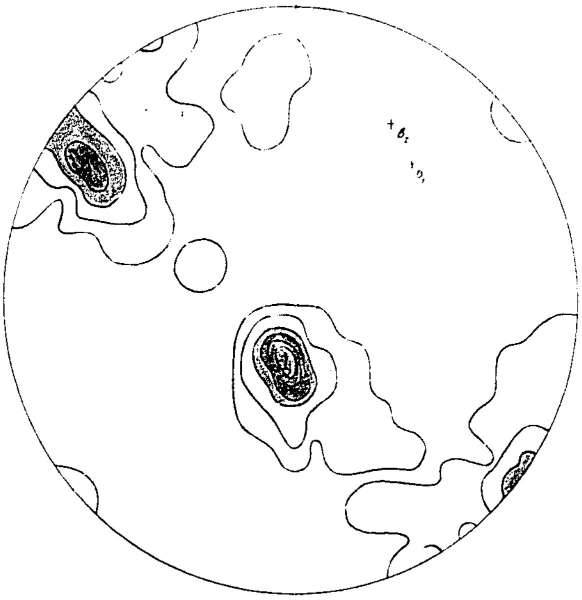
Luscar Creek



CT - II

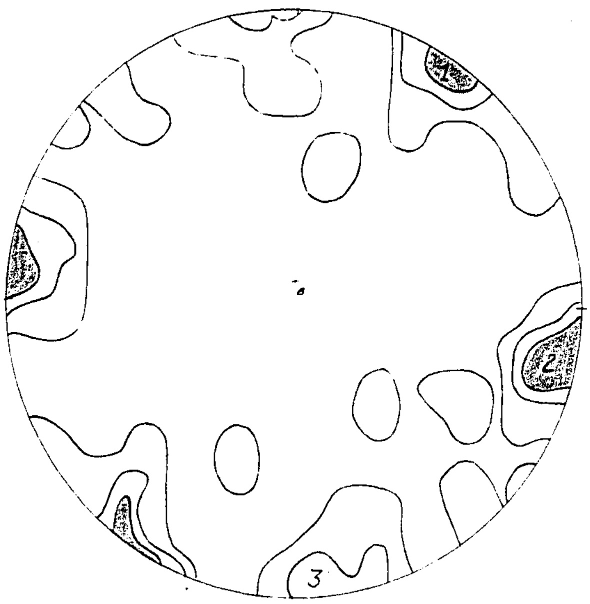
Luscar Creek

PLATE 35



CT - III

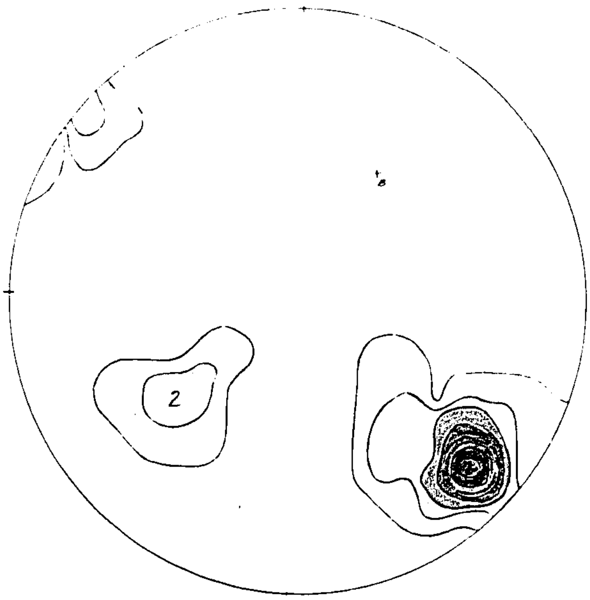
Luscar Creek



DD - I

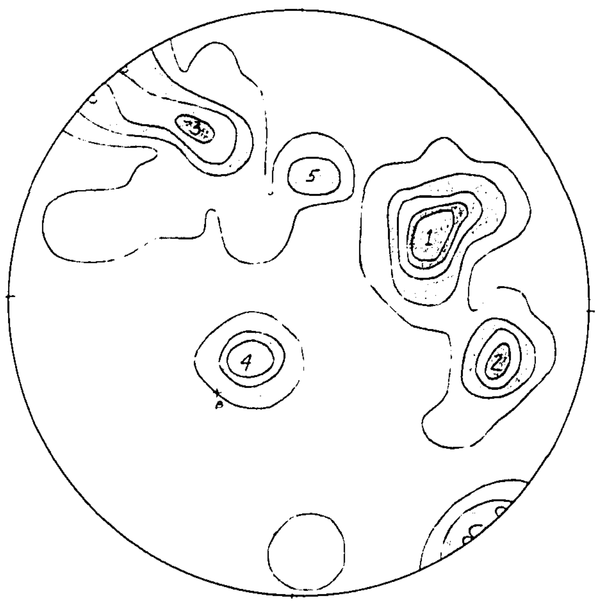
Wapiabi Creek

PLATE 36



DD - II

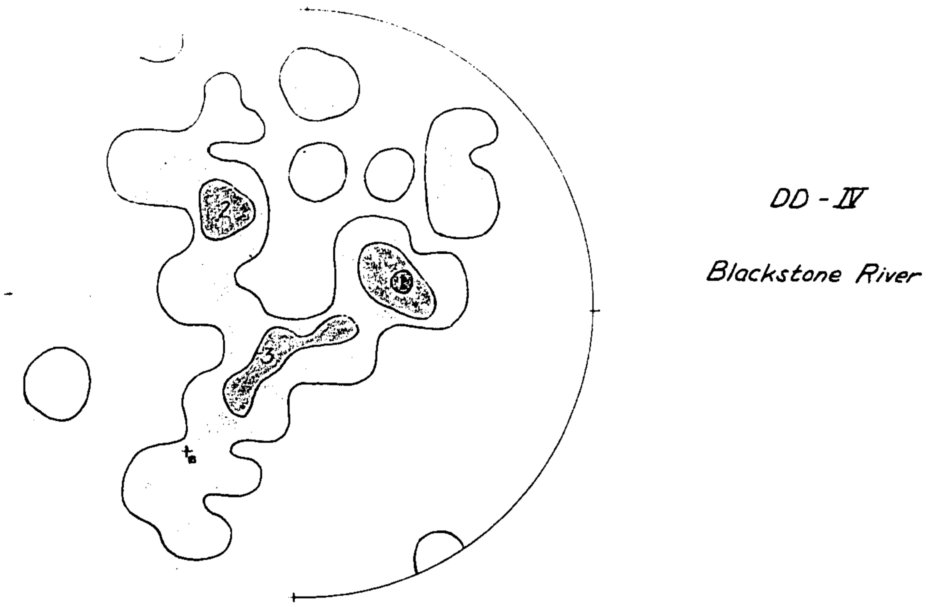
Wapiabi Creek



DD - III

Blackstone River

PLATE 37



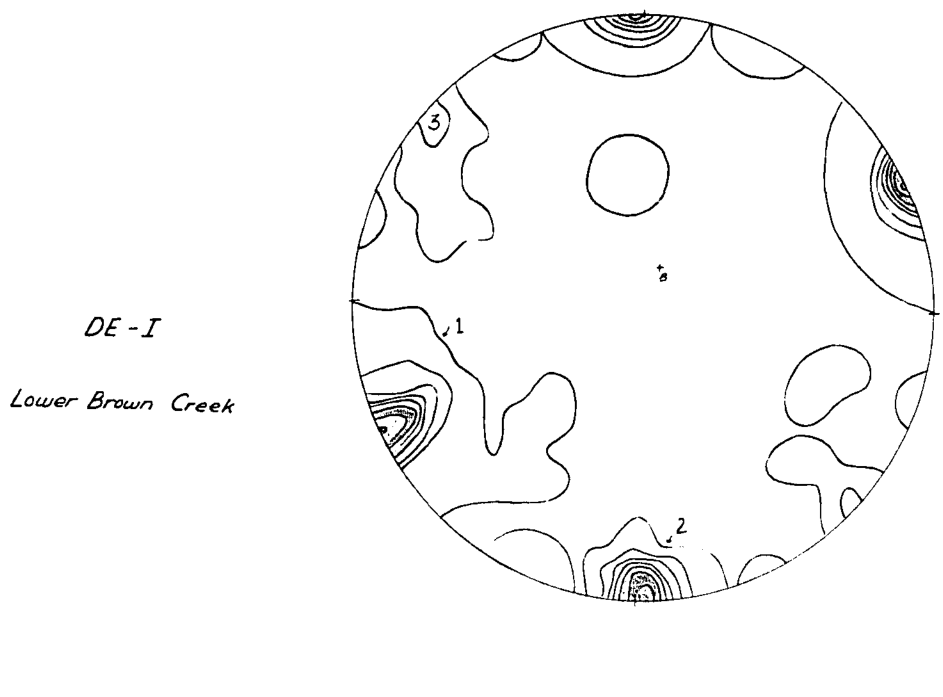
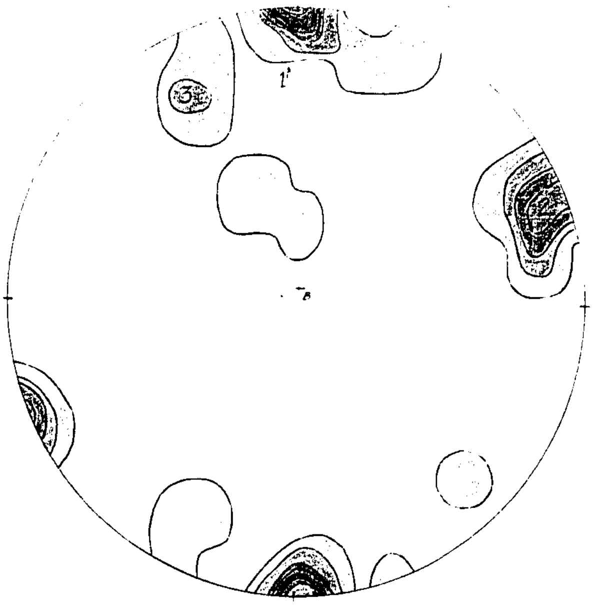
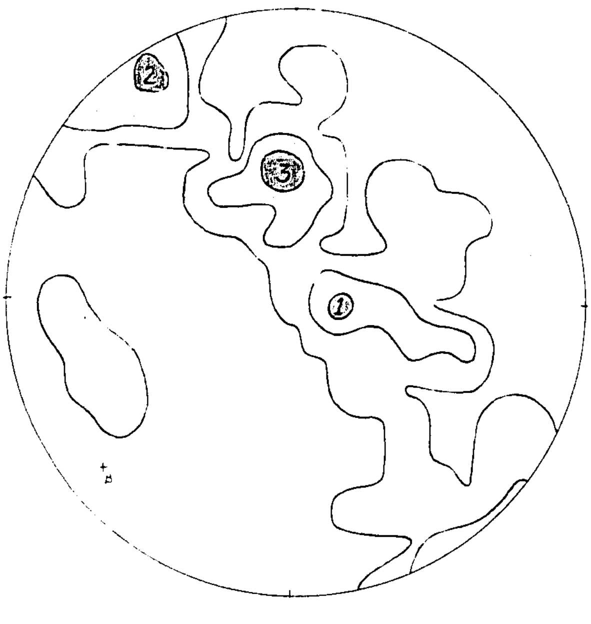


PLATE 38



DE - II

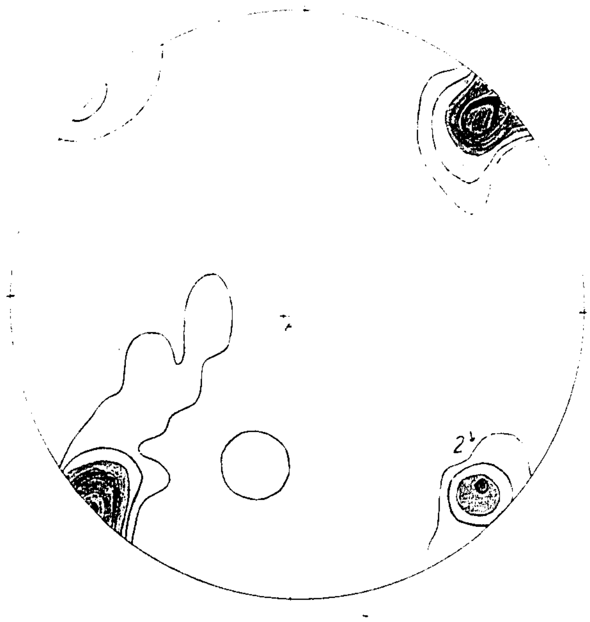
Lower Brown Creek



DF - I

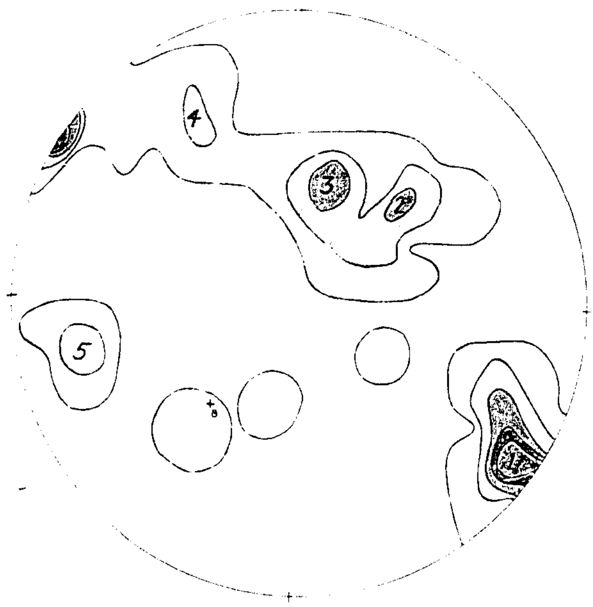
Middle Brown Creek

PLATE 39



DG - I

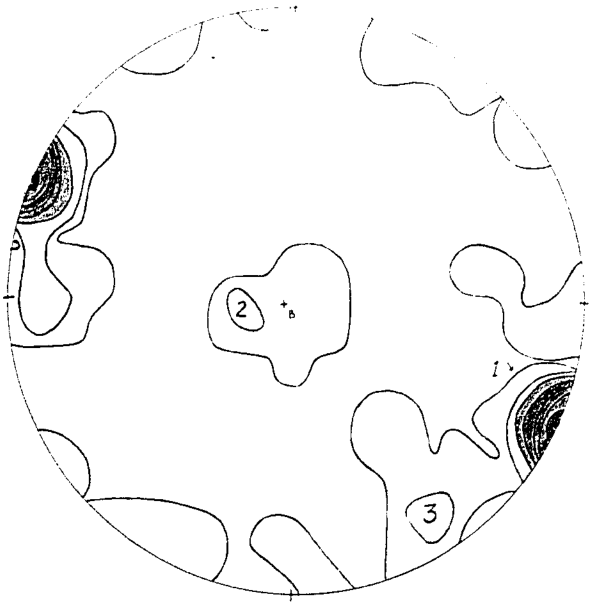
Southesk River



DH - I

Cardinal River

PLATE 40



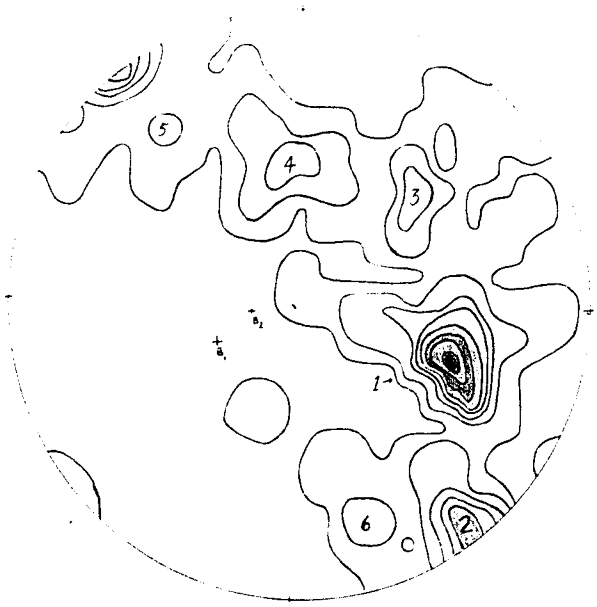
DH - II

Cardinal River

DH - III

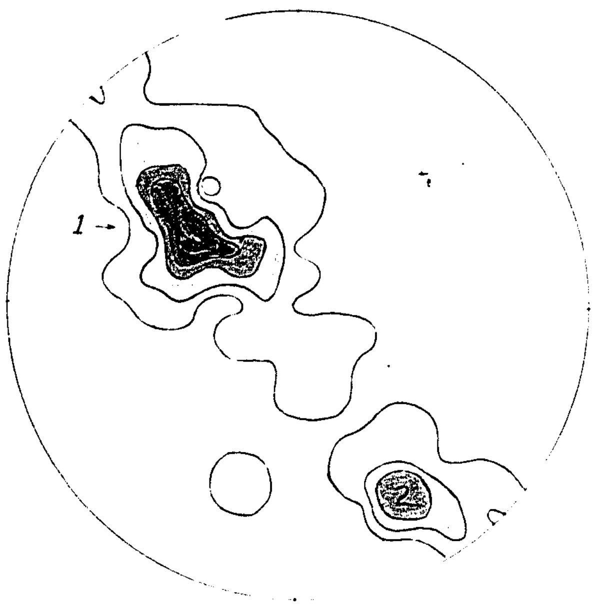
Cardinal River

PLATE 41



DH - IV

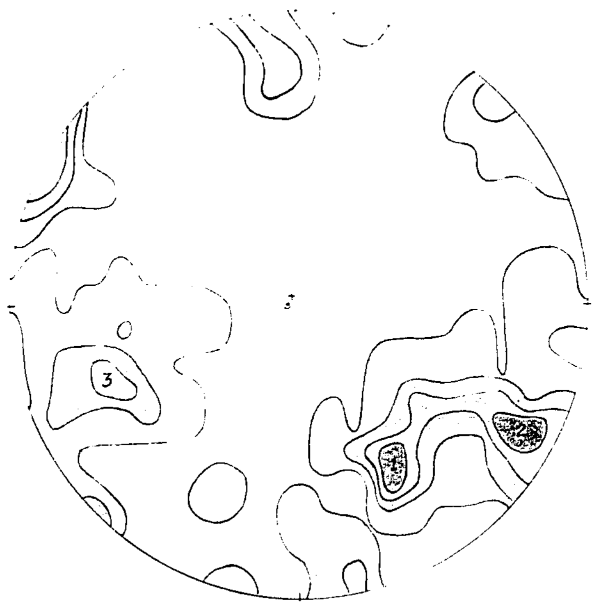
Lower Cardinal River



DI - I

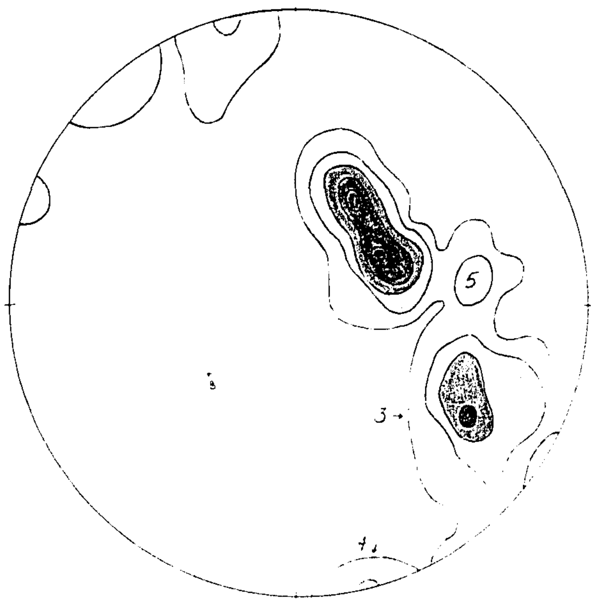
Thistle Creek

PLATE 42



DI - II

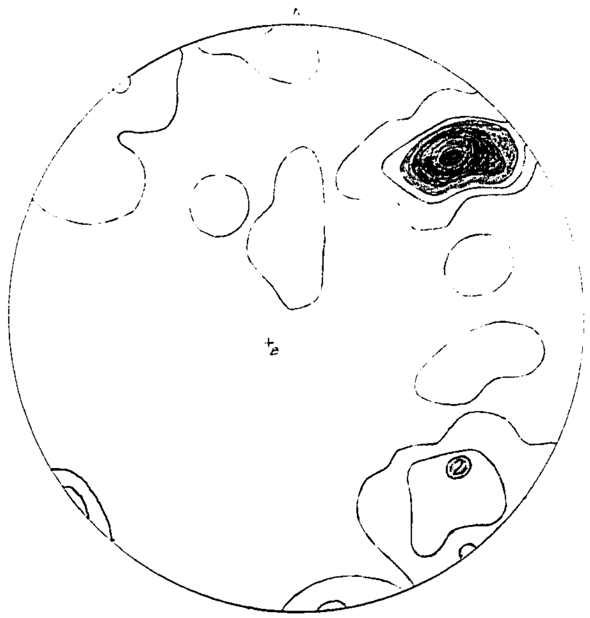
Thistle Creek



DI - III

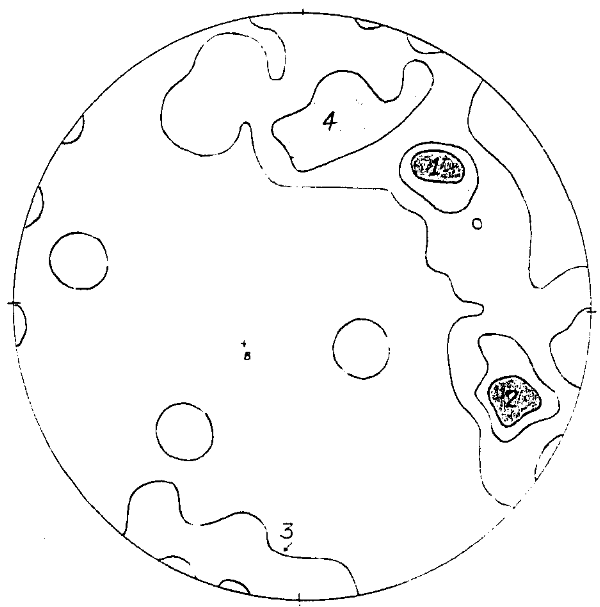
Thistle Creek

PLATE 43



DI-IV

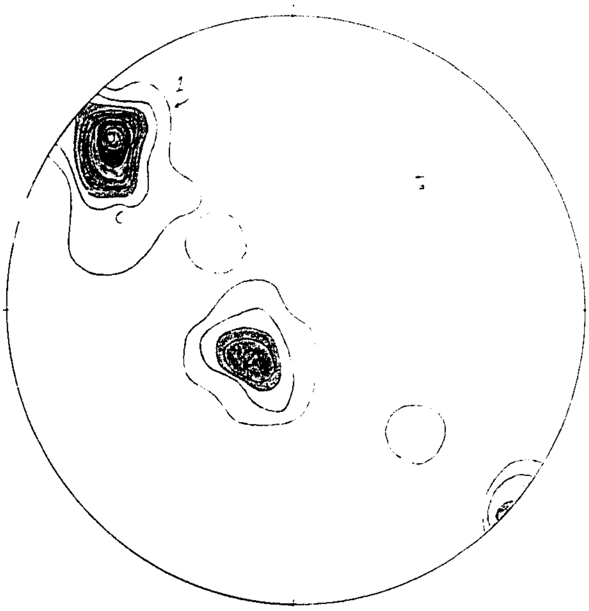
Upper Thistle Creek



DI-V

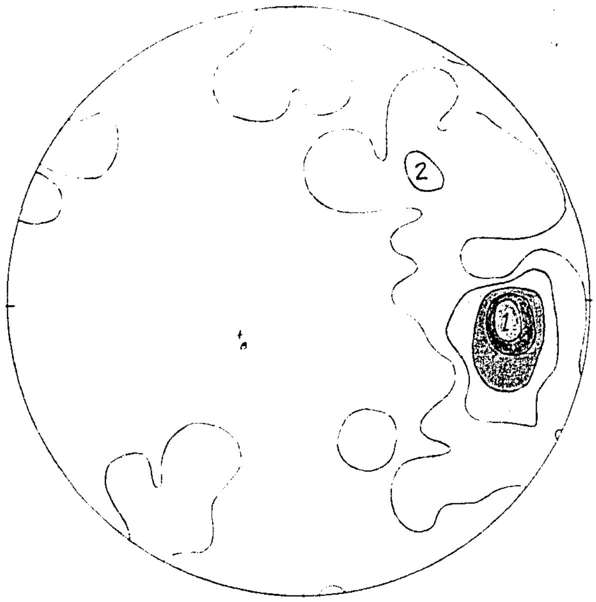
Upper Thistle Creek

PLATE 44



DJ - I

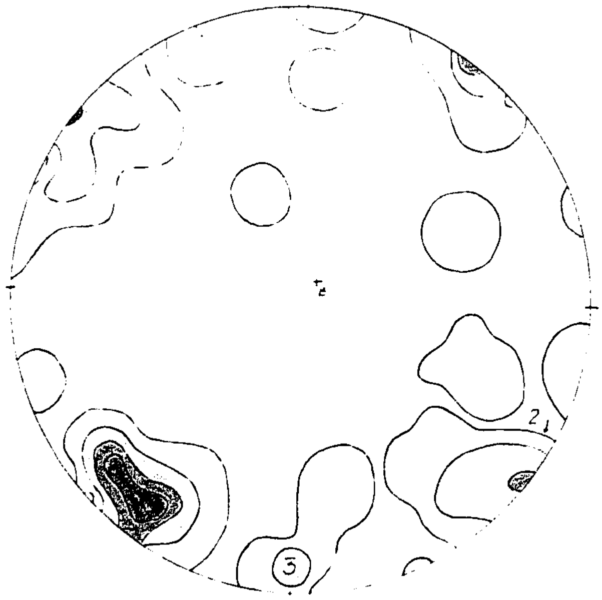
Brazeou River



DJ - II

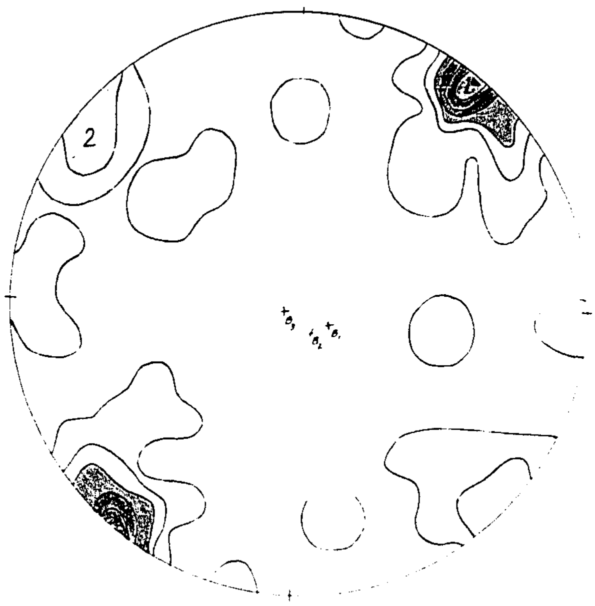
Brazeou River

PLATE 45



DJ-III

Brazeau River



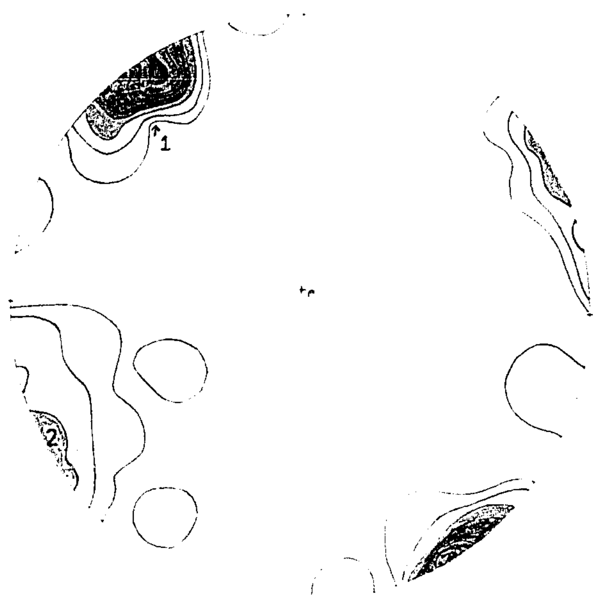
DJ-IV

Brazeau River

PLATE 46

DK - I

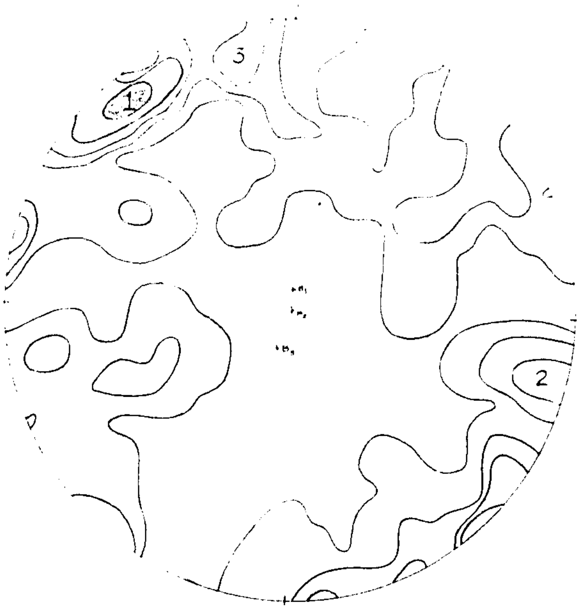
Crooked Creek



DK - II

Pembina River

PLATE 47



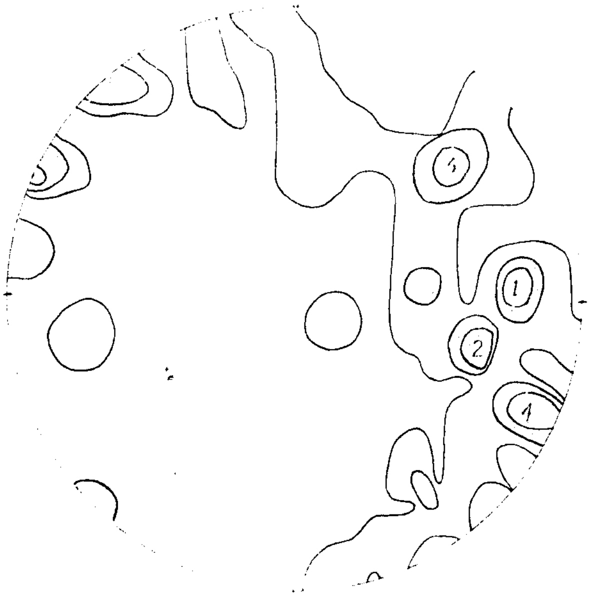
DK - III

Pembina River

DK - IV

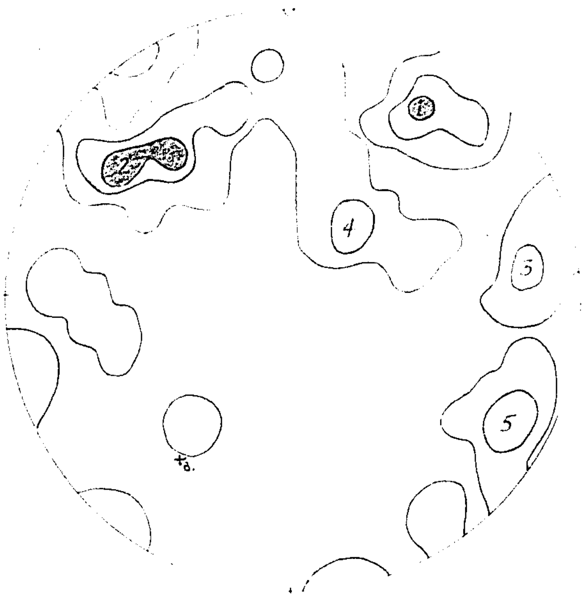
Upper Pembina River

PLATE 48



DK-V

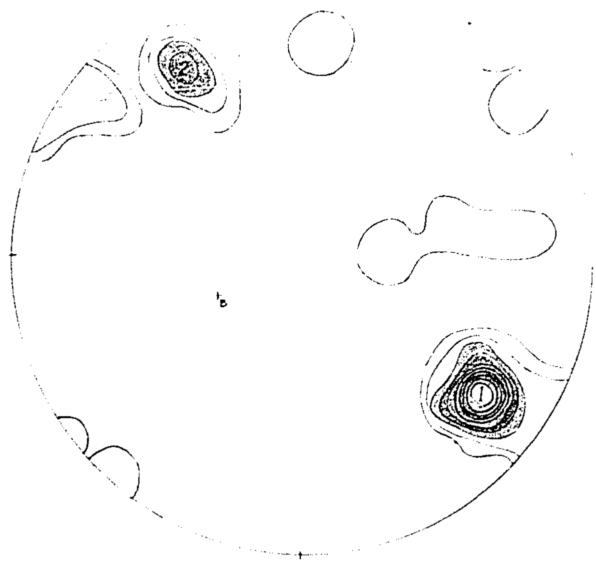
Upper Pembina River



DK-VI

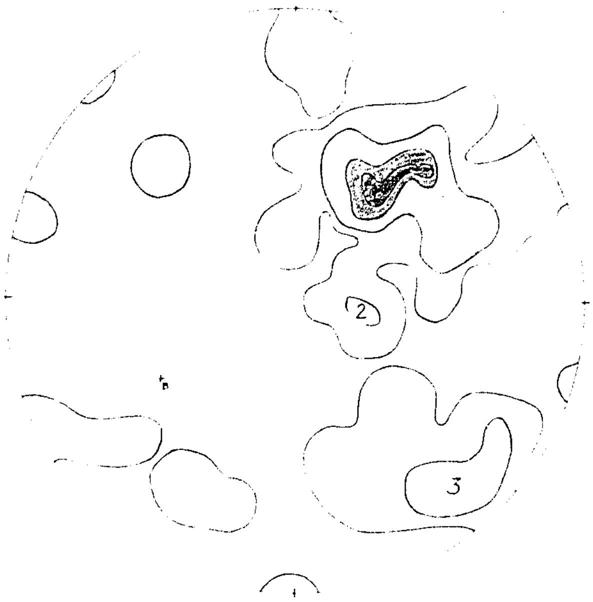
Upper Pembina River

PLATE 49



DK - VII

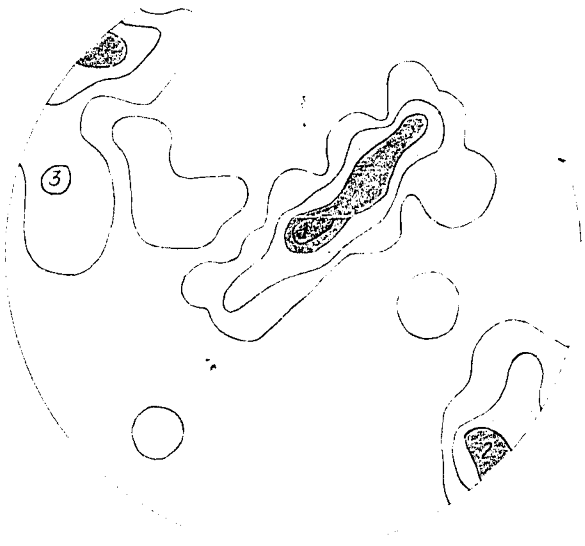
Upper Pembina River



DK - VIII

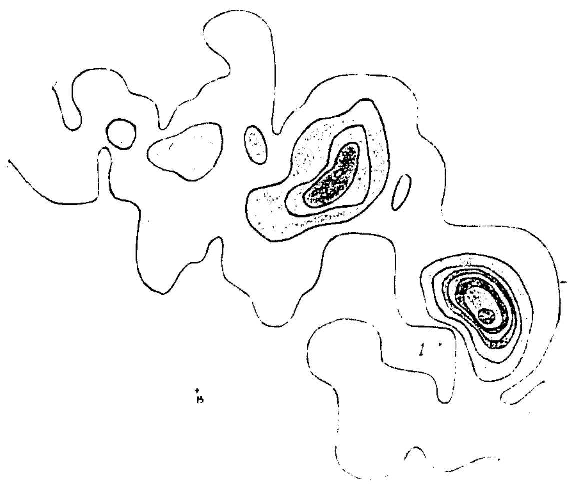
Upper Pembina River

PLATE 50



DL - I

Upper Honson Creek



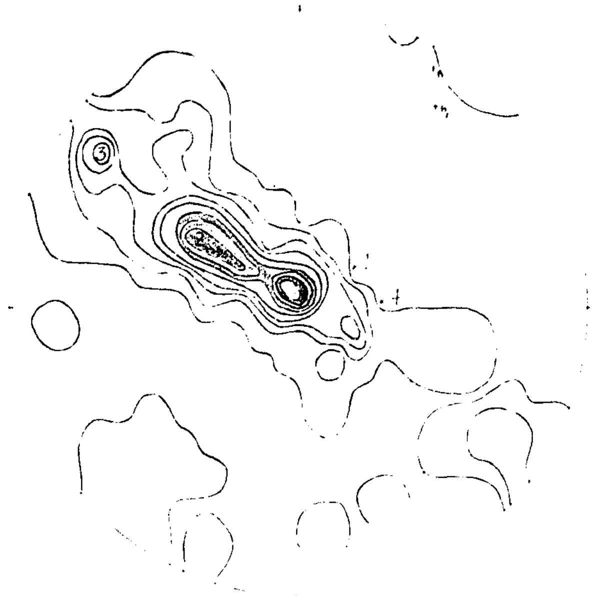
DN - I

Pembina River

PLATE 51

DN-II

Pembina River



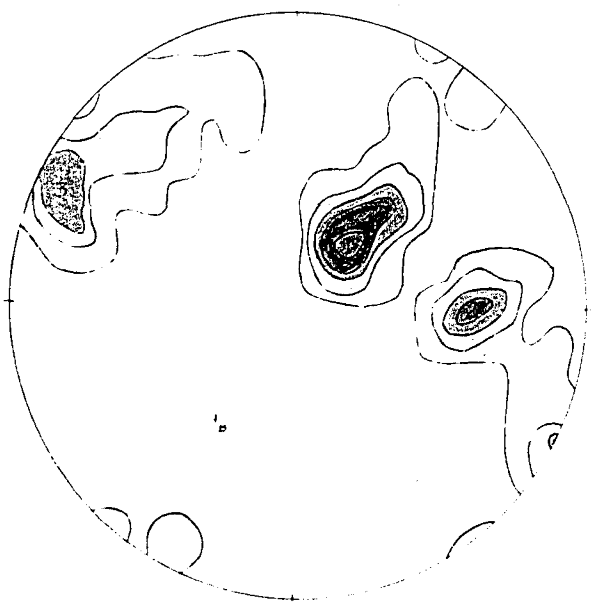
DN - III

Pembina River

PLATE 52

DN - IV

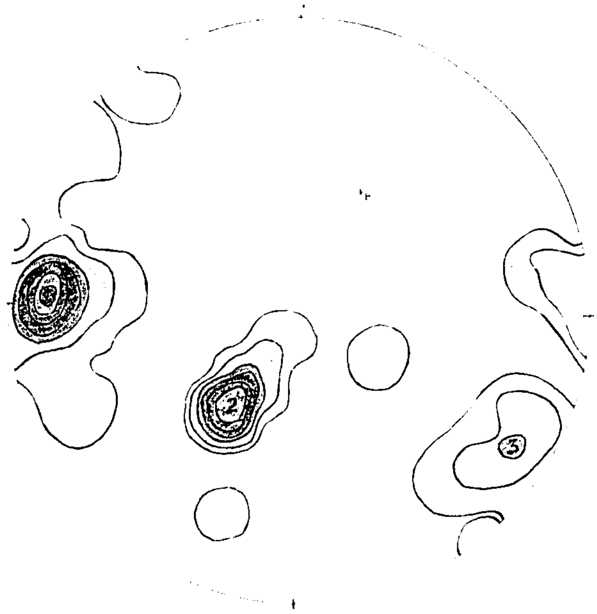
Pembina River



DN - V

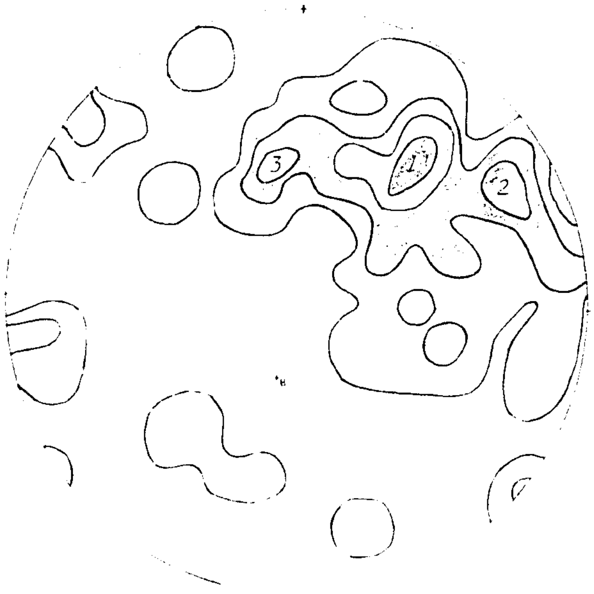
Pembina River

PLATE 53



DO - I

Mackenzie River



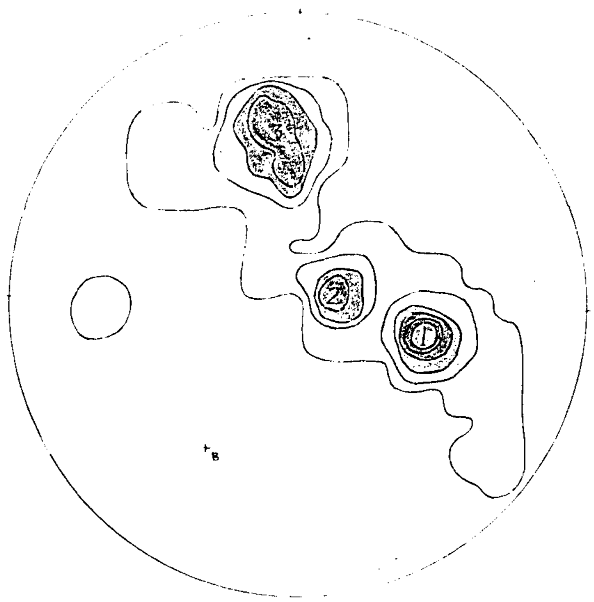
DO - II

Mackenzie River

PLATE 54

DO-III

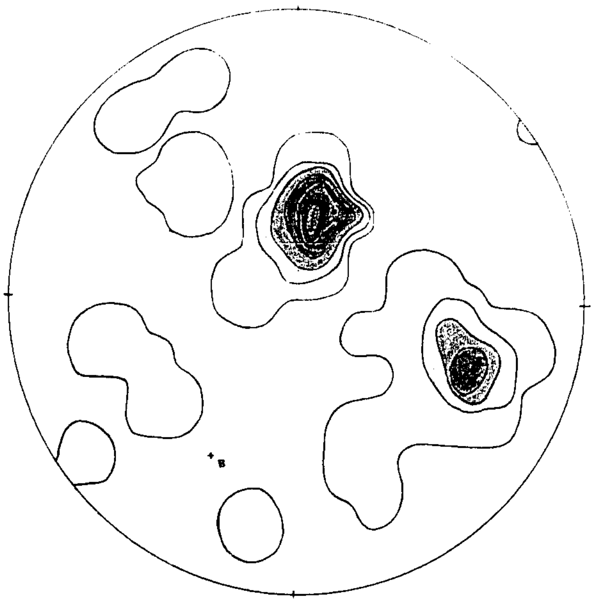
Mackenzie River



DO-IV

Mackenzie River

PLATE 55



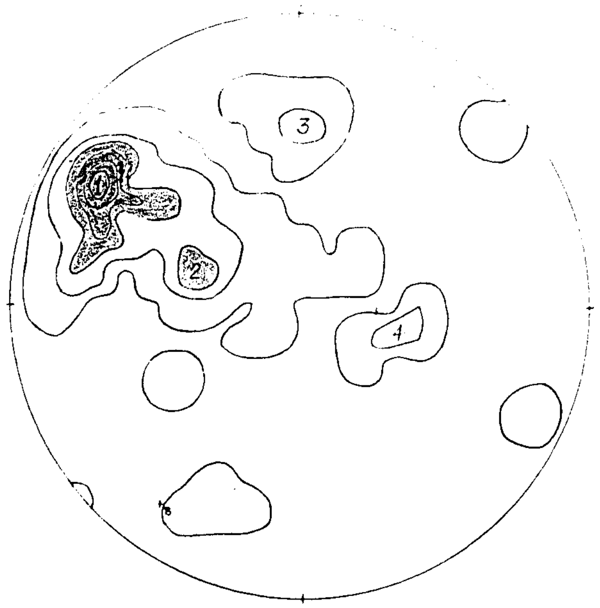
DO - V

Mackenzie River

DO - VI

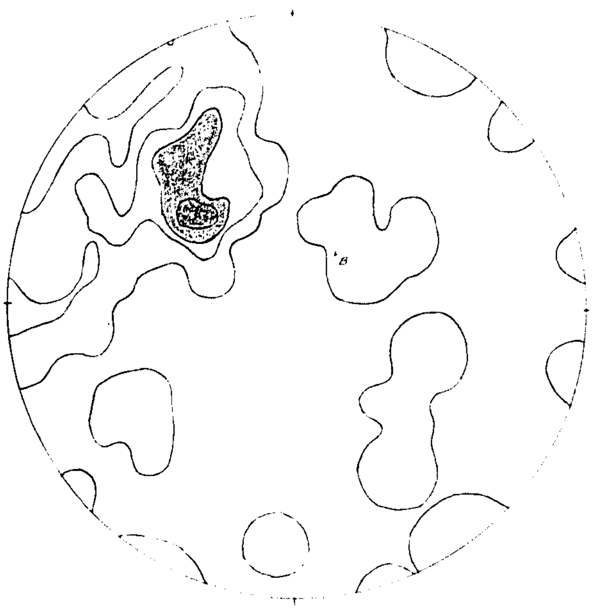
Mackenzie River

PLATE 56



DO-VII

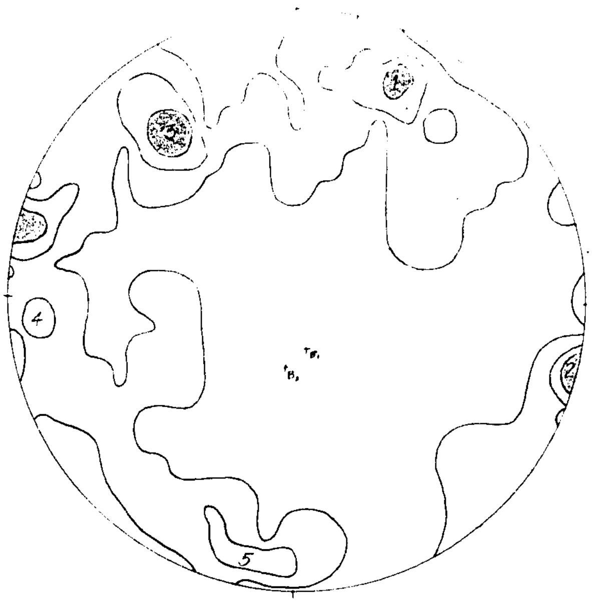
Mackenzie River



DO - VIII

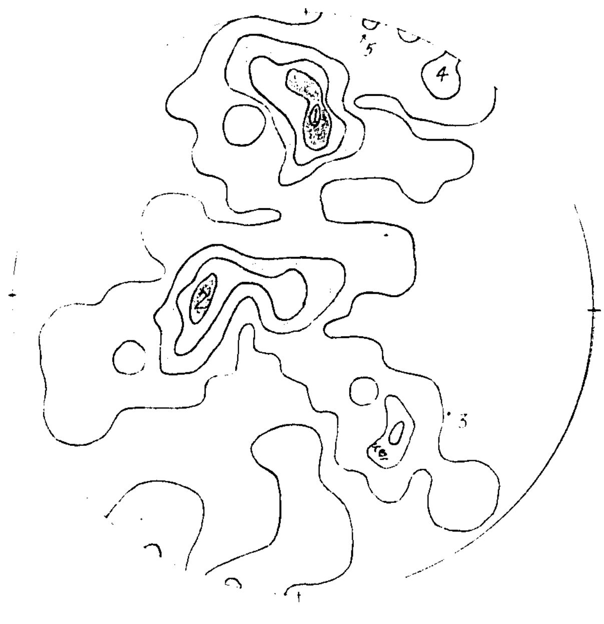
Mackenzie River

PLATE 57



DP - I

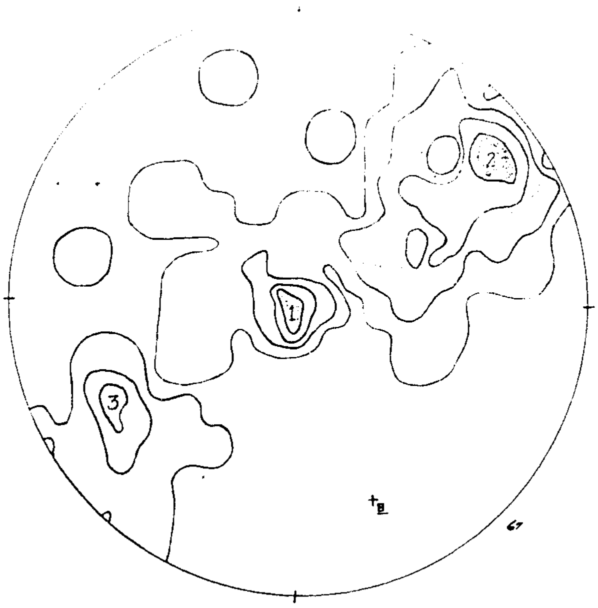
Watson Creek



DQ - I

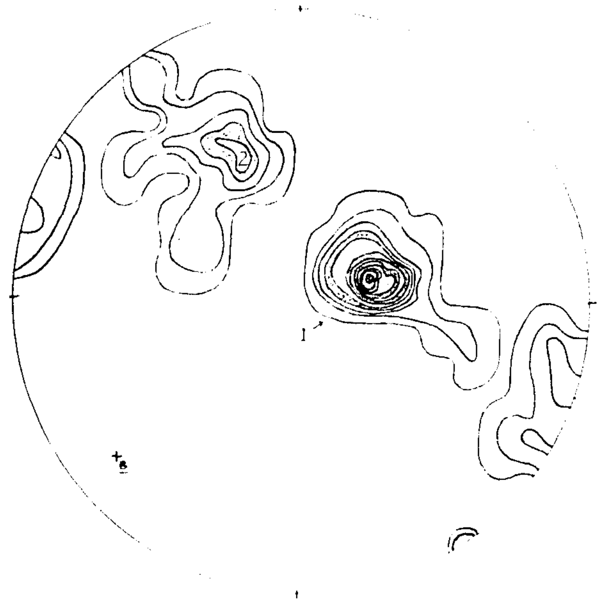
Pembina River

PLATE 58



DQ - II

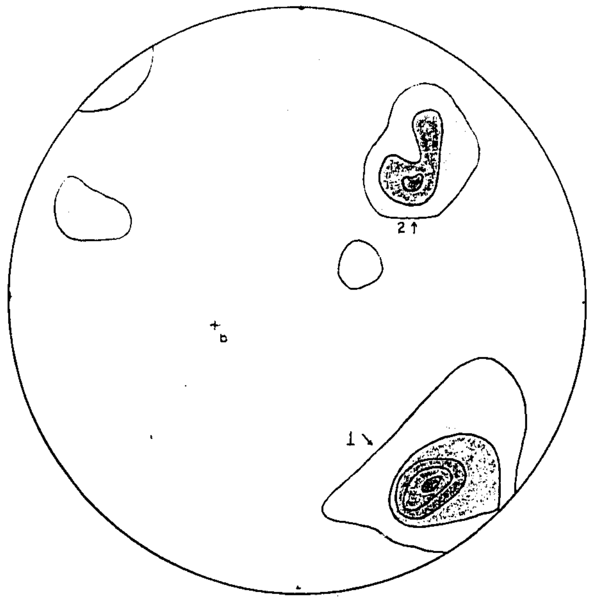
Pembina River



DQ - III

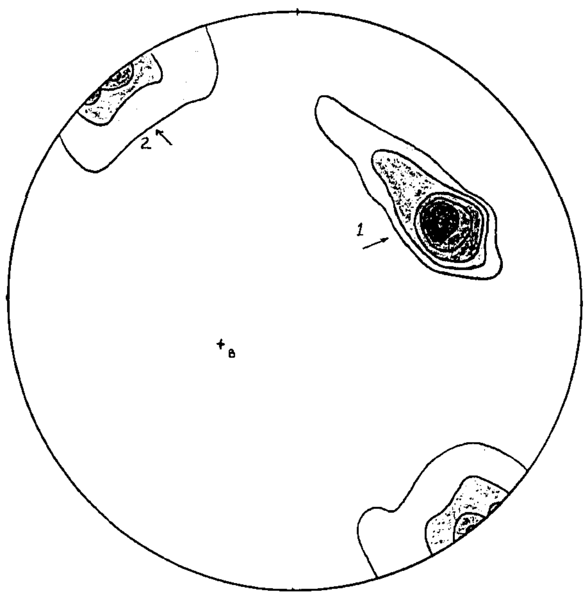
Pembina River

PLATE 59



EA - I

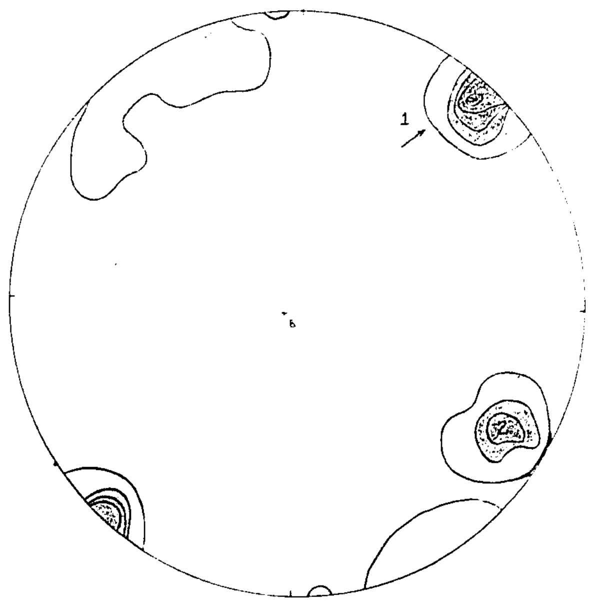
Bighorn Range



EA - II

Bighorn Range

PLATE 60



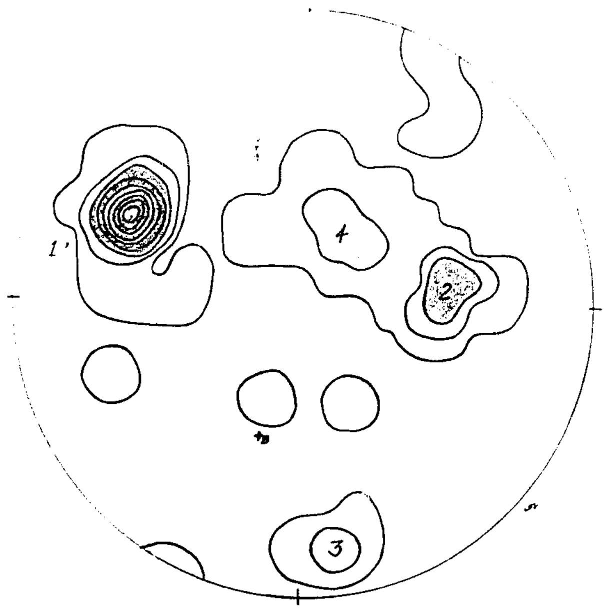
MA - I

Strip Mine - Nordegg

MB - I

Upper Brown Creek

PLATE 61



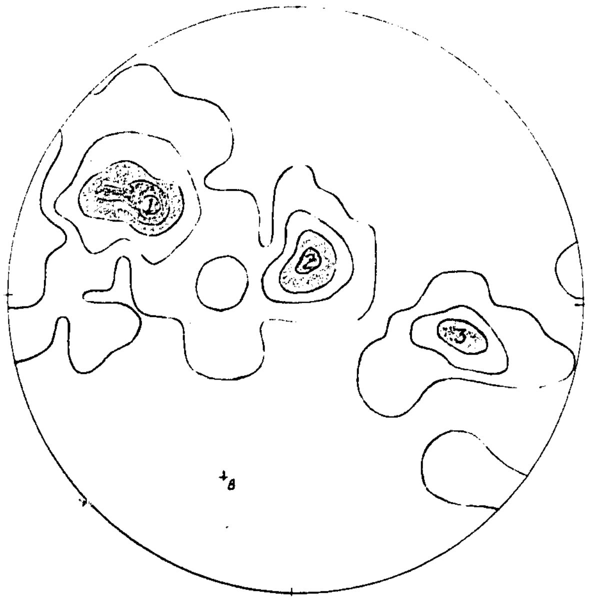
MC - I

Ruby Creek

MC - II

Ruby Creek

PLATE 62



MC - III

Ruby Creek

MD - I

Bighorn River

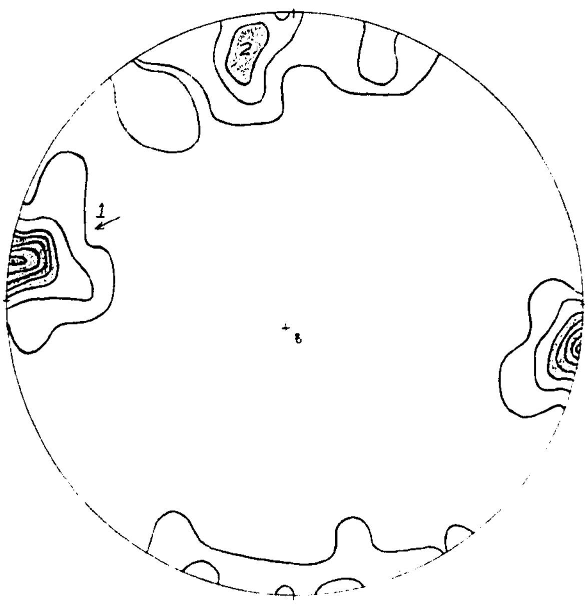


PLATE 63

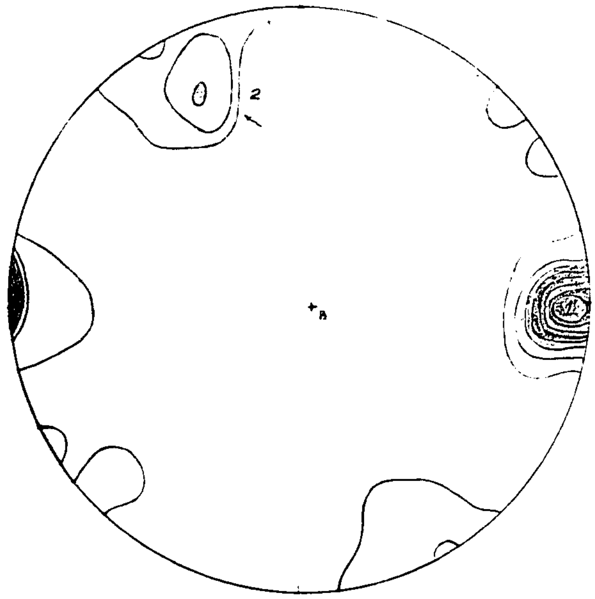
MD-II

Bighorn River

MD-III

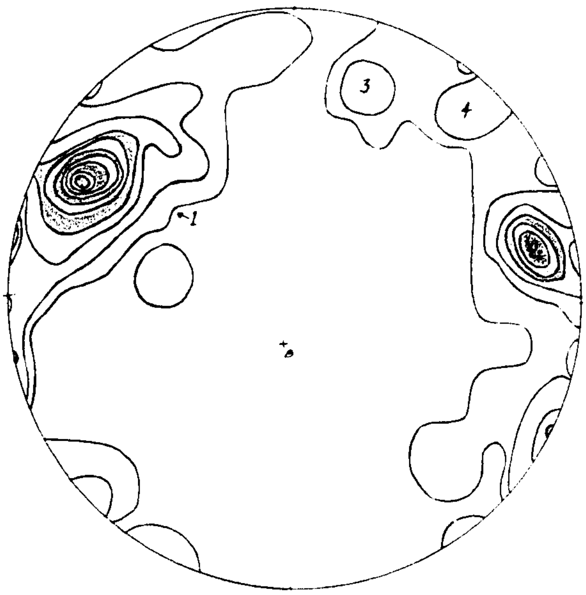
Bighorn River

PLATE 64



MD-IV

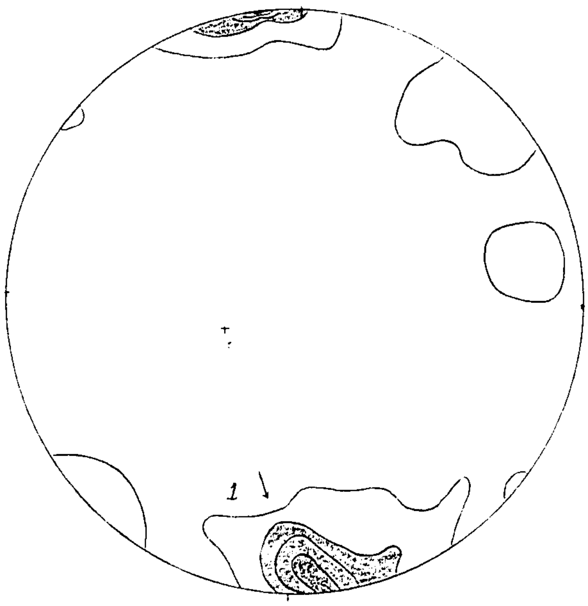
Bighorn River



NA-I

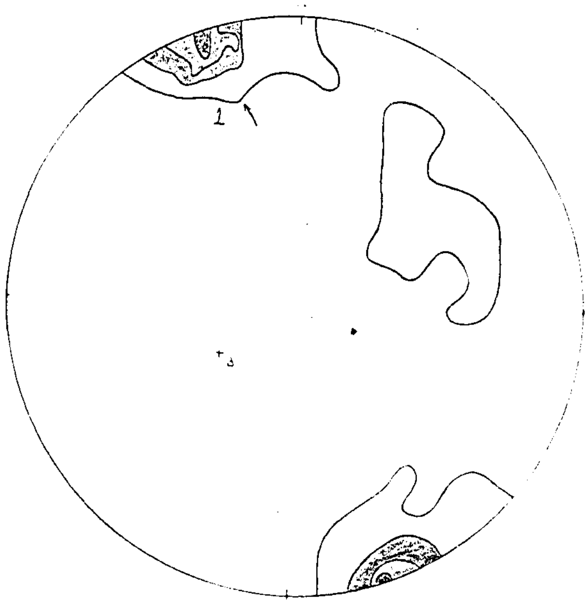
Upper Cardinal River

PLATE 65



NB - I

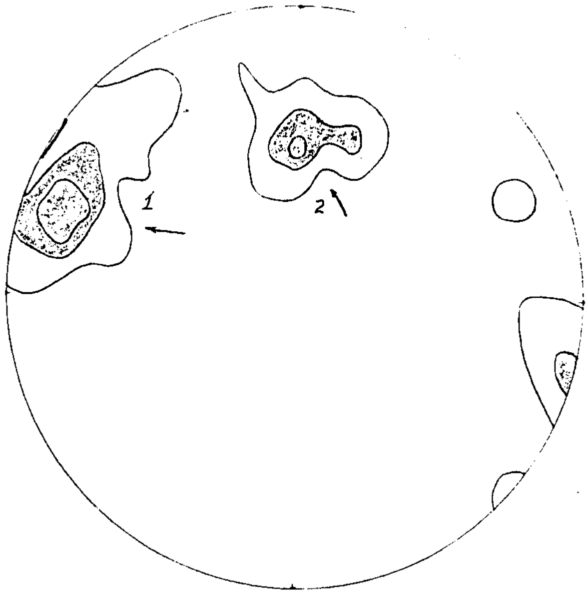
Bighorn Range



NB - II

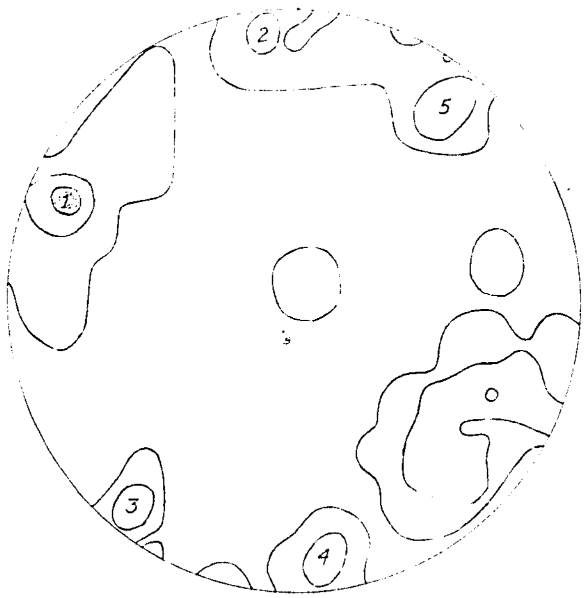
Bighorn Range

PLATE 66



NB - III

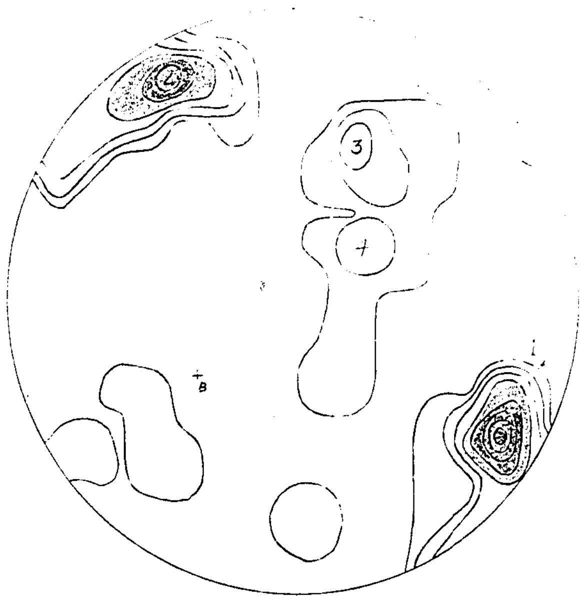
Bighorn Range



PGR - I

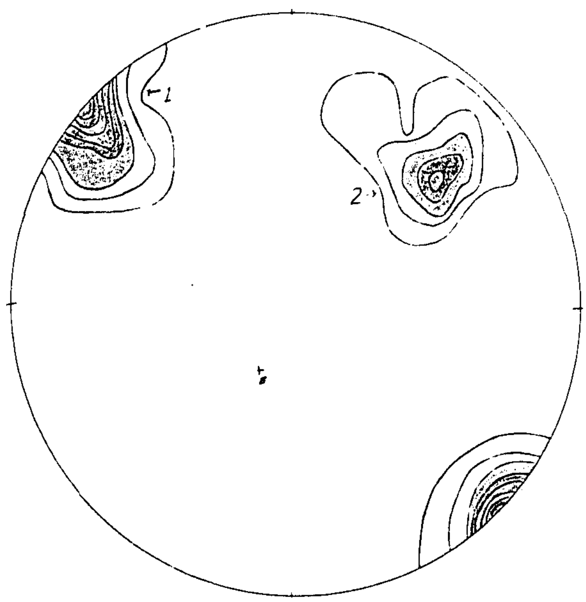
Ghost River

PLATE 67



SA - I

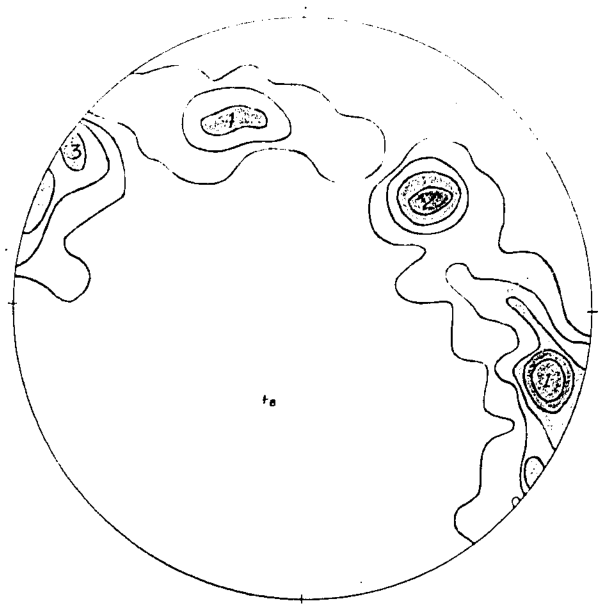
Upper Brown Creek



SB - I

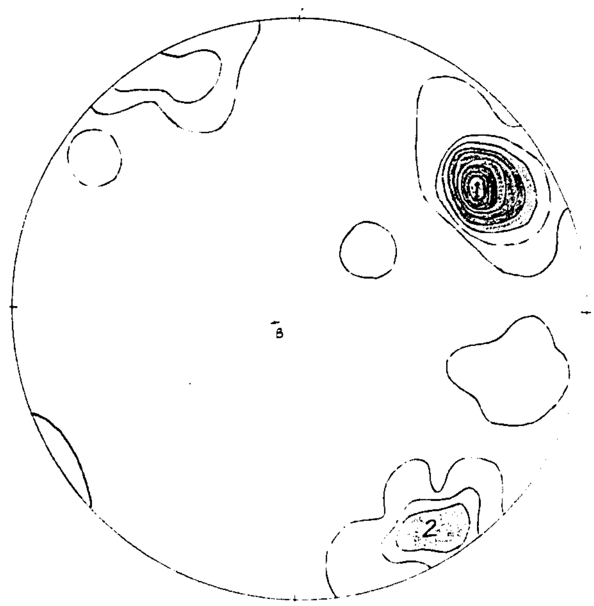
Mackenzie River

PLATE 68



SC - I

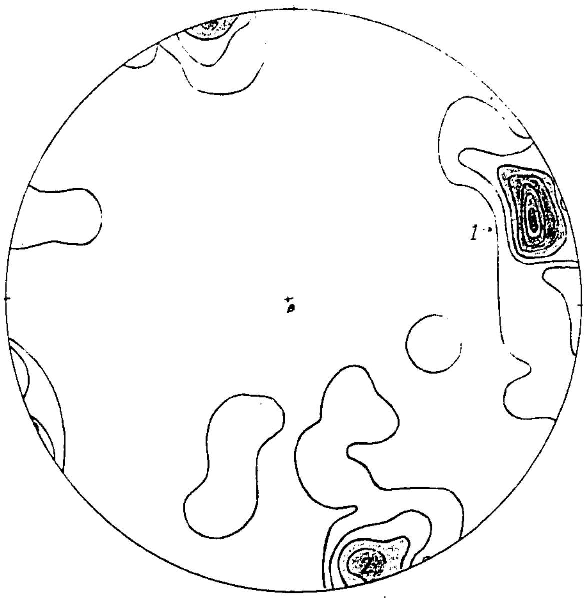
Mackenzie River



TA - I

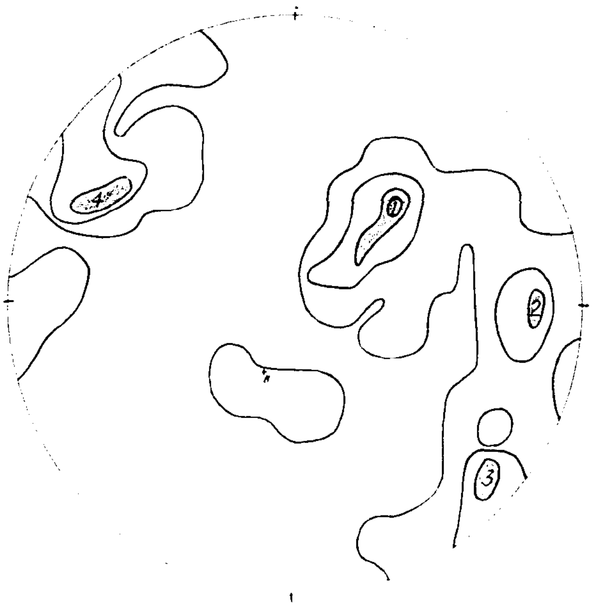
Brazeau River

PLATE 69



TA-II

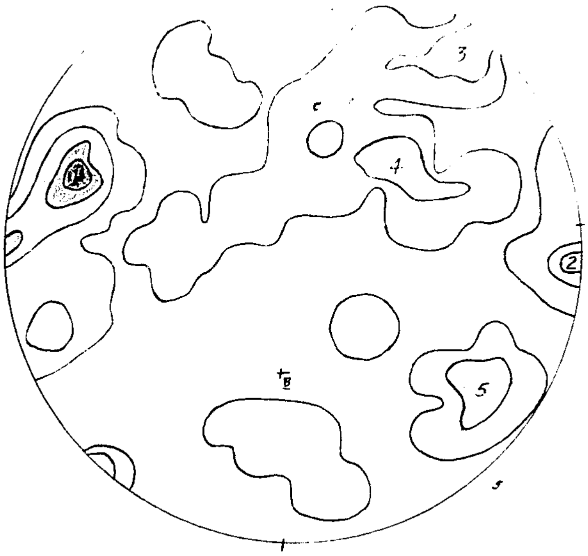
Brazeau River



TB-I

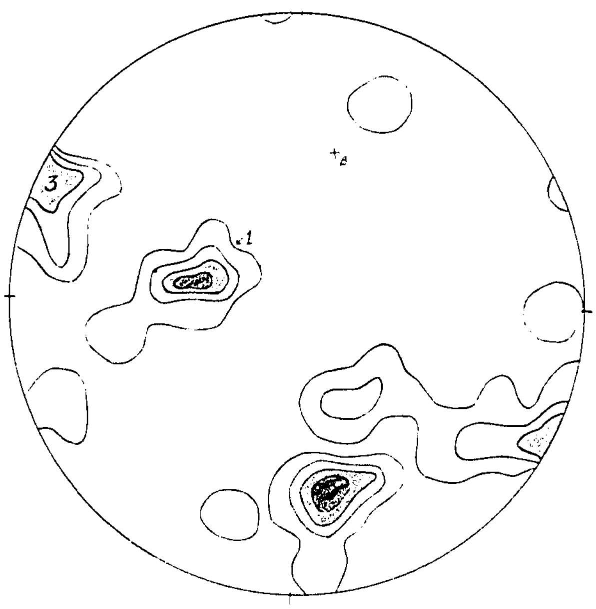
Pembina River

PLATE 70



TC - I

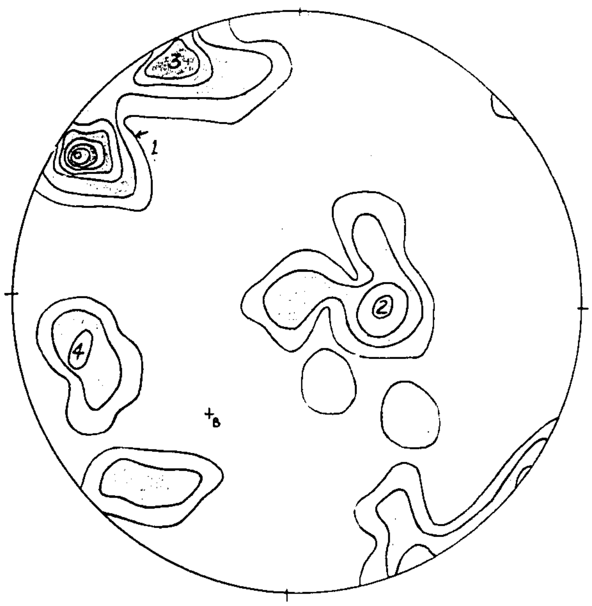
Coal Valley



TC - II

Coal Valley

PLATE 71



TC - III

Coal Valley

TC - IV

Coal Valley

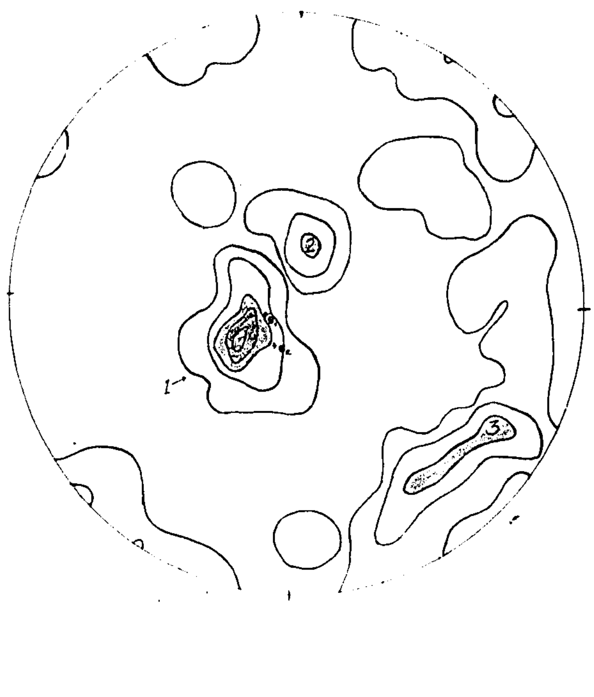
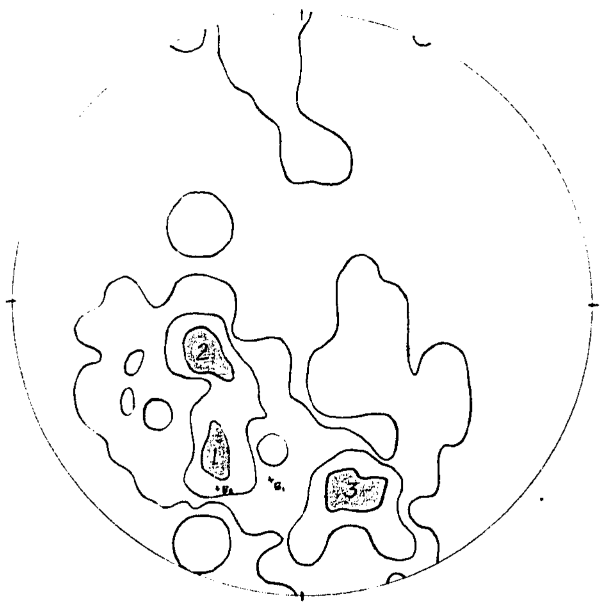


PLATE 72



TC - V

Coal Valley

WA - I

Upper Brown Creek

Geographic Localities of Joint Locations

Following is an index to the map location of every joint location discussed. Individual locations may be found by finding the Map Area by name (see Figure 2), and the rectangle number. The location may then be found along the stream listed.

Location	Plate No.	Map Area	Stream or Other	Rectangle
AA - I	1	Brazeau	Strip Mine	3
AB - I	1	Brazeau	Nameless Creek	4
AB - II	2	Brazeau	Nameless Creek	4
AC - I	2	Brazeau	Smallpox Creek	8
AD - I	3	Grave Flats	Cardinal River	5
AD - II	3	Grave Flats	Cardinal River	5
AD - III	4	Grave Flats	Cardinal River	4
AD - IV	4	Grave Flats	Cardinal River	4
AE - I	5	Grave Flats	Brazeau River	9
BB - I	5	Brazeau	C. N. R. Trestle	3
CC - I	6	Brazeau	Smallpox Creek	8
CD - I	6	Wapiabi Creek	Wapiabi Creek	8
CE - I	7	Wapiabi Creek	Wapiabi Creek	8
CF - I	7	Wapiabi Creek	Wapiabi Creek	8
CG - I	8	Wapiabi Creek	Wapiabi Creek	8
CH - I	8	Wapiabi Creek	Chungo Creek	1
CH - II	9	Wapiabi Creek	Chungo Creek	1
CH - III	9	Wapiabi Creek	Chungo Creek	1
CI - I	10	Pembina Forks	Brown Creek	9
CI - II	10	Pembina Forks	Brown Creek	9

Location	Plate No.	Map Area	Stream or Other	Rectangle
CI - III	11	Pembina Forks	Brown Creek	9
CI - IV	11	Pembina Forks	North of Brown Creek	8
CI - V	12	Pembina Forks	Brown Creek	9
CI - VI	12	Pembina Forks	Brown Creek	9
CJ - I	13	Pembina Forks	Canyon Creek	8
CJ - II	13	Pembina Forks	Canyon Creek	9
CJ - III	14	Pembina Forks	Canyon Creek	5
CJ - IV	14	Pembina Forks	Canyon Creek	5
CK - I	15	George Creek	Upper Brown Creek	1
CK - II	15	George Creek	Upper Brown Creek	1
CK - III	16	George Creek	Upper Brown Creek	1
CK - IV	16	George Creek	Upper Brown Creek	1
CK - V	17	George Creek	Upper Brown Creek	1
CL - I	17	Grave Flats	Thistle Creek	7
CL - II	18	Grave Flats	Thistle Creek	8
CL - III	18	Grave Flats	Thistle Creek	9
CM - I	19	Grave Flats	Cardinal River	5
CM - II	19	Pembina Forks	Cardinal River	4
CM - III	20	Pembina Forks	Cardinal River	4
CM - IV	20	Pembina Forks	Cardinal River	4
CM - V	21	Grave Flats	Cardinal River	6
CM - VI	21	Grave Flats	Cardinal River	6
CM - VII	22	Grave Flats	Cardinal River	4
CM - VIII	22	Grave Flats	Cardinal River	6
CN - I	23	Grave Flats	Brazeau River	9

Location	Plate No.	Map Area	Stream or Other	Rectangle
CN - II	23	Grave Flats	Brazeau River	9
CN - III	24	Pembina Forks	Brazeau River	4
CN - IV	24	Pembina Forks	Brazeau River	5
CN - V	25	Pembina Forks	Brazeau River	4
CN - VI	25	Pembina Forks	Brazeau River	5
CO - I	26	Grave Flats	Hanson Creek	6
CO - II	26	Grave Flats	Hanson Creek	6
CO - III	27	Grave Flats	Hanson Creek	6
CP - I	27	Grave Flats	Rat Creek	2
CP - II	28	Grave Flats	Rat Creek	2
CP - III	28	Grave Flats	Rat Creek	2
CP - IV	29	Grave Flats	Rat Creek	2
CQ - I	29	Grave Flats	Pembina River	1
CQ - II	30	Grave Flats	Pembina River	1
CQ - III	30	Grave Flats	Pembina River	1
CR - I	31	Mountain Park(East)	Pembina River	3
CR - II	31	Grave Flats	Pembina River	1
CR - III	32	Mountain Park(East)	Pembina River	3
CS - I	32	Mountain Park(East)	Mackenzie Creek	2
CS - II	33	Cadomin (East)	Mackenzie Creek	8
CS - III	33	Cadomin (East)	Mackenzie Creek	7
CT - I	34	Cadomin West	Luscar Creek	9
CT - II	34	Cadomin West	Luscar Creek	9
CT - III	35	Cadomin West	Luscar Creek	9
DD - I	35	Wapiabi Creek	Wapiabi Creek	5

Location	Plate No.	Map Area	Stream or Other	Rectangle
DD - II	36	Wapiabi Creek	Wapiabi Creek	5
DD - III	36	Wapiabi Creek	Blackstone River	6
DD - IV	37	Wapiabi Creek	Blackstone River	6
DE - I	37	East of Pembina Forks	Brown Creek	7
DE - II	38	East of Pembina Forks	Brown Creek	7
DF - I	38	George Creek	Brown Creek	2
DG - I	39	West of George Creek	Southesk River	2
DH - I	39	Grave Flats	Cardinal River	6
DH - II	40	Grave Flats	Cardinal River	6
DH - III	40	Grave Flats	Cardinal River	5
DH - IV	41	Pembina Forks	Cardinal River	5
DI - I	41	Grave Flats	Thistle Creek	8
DI - II	42	Grave Flats	Thistle Creek	8
DI - III	42	Grave Flats	Thistle Creek	8
DI - IV	43	Grave Flats	Thistle Creek	7
CI - V	43	Grave Flats	Thistle Creek	7
DJ - I	44	Grave Flats	Brazeau River	9
DJ - II	44	Pembina Forks	Brazeau River	4
DJ - III	45	Pembina Forks	North of Brazeau River	5
DJ - IV	45	Pembina Forks	North of Brazeau River	5
DK - I	46	Pembina Forks	Crooked Creek	1
DK - II	46	Grave Flats	Pembina River	3
DK - III	47	Grave Flats	Pembina River	3
DK - IV	47	Grave Flats	Pembina River	3
DK - V	48	Grave Flats	Pembina River	3

Location	Plate No.	Map Area	Stream or Other	Rectangle
DK - VI	48	Grave Flats	Pembina River	3
DK - VII	49	Grave Flats	Pembina River	3
DK - VIII	49	Grave Flats	Pembina River	3
DL - I	50	Grave Flats	Hanson Creek	5
DN - I	50	Grave Flats	Pembina River	1
DN - II	51	Grave Flats	Pembina River	1
DN - III	51	Grave Flats	Pembina River	1
DN - IV	52	Grave Flats	Pembina River	1
DN - V	52	Grave Flats	Pembina River	1
DO - I	53	Mountain Park(East)	Mackenzie River	2
DO - II	53	Cadomin (East)	Mackenzie River	8
DO - III	54	Mountain Park(East)	Mackenzie River	2
DO - IV	54	Cadomin (East)	Mackenzie River	8
DO - V	55	Cadomin (East)	Mackenzie River	8
DO - VI	55	Cadomin (East)	Mackenzie River	4
DO - VII	56	Cadomin (East)	Mackenzie River	4
DO - VIII	56	Cadomin (East)	Mackenzie River	4
DP - I	57	Cadomin (East)	Watson Creek	7
DQ - I	57	Grave Flats	North of Pembina River	1
DQ - II	58	Lovett (West)	North of Pembina River	7
DQ - III	58	Cadomin (East)	North of Pembina River	9
EA - I	59	George Creek	Bighorn Range	9
EA - II	59	George Creek	Bighorn Range	9
MA - I	60	Brazeau	Strip Mine	3
MB - I	60	George Creek	Brown Creek	1

Location	Plate No.	Map Area	Stream or Other	Rectangle
MC - I	61	Grave Flats	Ruby Creek	4
MC - II	61	Grave Flats	Ruby Creek	4
MC - III	62	Grave Flats	Ruby Creek	4
MD - I	62	Bighorn River	Bighorn River	6
MD - II	63	Bighorn River	Bighorn River	6
MD - III	63	Bighorn River	Bighorn River	6
MD - IV	64	Bighorn River	Bighorn River	6
NA - I	64	Grave Flats	Ruby Creek	4
NB - I	65	George Creek	Bighorn Range	9
NB - II	65	George Creek	Bighorn Range	9
NB - III	66	George Creek	Bighorn Range	9
PGR - I	66	West of George Creek	Brazeau River	2
SA - I	67	George Creek	Brown Creek	1
SB - I	67	Mountain Park(East)	Nikanassin Range	6
SC - I	68	Mountain Park(East)	Mackenzie Creek	1
TA - I	68	Pembina Forks	Brazeau River	6
TA - II	69	Pembina Forks	Brazeau River	6
TB - I	69	Pembina Forks	Pembina River	1
TC - I	70	Lovett (West)	Strip Mines	9
TC - II	70	Lovett (West)	Strip Mines	9
TC - III	71	Lovett (West)	Strip Mines	1
TC - IV	71	Lovett (West)	Little Pembina River	9
TC - V	72	Lovett (West)	Little Pembina River	9
WA - I	72	George Creek	South of Brown Creek	1

Table of Areal Density Factors

LOCATION	Density 1	A.D.F.	Density 2	A.D.F.	Density 3	A.D.F.	Density 4	A.D.F.	Density 5	A.D.F.
AA-I	55	1833	45	1500						
AB-I	38	1900	10	91	6	14				
AB-II	10.5	150	10.5	150	7.5	150	7.5	24	7.5	23
TC-III	22.5	2250	10.5	210	10.5	42	7.5	63		
TC-IV	18	450	10	167	10	26				
TC-V	10	42	10	31	10	26				
WA-I	6.7	13	6.7	9						

LOCATION	Density 1	A.D.F.	Density 2	A.D.F.	Density 3	A.D.F.	Density 4	A.D.F.	Density 5	A.D.F.
AA-I	55	1833	45	1500						
AB-I	38	1900	10	91	6	14				
AB-II	10.5	150	10.5	150	7.5	150	7.5	24	7.5	23
AC-I	26	40								
AD-I	18	120	14	200	6	15				
AD-II	19.5	650	10.5	350	7.5	36	7.5	138		
AD-III	25.5	850	25.5	638	10.5	87	1.5	3		
AD-IV	19.5	81	13.5	338	4.5	16	4.5	11		
AE-I	9	100	7	350	7	54	5	42		
BB-I	42	300	42	162						
CC-I	38	1900	18	60	6	33				
CD-I	22	550	22	200	14	140				
CE-I	18	180	14	67	6	23				
CF-I	26	371	10	56	6	25	6	13		
CG-I	21.5	717	13.5	225	13.5	112				
CH-I	22	200	14	350	10	42	10	32	6	17
CH-II	14	78	10	50	10	50	10	331	2	3
CH-III	22	147	6	32						
CI-I	27	245								
CI-II	13.5	225	13.5	225						
CI-III	10.5	31	7.5	83	7.5	38	4.5	8		
CI-IV	13.5	71	13.5	54	7.5	39				
CI-V	14	700	10	31						
CI-VI	14.7	92	6.7	29						
CJ-I	22	733	10	250	6	19				
CJ-II	22	275	14	47	14	156	6	10	6	7
CJ-III	14	36	10	48	6	19				
CJ-IV	14	175	10	77	6	21				
CK-I	18	200	6	15	6	11	2	3	6	17
CK-II	26	137	10	36	6	22				
CK-III	9	225	9	129						
CK-IV	16.5	127	7.5	25	7.5	27	7.5	20		
CK-V	14	117								
CL-I	25.5	425	19.5	325	4.5	13				
CL-II	10.5	62	7.5	83	7.5	54	7.5	29	7.5	107
CL-III	38	543	14	233						
CM-I	9	113	9	100	9	43	7	54		
CM-II	22	440	14	140						
CM-III	14	88	10	50	6	12				
CM-IV	18	450	14	117						
CM-V	18	600	14	108	14	54	10	38		
CM-VI	30	1500	22	733	10	20				
CM-VII	10.5	81	7.5	125	7.5	34	7.5	31	7.5	21
CM-VIII	18	120	6	18	6	12				
CN-I	22	440	22	440	10	83				
CN-II	10	67	10	42	10	21	6	5		

CK-III	9	225	9	129						
CK-IV	16.5	127	7.5	25	7.5	27	7.5	20		
CK-V	14	117								
CL-I	25.5	425	19.5	325	4.5	13				
CL-II	10.5	62	7.5	83	7.5	54	7.5	29	7.5	107
CL-III	38	543	14	233						
CM-I	9	113	9	100	9	43	7	54		
CM-II	22	440	14	140						
CM-III	14	88	10	50	6	12				
CM-IV	18	450	14	117						
CM-V	18	600	14	108	14	54	10	38		
CM-VI	30	1500	22	733	10	20				
CM-VII	10.5	81	7.5	125	7.5	34	7.5	31	7.5	21
CM-VIII	18	120	6	18	6	12				
CN-I	22	440	22	440	10	83				
CN-II	10	67	10	42	10	21	6	5		
CN-III	26	433	10	143	10	71	10	40	6	12
CN-IV	30	500	22	220	10	250				
CN-V	22	2200	6	46	6	22				
CN-VI	15	21	9	17						
CO-I	19.5	1950	7.5	9	4.5	14	4.5	16	4.5	4
CO-II	18	200	10	83	6	14				
CO-III	19.5	1950	4.5	14	4.5	12	4.5	9		
CP-I	10	40	6	5						
CP-II	22	147	6	33	6	11				
CP-III	18	180	10	125	10	40				
CP-IV	14	37	10	26	6	23				
CQ-I	14	127	6	38	6	33	6	12	6	5
CQ-II	18	450	6	16	6	10				
CQ-III	18	95	18	225	10	45				
CR-I	14	156	6	11	6	6				
CR-II	14	78	14	50	6	11				
CR-III	14	140	14	88						
CS-I	14	28	10	45						
CS-II	26	867	18	164	10	91	10	33		
CS-III	34	850	14	41						
CT-I	26	433	14	175	6	32	6	6		
CT-II	13.5	123	10.5	117	7.5	38				
CT-III	22	244	18	69						
DD-I	10	23	10	12	6	7				
DD-II	52	656	6	10						
DD-III	18	64	14	107	14	107	10	41	6	19
DD-IV	15	187	9	19	9	12				
DE-I	30	1500	26	650	6	22				
DE-II	32.5	217	17.5	60	7.5	36				
DF-I	10	125	10	52	10	38				
DG-I	44	293	14	350						
DH-I	18	69	10	71	10	35	6	23	6	16
DH-II	30	1500	6	29	6	18				

CS-III	34	850	14	41						
CT-I	26	433	14	175	6	32	6	6		
CT-II	13.5	123	10.5	117	7.5	38				
CT-III	22	244	18	69						
DD-I	10	23	10	12	6	7				
DD-II	52	656	6	10						
DD-III	18	64	14	107	14	107	10	41	6	19
DD-IV	15	187	9	19	9	12				
DE-I	30	1500	26	650	6	22				
DE-II	32.5	217	17.5	60	7.5	36				
DF-I	10	125	10	52	10	38				
DG-I	44	293	14	350						
DH-I	18	69	10	71	10	35	6	23	6	16
DH-II	30	1500	6	29	6	18				
DH-III	19.5	975	7.5	28	7.5	23				
DH-IV	15	250	9	45	5	20	5	15	3	18
DI-I	22	550	10	225						
DI-II	14	63	14	38	10	41				
DI-III	18	257	18	128	14	200	6	86	6	21
DI-IV	26	371	10	125						
DI-V	10	35	10	28	6	75	6	4		
DJ-I	60	2000	14	38						
DJ-II	18	90	6	27						
DJ-III	14	42	10	100	6	29				
DJ-IV	22	146	6	5						
DK-I	10.5	81	7.5	30	7.5	15	4.5	5	4.5	4
DK-II	30	1500	10	22						
DK-III	9	43	5	11	5	10				
DK-IV	34	850	10	20	6	15				
DK-V	7.5	44	7.5	38	7.5	34	7.5	25		
DK-VI	10	100	10	22	6	26	6	17	6	13
DK-VII	38	542	14	116						
DK-VIII	14	64	6	46	6	5				
DL-I	14	93	10	20	6	50				
DN-I	22.5	563	10.5	31						
DN-II	18	257	10	63	6	11				
DN-III	17	283	15	88	9	180	7	117		
DN-IV	18	200	10	200						
DN-V	18	163	14	140	10	17				
DO-I	26	520	22	138	10	111				
DO-II	10.5	33	7.5	21	7.5	38				
DO-III	22	169	10	48	10	17	6	21		
DO-IV	22	220	14	100	14	24				
DO-V	30	429	14	58						
DO-VI	22	314	10	36	6	24	6	12		
DO-VII	22	314	10	40	6	24	6	25		
DO-VIII	14	78								
DP-I	10	71	10	43	10	32	6	30	6	12

DK-VI	10	100	10	22	6	26	6	17	6	13
DK-VII	38	542	14	116						
DK-VIII	14	64	6	46	6	5				
DL-I	14	93	10	20	6	50				
DN-I	22.5	563	10.5	31						
DN-II	18	257	10	63	6	11				
DN-III	17	283	15	88	9	180	7	117		
DN-IV	18	200	10	200						
DN-V	18	163	14	140	10	17				
DO-I	26	520	22	138	10	111				
DO-II	10.5	33	7.5	21	7.5	38				
DO-III	22	169	10	48	10	17	6	21		
DO-IV	22	220	14	100	14	24				
DO-V	30	429	14	58						
DO-VI	22	314	10	36	6	24	6	12		
DO-VII	22	314	10	40	6	24	6	25		
DO-VIII	14	78								
DP-I	10	71	10	43	10	32	6	30	6	12
DQ-I	13.5	338	10.5	70	7.5	188	4.5	17	4.5	113
DQ-II	10.5	81	10.5	30	7.5	47				
DQ-III	34.5	3450	13.5	135						
EA-I	27	675	15	300						
EA-II	33	1650	21	525						
MA-I	45	1125	25	147						
MB-I	10	125	10	34						
MC-I	34	850	10	21	6	18	6	7		
MC-II	18	450	14	88	6	9	6	7		
MC-III	18	360	14	140	10	42				
MD-I	26	866	10	31						
MD-II	26	650	10	59	6	8				
MD-III	22	366	14	117	6	13		-		
MD-IV	48	343	10	250						
NA-I	19	950	11	73	3	8	3	4		
NB-I	36	1800								
NB-II	28	255								
NB-III	20	48	20	400						
PGR-I	10	77	6	32	6	24	6	18	6	11
SA-I	26	867	18	180	6	29	3	5		
SB-I	26	260	18	300						
SC-I	18	86	14	88	10	53	10	38		
TA-I	34	378	10	20						
TA-II	26	650	14	70						
TB-I	14	280	10	100	10	59	10	38		
TC-I	14	117	10	83	6	92	6	86	6	105
TC-II	14	156	14	70	10	20				
TC-III	22.5	2250	10.5	210	10.5	42	7.5	63		
TC-IV	18	450	10	167	10	26				
TC-V	10	42	10	31	10	26				
WA-I	6.7	13	6.7	9						

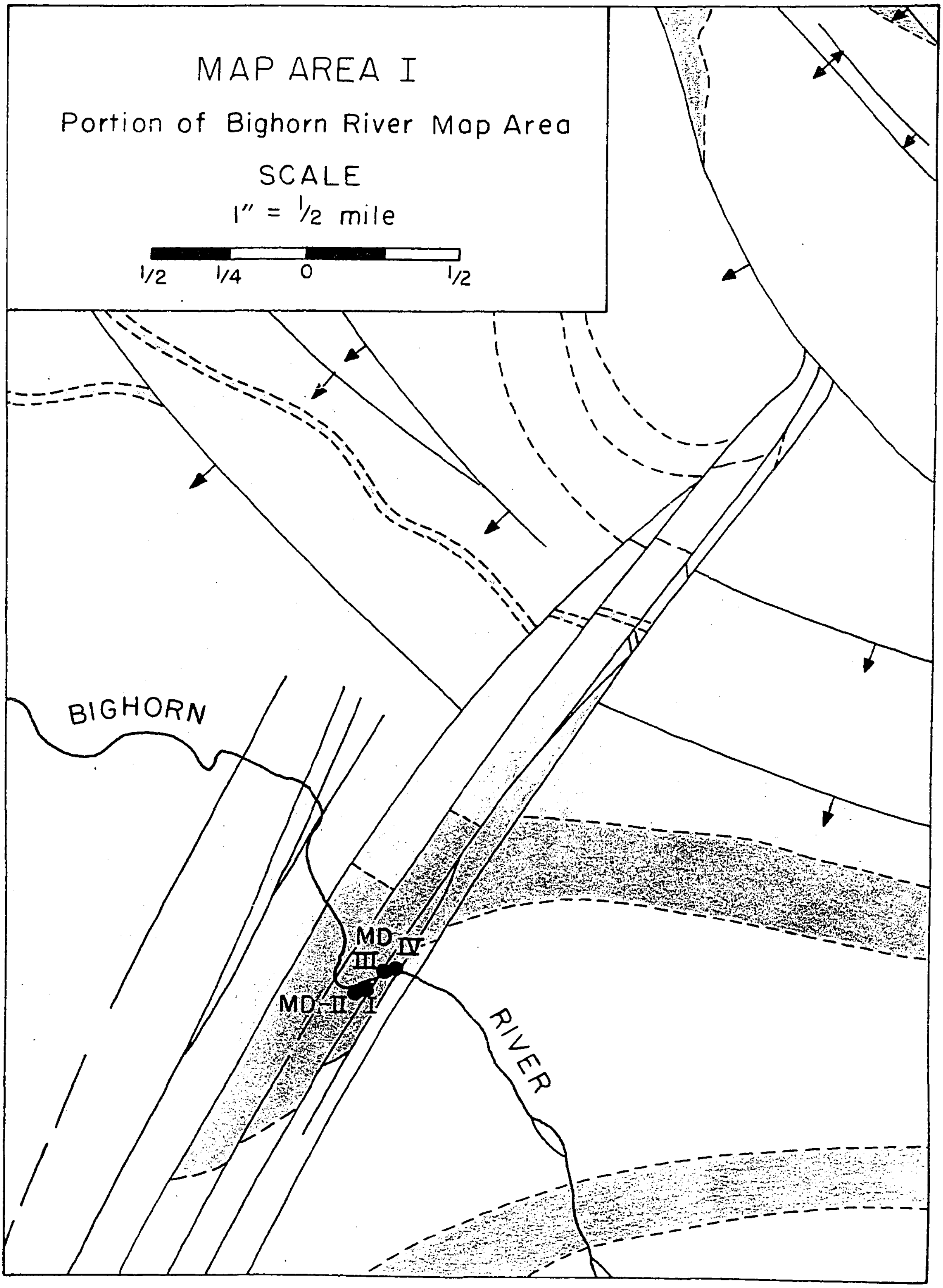
APPENDIX B

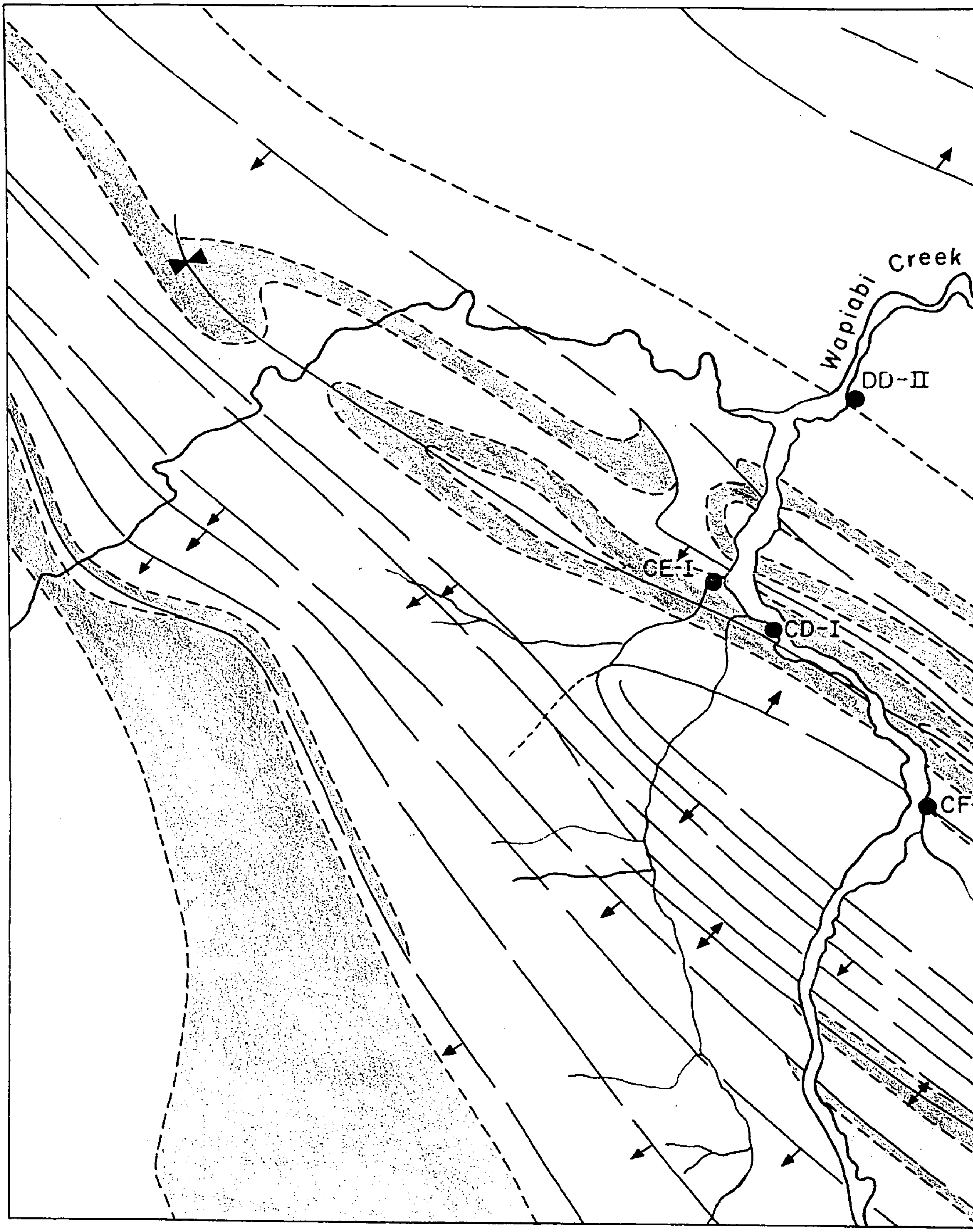
Concerning the Maps

The geologic maps reproduced here are the work of Robert J.W. Douglas of the Geological Survey of Canada. No changes or corrections were made on any of the eight local map areas, which were traced directly from the 1" to 1/2 mile unpublished drafts made while the field work was progressing. Brazeau and Bighorn River sheets have been published together in preliminary form in 1956 as Geological Survey of Canada Paper 55-34 entitled "Nordegg, Alberta".

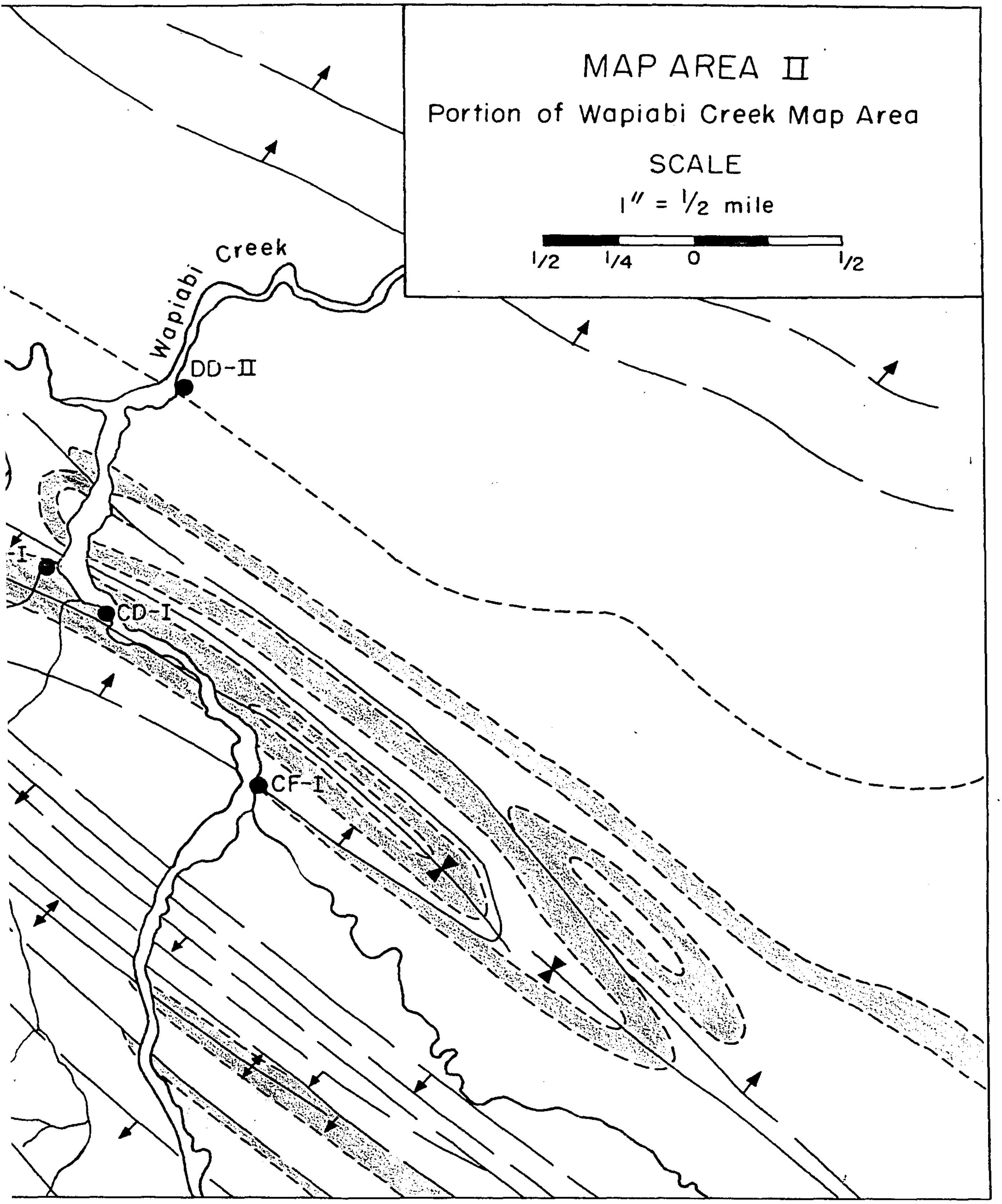
The two regional maps (A & B) have been compiled by the writer from the manuscript maps mentioned above and B.R. McKay's published maps of the Cadomin and Mountain Park Sheets. (G.S.C. Maps 209A and 208A respectively). The small area west of the Bighorn River map area was taken from a compilation of the Central Foothills Belt by B.R. McKay (1943) designated Preliminary Map 43-3. The area immediately west of the George Creek map Area was interpolated by the writer from the areas to the north and east and was drawn only for the purpose of continuity. No data on this area were available at the time the map was drawn, hence the location of the contacts and faults shown might well be in error. The maps were photographically reduced and re-traced on a scale of 1 inch to 2 miles. In some cases minor details were omitted for the sake of clarification.

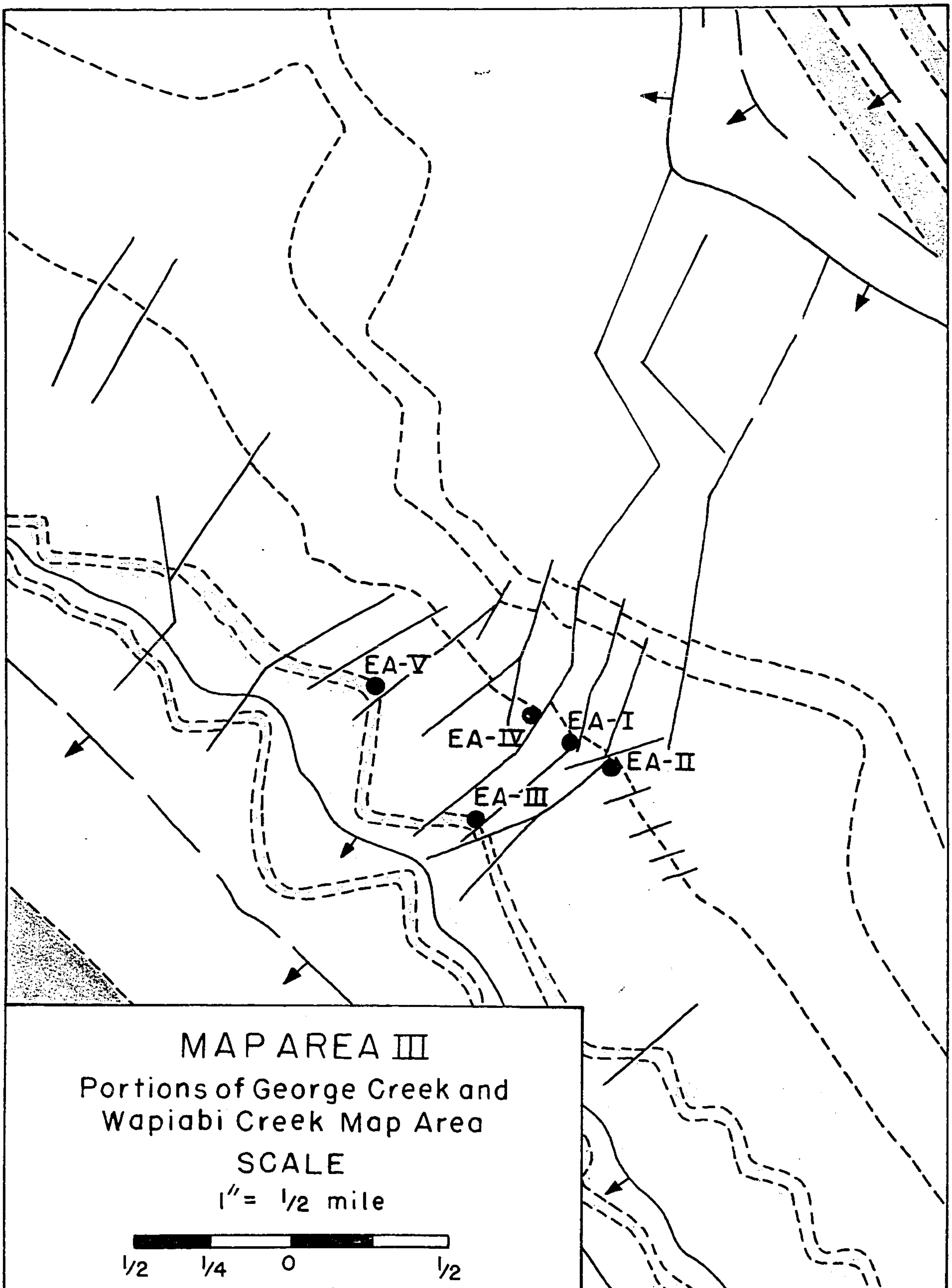
Although these maps are largely the work of Dr. Douglas, and must be credited to him, any errors or misinterpretations are the responsibility of the writer.


MAP AREA I
Portion of Bighorn River Map Area
SCALE
1" = 1/2 mile
1/2
1/4
0
1/2
BIGHORN
RIVER
MD III
IV
MD-II
I

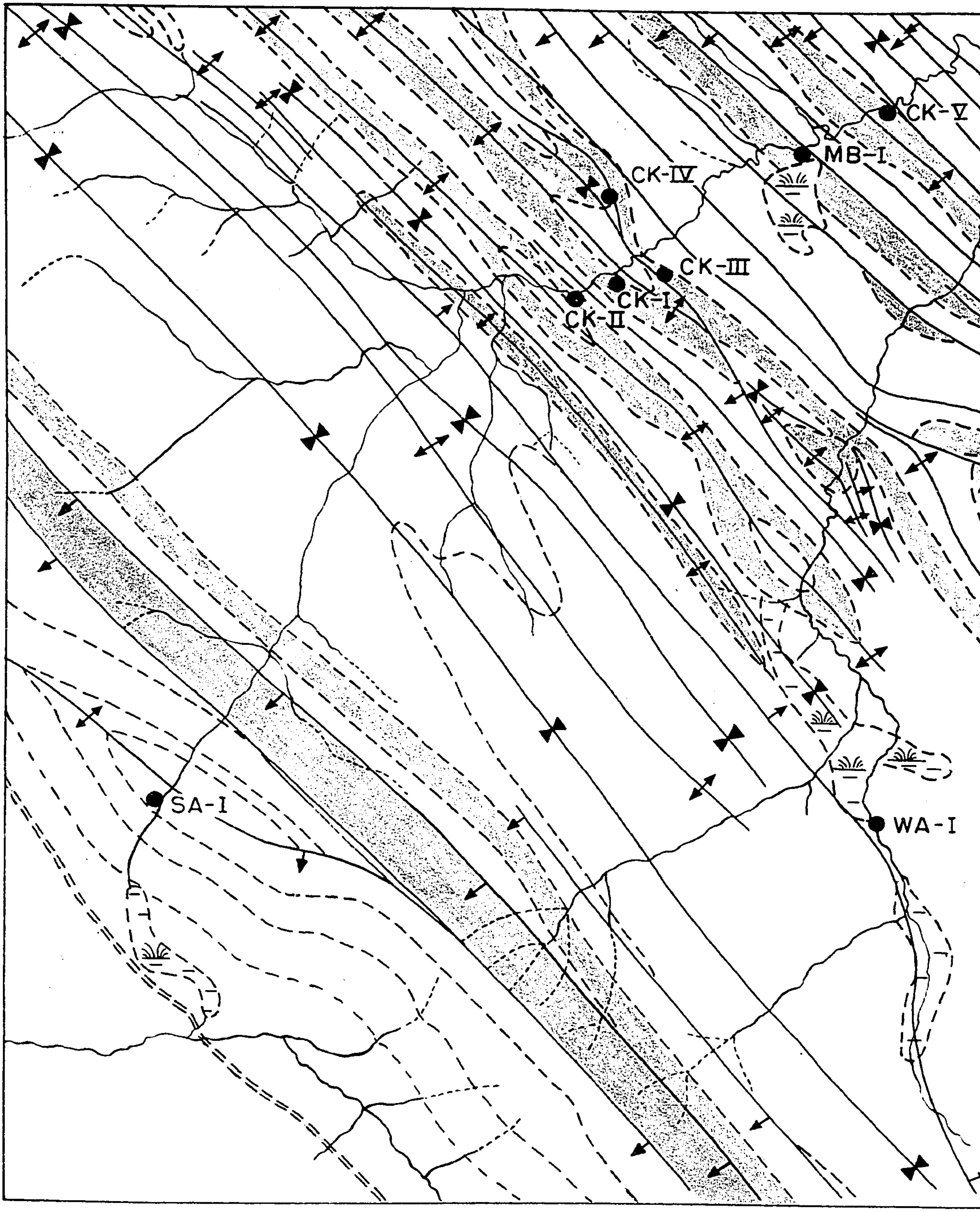


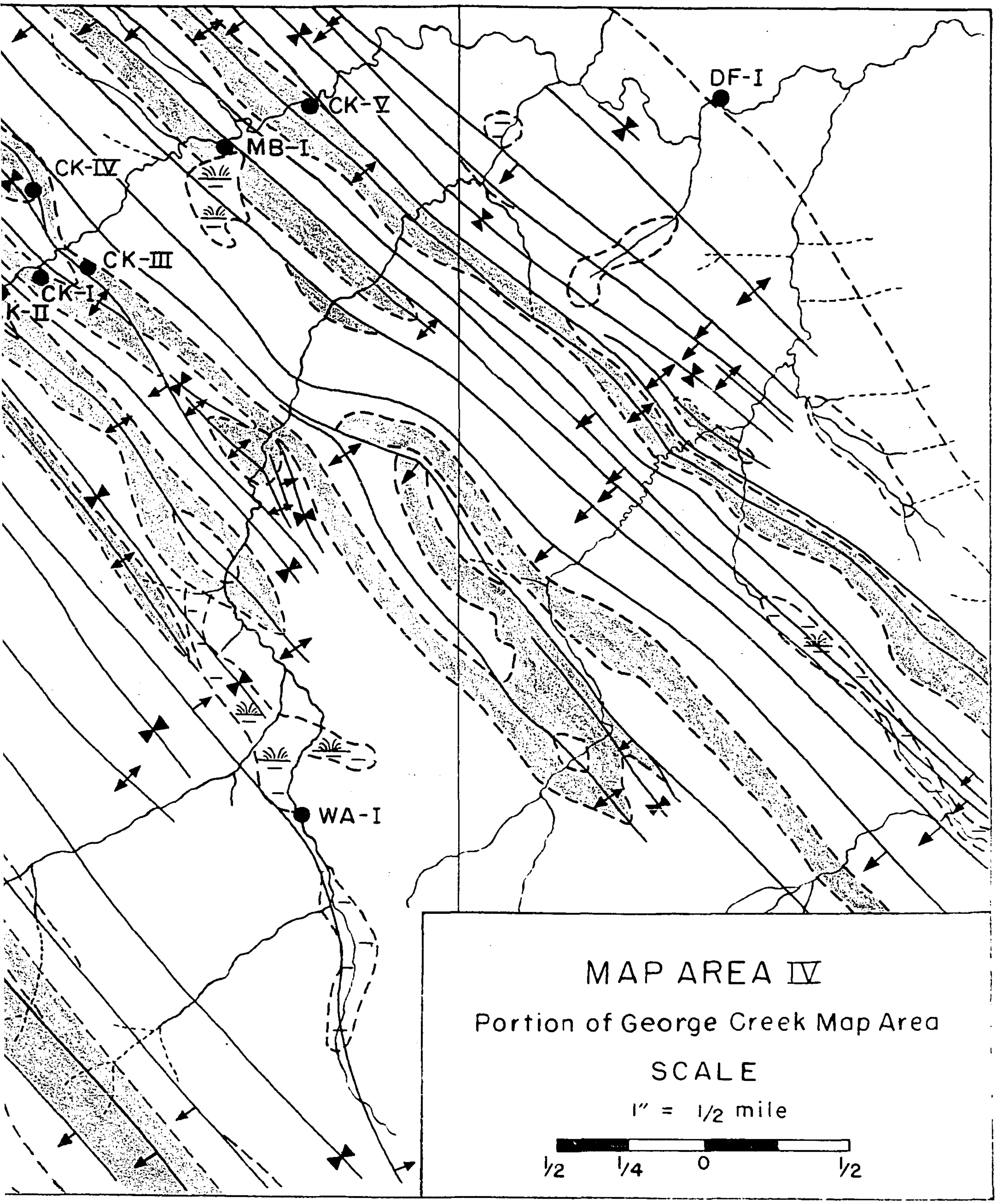
Wapiabi Creek
DD-II
CE-I
CD-I
CF-

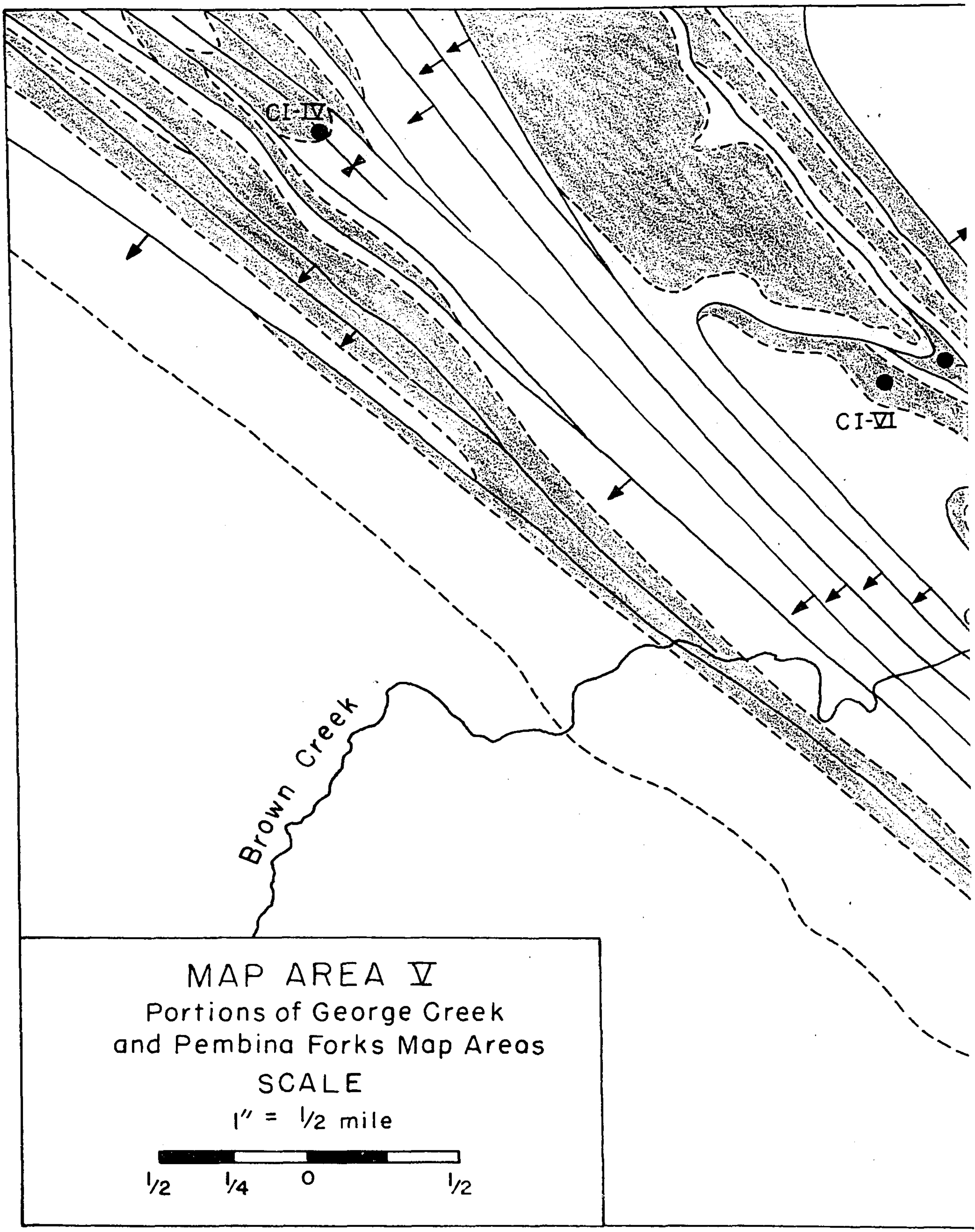

MAP AREA II
Portion of Wapiabi Creek Map Area
SCALE
1" = 1/2 mile
1/2
1/4
0
1/2
Wapiabi Creek
DD-II
CD-I
CF-I
I



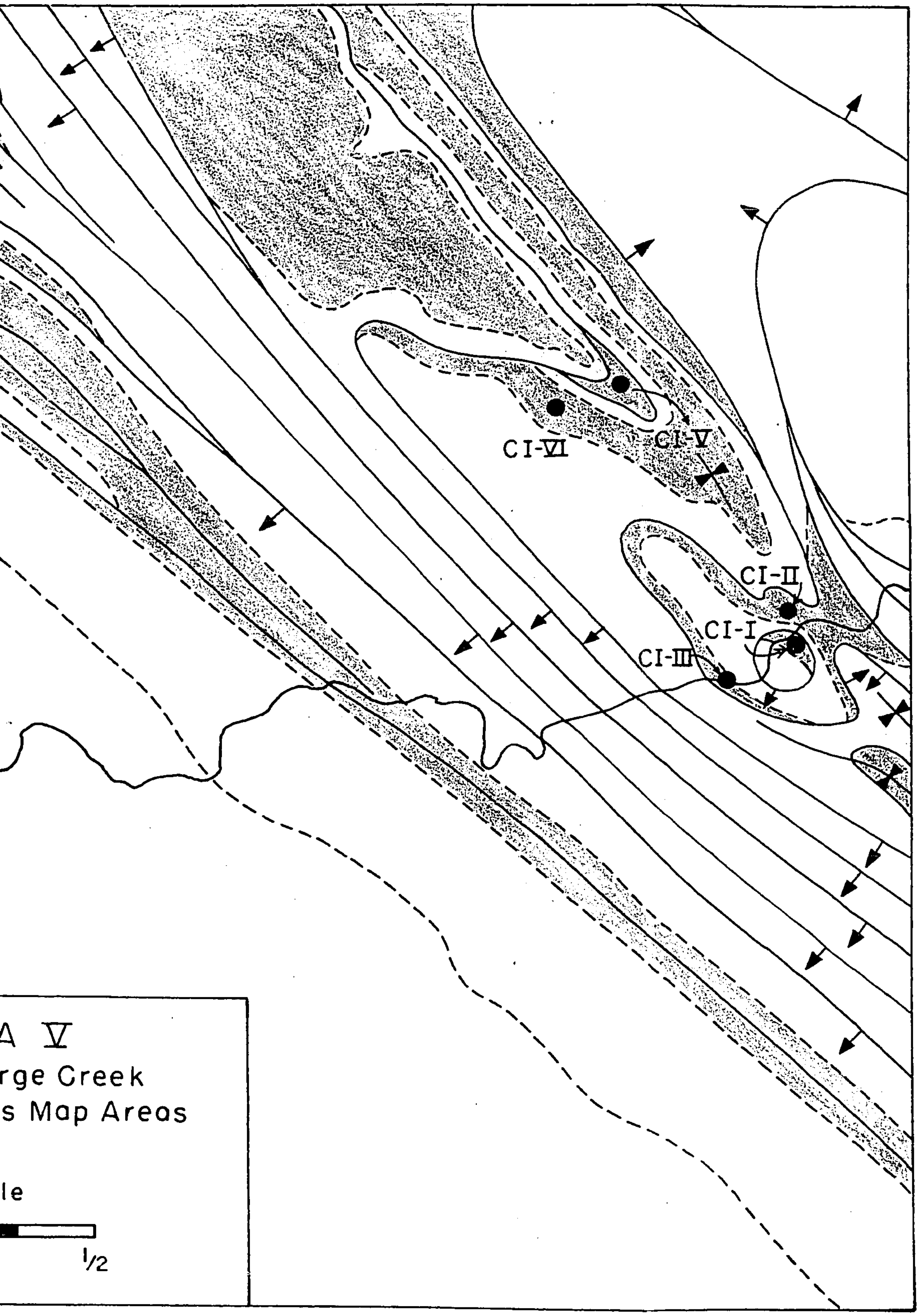
MAP AREA III
Portions of George Creek and
Wapiabi Creek Map Area
SCALE
1" = 1/2 mile

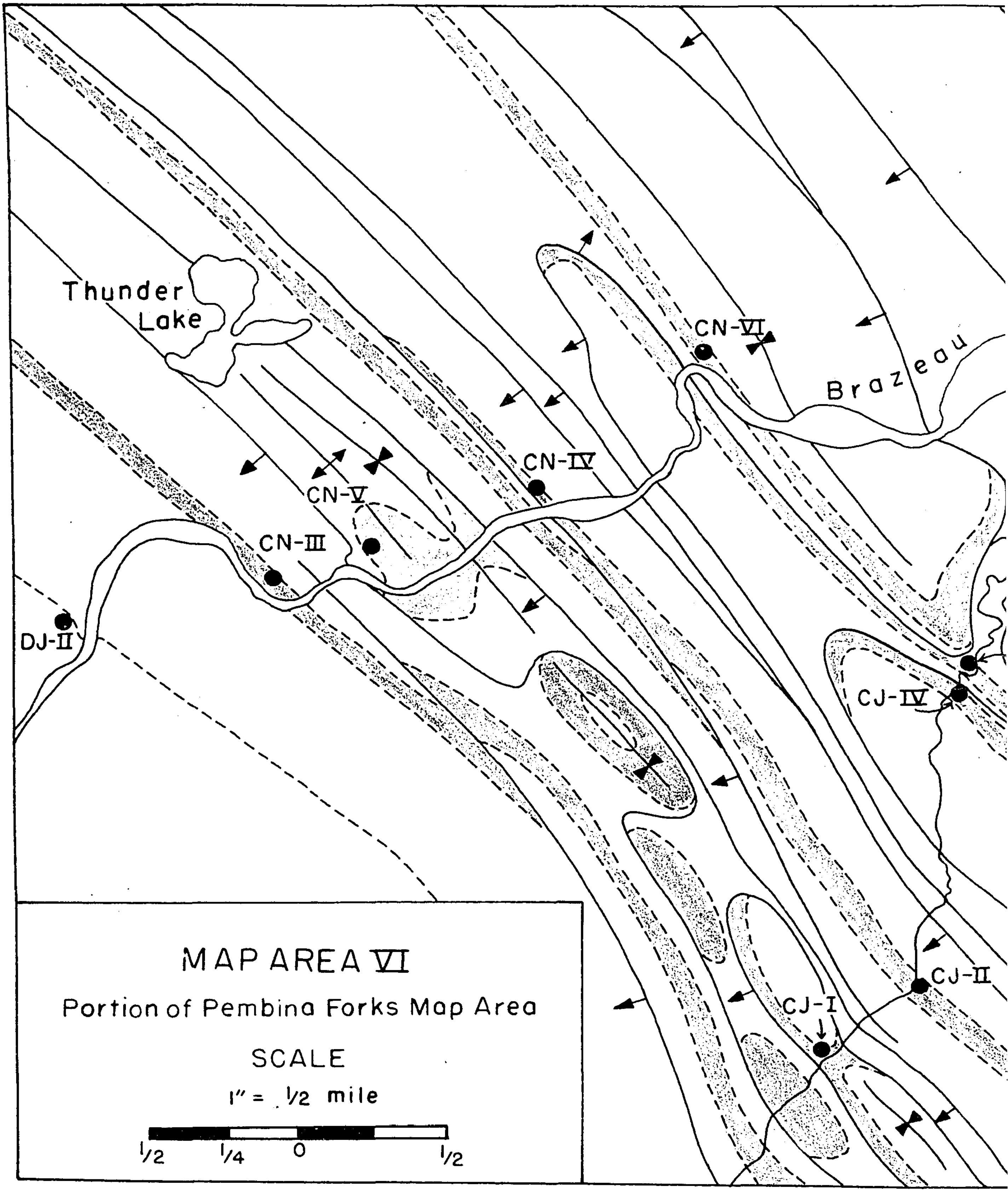

CK-V
MB-I
CK-IV
CK-III
CK-I
CK-II
SA-I
WA-I


CK-V
MB-I
CK-IV
CK-III
CK-I
K-II
DF-I
WA-I
MAP AREA IV
Portion of George Creek Map Area
SCALE
1" = 1/2 mile
1/2 1/4 0 1/2

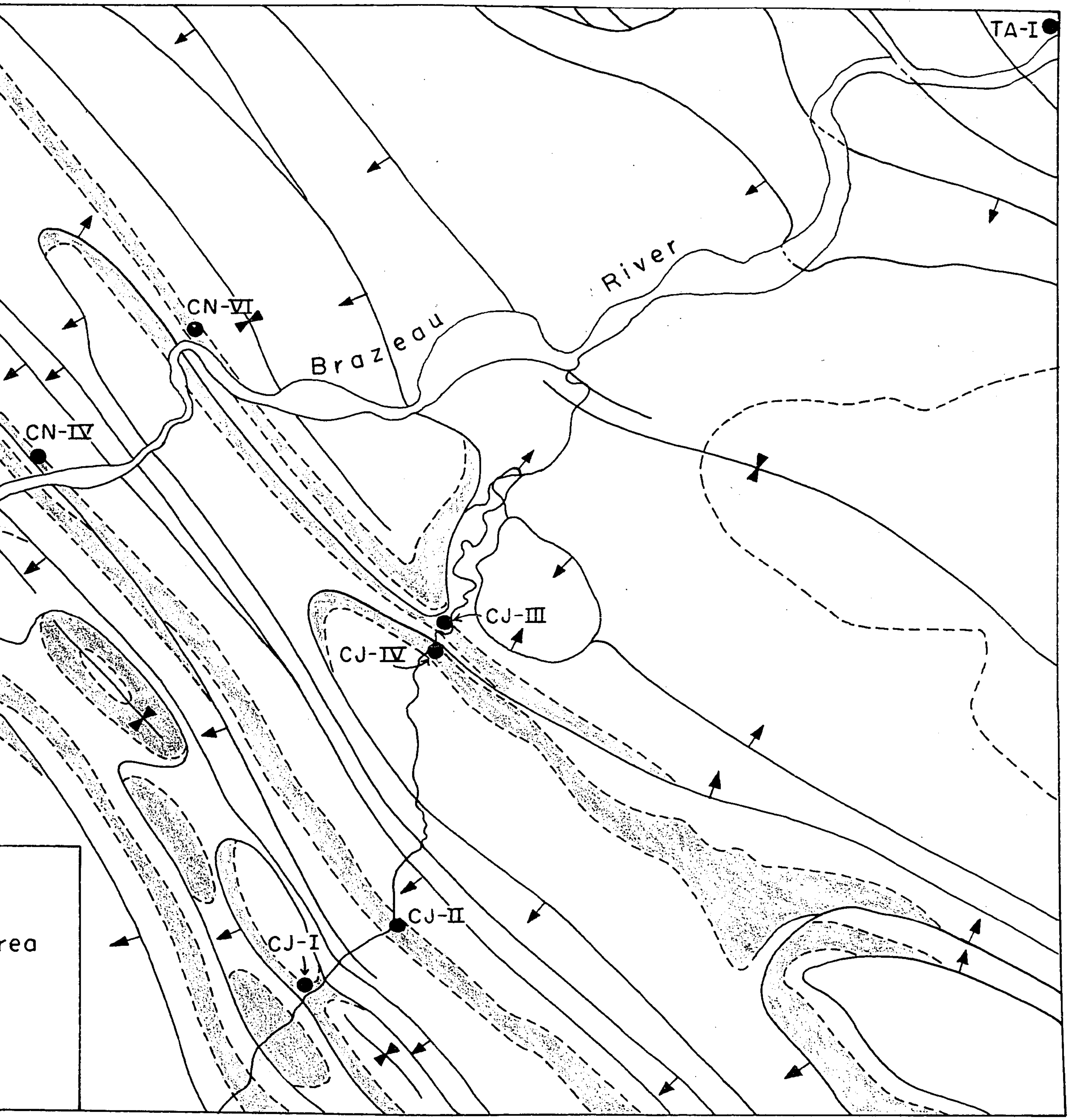


MAP AREA V
Portions of George Creek
and Pembina Forks Map Areas
SCALE
1" = 1/2 mile
1/2 1/4 0 1/2

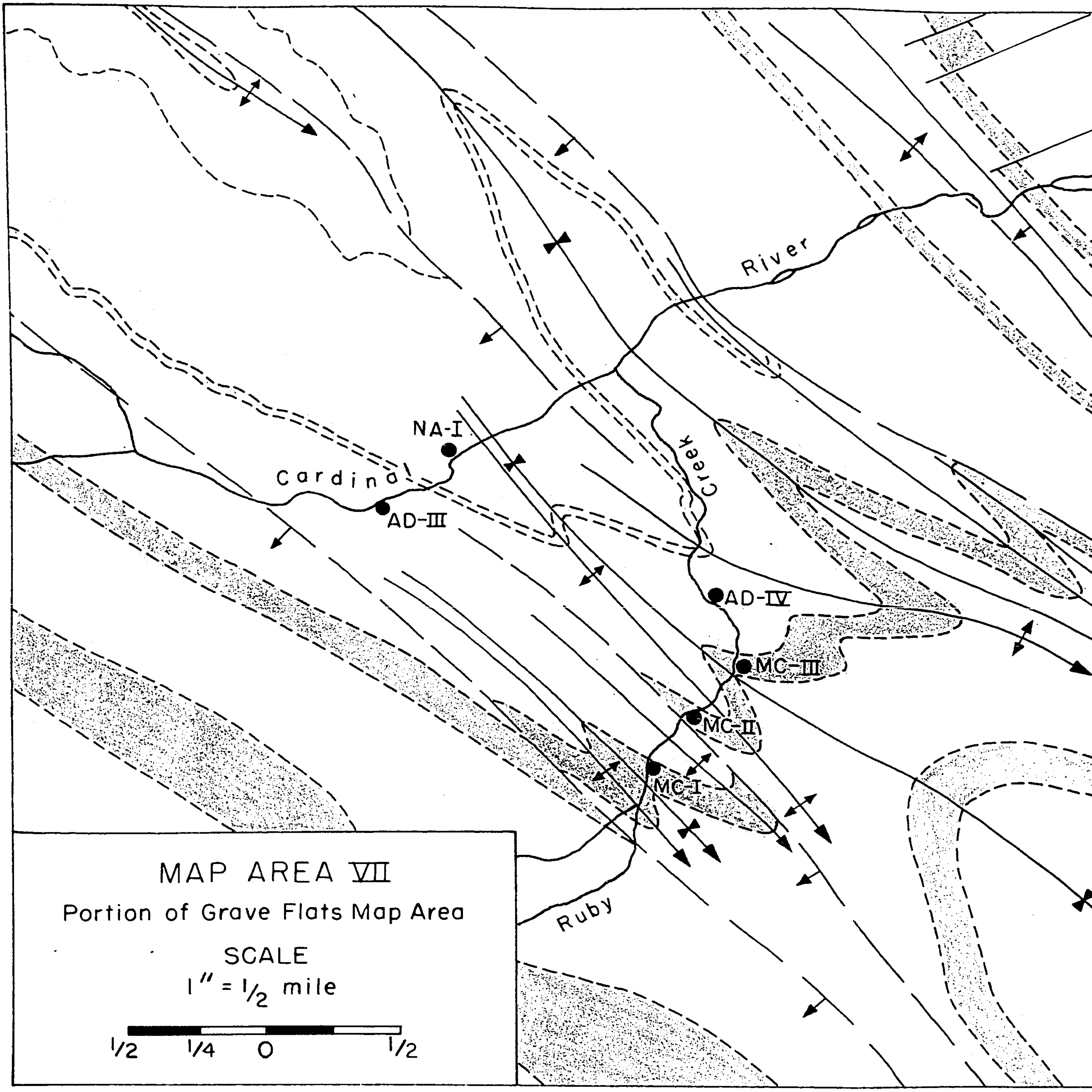

CI-VI
CI-V
CI-II
CI-I
CI-III
A V
rge Creek
s Map Areas
le
1/2



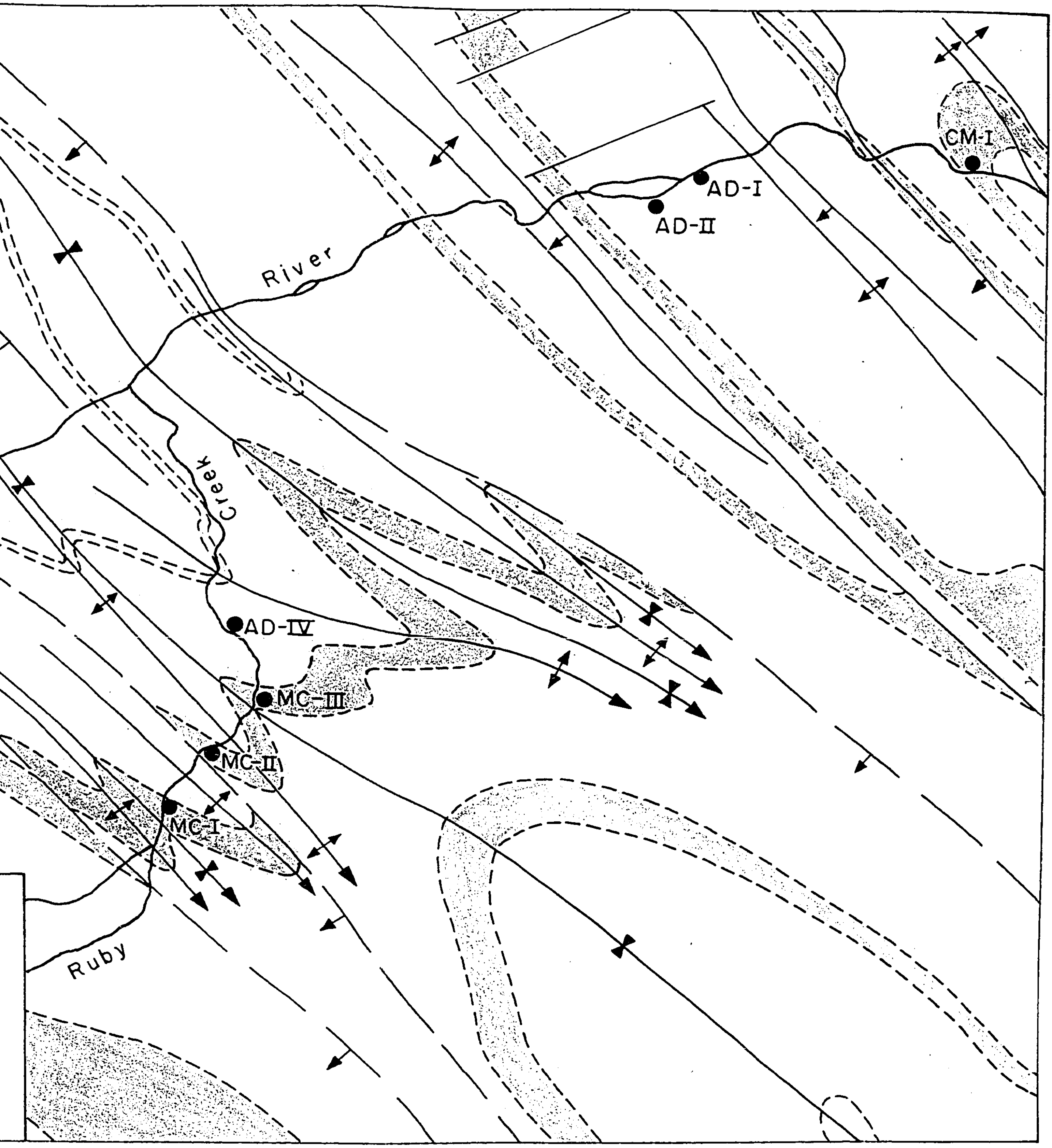
Thunder Lake
Brazeau
CN-VI
CN-IV
CN-V
CN-III
DJ-II
CJ-IV
CJ-II
CJ-I
MAP AREA VI
Portion of Pembina Forks Map Area
SCALE
1" = 1/2 mile
1/2 1/4 0 1/2

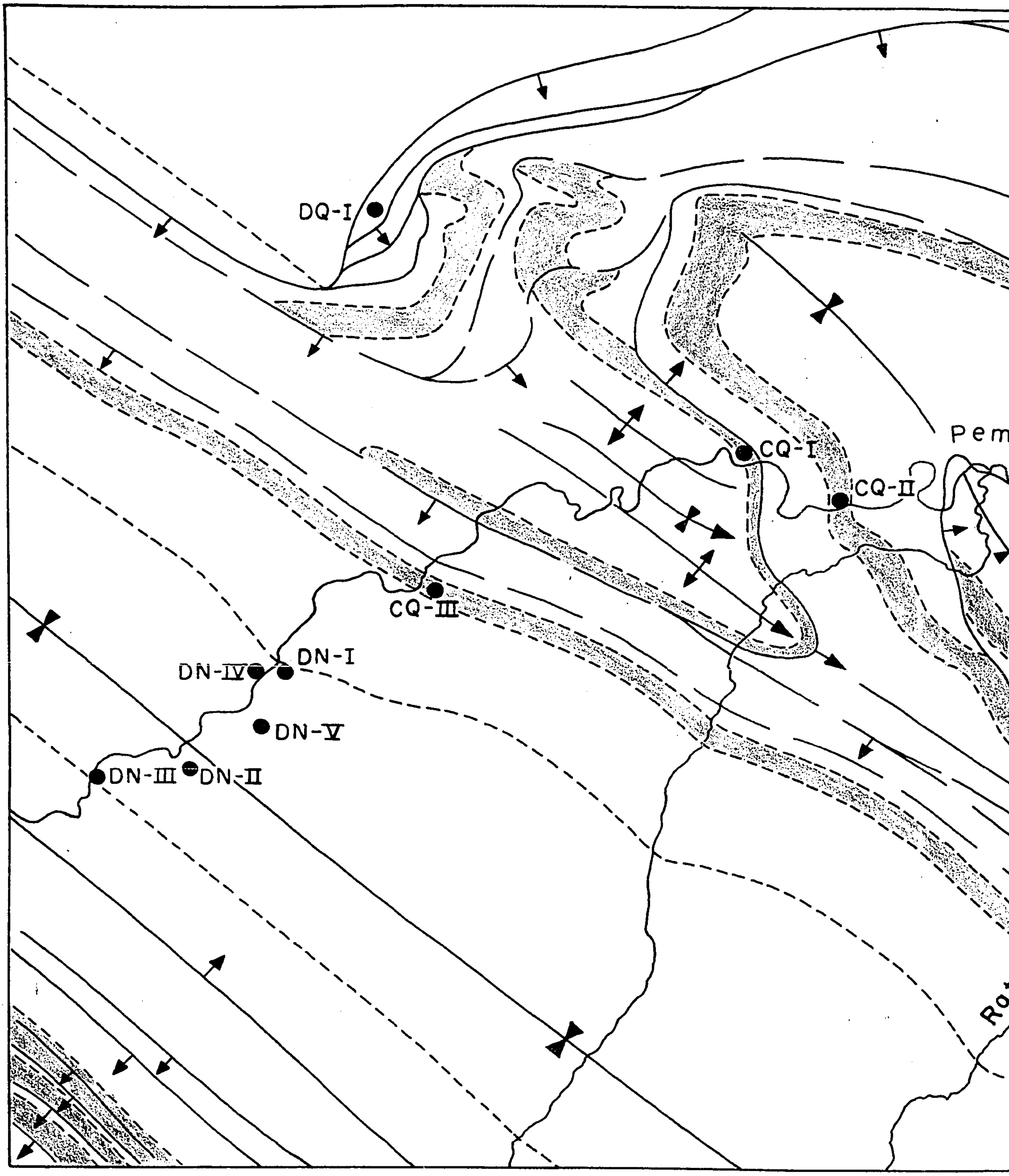


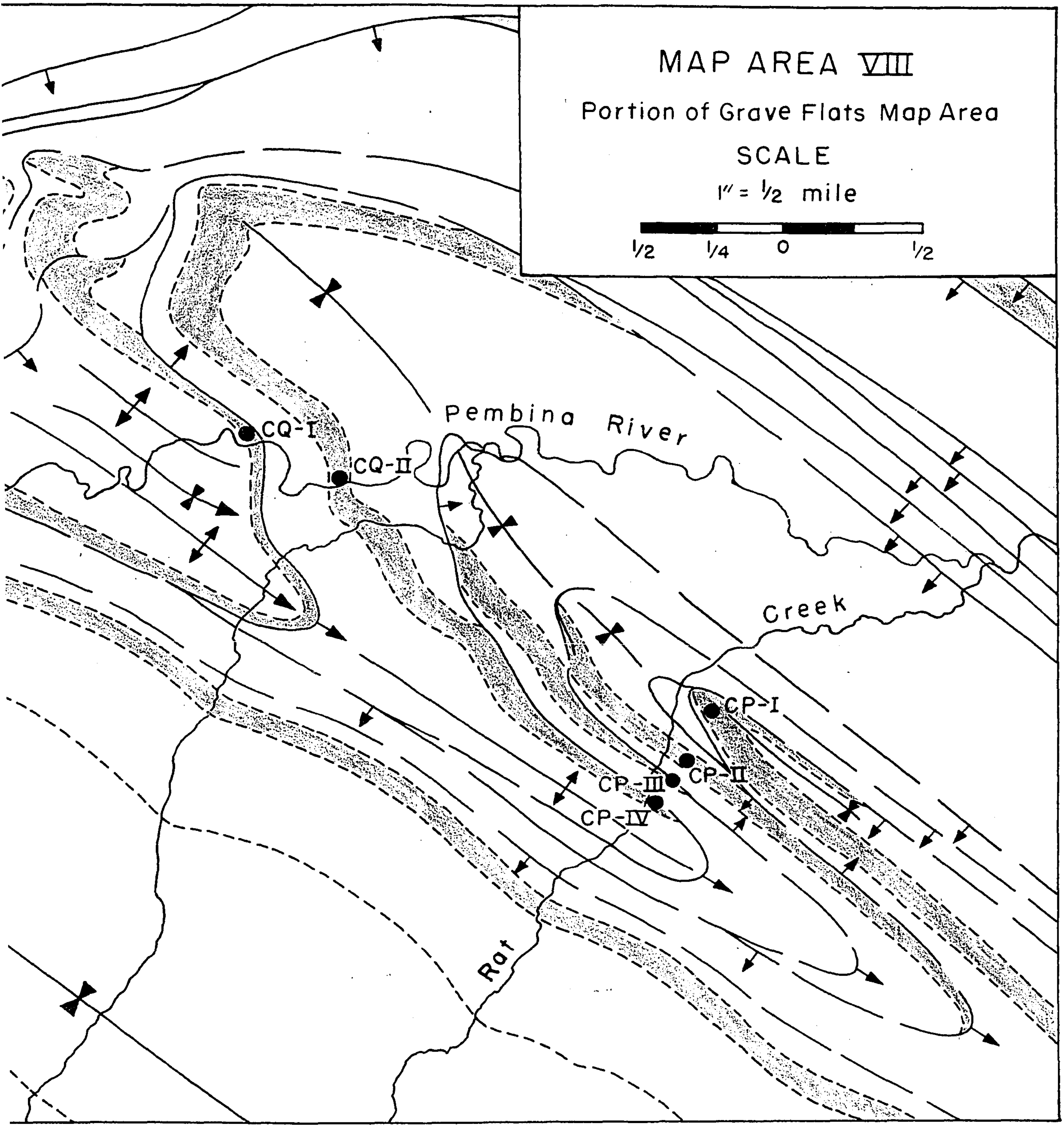
TA-I
River
Brazeau
CN-VI
CN-IV
CJ-III
CJ-IV
CJ-II
CJ-I
rea



River
Creek
Cardinal
Ruby
NA-I
AD-III
AD-IV
MC-III
MC-II
MC-I
MAP AREA VII
Portion of Grave Flats Map Area
SCALE
1" = 1/2 mile
1/2
1/4
0
1/2


CM-I
AD-I
AD-II
River
Creek
AD-IV
MC-III
MC-II
MC-I
Ruby


DQ-I
Pem
CQ-I
CQ-II
CQ-III
DN-I
DN-IV
DN-V
DN-III
DN-II


MAP AREA VIII
Portion of Grave Flats Map Area
SCALE
1" = 1/2 mile
1/2
1/4
0
1/2
Pembina River
CQ-I
CQ-II
Creek
CP-I
CP-II
CP-III
CP-IV
Rat

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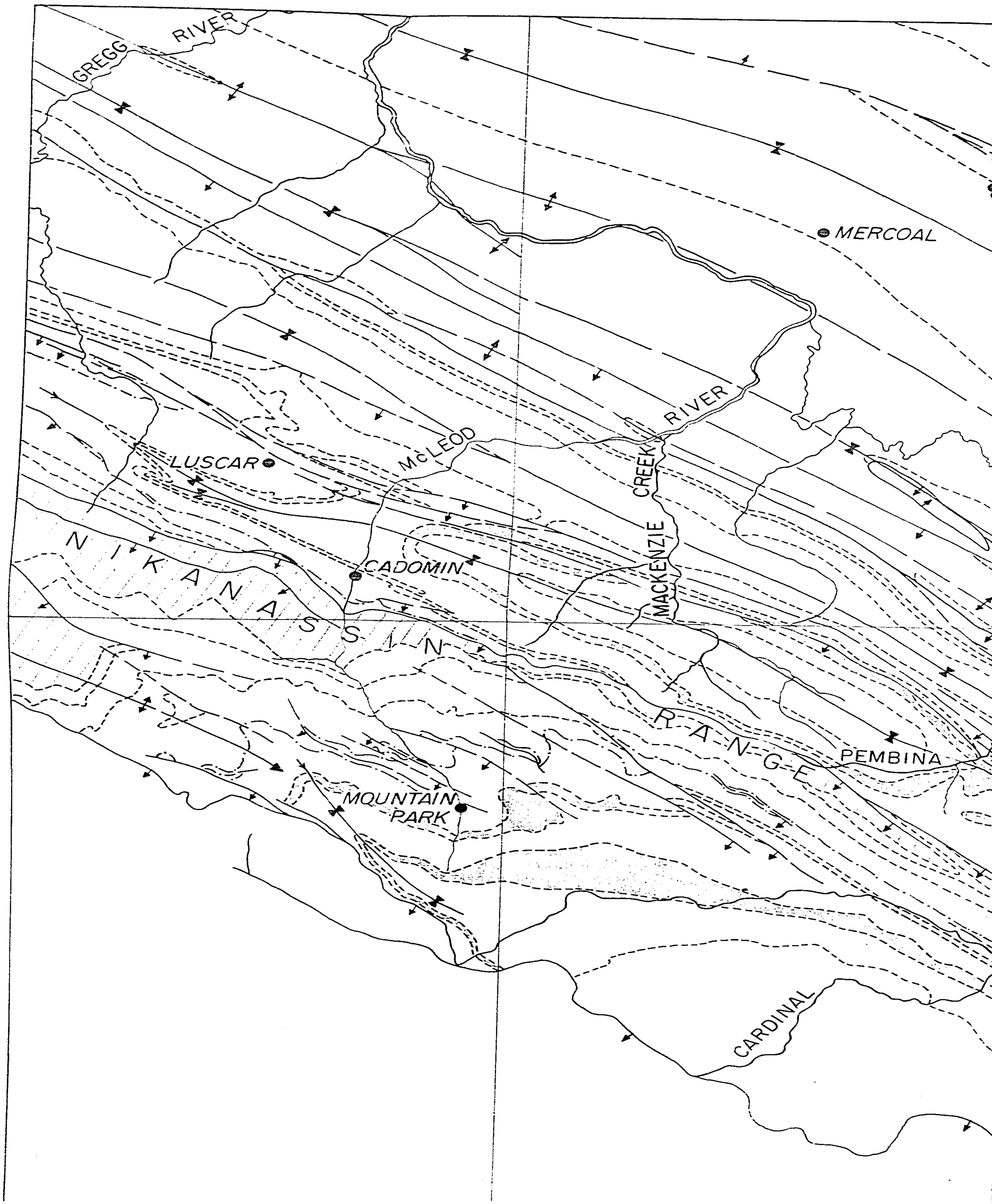
GREGG RIVER
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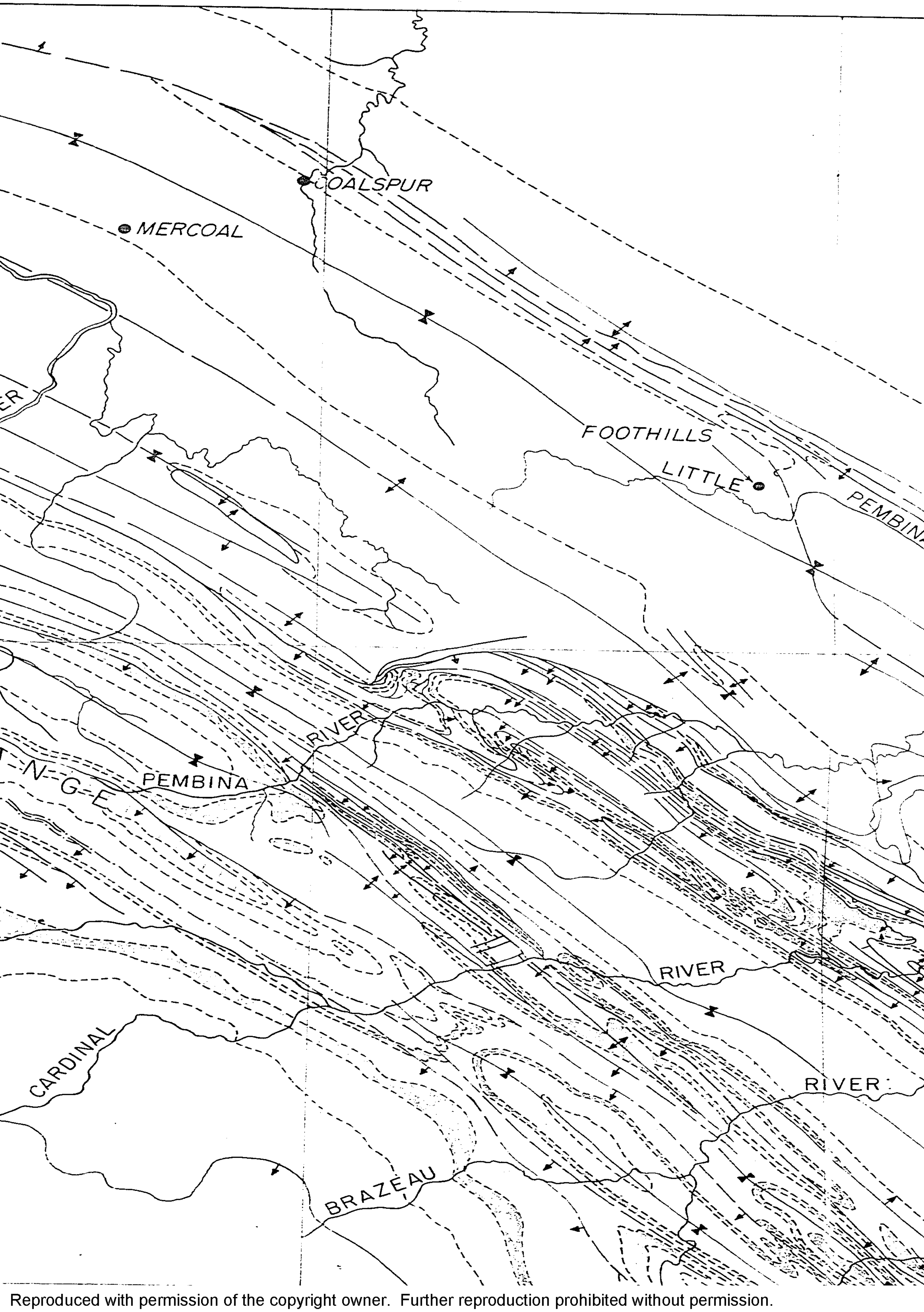

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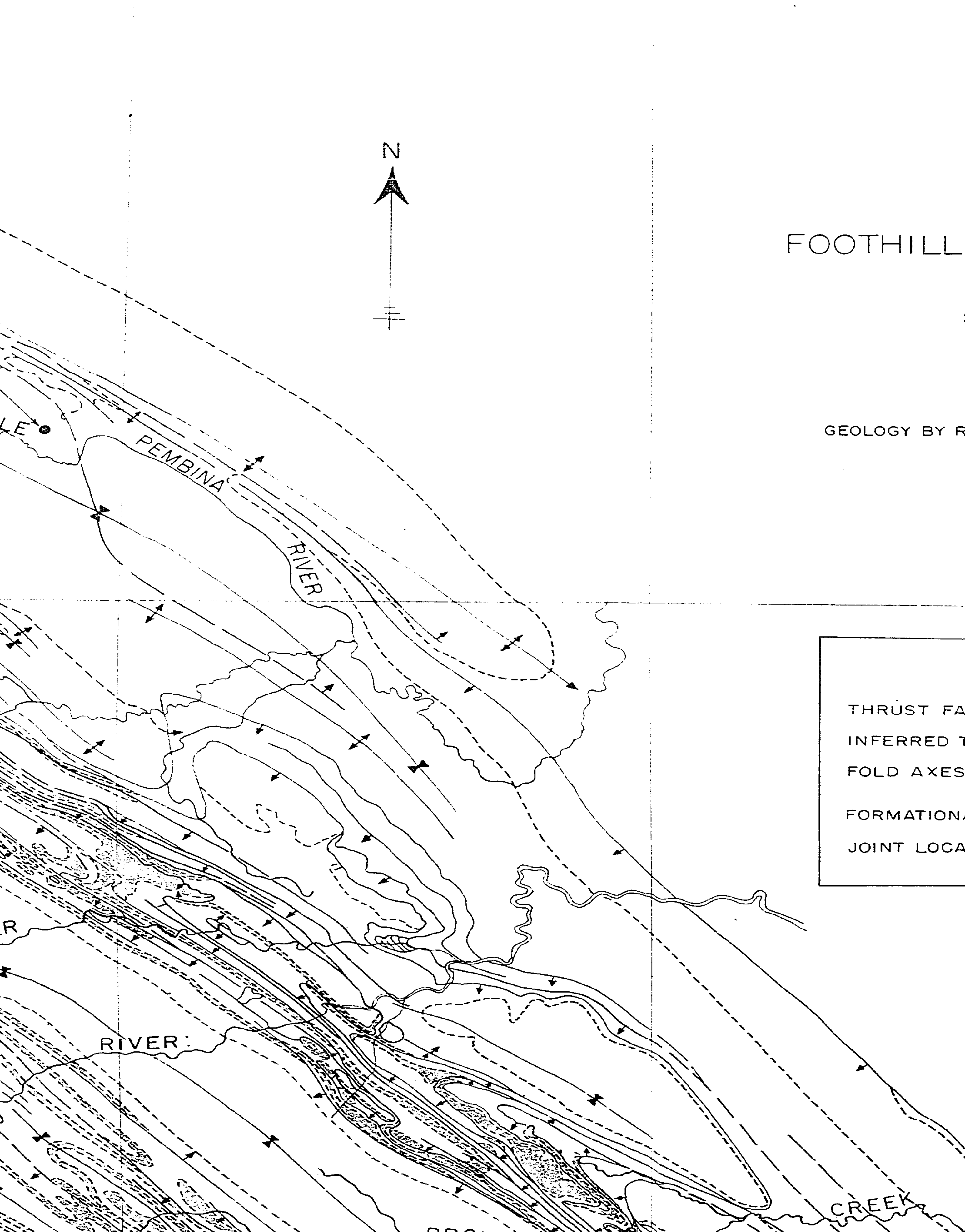
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REGIONAL MAP
A

HILLS BELT OF CENTRAL ALBERTA

SCALE — 1 INCH TO 2 MILES

2 1 0 2 4 0

OGY BY R.J.W. DOUGLAS — COMPILATION BY RONALD G. SCHMIDT

53

LEGEND

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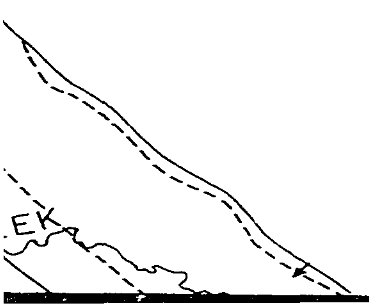
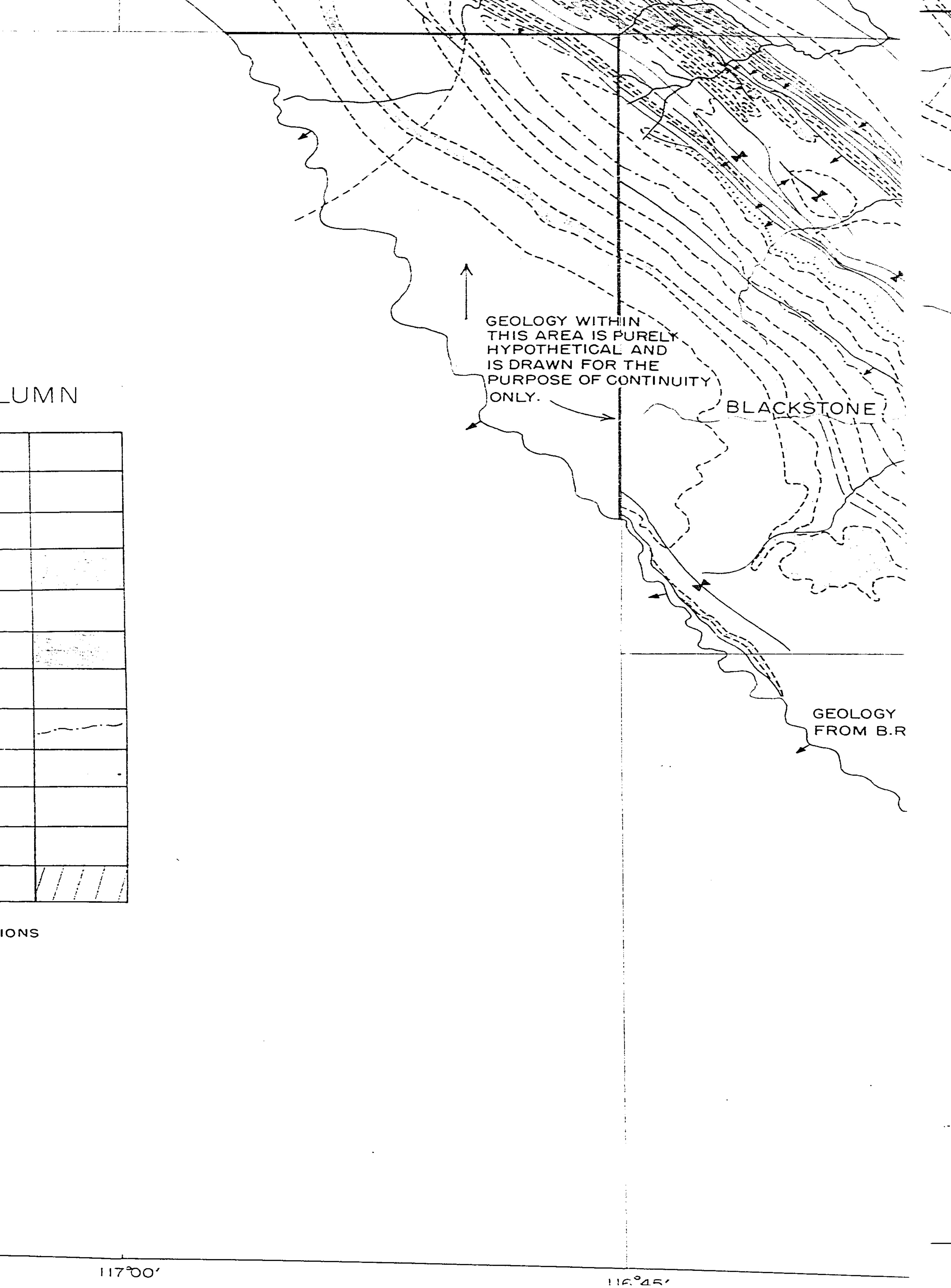
RMATIONAL CONTACT

NT LOCALITIES (SHOWN ON REGIONAL MAP B)

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GEOLOGY WITHIN THIS AREA IS PURELY HYPOTHETICAL AND IS DRAWN FOR THE PURPOSE OF CONTINUITY ONLY.
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GEOLOGY FROM B.R
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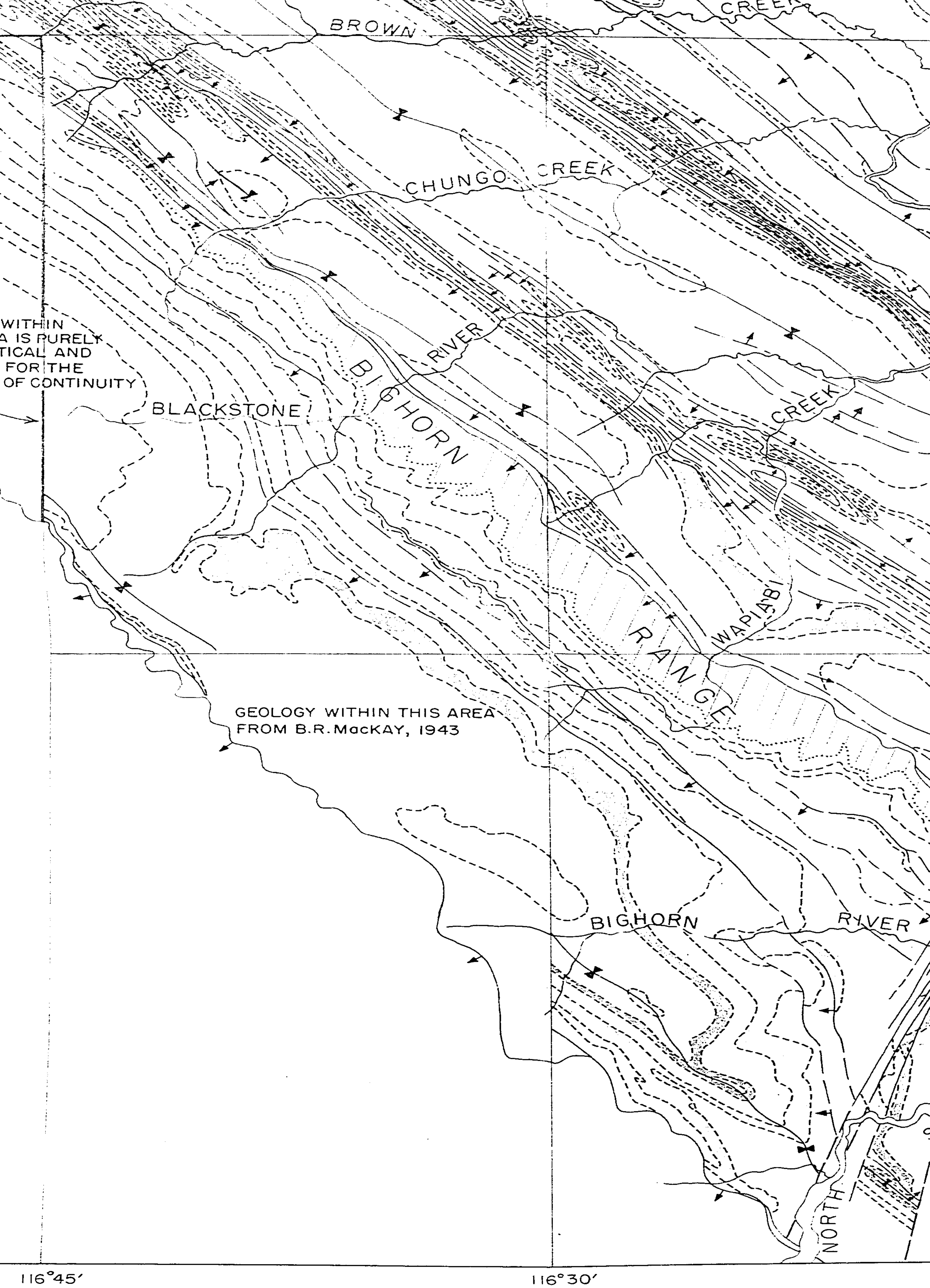
116°45′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BLACKSTONE
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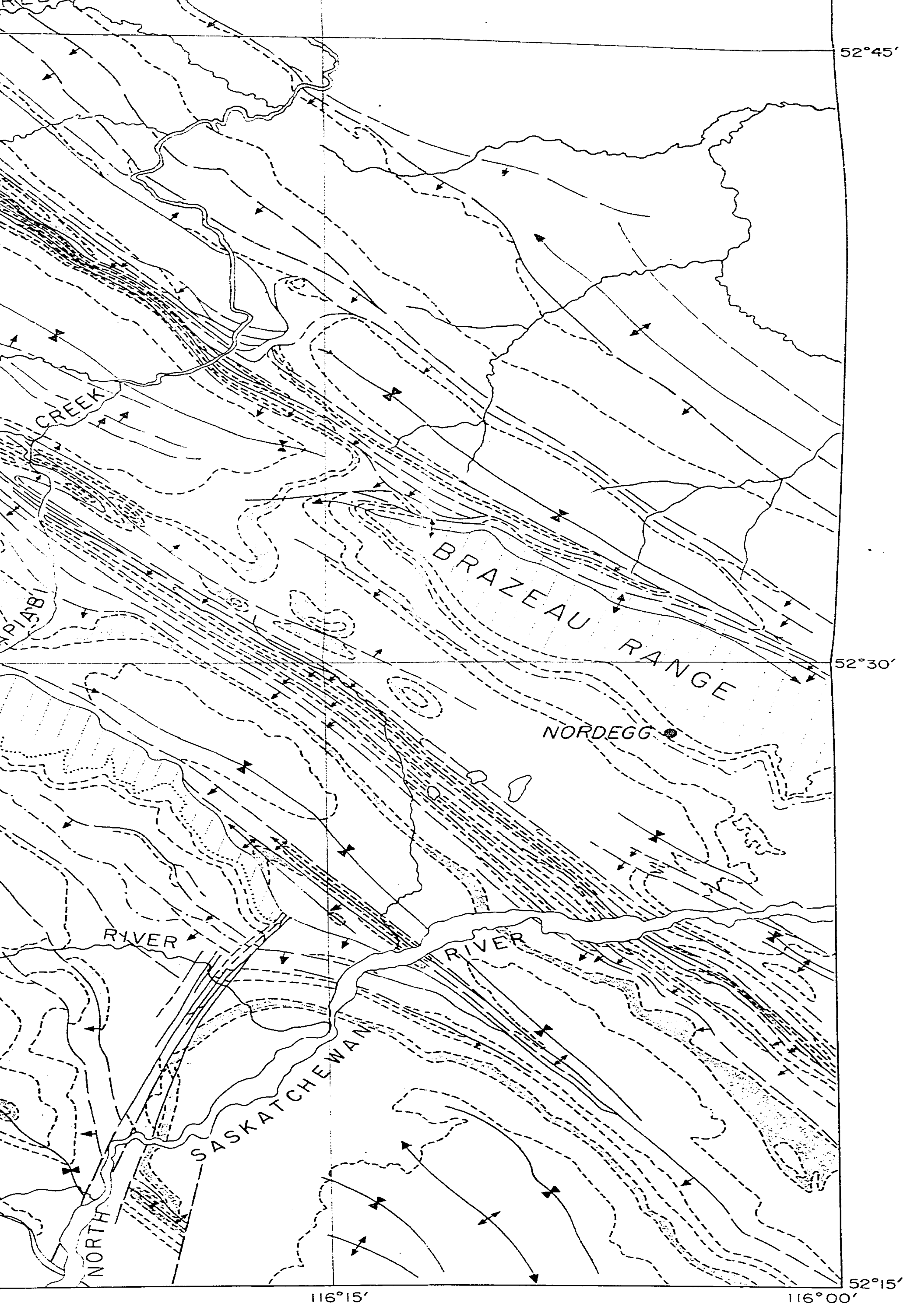
GEOLOGY WITHIN THIS AREA
FROM B.R. MacKAY, 1943
BIGHORN
RIVER
NORTH
116°45′
116°30′


52°45′
CREEK
BRAZEAU RANGE
52°30′
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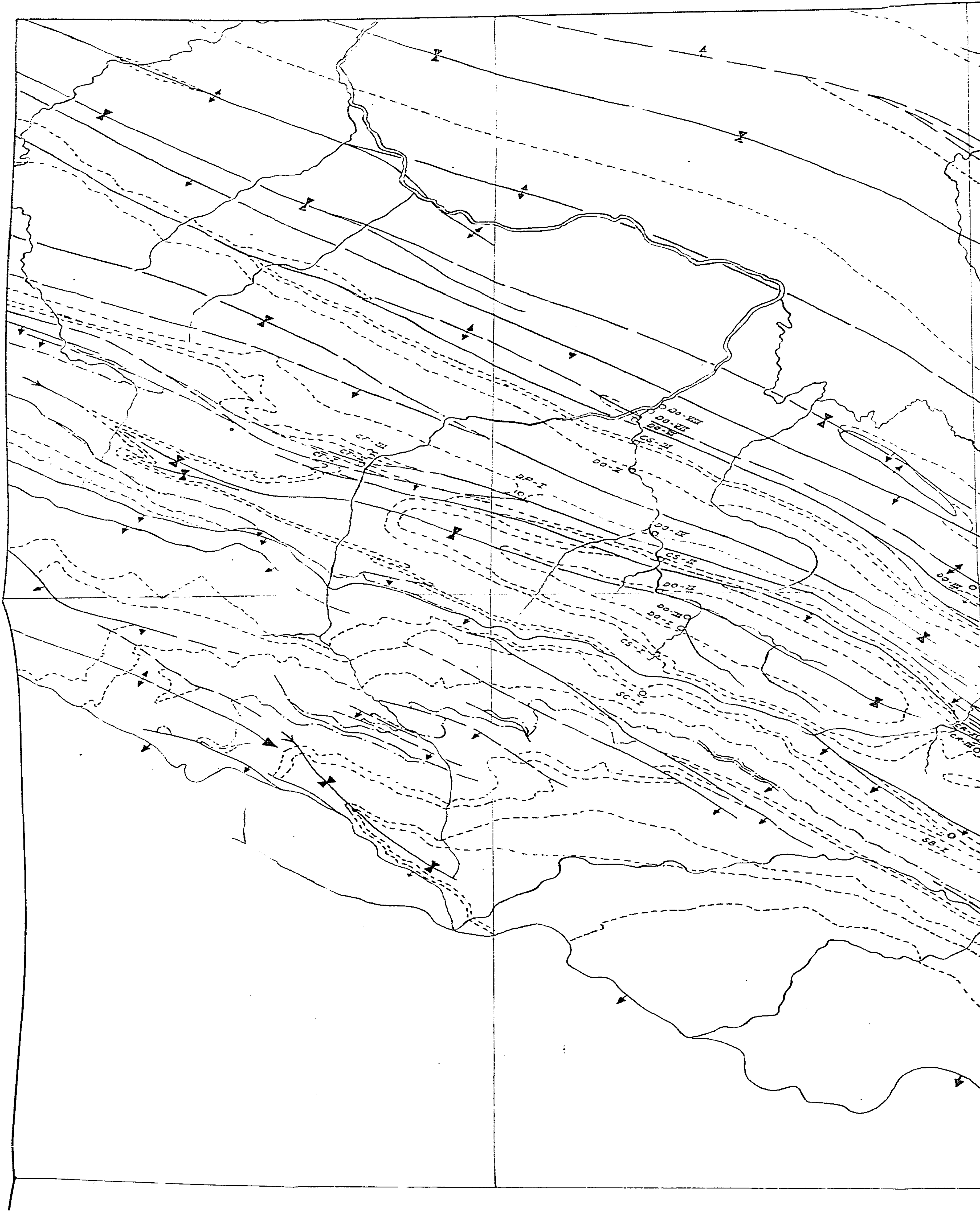
RIVER
SASKATCHEWAN
NORTH
52°15′
116°15′
116°00′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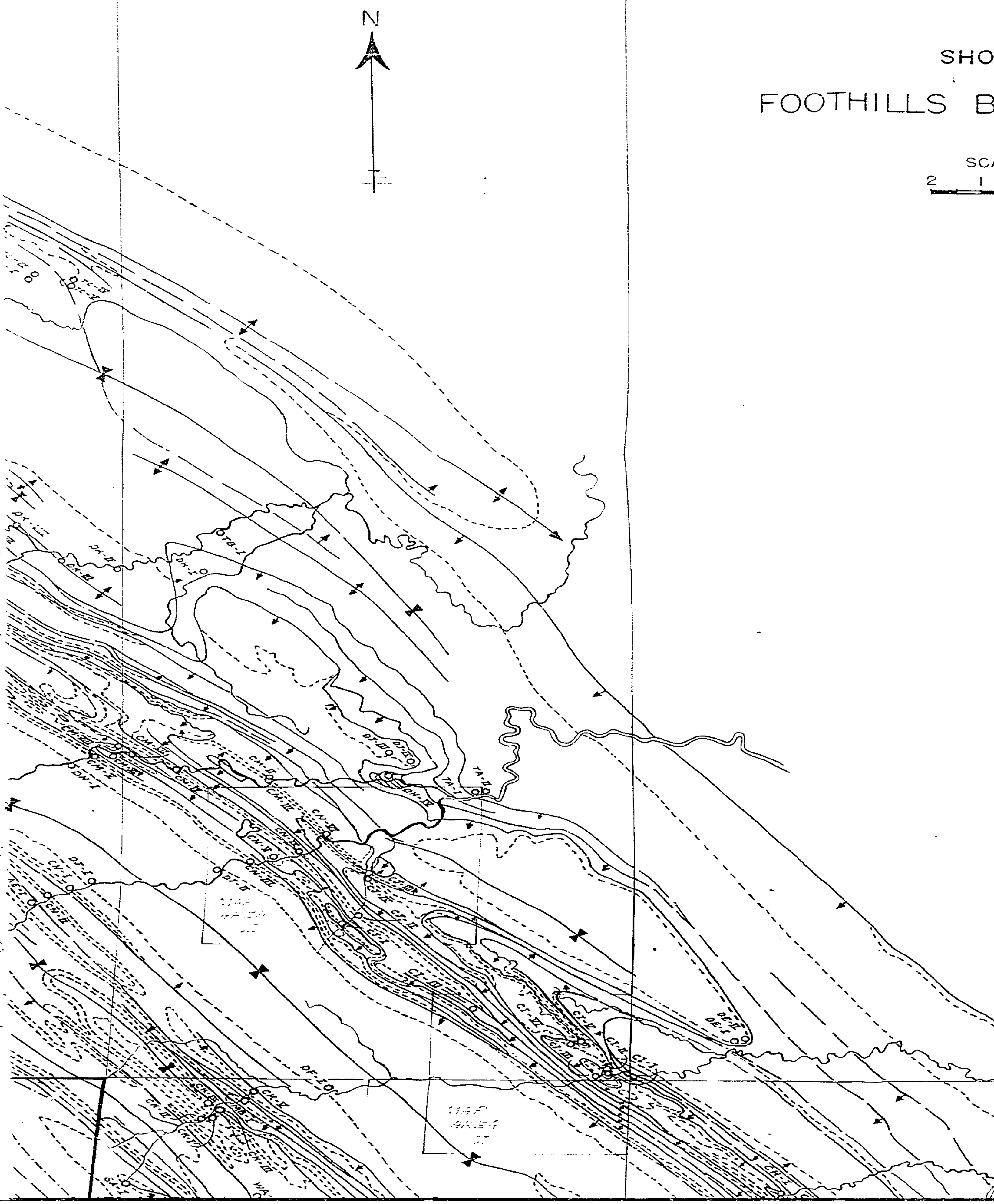
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REGIONAL MAP
B

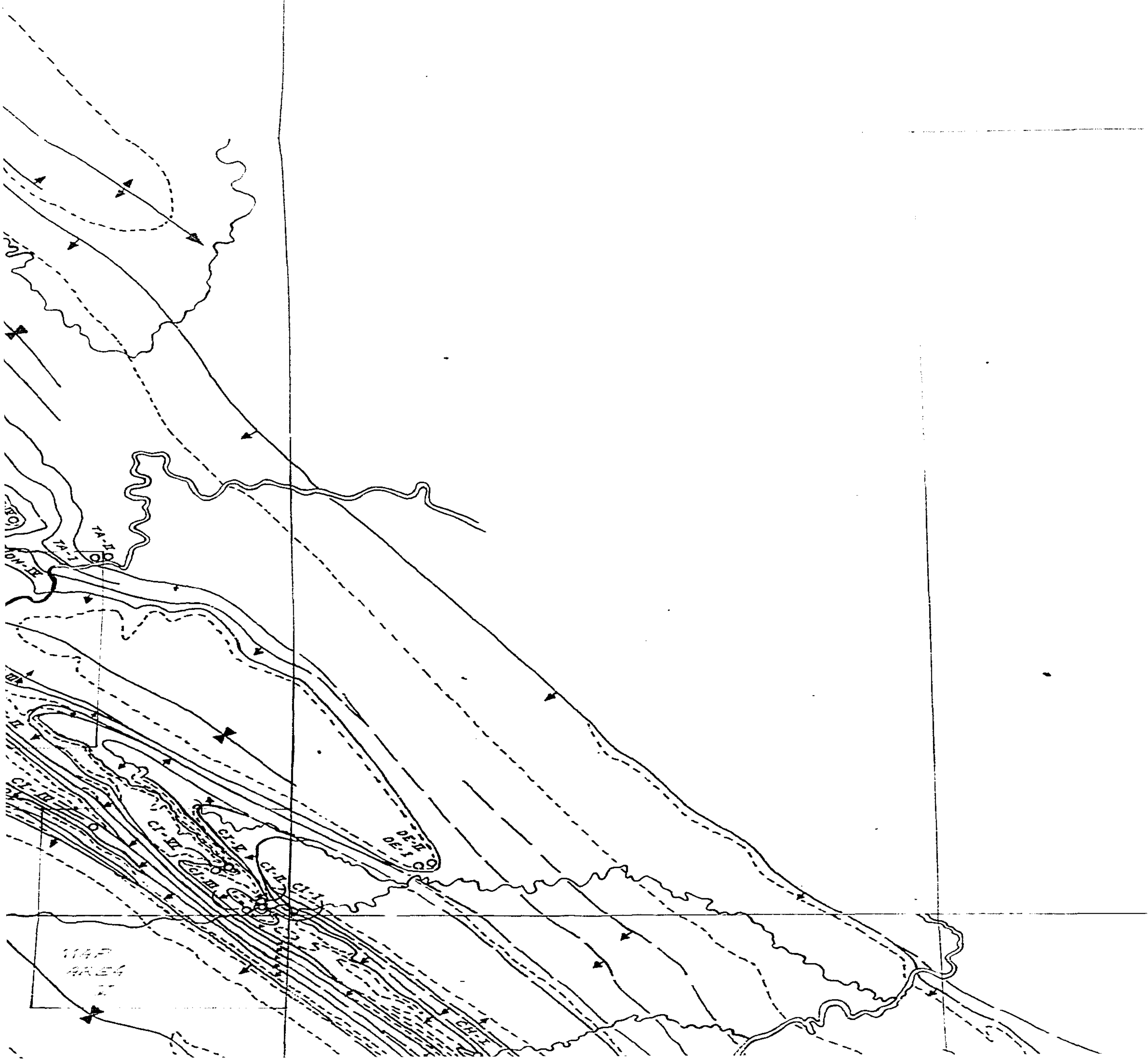
SHOWING JOINT LOCALITIE

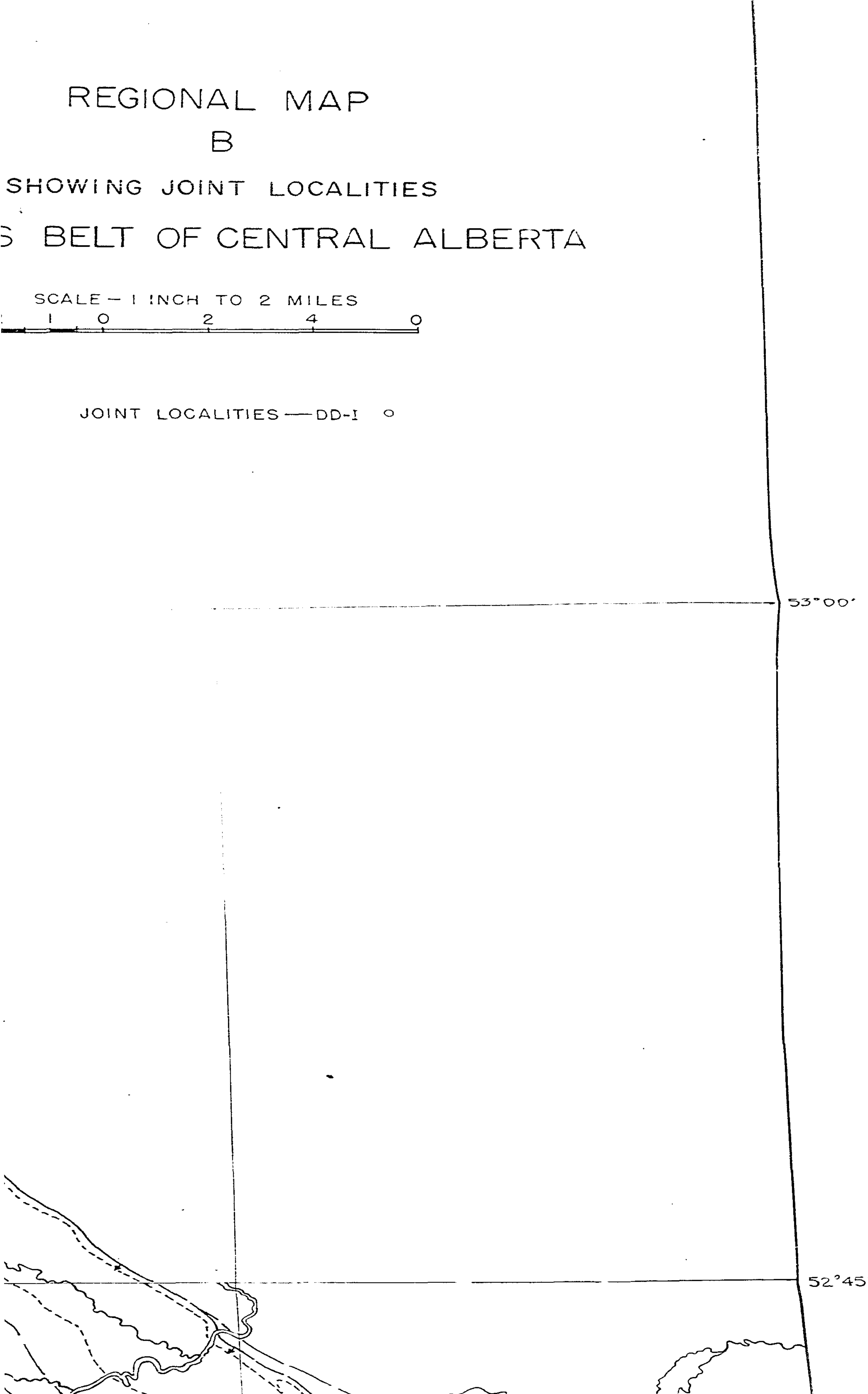
FOOTHILLS BELT OF CENTRAL

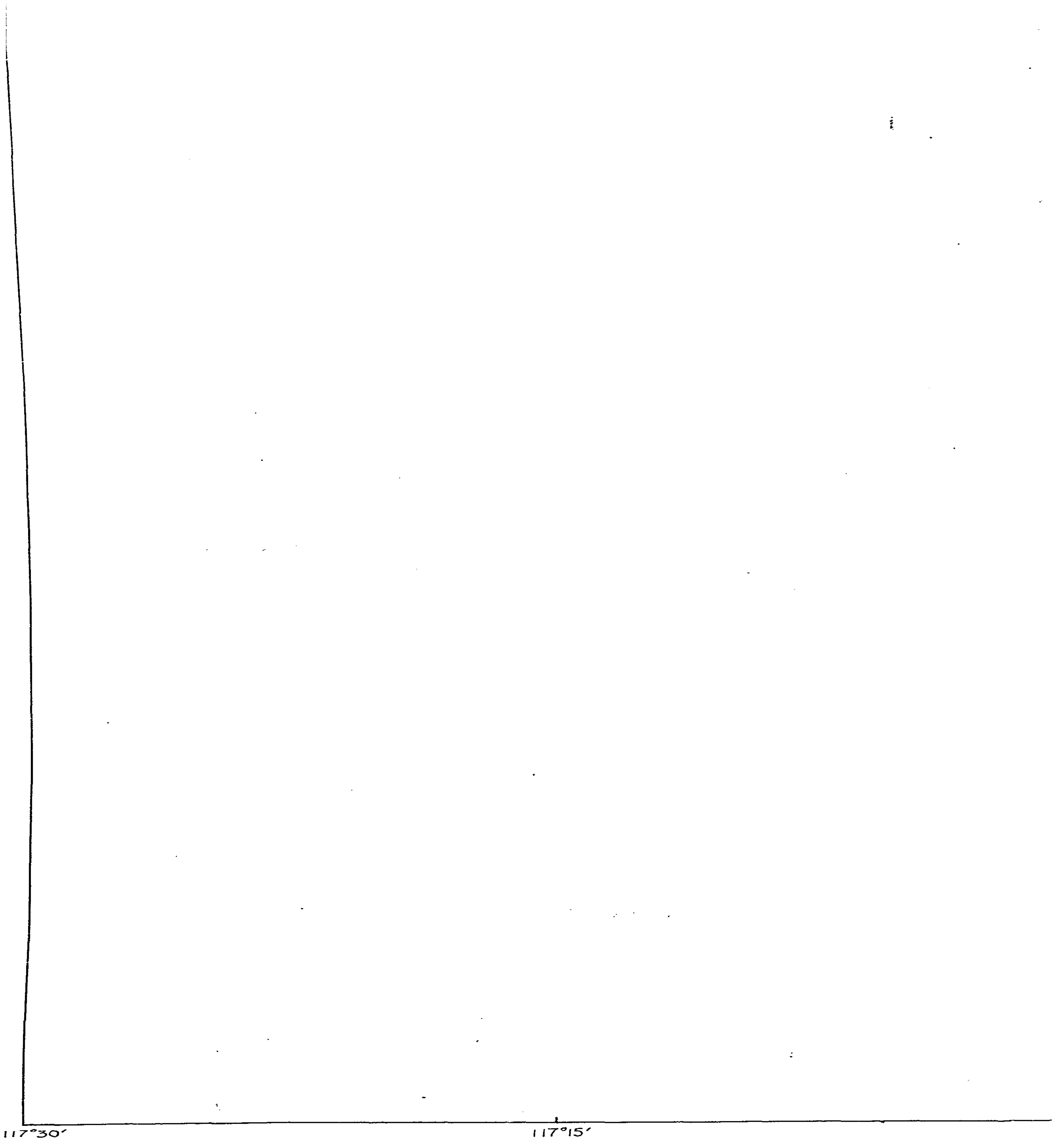
SCALE — 1 INCH TO 2 MILES

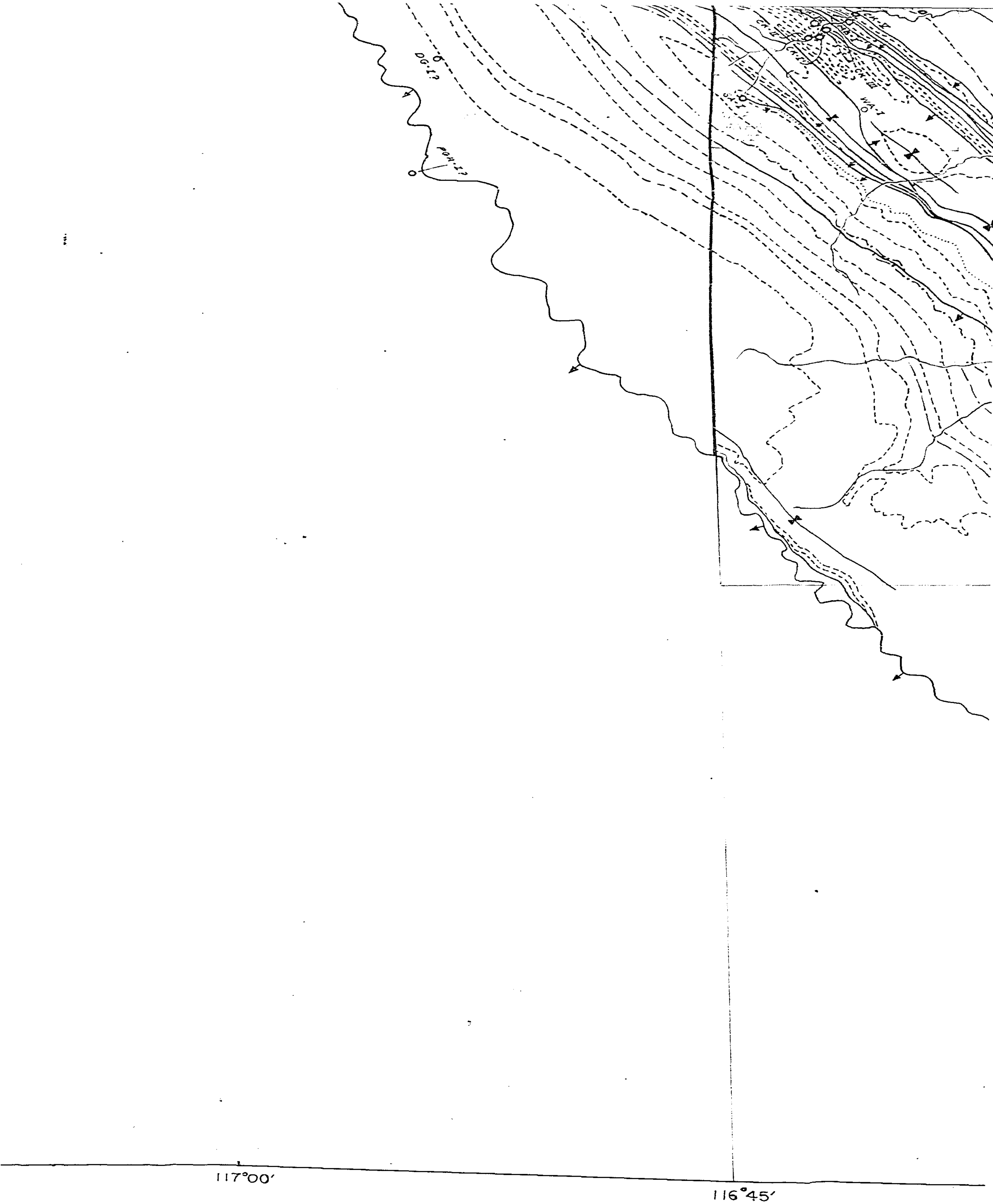
2 1 0 2 4

JOINT LOCALITIES —— DD-I ○



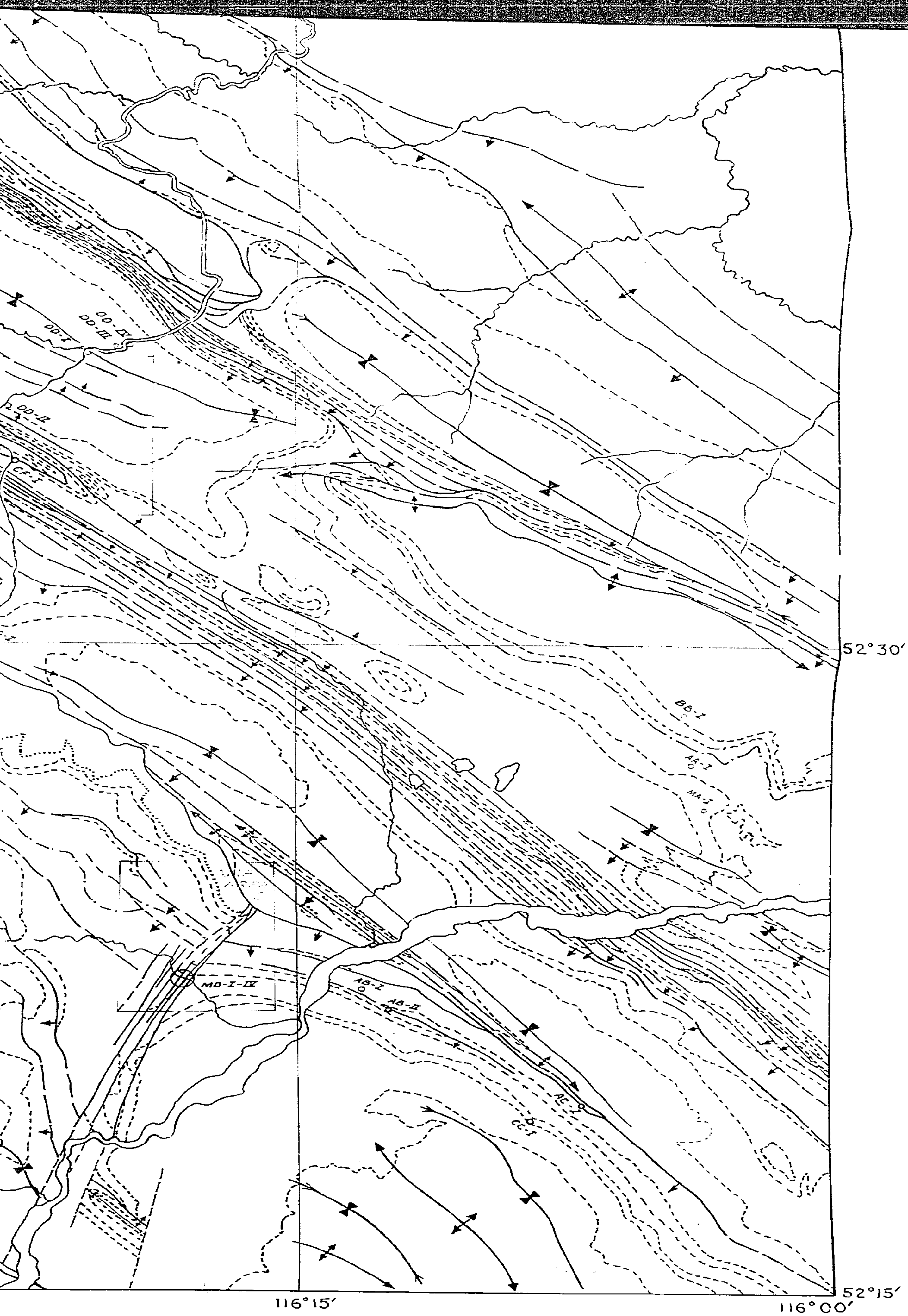

REGIONAL MAP
B
SHOWING JOINT LOCALITIES
BELT OF CENTRAL ALBERTA
SCALE — 1 INCH TO 2 MILES
1 0 2 4 0
JOINT LOCALITIES — DD-1 ○
53°00'
52°45'


117°30′
117°15′



117°00′
116°45′


116°45′
116°30′
DD-II
CE-I
CF-I
CG-I
WA-I


52°30′
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BB-I
AA-I
MA-I
AB-I
AB-II
AC-I
CC-I
MD-I-IV
DD-I
DD-II
DD-III
DD-IV