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GENERAL GEOLOGY, GEOMORPHOLOGY

AND

FRACTURE ANALYSIS SURVEY

OF

P.&N.G. PERMITS 5425 and 5426

GREAT BEAR LAKE AREA, N.W.T.

FOR

MICHIGAN DEVELOPMENTS LTD.

BY

WILLIAM G. CROOK, P. GEOL.

INDEX

GEOMORPHOLOGY

The Permit Numbers 5425 and 5426 lie on the interior plains area of the Northwest Territories about 240 miles west of the edge of the Pre-Cambrian Shield. The area was completely glaciated during Wisconsin time as is shown by the abundance of glacial landforms and by modification of the bedrock surface. These glacial features are not so dominant as to obliterate all other surface forms and features and much non-glacial geological information can be had from the mosaic. The direction of ice movement was obviously northwest-southeast.

The drainage pattern is not well defined in this area but, in general, the drainage is to the northwest towards the MacKenzie River and east towards Turton Lake. Within the mosaic much of the drainage is internal towards small lakes which have no drainage. Many of the small streams are intermittant and hold water only during the spring. The general drainage pattern is dendritic but it has been greatly altered by the glacial affects and the many lakes. It does not appear to be controlled by any subsurface feature.

There are no topographic forms present which indicate any geological feature.

GLACIAL FEATURES

The surface of the area has been modified on a very large scale by the passage of the glaciers and their subsequent melting. The bedrock itself, however, probably did not exert any influence on the ice flow pattern or the direction and pattern flow of the meltwater streams. There is a possibility that the strong lineations were present before glaciation and that the glacial flow simply took the line of least resistance and followed pre-existing lineations. This net effect would be an accentuation of the pre-glacial trends.

Small moraine belts are present throughout nearly all of the mosaic area. Nearly all of these are maturely dissected but the typical knob and kettle topography remains. The kettle lakes are very small compared to other lakes in the area often the small depressions contain no water at all. The knob hills are usually low and well rounded. The moraines are not as large or as conspicuous as those in the Province of Alberta.

Scattered throughout the moraine are countless drumlinoid forms. These are formed near the edge of the moving glacial ice and are parallel to the direction of movement of the ice. They are usually less than 50 feet high and several hundred feet in length. True drumlins are a distinct, easily recognised shape, but in this area post-glacial erosion has obliterated most of these features and no "drumlin fields" are present. Drumlins are

almost always composed of glacial till material and in their uneroded state are good indicators of the direction of ice flow. Many are present in the northeast corner of the mosaic.

Transverse ridge is the term applied to all drift ridges formed at right angles to the direction of ice flow. Many of these features are present throughout the two Permits and good examples can be seen in the area east of Tunago Lake. They are characterized by being short in length and are seldom more than a few tens of feet in height. These features often occur as small ridges in drumlin-fields and are at right angles to the long axis of the drumlins. On aerial photographs the transverse ridges give the terrain a cross-hatched appearance.

Ice block ridges are usually seen in glaciated areas but none can be seen on this mosaic. If they were once present they have been removed by erosion. Typically they are small ridges which surround or nearly surround irregularly shaped depressions. These ridges were formed in cracks between ice blocks into which ablation material was sloughed as the individual ice blocks melted.

Perhaps the most striking glacial feature anywhere is the esker. These are long sinuous ridges of gravel and till laid down by sub-glacial drainage streams. Some can be traced for astonishing distances - over 200 miles on the Canadian Shield.

They roughly parallel the direction of the ice flow. Within the mosaic area several short eskers can be identified but post-glacial erosion seems to have removed most evidence of their existence. Esker streams often erode channels through the bedrock where the bedrock forms a slight high between two low areas.

STRATIGRAPHY

Permits 5425 and 5426 are geographically located near Moon Lake and lie about 2[illegible] miles north-northwest of Norman Wells and immediately north of the Richardson Mountains. They lie near the western margin of the Norman Range of the Franklin Mountains and are about 6 miles east of the MacKenzie River which is located on the MacKenzie Plains. The Norman Range is approximately 30 miles wide in this vicinity and consists of a series of west to northwest trending anticlinal structures with associated faulting. The sedimentary section ranges in age from Cambrian to Upper Devonian with locally a relatively thin veneer of Cretaceous and Tertiary sediments overlying them. Regional isopachs indicate a thickness of approximately 7,700 feet of sediments should be present in this area, however, the faulted and folded nature of the area may greatly increase or decrease this figure at any given location. Subsurface control is provided by wells drilled at, or near Norman Wells, one of the nearest being Imperial Judile #1, located at 65°, 29', 23.6" N., and 127°, 35', 58.2" W., which is about 7 miles south of Permit 5426. Most wells have bottomed in the Bear Rock Formation with only widely scattered wells drilling into the Silurian-Ordovician and Cambrian sediments. To date no wells have been drilled east of the acreage under review. Regional isopach and facies maps, along with published geological reports have been used to describe the stratigraphic sequence which can be expected to underlie Permits 5425 and 5426.

CAMBRIAN AND/OR OLDER

KATHERINE GROUP

The Katherine Group, which represents the earliest Paleozoic sediments in this region is named from a section exposed in the Upper Carcajou River area which lies about 70 miles south of Permits 5425 and 5426. The section exposed consists of interbedded quartzites and black, platey shales. The shales are green, chocolate and black coloured with the black being platey and bituminous. They are contained as interbeds in the quartzites which are generally pink, buff, rusty and white coloured in outcrop. The top of the Katherine is placed at the base of a chocolate coloured shale succession. The base of the Katherine was not seen, leaving the total thickness unknown for this area. To date, the Katherine has not been penetrated by any well in this region which leaves the subsurface section an unknown quantity. While reservoirs are not described in outcrop it must none the less be expected that sand bodies such as offshore bars, beach sands and longshore bars will eventually be found in this group of sediments. Similar sands are found to be prolific producers in the Red Earth Creek area of northern Alberta. The delineation of prospective areas for encountering such sands is dependant on a knowledge of present Pre-Cambrian structure as well as its topographical expression during the deposition of the sands. A gravity meter and airborne magnetometer survey could be used to good advantage in locating areas requiring more detailed exploration such as a seismic reflection survey. The bituminous shales described in the Upper Carcajou River exposure should

provide an adequate source of hydrocarbons. This section should be considered in any exploratory plans for this area as major reserves could be contained in it. Anticlinal structures should provide another trapping mechanism for the area underlying Permits 5425 and 5426.

CAMBRIAN

MACDOUGAL GROUP

The type section of the Macdougal Group is located about 45 miles south of Permits 5425 and 5426 in the Dodo Canyon of Macdougal Creek. At the type section the Macdougal is divisable into a number of formations which total 997 feet in thickness. The base is placed at the bottom of a 130 foot thick chocolate brown shale while the top is placed above 50 feet of evenly bedded limestone with shale partings. Lithologically the group consists of interbedded limestones, sandstones, reddish coloured gypsum, black, petroliferous shales as well as green, red, and chocolate coloured shales. The section mapped by Laudon at Imperial River is about 27 miles southwest of the subject acreage and about 30 miles northwest of the type section. The Imperial River section is 1,839 feet thick, with the base not exposed, and consists of sandstones alternating with limestones, gypsum and vari-coloured shales. The basal part consists of sandstones with minor shale interbeds which appear to be a shallow water deposit since they are ripple marked and cross-bedded. The section becomes increasingly shaly upwards. There is considerable gypsum in the upper shales and Laudon attributes the crinkly, distorted shale beds

near the top to gypsum solution with accompanying collapse of the shales. A 146 foot bed of black to dark grey, laminated, algal limestone near the top of the section overlies soft, black, deepwater shales and is separated from them by an unconformity. The limestone which is sandy in part contains calcareous algae which are up to 3 feet in diameter.

The Macdougal at Norman Wells contains a bed of salt, 2,000 feet thick, which is correlated with the Saline River Formation. The type section of the Saline River Formation, which is 2 miles above the mouth of the Saline River where it joins the MacKenzie River, lies about 130 miles southeast of the Permits under review. The section here is 100 feet thick with neither the top nor the base seen. Estimated thickness of the Saline River Formation at the type section is 500 feet. It consists of red and green shales interbedded in part with gypsum and salt deposits. It is the source of salt springs in the area. The Saline River salt is believed to be present northwest of Norman Wells for the following reasons:

1. The overlying Ronning carbonates are brecciated at exposures in the northern Richardson Mountains west of Inuvik suggesting solution collapse.

2. Aeromagnetic coverage north of Inuvik has disclosed two features which bear a marked similarity to known salt domes in the Arctic Islands.

3. The gypsum in three diapiric structures which intrude Cretaceous beds on the east margin of the Richardson Mountains, west of Inuvik, contains evidence of early Paleozoic origin.

4. The western margin of the Saline River Salt is known in the Norman Wells area and a postulated extension of this margin can be made to the northwest and southeast of Norman Wells.

Permits 5425 and 5426 should be underlain by the Saline River Salt, however, no estimate of the thickness present can be made.

Solution of the Saline River Salt creates the possibility of salt structures in the overlying carbonate banks similar to those found to be productive in southeast Saskatchewan and at Rainbow Lake in northwestern Alberta. The crinkly, distorted shale beds noted by Laudon at Imperial River may be a product of salt solution rather than gypsum solution as was suggested by him. The algal laminate at Imperial River indicates some organic activity in the Macdougal seas and this, coupled with underlying salt structures, could give rise to hydrocarbon bearing reservoirs within this sequence. The petroliferous shales within the Macdougal group should provide adequate source rock for hydrocarbon generation. Imperial Vermilion Ridge #1, located at 65°, 07', 51" N., and 126°, 05', 00" W., which is about 44 miles southeast of the acreage in question, penetrated 3,177 feet of Macdougal beds

without reaching the underlying Katherine Group. About 41 miles northwest of the acreage Atlantic Col Car Shoals C-31 was drilled at 65°, 50', 7.5" N., and 128°, 51', 45" W. This well penetrated 395 feet of Macdougal before stopping. Neither well was drill stem tested in the Cambrian portion of the well bore and to date there have been no reservoirs encountered in wells which have drilled to the Cambrian in this region.

ORDOVICIAN - SILURIAN

RONNING FORMATION

As has been noted by various authors rocks of Ordovician age have not been definitely identified in this region, however, it seems to be generally accepted that they are present in the Norman Wells region. The contact with the underlying Macdougal is unconformable. Stelck mapped 1,500 feet of shales and argillites at outcrops in the Upper Peele River area which lies some 225 miles to the west of the Permits. About 100 miles south-southwest of the Permits, at the Keele and Twitya River confluence the Ordovician section was mapped by Keele as 4,000 feet of alternating beds of argillite, dolomite and limestone with 1,500 feet of sandstone overlying and separated from them by a 100 feet thick diabase sill. Some 35 miles east of this section the same sandstone was mapped as a 4,500 foot thick unit with only occasional shale partings. The sections described by Stelck and Keele from outcrops along with the scattered subsurface control available have been used to establish some regional lithofacies patterns for the Ordovician.

The Upper Peele River section is mapped as an open marine basinal sequence of shales and argillites. Flanking this basin are shelf edge carbonates which are reefal in part. The shelf edge carbonates are found along the central MacKenzie Mountains and on the Peele Plateau. Back of the shelf edge carbonates are the shelf carbonates proper which are generally clean, finely crystalline carbonates with variable porosity. They are present over most of the interior plains and probably underlie the Permits in question; however, there is a possibility that the Permits in question may be underlain by the reefal shelf edge carbonates. This possibility exists because of a long narrow trend of basinal sediments which extends from the Fort McPherson area past Permits 5425 and 5426 and then south to the Camsell Basin and Liard Plateau.

The distribution of Silurian age strata covers a much wider area than do the beds of Ordovician age. Lithologically, the Silurian rocks are very similar to the underlying Ordovician beds and for this reason, as well as ease of working with them, they have been grouped together as the Ronning Group. The sedimentary pattern for the Silurian is very similar to that established in the underlying Ordovician. In the Norman Wells area the Ronning Group can be divided into two formations, a lower one, named the Franklin Mountain, and an upper one, named the Mount Kindle. The Franklin Mountain Formation is generally composed of limestones and dolomites with abundant irregular shaped chert nodules. The Mount Kindle is usually found to consist of a sequence of chert poor limestones and dolomites which tend to thin in a

southerly and easterly direction. The Ronning Group should be in the order of 2,000 feet to 2,500 feet thick in the area covered by Permits 5425 and 5426, and they should consist of clean, finely crystalline shelf carbonates with abundant chert inclusions and variable degrees of porosity. The possibility for the occurrence of reefal shelf edge carbonates fronting a basinal sequence of shales to the west of them exists in this area in much the same way as was earlier described for the Ordovician rocks. Atlantic Col Car Shoals C-31 in 65°, 50', 7.5" N., and 128°, 51', 45" W., which lies about 35 miles northwest of the Permits, encountered 2,711 feet of Ronning sediments. A drill stem test near the top of the Ronning recovered 1,700 feet of salt water. The chlorinity of this water was 27,000 ppm which is indicative that the reservoir has not been flushed by fresh water. The Ronning is described in outcrop at a number of locations in this area.

In the Donnelly River area, which is about 15 miles northwest of the Permits, the Ronning is more than 1,000 feet thick and is overlain by the Bear Rock Formation. The Upper portion of the section contains beds from 3 inches to 2 feet thick of white novaculite plus a typical Niagara fauna. No chert was noted in the lower part of the section, possibly indicating that the Mount Kindle formation is relatively thin at this locale. About one mile south of Moon Lake, and the Permits, the Ronning limestones are also exposed, having been brought to surface by thrust faulting, associated with the Richard Mountains. The section at

Bear Rock, which is about 58 miles southeast of the Permits, consists of 600 feet of limestones, dolostones and shales with the brecciated sediments of the Bear Rock Formation overlying them and the Macdougal red and green gypsiferous shales underlying them. The Mount Kindle Formation is apparently not present here. Imperial Loon Creek #2, located at 65°, 07', 20" N., and 126°, 128', 51" W. which is about 38 miles south-southeast of the Permits penetrated 1,270 feet of Ronning which is close to the same thickness as mapped in outcrop at Mt. St. Charles which lies to the east of the well, about 50 miles. The Loon Creek well found the Ronning to consist mainly of white to grey, micro-crystalline to granular dolomites with some evaporite plugging. Scattered poor porosity was present throughout, however, no drill stem tests were run over the Ronning. The section at Mt. St. Charles which is on the Great Bear River, is mapped as 865 feet of Franklin Mountain Formation overlain by 480 feet of Mount Kindle carbonates. The Franklin Mountain Formation consists of a lower 200 foot sequence of cavernous limestones overlain by 195 feet of cherty limestone and grey limestone. This is in turn overlain by 470 feet of grey dolomitic limestone. The base of the Franklin Mountain Formation here is not exactly clear as various workers have included beds beneath those described above in the Ronning Group as well. They consist of gypsum, conglomeratic limestone with black, bituminous pebbles and highly bituminous limestones which lithologically would appear to be nearer the description of the Macdougal Group. The basal 210 feet of the Mount Kindle is a dolomitic limestone containing corals of

Niagaran age. Overlying them are 90 feet of limestone and chert beds while the upper 180 feet of Mount Kindle is a hard, grey, dolomite which is cherty in the lower part. The section is overlain by the brecciated dolomites of the Bear Rock Formation.

Four miles north of Norman Wells, at Schooner Creek, Stelck mapped a 100 foot section of massive, crystalline, porous limestone containing some coralline fauna. He correlated them with the lower portion of the Mount Kindle Formation. This section can be interpreted as a porous carbonate bank or bank edge deposit. The Mount Kindle is likely to have a number of these carbonate banks, or low transgressive reef fronts in this area since as can be seen from the various sections described above, it undergoes both facies and thickness changes in this region. Mount Kindle beds are also exposed at Oscar Creek which is about 10 miles south of the Permits under review. Oil staining has been described in the Upper Ronning Group at wells drilled in the Norman Wells area.

The trapping conditions which can be outlined in this area are quite varied. A few of the types of traps to prospect for are outlined below:

(a) The marked disconformity which separates the Ronning Group from the overlying Middle Devonian Bear Rock Formation may have produced erosional features, such as Scarps and Monodnocks, which would be sealed by the basal

evaporites of the Bear Rock. Leaching should enhance the reservoir properties and make this an effective hydrocarbon trap.

(b) As mentioned previously, low reef fronts or porous carbonate banks may be present and coupled with a seal provided by overlying Bear Rock evaporites could present a very extensive trap. Lateral facies changes from porous to semi-evaporitic carbonates could also provide a potential trap of considerable areal extent.

(c) Selective solution of the underlying Cambrian Saline River salt may give rise to one or two stage salt solution structures such as are found to be productive of oil in the Hummingbird area of southeast Saskatchewan. Partial solution of the salt prior to or during Mount Kindle deposition would have served to provide local elevations on the sea bottom where the salt was not removed. These local elevations would provide the loci for reef and/or carbonate banks to grow on. Traps of the Hummingbird type would involve early local solution of the salt. This may have occurred in late Cambrian or early Ronning time. The depressions created would have received an extra fill of sediments over that being deposited where the salt was not removed. Once sedimentation within the sink hole caught up, subsequent sediments would be deposited on a normal sea floor. The second stage in the formation of a Hummingbird type

of trap would involve the removal of the salt surrounding the original sink hole at some time subsequent to Mount Kindle deposition. This would leave the Mount Kindle reservoirs overlying the site of the original salt solution structurally high. The Bear Rock evaporites should provide an adequate reservoir seal. Evidence to support one or two stage salt removal in this region is present in the brecciated nature of the sediments composing the Lower Ronning and of the Bear Rock in exposed sections.

(d) Gentle to tight anticlinal folds along with thrust faulting are present in this region and could provide sizeable accumulations of hydrocarbons within them.

MIDDLE DEVONIAN

BEAR ROCK FORMATION

The Bear Rock Formation overlies the Ronning Group and is separated from it by a marked disconformity. The contact with the overlying Hume (Ramparts) may also be disconformable. The type section is located 58 miles southeast of Permits 5425 and 5426 at Bear Rock, near Fort [illegible]. The type section is mapped as two distinct facies, a basal 40 feet to 60 feet of white, gypsiferous, massive, lensing dolomite or limestone and an upper 175 feet of breccia composed of brown, dolomitic limestone boulders set in a matrix of dolomitic limestone. Separating the two facies is a 30 foot section of poorly bedded, dark grey limestone and dolomite. The contact with the overlying Hume (Ramparts) is

gradational and consists of 10 feet of bedded limestone and dolomite breccia.

The Bear Rock is a very widespread formation which undergoes a number of facies changes, grading from open marine basinal shale facies to evaporitic shoreline facies. The basinal shale facies, which is present in the Richardson Mountains, continues southeast along the western side of the MacKenzie Mountains. The basinal shales are flanked by a belt of shelf edge limestones and dolomites along their eastern side. Porosity is developed within these carbonates. Adjacent to the shelf edge carbonates, and covering much of the Interior Plains and Peele Plateau areas are the shelf limestone and dolomite facies. In the Peele Plateau they attain a thickness of some 2,000 feet and consist of micritic pellet and micritic skeletal limestones with intervals of finely crystalline, porous dolomite in the lower part. The shelf carbonates are in turn replaced by a relatively narrow belt of shelf dolomites which appear to be the prelude of the adjacent evaporite sequence. The shelf dolomites are present in the MacKenzie Mountains and extend in a line north through the Fort Good Hope region and south into the Camsell and Nahanni ranges. The shelf dolomites are in turn replaced by an evaporitic sequence along their entire length. This facies change begins to the west and north of Norman Wells. In the Norman Wells area, and also in the area of the Permits under discussion, the basal portion of the Bear Rock is commonly evaporitic, while the upper portion consists of carbonate breccias. The evaporite facies extends southward into northern Alberta where it is known as the

Chinchaga Formation. South of Norman Wells a strong depositional feature called the Camsell Basin occurs. Thickening from 2,000 feet to more than 5,000 feet accompanied by facies changes from evaporites through shelf carbonates to basinal sediments takes place into this basin. The shelf carbonates are cryptocrystalline to microcrystalline dolomites while the shelf edge facies is reefal with some of it at least being porous.

The Bear Rock carbonates in the Norman Wells area have been found to be very porous in some wells, while in others the porosity has been plugged by anhydrite and gypsum. Considerable bitumin has been encountered in places. Drill stem test results vary from mud recoveries to water flowing to surface. The Atlantic Col Car Shoals C-31 well, located in 65°, 50', 7.5" N., and 128°, 51', 45" W., which is about 41 miles northwest of the acreage, encountered 744 feet of Bear Rock sediments. A test was run over a 13 foot interval near the top of the formation which recovered 5 feet of oil, 180 feet of mud and 385 feet of water. A test run over the next 245 feet of Bear Rock recovered 2,800 feet of salt water. The water had a chlorinity of 24,000 PPM CL^- which is indicative of a reservoir that has not been flushed. There was no appreciable draw down in the reservoir pressures during the test. Relatively close to the Car Shoals C-31 well Atlantic had previously drilled a well called Atlantic Col Car Beavertail G-26 located in 65°, 55', 25" N., and 128°, 34', 25" W. They ran a number of drill stem tests over the Bear Rock, however, they did not recover any formation fluid. The well was cased through the

Bear Rock Formation and perforated in it. Swab tests recovered 5 gals. of water with a chlorinity of 4,200 PPM CL^- which is quite obviously not formation fluid. Subsequent to this the well was abandoned and the Car Shoals C-31 well spudded. The two wells drilled by Atlantic serve to illustrate the rapid changes in reservoir properties which can occur in the Bear Rock as well as to indicate that formation must be considered as a potential hydrocarbon bearing reservoir in this region. Oil shows were also encountered by Western Decalta, at their Rond Lake wells which lie about 100 miles north of the Permits. About 15 miles south of the Permits Imperial Morrow Creek #1, located in 65°, 23', 14.79" N., and 127°, 23', 07.11" W., encountered a stray flow of sulphur water from the Bear Rock which flowed at an estimated rate of 24,000 bbls. per day with a 160 pounds per square inch back pressure. About 7 miles northwest of this location at Imperial Hoosier Ridge #2, located in 65°, 25', 00" N., and 127°, 32', 11.25" W., the Bear Rock was acidized over an open hole section, however, no oil or gas was encountered. These two wells also serve to emphasize the rapid facies changes which occur in the Bear Rock as well as its hydrocarbon bearing potential. The Permits under review should be in an excellent position to test this formation.

The Bear Rock Formation is exposed in numerous outcrop sections in this region. It is found about 2 miles south of the Permits, in the Richard Mountains, and about 8 miles west of the Permits it is found on Carcajou Ridge where it consists of grey gypsum. At the Donnelly River exposure which is about 15 miles

northwest it consists of 720 feet of brecciated limestone and anhydrite. It is also exposed on the Hare Indian River about 45 miles north of the Permits where it consists of typical brecciated limestone and gypsum.

The brecciated nature of the Bear Rock was previously mentioned as being a probable product of the solution of the Cambrian Saline River Salt. A more conventional theory for the origin of the breccia is that it is a product of the sharp disconformity separating the Ronning Group from the overlying Bear Rock Formation. This theory is doubtlessly true for the basal portion of the Bear Rock. The section exposed on Mt. St. Charles, which is about 80 miles southeast of the Permits under review, may be considered as supporting evidence for the theory that the brecciation of the Bear Rock was caused by the solution of Saline River Salt during Bear Rock deposition. The section is described by Williams as, "... 340 feet of saccharoidal, coarse grained brown dolomites - overlain by 1,000 feet of thin bedded brown dolomites, in part brecciated." The top of the Bear Rock was not seen. In addition to the brecciation well up into the Bear Rock section, the great thickness of sediments mapped as Bear Rock could be considered suggestive of greater subsidence during deposition here than was occurring in adjacent areas. The thickness at Bear Rock, which is the type section, is about 265 feet. The anomalous thickness could also be due to erosional relief, or unrecognized thrust faults repeating the section; however, neither of these alternatives seems very plausible.

The rapid facies changes within the Bear Rock is further evidenced when one compares the section exposed 3 miles north of Mt. St. Charles to that exposed at Mt. St. Charles. Here the chert beds of the underlying Mount Kindle Formation are overlain by 500 feet of grey gypsum beds that are in turn overlain by limestone beds that are mapped as part of the overlying Hume (Ramparts) Formation. The Mt. St. Charles section has no evaporites. The difference in thickness between the two exposures is worthy of note also.

HUME FORMATION

Considerable confusion has existed in the literature concerning the relationship of the Ramparts or Hume, Hare Indian and the Kee Scarp Reef. A paper by H. G. Bassett in the Geology of the Arctic Symposium is probably the most important to an understanding of the Middle Devonian geology of this area.

Hume defined the Ramparts Formation as containing all definite Middle Devonian beds in the Norman Wells area as well as in the surrounding area. The base would be placed at the top of the underlying Bear Rock and the top at the contact with the overlying Fort Creek Shales. He divided the Ramparts into three members, a lower limestone member, a middle shale member and an upper limestone member. The lower limestone, which is relatively thin in the Norman Wells area, thickens in a northwest direction. About 60 miles west-northwest of Norman Wells, in the Imperial Range on Mountain River, the lower Ramparts is described as 445

feet of limestone, dark grey to black with irregular black shale partings, very fossiliferous in part. The middle Ramparts at this section consists of 700 feet of grey to green shales and limey shales with many thin limestone beds which are commonly coquinoid in the lower part. The upper Ramparts limestone at this section is 180 feet thick and is mapped as limestone, black to grey-brown, massive, grading to shale at the base. The upper portion consists of limestones, grey to dark grey, massive, with thin black shale partings.

The term Ramparts was discarded by Bassett in his paper. The section as redefined by Bassett consists of: the Hume Formation, which he equates with the Lower Ramparts of G.S. Hume's; the Hare Indian which is considered the correlative of the Middle Ramparts shale and the Kee Scarp which is correlated with the Upper Ramparts.

The type section of the Hume is located in the MacKenzie Mountains on the east branch of the Hume River where it consists of 400 feet of thinly bedded limestones which are light grey, argillaceous, very fossiliferous and of shallow water origin. The Hume is correlated diachronously with the Lower portion of the Keg River Formation of northern Alberta. The correlation is based on ostracod zones within the Hume and Lower Keg River Formations. The Hume has been found as far north as the Anderson River. The thickness of the Hume is quite variable as is readily apparent if the type section is compared to section at Schooner Creek which is

4 miles north of Norman Wells. The Hume here is only 8.5 feet thick, and consists of limestone, black, shaly to slaty and fossiliferous. The basal 1 foot is a conglomerate indicating a disconformable contact with the underlying Bear Rock.

The Hume Formation is generally encountered as a non-porous rock both in outcrop and in subsurface. The Keg River platform of northern Alberta is also normally a non-porous rock, however, it does develop into a marginal shoal along the north flank of the Peace River Arch. This marginal shoal is a very porous, granular, reefy dolomite which yields large quantities of water when drill stem tested. The marginal shoal is in turn replaced by back shoal mud flats, which in turn are replaced by shoreline sands. The sands have been found productive of oil in some locales. Patch reefs have also been found in the back shoal mud flats with free oil being tested from them. The facies pattern developed along the north flank of the Peace River Arch should have been repeated along the margins of the Pre-Cambrian Shield. The marginal shoal and the shoreline sands may have been removed by one of the many periods of deep erosion that have occurred in this region.

The Hume has been described at various localities as being very petroliferous in part. This situation is also duplicated in the Keg River platform of northern Alberta where it is overlain by the productive Keg River Pinnacle and a toll reefs. The Keg River platform is almost certainly the source of the oil

in these prolific reefs. Because of the similarities outlined above, any reservoirs developed within the Hume must be considered as prospective. Imperial Hoosier Ridge #1, located in 65°, 24', 15.6" N., and 127°, 32', 13.9" W., lies 14 miles south of the Permits under review and reported gas showings within the Hume Formation as well as traces of oil. The Hume is present at the various outcrop sections which are present near Permits 5425 and 5426.

HARE INDIAN

The contact of the Hare Indian with the underlying Hume is generally sharp and probably represents a sudden influx of mud into a clean, well aerated sea. It appears to represent a mud bank deposit with the source area lying to the northeast partially filling a large basin. The contact of the Hare Indian with the overlying Kee Scarp is somewhat diachronous since it is generally placed at the point the section changes from predominant shale to predominant limestone. Facies changes thus account for the diachronous nature of the contact as well as being the cause of some of the confusion which has surrounded correlations of the Devonian sediments in this region. The section at Carcajou Ridge, which is about 8 miles west of the Permits under study, serves to illustrate this problem. The section along the northeast part of the ridge consists of 6 feet to 70 feet of Kee Scarp Reef overlying from zero feet to 21 feet of Hare Indian shale while further to the west the Hare Indian shale attains a thickness approaching 700 feet. The section at Carcajou Ridge should probably be mapped as

containing much more Hare Indian, only as a limestone and shale facies and not strictly as a shale facies in this case. The Hare Indian generally consists of 500 feet to 700 feet of slightly calcareous, light greenish-grey to medium grey, bituminous (in part) shale with abundant micro fossils. However, due to the facies changes as described above, it can thin to less than 100 feet in a few miles. The Hare Indian is exposed in outcrop in the Donnelly River area, on Beavertail Mountain, in the Bat Hills, the East Mountain area and also immediately south of the Permits. The above exposures are all in close proximity to the area covered by Permits 5425 and 5426. Subsurface control is provided by wells such as Atlantic Col Car Shoals C-31 which lies 41 miles northwest of the Permits and encountered 768 feet of Hare Indian and by wells to the south and southwest, such as Imperial Hoosier Ridge #2 with 772 feet, Imperial Hoosier Ridge #1, with 570 feet, Imperial Judile #1, with 491 feet and Imperial Morrow Creek #1 with 506 feet of Hare Indian. The thickness around Norman Wells is usually about 100 feet. South of Norman Wells around the confluence of the MacKenzie and Redstone Rivers the Hare Indian is again about 500 feet. The thickness underlying the Permits should be in the neighborhood of 600 feet to 700 feet. The relationship between the Kee Scarp Reef and the underlying Hare Indian and Hume Formations appears to be somewhat analagous to the relationship between the Klua Shales and adjacent reefs in the Clarke Lake area of northeastern British Columbia. The Klua Shale, which is Middle Devonian, overlies the Keg River Formation and is overlain by the Slave Point Formation of bank carbonates in some wells

while in others reef growth initiated in the Keg River has continued on into the Slave Point with little or no interruption. In the latter case no Klua Shale was deposited.

KEE SCARP

The Kee Scarp Formation as redefined by Bassett, is a widely distributed formation. Ostracods have been used to establish the Kee Scarp as equivalent to the combined Sulphur Point - Slave Point carbonates of northern Alberta. The contact with the underlying Hare Indian Shale as previously mentioned, is diachronous. The Kee Scarp Formation in the Norman Wells area, consists of a lower platform unit which is about 75 feet to 165 feet thick and lithologically is a bedded limestone with abundant fossils. The platform unit is usually devoid of hydrocarbons. Overlying the platform or foundation unit is a biohernal reef which constitutes the reservoir for the Norman Wells oil Field. The reef is composed of materials such as corallites, bryozoans and stromatoporoids set in a coral sand matrix. The facies varies widely between wells as would be expected in a true reef. The thickness of the Kee Scarp Reef above the platform unit varies from zero feet to 350 feet in the Norman Wells area. The greatest overall measured thickness of Kee Scarp in the area is 495 feet. The Kee Scarp is overlain by the Canol Formation, or in its absence, the Fort Creek Shales which Bassett redefined as part of the Imperial Formation.

The platform unit of the Kee Scarp is undoubtedly the correlative of the Upper Ramparts limestone unit mapped by Hume.

This fact, as mentioned previously, means the Kee Scarp is a widespread formation. Since the Kee Scarp reef grows upwards from the foundation unit, any well drilled in this region must be considered a potential Kee Scarp producer. Maximum reef growth regionally has generally been found on the margins of Hare Indian thicks, however, the presence of them does not ensure Kee Scarp Reefs. The margins of the Hare Indian thicks, which were described under the discussion of that formation have not yet been found to contain reefs; however, they have not been adequately explored either. The thickness of the Hare Indian in the control wells indicates that the Permits under review are well located for potential Kee Scarp biohernal reef developments. It is present in outcrop nearby Carcajou Ridge.

The oil in the Norman Wells oil field is trapped in the updip end of a discrete Kee Scarp bioherm. The thickness of the reef varies up to a total of 495 feet. Reserves in the reef have been estimated as to be as high as 60,000,000 barrels. The productive area of the field is placed at 2,600 acres.

CANOL FORMATION

The Canol Formation was defined by Basset to include the black to very dark brown, non-calcareous, bituminous shales which overlie the Kee Scarp, or, in its absence, the Hare Indian Formation. The Canol is overlain by the Imperial Formation of Upper Devonian age. The Canol may be the equivalent of the lower part of the Besa River Shale of northeastern British Columbia. The Canol thickness ranges from zero feet to 400 feet in the

Norman Wells area. The thickness varies in relation to the underlying Kee Scarp Reef much in the same manner that the Ireton thickness is related to Leduc Reefs within the Province of Alberta, i.e., the Canol thins over the reef to nil in places and thickens in the off-reef direction, consequently the thickness variation is quite large. The Canol is exposed on Carcajou Ridge which is a short distance west of the Permits in question.

UPPER DEVONIAN

IMPERIAL FORMATION

The Imperial Formation was redefined by Basset to include all beds of Devonian age overlying the Canol Formation and which are unconformably overlain by Cretaceous strata. He recommended that the term Fort Creek Formation be discontinued as the above definition of the Imperial includes the Fort Creek Shales within it. The Imperial Formation consists of a sequence of greenish-grey shales overlain by a series of fine sandstones, siltstones and thin limestone beds. The Imperial is capped at many places by a grey shale sequence. The lithologies of the Imperial are extremely variable which makes correlations within it very difficult. The thickness of the Imperial may reach more than 3,000 feet where the processes of erosion have not cut very deeply. The Imperial Formation is exposed on Carcajou Ridge which as previously noted lies a short distance west of the Permits in question. It is also exposed immediately south of the Permits.

CRETACEOUS

SANS SAULT GROUP

The type section of the Sans Sault Group is along the Mountain River where it joins the MacKenzie River. The name is derived from the Sans Sault rapids which are near the type section and lie about 36 miles west of the Permits being discussed.

The Sans Sault is the basal group of Cretaceous sediments which lie directly above the disconformity separating Cretaceous and Devonian sediments. The top of the group is usually placed at the base of the first bentonite bed in the overlying thick shale sequence. The section consists of shales and sandstones of marine origin. Some beds are quite widespread and form good marker beds. The Cretaceous is exposed in a number of areas adjacent to Permits 5425 and 5426; however, workers in the area have not bothered to subdivide them. The thickness near the type section is about 1,411 feet.

SLATER RIVER FORMATION

The Slater River Formation overlies the Sans Sault Group and consists of thin bedded, black, friable shales with abundant ironstone concretions. There are also some beds of white and yellow alum and sulphur. Sandstone is only occasionaly present. There are many beds of bentonite which in outcrop are 1/8" to 1" thick. The Slater River also contains a fish scale horizon which is thought to indicate an Upper Cretaceous age for the formation. The section is about 1,000 feet thick at the type section. A partial section is exposed on Mountain River which

joins the MacKenzie at Sans Sault Rapids.

LITTLE BEAR FORMATION

The type section of the Little Bear Formation is found about 75 miles west of Fort Norman on the Little Bear River. The beds consist of sandstone, some conglomerate, sandy shales and coal seams. The beds are not correlatable between areas due to their lenticular nature. The type section is 780 feet thick and contains marine, brackish and freshwater fossils.

EAST FORK FORMATION

The East Fork Formation is named from a section exposed on the East Fork of the Little Bear River. The thickness at the type section is 850 feet. The section is composed of a series of well stratified, grey, conchoidal and plastic marine shales. There are some thin limey sandstone members and thin coal seams near the base.

The thickness of total Cretaceous beds which are present in any one place in this region is extremely variable. The control wells for Permits 5425 and 5426 have encountered thicknesses varying from less than 50 feet to more than 1,300 feet. The thickness present would appear to depend on the topography of the onderlying unconformity in part. The unconformity separating the Cretaceous and Devonian sediments has in places removed the entire Upper Devonian sequence. One such location is at Imperial Hoosier Ridge #1, located in 65°, 24', 15.6' N., and 127°, 32', 13.9" W., about 14 miles south of the Permits, where the Kee Scarp

Formation was encountered at a drilling depth of 60 feet. About one mile south of this well, Imperial Hoosier Ridge #2 encountered the Imperial Formation at 50 feet, the Canol Formation at 850 feet and the Kee Scarp at 920 feet. The above two wells are indicative of the extreme variations in depth of erosion by the Post Devonian unconformity.

TERTIARY

The Tertiary sediments in the Norman Wells area are not subdivided. They consist of conglomerates, gravels, shales, lignites, soft, coarse carbonaceous sands and soft clays. A thickness of 1,600 feet has been mapped on the Little Bear River. The East Fork has lignite beds 8 feet to 10 feet thick at its headwaters, while along both sides of its valley for 18 miles the high hills and valley sides are made up of Tertiary strata up to 1,200 feet thick. These two outcrops seems to form part of a basin which dips to the southwest. An indeterminate amount of Tertiary will likely be found over Permits 5425 and 5426.

STRUCTURE

The Franklin Mountains appear to have been formed by compression of a relatively thin sheet of sediments. The compressive forces appear to have acted from both the north-northwest and southwest and have thus produced a very intricate structural pattern. The mountains were glaciated during Pleistocene time by ice moving in a westerly direction. The mountains were apparently completely covered by the glaciers. In

the vicinity of the Permits there are four approximately parallel anticlinal folds within a distance of 25 miles. They are from south to north; Carcajou Ridge; East Mountain; Bat Hills and Beavertail Mountains. They all strike approximately east - west and plunge in a westward direction. These structures have all been sufficiently uplifted and eroded to expose Paleozoic rocks. The Greenhorn anticline, which is approximately 5 miles long, strikes in a northwesterly direction. The southeastern end of this anticline, which is rather obscure at this end, is present on Permit 5426. The anticline is outlined by a limestone bed in the Imperial shale, however, due to the scarcity of outcrops present, the amount of closure is not available. The anticline appears to be widest where it crosses Greenhorn Creek which drains out of Moon Lake. The width here is slightly over two miles. The strata of the Norman Range is usually found to dip to the southwest at a 10 degree to 15 degree angle with steeper dipping beds present locally. The dips on the Greenhorn anticline vary from 14 degrees to 70 degrees southwest on the west limb and from 20 degrees to 25 degrees northeast on the east limb.

It is recommended that further evaluation of the Permits under review consist of gravity meter and an airborne magnetometer survey. They should be of great assistance in outlining the distribution of the Saline River Salt and any salt structures associated with it. The magnetometer may be of some help in outlining the present Pre-Cambrian structure. The Greenhorn anticline should receive further work, either by a surface

geological party or by a photogeological study, or both. Further anticlinal structures should be present on these Permits and they may be revealed by some of these methods of investigation.

FRACTURE ANALYSIS

This section of the report discusses the results of a Detailed Fracture Analysis Survey carried out within, and in the immediate vicinity of, Petroleum and Natural Gas Permits 5425 and 5426. An aerial mosaic (scale 1.65 inches equals approximately 1 mile) made from Dominion Government aerial photographs accompanies this report. These same photographs were examined stereoscopically and the fractures plotted on the individual photographs, then transferred to the mosaic for analysis.

The theory that the earth's crust is abundantly and methodically fractured is the basic premise on which is built the exploration technique known as Fracture Analysis. A Fracture is defined as "... generally abundant, natural lineation discernible on aerial photographs".

Fracturing is largely caused by external stresses on the surface. The most important are:

(a) earth tides

(b) radial acceleration of the earth along its radius vector

(c) a gradual decrease of the earth's rate of rotation

As stated above, the earth is systematically fractured and the fracturesystem would approach symmetry if the crust were homogeneous. It is considered that irregularities are caused by

regional heterogeneous conditions within the earth's crust. Local departures from the norm are caused by structural or stratigraphic anomalies.

The term "photogeophysics" was introduced by Blanchet (1956) and deals with mapping, analysis and interpretation of fracture traces as recorded on aerial photographs. In a more general way "photogeophysics" can be defined as the methodical statistical analysis of linear features seen on aerial photographs and this system is applied by any method recording all observable lineations, or the totality of a certain type of linear feature, and the statistical presentation of the data on contoured intensity maps or dry plotting the fractures directly on the mosaic.

In this report a megafracture is longer than one mile and a microfracture is shorter than one mile.

GENERAL DISCUSSION

ORIGIN OF FRACTURES

Fracturing is largely caused by external stresses on the earth, although internal stresses may play some minor roll. The most important of these external forces are the diurnal earth tides due to the gravitational effects of the sun and moon; the change in radial acceleration of the earth along its radius vector and the gradual decrease of the earth's rate of rotation. The endless rhythemic action of these earth tides is probably the principal cause of the systematic fracture system seen over most of the world, even though the amplitude of these tides is only 9 - 13 inches. The fractures are most likely generated by the process of fatigue as the end result of these stresses which are repeated regularly over millions and millions of years. Metals fatigue in the same manner when subjected to continual vibration.

In general the initiating forces which generate fractures must have continued for a very long time and the process involved are continuous and are probably active at the present time. Furthermore, Mollard (1957) states, "The mechanism required to reflect lineaments to ground surface must be reasonably simple, for simple patterns are produced on diverse topography and in diverse types and depths of surficial deposits that overlie different kinds of relatively flat-lying sedimentary rocks of varying thickness. The mechanism producing the lineament pattern must persist over extensive and widespread belts of the earth's outer shell; that is today, the engendering mechanism must in fact be world wide".

External forces such as earth tides obviously fit these parameters. Some internal forces may also apply such as the action of deep seated tectonic forces, and the most probable of these is isostatic adjustment. Isostatic rebound following the melting of the glaciers may still be taking place and this will further accentuate fractures present before glaciation.

In general it can be said that fracture patterns are caused by either internal or external forces. If the forces are internal the result would be different orientation of the fracture systems in areas of similar tectonic history but different position. If the forces are external the orientation of the fracture arrangement should have world wide similarity. However, stable areas such as the masses of the continents may develop fracture patterns due to external forces and tectonically active areas may develop their own pattern due to internal forces.

If joints form early in the history of a sediment then systematic joints must be successively younger upwards through the section and the joint pattern is imposed on each new layer of sediments when they have become consolidated enough to fracture. This upward propagation is caused by the fatigue caused by stress, which in turn is caused by diurnal earth tides.

EXPRESSION OF FRACTURE

Fractures have been observed in aerial photographs from every climate and on every continent in the world. They are

expressed as topographic relief, vegetation differences and soil tonal differences.

TOPOGRAPHIC RELIEF LINEAMENTS

A common type are relief lineaments which can be manifested by a change (usually abrupt) of topographic elevation on either side of a relatively straight line. They may also be expressed as straight valleys or hills or by straight streams where the stream course is controlled by a fracture zone.

VEGETAL LINEAMENTS

Vegetal lineaments are the most common in the parkland and muskeg areas of western Canada and many excellent examples of fractures can be seen on almost any aerial photograph of northern Saskatchewan, Alberta or British Columbia. Straight lines of both deciduous and evergreen trees as well as scrub growth are universally visible. However, the most common vegetal lineament seen by this writer is a straight "edge" to a clump of trees or bushes. In many cases these fractures control the size and shape of the clumps of trees as well as the size and shape of cultivated fields. Excellent examples of this latter expression of fractures are present in the western part of the Peace River district.

SOIL TONAL LINEAMENTS

These reflect differentiation in soil moisture and general ground water conditions. These are common in the southern parts of Alberta and Saskatchewan, especially near large rivers.

Surface investigations have shown that fractures are associated with bedrock joints; however, in glaciated areas such as Western Canada, the photoanalyst must take care to establish the direction of ice flow over an area before he begins to statistically plot and analyse the fractures. Most areas in Western Canada show an abundance of grooves and flutes caused by the glacier and these must not be mistaken for fracture traces caused by subsurface structural conditions. In parts of the Lloydminster area of eastern Alberta the glacial scars are so deeply impressed on the surface that fracture analysis is at best difficult and often impossible.

INTERPRETATION OF FRACTURE DATA

The object of Fracture Analysis (Photogeophysics) is to locate shallow to deep-seated structural and stratigraphic anomalies. The actual count of fractures per unit area is made and values are contoured on a "Fracture Intensity Map". In areas of known reefs the fracture intensity is 2 - 3 times greater on the flanks of the reef than directly above the reef.

In any fracture pattern there are two mains systems of fractures; the axial system and the shear system. In both systems the fractures are sub-parallel and in general the two systems are at approximate right angles to each other.

Because of certain inherent limiting factors, Structure Incidence Surveys have a lower order of reliability than Detailed

Fracture Analysis Surveys. To some extent at least, surface conditions affect the fracture count. In areas covered by lakes, sloughs and rivers, the fracture count is zero. Cultivated areas generally yield a lower count than adjacent virgin territory. Consequently, a difference or contrast in fracture count (F/1) between two points may be in part due to structure, but, also due in part to different surface conditions. To some extent, this can be compensated for by applying appropriate weightings to the observed counts, but over or under corrections may result.

Nevertheless, in spite of these sources of error, it has been demonstrated in (plains) areas where abundant subsurface control is available, that the incidence of fracturing is considerably above normal in the surrounding area immediately out from the steepest part of the flanks of the structure. This is in contrast with a low or normal incidence over the crestal area, and also to a normal incidence off structure.

FRACTURE ANALYSIS OF PERMITS 5425 and 5426

The fracture pattern as shown on the enclosed mosaic and maps shows a great variation in intensity over various areas of the Permits. The two Permits are located in the muskeg area east of the MacKenzie River and are many miles from the closest settlement.

The sedimentary section is about 7,700 feet thick and several systems are represented. In addition a thin layer of Tertiary glacial till covers nearly all of the area. Potential reservoir horizons are present within both the Ordovician and Devonian sections.

Fractures as plotted on the mosaic show considerable variation in intensity. There are two areas where the fracture intensity is greater than normal and there are two areas where the fracture intensity is less than normal. The high intensity areas are shown in red and the low intensity areas are shown in green. The average length of the fractures is about 4,000 feet and both mega and micro fractures are present. It is worthy of special note to mention the glacial problem in this area.

Reference to the mosaic will show that the area is moderately scarred with glacial grooves and striations and that the direction of ice flow was about southeast. Some of these grooves are so deeply impressed on the surface that they control the shape of the lakes and of tree growth in the area. In any

area such as this the photoanalyst is faced with the difficult problem of eliminating the glacial scars from the fracture pattern without creating false anomalies. The removal of all fractures from a 10 - 12 degree arc in any area will create fracture anomalies and it requires delicate weighting of the whole pattern to adjust for these effects.

In any fracture pattern there are two main systems of fractures: the axial system and the shear system. In both systems the fractures are sub-parallel and in general, the two systems are at approximate right angles to each other. Within Petroleum and Natural Gas Permits 5425 and 5426 the statistical mean direction of the axial system is North 40 degrees West and the statistical mean direction of the shear system is North 30 degrees East. A third minor system, here termed the sub-axial system, trends nearly north-south.

No regional fractures of great length can be seen and as these are conceded to originate within the Basement, it is assumed that all fractures plotted on the mosaic originate within the sedimentary section. Furthermore, as the fractures are short for this area it is very likely that they originate in the upper two-thirds of the sedimentary section. As the surface of the Permits is relatively flat-lying no azimuth correction is necessary for this study. It has been demonstrated that the low incidence anomalies on a mosaic are considerably larger than the subsurface feature which causes them and thus any anomaly under Permits 5425

and 5426 is probably quite small.

There are two areas on the mosaic where the fractures are less intense than the surrounding area.

Some fractures are always present within these areas but they usually have a lower incidence than the surrounding area. These low intensity areas are important and it is quite likely that they are due to some subsurface feature. The type of feature will be discussed in the next section of this report.

STRUCTURE

Petroleum and Natural Gas Permits 5425 and 5426 are located on the interior plains of the Northwest Territories about 240 miles to the west of the edge of the Pre-Cambrian Shield. The strike of the sedimentary rocks is about North 40 degrees West and the units dip to the southwest at a few tens of feet per mile.

Structural features which could be present and which could cause the low incidence anomalies mentioned in this report are discussed in order of probability.

1. PRE-CAMBRIAN TOPOGRAPHY

Basement topography under Permits 5425 and 5426 is thought to be much the same as it is today along the southwest edge of the Shield. Low rounded hills separated by gentle to abrupt valleys are seen on the Shield and these features are undoubtedly present under the subject Permits. The effect of this Basement relief on the overlying sedimentary rocks is often great. The Granite Wash sand is usually present in the topographic "lows" on the Basement but absent on the "highs". The Granite Wash is an excellent potential reservoir.

Further effects of Basement topography on beds higher than the Granite Wash is the gentle folding present over Basement hills. These folds are anticlines in every sense and could form traps for oil or gas.

Many small faults have been reported by A. W. Noriss (1965) in the basement and immediately overlying rocks and these features could cause closure within the sedimentary units.

2. DEVONIAN REEFS

Devonian reefs strongly affect the fracture pattern and control the occurrence of gas and oil in the overlying beds. Furthermore, it is possible that some reefs are present in the area of Permits 5425 and 5426. Reefs are known in the Norman Wells area which is only 50 miles to the south.

3. TECTONIC FOLDING AND FAULTING

The presence of tectonic folds is very likely as the Permits are located in a belt of known folding and faulting.

4. TOPOGRAPHIC RELIEF ON AN INTRA-SEDIMENTARY

Unconformity, is a possible source of fracture intensity anomalies, but within the Permit area it is unlikely that the relief on any unconformities within the sedimentary section is great enough to affect the fracture pattern.

Reference to the Total Fracture Pattern Map which accompanies this report will show that there are two areas of "high" fracture intensity, and two areas of "low" fracture intensity (green). The general interpretation is that the low fracture intensity areas are underlain by topographic highs on the Basement. With this established, the deduction is that the Basement is high in the south part of Permit 5425 and the northeast part of Permit 5426.

These Basement high features are most interesting from the oil and gas point of view. The general shape of this feature is such that the causative feature must be a hill on the Basement surface. A fault is unlikely as the causative feature on these high areas as they are over one and one-half miles in width. If a fault caused the fracture "low" the width of the low would be about one mile or less. Area three could be caused by a Basement fault.

Three hypothetical structure cross-sections accompany this report and reference to them will show how Basement "highs" are inferred to be present beneath areas of low fracture intensity. Two profiles C-C^1 and B-B^1 run at right angles to the strike of the Basement while the third A-A^1 is parallel to strike.

Respectfully submitted by:

William G. Crook

William G. Crook, P. Geol.

WGC:mjh

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C

C'

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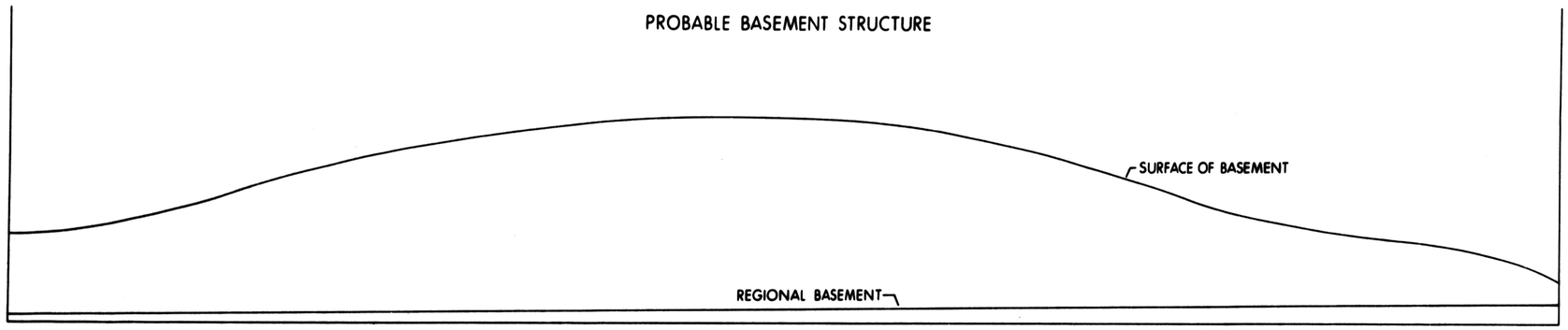


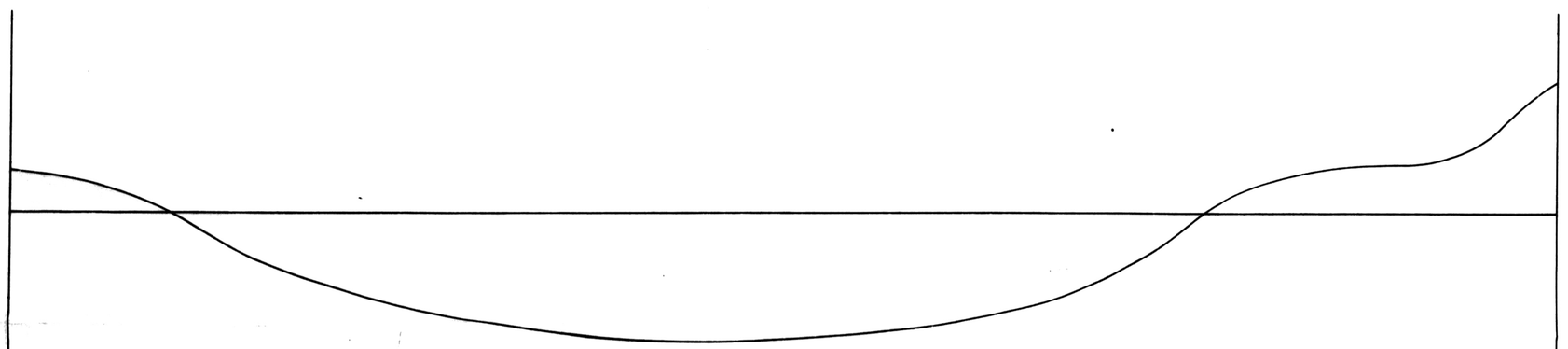
C

C'

1 of

HIGH

NORMAL



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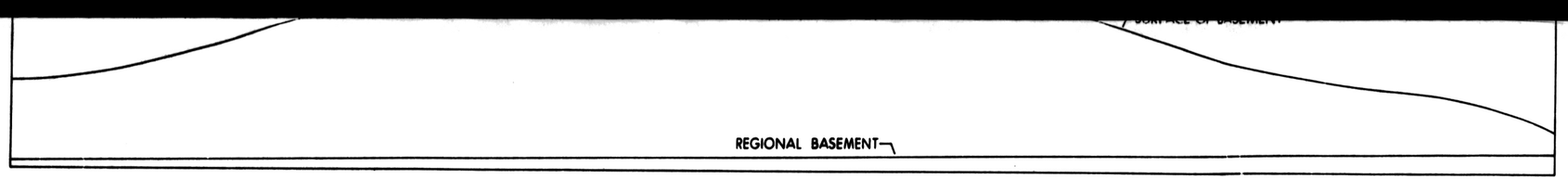

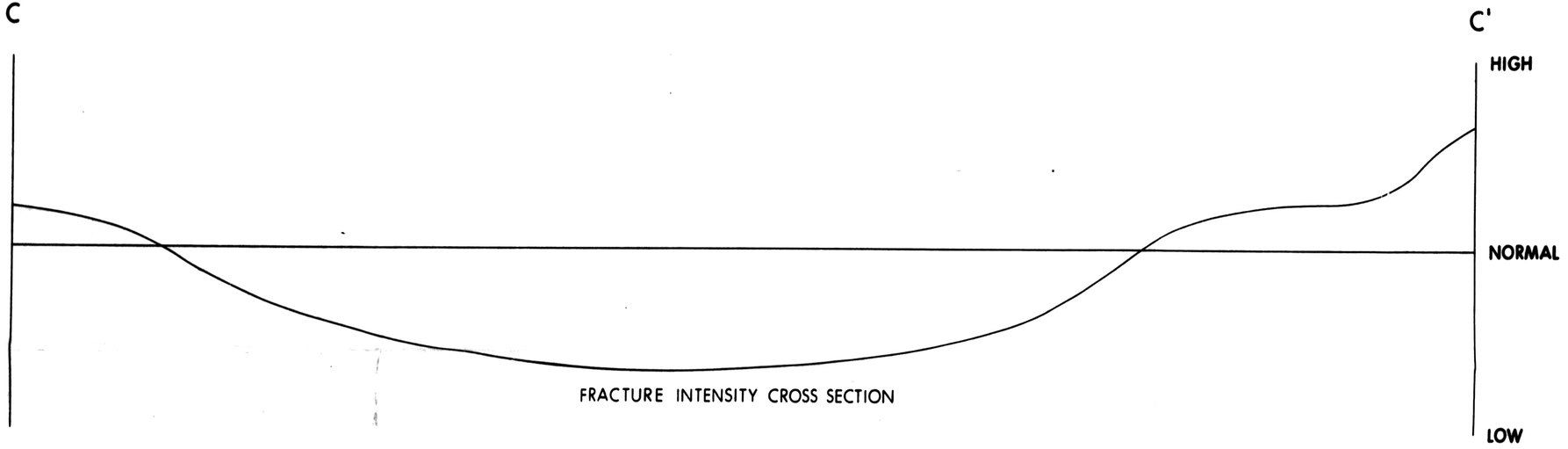

FRACTURE INTENSITY CROSS SECTION

MICHIGAN DEVELOPMENTS LTD.

P. & N.G. PERMITS 5425 & 5426

SCALE IN MILES

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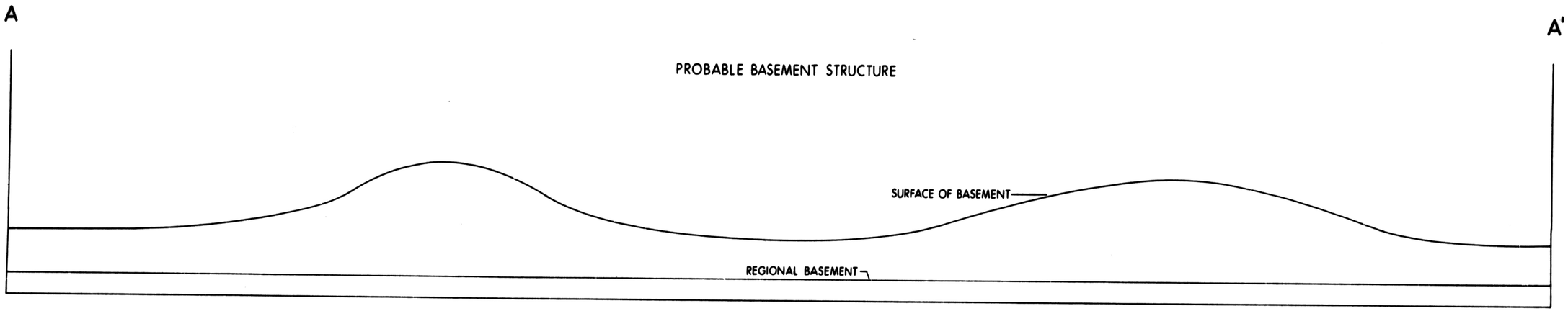
2 of 2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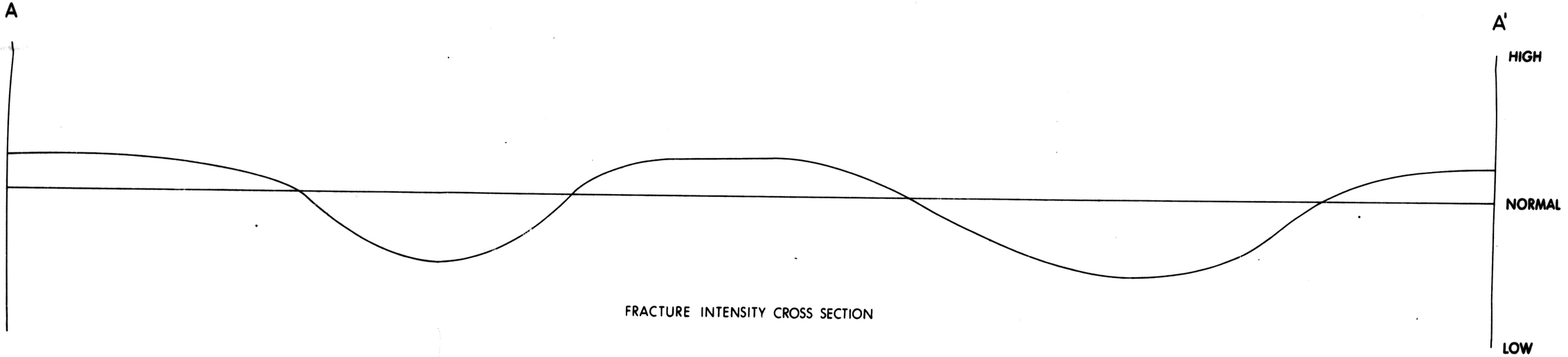
A'
PROBABLE BASEMENT STRUCTURE
SURFACE OF BASEMENT
REGIONAL BASEMENT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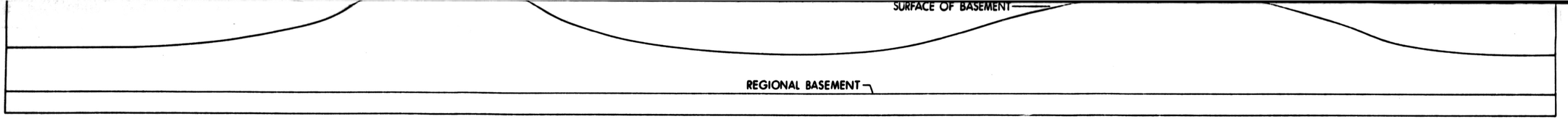
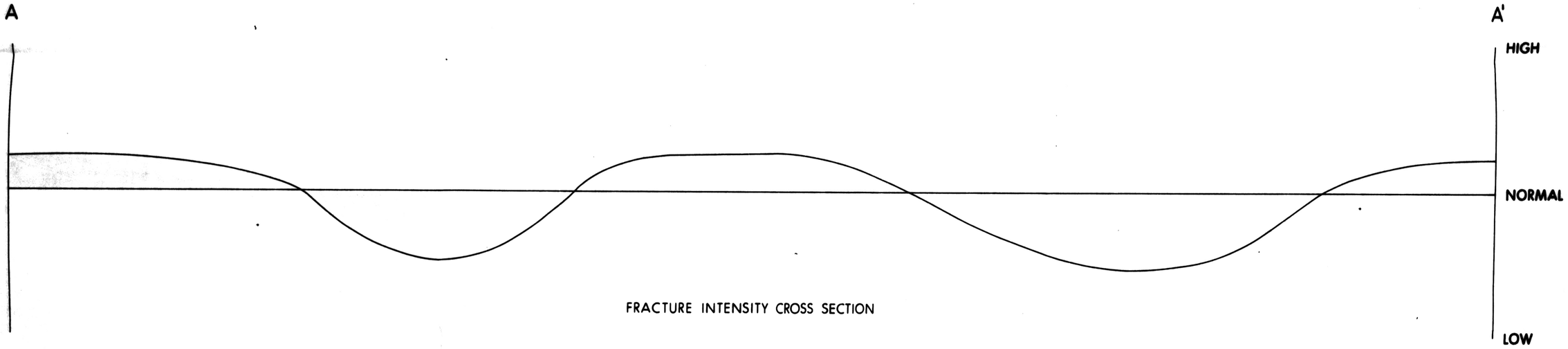
NORMAL
LOW
FRACTURE INTENSITY CROSS SECTION





FRACTURE INTENSITY CROSS SECTION

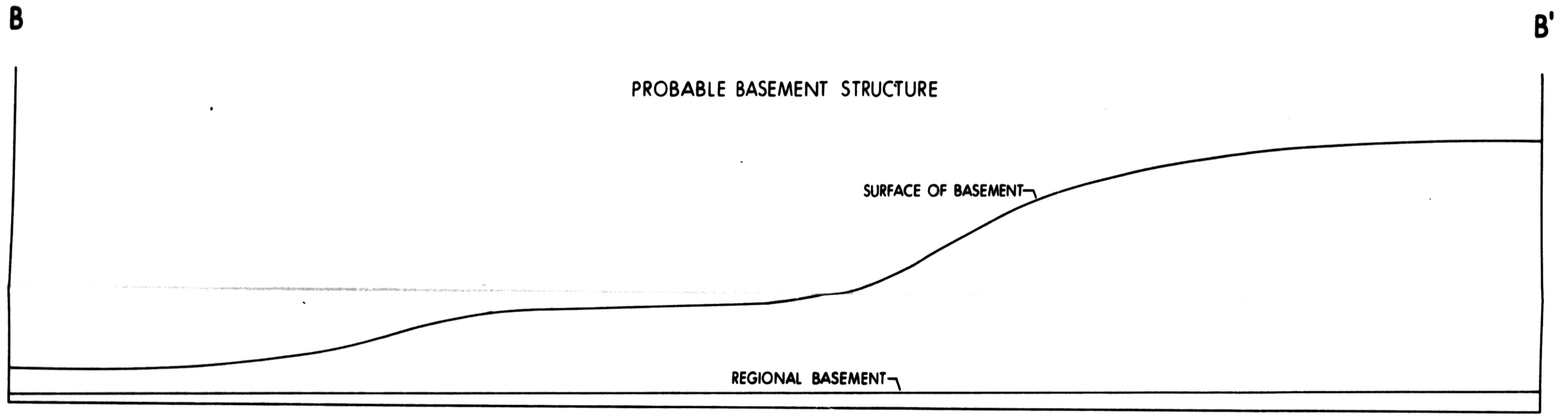
MICHIGAN DEVELOPMENTS LTD.

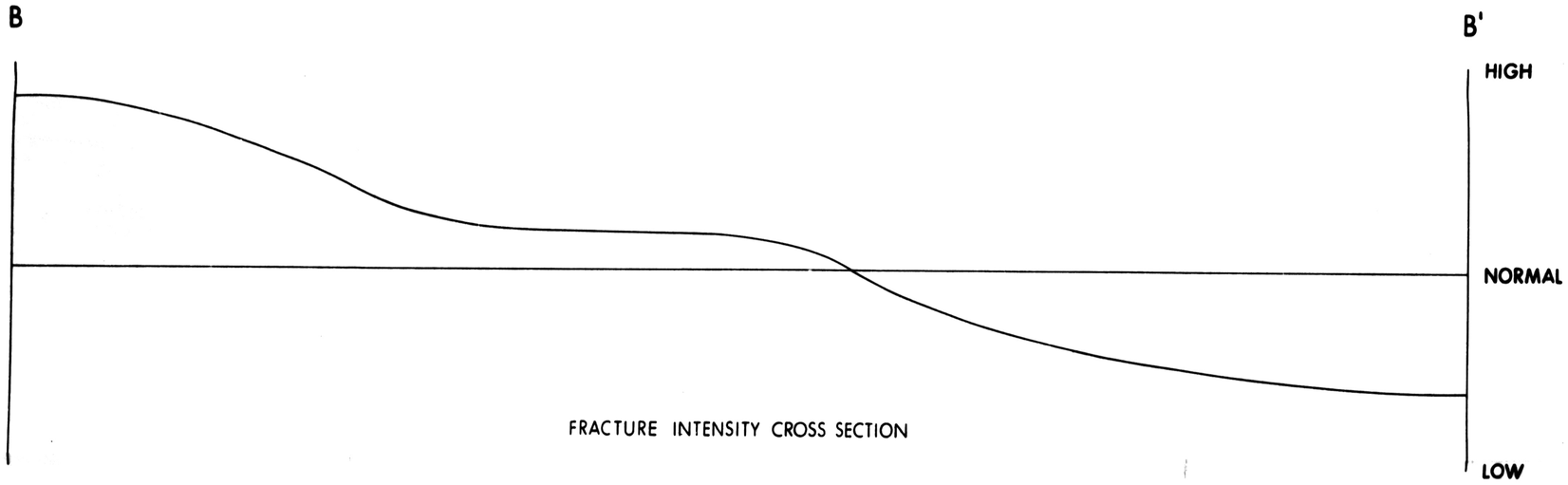
P. & N.G. PERMITS 5425 & 5426

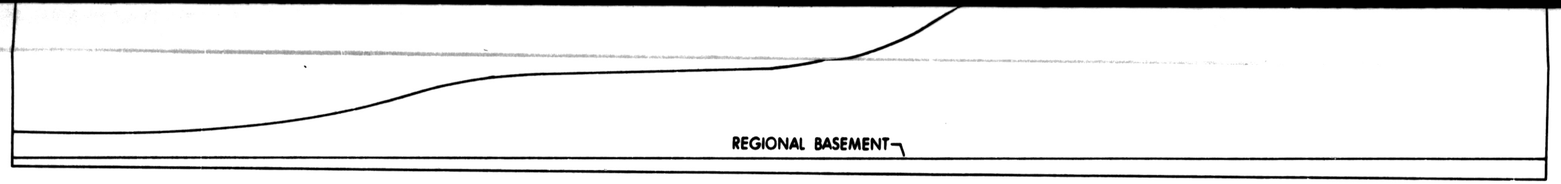
SCALE IN MILES

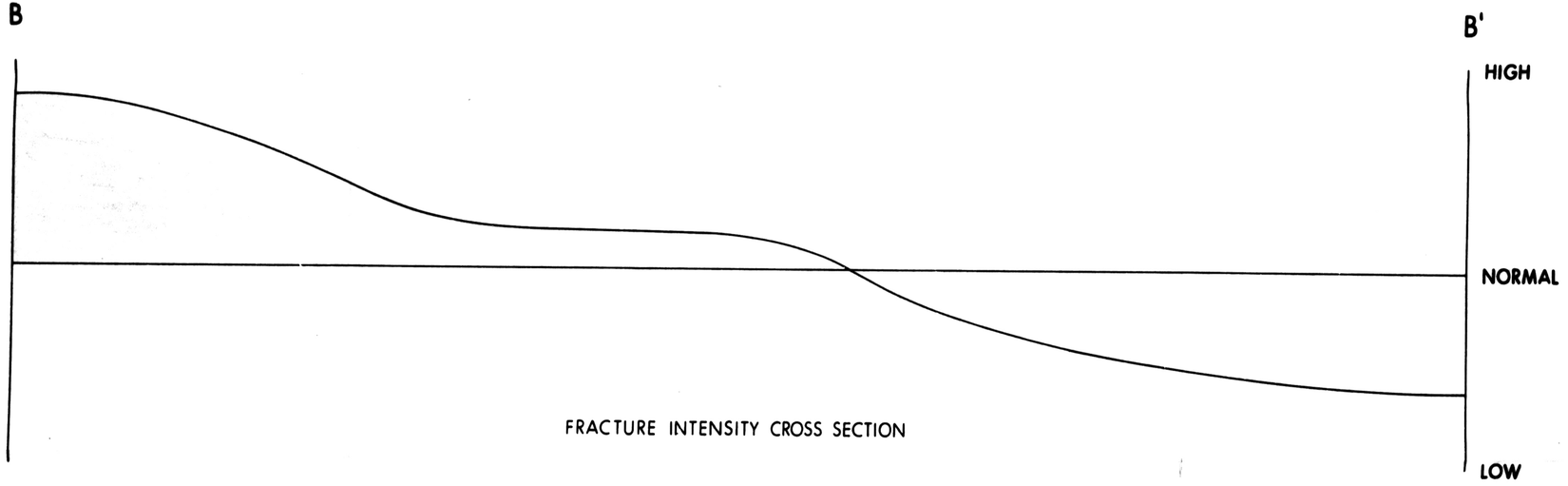
1 0 1 2 3

292


B
B'
PROBABLE BASEMENT STRUCTURE
SURFACE OF BASEMENT
REGIONAL BASEMENT


B
B'
HIGH
NORMAL
LOW
FRACTURE INTENSITY CROSS SECTION





FRACTURE INTENSITY CROSS SECTION

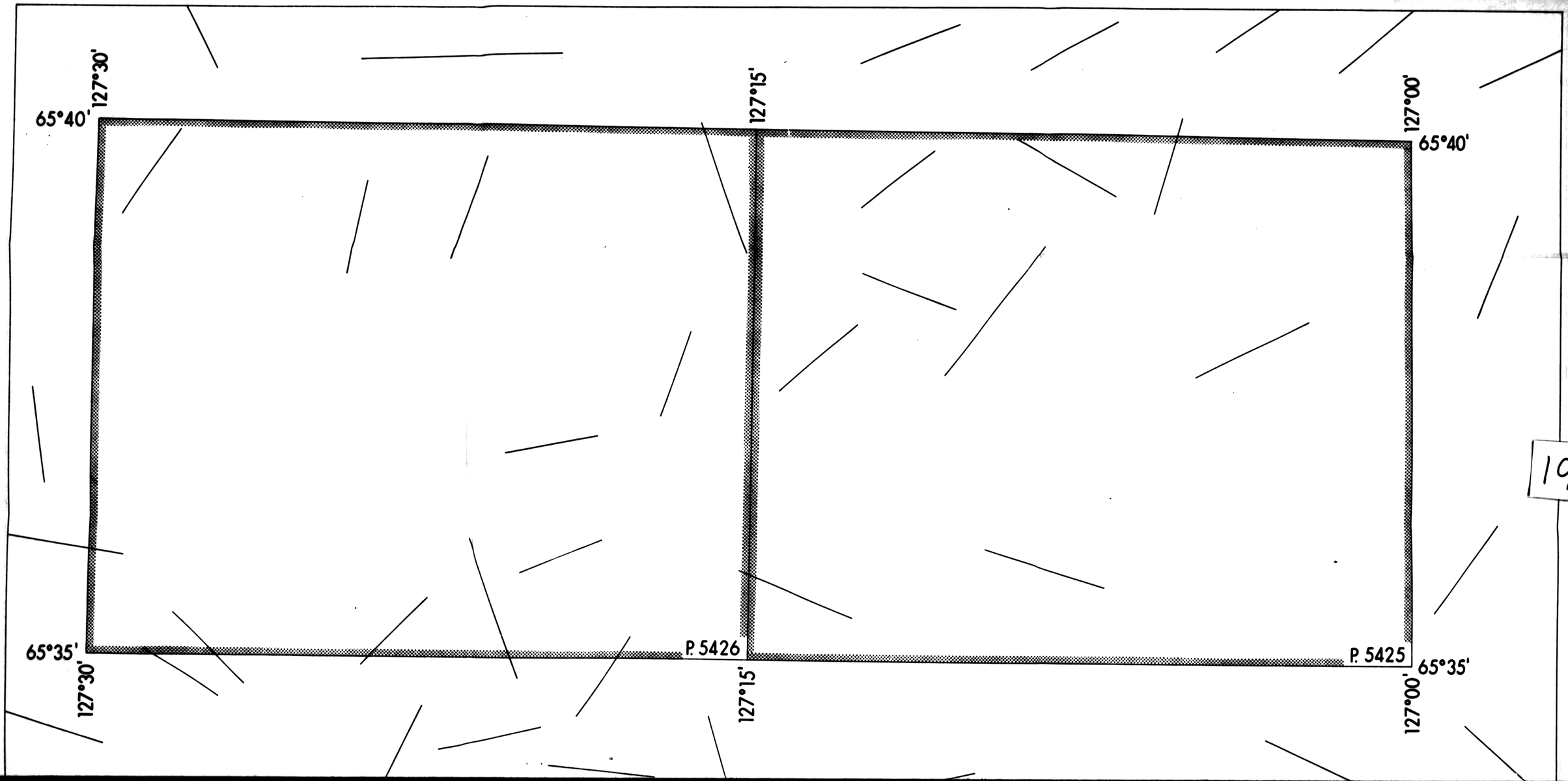
MICHIGAN DEVELOPMENTS LTD.

P. & N.G. PERMITS 5425 & 5426

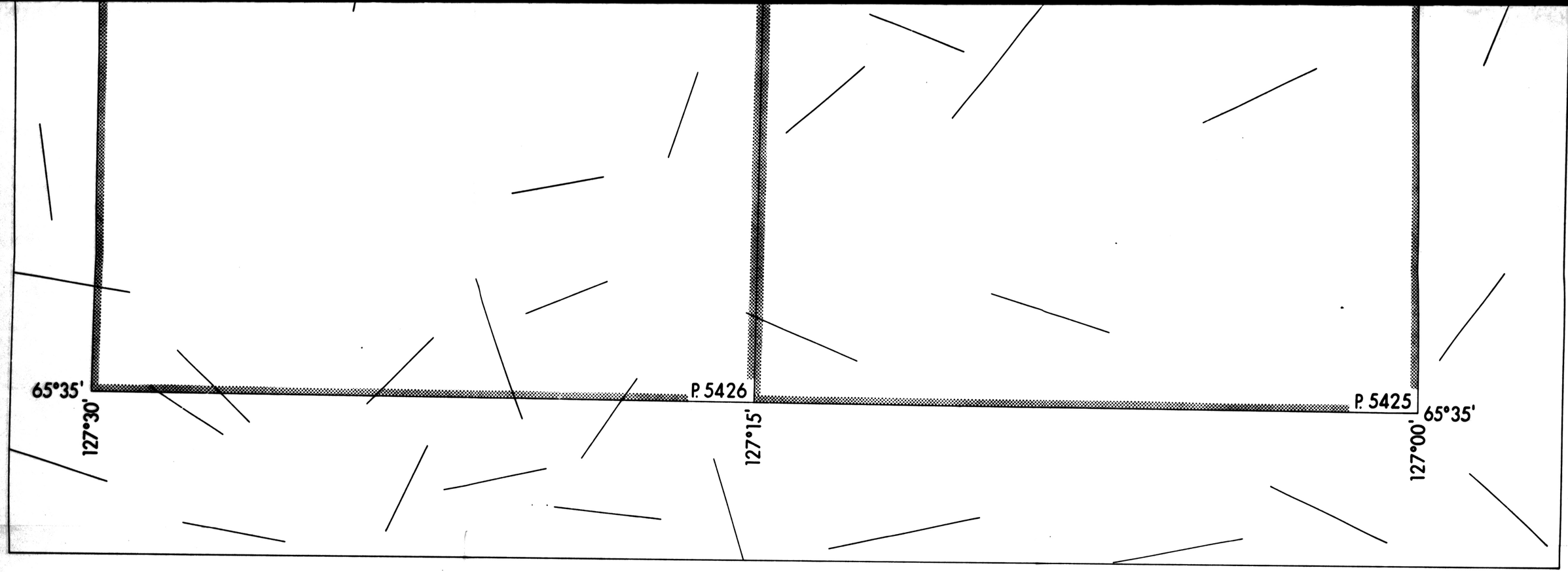
SCALE IN MILES

1 0 1 2 3

2 of 2


127°30'
127°15'
127°00'
65°40'
65°40'
65°35'
65°35'
P. 5426
P. 5425
127°30'
127°15'
127°00'

1 of



MICHIGAN DEVELOPMENTS LTD.

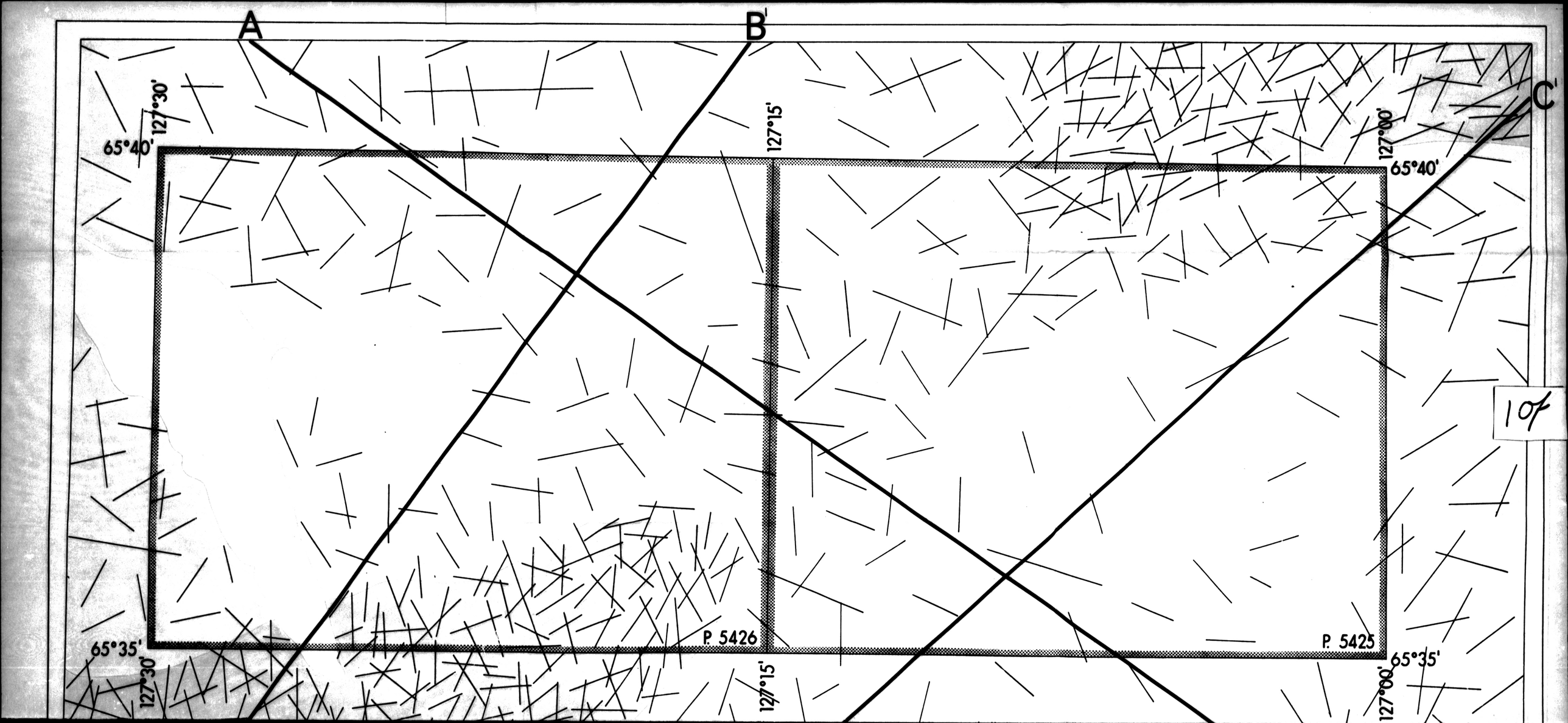
P. & N.G. PERMITS 5425 & 5426

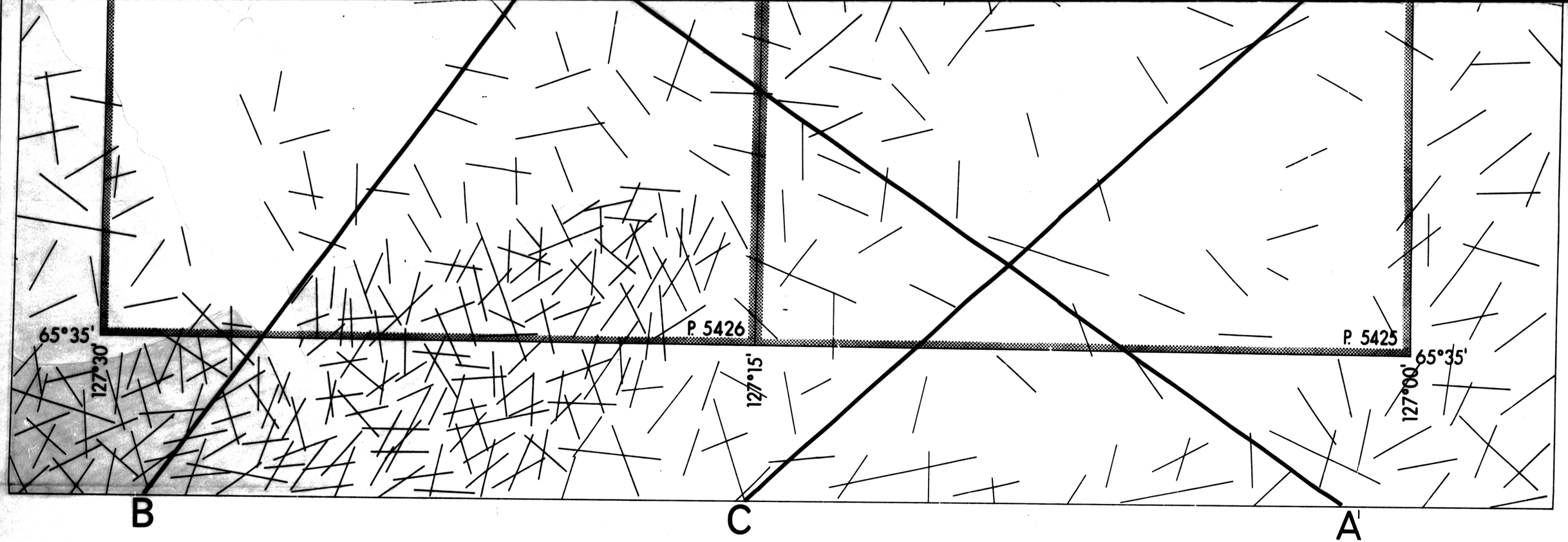
MEGA FRACTURE PATTERN

SCALE IN MILES

1 0 1 2 3

2 of 2


A
B
C
127°30'
127°15'
127°00'
65°40'
65°35'
P. 5426
P. 5425
1 of



MICHIGAN DEVELOPMENTS LTD.

P. & N.G. PERMITS 5425 & 5426

TOTAL FRACTURE PATTERN

SCALE IN MILES

1 0 1 2 3

LOW DENSITY | NORMAL DENSITY | HIGH DENSITY

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1 of

MICHIGAN DEVELOPMENTS LTD.

P. & N.G. PERMITS 5425 & 5426

SCALE IN MILES

1 0 1 2 3

THIS IS AN UNCONTROLLED MOSAIC AND SHOULD NOT BE TAKEN AS AN ACCURATE TOPOGRAPHIC MAP.

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