GENERAL GEOLOGY, GEOMORPHOLOGY AND FRACTURE ANALYSIS SURVEY OF P. & N.G. PERMITS 5266 and 5267 AUBRY LAKE AREA, N.W.T.

FOR

CARILLON DEVELOPMENT CORPORATION LIMITED

BY

WILLIAM G. CROOK, P.GEOL.

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GEOMORPHOLOGY

The Permit Numbers 5266 and 5267 lie on the interior plains area of the Northwest Territories about 130 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 north towards the Anderson River. Within the mosaic the drainage is all internal towards various lakes and some of these do not have any drainage. Many of these small streams are intermittant and hold water only during the spring. The general drainage pattern is dendritic but it has been 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 geologic 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 recognized 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 on the east side of the mosaic. 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 5266 and 5267 are geographically located in the Tedji Lake area which lies about 90 miles north of the Arctic Circle. 30 miles south of the Anderson River and 155 miles east-southeast of Inuvik. The acreage lies in a poorly drained area of generally low relief and is covered by numerous small lakes and streams. Surface elevations vary between 800 feet and 1,000 feet above sea level. Geologically, the Permits are located on the Interior Plains, approximately 130 miles west of the Pre-Cambrian Shield. The Sedimentary Section ranges from Cambrian to Devonian. Regional isopachs indicate about 6,000 feet of sediments should be present in this area. Structures for the region should be homoclinal to gently folded. Well control is very sparce in this region. Canada Southern Carnwath River #1, drilled at 67°, 44', 40" N., and 128°, 47', 53" W., lies 28 miles west-southwest of the acreage. The well bottomed at 2,308 feet in the Silurian-Ordovician. The nearest well control to the north is 125 miles away at two wells called Texaco Texcan C&E Nicholson N-45 and G-56. The stratigraphic section encountered at the Nicholson wells does not appear to correlate with the North Yukon - Lower MacKenzie River stratigraphic section. The nearest well control to the south is 50 miles away at Rond Lake where Western Decalta drilled five shallow tests in 1960. There is no well control between the Permits and the Pre-Cambrian Shield outcrop. Regional isopachs and facies studies have been employed, along with published geological reports, to obtain some

idea of the stratigraphic section underlying Permits 5266 and 5267.

CAMBRIAN AND/OR OLDER

KATHERINE GROUP

The earliest Paleozoic sediments encountered in this area consist of a series of interbedded quartzites and black platey shales. The quartzites are generally pink, white, buff and rusty with interbedded black, bituminous, platey shales and occasional chocolate brown and green shales. The thickness of the Katherine Group is undetermined for this general region; however, the top is usually placed at the base of a succession of chocolate brown shales. Reservoir beds have not been noted in this succession to date. Further drilling may, however, encounter shoreline sands and offshore sand bars similar to those found productive at Red Earth in northern Alberta. Mapping of the underlying Pre-Cambrian surface would be essential to outline the likely areas of sand development. Gravity meter and magnetometer surveys could be expected to outline the areas where these sand accumulations might be prospected for. The black, bituminous shales, described in outcrop sections may be expected to provide an adequate source rock for oil and gas.

CAMBRIAN

MACDOUGAL GROUP

In the Norman Wells area the Macdougal Group was described by Nauss from exposures in the Dodo Canyon of the Macdougal River. The type section consists of 997 feet of interbedded limestones, sandstones, reddish coloured gypsum, red

and green shales, chocolate coloured shales and black, petroliferous shales. At Imperial River, about 30 miles to the northwest of the type section, Laudon has described a succession of beds 1,839 feet thick. The base of the Macdougal in Dodo Canyon consists of alternating sandstones, limestones, gypsum and varicoloured shales. The lower part consists of tan sandstone with minor shale interbeds. The shale content increases upwards as does the gypsum. Near the top Laudon noted a 146 foot bed of limestone containing calcareous algae up to 3 feet in diameter. At Norman Wells the Macdougal Group contains a hatite layer 2,000 feet thick which is correlated with the Saline River formation of M. Y. Williams. The presence of salt north and west of Norman Wells is deduced from the following evidence:

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

2. 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 south of Norman Wells.

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

4. 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.

The Saline River salt may reasonably be expected to extend under Permits 5266 and 5267 with the eastern margin lying some unknown distance towards the Pre-Cambrian Shield outcrop area. The solution of these salt structures sets up 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 algal limestone described by Laudon at Imperial River indicates some organic activity in the Cambrian Seas of this region and coupled with underlying salt features could give rise to patch reefs throughout the area. The sandstones described in outcrop coupled with petroliferous shales may give rise to hydrocarbon bearing reservoirs within this sequence, however, it is difficult to imagine their being found in the same locale as the Saline River formation.

ORDOVICIAN - SILURIAN

Rocks of the Ordovician age have not, as was noted by Hume, been definitely recognized in this area although it has been suggested by a number of authors that beds of this age are present in the Norman Wells area. About 200 miles to the west of the subject Permits, outcrops of shales and argillites 1,500 feet thick were mapped by Stelck. Approximately 265 miles south-southwest, at the confluence of the Keele and Twitya Rivers it was noted by Keele that 4,000 feet of alternating beds of argillite, dolomite and limestone are overlain by about 1,500 feet of sandstone, lying on a diabase sill 100 feet thick. Some 35 miles to the east of this section Keele described this sandstone as being about 4,500 feet thick with only occasional shale partings. The sandstones described by Keele are not expected to occur in the area covered by Permits 5266 and 5267. The sections described by Stelck and Keele, coupled with the sparce subsurface control, help to establish a regional sedimentary pattern. The acreage in question should be underlain by clean, finely crystalline shelf carbonates with variable porosity since the shelf carbonates are present over most of the Interior Plains. On the Peel Plateau and along the MacKenzie Mountains the shelf carbonates are bordered by shelf edge carbonates which are reefal in part. The shelf edge carbonates are in turn replaced in the stratigraphic section by the basinal shales and argillites described by Stelck.

Strata of Silurian age are distributed over a wider area than the rocks previously described as Ordovician age. Due to lithological similarities they have, for practical purposes, been lumped together under the name, Ronning Group. As might be expected the Silurian age rocks were deposited in a sedimentary pattern very similar to the one established in Ordovician time. As is the case with subsurface control the occurrence of outcrop sections near the Permits is very limited. The nearest outcrop sections of Ronning age appear to be those found on the Hare Indian River, which is some 100 miles to the south of the acreage. The Ronning has been mapped at these outcrops as 750 feet of limestones, with neither the top nor the base of these beds being observed. The younger Bear Rock Formation of brecciated limestones and gypsum was found overlying them.

In the Norman Wells area, the Ronning Group can normally be divided into two units. The lower unit has been named the Franklin Mountain Formation and it generally consists of limestones and dolomites with abundant, irregular shaped chert nodules. The upper unit of the Ronning has been called the Mount Kindle Formation. Generally, the Mount Kindle is composed of a sequence of chert-poor limestones and dolomites which tend to thin out in a southerly and easterly direction. The Franklin Mountain Formation in the vicinity of Permits 5266 and 5267

should consist of approximately 1,000 feet of clean, finely crystalline shelf carbonates with abundant chert inclusions. Porosity will likely be found to be quite variable. The lower part of the Mount Kindle Formation has been mapped in outcrops north of Norman Wells as a 100 foot thick sequence of massive, crystalline, porous limestone containing a coralline fauna. This coralline bearing outcrop section together with the regional thickening of the Mount Kindle in a northerly and westerly direction from Norman Wells allows one to predict a series of porous carbonate banks or low relief transgressive reef fronts within this formation. The region within which Permits 5266 and 5267 lie should be favourably located with respect to this predicated carbonate bank and reef facies. Since oil staining has been encountered in the Upper Ronning Group in wells drilled at Norman Wells, the Group can not be overlooked as a potential hydrocarbon bearing reservoir in any wells drilled in the MacKenzie district.

The variety of trapping conditions which may be expected to occur in the vicinity of the Permits under study are quite varied. Some of the type which could occur are outlined below.

(a) The marked disconformity which separates the Ronning Group from the overlying Middle Devonian Bear Rock Formation may be expected to give rise to a variety of erosional trapping

features such as, Scarps and Monodnocks, which when capped by the overlying gypsum and/or anhydrite of the Bear Rock would consitute an effective hydrocarbon trap. As with most reservoirs exposed to erosion the porosity would likely be enhanced by leaching processes.

(b) Reef fronts and/or porous carbonate bank facies as outlined above may be capped by the younger Bear Rock evaporites. These porous beds will undoubtedly change facies laterally into associated tight carbonates of Ronning age.

(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 Saline River 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 Saline River salt. This may have

occurred in late Cambrian or early Ronning time. The depressions created would receive an extra load of sediments over that being received where the salt was not removed. Once sedimentation within the depression caught up, subsequent sediments would be laid down on a normal sea floor. The second stage of the formation of a Hummingbird type trap would be the solution of the remaining Saline River Salt at some time subsequent to Mount Kindle deposition. This would leave the Mount Kindle reservoirs overlying the site of original salt solution structurally high. The Bear Rock evaporites should provide an excellent reservoir seal. Supporting evidence for two stage solution in this region can be seen in the brecciated nature of sediments comprising the Lower Ronning and Bear Rock sediments in outcrop sections.

(d) Gentle anticlinal folds may have been formed by some of the numerous periods of structural activity which have occurred in this region.

MIDDLE DEVONIAN

BEAR ROCK FORMATION

The type section for the Bear Rock Formation is found at Bear Rock, Fort Norman, where it has been mapped with two

distinct facies. The basal 40 feet to 60 feet consists of non-bedded gypsiferous, massive dolomite or limestone. This is overlain by 30 feet of dark grey, poorly bedded limestone or dolomite. In turn the 30 feet of carbonates is overlain by 175 feet of breccia, composed of brown, dolomitic limestone boulders in a matrix of dolomitic limestone. The contact between the Bear Rock Formation and the overlying Ramparts Formation is gradational at the type section and consists of 10 feet of bedded limestone and dolomite breccia. Regionally the Bear Rock Formation undergoes a series of facies changes. It goes from a basinal shale facies in the Richardson Mountains, to shelf edge carbonates, to shelf carbonates and finally to an evaporitic sequence. In the Peel Plateau Basin the Bear Rock, which is of early Middle Devonian age, consists of some 2,000 feet of micritic pellet and micritic skeletal limestone with intervals of finely crystalline porous dolomite in the lower portion. In the vicinity of Norman Wells the facies change to evaporites takes place. The evaporitic sequence extends southeastwards into Alberta where it is known as the Chinchaga Formation. A strong depositional feature called the Camsell Basin occurs to the south of Norman Wells. 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. In this area the shelf carbonates are cryptocrystalline to micro-crystalline dolomites with the shelf edge facies is reefal with some of it being porous.

The shelf carbonate facies of limestones and dolomites in the Peel Plateau Basin extend northeastwards to the outcrop belt. This facies should be present at the subject Permits. However, it is quite possible the Permits are underlain by the relatively narrow band of shelf dolomites which mark the beginning of the facies change from shelf carbonates to evaporite facies. This shelf dolomite is present along most of the line marking the change to evaporites from carbonates. As was noted by Hume, the Bear Rock carbonates have been found to be very porous in some wells drilled in this area while in others the original pore space has been infilled by anhydrite and gypsum. In places it has been found to contain considerable bitumin. Decalta et al Rond Lake #2, located in 67°, 5', 27" N., and 128°, 25', 42" W. lost circulation near the top of the Bear Rock and sulphur water was bailed from this interval. Decalta et al Rond Lake #1, located in 67°, 04', 51" N., and 128°, 28', 18" W. flowed sulphurous water on a test conducted about 900 feet below the Bear Rock top. Subsequent to the completion of drilling a plug was set to 1,046 feet, the hole was bailed to 600 feet with oil cut sulphurous water being recovered. Three weeks later the hole was again bailed with oil cut sulphurous water again being recovered. Since Rond Lake #1 was located downdip to the #2 well and recovered oil cut water near the base of the Bear Rock, while #2 only recovered sulphurous water from the top of the Bear Rock, the two wells appear to have tested separate reservoirs. This separation would most likely be due to facies change. At Canada Southern Carnwath

River #1, located in 67°, 44', 40" N., and 128°, 47', 53" W., 819 feet of Bear Rock were penetrated. A drill stem test in the Bear Rock recovered 610 feet of muddy, sulphurous fresh water. The Rond Lake wells, although much further from Permits 5266 and 5267 than the Carnwath River well, would appear to be more indicative of the type of facies which might be expected to underly the Permits under discussion than the Carnwath River well. This facies would appear to have definite possibilities of providing a large regional accumulation of oil if encountered in a favourable structural position. Hydrocarbon traps within the Bear Rock Formation could also be provided by any of the various structural conditions outlined in the preceeding discussion of the Ronning Group.

The Bear Rock is present in outcrop along the Hare Indian River which is about 100 miles south of Permits 5266 and 5267. The section is described as typical brecciated limestone and gypsum. The brecciated nature of the Bear Rock was previously mentioned as possibly being a product of the removal of the underlying 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 and the overlying Bear Rock. This theory is no doubt true for the basal portion of the Bear Rock Formation. The section exposed on Mount Charles, which is 34 miles east of Fort Norman, may be considered as support for the theory proposing salt removal from the Saline River Formation 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 Formation was not seen. In addition to the brecciation well up into the Bear Rock section, the great thickness of sediments mapped as Bear Rock is anomalous and suggestive of greater subsidence during deposition than is found in adjacent areas. The section at Norman Wells varies between 200 feet and 500 feet in thickness. It is possible, of course, that in addition to the thrust fault which formed Mount Charles, other thrusts have repeated the Bear Rock and have not been recognized by workers in the area; however, this does not seem likely. The rapid facies changes found within the Bear Rock is evident when the Mount Charles section, in which no evaporites are described, is compared to an exposure 3 miles farther north. Here the chert beds of the underlying Mount Kindle Formation are overlain by 500 feet of grey gypsum beds which are in turn overlain by limestone beds that are mapped as part of the overlying Ramparts Formation.

RAMPARTS AND HUME FORMATIONS

All definite Middle Devonian beds in the Norman Wells area as well as in the surrounding area were placed in the Ramparts Formation by Hume. 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 northwesterly 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 (particularly corals) and very petroliferous 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 location, 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. Numerous other exposures of the Ramparts Formation are described in the literature dealing with this region, however, the paper by H. G. Bassett in the "Geology of the Arctic" symposium is probably most important to an understanding of the Middle Devonian geology in this area.

Bassett has discarded the name Ramparts in favour of the name Hume Formation. The Hume Formation is restricted to the unit which was previously termed the Lower Ramparts by Hume. The type section is found 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. This correlation is based on ostracod zones within the Hume and Lower Keg River Formations.

Bassett notes that the Hume Formation is present in the Anderson River area which as previously noted lies some 30 miles north of the subject Permits. The Canada Southern Carnwath #1 well, which lies 28 miles west-southwest of the subject Permits, encountered 209 feet of Hume beds. Some idea of the thickness variations encountered can be seen by comparing the type section with the section described by Stelck at Schooner Creek, 4 miles north of Norman Wells. The Hume here consists of 8.5 feet of limestone, black, shaly and fossiliferous. This section also includes 1 foot of fine basal conglomerate. Stelck notes that the contact with the underlying Bear Rock is possibly disconformable at this locality, as has Bassett at a number of other locations.

The Hume Formation appears to be generally encountered as a non-porous rock both in outcrop and in subsurface. The Keg River platform is also normally a tight facies, however, along the north flanks of the Peace River Arch it is present as a marginal shoal. The marginal shoal facies 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 black shoal mud flats, which in turn are replaced by shoreline sands that produce oil in scattered locales. The possibility that such a facies pattern may exist along the flanks of the Pre-Cambrian Shield in this area should not be discounted. There is, of course, the possibility that the marginal shoal may have been removed by one of the many periods of erosion that have

occurred in this region. The Keg River platform is very petroliferous where it underlies the productive Keg River pinnacle reefs in the Rainbow Lake and Zama Lake Fields of northwestern Alberta and is very likely the source of the oil found there. As was noted previously the Lower Ramparts (Hume Formation) is very petroliferous, in part, at the outcrop section in the Imperial Range on Mountain River. Any reservoirs found in the Hume might therefore be expected to contain hydrocarbons if located in a favourable structural position. The wells drilled by Western Decalta at Rond Lake, which lies 50 miles south of Permits 5266 and 5267, encountered up to 300 feet of Hume. No drill stem tests were run over the Hume Formation in any of these wells.

HARE INDIAN

The Hare Indian shale as is stated by Bassett is the equivalent of the Middle Ramparts shale member described by Hume at the Imperial Range section. The contact 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 between the Hare Indian and the overlying Kee Scarp is somewhat diachronous, since it is generally placed at the changeover from shale to predominant limestone. Facies changes in the Hare Indian thus account for the diachronous nature of the contact. The rapid

facies changes which occur in the Hare Indian have contributed to the confusion which has surrounded Devonian correlations in this region. A good example of this confusion is found at the Carcajou Ridge section which is exposed along the Mountain River west of Norman Wells. One interpretation of this section has it consisting of 6 feet to 70 feet of Kee Scarp reef overlying 900 feet (plus) of Hume Formation. The Hare Indian shale is observed to go from 21 feet to zero (0) feet in thickness. It would seem more likely that a good percentage of the underlying Hume is actually Hare Indian agecarbonates. 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 facies change, as mentioned above, it can thin to less than 100 feet in the space of a few miles.

The Hare Indian is recognized at Anderson River which is a short distance north of the Permits in question. Canada Southern encountered about 100 feet of it in their Carnwath River #1 well, 28 miles west-southwest of these Permits. While the Hare Indian thins regionally into the Norman Wells area where it is 100 feet or less in thickness; to the north of Norman Wells, centering around Fort Good Hope it has thickened to over 700 feet. This sequence thins towards the Peel Plateau to the west and also towards Permits 5266 and 5267. South of Norman Wells a thick Hare Indian sequence is again present. This thick centers about the confluence of the MacKenzie and Redstone rivers where it is

500 feet thick or more. The section found at Carcajou Ridge is somewhat similar to that found in the Clarke Lake region of northeast British Columbia. Here the Klua Shale, of Middle Devonian age, overlies the Keg River Formation in some areas, but in other areas continuous reef growth from Keg River through to and including the Slave Point has allowed no shale deposition.

KEE SCARP

The Kee Scarp as redefined by Bassett includes beds which Hume mapped as high Upper Ramparts limestone member. By using the correlation as defined by Bassett the Kee Scarp becomes a much wider distributed unit. Ostracods have been used to establish the Kee Scarp as equivalent to the combined Sulphur Point - Slave Point carbonates of northwestern Alberta. As noted previously the Kee Scarp at Norman Wells rests diachronously on the Hare Indian shale. The Kee Scarp reef is the reservoir of the Norman Wells oil field, where the oil is trapped in the updip end of a discrete reef. The Kee Scarp at Norman Wells consists of a lower platform unit which is about 75 feet to 165 feet thick, is composed of bedded limestones which usually contain abundant fossils and is generally barren of hydrocarbons. The foundation unit is overlain by true reef materials, such as corallites, bryozoans and stromatoporoids, set in a coral sand matrix. The facies varies widely between wells which is what one expects in a reef. The thickness of reef ranges up to 400 feet. Reserves of oil within the reef have been placed as high as 60,000,000 barrels from a productive area of 2,600 acres.

The platform unit which is present under Norman Wells is undoubtedly the Upper Ramparts limestone unit as mapped by Hume. As mentioned above this correlation means the Kee Scarp is quite widespread and for this reason alone any well drilled in the MacKenzie area must consider the possibility of discrete Kee Scarp reefs growing from this platform. Maximum reef growth regionally has been confined to the margins of thick Hare Indian shale, however, its presence does not ensure Kee Scarp reefs. The margins of the two Hare Indian thicks described previously have not been found to contain Kee Scarp reefs to date, however, they have not been explored adequately either, so that the prospect for finding them must be considered as good. No Kee Scarp reefs have been found north of 68° Latitude as yet. The area covered by Permits 5266 and 5267 is so poorly controlled that the possibility of finding a Kee Scarp reef here can not be disregarded entirely; however, it does seem likely that any reef here would be outcropping or very near surface.

UPPER DEVONIAN

CANOL FORMATION

Bassett has defined the Canol Formation as "the black shale unit which directly overlies the Kee Scarp Formation except where the latter is most thickly developed (or preserved)". Where the Kee Scarp is absent the Canol directly overlies the Hare Indian Formation. This is equivalent to the bituminous member of the Fort Creek Formation. The thickness varies in relation to the underlying Kee Scarp reef, i.e., it thickens away

from the reef. The thickness is reported to vary between zero (0) feet and 400 feet. The Canol has been found as far north as 68° Latitude which is of course the northern boundary of the Permits under study.

IMPERIAL FORMATION

Bassett has redefined the Imperial Formation to include all beds of Devonian age overlying the Canol Formation and which are unconformably overlain by Cretaceous strata. This of course includes the Fort Creek Formation. The Imperial consists of a sequence of greenish-grey shales and greenish sandstones which may reach a thickness of more than 3,000 feet where erosion has not cut too deeply. The sandstones are irregularly distributed within the formation and correlations are difficult.

CRETACEOUS

The Cretaceous in the Norman Wells area disconformably overlies the older Devonian beds. Erosion of these older formations is very pronouced which causes a wide variation in thickness of the underlying beds. North of Norman Wells this erosion has in places stripped away the entire Upper Devonian sequence, leaving the Middle Devonian Formations as subcrop. Since subsurface control, as well as outcrop data is so sparce in the vicinity of Permits 5266 and 5267 any attempt to estimate the depth of erosion that has occurred here is extremely hazardous. However, in light of the outcrops along the Hare Indian River, which, as has been mentioned before, lies 100 miles to the south,

and the drilling depths reported by Western Decalta from their Rond Lake wells 50 miles to the south, an estimate may be made. The writer's opinion is that the erosion may have cut as deeply as the Middle Devonian Hume; however, there is a possibility that some Imperial Formation is left and consequently a possibility that Kee Scarp reefs are present and preserved exists. As was noted in the discussion of Hare Indian - Kee Scarp, these reefs develop along the margins of Hare Indian thicks. Indications are that such a margin is trending in this direction.

SANS SAULT GROUP

The Sans Sault Group is the basal group of Cretaceous sediments which lie directly above the disconformity separating Cretaceous and Devonian sediments. The type section of the Sans Sault Group is composed essentially of shales and sandstones of marine origin and contains all Cretaceous strata up to the first bentonite bed. The thickness of the section which is located at Sans Sault Rapids is estimated at 1,411 feet.

SLATER RIVER FORMATION

This formation is composed of thin bedded, black, friable shales with abundant concretionary layers of ironstone nodules. It contains some thin sandstones, seams of alum, and sulphur. It has abundant thin bands of bentonite. The thickness of this unit is about 1,000 feet.

LITTLE BEAR FORMATION

The type section is on the Little Bear River where the strata is composed of sandstone, some conglomerate, sandy shales and coal seams. Bedding is lenticular and very local in nature. A thickness of about 780 feet has been given to this formation.

EAST FORK FORMATION

The East Fork section consists of a series of well bedded conchoildal, plastic marine shale, grey in colour. Its thickness at the type locality on the East Fork of the Little Bear River is 850 feet. It contains minor sandstone lenses and a thin coal seam.

Sparce surface and subsurface control also makes the prediction of the stratigraphic thickness of Cretaceous beds present at Permits 5266 and 5267 difficult. Regionally though it would seem likely that there is little more than a thin veneer of the Sans Sault Group present at best.

TERTIARY

A thickness of 1,600 feet of Tertiary beds have been mapped on the Little Bear River. The beds consist of soft, coarse, carbonaceous sands, gravels, conglomerates, shales and lignites. 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 seem to form part of a basin which dips to the southwest. If this is the case it would indicate that very little, if any, Tertiary age sediments will be found over Permits 5266 and 5267.

Further evaluation of the Permits in question should consist of a Gravity Meter Survey, in order to try and outline the present salt distribution within the Cambrian Saline River Formation. An airborne magnetometer survey may also be of some use in delineating Pre-Cambrian basement structures as well as the drilling depth to it.

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 5266 and 5267. 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 fracture system 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 in 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 may 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 be also 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 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.

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 5266 and 5267

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 hundreds of miles from the closest settlement.

The sedimentary section is about 6,000 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 three 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 5266 and 5267 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 5266 and 5267 is probably quite small.

There are three 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 fracture 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 5266 and 5267 are located on the interior plains of the Northwest Territories about 150 miles to the west of the edge of the Pre-Cambrian Shield. The strike of the sedimentary rocks is about North 20 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 5266 and 5267 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. However, it is unlikely that any reefs are present in the area of Permits 5266 and 5267. The only platform from which they could grow is the Keg River equivalent and so far, no evidence of reefing has been found in this area.

3. TECTONIC FOLDING AND FAULTING

The presence of tectonic folds is very unlikely, but some normal faulting is probably present.

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 three 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 low in the northeast corner of Permit No. 5267 as well as in the southwest corner of Permit No. 5266.

Of the two Basement high features the one in the northwest corner of the map is the 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 as the high area is 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.

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:

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WGC:mjh

REFERENCES

BLANCHET, P.H. - (1957)

"Development of Fracture Analysis as Exploration Method", Amer. Assoc. Petrol. Geol. Bull., Vol. 41, No. 8, 1748 - 1759.

HAMAN, P. J. - (1964)

"Geomechanics Applied to Fracture Analysis on Aerial Photographs", West Canadian Research Publications, Series 2, No. 2.

LAUDON, L. R. - (1950)

Imperial River Section MacKenzie Mountains, Northwest Territories, Canada. Bull. Am. Assoc. Pet. Geol., Vol. 34, No. 7, pp 1565 - 1577.

WILLIAMS, M. Y. (1922 and 1923)

Exploration East of MacKenzie River between Simpson and Wrigley; Geol. Surv., Canada, Sum. Rept. 1921, pt. B. pp 56 - 66 (1922)

Reconnaissance across Northeastern British Columbia and the Geology of the Northern Extension of Franklin Mountains, N.W.T., Geol. Surv., Canada, Sum. Rept. 1922, pt. B. pp 65 - 87 (1923).

HUME, G. S. - (1953)

The Lower MacKenzie River Area, Northwest Territories And Yukon. Geol. Surv., Canada, Memoir 273.

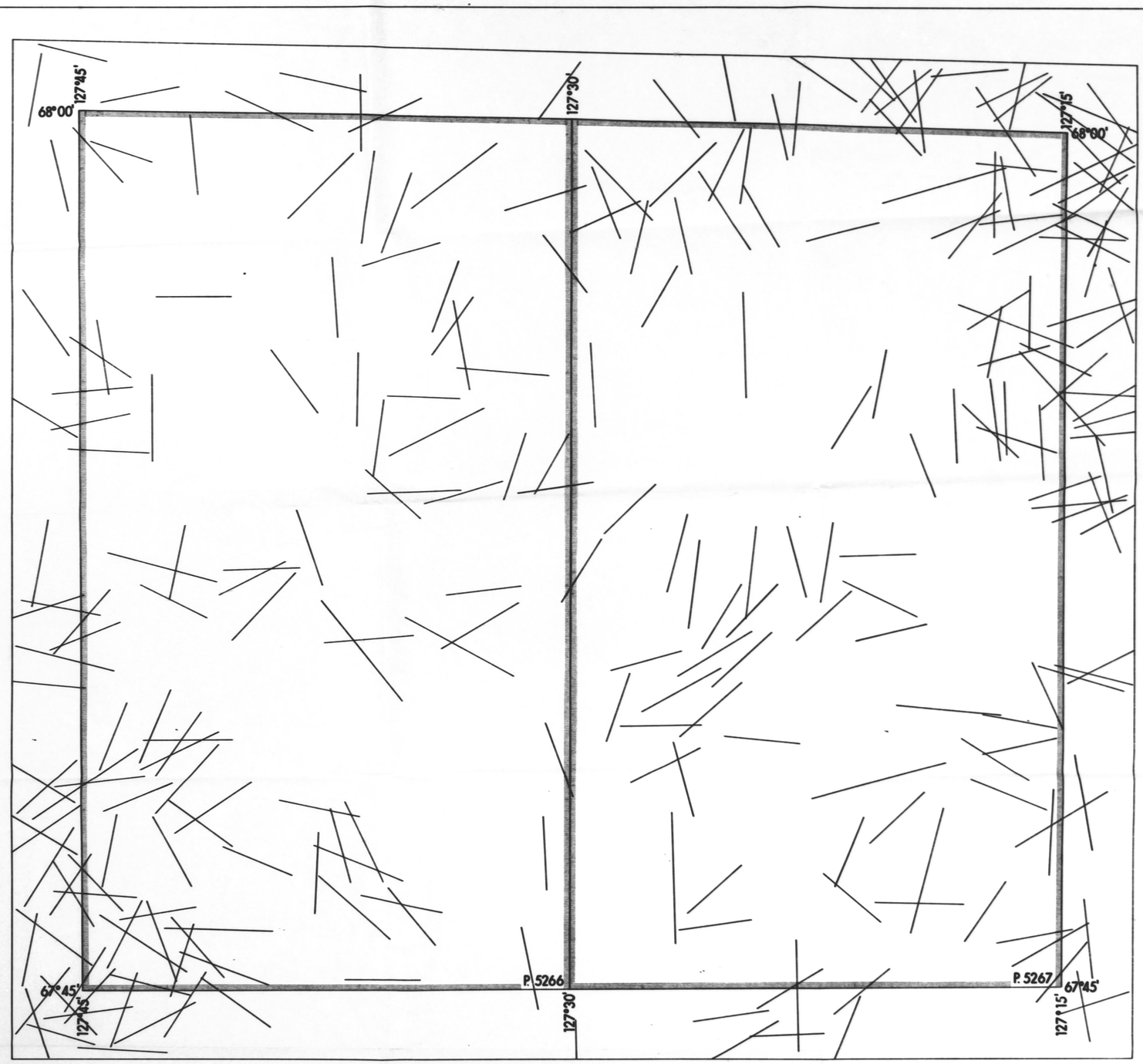
KEELE, Joseph - (1936)

A Reconnaissance across MacKenzie Mountains on the Pelly, Ross, and Gravel Rivers; Geol. Surv., Canada, Pub. 1097, 1910.

Formation Names in the MacKenzie River Valley; Science Vol. 83, No. 2140, pp 14 - 15.

BASSETT, H.G.

Devonian Stratigraphy, Central MacKenzie River Region, Northwest Territories, Canada. Geology of The Arctic, Vol. 1, pp 481 - 498



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P. & N.G. PERMITS 5266 & 5267

MEGA FRACTURE PATTERN

SCALE IN MILES

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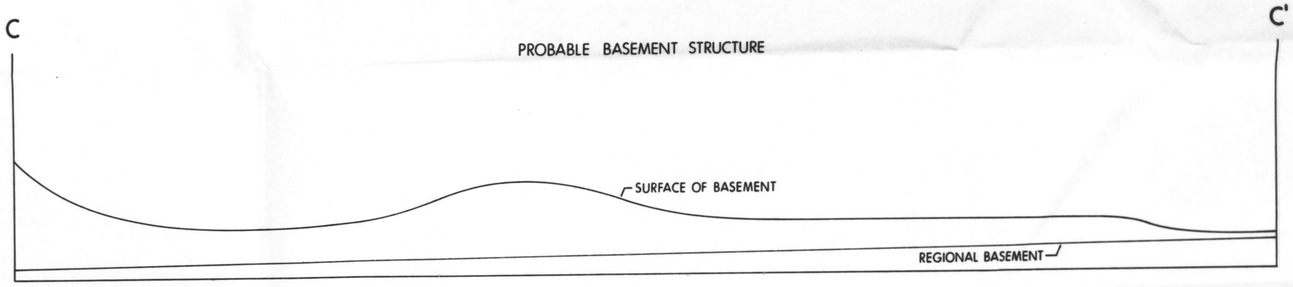
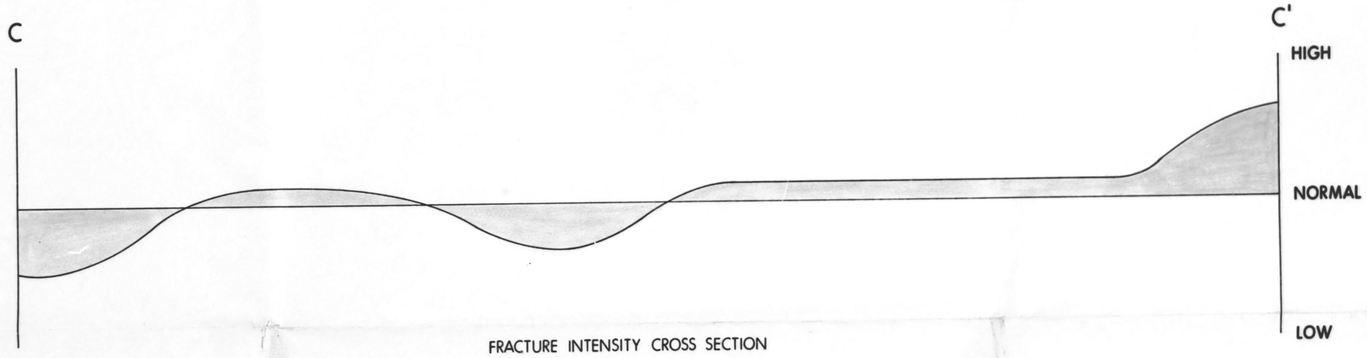




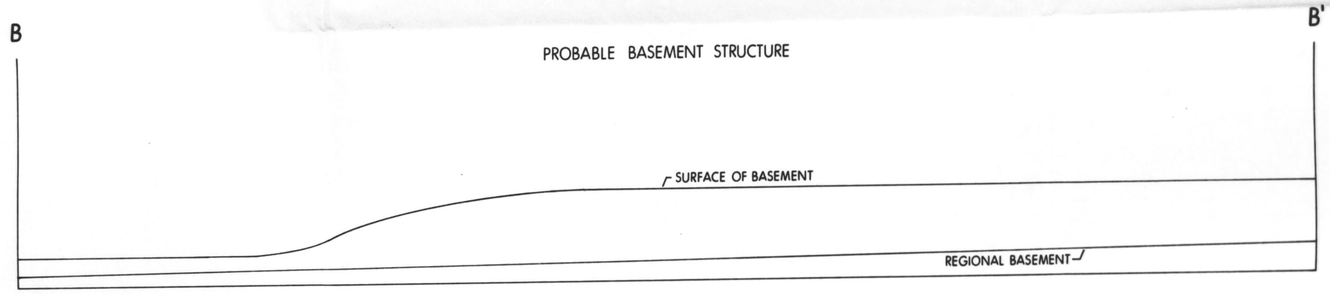
FRACTURE INTENSITY CROSS SECTION

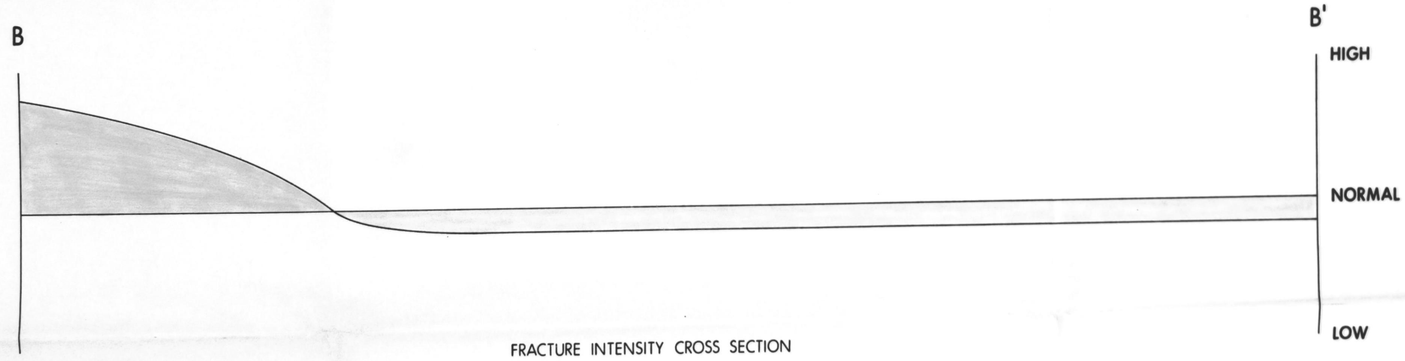
CARILLON DEVELOPMENT CORPORATION LIMITED

P. & N.G. PERMITS 5266 & 5267

SCALE IN MILES

1 0 1 2 3





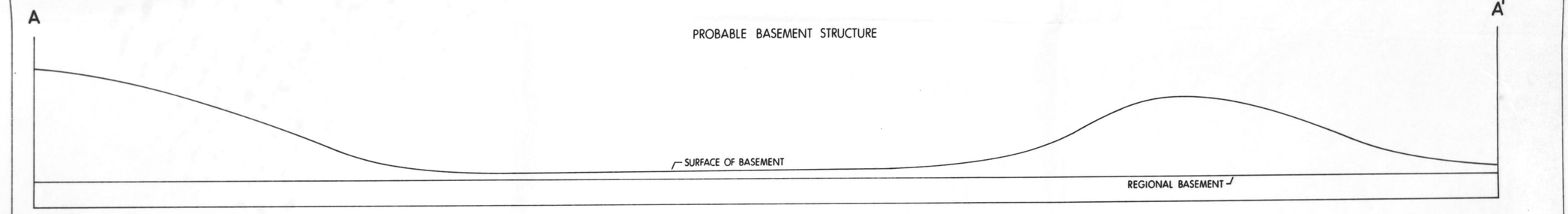
FRACTURE INTENSITY CROSS SECTION

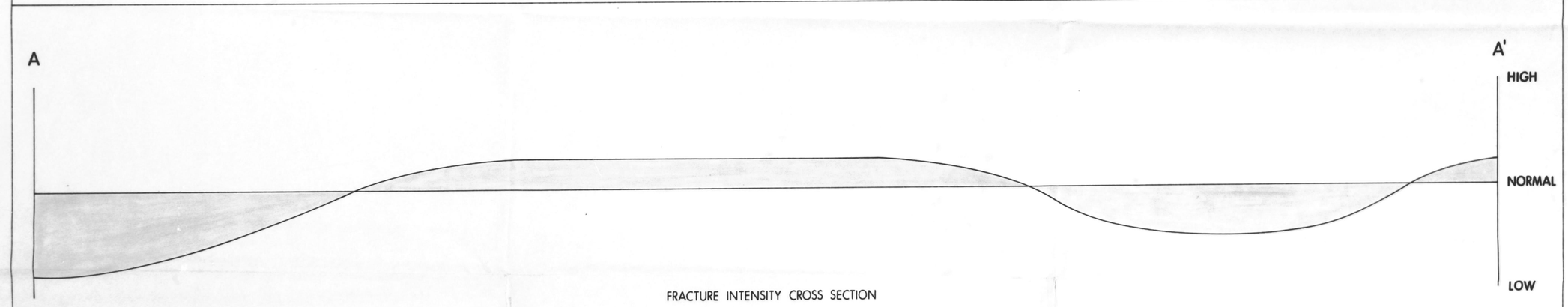
CARILLON DEVELOPMENT CORPORATION LIMITED

P. & N.G. PERMITS 5266 & 5267

SCALE IN MILES

1 0 1 2 3





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P. & N.G. PERMITS 5266 & 5267

SCALE IN MILES

1 0 1 2 3

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P. & N.G. PERMITS 5266 & 5267

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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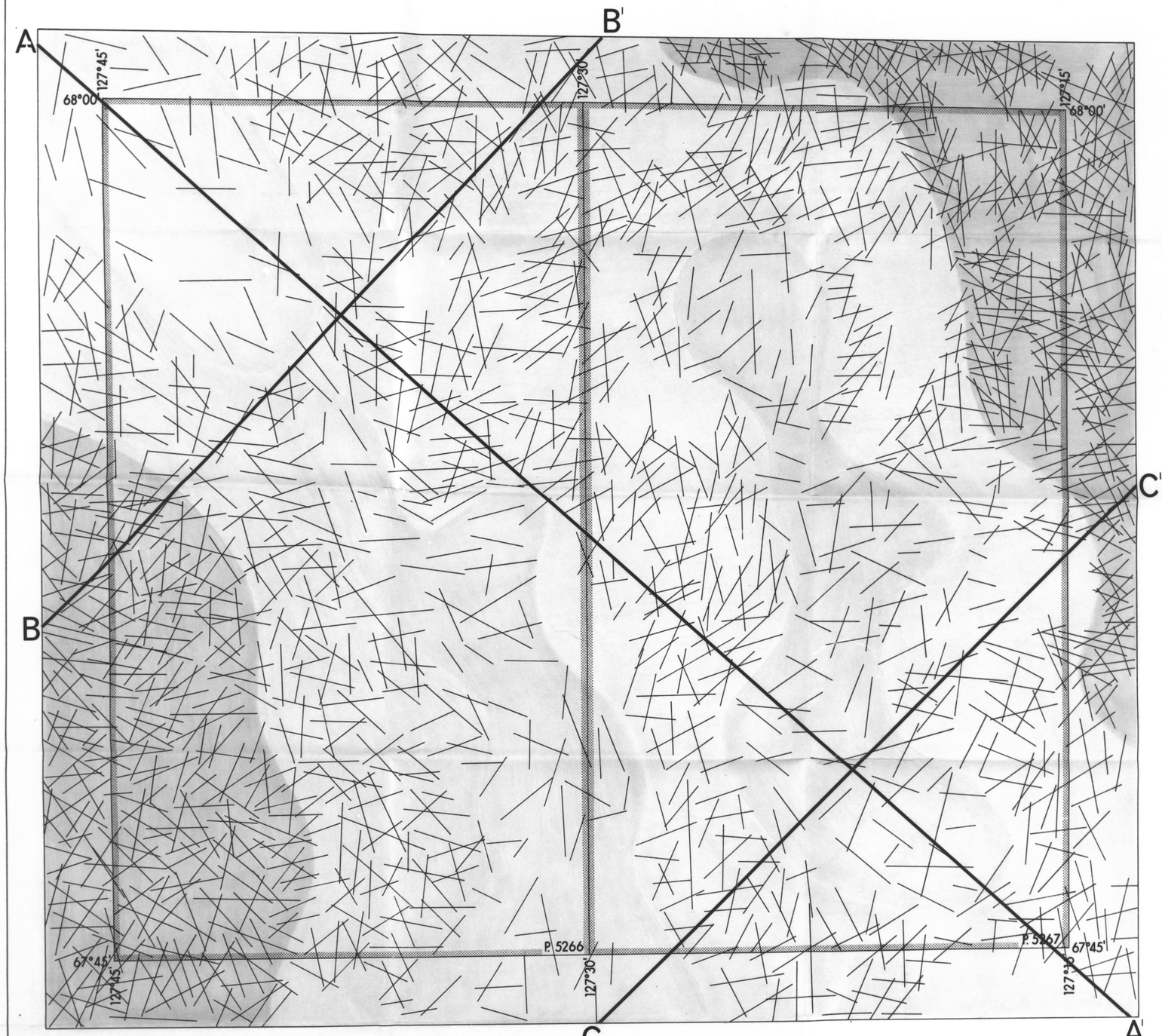
P. & N.G. PERMITS 5266 & 5267

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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P. & N.G. PERMITS 5266 & 5267
TOTAL FRACTURE PATTERN

SCALE IN MILES

1 0 1 2 3

LOW DENSITY

NORMAL DENSITY

HIGH DENSITY