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# A STATISTICAL STUDY OF BREAKOUTS IN OIL-WELLS IN ALBERTA

by

(C) CHRISTIAN KWAKU FORDJOR

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## ABSTRACT

Breakouts or preferred directional spalling along the walls of boreholes have been observed in many wells throughout the sedimentary basin in most parts of Alberta. Many studies have been carried out into the possible cause of this phenomenon. In this study, data focussing on the relationship of breakouts with depth, rock types and age of the rocks have been investigated in 50 wells scattered through most parts of Alberta plus one well in British Columbia. A regression of breakout azimuths on depths shows regression coefficients not significantly different from zero. Furthermore, it has been noted that breakouts have no relation with the rock types and the age of the rocks. The breakout azimuths in a well are tightly grouped around a mean direction which, in most cases, is NW-SE.

These observations and other evidences lead to the conclusion that breakout formations are better explained by the stress concentration at the walls of the boreholes, rather than the result of the drill encountering pre-existing fractures or zones of weaknesses. From this conclusion, the orientation of the smaller horizontal principal stress is NW-SE and the larger horizontal principal stress is NE-SW. The consistency of the breakout azimuths with depth, wherever these phenomena are observed, may imply that such large horizontal principal stresses are not necessarily limited to the top crustal sedimentary rocks but may be continued down into the deep and older

Precambrian igneous rocks of the Earth's crust.

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I also wish to thank Dr. J.S.Bell of B.P. Canada Ltd. for his cooperation in making raw data available to me. I must say that without Dr. Bell this thesis would not have materialised. I wish to thank also Mr. Ray Williams, Mrs. Elizabeth Kun together with other members of the Geological Services of B.P. Canada Ltd. for their assistance in gathering the data. I am indebted to Prof. Gough and Dr. Bell for permission to reproduce some of their figures, and I am particularly grateful to Dr. E. Nyland and Dr. E.R. Kanasewich for their kindness to me.

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C. K. Fordjor

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# I. THE PHENOMENON OF ALIGNED BREAKOUTS AND ITS MEANING

The primary purpose of borehole dipmeter surveys is to determine magnitudes and azimuths of dips of bedding planes from observations in a single hole. Prior to such surveys, the subsurface structural picture was determined primarily from seismic sections and correlation of marker horizons between three or more wells not drilled on a straight line. Unfortunately, geophysical surveys normally cover large areas and are good for determination of average regional dips but give poor resolution of local dip variations. In a like manner dip determination of marker horizons from correlation is valid only if the bed used is truly a plane surface and continuous between wells.

About 1970 the **Four Arm Dipmeter** (also known as **The High Resolution Dipmeter, HDT**) began to supersede the three arm type of tool. This thesis is largely concerned with oil-wells of non-circular section. Figure 1 reveals that the HDT is capable of determining two different diameters of a non-circular hole and their azimuths, whereas the three arm instrument cannot do this.

In the four arm dipmeter shown in Figure 2, the four arms are azimuthally spaced 90° apart. Each spring loaded arm carries a pad of electrodes which enables the electrical resistivity of the rock near the electrodes to be recorded. The four correlation curves in Figure 3 show typical resistivity variations which enable beds to be recognised and correlated. A plane can be fitted to the four depth

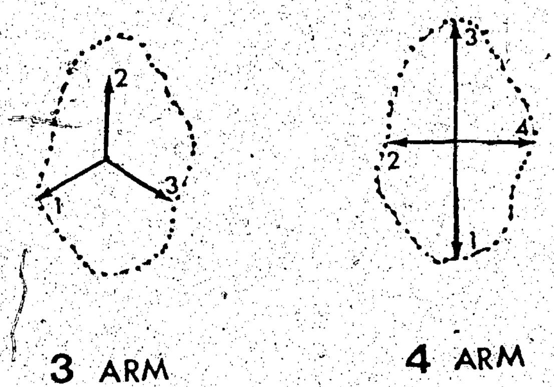


Figure 1.... Possible positions assumed by 3-arm caliper and 4-arm dual calipers in the same elongated hole. (schematic)

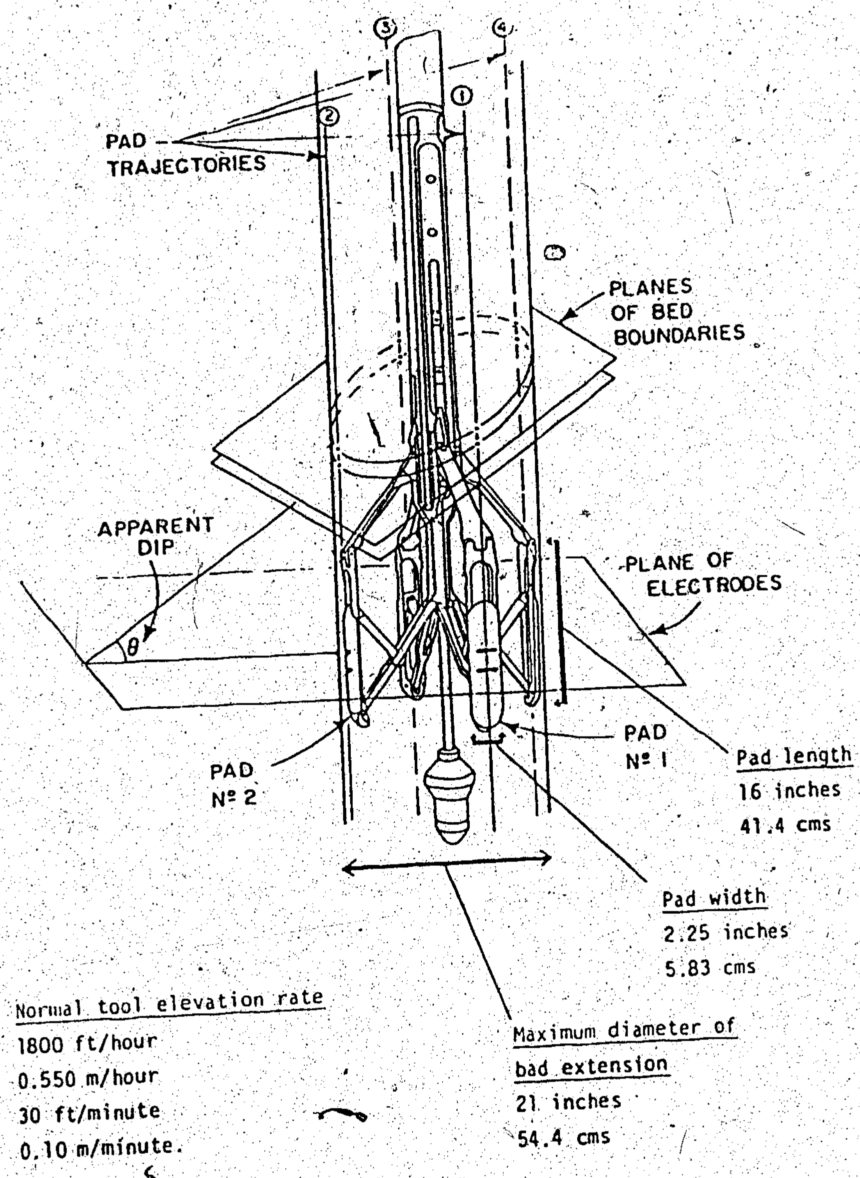


Figure 2.... Schlumberger 4-arm dipmeter tool.(courtesy of J. Cox)

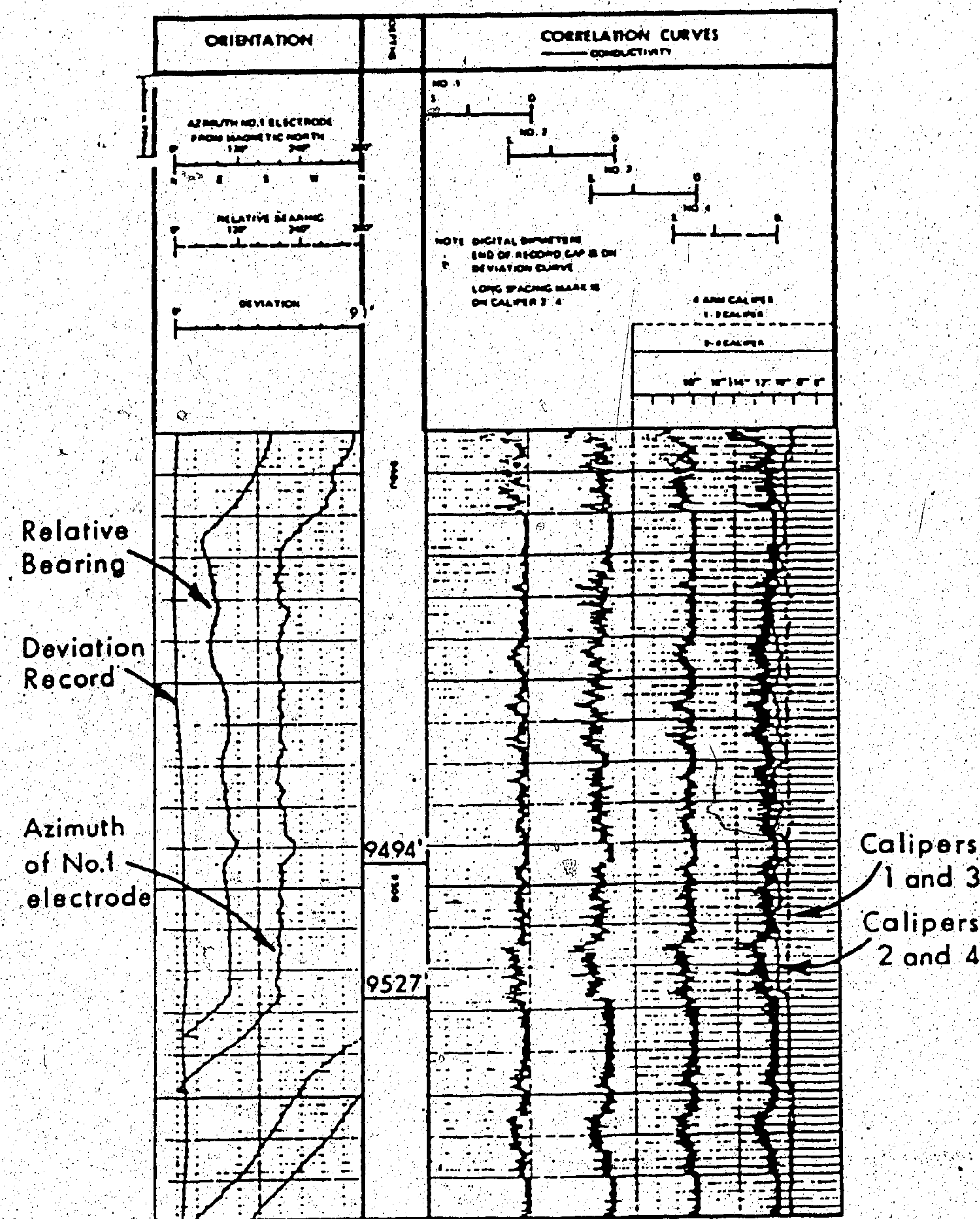


Figure 3.... Typical 4-arm dipmeter log record

values for a bed to give its dip in magnitude and direction. Resistivity changes on only one or two electrode pads may assist in identifying fractures as is illustrated schematically in figure 4.

Traces not yet discussed in figure 3 are of principal interest in this study. On the far right the two orthogonal diameters indicated by opposed pairs of calipers are recorded. These provide information concerning the shape of the borehole. On the left we require the trace which shows the azimuth of No.1 electrode, relative to a magnetic compass housed in the tool. Other traces on the left are;

1. The nearly vertical line which shows the deviation from verticality on a common scale from 0° to 9°.
2. A dashed line which runs diagonally or rotates as the tool is drawn up in the circular portions of the hole. This line ceases to rotate on encountering an elliptical zone and gives the relative bearing of the tool on a scale of 0 to 360 degrees with respect to azimuth of **No.1** elctrode. From this the bearing of the hole drift can be calculated.

The tool normally rotates as it is drawn up the well and in many depth ranges the calipers will indicate essentially equal diameters equal to the drill-bit diameter. This can be seen in the bottom and top sections of figure 3. It is observed, however, in other depth ranges that the tool ceases to rotate and the calipers indicate different diameters. This is the result of extensive fracturing

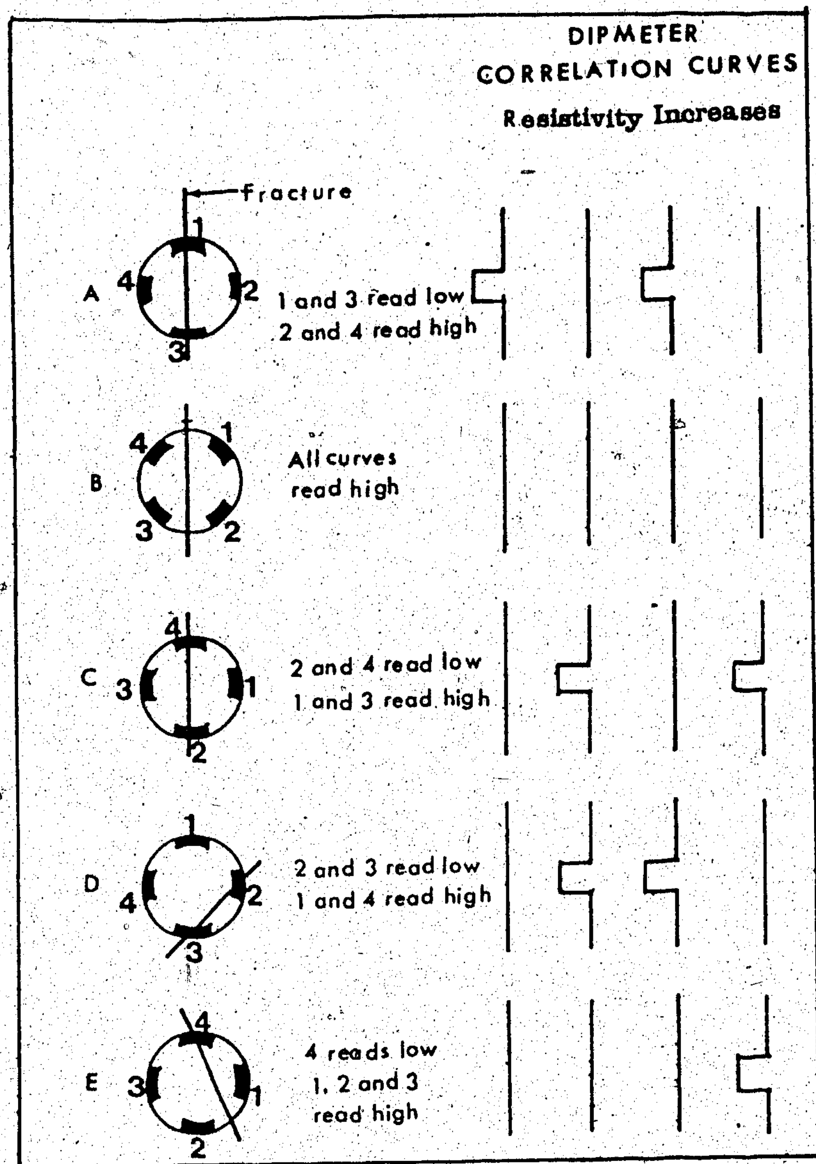


Figure 4.... Responses of HDT correlation curves to vertical fractures. (schematic)

causing the borehole to spall and wash out on opposite sides, thus becoming elliptical. Usually the smaller diameter is equal to the drill bit. This condition has been named by Babcock (1978) a **BREAKOUT**, and is illustrated in figure 5 D. Other situations encountered in a borehole are also shown in figures 5 A to C. In Figure 5 D one pair of calipers has become trapped in a locally elongated section of the hole. The orientation of the breakout can be estimated from the azimuth of the trapped caliper pads. In Figure 3, a breakout is shown between depths 9418 and 9527 feet. Calipers 2 and 4 (solid diameter line) indicate the greater diameter and the stationary azimuth trace shows No.1 electrode near 200°. The azimuth of the long axis of this breakout is near 200-90=110° relative to the magnetic north. The final orientation is 110° plus the magnetic declination.

The success of the HDT in determining sedimentary bedding planes has led to an extensive use of this tool in many areas, starting from the West Texas Ellenberger play in 1969, the cretaceous of North Louisiana and Mississippi and also in the limestone of the Mooringsport of the Waveland field of Mississippi.

During the interpretation of Schlumberger 4-arm dipmeter logs wells in Alberta, Cox (1970) observed that through the Wapiabi shale (a predominantly dark gray shale of both Colorado and post Colorado age in the upper cretaceous period) interval of the Strachen-Ricinus area (see Fig. 16 shaded portion) of West Central Alberta

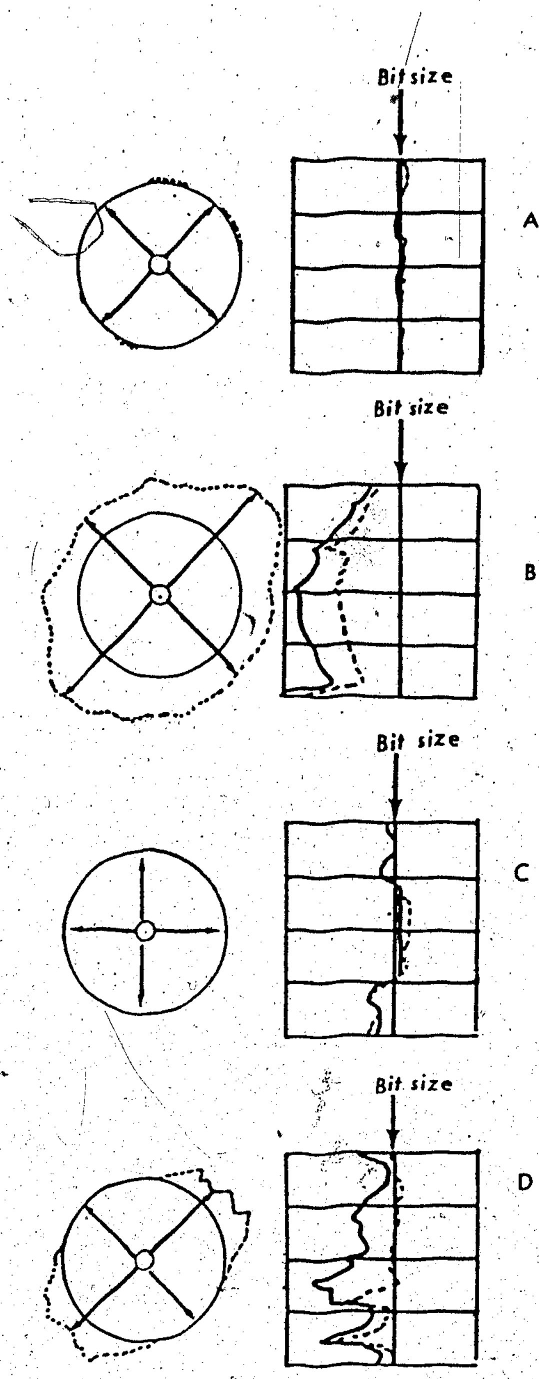


Figure 5.... Dual-caliper response to possible conditions of borehole shape.

adjacent to the Rocky Mountain foothills, where the borehole was not at bit size it was always elongated in the northwest-southeast direction. Structural dips were usually northeast or southwest. Nevertheless, several wells in this area in which structural dips were differently oriented showed the same northwest-southeast elongation. This observation led Cox to make a broader statistical study of 4-arm dipmeter logs in 31 zones from 17 wells scattered about Alberta and the North West Territories.

This new study ranged from Cretaceous shales to Devonian carbonates, in which dip values ranged from 0° to 30°. The orientation of the long axes of the holes had an average direction of N47°W to S47°E. A few elongations formed another group perpendicular to this major trend (Fig. 6 A). That the dip direction is not a controlling factor for the hole elongation is shown in figure 6 B.

An interesting feature of these elongations observed by Cox (1970) was that they were confined to discrete depth intervals within a hole and separated by uncaved beds. This observation led Babcock (1978) to suggest that the elongation might be caused by the drill encountering zones of steeply dipping fractures. Babcock later undertook a study of the phenomenon of hole elongation using the caliper portion of the 4-arm dipmeter logs, and extending his investigation to 23 wells in various sedimentary rocks widely distributed through Alberta.

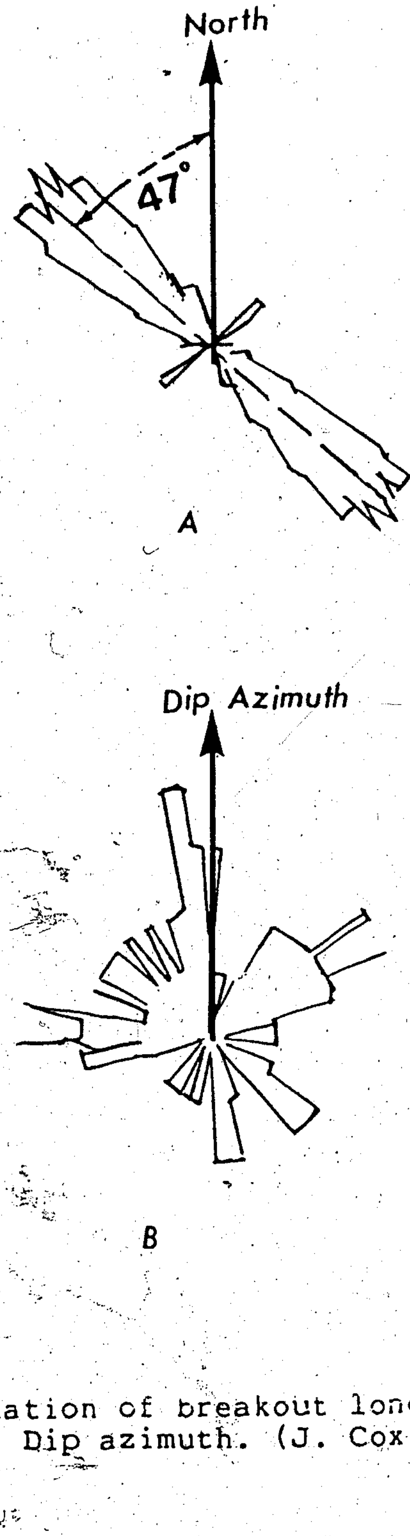


Figure 6.... Orientation of breakout long axis with respect to (A) North and (B) Dip azimuth. (J. Cox, 1970)

He noted the following properties of breakouts

1. The breakout zones may be short discrete events, or may persist over depth intervals of several tens or hundreds of feet.
2. A breakout of 2 to 4 feet commonly slows down the tool rotation or may have no noticeable effect on rotation; whereas a longer breakout is commonly associated with a cessation in the rotation of the tool.

To explain his observations, which were consistent with Cox's (1970) observations, Babcock turned to his study of the regional jointing in exposed bedrock of the Alberta plains and in the Fort McMurray area of northeast Alberta (Babcock, 1973,1974,1975). Within this area two orthogonal joint systems made up of vertically dipping extensional fractures are present. System 1 has sets striking northeast and northwest roughly normal to and parallel with the Rocky Mountain Belt. The northeast striking set is dominant in the sense that it is most commonly developed in that joints of this set usually cut across joints of other sets, which terminate against them. A second joint system (System 2, Babcock, 1973) having sets striking roughly North-South and East-West was also observed. This system was common in the Fort McMurray area and in the southernmost part of Alberta and occurred elsewhere in the province. These two joint systems were reported (Babcock, 1973) in nearly flat-lying sedimentary rocks ranging from late Devonian to Paleocene in age, in outcrops of shales, siltstone, sandstone, limestone dolomite and coal distributed through many thousands of square kilometers and several thousands of meters of the stratigraphic column. Out of a total of 1,236 nearly vertically dipping joints measured, Babcock observed that although joint sets were well defined at most stations, set directions between stations varied considerably. Nevertheless, the sets striking northeast and northwest were most developed.

Regions covered by Babcock in his study of breakouts included the Claresholm district. Here he compared the joint azimuths measured at 10 outcrops and the azimuths of elongations from five wells. The mean directions of the elongations he observed showed a variation in strike ranging from 129° to 155.5°, thus corresponding closely to the northwest-southeast striking joint set. However, the elongations showed much less variability than do the strikes of individual joints of the northwest striking set in the area. A comparison of all azimuths of elongation (41 in all) with that of all joint strikes (1,236) in the area is shown in Figure 7. Clearly there is no close correspondence as a result of the predominance of one joint set striking at approximately 175° (North-South), which falls under Babcock's System 2.

Similar comparisons were made by Babcock in his Red Deer study between 400 azimuths of joints in bedrocks and 67 breakout elongations in nearby oil wells. Here, however, joint sets belong to the System 1 and the dominant direction

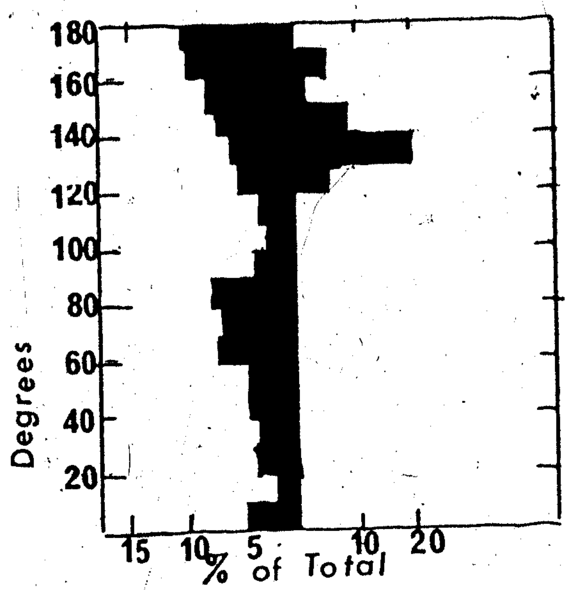


Figure 7.... Histogram comparing (left) strikes of 1,236 joints measured at 10 outcrops in Claresholm region, southwest Alberta, with (right) azimuths of 41 elongated breakouts from five wells. (Babcock, 1978)

of hole elongation was northwest-southeast at about 140 °.

Babcock's study of 23 wells scattered throughout Alberta led him to draw the following conclusions,some of which had been made by Cox (1970):

1. In most of the 23 wells studied, the breakouts are in the northwesterly direction. However, in some wells a small number of breakouts may follow a northeast trend.
2. The azimuths of elongation are parallel to well developed sets of regional joints which are present wherever joint directions have been studied.
3. Hole deviations from verticality, changes in the magnitudes and directions of bedding dips, and lithology are unrelated to breakouts.
4. The preferred orientation of breakouts could not be the result of the drill encountering vugs because this would lead to hole elongations with no preferred orientation.
5. Babcock further stated that through his informal discussion with engineers involved with hydraulic fracturing and from consideration of the tectonic setting, the inferred direction of intermediate stress in rocks of the Alberta plains is normal to the trend of the Rocky Mountain Belt or roughly Northeast Southwest and the maximum stress is vertical, with the minimum stress direction inferred to be Northwest Southeast parallel with the dominant azimuth of hole elongation.

From these general conclusions Babcock finally concluded that the breakouts occur as a result of the drill encountering steeply dipping fractures or zones of steeply dipping fractures, which may or may not be open. The oversize holes in carbonate rocks he related to solution-widened joints.

Bell and Gough (1979) found Babcock's hypothesis for the cause of breakouts very difficult to accept. Their most serious objection was the fact that the azimuthal distribution of breakouts is very unlike that of joint sets at the surface. They argued that given four concentrations of joint directions on the surface (Babcock 1973) NW, NE, N, and E, they would expect concentrations of breakout azimuths in all the four directions on Babcock's hypothesis, rather than only one significant concentration of subsurface breakout direction (NW).

Secondly, Bell and Gough wondered if such surface joint directions would necessarily be parallel to those at depths extending beyond 2 km at which breakouts have been observed. In this connection they remarked that sediments involved in the study in the Alberta Plains were laid down in varying tectonic settings between Devonian and Cretaceous times; and furthermore joints may arise in several ways after deposition of sedimentary rocks.

In an attempt to find an interpretation that would account for both the breakouts in the wells and the surface joints, System 1 of Babcock, Bell and Gough (1979) proposed that both features result from a general stress field acting throughout the Alberta Plains and oriented with the larger principal horizontal stress NE-SW and the smaller of the two horizontal stresses parallel to the Rocky Mountain fold axes. Using the Kirsch equations for the stress near a circular hole, in a medium under biaxial stress, they argued that with large enough, unequal horizontal stresses oriented as above, the holes themselves could concentrate the stresses so as to produce subsurface breakouts with long axes in the NW-SE direction. Such concentrations of stress are believed to arise at the time of drilling.

If the breakouts in Alberta are shear fractures caused by the concentration of stress at the walls of the borehole as proposed by Bell and Gough (1979), the larger horizontal compression is orthogonal to the azimuth of the breakouts and hence nearly Northeast-Southwest in Alberta. Their hypothesis provides no indication of the magnitudes of the principal stresses other than the fact that the horizontal principal stresses are large and unequal. Gough and Bell (1982) have recently made a quantitative study of shear fracturing near a borehole, and have shown that such fractures can form breakouts with the observed properties.

Stress measurements in mines in several continents reveal that the vertical principal stress approximates (within 20% or less in most cases) the overburden pressure (McGarr and Gay, 1978). Furthermore, the proximity of the thrust faults of the Rockies to areas covered in the studies by Cox (1970) and Babcock (1978) coupled with the fact that the Rockies are fold mountains led Bell and Gough (1979) to suggest that a situation with $S_1$ (the maximum principal stress) vertical ( a normal-fault stress field) is most unlikely in Alberta.

This fact is further strengthened by the occurence of breakouts at depths of 500 meters or less. Laboratory experiments by Gay (1973) indicate that the threshold pressure for spalling in a circular hole under equal orthogonal pressures is about 100 MPa. With unequal pressures, however, spalling would be expected with the larger compression around 30 MPa. But at a depth of 500 m the overburden pressure will be about 12 MPa. If $S_1$ is vertical then both $S_2$ and $S_3$, which are horizontal, will be smaller than this value (12 MPa) and may be too small to produce shear fractures. This now leaves us with either a thrust fault or a strike-slip (wrench) fault stress field. Bell and Gough's hypothesis fits either of these two stress fields and the breakouts are consistent with either case. It is worth noting that the breakouts alone cannot reveal which of the two stress situations prevails in Alberta.

In a later paper, Gough and Bell (1981) added additional wells in Alberta to their study of breakouts. They also extended the area covered into northeastern British Columbia. In addition results from hydraulic fracturing in an oil field in West-Central Alberta were discussed. They suggested that some local anomalies in breakout orientations might represent local variations in the stress field.

Lo and Morton (1976) attributed failures of tunnel roofs in Ontario to interaction of the tunnel with large horizontal compressive stresses transverse to the tunnel. Dusseault (1977) suggested that unequal horizontal compressive stresses prevail in several areas in Alberta, to account for the propagation of vertical fractures during hydraulic fracturing in Northeast-Southwest vertical planes. Such fractures imply a horizontal least principal stress ($S_3$)directed Northwest-Southeast. The formation of tensile fractures normal to $S_3$ during hydraulic fracturing was first proposed by Hubbert and Willis (1957). This leads to the expectation that in a thrust stress field ($S_3$ vertical) hydraulically formed fractures will be horizontal (Kehle, 1964). This is difficult to verify in many cases, because horizontal fractures are hard to detect. Zoback et al (1977) argue that the inflatable packers inhibit such horizontal fractures, and that horizontal fractures form only if fluid penetrates pre-existing planes of weakness. This contention is supported by laboratory experiments by Haïmson and Fairhurst (1970). Haimson (1976b) suggested that if $S_V = S_3$ then the induced fractures initiate in a vertical plane and then become horizontal as they propagate based on the fact that energy propagates along the path of least resistance. This can be observed in the pressure-time history where the asymptotic shut-in pressure is smaller than the instantaneous shut-in pressure. In such a situation the instantaneous shut-in pressure is not equal to the least principal stress but rather the smaller horizontal principal stress with the asymptotic shut-in pressure being equal to the least principal stress $S_3$.

In the J Lease of the Pembina Oilfield, Macleod (1977) noted during secondary oil recovery from Cardium Formation sandstone that permeability was greatest in the Northeast-Southwest direction. This observation implied either a fracture system or else a permeability trend oriented Northeast-Southwest. But Neilson (1957) showed the isopach axes in this formation and area to be trending Northwest-Southeast. Thus one would expect a permeability trend related to the process of deposition to run NW-SE. Gough and Bell (1981) therefore concluded that Macleod's observation could be better explained in terms of vertical fractures oriented NE-SW, which would imply a NW-SE orientation of $S_3$. Six wells logged with the HDT in this area were identified and studied by Gough and Bell. The breakouts occur in rocks of Paleozoic ages over depths from 2500 to 4500 meters. Azimuths of hole elongation were tightly grouped with mean values ranging between 132° and and 141°, with variations over approximately 20° in individual wells.

Imperial Oil in 1978 published information on their Cold Lake projects in far eastern Alberta. Induced vertical fracture orientations varied from N 30° E to N 45° E implying that the minimum principal stress was horizontal in this region and oriented between 120° and 135°. The larger horizontal stress would then lie between 30° and 45°. Imperial Oil ran no HDT logs in wells in the Cold Lake region (J.S.Bell, personal communication with the Company). However, Gough and Bell (1981) located one well in this region logged by the HDT. The azimuth of a single breakout, at depth 477 to 479 m in the Clearwater Formation, was 131° suggesting the major horizontal stress direction of 41°. Recently, Gough and Bell (1982) have reported comparisons of breakout azimuths in Colorado, in East Texas and in northwestern Canada with other indications of stress orientations in those regions. In every case the observations support their explanation of breakouts as a consequence of stress concentration by the borehole in an anisotropic stress field. The hydraulically induced fractures at West Pembina and at Cold Lake indicate a strike-slip type stress field ($S_1$ and $S_3$ horizontal, $S_2$ vertical) is most likely present in most parts of Alberta.

This thesis reports a study of the statistics of the azimuthal distribution of breakouts in oil-wells in Alberta in relation to depth, lithology, formation and age of rocks, together with the geophysical implications of breakouts.

# II. STRESS AND FRACTURE IN THE EARTH'S CRUST

## STRESS

If one considers a simple prism of cross-sectional area a subjected to a force **F**, as shown in Fig. 8, the stress $S_Z$ acting on the end surface ABCD is given by

$S_Z = F/a$ ---------------------------------------------------------2-1

It can be seen that the force **F** has no component acting parallel to the ABCD surface. This means it exerts no shear stress on this surface. By definition, any stress acting perpendicular to a surface along which the shear stress is zero is a principal stress. Thus in this case $S_Z$ is a principal stress. Here, the suffix indicates the direction in which the stress acts. Other principal stresses may be orientated parallel to the X- and Y- axes, and would be designated $S_X$ and $S_Y$ respectively. If the relative intensities of the principal stresses are known, they may be termed the maximum (or greatest), intermediate and minimum (or least) principal stresses (i.e. $S_1$, $S_2$, $S_3$ respectively).

If one considers the action of the force **F** on a surface GHIJ inclined at an angle Ø as shown in the Figure 8, the component of **F** acting normal to GHIJ is given by,

$F_n = F.\sin\emptyset$.

However, it will be seen that the area a' of GHIJ is greater than the area a of ABCD, and that

$a' = a/\sin\emptyset$ .

Therefore, the normal stress $S_n$ acting on the inclined

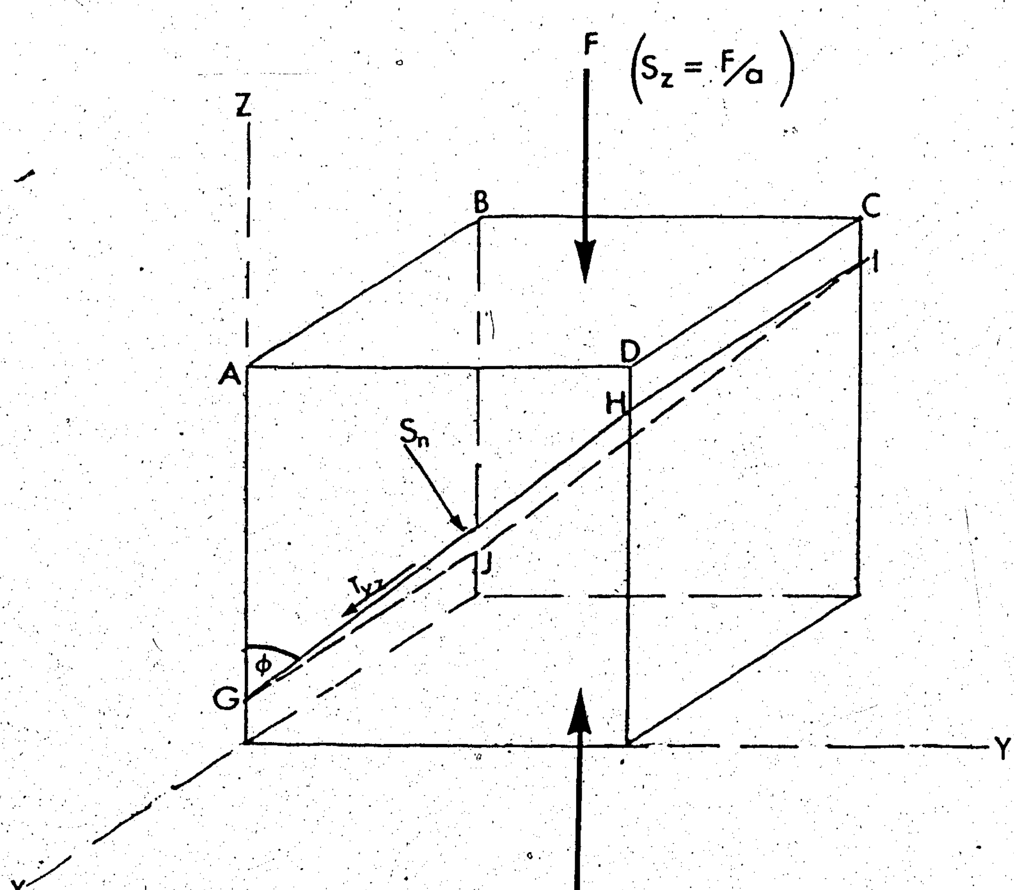


Figure 8.... Normal and Shear stresses acting on external and internal surfaces of a unit cube subjected to a force

surface is

$F_n/a' = F.\sin\emptyset/a' = (F/a).\sin^2\emptyset$

so that

$S_n = S_z.\sin^2\emptyset$ ---------------------------------------- 2-2

Similarly the component of F tangential to the inclined plane is given by

$F_t = F.\cos\emptyset.$

Consequently the shear stress (T) acting along the plane equals

$F_t/a' = F.\cos\emptyset/a' = (F/a).\cos\emptyset.\sin\emptyset$

that is

$T = S_z.\cos\emptyset.\sin\emptyset$ ---------------------------------------- 2-3

Shear stresses as well as other stresses may be related to co-ordinate axes. We denote by $T_{zy}$ the shear stress on yz-planes acting parallel to the y-axis. Similarly $T_{zx}$ denotes a shear stress acting in the zx-planes parallel to the x-axis. The stress across a plane whose normal is in the y-direction will have components $T_{yx}$, $S_y$, $T_{yz}$ and that across a plane whose normal is in the x-direction will have components $S_x$, $T_{xy}$, $T_{xz}$. The nine quantities below

$$\begin{matrix} S_x & T_{xy} & T_{xz} \\ T_{yx} & S_y & T_{yz} \\ T_{zx} & T_{zy} & S_z \end{matrix} \qquad \text{-------------------- 2-4}$$

are called the stress components and give a complete specification of the stress at a point. It can be shown that $T_{yx} = T_{xy}$, $T_{yz} = T_{zy}$ and $T_{zx} = T_{xz}$, so that only six quantities out of the nine are needed to specify the stress at a point.

The stress components in Eqn.(2-4) are in fact the components of a mathematical entity called a tensor,(and tensor analysis is much used in developing the higher parts of the theory of elasticity where x,y,z, are replaced by 1,2,3, respectively). A tensor in which $T_{xy} = T_{yx}$, $T_{yz} = T_{zy}$, $T_{xz} = T_{zx}$ is said to be symmetric.

In a biaxial stress field it can be inferred from Eqn. (2-2) and Eqn. (2-3) that the stresses acting normally and tangentially to a plane inclined at Ø to $S_1$ and hence (90+Ø) to $S_3$ will be represented (on superposition) by

$$S_n = S_1 . \sin^2 Ø + S_3 . \cos^2 Ø$$

and

$$T = (S_1 - S_3) . \sin Ø . \cos Ø \quad \text{------} 2\text{-}5$$

which can be written in terms of the double angle 2Ø as

$$S_n = (S_1 + S_3)/2 - ((S_1 - S_3) . \cos 2Ø)/2 \text{ and}$$

$$T = ((S_1 - S_3) . \sin 2Ø)/2 \quad \text{------} 2\text{-}6$$

Equation 2-6 may be represented graphically by means of Mohr's stress circle, which will be discussed later in this chapter.

Subsurface rocks are normally in a state of compressive stress except very near the surface because of the weight of overlying rocks. This overburden weight creates stresses in both the vertical and horizontal directions. The stress field at a point can be represented by $S_1$, $S_2$, $S_3$ as already defined. Over long periods of geologic time the earth has exhibited an appreciable degree of mobility during which rocks have been repeatedly stressed to the limit of failure to produce faulting and folding. The problem of rock squeeze (i.e. continuous deformation of the rock) has been recognised in parts of the crust. In Southern Ontario structures built in rocks have exhibited distress in various degrees during or subsequent to construction (Lo, 1978). Geological processes such as faulting,folding, and pop-ups or buckling of the surface rock strata, without any apparent change of external loading, may be interpreted as evidence of existence of high horizontal stresses. In a study of geological features and movements of structures in rock in New York State, Rose (1951) associated the rock squeeze with the possible existence of high horizontal in-situ stress in the rock formations. Such phenomena require that substantial differences must exist between the principal stresses. Sbar and Sykes (1973) have used information from postglacial geologic features such as east-west rock squeeze in western New York and Niagara, and bridge abutments moving together to infer that the maximum compressive stress in this area has an easterly trend. Postglacial buckles or pop-ups near Chippewa Bay, New York have also been ascribed by Sbar and Sykes as not due to any environmental factors other than large horizontal compressive stresses. Pop-ups have also been encountered elsewhere in western New York where the lithostatic load has been reduced by quarrying (Sbar and Sykes personal commun. with J. Davies, 1972). Deformation indicative of a high horizontal compressive stress was also observed in various parts of Ontario (Coates, 1964), where a pop-up about two and one half meters high, striking northwest, occurred overnight in a quarry after it had been excavated to a depth of 15 meters. Finally the results obtained from geologic features, in-situ stress measurements and earthquake distributions in eastern and central North America may be related to the presence of high stress.

The orientation of the trajectories of the principal stresses in space is largely determined by the condition which they must satisfy at the earth's surface. This is a free surface, on which normal and shear stresses vanish. Since the only planes on which the shear stresses are zero are those perpendicular to the principal stresses, it follows that one of the three trajectories of principal stress must end perpendicular to the surface of the ground, and the other two must be parallel to this surface. Therefore, in regions of gentle topography with simple geologic structures the principal stresses should be nearly horizontal and vertical, with the vertical stress approximately equal to the pressure of overlying material. Measurements of stress in mines in several continents show that in many cases the vertical normal stress is, within about 20%, equal to the overburden pressure $S_V = \rho . g . h$, where $\rho$ is the density of the material, g is gravity and h is the depth. If the lateral stress were due solely to elastic response of the rock $S_V$, the horizontal principal stresses would be $S = s = \nu/(1-\nu) . S_V = S_V/3$ where $\nu$ is Poisson's ratio. Such a stress field would produce normal faults at any depth at which the stress difference exceeded the strength of the rock. However, observations in underground structures, quarries and hydraulic fracturing in boreholes indicate that the horizontal stresses S and s S>s are not generally equal and do not vanish close to the surface, a necessary consequence if the horizontal stresses were due simply to elastic response of the rock to overburden pressure.

Measurements in several continents of in-situ stress in rocks show that in many cases the horizontal stresses are much higher than the vertical stress calculated from the overlying weight of the rock (McGarr and Gay, 1978 ; Hast, 1973; Herget, 1974). Frequently the horizontal stresses S and s increase linearly with depth. It is thus evident that large and unequal horizontal principal stresses are widespread in the continental crust of the earth.

**Relationships Between Principal Stresses at Failure**

Most substances behave elastically at low stresses. As the stress is increased the body will begin to yield at some point if it is ductile, while if the body is brittle it will fracture at some point without appreciable yielding. The term fracture implies the appearance of distinct surfaces of separation in the body and yield is used for the onset of plastic deformation. Flow is used for unrestricted plastic deformation. Both flow and fracture (also known as failure) are observed on large and small scales in geologic material so that the criteria for them are vital for the interpretation of geologic phenomena.

For brittle materials in tension, *tensile or cleavage* fracture takes place across a surface perpendicular to the direction of tension (Fig. 9 A). For brittle materials in compression, shear fracture takes place along a pair of planes or a cone approximately in the direction of the greatest shear stress but always between this direction and the direction of the largest compressive stress ( Fig. 9 B). The maximum shear stress theory, which dates back to Coulomb (1773), states that failure occurs at a point when the maximum shear stress is equal to the shear strength of the material. If $S_1 \geq S_2 \geq S_3$ are the principal stresses at a point, taking compressive stress positive, the maximum shear stress has magnitude $(S_1 - S_3)/2$ , and occurs across a plane containing the direction of $S_2$ and whose normal bisects the angle between the greatest and least principal stresses. The theory implies that if $C_0$ is the compressive strength of the material in an unconfined compression test in which $S_3 = S_2 = 0$, $S_1 = C_0$, the material will fail across any plane inclined at 45° to the direction of compression for a frictionless material. For real materials the angle is less than 45°. The theory also implies that the tensile and compressive strengths are equal. The theory has been modified by Navier to fit qualitatively most of the observed facts, and is used by Anderson in a discussion of the types of geological faulting. In this modification, instead of assuming that fracture takes place across the plane over which the shear

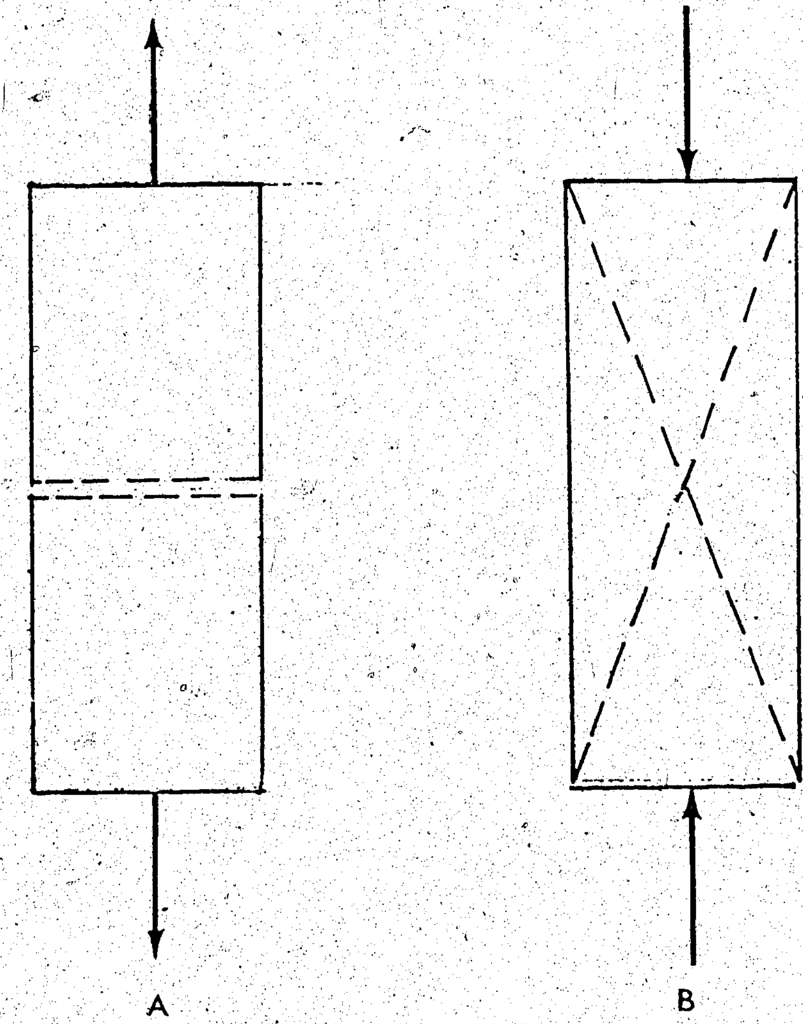


Figure 9.... Failure of a brittle material.(A) Tensile fracture and (B) Shear fracture

stress first becomes equal to the shear strength $S_0$ of the medium, it assumes that this shear strength is increased by a constant u times the normal pressure across the plane. Because of the analogy to ordinary friction in which the tangential force is u times the normal reaction, u is known as the coefficient of internal friction. Thus, if $S_n$ and T are the normal and shear stresses across a plane, fracture takes place on the plane at which the magnitude of T first becomes equal to $S_0 + u.S_n$. Therefore,

$$|T| = S_0 + u.S_n \quad \text{------------------------------------- 2-7}$$

This is the Navier-Coulomb criterion for shear failure. Let us discuss the case of two dimensions first. If $S_1$, and $S_2$ are the principal stresses, we can then write Eqn. (2-6) as

$$S_n = (S_1+S_2)/2 + (S_1-S_2)\cos2\phi/2$$

$$T = (S_1-S_2).\sin2\phi/2 \quad \text{---------------------------------- 2-8}$$

Only values of $\phi$ between 0 and 90° need be considered, since only the magnitude of T occurs in Eqn. (2-7), so that changing the sign of $\phi$ only changes the sign of $\sin2\phi$ and does not affect the magnitude of $S_n$ or T. The shear stress at failure is thus symmetrical about $\phi=0$. It can be shown that failure takes place across a plane whose normal makes $\phi$ with $S_1$ where $\tan2\phi = 1/u$. If u=0, then $\phi=45°$; if u=1, $2\phi=135°$ and $\phi=67.5°$; if u---> infinity, $\phi$-->90 that is as u increases the plane of fracture moves towards the direction of maximum stress. Values of u of the order of 1 are inferred from the directions of fracture of rocks in testing machines, and also from geological faulting (Jaeger, 1956;

Price, 1973). It should be remembered that, because of the symmetry in Ø mentioned earlier, the theory leads to two possible planes of fracture equally inclined to the principal stresses and gives no reason for preferring either. For failure under combined stress in terms of the compressive and tensile strengths, $C_0$ and $T_0$ of the material, the relation

$$C_0/T_0 = (\sqrt{(u^2+1)} + u)/(\sqrt{(u^2+1)} - u)$$

holds. The theory predicts that the compressive strength of a material is always greater than its tensile strength but the ratio is rather smaller than that found in practice. The theory also predicts that under any conditions the normal to the plane of fracture makes the same angle arctan(1/u)/2, with the direction of greatest principal stress. Although this is approximately true for compressive stresses, it is very far from the truth in the case of pure tension when the failure is usually by brittle fracture with the plane of fracture normal to the direction of tension. The reason may be that $T_0$ should not be the actual tensile strength but the value at which shear failure in tension would take place if tensile fracture did not occur in practice before this value is reached. Nevertheless, the theory gives a reasonably accurate account of the behaviour of rocks under combined compressive stresses.

Mohr's representation of stress and failure is useful (Fig. 10). Mohr's theory assumes that at failure across a plane the normal and shear stresses across the plane, $S_n$ and

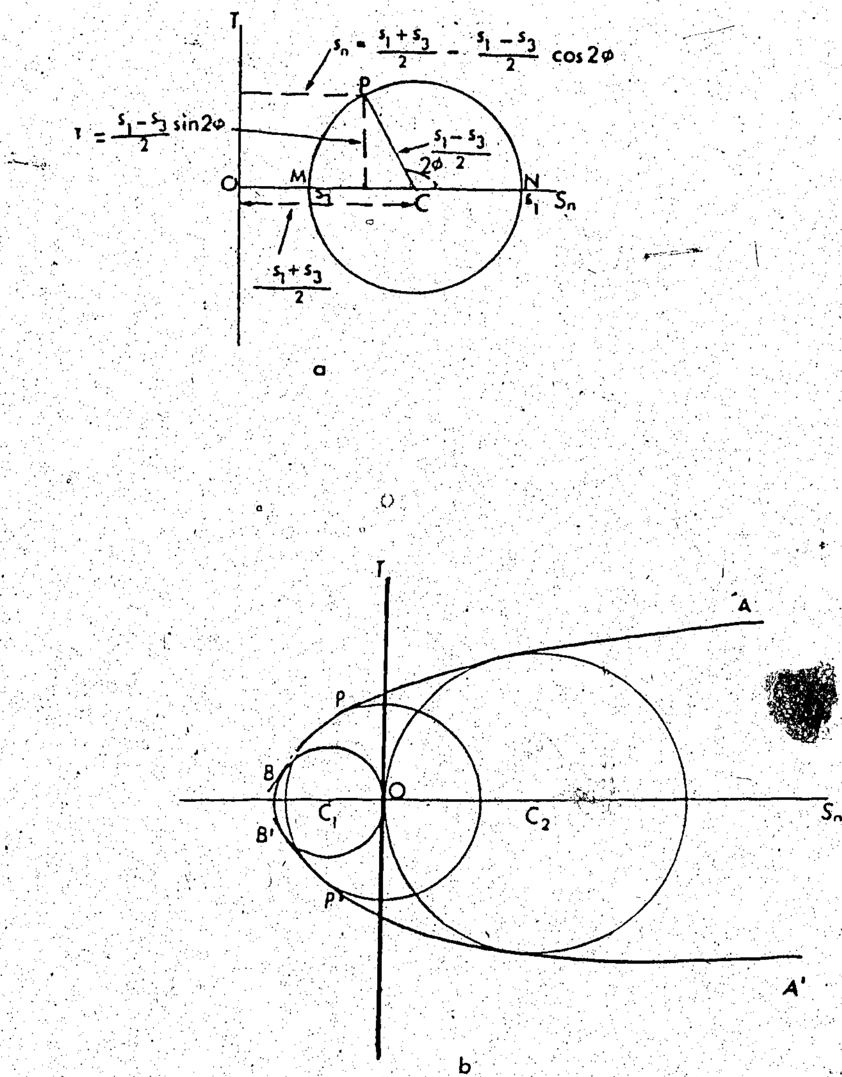


Figure 10.... Representation of stresses on any plane in a two-dimensional stress system by means of Mohr's stress circle.

T, are connected by some relation $T = f(S_n)$. This relation may be plotted on a ($S_n$, T) plane and since changing the sign of T simply changes the direction of failure but not the condition for it, the curve is symmetrical about the $S_n$-axis. Any state of stress can be represented by a Mohr circle on the ($S_n$, T) plane. In representing the normal and shear stress across a plane in a biaxial stress field on the Mohr's Stress circle, the normal stress $S_n$ and shear stress (T) are chosen as co-ordinate axes. Here the greatest principal stress $S_1$ and the least principal stress $S_3$ are represented by ON and OM respectively on the $S_n$-axis. The quantity $(S_1+S_3)/2$ of Eqn. (2-6) represents the mid-point C on the $S_n$ axis between M and N, while $(S_1-S_3)/2$ represents half the distance between M and N. If a circle is drawn with centre C and radius $(S_1-S_3)/2$, then for any specific values of $S_1$ and $S_3$, this circle represents the conditions of Equation 2-6 where $2\varnothing$ is measured as indicated in Fig. 10 a. This construction as we shall see is used in representing the values of shear and normal stresses at failure. If this circle lies wholly within the failure envelope ABA'B' in Fig. 10 b, the stresses involved nowhere attain the critical values. If any portion lies outside it the material could not withstand the stresses. Obviously, the limiting case is that of a circle such as those of centres $C_1$, O and $C_2$ which just touch the curves AB and A'B'. In this case failure will take place under stress conditions corresponding to the points PP', that is, over planes whose normals are inclined at angles of half the angle PCN (Fig. 10a) to the direction of the greatest principal stress. The curve AB will be the envelope of all the circles corresponding to all conditions at which fracture takes place and for this reason is known as the *Mohr envelope.*

In principle, three circles which touch the envelope can be found from simple experiments. These are those of centres $C_1$, Q and $C_2$ (Fig. 10 b), corresponding to tension, simple shear, and compression. But in practice it is difficult to perform shear or tensile tests on rock materials. An approximation to the Mohr envelope for many rocks, from results of triaxial tests, is the pair of straight lines

$$|T| = T_0 + u.S_n$$

corresponding to the Coulomb-Navier criterion for fracture under shear stress, where $T_0$ is the shear strength. In this case the normal to the plane of fracture makes an angle (in the second quadrant) arctan(1/u)/2 with the direction of the greatest principal stress. When applied to triaxial stress, the Mohr theory leads to the result that only the Mohr circles for the plane containing the greatest and least principal stresses need be considered and that fracture always takes place in planes containing the direction of the intermediate principal stress. This is not altogether consistent with the experimental results.

One important application of these results is the study of faults which are fractures of the rocks of the earth's crust (Fig. 11). Geologists distinguish three major types of faults and Anderson (1951) has shown that these are determined by the relative magnitudes of the principal stresses. One principal stress will always be vertical, and three cases arise according as this is the greatest, intermediate, or least principal stress. In the case where the vertical principal stress is the least in magnitude and the other two principal stresses are compressive (Fig. 11 A), the fault is known as a *thrust* fault. The planes of fracture pass through the direction of the intermediate principal stress and makes angles of less than 45° with the direction of the greatest compressive stress which is horizontal, (Fig. 11 B). This applies in regions of active tectonic compression or erosion or vertical unloading. When the intermediate principal stress is vertical, we have Figure 11 C. The failure can take place on either of two vertical planes (Fig. 11 D), which are equally inclined at angles of less than 45° to the direction of the greatest compressive stress. This type of fault is called a *transcurrent, wrench or strike-slip fault*. When the vertical principal stress is greatest as may often be the case at considerable depths, and in rift structures near the surface, the type of failure is called *normal faulting*. Here the faults make angles less than 45° with the vertical (Fig. 11 E).

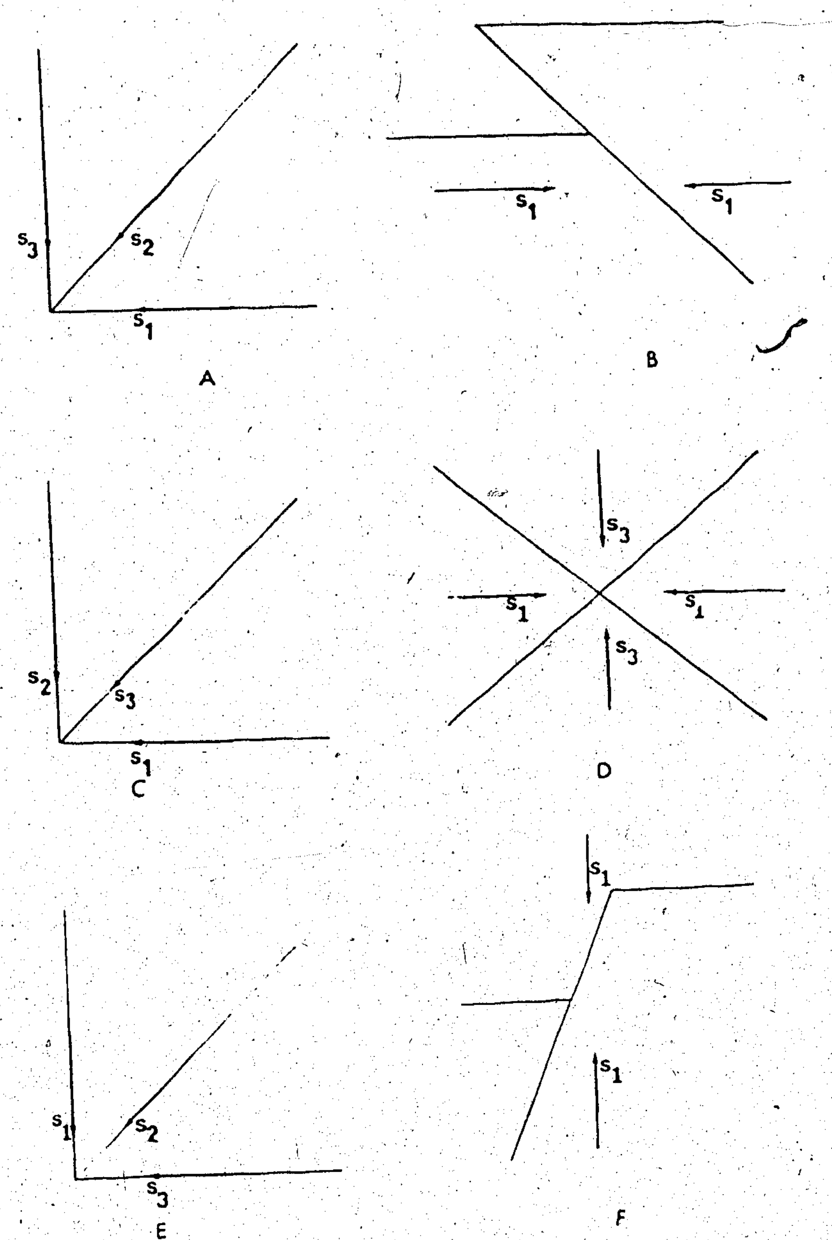


Figure 11.... Types of faulting in relation to the principal stresses; A and B, Thrust fault, C and D, Wrench fault, E and F, Normal fault.

Stress Concentration Caused by the Borehole

The presence of a borehole distorts the pre-existing stress field, because as discontinuities in the earth's crust, boreholes cause redistribution of stresses in the nearby rock. An approximate calculation of this distortion is made by assuming that the rock is elastic, the borehole smooth and cylindrical and the borehole axis vertical and parallel to one of the regional principal stresses. Kirsch (1898) found an analytic solution of the problem of the stress field near a small hole of radius a in a large plate under uniaxial compression S. The solution as given by Timoshenko and Goodier (1951) is given below.

Let Figure 12 represent a plate subjected to a uniform compression of magnitude S in the x-direction. If a small circular hole is made in the middle of the plate, the stress distribution in the immediate vicinity of the hole will be changed. However, by Saint-Venant's principle we know that the change will be negligible at distances which are large compared with a, the radius of the hole. Let us consider the portion of the plate within a concentric circle of radius b, large in comparison with a. The stresses at the radius b are effectively the same as in the plate without the hole and are therefore given from Equations (2-2) and (2-3) by

$(S_r)_{r=b} = S.\cos^2\emptyset = S/2.(1+\cos 2\emptyset)$

$(T_{r\phi})_{r=b} = -1/2\ S.\sin 2\emptyset$ ------------------------------------2-9

For stresses disposed symmetrically about a point of weakness in the earth's crust the direction of the principal

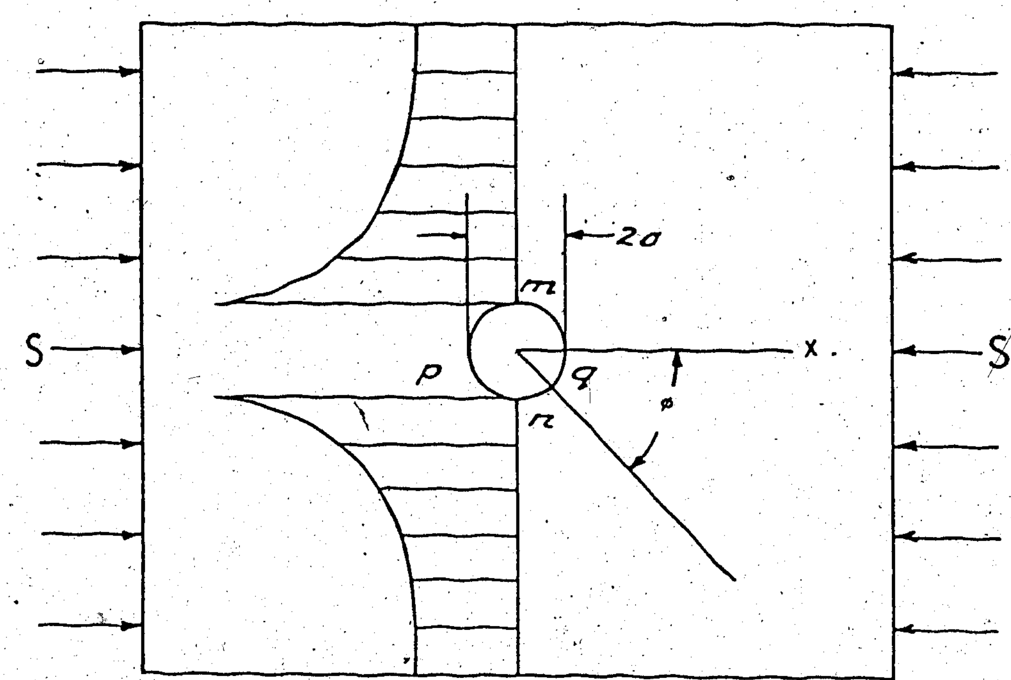


Figure 12.... A plate submitted to a uniform compression of magnitude S in the X-direction with a small hole in it

stresses will be vertical, radial, and tangential. The forces acting around the outside of the ring in Equation 2-9, having the inner and outer radii r=a and r=b give a stress distribution within the ring which can be considered as consisting of two parts. (a) The first is due to the constant 1/2 S of the normal forces. (b) The remaining part consists of the normal forces 1/2 S.cos2Ø together with the shearing forces -1/2 S.sin2Ø. The stresses produced by this second part may be derived from a stress function of the form

$$\Phi = f(r).\cos 2\phi \text{ ------------------------------------ } 2\text{-}10$$

This stress function can be substituted into the compatibility equation

$$\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{1}{r^2}\frac{\partial^2}{\partial \phi^2}\right)\left(\frac{\partial^2 \Phi}{\partial r^2} + \frac{1}{r}\frac{\partial \Phi}{\partial r} + \frac{1}{r^2}\frac{\partial^2 \Phi}{\partial \phi^2}\right) = 0$$

to yield an ordinary differential equation from which f(r) can be determined.

$$(d^2/dr^2+d/rdr-4/r^2)(d^2f/dr^2+ df/rdr-4f/r^2)=0$$

The general solution is

$$f(r) = A.r^2 + B.r^4 + C/r^2 + D$$

Equation 2-10 then becomes

$$\Phi=(A.r^2+B.r^4+C/r^2+D).\cos 2\phi \text{ ------------------------------ } 2\text{-}11$$

The stress components are;

$$S_r = \frac{1}{r}\frac{\partial \Phi}{\partial r} + \frac{1}{r^2}\frac{\partial^2 \Phi}{\partial \phi} = -\left(2A + 6\frac{C}{r^4} + 4\frac{D}{r^2}\right)\text{COSINE } 2\phi$$

$$S_\phi = \frac{\partial^2 \Phi}{\partial r^2} = \left(2A + 12Br^2 + 6\frac{C}{r^4}\right)\text{COSINE } 2\phi \text{ --------------- } 2\text{-}12$$

$$T_{r\phi} = -\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial \Phi}{\partial \phi}\right) = \left(2A + 6Br^2 - 6\frac{C}{r^4} - 2\frac{D}{r^2}\right)\text{SINE } 2\phi$$

The constants of integration A,B,C,D are determined from the conditions of Eqn. 2-9 for the outer boundary and from the condition that the wall of the hole is free from external forces. These conditions give

$$2A + 6C/b^4 + 4D/b^2 = -S/2$$

$$2A + 6C/a^4 + 4D/a^2 = 0$$

$$2A + 6Bb^2 - 6C/b^4 - 2D/b^2 = S/2$$

$$2A + 6Ba^2 - 6C/a^4 - 2D/a^2 = 0$$

For an infinitely large plate $a/b = 0$. These four equations can then be solved to yield $A=-S/4$, $B=0$, $C=-a^4.S/4$, $D=a^2.S/2$. These constants can now be substituted into equation 2-12, and by adding the stresses produced by the uniform compression S/2 on the outer boundary we obtain

$$S_r = S/2\,.(1-a^2/r^2) + S/2.(1+3a^4/r^4 - 4a^2/r^2).\cos 2\varnothing$$

as radial stress

$$S_\phi = S/2.(1+a^2/r^2)-S/2.(1+3.a^4/r^4).\cos 2\varnothing \quad \text{--------------2-13}$$

as the tangential stress and

$$T_r = -S/2.(1-3a^4/r^4+2a^2/r^2).\sin 2\varnothing$$

as the shearing stress, where the stresses are expressed in polar co-ordinates with the centre of the hole as the origin and the plane stress components are at a point ($\varnothing$, r) exterior to the hole of radius a in a plate under uniform uniaxial stress, with $\varnothing$ measured from the axis of the compressive stress S.

If $r>>a$, $S_r$ and $T_{r\phi}$ approach the values given in equation 2-9. At the edge of the hole r=a we find

$$S_r = T_{r\phi} = 0 \;;\; S_\phi = S-2S.\cos 2\varnothing \quad \text{------------------------2-14}$$

It can be seen from (2-14) that $S_\phi$ is greatest when $\emptyset = \pi/2$ or $3.\pi/2$ (i.e. when $\cos 2\emptyset=-1$) that is at the ends m and n of the diameter perpendicular to the direction of the compression. At these points $(S_\phi)_{max} = 3S$ which is the maximum compressive stress and is three times the uniform stress S applied at the end of the plate. At the points p and q, $\emptyset$ is equal to and 0 and we find $S_\phi = -S$. So there is a tensional stress, resulting from the applied compression, in the tangential direction at these points. For the cross section of the plate through the centre of the hole and perpendicular to the x-axis, $\emptyset = \pi/2$ and from Equation 2-13

$T_{r\phi} = 0$ ; $S_\phi = S/2.(2+a^2/r^2+3a^4/r^4)$ ------------------2-15

It is clear that the effect of the hole is of a very localised character, and as r increases the stress approaches the value S very rapidly, within a few hole diameters. The distribution of this stress $S_\phi$ as a function of r is shown in the Fig. 12 by the shaded area, regardless of the relative isotropy of a material. Having the solution equation 2-13 for compression or tension in one direction, the solution for compression or tension in two perpendicular directions can be easily obtained by superposition, of stresses given by (2-13) with $(\emptyset+90)$ for the angular co-ordinate.

A closer approximation to the geological situation is shown in Fig. 13 where unequal compressions S and s, S>s, are applied orthogonally to a plate with a small hole in it.

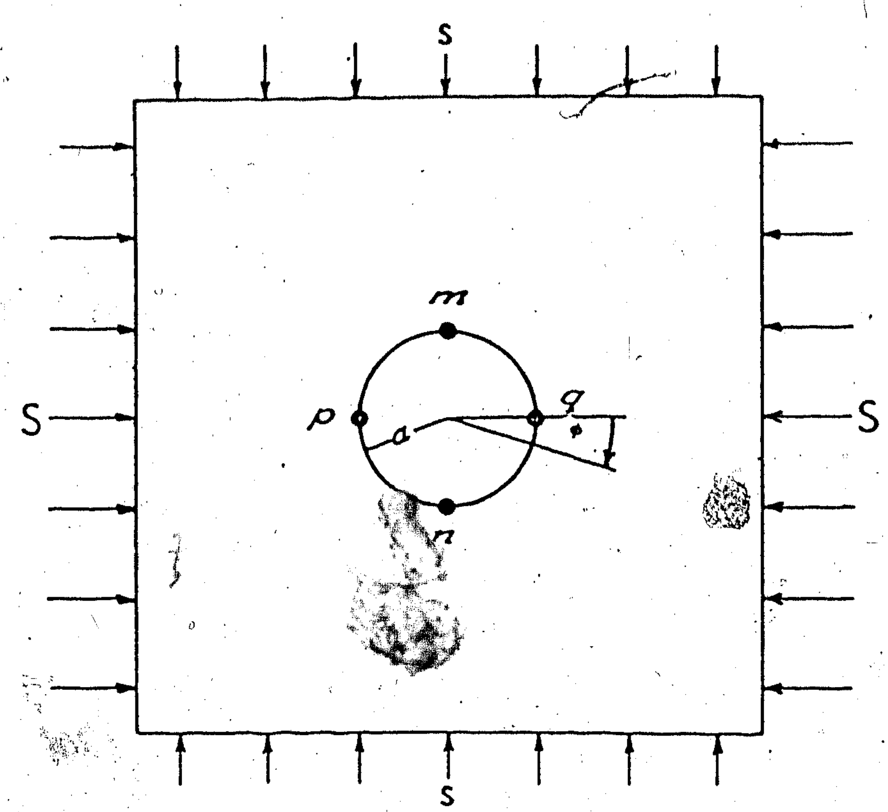


Figure 13..... A plate submitted to two compressions S and s with a small circular hole in it

At the hole boundary r=a, it follows from the superposition that

$S_r = T_{r\phi} = 0$ ; $S_\phi = S+s-2(S-s)\cos 2\phi$ ---------------------- 2-16

and $S_\phi$ is maximum, when $\cos 2\phi=-1$ with value (3S-s) when $\phi = \pi/2^\circ$, $3.\pi/2$ (at m, n), and minimum when $\cos 2\phi = 1$, with value (3s-S) when $\phi = 0, \pi$ (at p, q).

Where measurements have been made, horizontal principal stresses in the upper crust range from equality S=s to about S=4s or more (McGarr and Gay, 1978). The values of the horizontal stresses across the principal planes in the neighbourhood of the borehole have been calculated by Gough and Bell (1982) for various relative values of the S/s ratio and are shown in Figures 14 and 15. Figures 14 A and B show the individual stress distributions. The principle of the superposition of the two parts of the stress field is illustrated in Fig. 14 C for the case in which S/s =1.0. For S alone the tangential stress at the walls of the hole varies from a minimum value of -S (tensile) across the plane parallel to the S-axis to a maximum of +3S, across the plane normal to the S-axis. With the superposition, the stress field has radial symmetry and the tangential stress at the wall of the hole is +2S as can also be deduced from the equation 2-16. From equation 2-16 when $S_\phi = 2S = 2s$, it is independent of $\phi$ and so failure may occur but without a preferred azimuth. As the ratio of S to s approaches one, the determination of the magnitudes and directions of S and s becomes less reliable because of the lack of resolution.

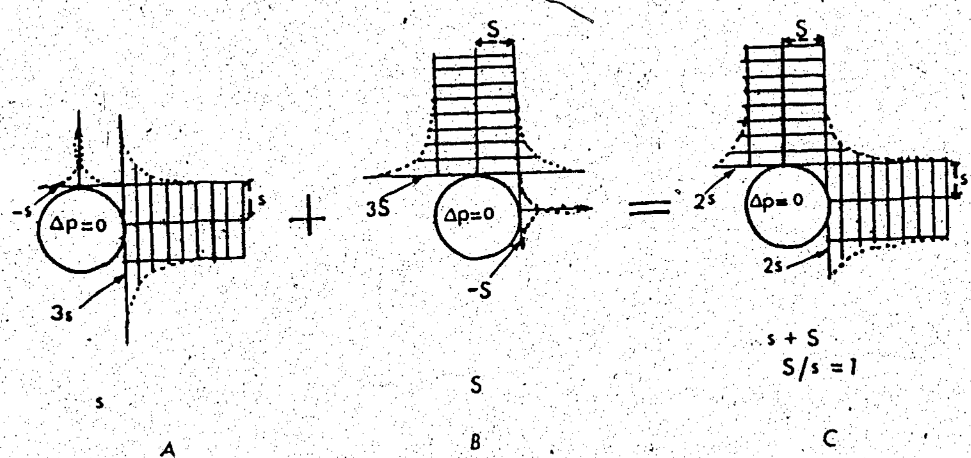


Figure 14.... Superposition of stress states about a borehole due to two horizontal principal stresses of equal magnitude.

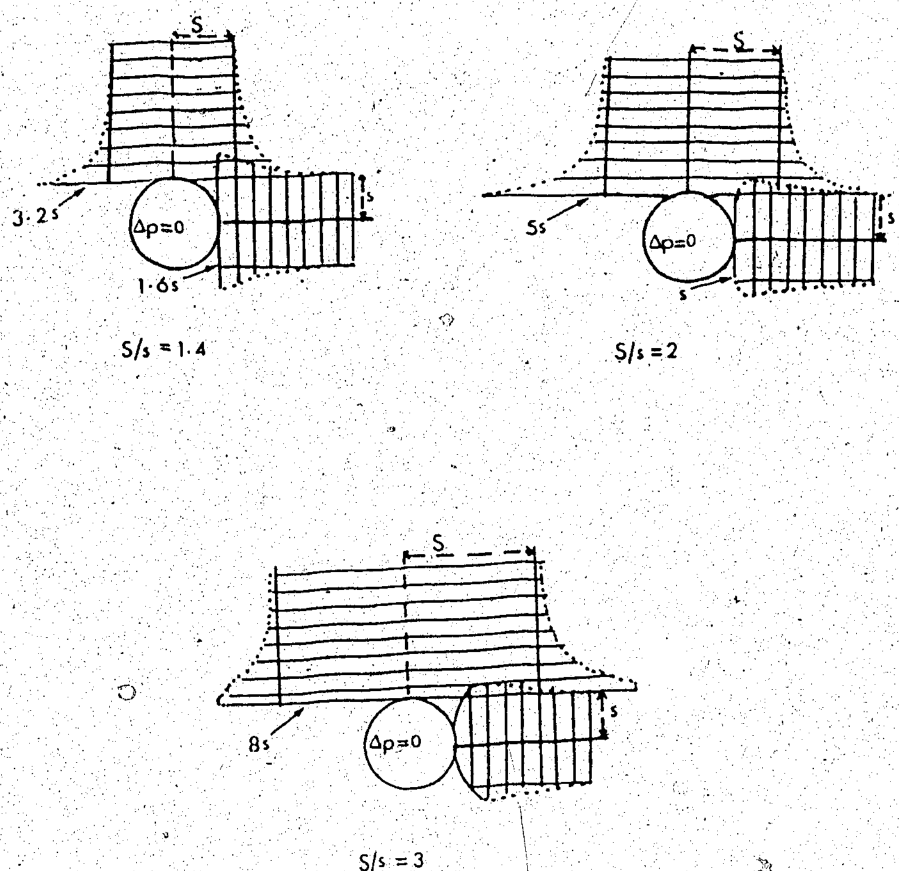


Figure 15.... Stress states about a borehole for regional stress-ratios S/s of 1.4, 2.0, and 3.0.

The resultant stress fields for other ratios of S/s are shown in figure 15. For the case when S/s = 3.0 the tangential stress at the walls of the hole varies from a minimum of 0 to a maximum of +8s (see Eqn. 2-16).

# III. DATA COLLECTION AND ANALYSIS

Data have been secured from wells distributed widely in the sedimentary basin of Alberta as shown in Figure 16. In analysing the records it was observed that in depth ranges characterised by oversized holes, the tool tended to rotate in some parts and ceased to rotate in other parts. On the other hand, the tool ceased to rotate in certain ranges in which the two orthogonal diameters were equal indicating a circular cross-section. Such observations led to the adoption of three criteria to be used in identifying breakouts. These are:

1. The tool ceases to rotate, with the azimuth of the No. 1 electrode approximately constant.
2. The two orthogonal diameters are definitely unequal with the smaller diameter at bit size.
3. The tool was rotating both below and above the breakout zone. This ensures that the rotation was stopped by the breakout and not by some other cause.

The application of these three criteria causes the rejection of many elongated zones,but ensures that only definitely identified breakouts are used in the study. Table 3.1 lists the breakouts identified by means of these three criteria, from the available log records.

## Representation and Statistics of Angular Data

We wish now to combine the various mean azimuths of the breakouts in order to obtain a representative breakout azimuth for each well. We may regard an angular observation

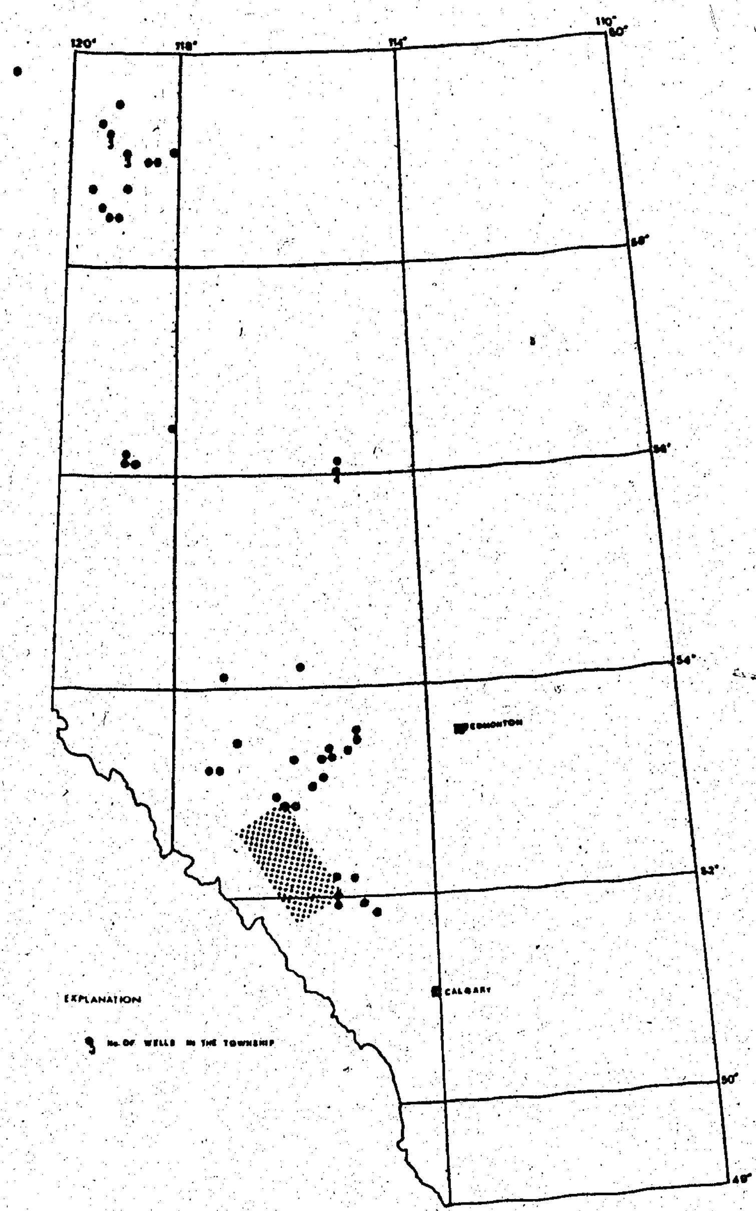


Figure 16.... Map of Alberta showing locations of wells analysed in this study

as a point on a circle of unit radius. A single observation $\emptyset$ ($0° \leq \emptyset \leq 360°$) measured in degrees is then a unit vector and the data can be described as circular data. If the vector is not directed, i.e if the angles $\emptyset$ ($0° \leq \emptyset \leq 180°$) and $180°+\emptyset$ are not distinguished, the data can be described as *axial or non-polar* data. Ungrouped angular data can be represented in two ways; (a) by points on the circumference of a unit circle, the same weight being assigned to each observation, or (b) by drawing the radii of a unit circle obtained by joining the origin to the observed points on the circumference,(figure 17).

Alternatively, angular data can be grouped by dividing the range 0 to 360 degrees into a certain number of class intervals. The frequency is then the number of observations within each class. The data can then be represented on a histogram similar to that used on a line, by constructing a block whose area is proportional to the frequency in that interval on the circumference of a unit circle. This diagram is called a *circular histogram*. This histogram can also be unrolled so that it sits on a straight line divided into the class intervals. The point of cut for unrolling the unit circle needs careful selection. For data that have a mode (a preferred direction) it is reasonable to use a cut such that the <u>centre of the linear histogram</u> approximately corresponds to this mode to avoid division of the modal peak between the ends of the histogram. This linear histogram is preferred to the circular histogram mainly because it is easier to

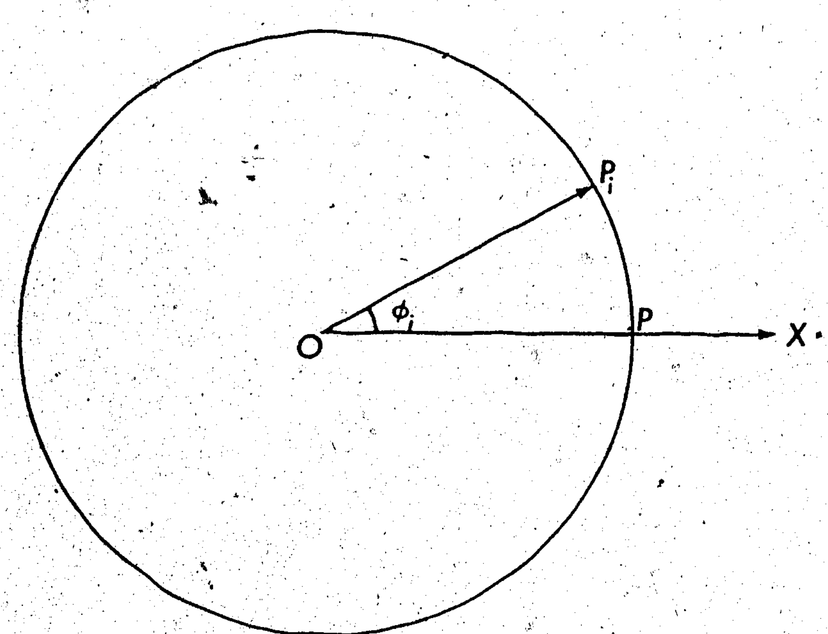


Figure 17.... Representations of the *i*th sample point $\emptyset_i$
OP=1

evaluate.

Another natural representation of angular data is a Rose diagram. In this approach we construct a sector, corresponding to each class interval, with apex at the origin and radius proportional to the class frequency (and arc substending the class interval). A disadvantage of this representation is that the area of each sector is proportional to $N^2$, where N is the frequency, so that the data appear much better grouped than they really are. However, the Rose diagram is widely used in geology.

**A Measure of Location**

In the first instance it is tempting to use the conventional measures on the line for a circular distribution. Let us consider a case where we have a sample of size 2 and the observed angles are $1°$ and $359°$. The arithmetic mean and the sample variance give unreasonable results. Intuitively, however, we infer the mean direction and the deviation about the mean to be in some sense $0°$ and $1°$ respectively. A sensible answer, however, results if we select the zero direction as the y-axis in place of the x-axis. This will then reduce the data to $269°$ and $271°$. Hence, the usual linear measures depend heavily on the choice of the zero direction and will not be appropriate for circular distributions. Let $X_1, \ldots, X_n$ be n observations on the line and let $X_1', \ldots, X_n'$ represent the same observations when the distances are measured from O' instead of the origin O along the x-axis. Let OO'= a. If L is a suitable measure of location on the line we should have

$L(X_1', \ldots, X_n') = L(X_1, \ldots, X_n) - a$ ------------------- 3-1

which implies that the position of the point whose x-coordinate is $L(X_1, \ldots, X_n)$ remains invariant under the choice of origin. Similarly it is desirable that the measure of circular location should not depend upon the choice of the zero direction.

Let $\phi_1', \ldots, \phi_n'$ be the angles obtained from $\phi_1, \ldots, \phi_n$ with respect to a new zero direction OA. If angle XOA = $\alpha$, then we have

$L(\phi_1', \ldots, \phi_n') = (L(\phi_1, \ldots, \phi_n) - \alpha) \bmod 2\pi$ ------------------- 3-2

The contrast between Equations 3-1 and 3-2 indicates the different natures of the problems on the line and on the circle.

**The Mean Direction**

Suppose $P_i$ is the point on the circumference of a unit circle corresponding to the angle $\phi_i$ , i = 1,...,n. Then the mean direction $\bar{\phi}$ of $\phi_1, \ldots, \phi_n$ is defined as the direction of the resultant of the unit vectors $\bar{OP_1}, \ldots, \bar{OP_n}$ . The cartesian coordinates of $P_i$ are $(\cos\phi_i, \sin\phi_i)$ so that the centre of gravity of these points is $(\bar{C}, \bar{S})$ such that

$\bar{C} = 1/n.\Sigma\cos\phi_i$ ; $\bar{S} = 1/n.\Sigma\sin\phi_i$ ------------------------ 3-3

If $\bar{R} = \sqrt{(\bar{C}^2 + \bar{S}^2)}$ -------------------------------------- 3-4

then $R = n\bar{R}$ is the length of the resultant and $\bar{\phi}$ is the solution of the equations

$\bar{C} = \bar{R}.\cos\bar{\phi}$ ; $\bar{S} = \bar{R}.\sin\bar{\phi}$ ---------------------------------- 3-5

It can be shown that $\bar{\phi}$ has some desirable properties as a measure of location.(see Appendix A)

**The Circular Variance**

Let $P_i$ be the point corresponding to $\emptyset_i$ on a unit circle and $\alpha$ be a fixed direction. If we assume initially that $\alpha=0$ and suppose that P is the corresponding point on the circle then a measure of the circular dispersion between P and $P_i$ is the smaller of the two angles that $OP_i$ makes with OP, say $\beta_i$ (see Fig. 17). We have

$$\beta_i = \min(\emptyset_i, 2\pi - \emptyset_i) = \pi - |\pi - \emptyset_i| \quad \text{------------------------3-6}$$

$1-\cos\beta_i$ is an increasing function of $\beta_i$. Let

$$D = 1/n \,.\, \Sigma(1-\cos\beta_i) \;,\; i = 1,..,n \quad \text{--------------------3-7}$$

be a measure of the dispersion of the points $P_i$. After shifting the zero direction to $\alpha$ using

$$\emptyset_i' = (\emptyset_i - \alpha) \bmod 2\pi \;,$$

we can write

$$D=1/n \,.\, \Sigma(1-\cos(\emptyset_i - \alpha)) \quad \text{-----------------------------------3-8}$$

The dispersion D is minimised at $\alpha=\bar{\emptyset}$. If we equate the derivative of (3-8) with respect to $\alpha$ to zero we have

$\Sigma\sin(\emptyset_i - \alpha)=0$, so that the dispersion is smallest about $\bar{\emptyset}$ (see Appendix A Equations A-1 and A-6.). This is similar to the expression for the ordinary sample variance. D can be written about $\bar{\emptyset}$ as $S_0$ where

$$S_0 = 1-1/n \,.\, \Sigma\cos(\emptyset_i - \bar{\emptyset}) \quad \text{-----------------------------3-9}$$

which can be simplified to

$$S_0 = 1 - \bar{R} \quad \text{----------------------------------------3-10}$$

$S_0$ is called the circular variance and $\bar{R}$ is the mean resultant vector magnitude. From (A-5), it can be seen that

$S_0$ is invariant under a change of the zero direction. Let R be the length of the resultant of the vectors $OP_i$ i.e. R = $n.\bar{R}$ so that

$S_0 = 1 - R/n$ ---------------------------------------- 3-11

Thus we see immediately that

$0 \le S_0 \le 1.0$ ---------------------------------------- 3-12

Since R tends to n for tightly grouped unit vectors, clearly $S_0$ tends to 0 for tight distributions and $S_0$ tends to 1.0 for random distributions. From (3-12) $S_0$ takes values in (0,1) unlike $\sigma^2$ for linear data whose range is (0,infinity). An appropriate transformation (first suggested by Von Mises in 1918) of $S_0$ to the range (0,infinity) is given by

$\sigma = \sqrt{(-2.\log_e(1 - S_0))}$ ---------------------------------------- 3-13

In (3-13) it has been assumed that the range of $\phi$ is $(0,2\pi)$. If the range of $\phi$ is $(0,2\pi/L)$ then we define

$\sigma = (-2\log_e(1 - S_0))^{1/2}/L$.

For grouped data we have

$\bar{C} = 1/n \,.\sum f_i \,.\cos\phi_i$ ; $\bar{S} = 1/n\sum f_i \,.\sin\phi_i$ , and $\bar{R} = (\bar{C}^2 + \bar{S}^2)^{1/2}$.

Then $\cos\bar{\phi} = \bar{C} / \bar{R}$ ; $\sin\bar{\phi} = \bar{S}/ \bar{R}$ , $S_0 = 1 - \bar{R}$ .

To obtain $\bar{\phi}$ it is convenient to use

$\bar{\phi} = \bar{\phi}'$ if $\bar{S} > 0$ , $\bar{C} > 0$ (1st quadrant)

$\bar{\phi} = \bar{\phi}' + \pi$ if $\bar{C} < 0$ , $\bar{S} > 0$ (2nd quadrant)

$\bar{\phi} = \bar{\phi}' + \pi$ if $\bar{C} < 0$ , $\bar{S} < 0$ (3rd quadrant)

$\bar{\phi} = \bar{\phi}' + 2\pi$ if $\bar{S} < 0$ , $\bar{C} > 0$ (4th quadrant)

where $\bar{\phi}' = \arctan(\bar{S} / \bar{C})$, and $-\pi/2 < \bar{\phi}' < \pi/2$. For axial (non-polar) data, in the range (0°-180°), we first double the angles to maintain the periodicity. Thus we have $\emptyset_i' = 2.\emptyset_i$ and carry out the calculations using the equations already listed, and the frequencies $f_i$ corresponding to the mid-points $\emptyset_i'$. Suppose $\bar{C}'$, $\bar{S}'$, $\bar{\emptyset}'$ etc. are the quantities for $\emptyset_i'$ corresponding to $\bar{C}$, $\bar{S}$, $\bar{\emptyset}$ etc. then an appropriate measure of the circular mean $\bar{\emptyset}$ for the $\emptyset_i$ can be taken as $\bar{\emptyset} = \bar{\emptyset}'/2$ and an appropriate measure of the circular variance $S_o$ for $\emptyset_i$ is $S_o = 1-(1-S_o')^{1/4}$. In general if the range of $\emptyset$ is $(0, 2\pi/L)$ we have

$$S_o = 1 - (1 - S_o')^{1/L^2} .$$

The result of applying these statistics to the raw azimuth data measured at every two feet depth interval within an identified breakout is shown in the column headed MEAN in Table 3.1 and also in columns 8 and 9 of Table 3.2. Table 3.2 shows the mean orientation of the various breakout zones in a well.

Statistical Decision

We are now near a position to make inferences on our data. Before making any inferences, however, we wish to look at the problem of the *regression* of one variable, in our case the azimuth, on another variable (independent variable), which is the depth in our situation. We shall then look at the correlation or the degree of relationship between the variables. We first consider the problem of how well a straight line explains the relationship between two variables. This requires the equation for the Least Square Regression Line. The least square regression line of Y on X

TABLE 3.1

Breakout azimuths in relation to rock types and age of rocks. (All lengths are in feet except where indicated).

e attached to a breakout depth range indicates that a section of the range shown does not satisfy the three criteria. N is number of observations.

WELL 6-30-46-17W5 60 ELONGATIONS 51 BREAKOUTS

| ELONGATED INTERVALS | | BREAKOUT INTERVALS | | | | STRATIGRAPHIC INFORMATION | | | |
|---|---|---|---|---|---|---|---|---|---|
| DEPTH RANGE | LENGTH | DEPTH RANGE | LENGTH | N | MEAN AZIMUTH(DEG) | PERIOD | Fm. TOP | FORMATION | LITHOLOGY |
| 3229-3541 | 312 | 3254-3521e | 174 | 28 | 138.0 | | | | |
| 3718-3750 | 31 | 3722-3732 | 10 | 3 | 134.3 | | | | |
| 3754-3792 | 38 | 3760-3790 | 30 | 6 | 51.2 | | | | |
| 3816-4069 | 253 | 3828-4050e | 178 | 32 | 137.3 | | | | |
| 4076-4145 | 69 | 4106-4120 | 14 | 4 | 74.5 | | | | |
| 4186-4526 | 340 | 4212-4486e | 244 | 38 | 11.6 | | | | |
| 4564-4646 | 82 | 4584-4630e | 22 | 10 | 141.4 | | | | |
| 4659-4728 | 69 | 4662-4724 | 62 | 9 | 149.9 | | | | |
| 4730-4762 | 32 | 30-40,56-62 | 16 | 5 | 153.0 | | | | |
| 4861-5144 | 283 | 4882-5132e | 174 | 30 | 145.9 | | | | |
| 5147-5176 | 29 | 5150-5168 | 18 | 3 | 139.7 | | | | |
| 5228-5336 | 108 | 5246-5332e | 24 | 10 | 142.7 | | | | |
| 5340-5370 | 30 | 5352-5368 | 16 | 5 | 39.2 | | | | |
| 5526-5820 | 294 | 5546-5812e | 160 | 40 | 144.8 | | | | |
| 5852-5935 | 83 | 5852-5922 | 70 | 14 | 142.2 | | | | |
| 5982-6002 | 20 | 5984-5996 | 12 | 3 | 34.3 | | | | |
| 6004-6053 | 49 | 6004-6028 | 24 | 7 | 154.1 | | | | |
| 6058-6075 | 17 | 6058-6072 | 14 | 4 | 35.0 | | | | |
| 6100-6340 | 240 | 6156-6320e | 84 | 26 | 162.6 | | | | |
| 6374-6452 | 78 | 6394-6438e | 28 | 8 | 78.0 | | | | |
| 6504-6526 | 22 | 6514-6522 | 8 | 3 | 150.3 | | | | |
| 6546-6576 | 30 | 6548-6570 | 22 | 4 | 75.5 | | | | |
| 6607-6781 | 174 | 6610-6744e | 82 | 18 | 140.6 | | | | |
| 6785-6804 | 19 | 6786-6796 | 10 | 3 | 152.3 | | | | |
| 6814-7076 | 262 | 6920-7028e | 46 | 12 | 157.6 | | | | |
| 7118-7192 | 74 | 18-30,72-84 | 24 | 6 | 158.5 | | | | |
| 7208-7243 | 35 | 7216-7230 | 14 | 3 | 135.7 | | | | |
| 7350-7448 | 98 | 68-80,7412-26 | 26 | 6 | 138.6 | | | | |
| 7450-7558 | 108 | 7494-7504 | 10 | 5 | 142.0 | | | | |
| 7615-8006 | 391 | 7710-7995e | 152 | 36 | 135.4 | U.CRETACEOUS | 7734 | LEA PARK | .... |
| 8034-8385 | 351 | 8036-8376e | 280 | 49 | 151.7 | U. CRE. | | LEA PARK | .... |
| 8426-8840 | 414 | 8430-8838e | 400 | 49 | 154.1 | U. CRE. | | LEA PARK | .... |
| 8848-8874 | 26 | 8854-8866 | 12 | 3 | 78.3 | U. CRE. | | LEA PARK | .... |
| 8876-9210 | 334 | 8978-9152e | 126 | 20 | 134.3 | U. CRE. | /9066/9204 | LEA/CARD ZN/CARD SD | ... |
| 9226-9284 | 58 | 9244-9274 | 30 | 4 | 141.5 | U. CRE. | 9204 | CARD SD | .... |
| 9346-9354 | 8 | 9346-9350 | 4 | 2 | 142.0 | U. CRE. | 9322 | BLKSTN | ...... |
| 9430-9436 | 6 | 9430-9436 | 6 | 3 | 141.0 | U. CRE. | | BLKSTN | ..... |
| 9491-9553 | 62 | 9498-9512 | 14 | 3 | 54.7 | U. CRE. | | BLKSTN | ..... |
| 9576-9645 | 69 | 32-36,40-44 | 10 | 5 | 81.2 | U. CRE. | | BLKSTN | .... |
| 9663-9672 | 9 | 9666-9672 | 6 | 3 | 129.0 | U. CRE. | | BLKSTN | ..... |
| 9701-9995 | 294 | 9718-9976e | 128 | 27 | 131.6 | U. CRE. | | BLKSTN | ..... |
| 10006-10319 | 313 | 10006-10262e | 68 | 15 | 133.4 | U. CRE. | | BLKSTN | ..... |
| 10359-10759 | 400 | 10368-10758e | 164 | 29 | 118.9 | L. CRE. | /10583/10672/10754 | BLKSTN/BFS/VIK/BLAIR | ... |
| 10800-10844 | 44 | 10804-10808 | 4 | 2 | 169.0 | L. CRE. | 10754 | BLAIR | .... |
| 11000-11050 | 50 | 11008-11020 | 12 | 5 | 28.2 | L. CRE. | | BLAIR | ..... |
| 11411-11424 | 13 | 11414-11418 | 4 | 2 | 141.0 | L. CRE. | | BLAIR | ..... |
| 11810-11826 | 16 | 11812-11820 | 8 | 4 | 144.5 | L. CRE | 11456 | BLUESKY | ..... |
| 11830-11848 | 18 | 11834-11842 | 8 | 4 | 133.5 | L. CRE. | | BLUESKY | ..... |
| 11896-11905 | 9 | 11898-11904 | 6 | 3 | 144.7 | JURASSIC | 11892 | ROCK CK | ..... |
| 11926-11956 | 30 | 11944-11948 | 4 | 2 | 146.0 | JURASSIC | | ROCK CK | .... |
| 11970-11980 | 10 | 11970-11976 | 6 | 3 | 129.3 | JURASSIC | | ROCK CK | ... |

ELONGATION ENDS 12010, LO FERNIE ; TOTAL DEPTH 15820 CAMBRIAN PROD. ZONE LO BLAIR.

WELL 7-9-49-24W5 144 ELONGATIONS 71 BREAKOUTS

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | STRATIGRAPHIC | | INFORMATION | |
|---|---|---|---|---|---|---|---|---|---|
| 1481-1503 | 22 | 1487-1497 | 10 | 5 | 146.0 | | | | |
| 1511-1535 | 24 | 1531-1535 | 4 | 3 | 146.3 | | | | |
| 1713-1821 | 208 | 1719-1813e | 114 | 60 | 89.3 | | | | |
| 1963-2018 | 55 | 1967-2011e | 28 | 14 | 135.6 | | | | |
| 2097-2153 | 56 | 2101-15,23-27 | 20 | 10 | 135.7 | | | | |
| 2158-2221 | 63 | 69-79,97-2221 | 36 | 18 | 82.9 | | | | |
| 2257-2295 | 38 | 2257-2273 | 16 | 9 | 91.0 | | | | |
| 2315-2327 | 12 | 2317-2327 | 10 | 6 | 143.6 | | | | |
| 2351-2457 | 106 | 2383-2451e | 52 | 23 | 136.3 | | | | |
| 2551-2587 | 36 | 2567-2575 | 8 | 5 | 73.0 | | | | |
| 2606-2683 | 77 | 2667-2681 | 14 | 8 | 60.0 | | | | |
| 2759-2820 | 61 | 69-89,95-2809 | 34 | 18 | 114.3 | | | | |
| 2970-3588 | 618 | 2979-3527e | 366 | 189 | 170.2 | U. CRETACEOUS | 3260 | WAPIABI | .... |
| 3590-3643 | 53 | 3591-3599 | 8 | 5 | 87.2 | U. CRE. | | WAPIABI | .... |
| 3681-3963 | 282 | 3683-5107e | 288 | 45 | 29.5 | U. CRE. | | WAPIABI | .... |
| 3967-3973 | 6 | 3967-3973 | 6 | 4 | 39.0 | U. CRE. | | WAPIABI | .... |
| 4009-4087 | 78 | 4055-4069 | 14 | 8 | 119.1 | U. CRE. | | WAPIABI | .... |
| 4198-4222 | 24 | 4201-4217 | 16 | 10 | 125.0 | U. CRE. | 4160 | BADH | .... |
| 4228-4276 | 48 | 38-51,71-75 | 26 | 15 | 133.7 | U. CRE. | | BADH | .... |
| 4277-4334 | 57 | 77-89,87-4321 | 36 | 20 | 38.8 | U. CRE. | | BADH | .... |
| 4346-4427 | 81 | 4377-4417 | 40 | 21 | 22.8 | U. CRE. | | BADH | .... |
| 4450-5107 | 657 | 4509-5003e | 62 | 38 | 162.2 | U. CRE | /4550/4710 | BADH/F BADH/2nd BADH | .... |
| 5300-5880 | 580 | 5309-5875e | 96 | 55 | 79.1 | U. CRE. | 5286/5640 | CARD SD/BLKSTN | .... |
| 5928-7311 | 1383 | 5943-7309e | 248 | 128 | 136.8 | U. CRE. | 7220 | BLKSTN/BFS | .... |
| 7312-7676 | 364 | 7313-7667e | 60 | 30 | 134.1 | L. CRE. | 7310/7460/7565 | F BFS/2nd BFS/MTN PARK | .... |
| 7682-7704 | 22 | 7683-7697 | 14 | 7 | 123.1 | L. CRE. | 7565 | MTN PARK | .... |
| 7710-7840 | 130 | 7717-7811e | 22 | 11 | 130.5 | L. CRE. | | MTN PARK | .... |
| 7857-7967 | 110 | 7861-7883 | 22 | 11 | 145.8 | L. CRE. | | MTN PARK | .... |
| 7984-8046 | 62 | 7989-7997 | 8 | 4 | 49.8 | L. CRE. | | MTN PARK | .... |
| 8102-8124 | 22 | 8107-8115 | 6 | 3 | 88.0 | L. CRE. | | MTN PARK | ..... |
| 8202-8221 | 19 | 8207-8213 | 6 | 3 | 144.6 | L. CRE. | | MTN PARK | ..... |
| 8242-8255 | 13 | 8245-8251 | 6 | 3 | 134.0 | L. CRE. | | MTN PARK | ..... |
| 8300-8316 | 16 | 8301-8311 | 10 | 5 | 143.2 | L. CRE. | | MTN PARK | .... |
| 8360-8498 | 138 | 8445-8451 | 6 | 3 | 55.3 | L. CRE. | | MTN PARK | .... |
| 8360-8498 | 0 | 8459-8479 | 20 | 10 | 146.1 | L. CRE. | | MTN PARK | .... |
| 8740-8792 | 52 | 55-63,67-71 | 12 | 6 | 168.0 | L. CRE. | | MTN PARK | .... |
| 9469-9497 | 28 | 9471-9477 | 6 | 3 | 127.3 | L. CRE. | 8910 | LUSCAR | .... |
| 9545-9555 | 10 | 9549-9555 | 6 | 3 | 96.3 | L. CRE. | | LUSCAR | .... |
| 10321-10358 | 37 | 10333-10339 | 6 | 3 | 2.0 | L. CRE. | 9839 | 2nd LUSCAR COAL | COAL |
| 10376-10415 | 39 | 10383-10387 | 4 | 2 | 112.0 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 10478-10549 | 71 | 10481-10549 | 58 | 23 | 160.5 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 10563-10685 | 122 | 10563-10659e | 66 | 34 | 53.0 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 10687-10857 | 169 | 10705-10835e | 86 | 45 | 159.8 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 10860-10893 | 33 | 10863-10867 | 4 | 2 | 133.5 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 10916-10923 | 7 | 10919-10923 | 4 | 2 | 55.0 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 10999-11133 | 134 | 11021-11071 | 50 | 25 | 125.6 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 11143-11167 | 24 | 11147-11155 | 8 | 4 | 154.3 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 11173-11195 | 22 | 11177-11185 | 8 | 4 | 141.0 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 11217-11252 | 35 | 11219-11223 | 6 | 3 | 154.7 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 11442-11527 | 85 | 11457-11501e | 24 | 12 | 177.2 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 11545-11570 | 25 | 11553-11569 | 16 | 9 | 35.4 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 11573-11703 | 130 | 11657-11685 | 28 | 14 | 33.4 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 11720-11799 | 79 | 11737-11791e | 56 | 29 | 180.0 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 11801-11858 | 57 | 11801-11833e | 22 | 11 | 156.3 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 12035-12065 | 30 | 12047-12059 | 12 | 6 | 146.5 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 12129-12150 | 21 | 12133-12141 | 8 | 4 | 142.8 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 12270-12295 | 25 | 12291-12297 | 6 | 3 | 134.3 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 12387-12403 | 16 | 12397-12401 | 4 | 2 | 69.0 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 12410-1/2418 | 8 | 12413-12417 | 4 | 2 | 147.5 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 12650-12683 | 33 | 12665-12675 | 10 | 5 | 45.6 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 12713-12798 | 85 | 12723-12735 | 12 | 6 | 174.0 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 12713-12798 | 0 | 12781-12785 | 4 | 2 | 86.5 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 12813-12953 | 140 | 55-91,12943-47 | 40 | 20 | 135.8 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 12965-13000 | 35 | 69-83,89-93 | 18 | 9 | 154.8 | L. CRE. | | 2nd LUSCAR COAL | COAL |
| 13022-13040 | 18 | 13025-13029 | 4 | 2 | 174.0 | L. CRE./JURASSIC | | 2nd LUSCAR COAL | COAL |
| 13276-13281 | 5 | 13277-13281 | 4 | 2 | 44.0 | JURASSIC | 13130 | NIKANASIN | .... |
| 13480-13496 | 16 | 13491-13495 | 4 | 3 | 163.7 | JURA. | | NIKANASIN | .... |
| 13502-13512 | 10 | 13505-13511 | 6 | 3 | 152.7 | JURA. | | NIKANASIN | ..... |
| 13537-13554 | 17 | 13549-13553 | 4 | 2 | 137.0 | JURA. | | NIKANASIN | .... |
| 13822-13851 | 29 | 13837-13845 | 8 | 4 | 136.5 | JURA. | | NIKANASIN | .... |
| 13856-13887 | 31 | 13871-13873 | 2 | 1 | 152.0 | JURA. | | NIKANASIN | .... |

ELONGATION ENDS 13887, NIKANASIN ; TOTAL DEPTH *****, NIKANASIN; D&A

**WELL 12-19-53-8W5 — 11 ELONGATIONS — 10 BREAKOUTS**

| ELONGATED INTERVALS | | BREAKOUT INTERVALS | | | | STRATIGRAPHIC INFORMATION | | | |
|---|---|---|---|---|---|---|---|---|---|
| 6489-6550 | 61 | 6504-6540 | 32 | 16 | 117.9 | | | | |
| 6606-6636 | 30 | 6606-6636e | 20 | 10 | 121.3 | | | | |
| 6706-6736 | 30 | 6712-6736 | 24 | 10 | 119.7 | | | | |
| 6746-6780 | 34 | 6746-6774 | 26 | 14 | 118.4 | | | | |
| 6854-6882 | 28 | 6854-6882 | 28 | 14 | 124.4 | | | | |
| 6910-6980 | 70 | 32-36,40-72 | 36 | 16 | 127.6 | | | | |
| 7226-7280 | 54 | 28-44,64-74 | 36 | 18 | 124.9 | | | | |
| 7410-7458 | 48 | 7412-7456 | 46 | 23 | 125.7 | | | | |
| 7513-7530 | 17 | 7516-7524 | 8 | 4 | 137.5 | | | | |
| 7782-7800 | 18 | 7782-7796 | 4 | 2 | 145.0 | | | | |

**WELL D-45-A-94-P-14 — 13 ELONGATIONS — 6 BREAKOUTS**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5726-5729 | 3 | 5727-5729 | 2 | 1 | 149.0 | U. DEVONIAN | 4328 | FT. SIMP | .... |
| 5846-5858 | 13 | 5845-5851 | 6 | 5 | 156.3 | U. DEV. | | FT. SIMP | .... |
| 5883-5895 | 12 | 5885-5893 | 8 | 5 | 68.5 | U. DEV. | | FT. SIMP | .... |
| 5913-5923 | 10 | 5913-5921 | 8 | 4 | 53.8 | U. DEV. | | FT. SIMP | .... |
| 5930-5938 | 8 | 5931-5937 | 6 | 3 | 53.7 | U. DEV. | | FT. SIMP | .... |
| 5954-5958 | 4 | 5956-5957 | 2 | 1 | 61.0 | U. DEV. | | FT. SIMP | ..... |

ELONGATION ENDS 5958, FT. SIMP; TOTAL DEPTH 6089, SLAVE POINT-6050. PROD. ZONE, SLAVE POINT (L. DEV.)

**WELL 6-12-50-11W5 m — 18 ELONGATIONS — 12 BREAKOUTS**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2480-2497 | 17 | 81-87,89-97 | 14 | 13 | 120.4 | MISSI/U.DEV | 2318/2481 | BANFF/WABAMUN | ..... |
| 2497-2505 | 8 | 2497-2505 | 8 | 8 | 129.3 | U. DEV. | | WABAMUN | ..... |
| 2507-2516 | 9 | 2507-2512 | 5 | 5 | 125.6 | U. DEV. | | WABAMUN | ..... |
| 2526-2535 | 9 | 2528-2535e | 4 | 4 | 124.3 | U. DEV. | | WABAMUN | ..... |
| 2535-2582 | 47 | 2536-2577e | 24 | 24 | 121.7 | U. DEV. | | WABAMUN | ..... |
| 2585-2588 | 3 | 2585-2588 | 3 | 3 | 133.0 | U. DEV. | | WABAMUN | .... |
| 2596-2611 | 15 | 2608-2610 | 2 | 2 | 123.0 | U. DEV. | | WABAMUN | ..... |
| 2615-2627 | 12 | 2615-2619 | 4 | 4 | 128.5 | U. DEV. | | WABAMUN | ..... |
| 2675-2680 | 5 | 2675-2678 | 3 | 3 | 132.0 | U. DEV. | | BLUERIDGE | ..... |
| 2702-2720 | 18 | 05-07,10-16 | 9 | 5 | 132.0 | U. DEV. | 2699 | BLUERIDGE | ..... |
| 2721-2731 | 10 | 2722-2730 | 8 | 8 | 137.6 | U. DEV. | | BLUERIDGE | .... |
| 2731-2735 | 4 | 2732-2735 | 3 | 3 | 136.0 | U. DEV. | | BLUERIDGE | |

ELONGATION ENDS 2874, IRETON ;TOTAL DEPTH 2876, IRETON=2858 ; PROD. ZONE, NISKU =2736m (U. DEV)

**WELL 14-20-60-12W5 — 28 ELONGATIONS — 24 BREAKOUTS**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 7425-7429 | 4 | 7425-7429 | 4 | 2 | 128.5 | L. CRETACEOUS-7030 | | BLAIR | |
| 7433-7439 | 6 | 7433-7435 | 2 | 1 | 123.0 | L. CRE. | | BLAIR | |
| 7485-7547 | 62 | 7477-7548e | 54 | 28 | 126.2 | L. CRE. | /7527 | BLAIR/GLAUC | |
| 7577-7596 | 19 | 7584-7590 | 6 | 3 | 124.7 | L. CRE. | 7569 | L MANY | |
| 7651-7709 | 58 | 7652-7704 | 52 | 23 | 122.9 | JURASSIC | 7626/7677 | BSL O/U FERNIE | |
| 7717-7737 | 20 | 18-24,28-36 | 14 | 7 | 127.3 | JURA. | 7707 | ROCK CK SS. | SS. |
| 7751-7783 | 32 | 7752-7780 | 28 | 10 | 125.2 | JURA. | | ROCK CK SS. | SS. |
| 7827-7868 | 41 | 28-36,48-64 | 24 | 18 | 120.0 | JURA. | 7828 | FERNIE SHALES | SHALES |
| 8148-8156 | 8 | 8150-8156 | 6 | 3 | 120.3 | MISSISSIPP. | 8150 | BANFF | ..... |
| 8181-8197 | 16 | 8188-8196 | 8 | 4 | 108.6 | MISS. | | BANFF | .... |
| 8215-8237 | 22 | 8218-8228 | 10 | 6 | 108.6 | MISS. | | BANFF | .... |
| 8255-8272 | 17 | 8256-8268 | 12 | 6 | 108.8 | MISS. | | BANFF | .... |
| 8280-8295 | 15 | 8286-8290 | 4 | 2 | 118.0 | MISS. | | BANFF | .... |
| 8445-8454 | 9 | 8446-8452 | 6 | 3 | 120.0 | MISS. | | BANFF | .... |
| 8678-8848 | 170 | 8696-8814e | 56 | 20 | 124.7 | U. DEVONIAN | 8680 | WABAMUN | ..... |
| 8851-8864 | 13 | 8852-8862 | 10 | 5 | 4.0 | U. DEV. | | WABAMUN | .... |
| 8895-8913 | 18 | 8896-8910 | 14 | 7 | 123.7 | U. DEV. | | WABAMUN | .... |
| 8937-8945 | 8 | 8938-8942 | 4 | 2 | 118.0 | U. DEV. | | WABAMUN | .... |
| 8949-8983 | 34 | 8968-8974 | 6 | 3 | 124.3 | U. DEV. | | WABAMUN | .... |
| 9097-9138 | 41 | 9100-9138e | 30 | 15 | 119.3 | U. DEV. | | WABAMUN | .... |
| 9207-9227 | 20 | 9208-9214 | 6 | 3 | 120.5 | U. DEV. | | WABAMUN | ..... |
| 9237-9251 | 14 | 9238-9242 | 4 | 2 | 131.0 | U. DEV. | | WABAMUN | .... |
| 9387-9473 | 86 | 9388-9464e | 48 | 24 | 117.0 | U. DEV. | 9388 | BLUERIDGE | ..... |
| 9487-9501 | 14 | 9488-9498 | 10 | 5 | 124.4 | U. DEV. | | BLUERIDGE | ..... |

ELONGATION ENDS 9501, BLUERIDGE; TOTAL DEPTH 11537, CAMBRIAN=11483 PROD. ZONE NISKU=9532 / L MANV=7569.(U.DEV/L.CRE)

**WELL 4-26-61-11W5 — 2 ELONGATIONS — 2 BREAKOUTS**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 8585-8607 | 22 | 8585-8605 | 20 | 11 | 128.1 | U. DEVONIAN | 8523 | WINTERBURN/GRAMINIA | .... |
| 8631-8665 | 34 | 8631-8663 | 32 | 17 | 114.6 | U. DEV. | 8652 | CALMAR | .... |

ELONGATION ENDS 8665, CALMAR ;TOTAL DEPTH 9120 IRETON=9082 PROD. ZONE NISKU=8682

WELL 3-32-47-13W5   28 ELONGATIONS   23 BREAKOUTS

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | STRATIGRAPHIC | | INFORMATION | |
|---|---|---|---|---|---|---|---|---|---|
| 9579-9599 | 20 | 9579-9587 | 8 | 4 | 108.8 | MISSISSIPPIAN | 9522 | PEKISKO | .... |
| 9619-9733 | 114 | 9619-9733 | 114 | 58 | 119.1 | MISS. | /9661 | PEKISKO/BANFF | .... |
| 9735-9757 | 22 | 9735-9749 | 14 | 8 | 125.0 | MISS. | | BANFF | .... |
| 9797-9833 | 36 | 9805-9827 | 22 | 12 | 113.3 | MISS. | | BANFF | ..... |
| 9847-9871 | 24 | 9849-9867 | 18 | 10 | 119.3 | MISS. | | BANFF | .... |
| 9887-9909 | 22 | 9889-9906 | 18 | 10 | 134.5 | MISS. | | BANFF | ..... |
| 10179-10261 | 82 | 10181-10259 | 78 | 40 | 125.0 | U. DEVONIAN | 10180 | WABAMUN | ..... |
| 10267-10279 | 12 | 10267-10273 | 6 | 3 | 131.0 | U. DEV. | | WABAMUN | ..... |
| 10391-10403 | 12 | 10391-10399 | 8 | 4 | 142.8 | U. DEV. | | WABAMUN | .... |
| 10479-10529 | 50 | 10501-10527 | 26 | 15 | 141.2 | U. DEV. | | WABAMUN | .... |
| 10555-10651 | 96 | 10557-10845e | 78 | 41 | 157.3 | U. DEV. | | WABAMUN | .... |
| 10667-10695 | 28 | 10669-10683 | 14 | 7 | 167.8 | U. DEV. | | WABAMUN | .... |
| 10715-10729 | 14 | 10715-10725 | 10 | 6 | 139.0 | U. DEV. | | WABAMUN | .... |
| 10747-10753 | 6 | 10747-10751 | 4 | 2 | 134.0 | U. DEV. | | WABAMUN | ..... |
| 10767-10771 | 4 | 10767-10771 | 4 | 2 | 126.3 | U. DEV. | | WABAMUN | ..... |
| 10789-10799 | 10 | 10791-10795 | 4 | 2 | 123.0 | U. DEV. | | WABAMUN | ..... |
| 10803-10813 | 10 | 10807-10813 | 6 | 3 | 158.0 | U. DEV. | | WABAMUN | ..... |
| 10847-10857 | 10 | 10851-10853 | 2 | 1 | 128.0 | U. DEV. | | WABAMUN | ..... |
| 10935-10971 | 36 | 10935-10963e | 26 | 14 | 132.4 | U. DEV. | 10867 | WINTERBURN | ..... |
| 10973-11011 | 38 | 10973-11011 | 38 | 20 | 122.3 | U. DEV. | | WINTERBURN | .... |
| 11133-11155 | 22 | 11135-11155 | 20 | 11 | 140.2 | U. DEV. | 11025 | NISKU | ..... |
| 11161-11165 | 4 | 11161-11165 | 4 | 2 | 143.0 | U. DEV. | | NISKU | ..... |
| 11171-11179 | 8 | 11171-11175 | 4 | 2 | 139.0 | U. DEV. | | NISKU | ..... |

ELONGATION ENDS 11179,NISKU ;TOTAL DEPTH 11493,IRETON******(U.DEV)   PROD. ZONE NISKU.

WELL 6-30-48-12W5   13 ELONGATIONS   12 BREAKOUTS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 10055-10061 | 6 | 10055-10061 | 6 | 3 | 132.3 | U. DEVONIAN | 9368 | WABAMUN | .... |
| 10085-10089 | 4 | 10085-10089 | 4 | 3 | 134.0 | U. DEV. | 10095 | BLUERIDGE | ..... |
| 10111-10231 | 120 | 11-29,53-10231 | 96 | 50 | 125.7 | U. DEV. | | BLUERIDGE | ..... |
| 10245-10259 | 14 | 10245-10255 | 10 | 5 | 127.4 | U. DEV. | /10246 | BLUERIDGE/NISKU | ..... |
| 10279-10285 | 6 | 10279-10283 | 4 | 3 | 132.0 | U. DEV. | 10246 | NISKU | .... |
| 10783-10805 | 22 | 10785-10795 | 10 | 8 | 141.0 | U. DEV. | 10536 | IRETON | .... |
| 10817-10835 | 18 | 10817-10833 | 16 | 8 | 132.3 | U. DEV. | | IRETON | .... |
| 10867-10881 | 14 | 10869-10877 | 8 | 5 | 142.0 | U. DEV. | | IRETON | ..... |
| 10905-10911 | 6 | 10905-10909 | 4 | 3 | 129.3 | U. DEV. | | IRETON | ..... |
| 11055-11073 | 18 | 11055-11073 | 18 | 10 | 137.1 | U. DEV. | | IRETON | ..... |
| 11117-11125 | 8 | 11117-11121 | 4 | 2 | 151.0 | U. DEV. | | IRETON | .... |
| 11319-11395 | 76 | 11321-11383 | 58 | 32 | 144.6 | U. DEV. | 11145 | DUVERNAY | |

ELONGATION ENDS 11395,DUV ; TOTAL DEPTH [illegible]640, B H L =11402(U.DEV)   PROD. ZONE SHUNDA=8858.(MISS.)

WELL 10-25-45-15W5   12 ELONGATIONS   11 BREAKOUTS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 10447-10521 | 74 | 10475-10517 | 42 | 21 | 142.4 | L.CRETACEOUS | 9750/10501 | BLAIR/ L BLAIR | ..... |
| 10579-10601 | 22 | 10581-10601 | 20 | 11 | 144.7 | L. CRE. | 10501 | L BLAIR | .... |
| 10677-10751 | 74 | 10677-10751 | 74 | 38 | 155.3 | L.CRE/JURA | 10501/10747 | L BLAIR/ ROCK CK | /SS |
| 10779-10805 | 26 | 10779-10785 | 6 | 3 | 135.7 | JURASSIC | 10747 | ROCK CK | SS. |
| 10817-10829 | 12 | 10819-10829 | 10 | 6 | 132.7 | JURA. | 10817 | FERNIE | .... |
| 10833-10837 | 4 | 10833-10837 | 4 | 2 | 135.0 | JURA. | | FERNIE | .... |
| 10871-10887 | 16 | 10873-10885 | 12 | 6 | 158.0 | JURA. | 10857 | NORDEGG | ..... |
| 10917-10947 | 30 | 10917-10939 | 22 | 12 | 143.5 | JURA. | | NORDEGG | ..... |
| 11065-11079 | 14 | 11071-11077 | 6 | 3 | 152.5 | MISSISSIPP. | 11034 | SHUNDA | ..... |
| 11109-11113 | 4 | 11109-11112 | 4 | 2 | 152.0 | MISS. | | SHUNDA | ..... |
| 11307-11315 | 8 | 11309-11313 | 4 | 3 | 154.3 | MISS. | 11277 | PEKISKO | ..... |

ELONGATION ENDS 11315, PEKISKO; TOTAL DEPTH 11337,PEKISKO; D&A

WELL 16-16-52-21W5   15 ELONGATIONS   13 BREAKOUTS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 12137-12187 | 50 | 12139-12187 | 48 | 25 | 135.6 | U.DEVONIAN | 12125 | WABAMUN | DOL. |
| 12293-12317 | 24 | 12293-12317 | 24 | 13 | 125.8 | U. DEV. | | WABAMUN | DOL/LST |
| 12433-12531 | 98 | 12435-12525e | 80 | 44 | 112.3 | U. DEV. | | WABAMUN | LST/DOL |
| 12537-12571 | 34 | 12539-12571e | 22 | 13 | 129.3 | U. DEV. | | WABAMUN | DOL. |
| 12585-12611 | 26 | 12585-12609e | 15 | 10 | 128.4 | U. DEV. | | WABAMUN | LST. |
| 12623-12629 | 6 | 12625-12629 | 4 | 3 | 129.7 | U.DEV. | | WABAMUN | LST. |
| 12577-12857 | 20 | 12579-12651 | 12 | 7 | 139.6 | U. DEV | | WABAMUN | DOL. |
| 12713-12725 | 12 | 12717-12725 | 8 | 5 | 121.6 | U. DEV | | WABAMUN | DOL. |
| 12861-12899 | 38 | 12861-12887e | 16 | 5 | 134.0 | U. DEV. | 12843 | BLUERIDGE | DOL/SH. |
| 12977-12991 | 14 | 12979-12983 | 4 | 3 | 125.0 | U. DEV. | | BLUERIDGE | DOL. |
| 13013-13071 | 58 | 13015-13059e | 24 | 14 | 123.4 | U. DEV. | 13000/13015 | CALMAR/NISKU | DOL,SH. |
| 13259-13279 | 20 | 13259-13275e | 10 | 7 | 124.1 | U. DEV. | 13015 | NISKU | DOL/LST |
| 13357-13381 | 24 | 13357-13381 | 24 | 13 | 123.6 | U. DEV. | 13308 | LEDUC | DOL. |

ELONGATION ENDS 13451, LEDUC; TOTAL DEPTH 13513 LEDUC(U.DEV)   PROD. ZONE WABAMUN/ELKTON= /11274 ( /MISS.)

WELL 10-27-45-18W5    20 ELONGATIONS    14 BREAKOUTS

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | STRATIGRAPHIC | INFORMATION | | |
|---|---|---|---|---|---|---|---|---|---|
| 12148-12503 | 354 | 12233-12495e | 106 | 57 | 143.1 | MISSISSIPP. | 12109 | PEKISKO | ---- |
| 12527-12665 | 138 | 12565-12611 | 46 | 24 | 150.2 | MISS. | 12270 | BANFF | ----- |
| 12759-13500 | 741 | 12789-13499e | 314 | 157 | 137.0 | /MISS/U.DEV. | /12777/12787 | BANFF/EXSHAW/WABAMUN | ---- |
| 13501-13865 | 364 | 13501-13861e | 324 | 161 | 131.0 | U. DEVONIAN | 13502 | NISKU | ----- |
| 13885-14103 | 218 | 13885-14095 | 210 | 106 | 132.8 | U. DEV. | 13502/14008 | NISKU/IRETON | ----- |
| 14129-14151 | 22 | 14131-14145 | 14 | 7 | 130.4 | U. DEV. | 14008 | IRETON | ---- |
| 14153-14247 | 94 | 14153-14247 | 94 | 47 | 133.4 | U. DEV. | | IRETON | ---- |
| 14263-14295 | 32 | 14275-14295 | 20 | 10 | 132.4 | U. DEV. | | IRETON | ---- |
| 14301-14341 | 39 | 14313-14339 | 26 | 13 | 135.0 | U. DEV | | IRETON | ---- |
| 14399-14431 | 32 | 14399-14423 | 24 | 14 | 131.7 | U. DEV. | | IRETON | ---- |
| 14659-14669 | 10 | 14659-14669 | 10 | 5 | 143.0 | U. DEV. | 14655 | DUVERNAY | ---- |
| 14729-14841 | 112 | 14737-14835e | 60 | 33 | 133.2 | U. DEV. | 14658/14788 | DUY./B H L | ----- |
| 14859-14901 | 42 | 14861-14869 | 8 | 4 | 143.0 | U. DEV. | 14788 | BEAVERHILL LAKE | ----- |
| 15101-15407 | 306 | 15107-15399e | 85 | 44 | 136.8 | U. DEV. | /15162 | B H L / SWAN HILLS | ---- |

ELONGATION ENDS 15407 CAMBRIAN; TOTAL DEPTH 15448 CAMBRIAN=15245    D & A.

WELL 13-9-52-8W5    36 ELONGATIONS    20 BREAKOUTS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1526-1594 | 68 | 1540-1584 | 24 | 14 | 139.2 | | | | |
| 1612-1620 | 8 | 1612-1620 | 8 | 3 | 144.7 | | | | |
| 1626-2294 | 668 | 1638-2294e | 422 | 104 | 145.9 | | | | |
| 2398-2435 | 37 | 2398-2424e | 8 | 3 | 125.7 | | | | |
| 2440-2462 | 22 | 2456-2462 | 6 | 3 | 141.3 | | | | |
| 2474-2550 | 76 | 2476-2532e | 30 | 11 | 132.5 | | | | |
| 2638-2670 | 32 | 2654-2666 | 12 | 6 | 132.8 | | | | |
| 2754-2900 | 146 | 2770-2900e | 122 | 25 | 128.2 | | | | |
| 2906-2942 | 36 | 2908-2920 | 12 | 6 | 128.2 | | | | |
| 2950-3140 | 190 | 2986-3084e | 48 | 22 | 81.1 | | | | |
| 3142-3200 | 58 | 44-50,72-89 | 23 | 7 | 45.1 | | | | |
| 3294-3496 | 202 | 3412-3482e | 70 | 24 | 175.7 | U.CRETACEOUS | 3413 | LEA PARK | ---- |
| 3569-3641 | 72 | 3616-3632 | 16 | 8 | 134.1 | U. CRE. | | LEA PARK | ----- |
| 3700-4376 | 676 | 3730-4342e | 464 | 110 | 135.5 | U. CRE | 3413/3818/4317 | LEA/1st WS/CARD ZONE | --/SH/-- |
| 6762-6864 | 102 | 6784-6864e | 80 | 24 | 130.6 | L. CRE. | 6782 | D-1 | ---- |
| 6852-6876 | 24 | 6960-6972 | 12 | 6 | 125.0 | L. CRE. | | D-1 | ---- |
| 6980-7012 | 32 | 6988-6994 | 6 | 3 | 120.7 | L. CRE. | | D-1 | ---- |
| 7015-7042 | 27 | 7030-7042 | 12 | 4 | 128.8 | L. CRE. | | D-1 | ---- |
| 7082-7132 | 50 | 7086-7130 | 36 | 13 | 124.6 | L. CRE. | | D-1 | ---- |
| 7136-7194 | 58 | 7154-7194 | 40 | 10 | 125.5 | L. CRE. | | D-1 | ---- |

ELONGATION ENDS 7194, D-1; TOTAL DEPTH 8100 IRETON=7998;(U.DEV) PROD. ZONE   NISKU =7864(U.DEV)

WELL 8-8N-51-9W5 m    11 ELONGATIONS    8 BREAKOUTS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2242-2255 | 13 | 2247-2249 | 2 | 2 | 145.5 | U. DEVONIAN | 2212.3m | WABAMUN | ---- |
| 2256-2259 | 3 | 2256-2258 | 2 | 2 | 139.0 | U. DEV. | | WABAMUN | ---- |
| 2287-2290 | 3 | 2287-2289 | 2 | 2 | 131.0 | U. DEV. | | WABAMUN | ---- |
| 2296-2303 | 7 | 2296-2300 | 4 | 4 | 127.0 | U. DEV. | | WABAMUN | ---- |
| 2343-2350 | 7 | 2344-2349 | 5 | 5 | 128.0 | U. DEV. | | WABAMUN | ---- |
| 2431-2440 | 9 | 2431-2439 | 8 | 8 | 140.0 | U. DEV. | 2419.5m | BLUERIDGE | ---- |
| 2442-2445 | 3 | 2442-2444 | 2 | 2 | 118.0 | U. DEV. | | BLUERIDGE | ---- |
| 2446-2452 | 6 | 2446-2451 | 5 | 5 | 140.8 | U. DEV. | | BLUERIDGE | ----- |

ELONGATION ENDS 2451.5, BLUERIDGE. TOTAL DEPTH 2654m IRETON=2584m

WELL 6-20-50-15W5    46 ELONGATIONS    41 BREAKOUTS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 9149-9161 | 12 | 9151-9159 | 8 | 4 | 143.0 | JURA/MISS. | 8972/9157 | NORDEGG/SHUNDA | ----- |
| 9167-9171 | 4 | 9169-9171 | 2 | 1 | 134.8 | MISSISSIPP. | 9157 | SHUNDA | ----- |
| 9173-9181 | 8 | 9173-9181 | 8 | 5 | 143.0 | MISS. | | SHUNDA | ---- |
| 9195-9199 | 4 | 9195-9199 | 4 | 3 | 140.3 | MISS. | | SHUNDA | ---- |
| 9201-9205 | 4 | 9201-9205 | 4 | 3 | 137.0 | MISS. | | SHUNDA | ----- |
| 9229-9233 | 4 | 9229-9233 | 4 | 3 | 123.3 | MISS. | | SHUNDA | ----- |
| 9237-9253 | 16 | 9237-9253 | 16 | 9 | 120.9 | MISS. | | SHUNDA | ---- |
| 9267-9291 | 24 | 9267-9291 | 24 | 12 | 3.1 | MISS. | | SHUNDA | ---- |
| 9297-9381 | 84 | 9297-9381 | 84 | 43 | 12.0 | MISS. | 9157/9330 | SHUNDA/PEKISKO | ---- |
| 9411-9417 | 6 | 9411-9413 | 2 | 1 | 124.0 | MISS. | 9230 | PEKISKO | ---- |

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | STRATIGRAPHIC INFORMATION | | | |
|---|---|---|---|---|---|---|---|---|---|
| 9427-9439 | 12 | 9433-9439 | 6 | 4 | 124.3 | MISS. | | PEKISKO | ---- |
| 9439-9449 | 10 | 9441-9445 | 4 | 3 | 130.7 | MISS. | | PEKISKO | ---- |
| 9469-9477 | 8 | 9468-9476 | 6 | 4 | 133.8 | MISS. | | PEKISKO | ---- |
| 9503-9511 | 8 | 9503-9511 | 8 | 5 | 123.6 | MISS. | | PEKISKO | ---- |
| 9521-9539 | 14 | 9525-9539 | 14 | 8 | 123.6 | MISS. | | PEKISKO | ---- |
| 9581-9589 | 8 | 9581-9589 | 8 | 5 | 126.2 | MISS. | | PEKISKO | ---- |
| 9681-9689 | 8 | 9693-9701 | 8 | 5 | 128.8 | MISS. | | PEKISKO | ---- |
| 9693-9701 | 8 | 10001-10005 | 4 | 2 | 129.0 | U. DEVONIAN | 10002 | WABAMUN | ---- |
| 10001-10010 | 9 | 10023-10151 | 128 | 63 | 132.6 | U. DEV. | | WABAMUN | ---- |
| 10021-10171 | 150 | 10223-10329 | 106 | 54 | 125.3 | U. DEV. | | WABAMUN | ---- |
| 10221-10331 | 110 | 10337-10345 | 8 | 5 | 132.6 | U. DEV. | | WABAMUN | ---- |
| 10337-10345 | 8 | 10347-10475 | 128 | 65 | 128.7 | U. DEV. | | WABAMUN | ---- |
| 10347-10481 | 134 | 10485-10515 | 30 | 16 | 128.0 | U.DEV. | | WABAMUN | ---- |
| 10485-10515 | 30 | 10519-10531 | 12 | 7 | 124.6 | U. DEV. | | WABAMUN | ---- |
| 10517-10531 | 14 | 10533-10539 | 6 | 4 | 123.5 | U. DEV. | | WABAMUN | ---- |
| 10533-10541 | 8 | 10545-10547 | 2 | 1 | 125.0 | U. DEV. | | WABAMUN | ---- |
| 10543-10549 | 6 | 10555-10559 | 4 | 4 | 120.5 | U. DEV. | | WABAMUN | ---- |
| 10555-10575 | 20 | 10613-10617 | 4 | 3 | 127.0 | U. DEV | 10710 | WINTERBURN, GRAMINIA | ---- |
| 10613-10625 | 12 | 33-41,45-51 | 14 | 9 | 124.8 | U. DEV. | | WINTERBURN, GRAMINIA | ---- |
| 10731-10771 | 40 | 75-83,85-97 | 20 | 12 | 124.5 | U.DEV. | | WINT, GRAM/CALMAR | ---- |
| 10778-10788 | 24 | 10805-10843 | 38 | 19 | 120.7 | U. DEV. | 10710/10842 | NISKU | ---- |
| 10805-10849 | 44 | 10870-10916 | 46 | 28 | 120.7 | U. DEV. | 10888 | NISKU | ---- |
| 10870-10923 | 53 | 11170-11253 | 83 | 50 | 137.0 | U. DEV. | 11276 | IRETON SH | SHALE |
| 11167-11253 | 86 | 11332-11382 | 50 | 30 | 126.3 | U. DEV. | | IRETON SH | SHALE |
| 11332-11395 | 63 | 11586-11616 | 20 | 12 | 135.0 | U. DEV. | | IRETON SH | SHALE |
| 11590-11626 | 36 | 11639-11642e | 3 | 2 | 126.0 | U. DEV. | | IRETON SH | SHALE |
| 11636-11646 | 10 | 11652-11659 | 7 | 4 | 138.0 | U. DEV. | | IRETON SH | SHALE |
| 11652-11659 | 7 | 11666-11682 | 16 | 10 | 134.0 | U. DEV. | | IRETON SH | SHALE |
| 11655-11682 | 16 | 11682-11695 | 7 | 4 | 139.5 | U. DEV. | | IRETON SH | SHALE |
| 11688-11695 | 7 | 11728-11735 | 7 | 4 | 135.0 | U. DEV. | 12019 | BEAVERHILL LAKE | ---- |
| 11728-11735 | 7 | 12048-12081e | 23 | 14 | 141.0 | U. DEV. | | | |
| 12035-12088 | 53 | | | | | PROD. ZONE | | ROCK CK 8837(JURA) | |

TOTAL DEPTH 12620, CAMBRIAN=12523

ELONGATION ENDS 12088, B H L;

WELL 3-36-49-23W5 143 ELONGATIONS 84 BREAKOUTS

| | | | | | |
|---|---|---|---|---|---|
| 1567-1723 | 156 | 1587-1657e | 52 | 29 | 26.1 |
| 1735-2795 | 1060 | 1787-2791e | 260 | 140 | 128.4 |
| 2795-2820 | 24 | 2789-2808 | 10 | 5 | 90.2 |
| 2850-2892 | 42 | 2863-2893 | 30 | 15 | 124.5 |
| 2809-3262 | 352 | 2809-3257e | 228 | 121 | 158.7 |
| 3264-3297 | 33 | 3267-3279 | 12 | 7 | 3.1 |
| 3370-3466 | 96 | 3381-3411 | 30 | 15 | 161.5 |
| 3468-3488 | 20 | 3469-3485 | 16 | 8 | 155.3 |
| 3488-3588 | 100 | 3543-3549 | 6 | 3 | 136.0 |
| 3607-3679 | 72 | 3609-3645 | 36 | 18 | 144.4 |
| 3683-4113 | 430 | 3769-4103e | 82 | 42 | 138.3 |
| 4129-4473 | 344 | 4189-4473e | 54 | 30 | 11.7 |
| 4480-4505 | 25 | 4493-4505 | 12 | 8 | 176.0 |
| 4520-4532 | 12 | 4521-4529 | 8 | 5 | 88.0 |
| 4543-4570 | 27 | 4551-4569 | 18 | 10 | 178.4 |
| 4582-4633 | 51 | 4582-4633e | 16 | 10 | 178.0 |
| 4643-4678 | 35 | 4643-4677 | 24 | 14 | 174.4 |
| 4707-4725 | 18 | 4707-4725 | 18 | 10 | 79.7 |
| 4810-4825 | 15 | 4811-4825 | 14 | 8 | 174.3 |
| 4828-4851 | 23 | 4828-4839 | 10 | 6 | 86.5 |
| 4888-6041 | 1155 | 4827-5989e | 440 | 235 | 154.5 |
| 6133-6188 | 55 | 6145-6185e | 36 | 20 | 169.1 |
| 6188-6319 | 131 | 6241-6251 | 10 | 6 | 125.7 |
| 6188-6319 | 0 | 6315-6319 | 4 | 3 | 33.0 |
| 6335-6566 | 231 | 6365-6565e | 162 | 84 | 143.5 |

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | STRATIGRAPHIC INFORMATION | | | |
|---|---|---|---|---|---|---|---|---|---|
| 6520-6730 | 110 | 6675-6685 | 10 | 5 | 172.5 | | | | |
| 6620-6730 | 0 | 6685-6695 | 10 | 5 | 82.8 | | | | |
| 6741-6825 | 84 | 6745-6805e | 38 | 20 | 151.7 | | | | |
| 6825-6850 | 25 | 6843-6849 | 6 | 4 | 157.6 | | | | |
| 6858-6924 | 66 | 6858-6924 | 66 | 5 | 153.4 | | | | |
| 6861-6879 | 18 | 6861-6867 | 6 | 3 | 142.6 | | | | |
| 6983-7011 | 28 | 7001-7009 | 8 | 5 | 144.2 | | | | SH/SS |
| 7019-7189 | 170 | 7045-7157e | 52 | 31 | 144.8 | U.CRETACEOUS | 7140 | SOLOMON | SH/SS |
| 7197-7280 | 83 | 7239-7279e | 34 | 19 | 4.3 | U. CRE. | | SOLOMON | SH,SILTST,SS |
| 7389-7680 | 291 | 7389-7647e | 126 | 63 | 158.6 | U.CRE. | 7140 / 7463 | SOLOMON/WAPIABI | SILTST. |
| 7703-7712 | 9 | 7703-7707 | 4 | 3 | 124.0 | U. CRE. | 7463 | WAPIABI | SH/SILTST. |
| 7713-7845 | 132 | 7717-7809e | 56 | 30 | 15.4 | U. CRE. | | WAPIABI | SH/SILTST. |
| 7847-7875 | 28 | 7847-7875 | 28 | 15 | 0.0 | U. CRE. | | WAPIABI | SH/SILTST. |
| 7882-7921 | 39 | 7883-7889 | 6 | 4 | 6.5 | U. CRE. | | WAPIABI | SILTST/SH |
| 7938-8003 | 66 | 7938-7978 | 40 | 21 | 134.0 | U. CRE. | | WAPIABI | SH/SILTST. |
| 8009-8049 | 40 | 8011-8031e | 12 | 8 | 138.5 | U. CRE. | | WAPIABI | SH/SILTST. |
| 8063-8155 | 92 | 8129-8139 | 10 | 6 | 70.7 | U. CRE. | | WAPIABI | SHALE |
| 8157-8511 | 354 | 8161-8511e | 114 | 62 | 147.7 | U. CRE. | /8495 | WAPIABI/BADHEART (BADH) | SILTST/SH |
| 8523-8536 | 13 | 8525-8535 | 10 | 6 | 22.5 | U. CRE. | | BADHEART | SILTST/SH |
| 8730-8928 | 208 | 8733-8763 | 30 | 15 | 140.4 | U. CRE. | | BADHEART | SILTST/SH |
| 8730-8928 | 0 | 8773-8789 | 16 | 8 | 2.8 | U. CRE. | | BADHEART | SILTST. |
| 8954-9200 | 246 | 8877-8883 | 6 | 3 | 131.0 | U. CRE. | /8840/9019/9102 | BADH/CARD ZN/ / | SS,SH |
| 8954-9200 | 0 | 8993-9199e | 18 | 9 | 6.0 | U. CRE. | /8840/9019/9102 | BADH/CARD ZN/CARD SD/BLKSTN | SILTST/SH |
| 9433-9511 | 78 | 9441-9475 | 34 | 17 | 174.3 | U. CRE. | 9102 | BLACKSTONE (BLKSTN) | SHALE |
| 9597-9675 | 78 | 9607-9659 | 52 | 26 | 175.2 | U. CRE. | | BLACKSTONE | SHALE |
| 9761-9773 | 12 | 9761-9773 | 12 | 6 | 89.7 | U. CRE. | | BLACKSTONE | SH/SILTST |
| 9784-9845 | 61 | 9817-9839 | 22 | 12 | 175.6 | U. CRE. | | BLACKSTONE | SILTST/SH/SS |
| 9916-10027 | 111 | 9919-9925 | 6 | 5 | 30.5 | U. CRE. | | BLACKSTONE | SH/SILTST/SS |
| 10135-10201 | 66 | 10161-10179 | 18 | 9 | 127.4 | U. CRE. | | BLACKSTONE | SILTST/SH/SS |
| 10349-10549 | 200 | 10349-10515e | 54 | 26 | 156.9 | U. CRE. | | BLACKSTONE | SILTST/SH/SS |
| 10572-10849 | 277 | 10599-10849e | 46 | 29 | 142.0 | U. CRE. | 9102/10740 | BLKSTN/BFS | SS/SH |
| 10860-11069 | 209 | 10861-10867 | 6 | 4 | 137.0 | L. CRE. | 10860 | MTN PARK | SS/SH |
| 10860-11069 | 0 | 10869-10885 | 16 | 9 | 44.9 | L. CRE. | | MTN PARK | SS/SH |
| 10860-11069 | 0 | 10949-10959 | 10 | 6 | 139.0 | L. CRE. | | MTN PARK | SH/SILTST |
| 10860-11069 | 0 | 11049-11059 | 10 | 5 | 158.4 | L. CRE. | | MTN PARK | SH/SILTST/COAL |
| 11122-11169 | 47 | 11123-11135 | 12 | 7 | 166.6 | L. CRE. | 11101 | LUSCAR | SS/SH/COAL |
| 12005-12051 | 46 | 12009-12023 | 14 | 7 | 135.0 | L.CRE. | 11420 | BSE COAL | SS/SH/SILT/COAL |
| 12057-12398 | 341 | 12059-12389e | 170 | 85 | 158.0 | L. CRE. | | BSE COAL | |
| 12489-12786 | 297 | 12513-12783e | 126 | 68 | 134.4 | L.CRE/JURA | 12480/12520/12690/ | CADOMIN/NIK/U FERNIE/ROCK CK | SS,SH,SILT. SS |
| 12813-12824 | 11 | 12815-12823 | 8 | 4 | 125.0 | JURASSIC | 12780 | ROCK CK/L FERNIE | SS,SH |
| 12880-12935 | 55 | 12909-12925 | 16 | 8 | 126.3 | JURA. | /12905 | TRI COOUINA | SH/DOL/SS |
| 13184-13452 | 266 | 13189-13433e | 102 | 54 | 134.0 | TRIASSIC | 13130 | TURNER VALLEY (TV) | DOL/SS |
| 13454-13500 | 46 | 13475-13489e | 8 | 4 | 150.0 | MISSISSIPPIAN | 13350 | 2nd TY | DOL/SS |
| 13722-13745 | 23 | 13725-13729 | 4 | 3 | 121.3 | MISS. | 13685 | 2nd TY | DOL. |
| 13838-13847 | 9 | 13841-13845 | 4 | 2 | 104.5 | MISS. | | 2nd TY | DOL/SH |
| 13877-13890 | 13 | 13877-13887e | 6 | 3 | 146.3 | MISS. | | PEKISKO | LST. |
| 14091-14104 | 13 | 14093-14101 | 8 | 4 | 140.0 | MISS. | 14085 | PEKISKO/BANFF | LST,DOL,ANHY,SS |
| 14155-14233 | 78 | 14159-14233e | 32 | 17 | 134.9 | MISS. | /14220 | BANFF/WAB./WINT. | LST,SH,DOL |
| 14273-15511 | 1238 | 14529-14599e | 55 | 28 | 12.5 | MISS./U.DEVONIAN | /14727/15500 | WINT./NISKU EOUIV | SH,LST,SS |
| 15514-15534 | 20 | 15515-15523 | 8 | 4 | 140.0 | U.DEV. | /15532 | NISKU EOUIV. | DOL/ANHY |
| 15579-15592 | 13 | 15583-15587 | 4 | 2 | 142.0 | U.DEV. | | NISKU EOUIV. | DOL. |
| 15817-15966 | 149 | 15829-15835 | 6 | 4 | 133.5 | U.DEV. | | D-3/8 M L | DOL,LST |
| 16832-17150 | 318 | 16851-17097e | 72 | 37 | 128.9 | U. DEV. | 16190/16925 | CAMBRIAN | DOL. |
| 17235-17325 | 90 | 17263-17321e | 30 | 17 | 143.6 | CAMBRIAN | 17230 | CAMBRIAN | SS. |
| 17375-17382 | 7 | 17375-17381 | 6 | 3 | 150.7 | CAM. | | CAMBRIAN | DOL. |
| 17422-17469 | 47 | 17431-17441 | 10 | 5 | 146.2 | CAM. | | CAMBRIAN | DOL/SS |
| 17472-17485 | 13 | 17477-17483 | 6 | 3 | 151.7 | CAM.N | | CAMBRIAN | LST/SH |
| 17631-17795 | 164 | 17635-17665e | 20 | 10 | 164.3 | CAM. | | CAMBRIAN | SH. |
| 17960-17999 | 39 | 17961-17997 | 36 | 18 | 135.3 | CAM. | | CAMBRIAN | |

ELONGATION ENDS 17999, CAMBRIAN; TOTAL DEPTH 18300, CAMBRIAN      PROD. ZONE TURNER VALLEY (MISS)

WELL 5-8-51-9W5      4 ELONGATIONS      2 BREAKOUTS

| | | | | | |
|---|---|---|---|---|---|
| 6750-7550 | 800 | 6767-7395e | 216 | 113 | 144.6 |
| 7562-8024 | 462 | 7589-7806e | 124 | 65 | 153.4 |

ELONGATION ENDS 8024, TOTAL DEPTH 8649, IRETON=8488      PROD. ZONE NISKU=8148.

WELL 5-33-109-8W6      5 ELONGATIONS      3 BREAKOUTS

| | | | | | |
|---|---|---|---|---|---|
| 5214-5332 | 118 | 5216-5332e | 110 | 55 | 97.9 |
| 5349-5400 | 51 | 5354-5382 | 30 | 15 | 174.3 |
| 5540-5570 | 30 | 5546-5564 | 20 | 10 | 121.6 |

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | STRATIGRAPHIC INFORMATION |
|---|---|---|---|---|---|---|
| **WELL 7-18RN-109-7W6** | | **12 ELONGATIONS** | **9 BREAKOUTS** | | | |
| 4912-4922 | 10 | 4912-4920 | 10 | 5 | 15.5 | |
| 5040-5074 | 34 | 5044-5072 | 30 | 15 | 172.0 | |
| 5516-5562 | 46 | 5522-5552e | 40 | 20 | 16.0 | |
| 5604-5614 | 10 | 5604-5612 | 10 | 5 | 12.6 | |
| 5628-5638 | 10 | 5628-5636 | 10 | 5 | 11.2 | |
| 5740-5750 | 10 | 5740-5748 | 10 | 5 | 27.8 | |
| 5780-5790 | 10 | 5780-5788 | 10 | 5 | 13.4 | |
| 5800-5810 | 10 | 5800-5808 | 10 | 5 | 26.7 | |
| 5850-5886 | 36 | 5864-5872 | 10 | 5 | 35.4 | |
| **WELL 10-17RN-110-9W6** | | **11 ELONGATIONS** | **5 BREAKOUTS** | | | |
| 4140-4288 | 148 | 4142-4280 | 140 | 70 | 41.7 | |
| 4290-4358 | 68 | 4298-4356 | 60 | 30 | 58.0 | |
| 4368-4410 | 42 | 4374-4402 | 30 | 15 | 88.0 | |
| 4452-4564 | 112 | 4466-4564 | 100 | 50 | 56.0 | |
| 5656-5700 | 44 | 5656-5684 | 30 | 15 | 184.0 | |
| **WELL 2-20-81-9W5** | | **7 ELONGATIONS** | **5 BREAKOUTS** | | | |
| 4084-4210 | 126 | 4084-4192 | 110 | 55 | 117.8 | |
| 4224-4264 | 40 | 4224-4262 | 40 | 20 | 118.8 | |
| 4266-4384 | 118 | 4268-4376 | 110 | 55 | 114.5 | |
| 4414-4564 | 150 | 4494-4552 | 60 | 30 | 111.3 | |
| **WELL 4-15-81-9W5** | | **7 ELONGATIONS** | **3 BREAKOUTS** | | | |
| 4808-4882 | 74 | 4912-4970 | 20 | 10 | 117.1 | |
| 5054-5098 | 44 | 5058-5074 | 20 | 10 | 125.9 | |
| 5122-5208 | 86 | 5140-5168 | 30 | 15 | 112.0 | |
| **WELL 5-3-81-9W5** | | **20 ELONGATIONS** | **9 BREAKOUTS** | | | |
| 3316-3348 | 32 | 3320-3338 | 20 | 10 | 61.6 | |
| 4062-4172 | 110 | 4062-4150 | 90 | 45 | 103.1 | |
| 4208-4218 | 10 | 4208-4216 | 10 | 5 | 159.5 | |
| 4224-4478 | 254 | 4302-4476 | 100 | 50 | 98.0 | |
| 4490-5126 | 636 | 4856-5098 | 240 | 120 | 98.4 | |
| 5378-5472 | 94 | 5378-5456 | 80 | 40 | 97.5 | |
| 5478-5510 | 32 | 5488-5496 | 10 | 5 | 94.1 | |
| 5530-5600 | 70 | 5530-[illegible]78 | 50 | 25 | 92.8 | |
| 5628-5654 | 26 | 5628-5646 | 20 | 10 | 93.7 | |
| **WELL 4-20-81-9W5** | | **28 ELONGATIONS** | **17 BREAKOUTS** | | | |
| 654-1022 | 368 | 786-984 | 200 | 100 | 116.0 | |
| 1094-1116 | 22 | 1094-1112 | 20 | 10 | 143.8 | |
| 1126-1150 | 24 | 1126-1144 | 20 | 10 | 15.5 | |
| 1232-1282 | 50 | 1244-1282 | 40 | 20 | 132.0 | |
| 1310-1628 | 318 | 1350-1602 | 250 | 125 | 121.8 | |
| 1682-1694 | 12 | 1682-1690 | 10 | 5 | 118.0 | |
| 4144-4154 | 10 | 4144-4152 | 10 | 5 | 114.2 | |
| 4156-4166 | 10 | 4158-4164 | 10 | 5 | 120.7 | |
| 4188-4234 | 46 | 4190-4208 | 20 | 10 | 114.7 | |
| 4270-4296 | 26 | 4270-4278 | 10 | 5 | 103.7 | |
| 4308-4450 | 142 | 4308-4438 | 130 | 65 | 117.5 | |
| 4466-4606 | 140 | 4546-4594 | 50 | 25 | 124.0 | |
| 4738-4758 | 20 | 4738-4756 | 20 | 10 | 60.8 | |
| 4776-4814 | 38 | 4780-4788 | 20 | 10 | 71.9 | |
| 4878-4982 | 104 | 4882-4980 | 100 | 50 | 138.4 | |
| 4982-5006 | 24 | 4984-5002 | 20 | 10 | 145.4 | |
| 5008-5068 | 60 | 5008-5066 | 60 | 30 | 152.7 | |
| **WELL 14-9-118-8W6** | | **27 ELONGATIONS** | **4 BREAKOUTS** | | | |
| 942-1044 | 102 | 994-1042 | 50 | 25 | 147.2 | |
| 1138-1450 | 312 | 1406-1444 | 40 | 20 | 105.4 | |
| 2260-2286 | 26 | 2260-2278 | 20 | 10 | 169.3 | |
| 2568-2608 | 40 | 2572-2602e | 30 | 15 | 153.5 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| WELL 2-36-118-8W6 | | 10 ELONGATIONS | | 4 BREAKOUTS | | | | | | |
| ELONGATED INTERVALS | | BREAKOUT INTERVALS | | | | | STRATIGRAPHIC INFORMATION | | | |
| 4884-4934 | 50 | 4884-4922 | 40 | 20 | 142.3 | | | | | |
| 4964-4978 | 14 | 4964-4972 | 10 | 5 | 80.1 | | | | | |
| 5198-5268 | 70 | 5214-5262 | 50 | 25 | 146.4 | | | | | |
| 5410-5482 | 72 | 5422-5468 | 40 | 20 | 168.1 | | | | | |
| WELL 9-15-118-8W6 | | 8 ELONGATIONS | | 3 BREAKOUTS | | | | | | |
| 5164-5286 | 122 | 5178-5280* | 90 | 45 | 128.2 | | | | | |
| 5356-5386 | 30 | 5356-5374 | 20 | 10 | 133.0 | | | | | |
| 5446-5468 | 22 | 5448-5466 | 20 | 10 | 126.2 | | | | | |
| WELL A9-5-82-9W5 | | 4 ELONGATIONS | | 3 BREAKOUTS | | | | | | |
| 5142-5170 | 28 | 5148-5166 | 20 | 10 | 78.2 | | | | | |
| 5206-5222 | 16 | 5206-5214 | 10 | 5 | 63.3 | | | | | |
| 5272-5298 | 26 | 5272-5280 | 10 | 5 | 81.2 | | | | | |
| WELL 14-21-81-9W5 | | 14 ELONGATIONS | | 1 BREAKOUT | | | | | | |
| 5680-5820 | 140 | 5680-5782* | 80 | 40 | 120.9 | | | | | |
| WELL 10-9-81-9W5 | | 11 ELONGATIONS | | 1 BREAKOUT | | | | | | |
| 5560-5608 | 48 | 5560-5598 | 40 | 20 | 123.4 | | | | | |
| WELL 3-21-112-6W6 | | 6 ELONGATIONS | | 2 BREAKOUTS | | | | | | |
| 4384-4414 | 30 | 4386-4412 | 30 | 15 | 160.0 | ---- | ---- | ----- | SH/LST. | |
| 4650-4664 | 14 | 4654-4662 | 10 | 5 | 154.0 | --- | ---- | ----- | DOL/LST | |
| ELONGATION ENDS*******, | | TOTAL DEPTH 5430, KEG RIVER Fm. | | | | | | | | |
| WELL 3-1-119-9W6 | | 18 ELONGATIONS | | 4 BREAKOUTS | | | | | | |
| 824-1800 | 976 | 1540-1578 | 40 | 20 | 155.0 | | | | | |
| 4700-4782 | 82 | 4700-4768 | 70 | 35 | 133.1 | | | | | |
| 5166-5290 | 124 | 5186-5214 | 30 | 15 | 54.7 | | | | | |
| 5728-5752 | 24 | 5728-5746 | 20 | 10 | 148.7 | | | | | |
| WELL 13-35-112-10W6 | | 22 ELONGATIONS | | 13 BREAKOUTS | | | | | | |
| 4400-4640 | 240 | 4522-4560 | 40 | 20 | 85.0 | | | | | |
| 4658-4668 | 10 | 4658-4666 | 10 | 5 | 144.9 | | | | | |
| 4844-4884 | 40 | 4844-4872 | 30 | 15 | 154.7 | | | | | |
| 4980-5036 | 54 | 5016-5034 | 20 | 10 | 117.7 | | | | | |
| 5088-5146 | 58 | 5088-5136 | 50 | 25 | 164.8 | | | | | |
| 5190-5300 | 110 | 5206-5264 | 60 | 30 | 150.6 | | | | | |
| 5316-5364 | 48 | 5316-5356 | 40 | 20 | 154.4 | | | | | |
| 5372-5386 | 14 | 5372-5380 | 10 | 5 | 158.9 | | | | | |
| 5524-5542 | 18 | 5532-5540 | 10 | 5 | 156.5 | | | | | |
| 5590-5600 | 10 | 5590-5598 | 10 | 5 | 178.5 | | | | | |
| 5680-5722 | 42 | 5680-5718 | 40 | 20 | 182.0 | | | | | |
| 5750-5774 | 24 | 5750-5768 | 20 | 10 | 137.0 | | | | | |
| 5886-5912 | 26 | 5886-5904 | 20 | 10 | 145.2 | | | | | |
| WELL 12-33-116-6W6 | | 38 ELONGATIONS | | 8 BREAKOUTS | | | | | | |
| 790- 954 | 164 | 802-850 | 50 | 25 | 139.2 | | | | | |
| 4264-4286 | 22 | 4268-4276 | 10 | 5 | 48.4 | | | | | |
| 4374-4388 | 14 | 4374-4388 | 10 | 5 | 121.7 | | | | | |
| 4500-4520 | 20 | 4500-4518 | 20 | 10 | 139.3 | | | | | |
| 4820-4830 | 10 | 4820-4828 | 10 | 5 | 18.5 | | | | | |
| 4728-4796 | 68 | 4750-4788 | 40 | 20 | 56.0 | | | | | |
| 4856-4868 | 12 | 4856-4884 | 10 | 5 | 148.8 | | | | | |
| 4950-5020 | 70 | 4950-4978 | 30 | 15 | 144.3 | | | | | |
| WELL 12-33-114-5W6 | | 1 ELONGATIONS | | 1 BREAKOUT | | | | | | |
| 4770-4910 | 140 | 4777-4905 | 120 | 60 | 119.6 | | | | | |

WELL 14-36-116-6W6 4 ELONGATIONS 3 BREAKOUTS

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | STRATIGRAPHIC | INFORMATION | | |
|---|---|---|---|---|---|---|---|---|---|
| 4408-4418 | 10 | 4408-4416 | 10 | 5 | 95.3 | | | | |
| 4750-4770 | 20 | 4750-4758 | 10 | 5 | 81.5 | | | | |
| 4798-4882 | 86 | 4798-4854 | 60 | 30 | 28.0 | | | | |

WELL 3-11-121-7W6 4 ELONGATIONS 2 BREAKOUTS

| | | | | | |
|---|---|---|---|---|---|
| 4860-4872 | 12 | 4860-4868 | 10 | 5 | 161.2 |
| 5304-5350 | 46 | 5304-5322 | 20 | 10 | 158.0 |

WELL 12-24-82-6W6 19 ELONGATIONS 10 BREAKOUTS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4864-4908 | 44 | 4864-4882 | 20 | 10 | 80.1 | MISSISSIPP. | 4812 | DEBOLT | LST. |
| 4912-5034 | 122 | 4918-5026 | 110 | 55 | 76.8 | MISS. | | DEBOLT | LST/DOL. |
| 5038-5150 | 112 | 5046-5134 | 90 | 45 | 119.5 | MISS. | | DEBOLT | LST/DOL/ANHY/SILT |
| 5256-5296 | 40 | 5256-5294 | 40 | 20 | 114.0 | MISS. | | DEBOLT | LST/SH |
| 5312-5342 | 30 | 5316-5334 | 20 | 10 | 78.5 | MISS. | | DEBOLT | LST/SILTST. |
| 5362-5570 | 208 | 5372-5528e | 100 | 50 | 114.8 | MISS. | /5518 | DEBOLT/ELKTON | LST,SH,DOL |
| 5670-5700 | 30 | 5670-7698 | 30 | 15 | 102.6 | MISS. | 5643 | SHUNDA | SH/ LST. |
| 5700-5734 | 34 | 5700-5728 | 30 | 15 | 100.0 | MISS. | | SHUNDA | LST. |
| 5756-6190 | 434 | 5760-6178 | 380 | 190 | 110.2 | MISS. | /6174 | SHUNDA/BANFF | LST,SH,DOL |
| 6310-6446 | 136 | 6334-6446e | 90 | 45 | 109.5 | MISS. | 6174 | BANFF | LST/SH/ANHY/SILTS |

ELONGATION ENDS 6958, WABAMUN (DEVONIAN)=6838 ; TOTAL DEPTH 7085, PRECAMBRIAN=6985 D&A.

WELL 11-29-82-5W6 31 ELONGATIONS 19 BREAKOUTS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4300-4320 | 20 | 4300-4308 | 10 | 5 | 86.5 | TRIASSIC | 3530 | TOAD GRAYLING | SS. |
| 4334-4374 | 40 | 4350-4368 | 20 | 10 | 107.3 | TRI/PERMIAN | /4367 | TOAD GRAYLING/BELLOY | SILTST,SS,DOL |
| 4448-4458 | 10 | 4448-4454 | 10 | 5 | 72.0 | PERMIAN | 4367 | BELLOY | SS/DOL |
| 4528-4542 | 14 | 4522-4536 | 10 | 5 | 104.6 | PERM. | | BELLOY | SS/SH/DOL |
| 4880-4904 | 24 | 4880-4898 | 20 | 10 | 63.9 | MISSISSIPP. | 4774 | DEBOLT | LST. |
| 5002-5056 | 54 | 5002-5050 | 50 | 25 | 76.8 | MISS. | | DEBOLT | LST/DOL |
| 5062-5112 | 50 | 5092-5110 | 20 | 10 | 66.6 | MISS. | | DEBOLT | LST/SH/DOL |
| 5400-5448 | 48 | 5408-5438 | 30 | 15 | 114.7 | MISS. | | DEBOLT | LST/SH |
| 5482-5528 | 46 | 5482-5520 | 40 | 20 | 111.6 | MISS. | /5488 | DEBOLT/ELKTON | LST/SH |
| 5724-5758 | 34 | 5724-5752 | 30 | 15 | 120.0 | MISS. | 5617 | SHUNDA | SH/LST/DOL. |
| 5898-5930 | 32 | 5898-5928 | 30 | 15 | 117.3 | MISS. | | SHUNDA | LST/SH |
| 6010-6040 | 30 | 6010-6038 | 30 | 15 | 45.3 | MISS. | 5940 | PEKISKO | LST/SH |
| 6042-6062 | 20 | 6042-6050 | 10 | 5 | 126.8 | MISS. | | PEKISKO | SH |
| 6160-6212 | 52 | 6180-6208 | 40 | 20 | 101.4 | MISS. | /6181 | PEK/BANFF | SH,LST, SILTST. |
| 6246-6310 | 64 | 6246-6304 | 60 | 30 | 128.0 | MISS. | 6181 | BANFF | SILTS/SH. |
| 6368-6410 | 42 | 6368-6396 | 30 | 15 | 105.3 | MISS. | | BANFF | LST/SILTST/SH |
| 6412-6444 | 32 | 6420-6430 | 10 | 5 | 116.8 | MISS. | | BANFF | LST |
| 6456-6554 | 98 | 6466-6544 | 80 | 40 | 106.0 | MISS. | | BANFF | LST/SH |

ELONGATION ENDS 7058 WABAMUN (DEVONIAN)=6980; TOTAL DEPTH 7315 PRECAMBRIAN=7283; PROD ZONE WABAMUM/BANFF/DEBOLT.

WELL 15-29-115-3W6 29 ELONGATIONS 12 BREAKOUTS

| | | | | | |
|---|---|---|---|---|---|
| 1590-1648 | 58 | 1604-1622 | 20 | 10 | 121.0 |
| 1762-1820 | 58 | 1780-1818 | 40 | 20 | 157.0 |
| 1832-1900 | 68 | 1832-1880 | 50 | 25 | 186.3 |
| 1932-1968 | 36 | 1932-1960 | 30 | 15 | 137.3 |
| 1968-2054 | 86 | 1980-2058e | 40 | 20 | 178.2 |
| 2090-2196 | 106 | 2090-2178 | 90 | 45 | 5.3 |
| 2240-2354 | 114 | 2242-2330 | 90 | 45 | 6.0 |
| 3310-3500 | 190 | 3310-3498 | 190 | 95 | 6.6 |
| 3500-3600 | 100 | 3500-3598 | 100 | 50 | 14.8 |
| 3692-3716 | 24 | 3696-3714 | 20 | 10 | 117.6 |
| 3810-3840 | 30 | 3814-3822 | 10 | 5 | 120.9 |
| 4214-4230 | 16 | 4218-4226 | 10 | 5 | 157.5 |

WELL 5-28-115-4W6 5 ELONGATIONS 3 BREAKOUTS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4430-4472 | 42 | 4430-4462 | 30 | 15 | 157.5 | DEVONIAN | 4252 | MUSKEG | ANHY/DOL. |
| 4508-4534 | 26 | 4510-4518 | 10 | 5 | 162.8 | DEVONIAN | | MUSKEG | ANHYDRITE |
| 4632-4684 | 28 | 4644-4662 | 20 | 10 | 144.5 | DEVONIAN | | MUSKEG | ANHY/DOL/ |

ELONGATION ENDS 4778, KEG RIVER (DEVONIAN)=****, TOTAL DEPTH 5210
LOWER ELK POINT (DEVONIAN)=5184

WELL 5-5-35-11W5 33 ELONGATIONS 12 BREAKOUTS

STRATIGRAPHIC INFORMATION

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | |
|---|---|---|---|---|---|---|
| 14436-14454 | 18 | 14441-14449 | 10 | 5 | 47.2 | |
| 14462-14474 | 12 | 14463-14471 | 10 | 5 | 34.3 | |
| 14478-14486 | 20 | 14477-14485 | 10 | 5 | 31.9 | |
| 14644-14670 | 26 | 14659-14668 | 10 | 5 | 132.6 | |
| 14702-14784 | 82 | 14703-14777e | 60 | 30 | 157.3 | |
| 14850-14984 | 134 | 14853-14961 | 110 | 55 | 145.1 | |
| 14984-15004 | 20 | 14993-15001 | 10 | 5 | 90.4 | |
| 15086-15108 | 22 | 15089-15097 | 10 | 5 | 132.7 | |
| 15940-16096 | 156 | 15941-16089 | 150 | 75 | 176.5 | |
| 16096-16600 | 504 | 16151-16589 | 440 | 220 | 175.8 | |
| 16600-16748 | 148 | 16603-16711 | 100 | 50 | 0.6 | |
| 16802-16868 | 66 | 16811-16829 | 20 | 10 | 147.5 | |
| 16802-16868 | | | | | | |

WELL 7-7-88-1W6 30 ELONGATIONS 4 BREAKOUTS

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5578-5600 | 20 | 5579-5597 | 20 | 10 | 125.8 | MISSISSIPP 4966 | BANFF | DOL/LST. |
| 5608-5632 | 24 | 5609-5617 | 10 | 5 | 142.3 | MISS. | BANFF | LST/SH |
| 5804-5842 | 38 | 5805-5833 | 30 | 15 | 100.0 | MISS/U.DEV /5838 | BANFF/WABAMUN | LST. |
| 6506-6624 | 118 | 6511-6641 | 112 | 56 | 118.8 | U.DEVONIAN 6502 | IRETON | LST/DOL. |

ELONGATION ENDS 6624 IRETON; TOTAL DEPTH 7214 PRECAMBRIAN=7193;D&A

WELL 9-18-83-6W6 12 ELONGATIONS 10 BREAKOUTS

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | |
|---|---|---|---|---|---|---|
| 5128-5138 | 10 | 5128-5136 | 10 | 5 | 142.3 | |
| 5640-5870 | 30 | 5646-5664 | 10 | 5 | 103.1 | |
| 5812-6616 | 354 | 5812-6180 | 350 | 175 | 117.0 | |
| 6178-6200 | 22 | 6178-6196 | 20 | 10 | 113.3 | |
| 6450-6594 | 144 | 6450-6588 | 140 | 70 | 114.4 | |
| 6646-6782 | 136 | 6646-6774 | 130 | 65 | 112.0 | |
| 7252-7288 | 36 | 7260-7268 | 10 | 5 | 152.4 | |
| 7380-7410 | 30 | 7386-7394 | 10 | 5 | 37.1 | |
| 7504-7528 | 24 | 7504-7512 | 10 | 5 | 125.7 | |
| 7558-7570 | 12 | 7580-7588 | 10 | 5 | 111.2 | |

WELL 14-21-37-11W5 38 ELONGATIONS 30 BREAKOUTS

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | | | |
|---|---|---|---|---|---|---|---|---|
| 7260-7700 | 440 | 7280-7388e | 370 | 185 | 148.1 | U.CRETACEOUS 5708/7318 | MAIN FAULT/BEARPAW | SS,SILT,SH |
| 7800-8162 | 362 | 7802-8160 | 360 | 180 | 144.0 | U.CRE. 7598 | BELLY RIVER | SS/SH. |
| 8430-8480 | 60 | 8432-8490 | 60 | 30 | 142.7 | U. CRE. | BELLY RIVER | SS/SH |
| 8564-8622 | 58 | 8570-8618 | 50 | 25 | 163.2 | U. CRE. | BELLY RIVER | SS/SH |
| 8754-8854 | 100 | 8754-8852 | 100 | 50 | 156.4 | U. CRE. | BELLY RIVER | SS/SH |
| 8976-8990 | 14 | 8976-8984 | 10 | 5 | 85.5 | U. CRE. | BELLY RIVER | SS |
| 8990-9038 | 48 | 9028-9036 | 10 | 5 | 156.6 | U. CRE. | BELLY RIVER | SS/SH |
| 9078-9142 | 64 | 9084-9132 | 50 | 25 | 156.0 | U. CRE. | BELLY RIVER | SS |
| 9206-9534 | 328 | 9316-9530e | 160 | 80 | 152.8 | U. CRE. | BELLY RIVER | SS/SH. |
| 9594-10182 | 588 | 9622-10180 | 550 | 280 | 155.4 | U. CRE. | BELLY RIVER | SH/SILTST/SS |
| 10184-10240 | 46 | 10194-10212 | 20 | 10 | 100.3 | U. CRE. | BELLY RIVER | SILTST. |
| 10248-10316 | 68 | 10284-10312 | 30 | 15 | 117.3 | U. CRE. | BELLY RIVER | SH/SS |
| 10318-10826 | 508 | 10330-10768 | 440 | 220 | 153.0 | U. CRE. | BELLY RIVER | SH /SILTST. |
| 10836-10904 | 68 | 10864-10882 | 20 | 10 | 154.0 | U. CRE. 10825 | CARDIUM | SH/SS. |
| 10932-10952 | 20 | 10940-10948 | 10 | 5 | 157.7 | U. CRE. | CARDIUM | SH/SS |
| 10958-11294 | 336 | 10960-11278 | 320 | 160 | 147.9 | U. CRE. | CARDIUM | SH/SILTST/SS |
| 11340-11440 | 100 | 11346-11424 | 80 | 40 | 159.5 | U. CRE. | CARDIUM | SS/SH. |
| 11488-11580 | 94 | 11460-11488 | 30 | 15 | 164.0 | U. CRE. | CARDIUM | SH |
| 11550-11640 | 90 | 11552-11630 | 80 | 40 | 162.0 | U CRE. | CARDIUM | SH/SS |
| 11650-11700 | 50 | 11658-11696 | 40 | 20 | 161.0 | U. CRE. | CARDIUM | SH |
| 11700-11858 | 158 | 11700-11838 | 140 | 70 | 161.7 | U. CRE. | CARDIUM | SH/SILTST/SS |
| 11894-12030 | 136 | 11908-12012e | 90 | 45 | 158.2 | L. CRE. /11994 | CARD / BFS | SH,SS. |
| 13138-13200 | 82 | 13170-13208 | 40 | 20 | 143.0 | JURASSIC 13100/13177 | FERNIE/ROCK CK | SS. |
| 15826-16134 | 308 | 15850-16118 | 270 | 135 | 146.5 | U.DEVONIAN 15578 | IRETON | SH/GYP/MARLST. |
| 16244-16290 | 46 | 16250-16278 | 30 | 15 | 149.3 | U. DEV. 16146/16252 | DUVERNAY/B H L | LST,SH |
| 16352-16414 | 62 | 16356-16404 | 50 | 25 | 148.0 | U. DEV. 16252 | BEAVERHILL LAKE | LST/SH |
| 16460-16594 | 134 | 16462-16580 | 120 | 60 | 149.0 | U. DEV. | B H L | LST/SH |
| 16634-16662 | 28 | 16636-16654 | 20 | 10 | 140.4 | U.DEV. | B H L | LST. |
| 16744-16826 | 82 | 16744-16812 | 70 | 38 | 147.5 | U. DEV. /16748 | B H L/SLAVE POINT | DOL |
| 16842-16902 | 60 | 16846-16894 | 50 | 25 | 141.6 | U. DEV. | SLAVE POINT | DOL/LST. |

ELONGATION ENDS 16902, SLAVE POINT; TOTAL DEPTH 16980, 2nd H= (MID. DEV.)

POOR COPY
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WELL 2-29-59-22W5    72 ELONGATIONS    41 BREAKOUTS

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | STRATIGRAPHIC | | INFORMATION | |
|---|---|---|---|---|---|---|---|---|---|
| 7700-7804 | 104 | 7702-7786 | 80 | 40 | 108.5 | L.CRETACEOUS | 7674/7725/7752 | VIKING/JOLI F/MANNVILLE | SS,SH,SILTST. |
| 7806-7820 | 14 | 7810-7818 | 10 | 5 | 86.4 | L. CRE. | 7752 | MANNVILLE | SS/SH |
| 7840-8004 | 164 | 7862-8000 | 140 | 70 | 164.3 | L. CRE. | | MANNVILLE | SS/SILTST/SH |
| 8130-8176 | 44 | 8132-8170 | 40 | 20 | 73.0 | L. CRE. | | MANNVILLE | SILT/SS/SH/COAL |
| 8186-8340 | 154 | 8190-8328 | 140 | 70 | 134.3 | L. CRE. | | MANNVILLE | SS/SILT/COAL/SH |
| 8356-8486 | 130 | 8370-8478 | 110 | 55 | 120.7 | L. CRE. | | MANNVILLE | SH/SS/SILTST. |
| 8542-8584 | 42 | 8546-8574 | 30 | 15 | 142.7 | L. CRE. | | MANNVILLE | SH/SS/SSILTST. |
| 8600-8634 | 34 | 8600-8618 | 20 | 10 | 5.3 | L. CRE. | /8603 | MANNV/L MANNVILLE | SH,SS,SILTST. |
| 8672-8684 | 10 | 8672-8680 | 10 | 5 | 125.2 | L. CRE. | 8603 | LOWER MANNVILLE | SS/SILTST. |
| 8714-8730 | 16 | 8718-8728 | 10 | 5 | 129.4 | L. CRE. | | L MANNVILLE | SS/SILTST. |
| 8764-8776 | 12 | 8764-8772 | 10 | 5 | 138.3 | L. CRE. | | L MANNVILLE | SS/COAL/SH |
| 8796-8818 | 22 | 8796-8804 | 10 | 5 | 137.7 | L. CRE. | | L MANNVILLE | SS/SH/SILTST. |
| 8826-8838 | 10 | 8826-8834 | 10 | 5 | 148.1 | L. CRE. | | L MANNVILLE | SH/SILTST. |
| 8912-8972 | 60 | 8912-8970 | 60 | 30 | 130.0 | L. CRE. | | L MANNVILLE | SS/SILTST/SH |
| 9398-9488 | 90 | 9424-9484 | 40 | 20 | 130.0 | CRE/MISS | /9420 | L MANNY/DEBOLT | DOL/SILT/SS. |
| 9496-9516 | 20 | 9500-9508 | 10 | 5 | 109.0 | MISS. | 9420 | DEBOLT | DOL/SH |
| 9590-9618 | 28 | 9602-9610 | 10 | 5 | 134.6 | MISS. | 9517 | ELKTON | DOL. |
| 9622-9638 | 16 | 9622-9630 | 10 | 5 | 142.7 | MISS. | /9635 | ELKTON/SHUNDA | LST,DOL,SH |
| 9686-9708 | 22 | 9696-9704 | 10 | 5 | 146.2 | MISS. | 9635 | SHUNDA | DOL/LST/SH |
| 9758-9808 | 50 | 9756-9794 | 40 | 20 | 133.0 | MISS. | | SHUNDA | LST/DOL/SH |
| 10012-10028 | 16 | 10012-10020 | 10 | 5 | 54.2 | MISS. | 10010 | BANFF | SH/SILTST/SS |
| 10050-10098 | 48 | 10056-10094 | 40 | 20 | 55.0 | MISS. | | BANFF | DOL/SILT/SH |
| 10124-10154 | 30 | 10128-10146 | 20 | 10 | 93.0 | MISS. | | BANFF | SILTST/SH |
| 10162-10178 | 16 | 10162-10170 | 10 | 5 | 141.1 | MISS. | | BANFF | SILTST/DOL |
| 10196-10230 | 34 | 10198-10218 | 20 | 10 | 118.8 | MISS. | | BANFF | SH/SS/LST |
| 10270-10282 | 12 | 10272-10280 | 10 | 5 | 107.0 | MISS. | | BANFF | LST. |
| 10340-10392 | 52 | 10340-10378 | 40 | 20 | 73.0 | MISS. | | BANFF | SH/LST/SILTST. |
| 10590-10604 | 14 | 10592-10600 | 10 | 5 | 145.8 | MISS. | | BANFF | LST/SILTST. |
| 10648-10972 | 324 | 10648-10966 | 320 | 160 | 140.1 | U.DEVONIAN | 10620 | WABAMUN | LST/DOL. |
| 10984-11214 | 230 | 10986-11204 | 220 | 110 | 139.5 | U. DEV. | | WABAMUN | LST/DOL. |
| 11218-11404 | 186 | 11228-11378 | 150 | 75 | 136.3 | U. DEV. | /11362 | WABAMUN/WINTERBURN | LST/DOL. |
| 11444-11482 | 38 | 11444-11472 | 30 | 15 | 130.7 | U. DEV. | 11362 | WINTERBURN | DOL |
| 11490-11516 | 26 | 11494-11512 | 20 | 10 | 155.5 | U. DEV. | 11490 | NISKU | LST. |
| 11532-11542 | 10 | 11532-11540 | 10 | 5 | 124.3 | U. DEV. | | NISKU | LST |
| 11552-11572 | 20 | 11552-11570 | 20 | 10 | 121.5 | U. DEV. | | NISKU | LST. |
| 11888-11900 | 12 | 11890-11898 | 10 | 5 | 168.4 | U. DEV. | 11810 | TRETON | ANHYDRITE |
| 12600-12612 | 12 | 12600-12608 | 10 | 5 | 156.4 | U. DEV. | 12379 | LEDUC | DOL. |
| 12658-12746 | 88 | 12658-12736 | 80 | 40 | 138.0 | U. DEV. | /12667 | LEDUC/B H L | LST/DOL. |
| 12794-12826 | 32 | 12796-12824 | 30 | 15 | 144.3 | U. DEV. | 12667 | BEAVERHILL LAKE | LST/DOL |
| 12836-12850 | 14 | 12838-12846 | 10 | 5 | 144.5 | U. DEV. | | B H L | LST/DOL |
| 12854-12864 | 10 | 12854-12862 | 10 | 5 | 132.9 | U. DEV. | | B H L | LST |

ELONGATION ENDS 12864, B H L; TOTAL DEPTH 12865, B H L;
PROD. ZONE LOWER MANNVILLE.

WELL 10-7-80-14W5    16 ELONGATIONS    11 BREAKOUTS

| | | | | | |
|---|---|---|---|---|---|
| 7452-7464 | 12 | 7454-7462 | 10 | 5 | 115.5 |
| 7558-7600 | 42 | 7558-7588 | 30 | 15 | 24.5 |
| 7634-7664 | 30 | 7634-7662 | 30 | 15 | 158.0 |
| 7672-7722 | 50 | 7686-7714 | 30 | 15 | 133.3 |
| 8034-8054 | 20 | 8034-8052 | 20 | 10 | 159.1 |
| 8096-8184 | 88 | 8098-8178 | 80 | 40 | 150.5 |
| 8260-8272 | 12 | 8260-8268 | 10 | 5 | 166.0 |
| 8284-8374 | 90 | 8284-8362 | 80 | 40 | 162.0 |
| 8520-8560 | 40 | 8522-8550 | 30 | 15 | 141.3 |
| 8572-8584 | 12 | 8574-8582 | 10 | 5 | 150.7 |
| 8650-8660 | 10 | 8650-8658 | 10 | 5 | 148.2 |

WELL 3-32-34-8WS 15 ELONGATIONS 9 BREAKOUTS

STRATIGRAPHIC INFORMATION

| ELONGATED INTERVALS | | BREAKOUT INTERVALS | | | |
|---|---|---|---|---|---|
| 4558-5112 | 554 | 4550-4618 | 58 | 29 | 123.0 |
| 4558-5112 | 0 | 4640-4858 | 218 | 109 | 155.0 |
| 4558-5112 | 0 | 4860-4918 | 58 | 29 | 165.0 |
| 4558-5112 | 0 | 4920-5078 | 158 | 79 | 154.0 |
| 4558-5112 | 0 | 5080-5112 | 32 | 16 | 128.0 |
| 5074-5518 | 444 | 5078-5518 | 440 | 220 | 133.0 |
| 5638-5788 | 152 | 5636-5708 | 72 | 36 | 133.0 |
| 5636-5788 | 0 | 5720-5750 | 30 | 15 | 135.0 |
| 5638-5788 | 0 | 5760-5788 | 28 | 14 | 135.0 |
| 5798-5940 | 144 | 5796-5940 | 144 | 72 | 133.0 |
| 6950-7150 | 100 | 7100-7148 | 48 | 24 | 188.0 |
| 7164-7400 | 236 | 7190-7368 | 178 | 89 | 116.0 |
| 7470-7876 | 406 | 7768-7806 | 40 | 20 | 142.0 |
| 7946-8722 | 780 | 8078-8120 | 42 | 21 | 162.0 |
| 7946-8722 | 0 | 8122-8282 | 150 | 80 | 142.0 |
| 7946-8722 | 0 | 8282-8300 | 18 | 9 | 134.0 |
| 7946-8722 | 0 | 8510-8716 | 206 | 103 | 130.0 |
| 8900-9012 | 112 | 8902-9000 | 98 | 49 | 127.0 |

WELL 6-17-37-8WS 41 ELONGATIONS 39 BREAKOUTS

| ELONGATED INTERVALS | | BREAKOUT INTERVALS | | | |
|---|---|---|---|---|---|
| 7106-7138 | 32 | 7106-7138 | 32 | 16 | 126.0 |
| 7154-7180 | 26 | 7156-7176 | 20 | 10 | 126.0 |
| 7280-7316 | 36 | 7280-7316 | 36 | 18 | 128.0 |
| 7326-7336 | 10 | 7326-7336 | 10 | 5 | 123.0 |
| 7346-7356 | 10 | 7346-7352 | 6 | 3 | 118.0 |
| 7384-7388 | 32 | 7384-7394 | 30 | 15 | 125.0 |
| 7440-7520 | 80 | 7444-7520 | 76 | 38 | 125.0 |
| 7528-7568 | 40 | 7530-7566 | 36 | 18 | 119.0 |
| 7578-7590 | 14 | 7576-7590 | 14 | 7 | 118.0 |
| 7594-7662 | 68 | 7602-7658 | 56 | 28 | 128.0 |
| 7584-7714 | 20 | 7694-7714 | 20 | 10 | 135.0 |
| 7728-7744 | 20 | 7732-7744 | 12 | 6 | 120.0 |
| 7764-7774 | 10 | 7766-7774 | 8 | 4 | 121.0 |
| 7904-7942 | 38 | 7904-7942 | 38 | 19 | 120.0 |
| 7946-8050 | 114 | 7946-8050 | 114 | 57 | 117.0 |
| 8078-8086 | 8 | 8080-8086 | 6 | 3 | 122.0 |
| 8136-8164 | 28 | 8136-8164 | 28 | 14 | 125.0 |
| 8196-8222 | 26 | 8186-8212 | 16 | 8 | 127.0 |
| 8260-8280 | 20 | 8260-8280 | 20 | 10 | 123.0 |
| 8300-8370 | 70 | 8310-8370 | 60 | 30 | 115.0 |
| 8380-8400 | 20 | 8380-8398 | 18 | 9 | 120.0 |
| 8410-8424 | 14 | 8414-8424 | 10 | 5 | 121.0 |
| 8440-8476 | 36 | 8442-8474 | 32 | 16 | 114.0 |
| 8540-8550 | 10 | 8540-8550 | 10 | 5 | 130.0 |
| 8636-8660 | 24 | 8626-8660 | 24 | 12 | 125.0 |
| 8760-8776 | 16 | 8764-8778 | 12 | 6 | 127.0 |
| 8786-8870 | 84 | 8786-8866 | 80 | 40 | 130.0 |
| 8884-8914 | 30 | 8888-8914 | 26 | 13 | 114.0 |
| 8948-8966 | 18 | 8848-8864 | 16 | 8 | 117.0 |
| 8990-9006 | 16 | 8990-9006 | 16 | 8 | 116.0 |
| 9026-9032 | 8 | 9028-9032 | 6 | 3 | 112.0 |
| 9034-9212 | 178 | 9034-9212 | 178 | 89 | 115.0 |
| 9260-9400 | 140 | 9260-9398 | 138 | 69 | 128.0 |
| 9502-9526 | 24 | 9502-9526 | 24 | 12 | 133.0 |
| 9560-9622 | 62 | 9560-9622 | 62 | 31 | 124.0 |
| 9576-9882 | 206 | 9678-9878 | 202 | 101 | 117.0 |
| 9926-10058 | 132 | 9930-10058 | 128 | 64 | 120.0 |
| 10086-10194 | 108 | 10100-10140 | 40 | 20 | 122.0 |
| 10086-10194 | 0 | 10160-10194 | 34 | 17 | 135.0 |
| 10212-10258 | 46 | 10214-10250 | 36 | 18 | 119.0 |

WELL A2-13-34-11W5 8 ELONGATIONS 7 BREAKOUTS

| ELONGATED | INTERVALS | BREAKOUT | INTERVALS | | | STRATIGRAPHIC | | INFORMATION | |
|---|---|---|---|---|---|---|---|---|---|
| 12840-12858 | 18 | 12840-12852 | 12 | 6 | 140.0 | MISSISSIPP. | 12771 | BELLOY | LST/SH |
| 12964-13010 | 46 | 12968-13010 | 42 | 21 | 135.0 | MISS. | | BELLOY | LST/SH |
| 13300-13340 | 40 | 13302-13336 | 34 | 17 | 130.0 | MISS. | | BELLOY | LST/SH |
| 13560-13582 | 22 | 13560-13568 | 8 | 4 | 159.0 | MISS. | 13552 | PEKISKO | DOL/LST/ANHY |
| 13580-13582 | 0 | 13574-13582 | 8 | 4 | 125.0 | MISS. | | PEKISKO | SHALE |
| 13700-13740 | 40 | 13714-13728 | 14 | 7 | 172.0 | MISS. | | PEKISKO | LST/SH |
| 13836-13842 | 6 | 13836-13840 | 4 | 2 | 122.0 | MISS. | | PEKISKO | DOL/ANHY |
| 15348-15358 | 10 | 15350-15356 | 6 | 3 | 136.0 | U.DEVONIAN | 15343 | CALMAR | DOL/ANHY |

ELONGATION ENDS 15358, CALMAR; TOTAL DEPTH 15497

WELL 7-17-33-7W5 31 ELONGATIONS 17 BREAKOUTS

| | | | | | |
|---|---|---|---|---|---|
| 1585-1715 | 130 | 1610-1705 | 95 | 48 | 8.0 |
| 1788-1860 | 72 | 1798-1850 | 52 | 26 | 80.0 |
| 2120-2220 | 100 | 2120-2144 | 24 | 12 | 128.0 |
| 2120-2220 | 0 | 2146-2220 | 74 | 37 | 148.0 |
| 2636-2666 | 30 | 2636-2666 | 30 | 15 | 132.0 |
| 2700-2808 | 108 | 2702-2808 | 106 | 53 | 66.0 |
| 2814-2850 | 36 | 2814-2846 | 32 | 16 | 74.0 |
| 2850-2880 | 30 | 2856-2876 | 20 | 10 | 81.0 |
| 2880-3320 | 440 | 2880-2908 | 28 | 14 | 122.0 |
| 2880-3320 | 0 | 2932-3000 | 68 | 34 | 128.0 |
| 2880-3320 | 0 | 3002-3062 | 60 | 30 | 98.0 |
| 3320-3966 | 646 | 3320-3410 | 90 | 45 | 129.0 |
| 3320-3966 | 0 | 3440-3500 | 60 | 30 | 157.0 |
| 3320-3966 | 0 | 3840-3966 | 126 | 63 | 28.0 |
| 4770-5028 | 258 | 4802-4828 | 26 | 13 | 180.0 |
| 4770-5028 | 0 | 4920-5028 | 108 | 53 | 149.0 |
| 5310-5430 | 120 | 5376-5420 | 44 | 22 | 130.0 |
| 5434-6112 | 678 | 5450-5628 | 178 | 89 | 140.0 |
| 5434-6112 | 0 | 5654-5704 | 50 | 25 | 4.0 |
| 5434-6112 | 0 | 5716-5758 | 42 | 21 | 6.0 |
| 5434-6112 | 0 | 5902-6108 | 206 | 103 | 146.0 |
| 6150-6388 | 238 | 6152-6192 | 40 | 20 | 114.0 |
| 6150-6388 | 0 | 6228-6382 | 154 | 77 | 142.0 |
| 6924-7250 | 326 | 6940-7000 | 60 | 30 | 122.0 |
| 6924-7250 | 0 | 7002-7042 | 40 | 20 | 133.0 |
| 6924-7250 | 0 | 7044-7070 | 26 | 13 | 141.0 |
| 6924-7250 | 0 | 7072-7136 | 64 | 32 | 158.0 |
| 6924-7250 | 0 | 7200-7240 | 40 | 20 | 147.0 |
| 7310-7510 | 200 | 7310-7484 | 174 | 87 | 142.0 |
| 7740-7770 | 30 | 7742-7768 | 26 | 13 | 143.0 |
| 8054-8070 | 16 | 8054-8062 | 8 | 4 | 137.0 |

BIMODAL WELLS.

WELL 15-8-116-8W5 2 ELONGATIONS 2 BREAKOUTS

| | | | | | |
|---|---|---|---|---|---|
| 4316-4328 | 12 | 4316-4326 | 10 | 5 | 86.2 |
| 4408-4474 | 66 | 4408-4438 | 30 | 15 | 172.2 |

WELL 3-1-116-1W6 2 ELONGATIONS 2 BREAKOUTS

| | | | | | |
|---|---|---|---|---|---|
| 4962-4974 | 12 | 4962-4972 | 10 | 5 | 145.4 |
| 5122-5142 | 20 | 5126-5136 | 10 | 5 | 65.3 |

TABLE 3.2

Statistics of breakout azimuths for wells listed in Table 3.1
(All lengths are in feet except where indicated)

| WELL | LOGGED | ELONGATIONS | LENGTH | BREAKOUTS | LENGTH | N | MEAN AZIMUTH(DEG) | S.D(DEG) | S.E(DEG) |
|---|---|---|---|---|---|---|---|---|---|
| 6-30-46-17W5 | 3224-12108 | 80 | 7148 | 61 | 3080 | 1540 | 145.9 | 10.6 | 0.3 |
| 7-9-48-24W5 | 1418-13939 | 144 | 8357 | 71 | 2[illegible] | 1168 | 186.7 | 21.2 | 0.6 |
| 12-19-53-8W5 | 6360-7827 | 11 | 420 | 10 | 262 | 131 | 123.6 | 2.4 | 0.2 |
| D-45-A-94-P-14 | 5650-6069 | 13 | 103 | 6 | 32 | 16 | 80.9 | 17.1 | 4.6 |
| 6-12-50-11W5 m | 481-2874.5m | 16 | 249 | 12 | 87 | 46 | 126.3 | 2.8 | 0.4 |
| 14-20-50-12W5 | 1220-9558 | 26 | 831 | 24 | 418 | 209 | 122.4 | 4.7 | 0.3 |
| 4-26-51-11W5 | 6464-912[illegible] | 2 | 56 | 2 | 52 | 26 | 119.8 | 3.3 | 0.7 |
| 3-32-47-13W5 | 9568-11494 | 28 | 758 | 23 | 526 | 263 | 131.3 | 7.8 | 0.5 |
| 6-30-56-12W5 | 10011-11830 | 13 | 318 | 12 | 242 | 121 | 133.9 | 4.1 | 0.4 |
| 10-25-46-15W5 | 10450-11335 | 13 | 298 | 11 | 204 | 102 | 148.3 | 3.8 | 0.4 |
| 16-18-52-21W5 | 9000-13452 | 15 | 514 | 13 | 292 | 146 | 124.8 | 4.5 | 0.4 |
| 10-27-45-16W5 | 13500-15407 | 20 | 2624 | 14 | 1342 | 671 | 135.3 | 2.3 | 0.1 |
| 13-9-52-8W5 | 1526-7420 | 36 | 3098 | 20 | 1462 | 730 | 137.4 | 7.5 | 0.3 |
| 5-6N-51-9W5 m | 2200-2451.5m | 11 | 75 | 8 | 30 | 16 | 134.7 | 3.8 | 1.0 |
| 6-20-50-15W5 | ----- | 46 | 1330 | 41 | 976 | 491 | 132.5 | 9.1 | 0.4 |
| 3-36-49-23W5 | 1507-18002 | 143 | 14518 | 84 | 3344 | 1672 | 151.2 | 10.6 | 0.3 |
| 6-9-51-9W5 | 5560-8024 | 4 | 2465 | 2 | 340 | 170 | 147.8 | 2.1 | 0.2 |
| 10-7-60-14W5 | 7500-8736 | 16 | 460 | 11 | 340 | 170 | 154.3 | 8.8 | 0.7 |
| 2-29-59-22W5 | 7700-12864 | 72 | 2717 | 41 | 1880 | 940 | 136.0 | 10.4 | 0.3 |
| 14-21-37-11W5 | 5084-12040e | 37 | 5016 | 30 | 3060 | 1530 | 151.0 | 4.7 | 0.1 |
| 7-7-86-1W6 | 795-7213 | 30 | 2453 | 4 | 190 | 95 | 114.3 | 3.4 | 0.4 |
| 9-18-83-6W6 | 6000-7675 | 12 | 876 | 10 | 710 | 355 | 115.4 | 4.5 | 0.2 |
| 5-5-35-11W5 | 14205-18000 | 33 | 1560 | 12 | 940 | 470 | 170.7 | 8.5 | 0.4 |
| 15-29-115-3W6 | 3500-4644 | 29 | 2215 | 12 | 690 | 345 | 0.8 | 10.2 | 0.5 |
| 6-28-115-4W6 | 4368-5205 | 5 | 165 | 3 | 60 | 30 | 153.3 | [illegible] | 0.7 |
| 12-24-82-6W6 | 4100-7079 | 19 | 1582 | 10 | 910 | 455 | 105.4 | [illegible] | 0.3 |
| 11-29-82-5W6 | 4100-7311 | 31 | 1182 | 19 | 570 | 285 | 104.4 | 10.[illegible] | [illegible] |
| 3-21-112-6W6 | 4150-4802 | 6 | 146 | 2 | 40 | 20 | 158.0 | 0.9 | [illegible] |
| 13-35-112-10W6 | 4400-6200 | 22 | 948 | 13 | 360 | 180 | 150.8 | 11.4 | 0.9 |
| 3-1-119-5W6 | 4650-5774 | 16 | 2442 | 4 | 160 | 80 | 140.4 | 15.2 | 1.7 |
| 3-11-121-7W6 | 4800-5624 | 4 | 90 | 2 | 30 | 15 | 160.0 | 0.0 | 0.0 |
| 12-33-116-8W6 | 4250-5076 | 36 | 2385 | 8 | 160 | 80 | 140.7 | 20.8 | 2.2 |
| 14-36-116-6W6 | 4200-5300 | 4 | 146 | 3 | 80 | 40 | 37.1 | 13.0 | 2.1 |
| 14-9-118-8W6 | 648-6091 | 27 | 2236 | 4 | 140 | 70 | 141.3 | 11.9 | 1.4 |
| 9-15-118-8W6 | 5042-6142 | 6 | 256 | 3 | 130 | 65 | 128.7 | 0.8 | 0.1 |
| 2-36-118-8W6 | 4600-6135 | 10 | 628 | 4 | 140 | 70 | 153.0 | 9.6 | 1.2 |
| 5-33-108-8W6 | 692-6024 | 5 | 239 | 3 | 160 | 80 | 103.4 | 14.1 | 1.6 |
| 7-18RN-108-7W6 | 4800-5888 | 12 | 188 | 9 | 140 | 70 | 13.0 | 5.4 | 0.8 |
| 10-17RN-110-9W6 | 5400-5612 | 11 | 1350 | 5 | 360 | 180 | 47.3 | 11.5 | 0.9 |
| 2-20-81-9W5 | 4000-5848 | 7 | 520 | 5 | 330 | 165 | 115.3 | 0.8 | 0.1 |
| 4-20-81-9W5 | 622-5855 | 26 | 1730 | 17 | 990 | 495 | 123.1 | 8.7 | 0.4 |
| 5-3-87-9W5 | 3200-5871 | 20 | 1610 | 9 | 620 | 310 | 97.8 | 4.9 | 0.3 |
| 4-15-81-9W5 | 4900-5927 | 7 | 446 | 3 | 70 | 35 | 116.9 | 2.5 | 0.4 |
| A9-5-82-8W5 | 5100-5590 | 4 | 88 | 3 | 40 | 20 | 67.1 | 5.0 | 1.2 |
| 3-32-34-8W5 | 4000-8430 | 15 | 3034 | 9 | 2020 | 1010 | 139.3 | 7.2 | 0.2 |
| 6-17-37-8W5 | 7100-10283 | 41 | 1886 | 39 | 1730 | 865 | 121.9 | 2.9 | 0.1 |
| A2-13-34-11W5 | UNSPECIFIED | 9 | 182 | 7 | 128 | 64 | 138.3 | 5.8 | 0.7 |
| 7-17-33-7W5 | 794-8200 | 31 | 3460 | 17 | 2204 | 1102 | 135.3 | 13.1 | 0.4 |

is given as

$$Y = a_0 + a_1.X \quad \text{------------------------------------- 3-14}$$

where $a_0$ and $a_1$ are obtained from the normal equations

$$\Sigma Y = a_0.N + a_1.\Sigma X$$

$$\Sigma XY = a_0.\Sigma X + a_1.\Sigma X^2 \quad \text{------------------------------------- 3-15}$$

which yield

$$a_0 = \frac{(\sum Y)(\sum X^2) - (\sum X)(\sum XY)}{N\sum X^2 - (\sum X)^2}$$

$$a_1 = \frac{N\sum XY - (\sum X)(\sum Y)}{N\sum X^2 - (\sum X)^2} \quad \text{------------------------------------- 3-16}$$

$a_1$ is known as the regression coefficient of Y on X. In our case Y represents the azimuth of a breakout and X the depth. To evaluate the significance of a regression coefficient one must consider the scatter or spread of points about the regression line of Y on X. This is given by the statistic *Standard Error Of Estimate of Y on X.* ($S_{y,x}$). Suppose we let $Y_{est}$ represent the values of Y for given values of X as estimated from (3.14), then

$$S_{y,x} = \sqrt{\{\Sigma(Y-Y_{est})^2/n\}} \quad \text{------------------------------------- 3-17}$$

Equation 3-17 can be written as

$$S^2_{y,x} = 1/n.(\Sigma Y^2 - a_0.\Sigma Y - a_1.\Sigma XY) \quad \text{---------------------- 3-18}$$

This standard error of estimate has properties analogous to those of the standard deviation in the sense that if lines are constructed parallel to the regression line of Y on X at respective vertical distances $S_{y,x}$, $2S_{y,x}$, and $3S_{y,x}$ from it, it is found (if n is large enough) that there would be included between these lines about 68% , 95% , and 99.7% of the sample points respectively. Now that a least square regression line has been fitted to the points, we would like to know how well a straight line fits the points or describes the relationship between the variables. In other words we want to determine the goodness of fit of the line fitted to the data. The quantity which does this is the coefficient of correlation (r). r is a dimensionless quantity which varies between -1 and +1. If Y tends to increase as X increases we have a positive or direct correlation. If Y tends to decrease as X increases we have negative or inverse correlation. If r is near zero it means there is almost no linear correlation between the variables. r can be expressed in several ways but for computational purposes we write

$$r = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{\{N\sum X^2 - (\sum X)^2\}\{N\sum Y^2 - (\sum Y)^2}} \text{ ------------------------ } 3\text{-}19$$

It is worth noting that a high correlation coefficient (i.e. near 1 or -1) does not necessarily indicate a direct dependence of the variables.

**Tests of Hypothesis and Significance**

In order for any test of hypothesis or rules of decision to be good they must be designed so as to minimise errors of decision. Obviously this is not simple at all since, for a given sample an attempt to decrease one type of error is accompanied by an increase in other types of error. However, one type of error may be more serious than another which may call for a compromise in favour of a limitation of the more serious error. The only way to reduce all types of errors is to increase the sample size which may or may not be possible.

**Level of Significance**

Rejection of a hypothesis when it should be accepted is defined as *a Type I error*. Acceptance of a hypothesis which should be rejected is defined as *a Type II error*. In testing a given hypothesis, the maximum probability with which we wish to risk a Type I error is called the *Level of Significance* of the test. It represents the probability of our being wrong in rejecting the hypothesis.

The regression equation $Y = a_0 + a_1.X$ was obtained on the basis of sample data. We are often interested in the corresponding regression equation for the population from which the sample was drawn.

$$Y_{pop} = A_0 + A_1.X_{pop}$$

If we wish to test the hypothesis that the regression coefficient of the population $A_1$ is zero at some chosen significance, we use the fact that the statistic t has Student's distribution, with (n-2) degrees of freedom, where

$$t = ((a_1 - A_1).Sx).(n-2)^{1/2}/Sy,x = (a_1 - A_1).\sqrt{\{(n-2)/(1-r^2)\}} \quad 3\text{-}20$$

Here Sy,x is the standard error of estimate of Y on X, Sx is the standard deviation of X, and r is the correlation coefficient. This fact can be used to find the confidence intervals for population regression coefficients from sample values.

In applying Equations 3-14 through and including Equation 3-20 to our data we can then compare our t values to the Student's t-distribution table (given in many statistical text books), with the correct number of degrees of freedom, and find at what level of significance the hypothesis is to be accepted or rejected.

Table 3.3 presents regression results for 21 wells in which breakouts were measured over a depth range greater than 2000 feet. Column 3 shows values for the regression coefficient $a_1$ for the sample and column 4 gives the standard error of estimate of the azimuths on depths. Column 6 shows the various t-distribution values and column 7 shows the degrees of freedom which can be used to find the level of significance at which the test can be accepted by reading the appropriate t-value and degree of freedom from tables in text books. In column 5 we have the values of the correlation coefficient.

**Results**

It is clear that the regression coefficient $a_1$ is in all wells small enough to have arisen with more than 5 percent probability, in a population having $a_1=0$. Of the 21 wells listed in Table 3.3, 10 have $a_1 > 0$ and 11 have $a_1 < 0$. We cannot reject the hypothesis that the azimuths of the breakouts are unrelated to depth and the variation observed with depth is only by chance

TABLE 3.3

Regression of breakout azimuths on depths showing the regression coefficients $a_1$ (deg/ft), the correlation coefficient r, the standard error of estimate $S_{y \cdot x}$(deg), the t-distribution, and the degrees of freedom df. (Only wells with the entire breakout intervals extending through 2000 feet depth intervals are listed here).

| Well | $a_0$ (deg) | $a_1$ (d/ft) | Sy,x(deg) | r | t | df |
|---|---|---|---|---|---|---|
| 6-30-46-17W5 | 155.57 | -0.00232 | 28.3 | -0.183 | -0.059 | 619 |
| 7-9-49-24W5 | 116.95 | 0.00112 | 45.7 | 0.087 | 0.038 | 1121 |
| 14-20-50-12W5 | 129.78 | -0.00080 | 10.8 | -0.052 | -0.011 | 199 |
| 10-27-45-16W5 | 175.12 | -0.00290 | 4.1 | -0.460 | -0.085 | 680 |
| 13-9-52-8W5 | 143.37 | -0.00242 | 19.3 | -0.203 | -0.050 | 405 |
| 6-20-50-15W5 | 281.75 | -0.01416 | 1[illegible] | -0.475 | -0.345 | 459 |
| 3-36-49-23W5 | 143.06 | 0.00042 | 28.7 | 0.062 | 0.018 | 1757 |
| 5-3-81-9W5 | 95.82 | 0.00046 | 10.5 | 0.024 | 0.008 | 308 |
| 4-20-81-9W5 | 122.32 | 0.00055 | 18.9 | 0.050 | 0.012 | 493 |
| 3-1-119-9W6 | 172.69 | -0.01128 | 30.8 | -0.489 | -0.114 | 78 |
| 12-33-116-6W6 | 144.05 | -0.00677 | 41.2 | -0.269 | -0.066 | 88 |
| 11-29-82-5W6 | 35.66 | 0.01150 | 20.2 | 0.356 | 0.200 | 263 |
| 15-29-115-3W6 | 153.81 | 0.00856 | 20.3 | 0.304 | 0.166 | 343 |
| 5-5-35-11W5 | -289.62 | 0.02845 | 19.1 | 0.716 | 0.881 | 468 |
| 9-18-83-6w6 | 164.52 | -0.00786 | 10.6 | -0.306 | -0.154 | 348 |
| 14-21-37-11W5 | 151.93 | -0.00011 | 8.1 | -0.037 | -0.005 | 1838 |
| 2-29-59-22W5 | 113.99 | 0.00178 | 22.9 | 0.115 | 0.055 | 938 |
| 3-32-34-8W5 | 167.45 | -0.00442 | 11.9 | -0.446 | -0.158 | 1022 |
| 6-17-37-9W5 | 130.71 | -0.00105 | 5.5 | -0.176 | -0.031 | 863 |
| A2-13-34-11W5 | 65.50 | 0.00553 | 14.5 | 0.194 | 0.044 | 62 |
| 7-17-33-7W5 | 72.14 | 0.01084 | 31.9 | 0.533 | 0.420 | 1073 |

# IV. BREAKOUTS AND STRESS ORIENTATIONS IN THE WESTERN CANADIAN SEDIMENTARY BASIN

## Relation of Breakouts to Location and Lithology

In Chapter III the statistical distribution of breakout azimuths has been set out. In most holes, azimuths are closely grouped together, as shown by the mean orientations of the various breakout zones within each hole (Table 3.1), and the standard deviations listed in Table 3.2. In the holes logged through a sufficient range of depth to allow investigation of regression of azimuth on depth, such regression is not significantly different from zero (see Table 3.3.). Figure [illegible] is a map showing how the azimuths change with location. The azimuth referred to is the representative azimuth of breakout for the well as a whole obtained by combining the various breakout azimuths in the well given in Table 3.2. The central dot shows the position of the hole and the mean orientation of the breakout is shown by the line through it. The number attached to the line is the mean orientation of the various sections in the well.

We now consider the relation of the breakout azimuth to the geological age (i.e. period), formation and lithology. These data are shown in Table 3.1 under the columns Formation (Fm) , Lithology (Lith), and Period (Age), and have been obtained from the sample descriptions for the wells. Sections under these columns which are blank indicate that the information was not available for those wells. It

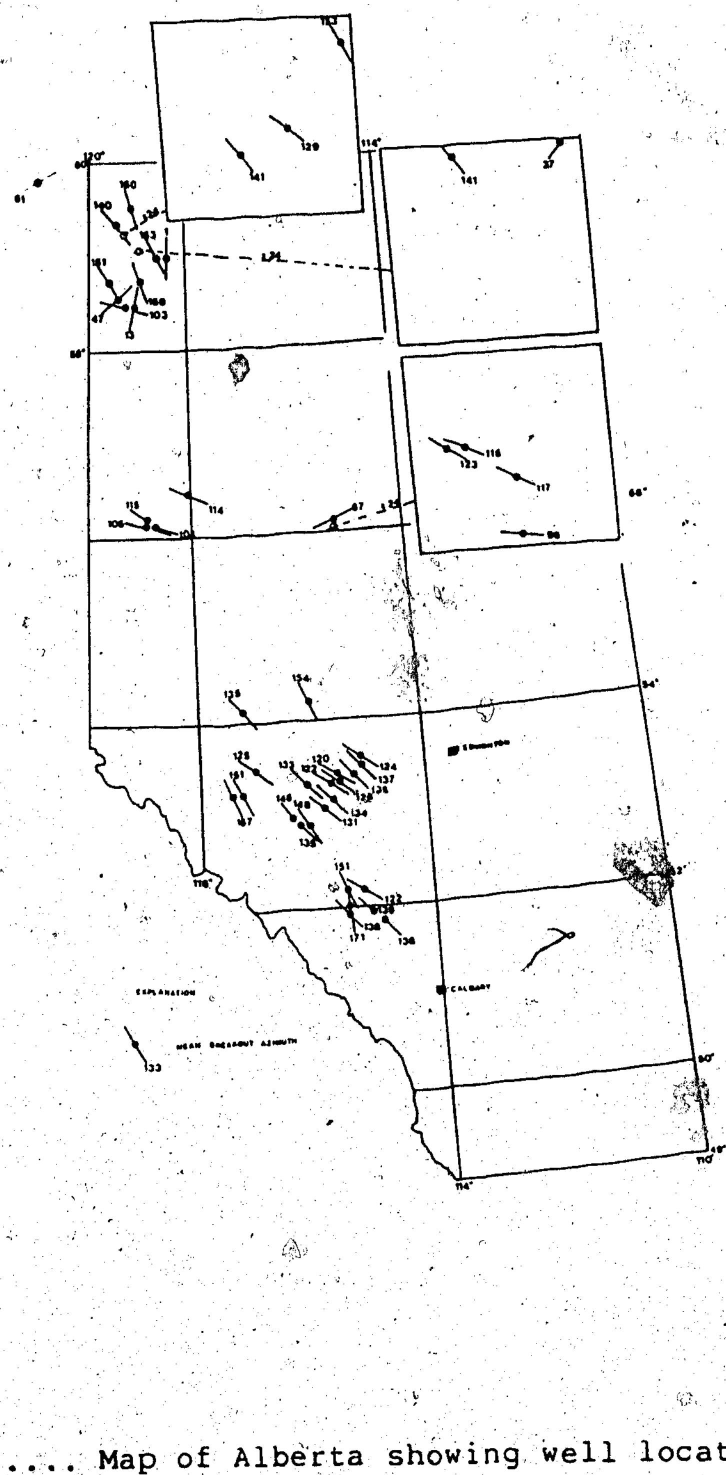

Figure 18.... Map of Alberta showing well locations and breakout azimuths

is evident, however, from these columns that breakouts have occurred throughout the sedimentary basins in rocks ranging from Devonian to Cretaceous in age. In some cases breakouts have been observed at different depth intervals running through the entire depth of the hole.

A look at the columns headed formation and lithology reveals many interesting points. Breakouts have occured in formations like Elk Point, Wabamun etc. in the Devonian right to Belly River and Bearpaw formations in the Upper Cretaceous period. Within a given formation some sections show breakouts but other sections do not, for reasons which are obscure. Breakouts may occur in any position such as the top, middle or bottom sections of the formation. The pattern does not appear to be regulated by the type of the lithology. A word of caution must be sounded here. The sample descriptions from which our stratigraphic information was obtained merely stated the predominant lithologies found and only stated the traces present but not the percentages of these traces. A knowledge of the percentages of such traces would be useful in view of the fact that there are several diagenetic processes involved in the transformation of unconsolidated sediments to consolidated sedimentary rocks. However, there are formations in which only one kind of lithology, without any traces, runs through the entire depth range in which breakouts occur in certain depth intervals separated by uncaved intervals.

Although the elongated sections which did not satisfy our three criteria for selecting a breakout are not included in Table 3.1, a careful study of the ages, formations, and lithologies of these zones was carried out. The entire study shows that breakouts are not lithologically controlled. They have occurred through most parts of the Western Canadian sedimentary basin cutting through limestone, dolomite, shale, sandstone, anhydrites, cherty shales, siltstone, and varying combinations of these sedimentary rocks. At the same time, the intervening zones without breakouts have exactly the same types of lithology as already listed. It can therefore be safely concluded that the breakouts and/or elongated zones are not significantly related to the lithology and age of formation. There is no evidence of any significant relation between breakout azimuths and the properties of the rock.

This agrees with the observation of Babcock (1978) on a smaller sample of breakout data. The logs used in this study give no indication of the dip angles of the various strata. This study therefore cannot add to the evidence given by Cox (1970) and Babcock (1978) that the breakouts and their azimuths are unrelated to the dip.

There are two wells included in this study in which the two breakout zones selected using the three criteria have azimuths approximately orthogonal to each other. These wells are included in Table 3.1. Some other wells have one or two intervals with breakout azimuths differing by as much as 90°

from the dominant azimuths. Such wells have not been referred to as bimodal wells. This study has shown that whatever their cause, a predominant direction of breakout is almost always present. Variations in this direction with position may represent local variations in the orientation of the horizontal stresses.

Pore water pressure $P_w$ and the pressure $P_m$ in the drilling mud which fills the hole were also disregarded in the discussion in Chapter II. These have no effect on the orientations of the fractures (Gough and Bell, 1982) nevertheless, they modify the magnitude of the stress differences. At points P and Q (p, q) of figures 12 and 13

$S_r = P_m - P_w$ and the tangential stress is

$S_\phi = 3S - s - P_w$ and $T_{r\phi} = 0$.

Thus the stress difference becomes

$S_\phi - S_r = 3S - s - P_m$ .

The Mohr circle Fig. 10 contracts in diameter by $P_m$ and moves to the left by $P_w$. $P_w$ is often lithostatic and cannot be less than hydrostatic, so that $P_m$ may often be comparable to $P_w$. The shear strength $T_0$ required to resist failure will be reduced somewhat as a result of the shift of the Mohr's circle to the left and the nature of the envelope. The shift of the circle to the left implies a reduction of the stresses, in a biaxial stress field, needed to cause failure.

## Hydraulic Fracturing

In-situ measurement of stress by hydraulic fracturing can both provide the orientation and magnitude of the principal components of stress, if $S_3$ is not vertical (Kehle, 1964 ; Fairhurst, 1964), provided the fracture pressure, the instantaneous shut-in pressure (ISIP), the pore pressure and the tensile strength of the rock are measured. Hydraulic fracturing is a petroleum engineering technique carried out at depths of several thousand feet to stimulate production of oil bearing horizons. An understanding of the basic principles which govern the development of the fractures is a prerequisite to its successful application. It is assumed that the hole is drilled parallel to one regional principal stress usually the vertical stress $S_v$, which is assumed to be equal to the lithostatic load $\rho$.g.h. The stresses S and s normal to the hole axis are then the other two principal stresses and are horizontal. The pre-existing regional stresses produce stress concentration close to the borehole with the maximum value of (3S-s) and a minimum of (3s-S) in the tangential direction. The smallest tangential stress of (3s-S) at the ends of the diameter parallel to S may be greater than, or equal to, or less than zero depending on the S/s-ratio. If a section of the hole is sealed and pressurized to a pressure p, a second stress system will be superimposed on that just described. In the region close to the packers, Kehle (1964) assumed that the packers are held in place by a band of uniform shear stresses and made an analysis to determine these stresses. His results indicate that high tensile vertical stress of the order of the applied pressure (-p) is induced in the immediate vicinity of the packers, and in about 80% of the central region of the interval a tangential tensile stress is generated. If however inflatable packers are used to seal the hole a normal pressure will be exerted resulting in a considerable reduction of the axial tension and will require a much higher pressure for the initiation of horizontal fractures. Before such high pressures are reached a fracture will be initiated vertically (Zoback et al, 1977). As the pressure in the hole is increased a fracture will be initiated at the wall of the borehole when the tension generated by the fluid is sufficient to overcome the combined effect of the regional compression (3s-S) and the rock strength. The plane along which a fracture will commence will be that across which the resultant of the effective compressive and tensile strengths are first reduced to zero. In the case of a smooth cylindrical wellbore this plane must be vertical and perpendicular to the least principal regional stress. If the vertical stress is the minimum principal stress a horizontal tensile fracture might be expected to form (Kehle, 1964; Hubbert and Willis, 1957) However, Zoback et al (1977) have argued against this. This contention of Zoback et al is supported by laboratory experiments reported by Haimson and Fairhurst (1970). Haimson (1976b) suggested that if $S_v = S_3$ then induced fractures initiate in a vertical plane and then become horizontal as they propagate a few hole radii from the wall into the undisturbed regional stress field.

The breakdown pressure $P_b$ is recorded. If the pump is shut off immediately and the hydraulic circuit is kept closed an instantaneous shut-in pressure, a pressure that is just sufficient to hold the fracture open, is recorded. The theory derived by Hubbert and Willis (1957) and Kehle (1964) for fracture around a pressurized borehole is used to relate $P_b$, the breakdown pressure, the instantaneous shut-in pressure ISIP, to the in-situ principal stresses and the tensile strength, T, of the rock. For a vertical borehole, the tensile fracture should be oriented in a direction perpendicular to s, the least horizontal principal stress, at least within the immediate vicinity of the borehole, and the magnitude of s is equal to ISIP. S, the maximum horizontal principal stress, is determined from the equation

$$P_b = 3s - S - p + T \qquad \text{-----------------------------------4-1}$$

where p is the static pore pressure in the rock surrounding the borehole. T can be measured in the laboratory and p in the field. From the discussion so far it is clear that the hydraulic fracture will generally take place parallel to the maximum horizontal principal stress. Breakouts on the other hand occur parallel to the lesser horizontal principal stress or perpendicular to the larger horizontal principal stress. It is therefore, not surprising that fractures detected by the 4-arm dipmeter tool may occasionally show two trends one being a major one, if mud pressure has occasionally produced inadvertent hydraulic fracturing.

The question to be asked will therefore be, how the hydraulic fracturing comes into play? Prior to the deliberate application of hydraulic fracturing by man, its occurence has been detected during water flooding and squeeze cementation processes. Rocks have been accidentally fractured ,during grouting treatments and when high specific gravity muds have been used in drilling wells. Furthermore, it has been observed (Von Schonfeldt and Fairhurst, 1969) that formations without any measurable permeability under natural conditions have a noticeable effect of rate of loading. At a low rate of application of pressure, the formation breakdown is lower than at a higher loading rate. Such a loading rate may be likened to the varying rate at which drilling is done depending on the commercial importance of the zone being drilled. Accidental hydraulic fracturing during the drilling stage with high specific gravity mud can therefore not be ruled out. It is worth mentioning also that although the vertical stress approximates the overburden, thus implying a reduced effect of accidental hydraulic fracturing, we should not lose sight of the fact that the oil wells are restricted to sedimentary layers. Sediments are sheet-like deposits of various competency stacked one upon another. Layered sequences of unlike materials transfer stress much differently than homogeneous and isotropic materials, a phenomenon known as *arching*. Arching may also involve the reaction with time between beds of different competency and hence disrupts the uniform stress distribution with depth which is assumed under homogeneous and isotropic conditions. Such an effect creates regions of both high and low stress concentrations. As a result of the alteration of the stress distribution by arching we can expect that in the same oil field, for a given horizon, breakdown pressure can vary significantly as evidenced by the results obtained in the Gulf Coast area where vertical fractures have occured at injection pressures far less than the total overburden pressure ( Scotts, Bearden, and Howard, 1953).

Another point which may need examination is the assumption that one principal stress is vertical and that the borehole is drilled parallel to this regional principal stress. The assumption that the hydraulic fracture propagates perpendicular to the least principal stress ( Hubbert and Willis, 1957) has been supported by agreement between hydraulic fracturing , geological and seismologically determined stress field indicators (Zoback and Zoback, 1980 ) However, McGarr and Gay (1978) found that in South Africa the directions of the most nearly vertical principal stress fall within a circle of 30° about the vertical. They also mentioned that stress measurements in deep mines in Canada, the United States and in Australia support significant departures from the assumption that one of the principal stress directions is vertical. This implies that the two initially assumed horizontal stresses are not truly horizontal. Recognition of such a fact will also help in accounting for the irregular nature of fractures.

**Breakout and Stress Orientations in Western Canada**

Figure 19 shows the directions of the long axes of breakouts (or the direction of the least principal horizontal stress) and figure 20 indicates the inferred orientations of the maximum horizontal principal stresses for the results presented by Babcock (1978), by Gough and Bell (1981) and in this study, for the West Canadian Sedimentary Basin. It can be seen from this map that breakouts can serve as a useful method for mapping the various tectonic stress zones based on the stress trajectories in any given locality where directional spalling of the walls of a well are observed. The absence of significant variation of azimuths with depth, wherever these phenomena are observed, may imply that such large horizontal principal stresses are not necessarily limited to the top crustal sedimentary rocks but may be continued down into the deep and older Precambrian igneous rocks of the earth's crust

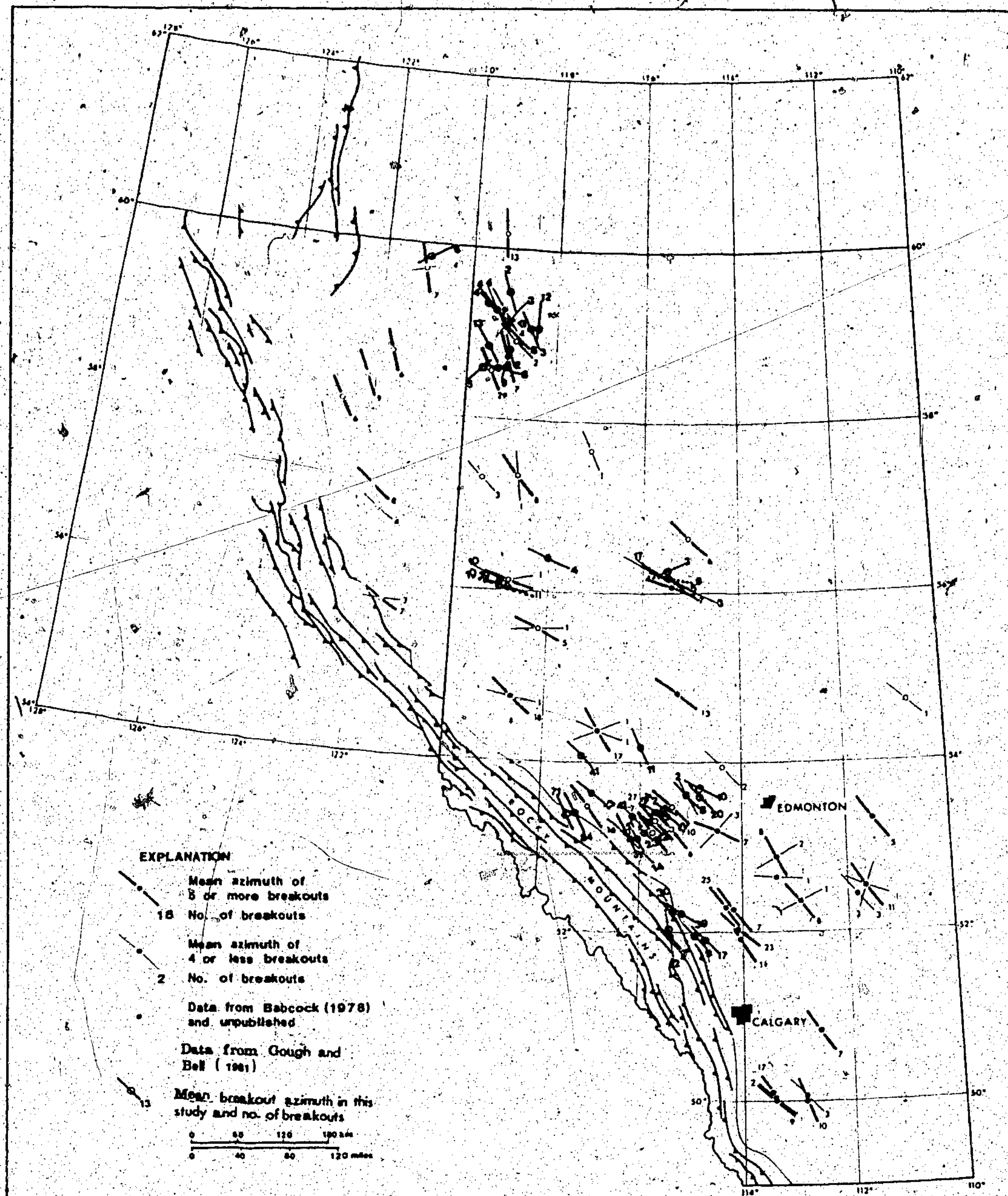


Figure 19.... Map of Alberta showing the orientations of the smaller principal horizontal stresses as inferred from the breakouts

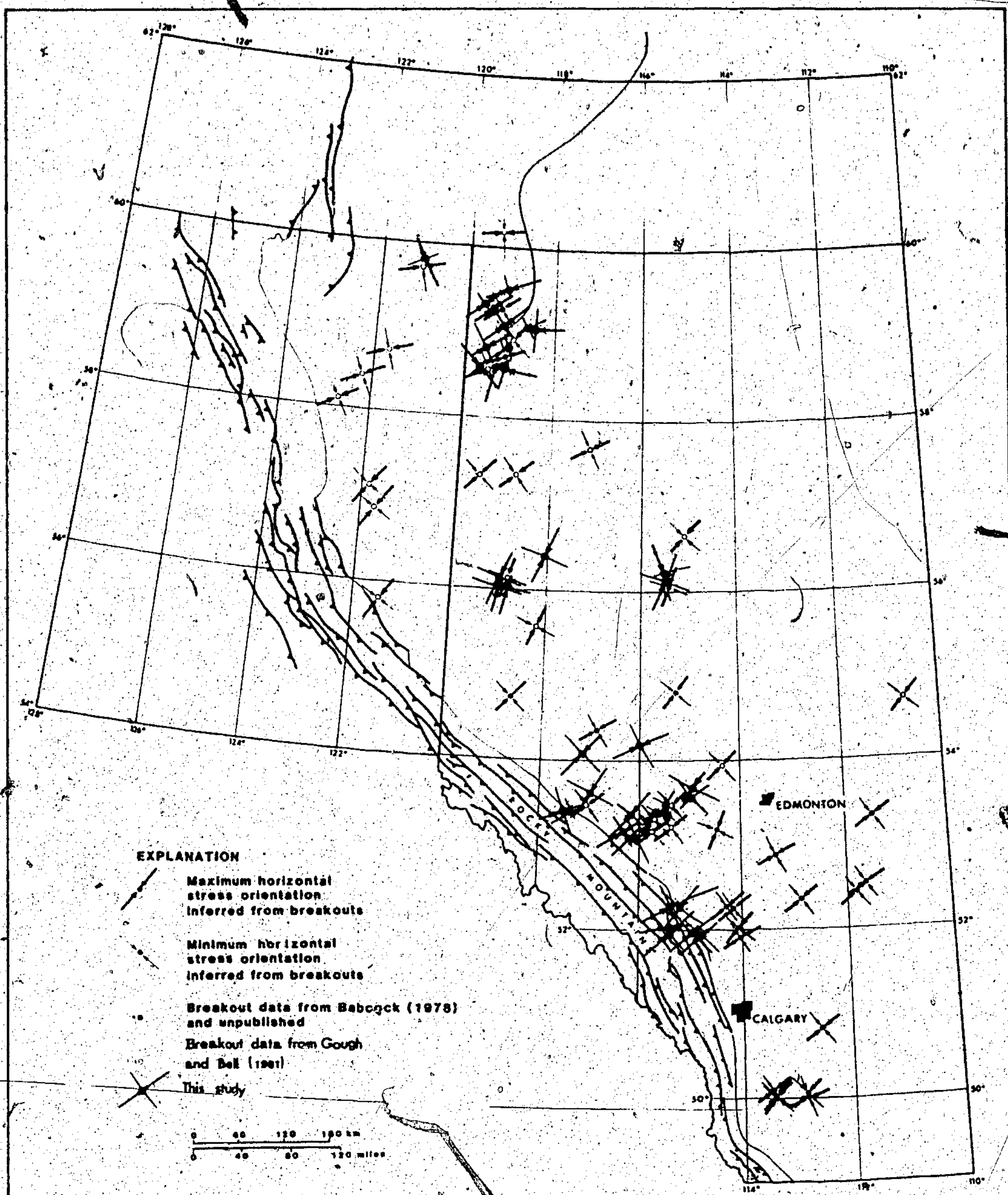


Figure 20.... Inferred directions of the larger horizontal principal stresses for the results presented by Babcock (1978), Gough and Bell (1981) and in this study

## V. DISCUSSION

### The Physical Significance of the Breakouts

Babcock (1978) concluded on the basis of his joint-sets study in Alberta (1973) that breakouts are a result of the drill encountering steeply dipping zones of pre-existing faults or joint-sets, which may or may not be open. Preferential breakage, in his view, is then controlled by a near-vertical joint which intersects the well and which in carbonate rocks may be solution-widened. In his view, the parallelism between azimuths of elongation and regional joint sets in Alberta and the consistency of the azimuths of elongation within, and between wells in varying lithologies all indicate an origin caused by the drill encountering a fracture or zone of fracture.

However, his study of joint-sets revealed four concentrations of joint directions on the surface, (NW, NE, N, and E). On a non-polar or axial data basis these four joint-sets directions may be represented as NW-SE, NE-SW, N-S, and E-W. Babcock's study of breakouts showed only one significant concentration of subsurface breakout direction that is NW or NW-SE. Bell and Gough (1979) argued that on Babcock's hypothesis the other joint directions would be expected to be represented in the breakout azimuths, but they are not. In addition Bell and Gough doubted that the joint directions at the present surface would necessarily be parallel to those at depths in excess of 2 km at which breakouts occurred, in view of the fact that sediments involved in his study might have been laid down in varying tectonic settings between Devonian and Cretaceous times and that joints in general arise in several ways; such as soon after deposition of a sedimentary rock, or during later deformation, or as it undergoes erosion. These facts led Bell and Gough to put forward an alternative hypothesis to better explain the cause of breakouts and, perhaps, also the cause of surface joints of Babcock's System 1 (NE and NW strikes). They therefore proposed that in a general stress field, with large and unequal horizontal stresses, the holes themselves concentrate the stresses so as to produce subsurface breakouts with the breakout azimuth parallel to the smaller horizontal stress and normal to the larger horizontal stress. The analysis of such stress concentration by a circular hole was first found by Kirsch and has been discussed in chapter II.

From the present study, it is observed that the significant breakout azimuth or the preferred breakout orientation is SE, that is NW-SE when expressed axially. Thus only one of the four surface joint directions is significant, although a few breakout zones tend to show the NE or NE-SW strike. In short only the NW-SE set of Babcock's System 1 of surface joints is observed as breakouts. On Bell and Gough's hypothesis that breakouts are stress controlled, the observed irregularities have been fully accounted for. Babcock's hypothesis fails to explain why breakout azimuths do not exhibit the other surface joint directions. Babcock's study also revealed that breakouts are unrelated to depth, lithology and the age of the formation. It is further observed by Babcock and in this study that breakouts are discrete, beginning and ending sharply, independently of depth, lithology and age of formation. It is very difficult to understand how breakouts can begin and end sharply, within and between formations, separated by similar lithologies with no regard to depth. In view of the various diagenetic processes involved in the transformation of the deposited sediments to consolidated sedimentary rocks from the Devonian to the Cretaceous age, which is more than $10^8$ years, one wonders how surface joints can be a reflection of subsurface joints. In fact factors like cementation, compaction, recrystallisation, and many other processes involved in diagenesis coupled with the high temperatures and duration of the tectonic stresses will modify the response of the rock to stress, while any failure remains brittle. Such variables may lead to failure in some intervals in the sedimentary column, whereas the same material in adjoining area may not fail under the existing stress field. Consequently Bell and Gough's hypothesis can account for this discrete nature of breakout occurrence in wells. The presence of pre-existing fractures would also result in enormous circulation loss, which is however very small in this region. It is known that extensive circulation loss often leads to formation damage. Such damage often requires that hydraulic fracturing be carried out, this time not just as a means of providing an increased permeability path into the otherwise tight formation, but as a means of creating a conducting channel through the damaged zones into the virgin formation. The absence of such effects as high circulation loss, damaged formation resulting from the drilling fluid escaping into the formation, and the complete absence of massive hydraulic fracturing processes in Alberta only go to support the point that pre-existing fractures of size as implied by Babcock are unlikely in the subsurface of Alberta. The only hydraulic fracturing process reported is the one at West Pembina (MacLeod, 1977). The fracturing direction is in agreement with the known theory on hydraulic fracturing and thus lends support to Bell and Gough's hypothesis (Gough & Bell, 1981). It is therefore, the present author's opinion that in the absence of positive extrapolation of surface joints to subsurface ones, Babcock's hypothesis does not account for the azimuthal alignment of breakouts. It is therefore concluded, subject to comparison with other stress measurement techniques in future, that breakouts are a result of the stress concentration by the borehole, in a general stress field having large and unequal horizontal stresses, at the walls of the hole resulting in the failure of some of the rocks. This is the hypothesis postulated by Bell and Gough.

Based on the Bell-Gough hypothesis, we find that the greatest horizontal principal stress trends N 25° E to N 60° E, with the majority occuring around N 42° E, and that the least principal horizontal stress is directed N 30° W to N 65° W, with the majority around N 48° W throughout most parts of Alberta. Sbar and Sykes (1973) have reported the greatest principal horizontal compressive stress to be trending East to Northeast in Eastern North America and in the intermountain seismic belt in Montana, Idaho and Utah the minimum compressive stress trends East to Southeast. Our result thus fits closely to the general pattern of principal stress orientations reported in the older craton of the North American continent.

**Implications of the Study**

Measurement of stress by in-situ techniques can provide both the orientations and magnitudes of the principal components of stress. Such measurement of the stress field within the crust can provide, perhaps, the most useful information concerning the forces responsible for various tectonic processes, such as earthquakes. For example Sykes et al (1972) reported the occurrence of a series of small earthquakes generated in 1971 by the high pressure injection of fluids in a salt recovery well near Dale, about 10km east of Attica in Western New York State. When the high pressure injection ceased seismic activity dropped in three days from a rate of about 100 events per day to a rate of a few events per month. The triggering of the earthquakes was attributed to the increase of fluid pressure in the rocks under high tectonic stress. Healy et al (1968) also reported the Denver earthquakes. The Rocky Mountain Arsenal disposal well, which was drilled through 3761 metres of sedimentary rocks of the Denver Basin near the city of Denver, Colorado, was intended for the disposal of waste fluids. The injection of fluid which was started from March 1962 to September 1963 was at a rate of about $2.1*10^7$ litres per month. Fluid injection ceased from October 1963 to August 1964, but was resumed under gravity from September 1964 until March 1965 at a rate of about $7.5 * 10^6$ litres per month. The rate was then increased to about $1.7 * 10^7$ litres per month until February 1966 when the exercise was terminated because of growing evidence of its connection with local earthquakes. Evans (1966) used the epicentral locations by Wang (1965) of earthquakes near the well and showed a correlation between rate of fluid injection and the earthquake frequency, with a lag of the earthquakes in the order of a few weeks behind the injection. The events which initially had epicentres less than 6 km from the well, were observed to continue with migration of the foci to the northwest. Healy et al examined the probability of a chance association, in both time and place, between the fluid injection and the earthquake swarm on the basis of the seismicity of the region and estimated this probability to be about 1 in 2.5 million. Healy et al (1968) therefore explained both the occurence of the northward migration and the occurrence of the three large earthquakes, among a series of earthquakes, of magnitude ≥5.0 to the outward diffusion from the well of a pressure front in the pore water. This diffusion would imply that the volume of rock affected by the increased water pressure likewise grows and this increased volume is thus associated with the the large earthquakes in a large volume of major strain. But it is well known that the increase of the pressure of the water in pores and cracks produces no shear stress and therefore cannot cause an earthquake. The induction process of the observed earthquakes was attributed to the presence of a nearly critical initial stress which could eventually cause failure of rock by triggering through by increase of pore water pressure as the Mohr circle is shifted to the left. This explanation is based on the Mohr-Coulomb failure theory, and the Hubbert and Rubey hypothesis of effective stress (1959) ( Healy et al, 1968; Gough and Gough, 1976; Gough, 1978).

The Rangely Experiment carried out by the United States Geological Survey at the Rangely Oilfield in Northwestern Colorado (Raleigh et al, 1972, 1976) was designed to verify quantitatively the explanation of the induced seismicity at Denver. There was an excellent agreement with the hypothesis. Raleigh et al (1976) also pointed out that this verification might have implications for the control of natural earthquakes at least in cases where it might be possible to pump water in and out of an active fault. This could possibly relieve the stress by first reducing the water pressure in wells at two points to strengthen the fault at those points, and then finally triggering an earthquake between the two points by injecting water there.

Knowledge of the state of stress is also critical to the design of underground excavations for mining and for nuclear waste disposal ( Jaeger and Cook, 1969; Gough, 1978). The massive hydraulic fracturing of formations in oil and gas fields to stimulate production is another field for which knowledge of the stress field at depth is very important. Application of stress measurements to the solution of problems in tectonics is not as straightforward as in engineering problems. The engineer is concerned with the stress field affecting the rock, whereas the geophysicist or geologist attempts to deduce the processes that might have caused the stresses. Thus the importance of the knowledge of principal stress orientations cannot be overemphasized. The use of breakouts to add principal stress orientations to the existing information on seismicity and tectonics will significantly increase the data base relevant to intra-plate earthquakes. Maps such as that shown in Figure 20 of the orientation of the horizontal principal stresses, will be of great value to engineering purposes and in addition will have important implications for the geophysics and structural geology of the area.

It must be emphasized that any attempt to relate the stress field to tectonic processes, must be based on a correct interpretation of the stress field. A variety of postglacial geologic features such as folds, faults, pop-ups, and other rock squeeze indicators may show high compressive stress in a region. Residual stresses may exist in a rock according to its history of processes such as burial, lithification, denudation, heating, cooling, and past tectonic events and may persist to some extent after the rock is freed of boundary loads ( Friedman, 1972). Such residual stresses may complicate the interpretation of stress observations. However, it would be difficult to attribute a consistently oriented stress field over a large area, as in the entire Western Canadian sedimentary basin, to residual stresses. The observed stress field almost certainly reflects tractions now acting on this part of the North American plate. The recent review by Zoback and Zoback (1980) shows that northeast-southwest horizontal larger compressions dominate the older craton of North America, as in the Northeastern United States ( Sbar and Sykes, 1973) and the Western Canadian data fit well in this overall picture.

A knowledge of the orientation of the horizontal stresses is of great importance in the planning of a hydraulic fracture program. Near-surface ore bodies can be economically mined by open pit methods. Below the practical depth of open pit mining, new mining methods must be sought and developed to make deep ore bodies available to economic extraction. Solution mining has become a major method of extracting subsurface evaporite minerals because it is both economical and efficient. Hydraulic fracturing, apart from the fact that it is the only method currently in use that enables measurement of stress to be made at large distances from a free surface, is used to develop permeable surface areas exposed to solvent for solution mining. Thus cross-connection of salt wells (and perhaps oil wells in future) by means of extending a hydrofracture from one well to the other has become a boon to the salt industry (Pullen Jr., 1958). The two wells so connected may be referred to as source and target wells, with the pressurized well from which the hydrofracture originates as a source. The target well acts in one of two ways. Ideally the target well should act like a sink so that the propagating fracture will want to intersect it. In some cases however, with the high stress concentrations around it, it may act as a barrier to the approaching fracture and most target wells act like minor sources, and thereby deflect the propagating fracture around themselves. To overcome this secondary role of the target well several techniques proposed have had promising effect. It will always be good practice to produce hydraulic fractures from the target well either before or during the major fracture attempt from the source, (Bays et al, 1960). Back fracturing has proved to be successful in several cases where a fracture connection was not successful in the original direction. It is also thought that much of the stress concentration around the target well might be reduced, if the target well were pressured up and held during the fracture operation of the source well, at a pressure less than the breakdown pressure. Crawford and Collins (1954) point out the adverse effects on the efficiency of a fluid injection project when injection and production wells are not oriented with the natural and induced fractures. If wells are properly oriented and fractures of adequate length are induced, radial flow is reduced and areal-sweep problems are minimised.

We now consider the attempt to look critically at the lithologies in this study. The phenomenon of stress redistribution at depth in layered sequences of unlike rocks, known as arching, has been mentioned earlier. Arching may also be visualised in terms of massive competent beds acting as beams to carry the load imposed by crustal stress field and thereby reduce the stress on the less competent beds. Such an effect is important to the design of any subsurface opening. Perhaps the greatest importance of arching is its influence through the stress distribution on the breakdown pressure. The object of a multiple fracturing process (multifrac) is to obtain greater fracture area through closer fracture spacing, than could be obtained from the same number of wells with single vertical fractures. This method requires substantial deviation of the wells from the vertical and, therefore both the measured well length and drilling cost per unit length are increased when compared with a vertical well. Theory predicts a vertical hydraulically induced fracture in a strike-slip stress field, and such observations as are available confirm that in the Alberta sedimentary basin hydraulic fractures are generally vertical (Macleod, 1977 ). Thus it should be possible to generate several fractures from a suitably deviated hole. Hydraulic fracturing theory predicts that fractures will propagate in a direction normal to the least principal in-situ stress or parallel to the maximum principal stress. Some experiments with non penetrating fluid indicate fractures may at least initiate parallel to the axis of the wellbore. A fracture initiated from an inclined open-hole wellbore might then result in a configuration unsuitable for the development of multiple vertical fractures. However, by casing the wellbore and perforating the casing over a small depth range, fracture initiation can be made to occur from a point or a small spherical cavity (Strubhar et al, 1975). The orientation should then be governed by the in-situ stress condition. Strubhar et al have shown experimentally that if the fractures are indeed oriented as dictated by in-situ stresses, the fractures will be sufficiently parallel and therefore be effective. The productivity index they found was two and three times that of a conventionally fractured well in the field.

**Conclusions**

It has been argued earlier in this chapter and elsewhere that the consistency of the breakout azimuths irrespective of depth, lithology and age of the formation in almost all the wells, and the fact that the breakout azimuths reflect only one out of the two joint systems of Babcock, lead to a safe conclusion that the breakouts are stress controlled or possibly both.

It is probable that some of the deviations from the generally northwest-southeast orientation of the breakouts can be attributed to local stress anomalies and some also to accidental hydraulic tensile fracturing during drilling with high-density mud. Zoback and Pollard (1978) noted that although high viscosity fluid reduces fluid penetration into pre-existing fractures or into permeable rocks, it has the disadvantage that such fluid may lead to hydraulic fractures significantly in advance of the observed breakdown in the pressure-time history.

On the hypothesis that breakouts are stress controlled, the following conclusions can be made.

1. The state of stress in the earth's crust is not in general lithostatic. There are high horizontal stresses relative to the vertical stress irrespective of depth. Tectonic conditions and the various sedimentary layers may, however, influence this state of stress.
2. Perhaps, some horizontal fractures were wrongly taken for vertical ones. Such horizontal fractures are believed to result from local inhomogeneities like bedding planes, joint-sets and the phenomenon of arching.
3. Although breakouts tend to occur in preferential directions dictated by the orientation of the regional stresses, induced vertical fractures may also be expected to have a preferential direction. In most cases

this direction is not identical to that of breakouts, but at right angles to them.

**Concluding remarks**

The consistency of the data in this region of North America and elsewhere on the continent strongly suggests that this measurement does not merely reflect local stresses but does, in fact, reflect a regional pattern. The existence of high stresses is not confined to any member of the rock formations, nor to any particular age of the formations. The phenomena of high stresses exist elsewhere in the North American continent and the world (Sbar and Sykes, 1973; Hast, 1973,1974; Lo, 1978; McGarr and Gay,1978; Gough, 1978; Zoback and Zoback, 1980) as evidenced by features like breakouts, folds, postglacial faults,and pop-ups. These stresses are probably related to the current tractions on the North American plate in the overall context of plate tectonics.

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# APPENDIX A

## A. Properties Of $\bar{\phi}$

Let $\phi_1', \ldots, \phi_n'$ be the angles obtained from $\phi_1, \ldots, \phi_n$ when the new zero direction is $\alpha$. Let

$$\bar{C}' = 1/n \,.\, \Sigma\cos\phi_i' \;;\; \bar{S}' = 1/n \,.\, \Sigma\sin\phi_i' \quad\text{------ A-1}$$

We have $\phi_i' = (\phi_i - \alpha) \bmod 2\pi$. So that

$$\bar{C}' = \bar{R}.\cos(\bar{\phi}-\alpha) \;;\; \bar{S}' = \bar{R}.\sin(\bar{\phi}-\alpha) \quad\text{------ A-2.}$$

If we write (A-2) as

$$\bar{C}' = \bar{R}'.\cos\bar{\phi}' \;;\; \bar{S} = \bar{R}'.\sin\bar{\phi}' \quad\text{------ A-3}$$

then we have

$$\bar{\phi}' = (\bar{\phi}-\alpha) \bmod 2\pi \;;\; \bar{R}' = \bar{R} \quad\text{------ A-4.}$$

Hence Equation 3-2 is satisfied. Also from (3-4) and (3-5) we have

$$\Sigma\sin(\phi_i - \bar{\phi}) = 0 \quad\text{------ A-5}$$

which corresponds to the equation in the linear case $\Sigma(X_i - \bar{X}) = 0$, i.e.the sum of deviation about the mean vanishes.

Circular Standard Deviation

. We have seen that $S_o$ lies in the range (0, 1). To relate $S_o$ to the standard deviation on the line, it is natural to use the following result for the wrapped normal distribution.

$1-S_o = e^{-\sigma^2/2}$. We can then define the circular standard deviation as

$$\sigma = \sqrt{(-2.\log_e(1-S_o))} \quad\text{------ A-6}$$

The range of is of course $(0,\infty)$. For small $S_o$, Equation A-6 reduces to $\sigma = (2.S_o)^{1/2}$. a transformation first suggested by Von Mises, 1918).