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Geology and Coal Resources of the Horseshoe Canyon Formation of Central Alberta

by

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Sample No.	Test Hole	Montmorillonite (%)	Kaolinite (%)	Illite (%)	Chlorite (%)	Additional Silicates
1	7-75	70	15	15	--	Quartz
2	7-75	100	--	--	--	Quartz
3	7-75	80	10	--	--	Quartz (10%)
5	12-75	75	5	--	trace	Quartz (20%)
6	12-75	100	--	--	--	--
7	12-75	100	--	--	--	--
8	21-75	30	55	15	5	--
11	21-75	70	10	15	5	Quartz
16	21-75	90	5	5	--	--
17A	35-75	100	--	--	--	--
18	35-75	80	5	15	trace	--
19	35-75	90	10	--	trace	Quartz
20	43-75	75	5	20	trace	--
21	43-75	100	--	--	--	Quartz
22	51-75	90	trace	10	trace	--
23	51-75	100	--	--	--	--
28	51-75	100	--	--	--	--
29	51-75	100	--	--	--	--
30	60-75	75	5	20	--	--
31	60-75	85	trace	10	5	--
32	73-75	100	--	--	trace	--
34	73-75	100	--	--	--	--
35	73-75	55	20	20	5	--
37	86-75	80	10	10	trace	--
38	86-75	85	5	10	--	--
40	86-75	100	--	--	--	--

Table 1 - Relative percentages of clay minerals in roof rock

Sample No.	Test Hole	Depth	Lithology	Permeability to Air in Millidarcy's		Porosity (Per cent)
				Kmax	Kv	
7	12-75	542'	silty shale	48.50	-0.01	1.3
16	21-75	378'	sandstone	47.90	22.10	2.1
21	43-75	384'	silty shale	23.40	-0.01	3.6
22	51-75	324'	silty shale	9.14	6.80	2.6
29	51-75	413'	shale	-0.01	-0.01	0.9

Table 2 - Permeability and porosity factors

ABSTRACT

The Horseshoe Canyon Formation includes numerous beds of subbituminous coal within the lowermost 400 to 500 feet which can only be correlated on a regional basis with great difficulty. Two coal zones are tentatively traced across much of the area. The Clover Bar equivalent is recognized as a major zone in the Edmonton area and as far south as Township 42. The Drumheller equivalent is stratigraphically lower and may be correlated from the central part of the region as far south as Drumheller.

Areas in which the best coal seam exceeds 5 feet thick are outlined. Aggregate thicknesses of coal are presented which include the sum of all seams exceeding 3 feet thick in any one section. Areas of potential coal development are defined from these presentations.

Lithofacies studies show generalized variations in facies patterns at consecutive 200-foot thick intervals above the Bearpaw Formation.

The rock strength properties of roof rock are summarized in terms of laboratory testing of core samples and log interpretation. Mapping of log results suggests a westward progression of increasing minimum rock strengths for approximately the same stratigraphic horizon.

Horseshoe Canyon coal reserves between the depths of 300 feet and about 800 feet amount to 12 billion tons for conventional underground mining or 44 billion tons for multiple seam development methods such as in-situ gasification.

INTRODUCTION

The investigation of coal resources of the Alberta plains region continued into 1975 under the auspices of Alberta Energy and Natural Resources with an evaluation of the Horseshoe Canyon Formation. Study of the formation was concentrated at depths between approximately 400 and 1000 feet in a 12,000,000 acre area between Edmonton and Drumheller (Fig. 1). One test hole was successfully drilled in each of 92 townships throughout the area and the principal data collected included gamma-ray density logs, acoustic logs, gamma-ray neutron logs, induction electric logs, drill cuttings, and core. Lithologic descriptions were made of cuttings samples during the course of drilling and representative washed and dried samples were retained. In addition, coal cuttings were sampled through major seam intervals and submitted for proximate analyses. Nine test holes located at evenly-spaced positions throughout the area were cored after pilot holes were drilled at each site to establish the most prolific coal zones. Each core was described in detail and representative coal sections were fully sampled for proximate and ultimate analyses. Results of analyses were used to prepare computer-computated logs of lithology, coal quality and rock strength parameters. Core from above and below major coal seams was extensively sampled for determination of rock strength properties, porosity-permeability factors, X-ray diffraction analyses and for cutting thin sections.

Five exploratory testholes drilled in the area in 1974 provided additional information of equal quality to that collected in 1975.

ACKNOWLEDGEMENTS

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Hi-Rate Drilling Co. Ltd. and Satellite Drilling Ltd. jointly handled drilling operations and their efficient services are acknowledged. Geophysical logging was carried out by Dresser Industries Inc. and the log computation work was directed by J. Kowalski as part of the Dresser contract. Christensen Diamond Products (Canada) Ltd. very capably supervised coring activities. Analytical work on coal samples was carried out by Cyclone Engineering Sales Ltd. M. Dusseault and P. Kaiser of the University of Alberta performed rock mechanics tests on selected core samples. Laboratory work on core samples was also carried out at the Research Council by M. Hnit and M. Baaske.

REGIONAL STRATIGRAPHY AND NOMENCLATURE

Several workers have studied that portion of the stratigraphic section referred to herein as the Horseshoe Canyon Formation. The unit was initially designated as "Edmonton" strata by Selwyn (1874) following his observations of sections in the Edmonton area. Tyrell (1886) described equivalent beds along the Red Deer River and applied the same term as a formational one. The entire succession between the Bearpaw shales and the Ardley coal zone was included in the formation which is considered to be Cretaceous in age. The most significant stratigraphic study carried out following that of Tyrell was by Allan and Sanderson (1945). In the latter work the Edmonton Formation included all strata above the Bearpaw Formation and below the basal Paskapoo sandstones (Fig. 2). The formation included over 1000 feet of beds as measured in the Drumheller area and was subdivided into three main units designated as the Lower, Middle and Upper Edmonton. The upper limit of the lower unit was established below the top of the so-called Drumheller marine tonque, a 25-foot thick zone including fossiliferous limestone beds which is widespread throughout the Drumheller area. The Lower Edmonton averages about 600 feet thick and is characterized by abundant coal seams, high bentonite content of the rocks, and considerable variation in lithology. Deltaic sediments are common at or near the base. The top of the Middle Edmonton was placed at the top of a laterally persistent tuff-bearing succession known as the Kneehills tuff zone. The middle unit is approximately 300 feet thick. Minor coal seams are present and associated beds show no exceptional features, apart from the presence of the tuff

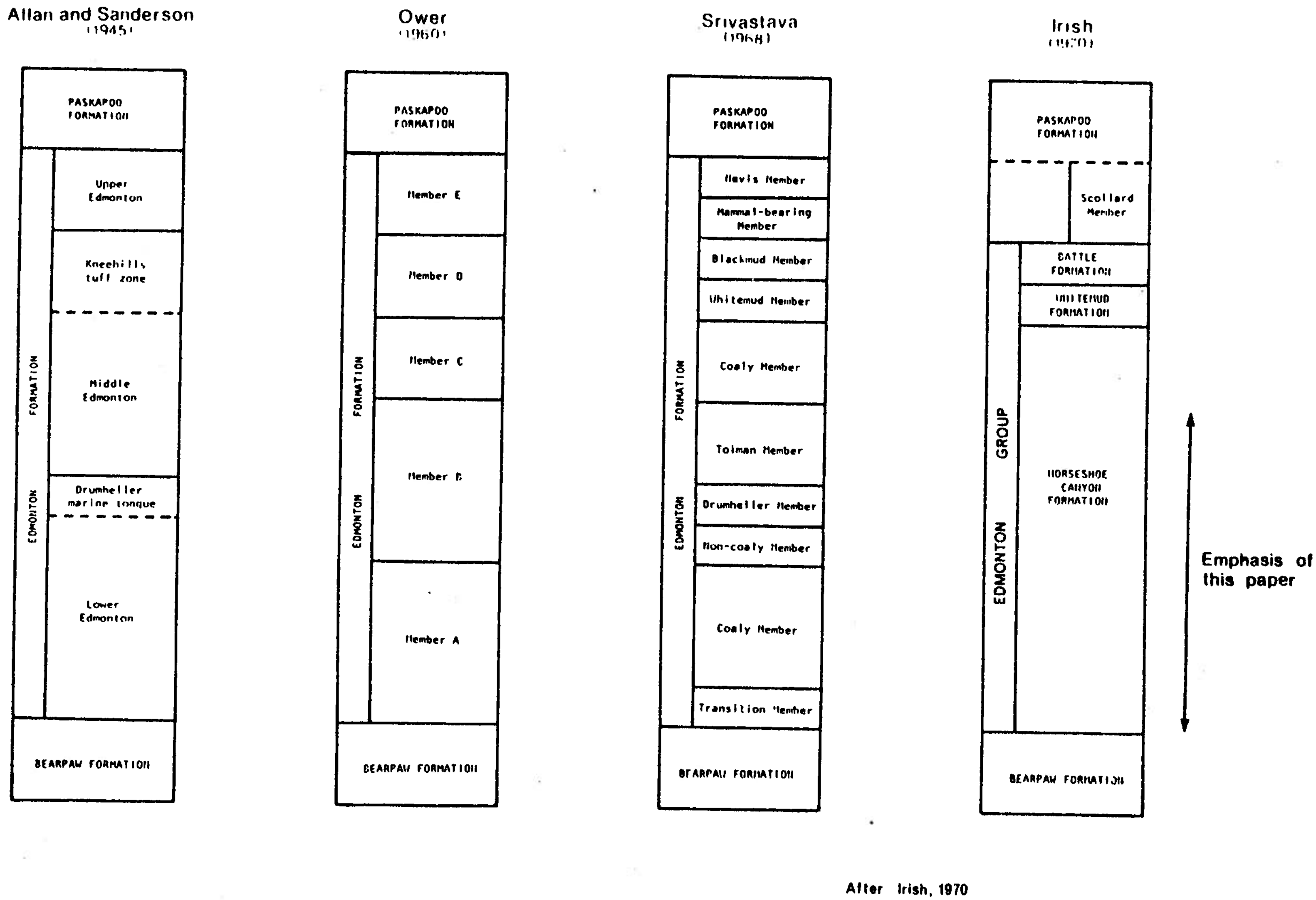

FIGURE 2. Stratigraphic Table

zone. The Upper Edmonton includes nearly 300 feet of light colored sandstones and siltstones with local argillaceous and ferruginous lenses. This unit also includes the Ardley coal zone which occurs near the top.

Ower (1960) modified Allan and Sanderson's work by règionally defining five members (Members A to E, in ascending order) from studies of outcrop and oil and gas test hole logs. The lowest member, Member A, was recognized by its abundance of coal seams and carbonaceous matter. The top of the unit was placed some distance below the Drumheller marine tonque and approximately 450 feet above the Bearpaw shale. An overlying series of strata averaging 25 feet thick included the marine tonque and was designated as Member B. Ower described the member as paler in color and finer textured than Member A. It was noted to be barren of coal. Member C is similar in lithology to Member A and was measured as approximately 85 feet thick. A seam thought to be equivalent to the Thompson seam (No. 12 seam) of Allan and Sanderson marked the top of the member. Member D is equivalent to the Kneehills tuff zone. The uppermost unit, Member E, equates to the Upper Edmonton.

Later work by Strivastava (1968) led to a further subdivision of Owers' members. The most significant change included recognizing two regionally correlative units in Member D. The Whitemud Member, a lower succession of pale-colored beds, was correlated with the type section of the Whitemud Formation established by Furnival (1946) in the Cypress Hills area. The overlying tuff-bearing, dark-colored beds were included in the newly-designated Blackmud Member.

A major revision of the nomenclature was carried out by Irish (1970). The Edmonton Formation was raised to group status and those beds above the Middle Edmonton of Allan and Sanderson (1945), Member D of Ower (1960), and the Blackmud Member of Strivastava (1969) were excluded from the group. The Edmonton Group was subdivided into three formational units. The Horseshoe Canyon Formation was established to include all strata below the Whitemud Member (previously included as the basal part of Member D or the Kneehills tuff zone). The Whitemud Member was elevated to formational status and the Blackmud Member was renamed the Battle Formation, an extension of Furnival's (1946) usage.

PREVIOUS COAL SEAM NOMENCLATURE

Specific designations have been applied to Horseshoe Canyon coal seams at several localities throughout the study area. Supplementary structural cross sections 1 to 5 (Figs. 3 to 7) illustrate the major seams documented in the literature and the relationship of such seams to exploration data and past or present mining ventures.

Beach (1934) extensively studied outcrop, mine sections and borehole records of coal seams in the Edmonton area and a summary of his nomenclature is presented in figure 3. A system of seam numbers and local names was employed and ten significant seams (Nos. 1 to 10, from base to top) were documented over a 500-foot thick basal succession of the formation. Former usages of seam nomenclature included the Lower (No. 3), Clover Bar (No. 4), Weaver (No. 7; two seams according to Taylor, 1971), Big Island (No. 9) and Rabbit Hill seams. Ower (1960) attempted to recognize the Clover Bar and Weaver seams on oil and gas test hole logs (B. A. Pyrcz No. 1 well, Lsd. 12-25-50-26W4, Fig. 3). A third major seam, the Leduc seam, was recorded in subsurface and appears to be stratigraphically higher than the highest seam of Beach. Later drilling by Pearson (1961) verfied the lateral persistence of the Clover Bar seam in the Edmonton area (TH No. 1, Sec. 13-53-23W4, Fig. 3).

Detailed stratigraphic studies in the Drumheller area by Allan and Sanderson (1945) established eleven major seams in the lower 500 feet of the Horseshoe Canyon Formation and these were numbered from 0 to 10 in ascending order. Previously existing seam designations included the Drumheller (No. 1), Newcastle (No. 5) and Daly (No. 7) seams. Two additional seams were recorded near the top of the formation (Nos. 11 and 12, or Carbon and Thompson seams respectively). Recent detailed outcrop work by Singh (1975, see measured outcrop sections, Fig. 7) shows close agreement with the interpretations of Allan and Sanderson with the exception that a seam immediately overlying the Drumheller marine tonque is included in the numerical sequence as the No. 10 seam. Allan and Sanderson failed to formally recognize this bed and instead record two seams at the No. 8 level (Nos. 8 and 9) such that their somewhat higher No. 10 seam occurs below the fossiliferous limestone strata.

Numerous informal designations have been applied to Horseshoe Canyon coal seams. For example, Campbell (1975) makes reference to the Dodds-Tofield seam (occurring in sections in Fig. 4), the Paintearth zone (Tp. 43, R. 17), and the Battle River seam (Tp. 40, R. 15; see Fig. 5). The Sheerness area coal occurrences have been referred to by Campbell (1974) as the Sheerness lens (Fig. 6).

HORSESHOE CANYON COAL MINES

Numerous small mines have produced coal from the Horseshoe Canyon

Formation over the last several decades (Fig. 8). The highest concentrations of mining activity were in the Drumheller and Edmonton areas where mines were in operation before the turn of the century. Detailed information on early coal mines is available from Allan and Sanderson (1945), Beach (1935), Campbell (1964) and Taylor (1971).

Six coal mines are presently producing from Horseshoe Canyon seams at annual rates of at least 10,000 tons each and these locations are indicated on figure 8. The Egg Lake, Star Key and Atlas mines are relatively small operations which produced 22,000, 10,000 and 40,000 tons respectively during 1974 (Energy Resources Conservation Board, 1975). The Egg Lake operation is a strip mine whereas the latter two are underground developments.

The Vesta strip mine near Halkirk is operated by Manalta Coal Ltd. and produced about 422,000 tons in 1974. The nearby Forestburg Collieries Ltd. stripping operations produced approximately 618,000 tons during the same year. Both mines supplied the majority of the total production to the Alberta Power Ltd. thermal generation plant in the area.

Manalta Coal Ltd. operates the Roselyn strip mine at Sheerness which mined nearly 36,000 tons in 1974 most of which was supplied to a thermal electric generating plant at Saskatoon, Saskatchewan.

The proposed Dodds-Round Hill mine site northeast of Camrose is scheduled for future development as a stripping operation by Calgary Power Ltd. and CamPac Minerals. It will be designed to ultimately supply a thermal electric plant in the area with up to 10 million tons of coal annually (Edmonton Journal, November 19, 1975).

Figures 3 to 7 illustrate the approximate stratigraphic relationships between the seam mined at shallow depths and those penetrated during the 1975 drilling program.

HORSESHOE CANYON COAL SEAMS

A. Structure

The base of the Horseshoe Canyon Formation (or top of the Cretacous Bearpaw Formation) proved to be the only satisfactory stratigraphic marker available for structural control both for field operations and final study purposes. However, several problems are inherent in the interpretation of the resulting map shown in figure 9. The basal buff-colored sands of the Horseshoe Canyon strata are of continental deltaic origin and commonly interdigitate with the underlying dark grey and brown marine shales of the Bearpaw Formation. In addition, the Bearpaw shales are over 400 feet thick in the southern part of the area and gradually thin and disappear to the north. As a result the Bearpaw Formation cannot be traced beyond a short distance north of Edmonton.

For purposes of this report the top of the highest occurrence of marine shale was utilized as the top of the Bearpaw Formation. This procedure respects both the final change from a marine facies to a continental one as well as the observation that few significant coal seams are present below the highest marine shale bed.

Considerable difficulty is commonly experienced in determining the top of the Bearpaw Formation. The shales are very distinctive in outcrop but seldom can be recognized with ease in wet, unoxidized drill cuttings. Gamma-ray logs normally exhibit high positive responses within the Bearpaw beds but radioactivity levels are not typically of much greater magnitudes than those of shaly successions within the Horseshoe Canyon strata. Drilling was normally terminated within the upper succession of the Bearpaw Formation resulting in a foreshortened section for study and comparison with previously-existing log data, thus presenting yet another complication towards presentation of an accurate structure contour map.

On the basis of data presented in figure 9 the basal Horseshoe Canyon beds dip west at rates of between approximately 10 and 30 feet per mile. The average rate of dip is about 22 feet per mile. Significant large structures are present such as the apparent synclinal development with 100 feet of amplitude, located across Township 40. Minor localized flexuring is common.

B. Depths of Burial

Figure 10 illustrates the variations in depth to the top of the Bearpaw Formation within the study area. The figure also approximates an isopach map of the Horseshoe Canyon Formation. Recent and Pleistocene deposits are included in the calculated isopach values. These surficial materials vary from a few feet to as much as 150 feet thick throughout the area although commonly less than 40 feet are present. The thickest Horseshoe Canyon coal seams are normally located within 200 feet of the base of the formation and a few significant seams are up to 400 feet above the top of Bearpaw shale. Figure 10 therefore serves as an indicator of maximum depth of burial of coal seams at any given location.

C. Stratigraphy

Nine test holes were cored to provide a basis for standardization of log values. Figure 11 illustrates the comparison of gamma ray-density log profiles and laboratory analyses of coal from core. Coal of relatively high quality (40 per cent fixed carbon, as received; approximately 9000 B.T.U./lb., calorific value) corresponds to log density values of about 1.75 gms./cc. Shale contents are directly proportional to gamma ray counts. Thus, the combination of gamma ray-density logs and core or drill cuttings is adequate to determine lithologies with reasonable accuracy.

Supplementary structural cross sections 1 to 5 (Figs. 3 to 7) clearly demonstrate the problems in attempting regional coal seam correlations. Early studies of stratigraphy near Edmonton and Drumheller have resulted in detailed definitions of coal seams, mainly from mine and outcrop data. However, correlation of seams to subsurface data is difficult as exemplified by the relationships shown on figure 3 between the composite section of Beach (1934) and Alberta Research TH 76-74 (N.E. 33-52-26W4), Dresser Atlas No. 1 (N.E. 28-52-24W4) and Alberta Research TH 6-75 (N.E. 17-52-23W4). The same problem prevails in the Drumheller area where correlations between established outcrop sections and subsurface data are uncertain. Figure 7 presents detailed composite outcrop descriptions by Allan and Sanderson (1945) and Singh (1975) compared with Alberta Research TH 83-75 (N.E. 9-28-18W4) and Alberta Research TH 90-75 (N.E. 21-38-20W4). Both major seams and thin beds of coal are only traceable in a sporadic manner.

Exploration programs confined to an evaluation of a single seam or zone understandably provide better opportunity for correlation work. For example, the Clover Bar seam is confidently traced from TH No. 1 (Sec. 13-53-23W4; Pearson, 1961) to Alberta Research TH 4-75 (N.E. 8-53-22W4) as shown on figure 4. A similar situation occurs in the vicinity of Halkirk. Only one major seam occurs in the area and the problems of local seam correlation are obviously simplified. Multiple seam correlation is possible in places, such as in the Dodds-Round Hill area where at least four major seams are recognizable which may be traced from shallow to deep hole data (Fig. 4).

The problems of seam recognition are compounded by the relatively broad spacing of test holes as employed in the 1975 program. In an attempt to at least show regional stratigraphic relationships, seams were arbitrarily grouped together as informal, unnamed units (Figs. 3 to 7 and 12 to 16). Significant sections of barren intervening strata separate the units and seam correlation between units were attempted wherever possible. The upper or lower limits of the coal-bearing intervals were normally based on seam correlations. As many as six such units are delineated on the lines of section provided. The variation of lateral persistence of these gross coal units across the area emphasizes the severe problems in establishing mappable entities. Several units may be traced nearly the entire length of the area, from north to south. One seam, believed to be equivalent to the Clover Bar seam of the Edmonton area, is traceable up to 90 miles with a relatively low degree of confidence. Seam splitting is very common which adds to the complexity of correlation problems. Lateral termination of seams and entire coal-bearing intervals between adjacent test holes is also common.

Figures 12 to 14 (north-south cross sections) are based on ground level as datum because of the limited value of illustrating structure parallel to the strike of bedding. Figures 15 and 16 show structure normal to the strike and are useful for illustrating additonal stratigraphic relationships. For example, Alberta Research Council test holes in figure 15 are compared with the McColl Frontenac Bigstone Creek 1-20-46-26 well (Lsd. 1-20-46-26W4) of Ower (1960). In this region the complete section of the Horseshoe Canyon Formation is over 1200 feet thick but significant seams are only observed in the lower 500 feet. A minimum of 400 feet above this is barren and the few seams recorded in the uppermost 150 feet are of no commercial importance.

Figure 16 compares 1975 test holes structurally and stratigraphically with other pertinent sections. The east end of the cross section correlates Alberta Research TH 68-75 (N.E. 20-33-15W4) with Alberta Research TH 12-62 (N.E. 12-33-14W4; from Campbell, 1974). The difficulty experienced in attempting the projection of the deep seams to the shallow drilling and outcrop occurrences is typical of the Horseshoe Canyon Formation. Alberta Research TH 21-75 (N.E. 21-33-21W4) shows a possible correlation with sections observed in the Red Deer River valley by Singh (1975). Only a thin equivalent of the Carbon or No. 11 seam of Allan and Sanderson (1945) was noted in TH 21-75. Tentative boundaries of the Whitemud and Horseshoe Canyon Formations were established in this test hole. Stratigraphically higher units may be traced farther to the east utilizing data from two Geolcgical Survey of Canada test holes (TH 2-73, S.W. 2-6-34-22W4 and TH 3-73, N.E. 8-7-34-24W4) and Alberta Research TH 1-74 (N.E. 8-32-25W4; Holter, Yurko and Chu, 1975).

Additional evidence to show the nature of the entire succession of the Horseshoe Canyon Formation in subsurface is presented in figure 6. Alberta Research TH 85-75 (N.E. 2-30-17W4) was drilled to nearly 1200 feet in depth on top of the Hand Hills in an attempt to evaluate the upper part of the formation at a location central to other tests drilled in stratigraphically lower successions. The Bearpaw Formation was not penetrated but it is unlikely that more than a few tens of feet of Horseshoe Canyon Formation are below the total depth level of TH 85-75. Comparison of the same test hole with the nearby B. A. Hand Hills 7-14-30-17 well (Lsd, 7-14-30-17W4) which was studied by Ower (1960) shows the formation to be 700 feet thick with major coal seams concentrated in the lower 400 feet. Minor thin stringers of coal are found in the upper 100 feet. Farther to the east the lower 200 feet is barren of coal (Alberta Research TH 88-75, N.E. 21-28-15W4). The Sheerness lens which is shown in the pipeline trench section (Lsd. 5-28-13W4) examined in 1975, Alberta Research TH 225-62 (N.E. 12-29-13W4) and the Roselyn mine section is apparently an anomalous development near the base of the formation.

D. Economics and Reserves

Two approaches are attempted in this study towards establishing meaningful reserve estimates of Horseshoe Canyon coal. The first method is based on the best thickness of coal intersected at any one test hole which is 5 feet or greater in thickness and bounded above and below by non-coaly beds greater than 2 feet thick. Determination of coal is based on those sections in which log computed values of fixed carbon are greater than 40 per cent(as received basis) or Densilog readings are less than 1.75 gms./cc. Intervening beds of lesser quality which are less than 3 feet thick are not included in the thickness calculations. The relative depth of the individual seams is not given separate consideration in the evaluation of the coal. The results of mapping are shown in figure 17. No attempt was made to isopach the values because of the uncertainties of seam correlations. As noted previously the Clover Bar seam in the Edmonton area may be traced with a limited degree of certainty over much of the northern part of the area. The Clover Bar seam (or seams which are closely related stratigraphically) form the best developed coal beds at each 1975 test hole site from the northern limits of drilling to as far south as Township 41, with the exception of test holes 9, 10, 13, 17 and 18. A stratigraphically higher seam is better developed at the latter locations. South of Township 41 a seam stratigraphically lower than the Clover Bar equivalent is more prominent. It appears to be approximately equivalent to the Drumheller or No. 1 seam of Allan and Sanderson (1945) and it constitutes the most important single coal succession as far south as Township 29. South of Township 29 successively higher coal seams become prominent. Test holes 90 and 93 intersected a significant coal seam higher than the Drumheller which is probably equivalent to the Newcastle or No. 5 seam.

Thin coal seams encountered in test holes 94, 95 and 96 along the south edge of the study area are stratigraphically higher than the Newcastle seam.

At least one coal seam 5 feet or greater in thickness is present within a region between Edmonton and Stettler. The best developments documented within this area are in Township 49, Range 23W4 (13 feet), and Township 44, Range 19W4 (20 feet). A smaller region between Townships 32 and 37 is underlain by at least one seam exceeding 5 feet thick and maximum developments exceed 10 feet thick (at test holes 58, 59 and 73). The Newcastle seam which was penetrated in test hole 86 appears to be here in a localized area where the coal exceeds 5 feet thick in subsurface, south of Township 32.

A second appraoch to documenting the occurrence and extent of coal seams is summarized in figure 18. All seams exceeding 3 feet in thickness were summed for each hole. The areas of prominent coal development thus defined are somewhat similar to those outlined for the best single coal seam. A region centered in Township 49, Range 22W4 is exceptionally endowed with coal (over 40 feet). Between an area east of Edmonton to as far south as Township 43 aggregate thicknesses commonly exceed 15 feet or more. Smaller areas of good development are noted to the south. One test hole in Township 39, Range 13W4 penetrated 20 feet of coal as did two other tests in Township 36, Ranges 17 and 18W4.

The areas of best seam development are outlined on figure 19. The eastern limits are arbitrarily located at 300 feet of thickness of the Horseshoe Canyon Formation and the western edge is delineated somewhat beyond the western extent of drilling. The reserve figures refer to seams at maximum depths of approximately 800 feet. An average specific gravity of 1.5 is assumed for the coal and a 15 per cent loss factor is allowed for due to undefined shale partings or similar factors. The coal reserves are estimated to be approximately 12 billion tons and as the calculations are based on a thickness of 5 feet the value is regarded as minimal.

Tonnages of aggregate thicknesses of coal are reserves of coal available for development by multiple seam production methods. A lesser minimum seam thickness of 3 feet is adopted for these calculations. Coal gasification techniques are envisioned as the means by which such reserves may be exploited. The areas which are considered to be of interest in terms of aggregate thicknesses of seams are shown in figure 19. Reserves are calculated to be 44 billion tons within areas where the total thicknesses exceed 10 feet.

Core analyses indicate the maximum quality of the coal to be Subbituminous A (12,000 B.T.U./lb., dry basis). An attempt was made to outline regions of maximum quality and establish trends of occurrence. Figure 20 shows a plot of the maximum calorific values of coal derived from drill cuttings analyzed on the dry basis. No firm conclusions may be made from the information.

LITHOFACIES STUDIES

The Horseshoe Canyon Formation was arbitrarily subdivided into 200-foot thick units at consistent intervals above the top of the Bearpaw Formation in order to evaluate lithofacies patterns (Fig. 21). The lowermost 200 feet shows a pronounced concentration of shaly and silty successions to the north in the Edmonton area (Fig. 21A). The remainder of the region is characterized by coarser beds. A localized trend towards strata represented by somewhat greater amounts of coal is mapped west of Camrose. Within an interval 200 to 400 feet above the Bearpaw Formation the Horseshoe Canyon Formation contains more shale and silt (Fig. 21B). This is in accordance with a depositional change from a transitional continental-marine (deltaic) environment to one which was almost strictly continental (alluvial). North of Stettler there are large areas in which coal facies form a considerable proportion of the succession. Figure 21C shows a generalized trend towards clastics of medium texture within 400 to 600 feet above the Bearpaw shales although sections which are very fine-grained predominate in several lo-

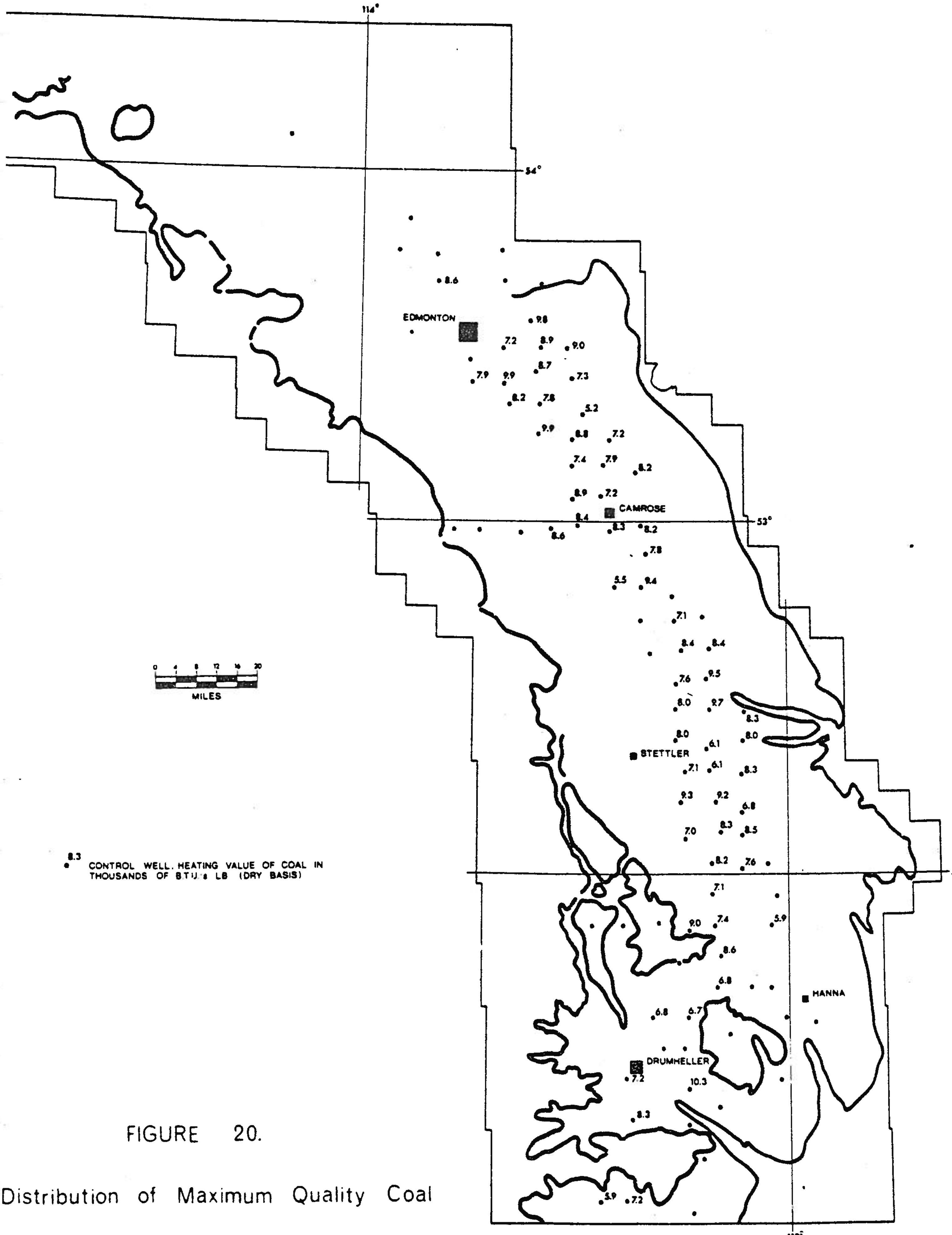

FIGURE 20.

Distribution of Maximum Quality Coal

calized areas. A few sandy successions occur along the eastern edges of the study area. No strata with large ratios of coal were delineated within this interval. Less control is available in the remaining succession, 600 feet or more above the Bearpaw Formation (Fig. 21D). There is representation of nearly all facies within the range of clastics which include little coal. No significant trends are noticeable. A lithofacies analysis of the total Horseshoe Canyon Formation (Fig. 21E) serves to show generalized trends such as concentration of finer clastics in the Edmonton area and several centres of coarser clastic development along the eastern fringes of the area. The latter areas are also ones which include slightly greater proportions of coal. The trends noted for the total thickness of the formation are largely an expression of the eastward truncation of the beds resulting in greater representation of stratigraphically lower coarse-grained and coal-bearing successions nearer the subcrop edge.

Several maps indicate relatively well developed east-west lineations although these individual features are not common to more than any two maps. North-south lineations are rare and it is therefore suggested that east-west orientated alluvial systems were responsible for deposition. The axes of river were not fixed but meandered considerably throughout the depositional history of the formation. Adjacent swamps, rich in vegetation, obviously afforded environments conducive to development of carbonaceous sediments throughout the area.

ROCK PROPERTIES

The physical characteristics of the strata were examined by means of several techniques with a view towards relating some of the qualities to mineability parameters. The non-coaly strata range from montmorillonitic shales and bentonite seams to shaly siltstones and sandstones. Bedding varies from massive to very finely laminated. Plates 1 and 2 typify rock types observed in core sections. Sandstones and siltstones are normally even-grained and feldspathic with angular particles (Plate 3). Shales contain highly variable contents of silt-sized grains and carbonaceous particles (Plate 4).

Table 1 summarizes the results of X-ray diffraction analyses of 41 representative core samples and typical patterns are given in figure 22. Most of the samples have percentages of montmorillonite exceeding 80 per cent of the total clay mineral content. A few are relatively rich in kaolinite and illite. Chlorite contents may be detected but are relatively low.

The same 41 samples were also subjected to uniaxial compression testing, the results of which are tabulated in figure 23. Stress-strain graphs are provided on figure 24 for 16 core specimens. It should be noted that curve reversals are not fully shown for the graphs because of technical problems of presentation. Several moduli were determined in the laboratory by means of both conventional testing and sonic methods. Comparison of results indicate parallel relationships of sonic-derived results and Epilog presentations for Young's and Bulk Moduli. Poisson's ratios from laboratory methods and Acoustilog calculations are also in relatively parallel agreement.

Failure strengths of the materials vary from approximately 150 p.s.i. to greater than 4000 p.s.i.. There appears to be no direct correlation between strength and rock type except in a very generalized sense. For example, sandstones appear to be of medium strength (about 500 p.s.i.

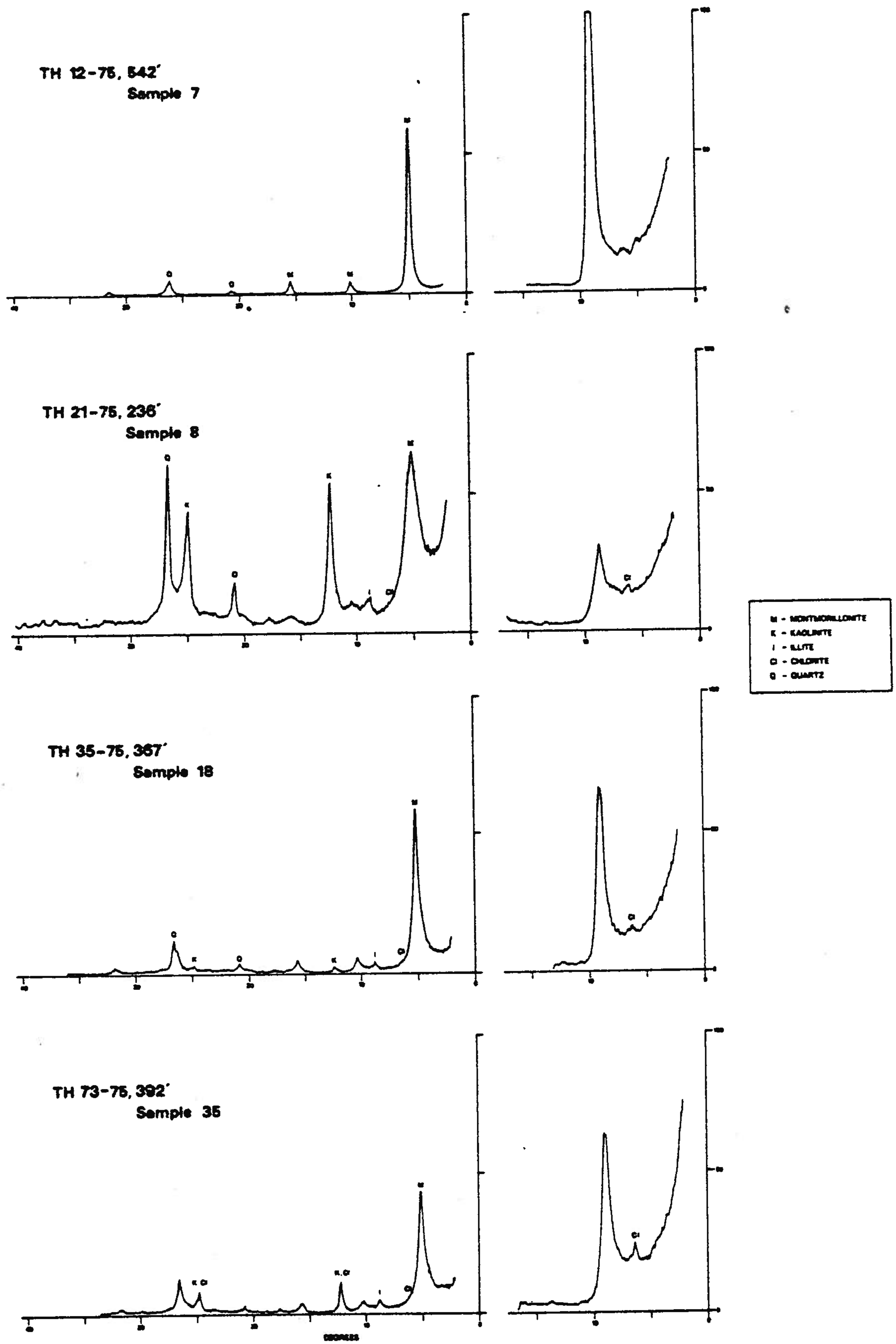

FIGURE 22. X-ray Diffraction Patterns

failure strength) and the higher values pertain to silty shales.

The Young's Moduli from Epilogs for sections 50 feet above the best coal seam were studied in some detail. Young's Modulus was chosen because of the greater amount of comparative information between laboratory and field results. The 40-foot interval above the seam was arbitrarily chosen as an optimum interval within which failure of roof rock could be anticipated. The minimum values of the modulus were recorded and mapped as shown in figure 25. There is a trend of increasing values to the west which may be an expression of greater effects of comapction and consolidation on the roof rock or, conversely, overburden loading. A similar trend is suggested for laboratory sonic readings and therefore loading effects are not suspected as the overwhelming cause of the trend.

Porosity and permeability factors of roof rock are of considerable interest for several reasons pertinent to the mineability of the coal. The ability of the strata overlying commercially important coal seams to hold and transport water or gases will dictate the operational success of both conventional underground mines and in situ gasification processes. Table 2 shows the wide variations in vertical and horizontal (or maximum) permeability as well as porosity. The information is not otherwise diagnositic, except to outline the important need to allow for the monitoring of such parameters.

SUMMARY

Two coal zones are tentatively recognized as correlative units within the Horseshoe Canyon Formation. The Clover Bar equivalent may be traced from the Edmonton area south as far as Township 42. The Drumheller equivalent occurs from the central part of the study area as far south as Drumheller. Numerous other coal zones are present in the section but these cannot be correlated with the same degree of confidence.

An area underlain by the best 5-foot-thick interval of coal (at depths between 300 and 700 feet) is outlined. Reserves of coal are estimated to be 12 billion tons. A nearly continous area between Edmonton to a region north of Drumheller is thus defined for conventional underground development.

A determination of the aggregate thickness of coal at each drill site results in several regions being outlined for multiple seam development between Edmonton and an area south of Hanna. The total reserves calculated for areas underlain by a minimum aggregate thickness of 10 feet are 44 billion tons.

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PLATES 1 - 4

PLATE 1

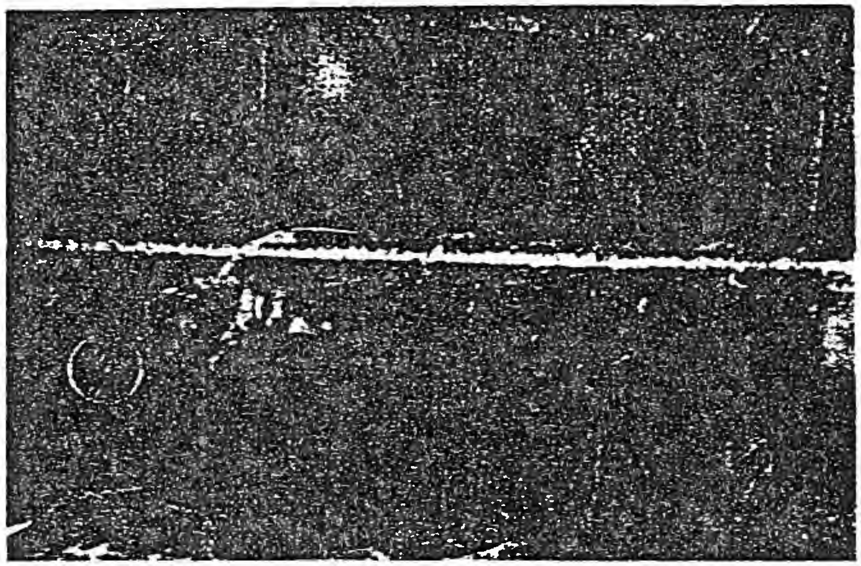

FIGURE 1 Core section of laminated siltstone, TH 73-75, 390', top of core at upper left-hand corner.

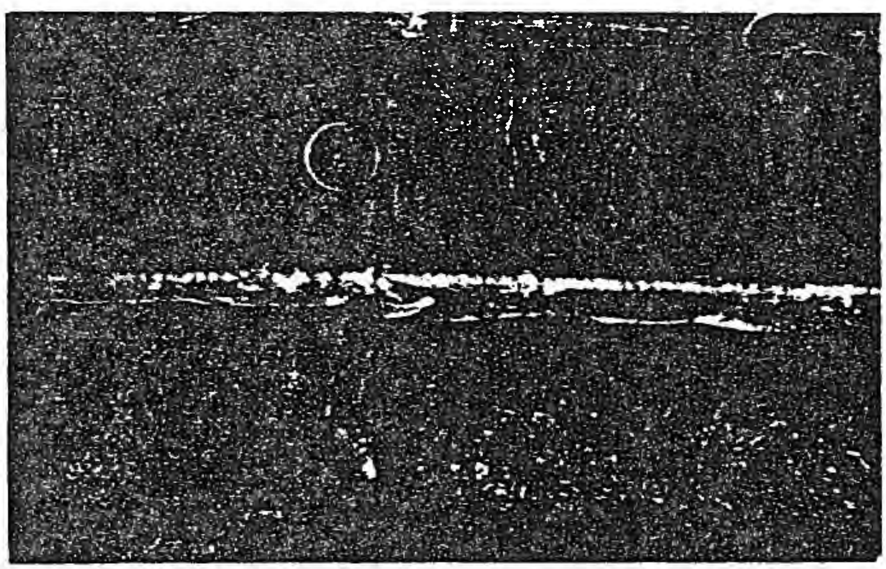

FIGURE 2 Core section of siltstone and coal, TH 73-75, 383', top of core at upper left-hand corner.

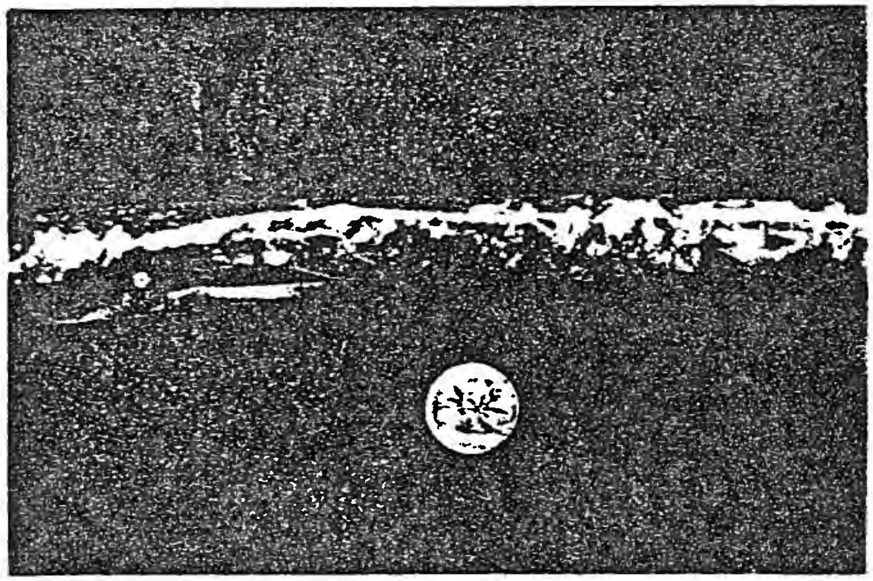

FIGURE 1 Core section of sandstone and carbonaceous shale, TH 21-75, 381', top of core at upper right-hand corner.

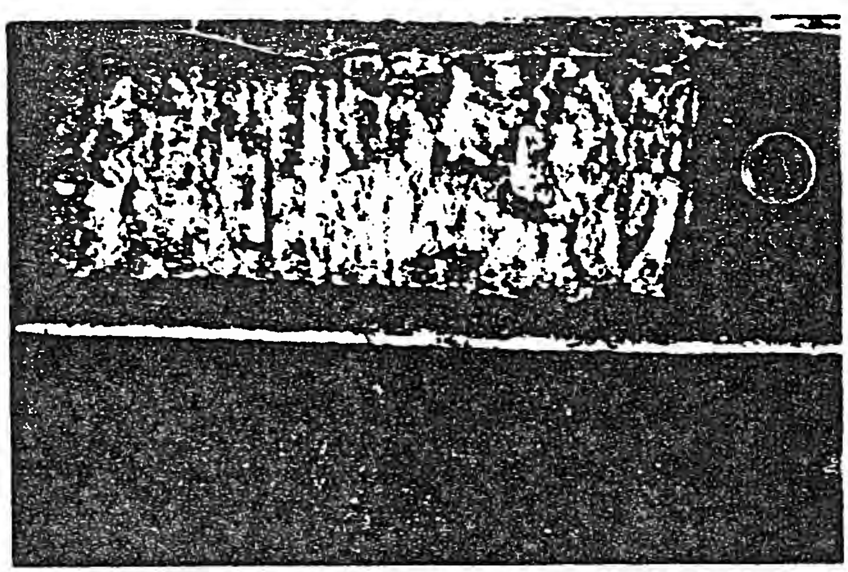

FIGURE 2 Core section of coal and bentonite bed, TH 51-75, 416', top of core at upper left-hand corner.

PLATE 3

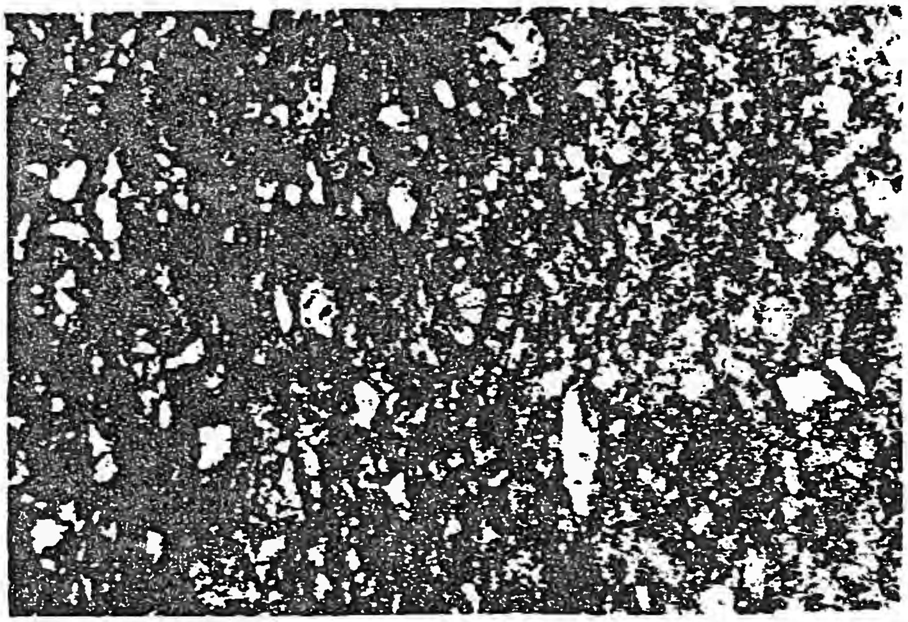

FIGURE 1 Shale with carbonaceous stringers and blebs, TH 7-75, 262' (Sample 3), 160X.

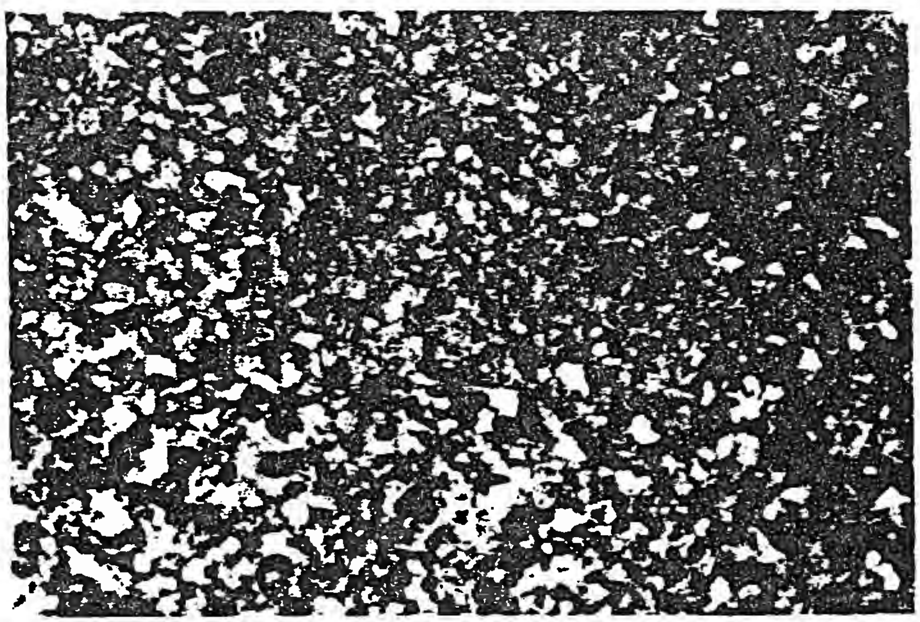

FIGURE 2 Silty shale with carbonaceous blebs, TH 51-75, 412' (Sample 28), 160X.

PLATE 4

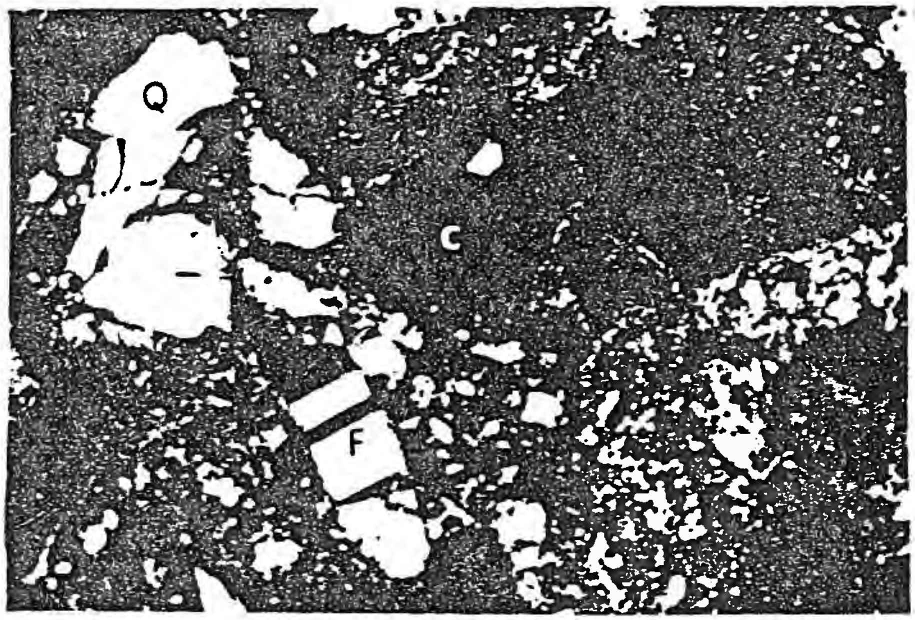

FIGURE 1 Bentonitic sandstone with quartz (Q), chert (C) and feldspar (F) grains, crossed nicols, TH 51-75, 335' (Sample 23), 160X.

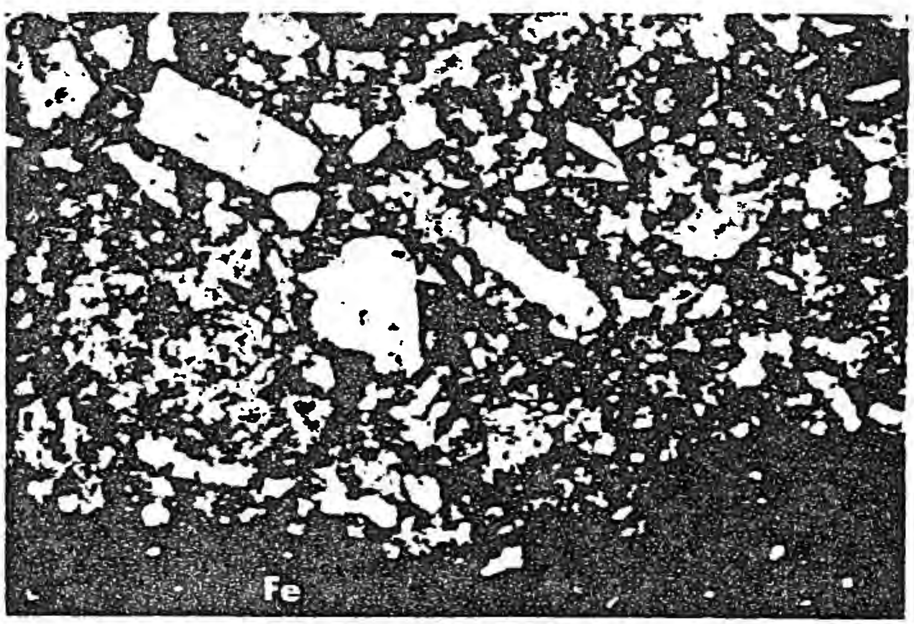

FIGURE 2 Silty and sandy shale at edge of small ironstone concretion (Fe), TH 51-75, 324' (Sample 22), 160X.

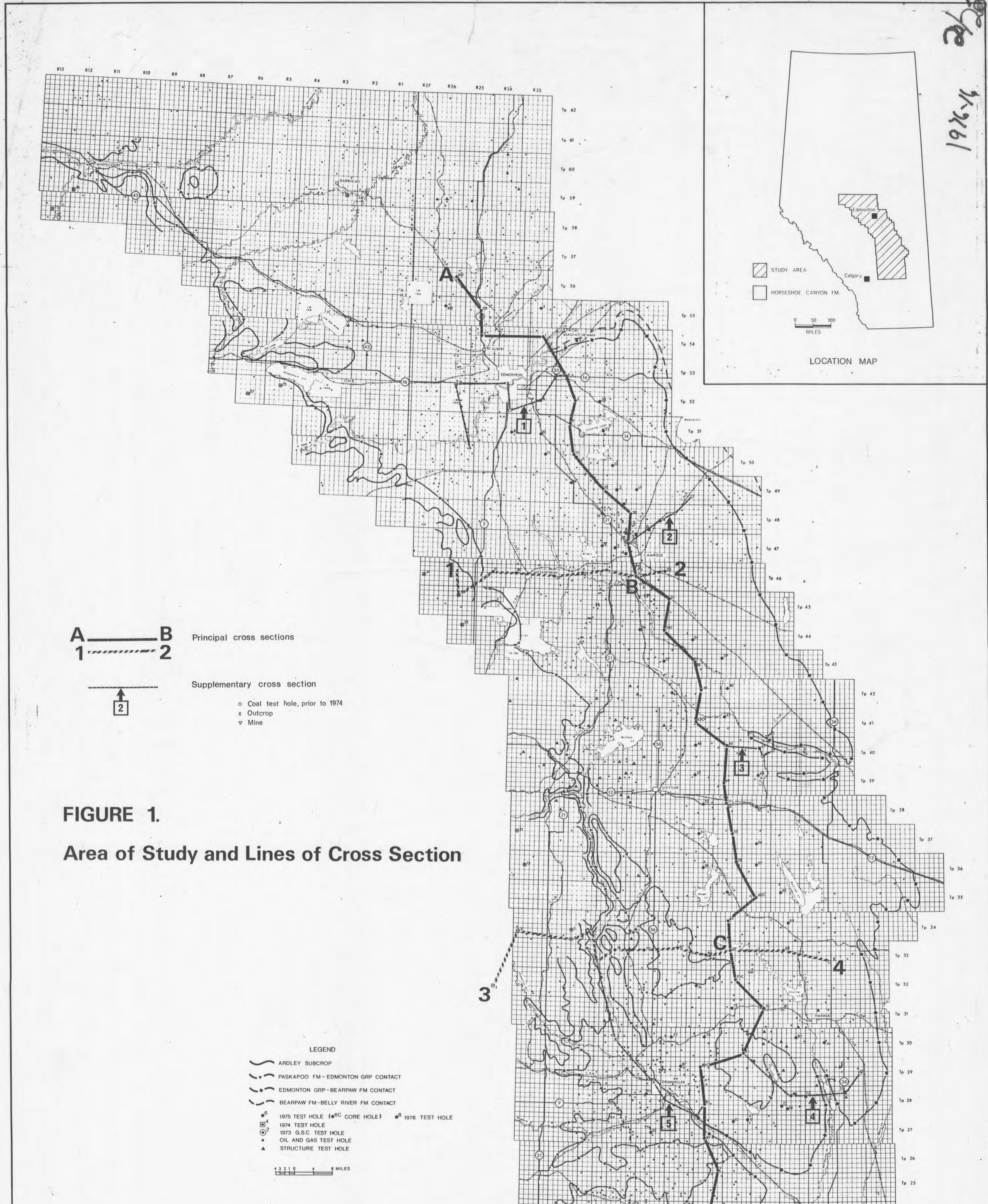

FIGURE 1.

Area of Study and Lines of Cross Section

To accompany Alberta Research Council Report by M. E. Holter, M. Chu and J. R. Yurko

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FIGURE 3.

Supplementary Structural Cross Section No. 1

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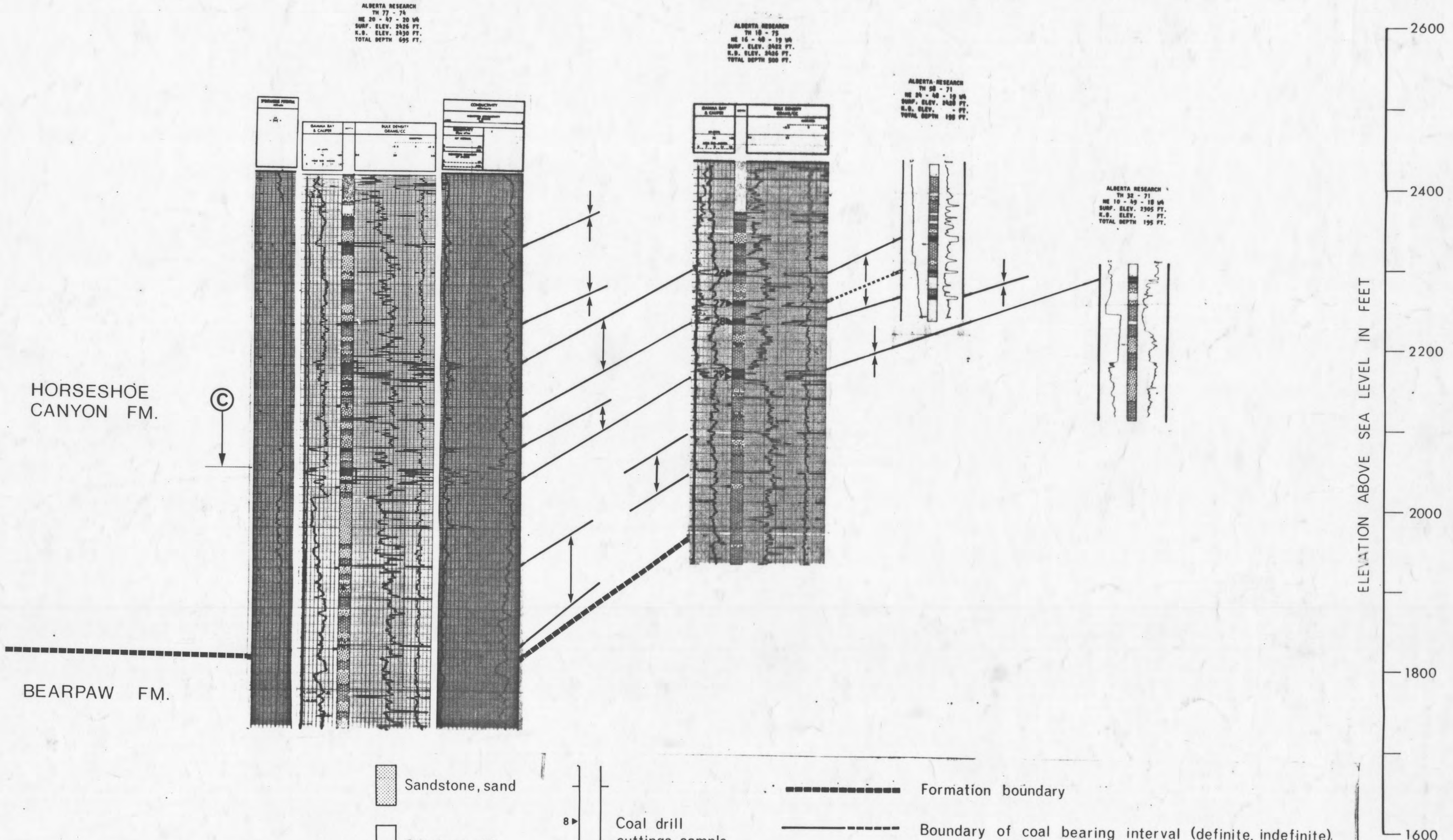
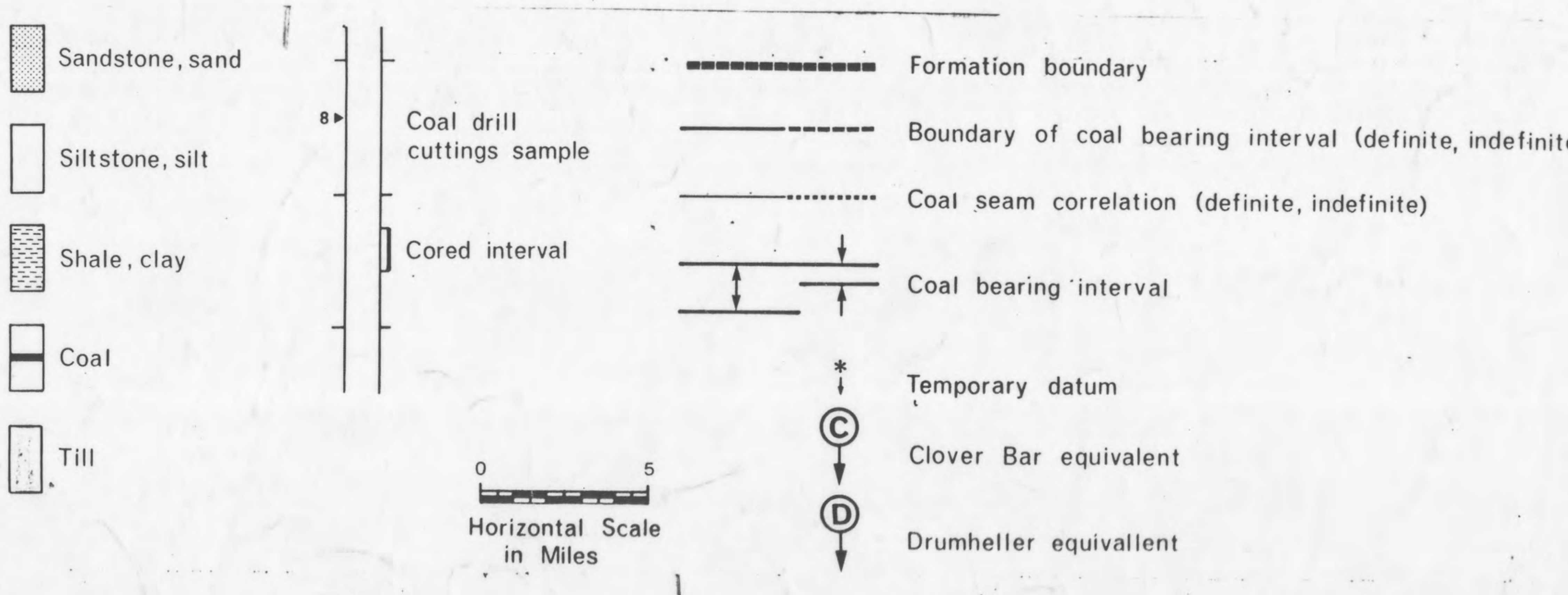
FIGURE 4.

Supplementary Structural Cross Section No. 2





To accompany Alberta Research Council Report by M. E. Holter, M. Chu, and J. R. Yurko.

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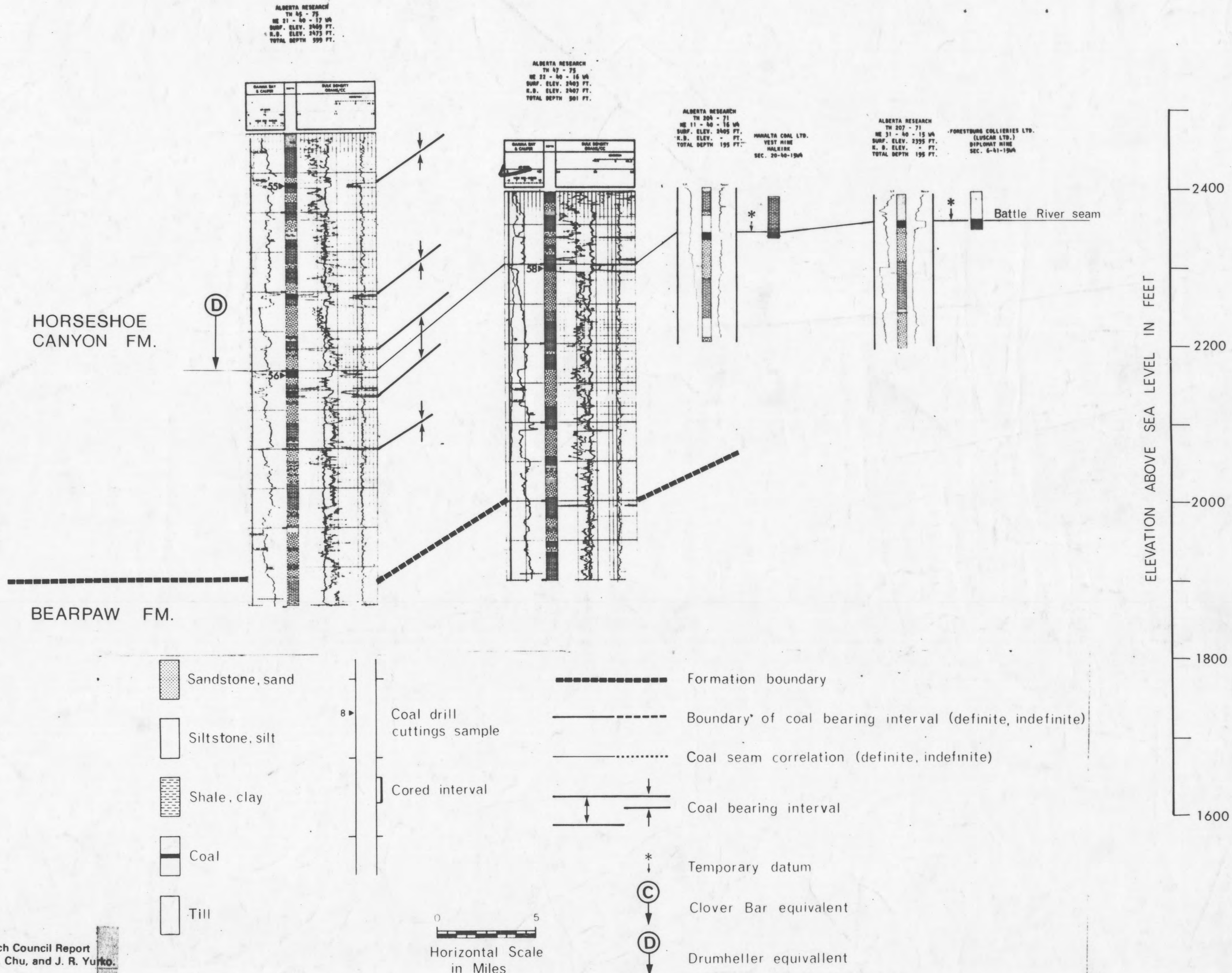
FIGURE 5.

Supplementary Structural Cross Section No. 3



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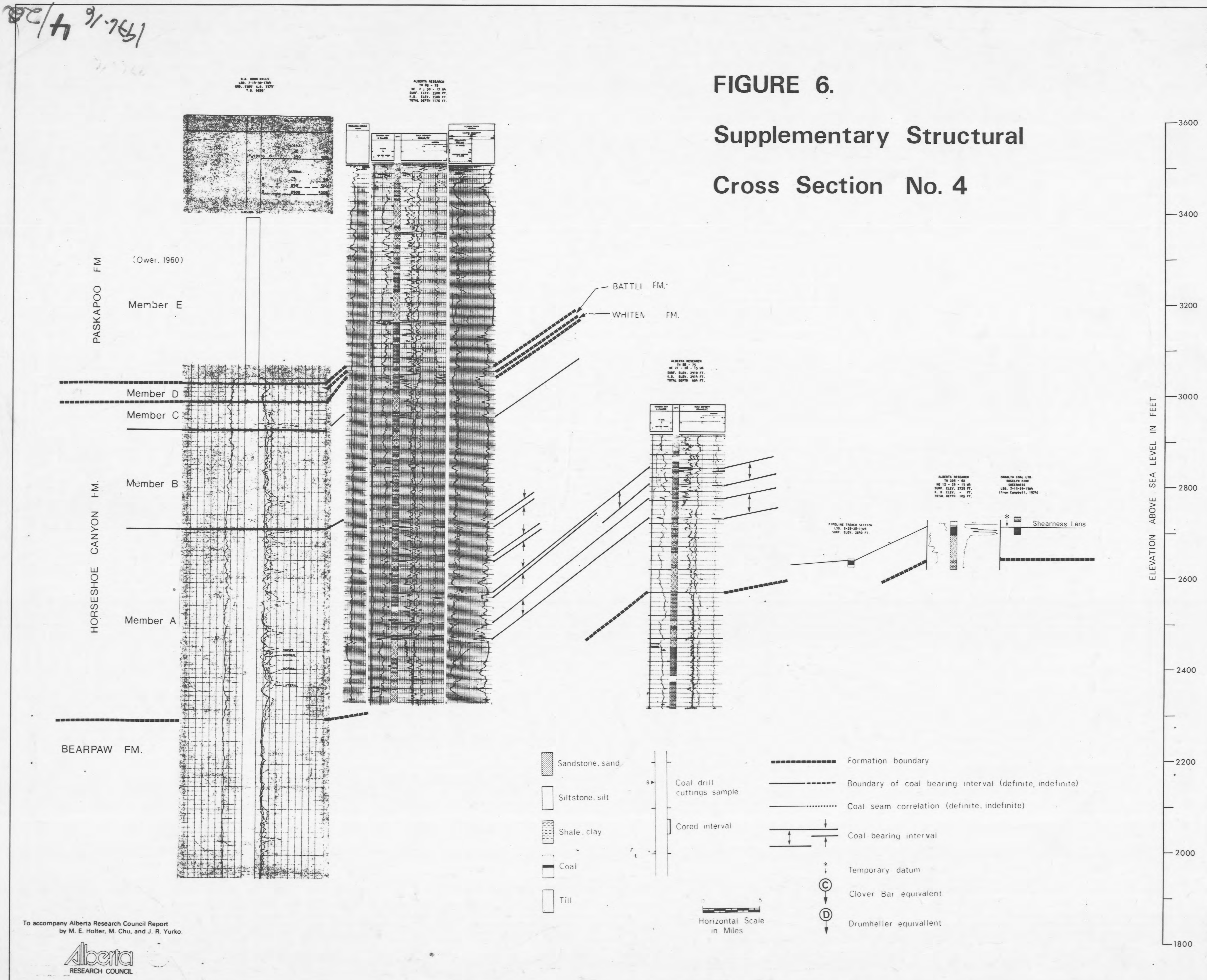

FIGURE 6.

Supplementary Structural Cross Section No. 4

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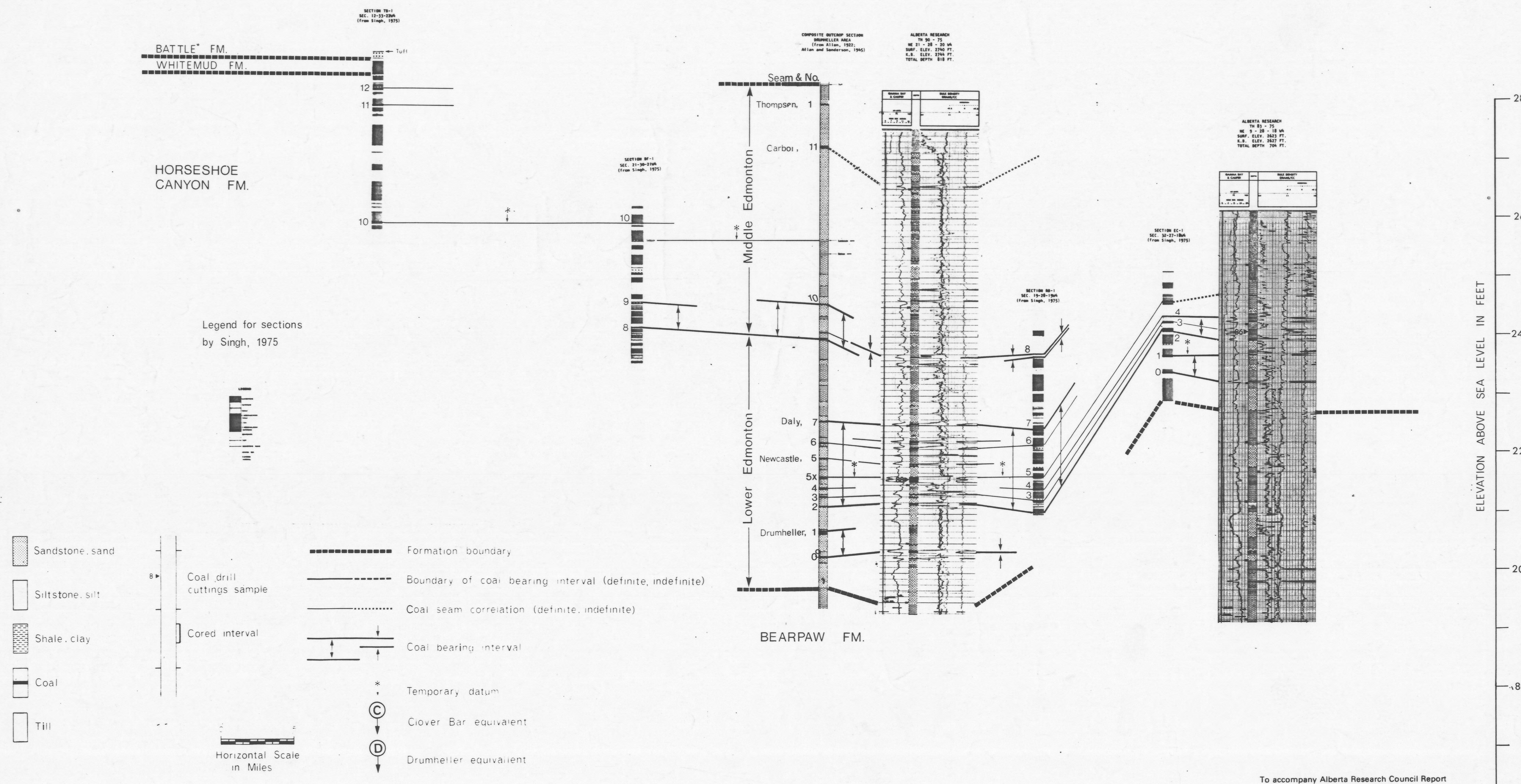
FIGURE 7.
Supplementary Structural Cross Section No. 5



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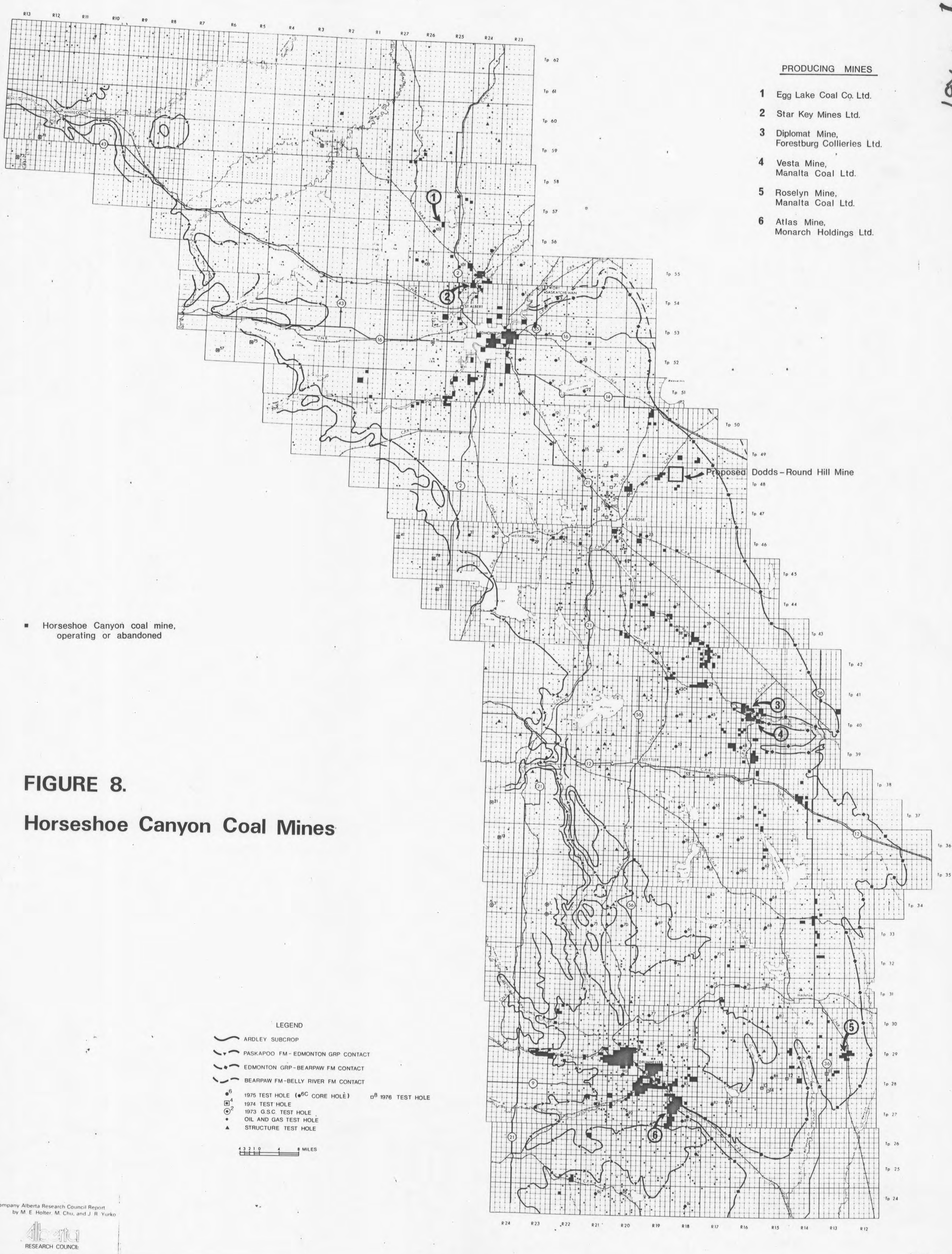

FIGURE 8.

Horseshoe Canyon Coal Mines

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1975 TESTHOLES

TH	Bearpaw Subsea	TH	Bearpaw Subsea	TH	Bearpaw Subsea
5	1958	48	2150	94	2490
6	1754	50	2297	95	2295
9	1872	51	2040	96	2116
10	1764	57	2347		
11	1626	58	2210		
12	1822	59	2066		
13	1944	60	2211		
15	1892	61	2155		
18	1964	62	2256		
19	1943	63	2126		
20	1906	64	2431		
21	1819	66	2045		
26	1846	67	2224		
33	1866	68	2467		
34	1934	73	2219		
35	1840	75	2190		
36	1799	76	2314		
37	1909	77	1996		
38	1951	78	2210		
39	1971	82	2245		
40	2011	83	2281		
42	2030	86	2250		
43	1905	87	2187		
44	1790	88	2566		
45	1908	89	2354		
46	1832	90	1940		
47	2007	91	2469		

1976 TESTHOLES

TH	Bearpaw Subsea
1	1863
2	1914
3	1764
4	1800
5	1855
7	1796
8	1836
9	2507
11	2381
12	2572
13	2577
14	2539

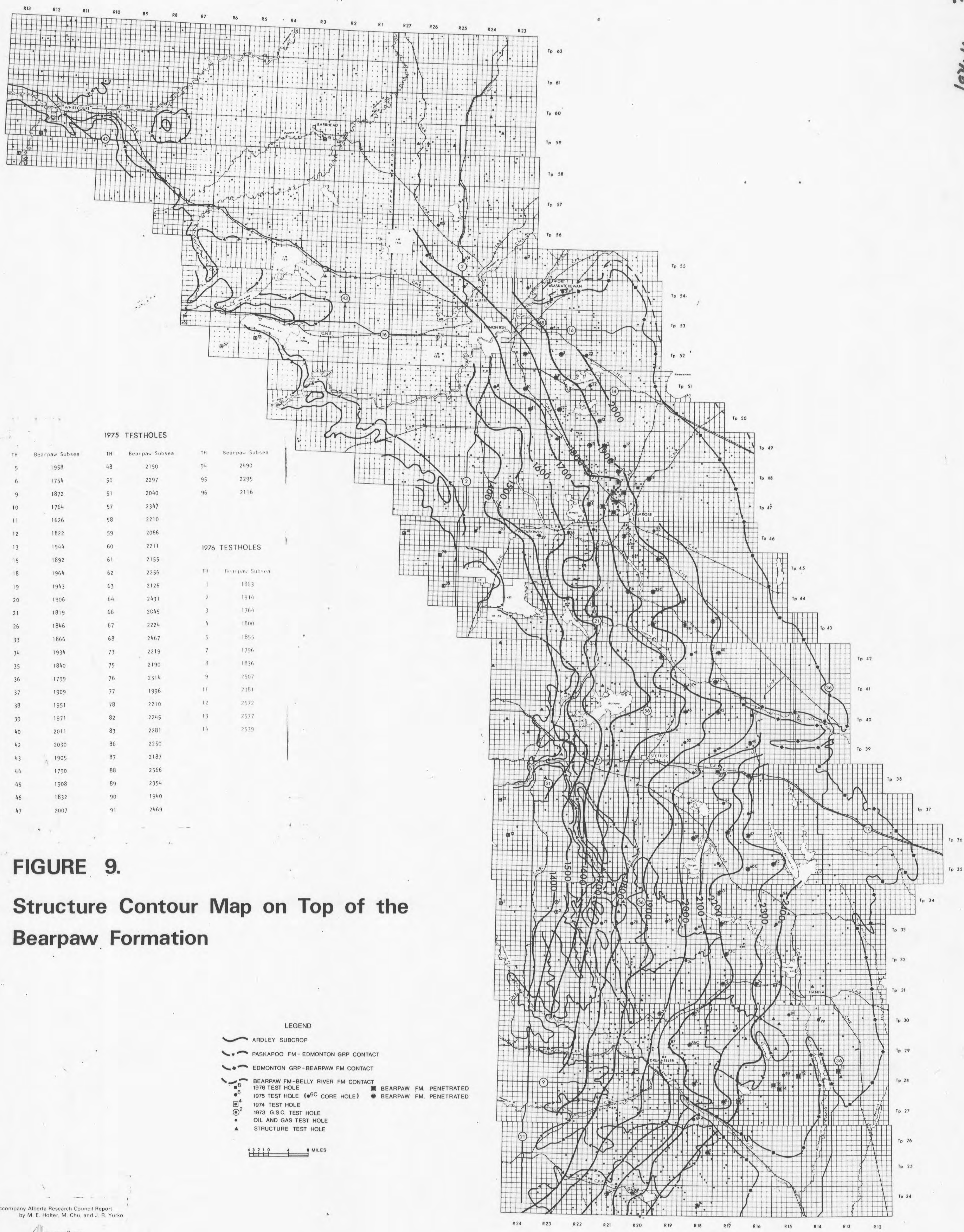

FIGURE 9.

Structure Contour Map on Top of the Bearpaw Formation

To accompany Alberta Research Council Report
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1975 TESTHOLES

TH	Top Bearpaw	TH	Top Bearpaw	TH	Top Bearpaw
5	466	48	346	94	404
6	610	50	424	95	634
9	610	51	626	96	738
10	660	57	482		
11	834	58	546		
12	722	59	660		
13	608	60	678		
15	660	61	601		
18	462	62	473		
19	716	63	646		
20	560	64	258		
21	612	66	705		
26	580	67	470		
33	470	68	352		
34	420	73	520		
35	610	75	689		
36	726	76	485		
37	672	77	706		
38	476	78	626		
39	408	82	494		
40	420	83	346		
42	412	86	614		
43	594	87	472		
44	816	88	348		
45	565	89	540		
46	682	90	804		
47	400	91	520		

1976 TESTHOLES

TH	Top Bearpaw
1	670
2	660
3	722
4	680
5	580
7	636
8	590
9	500
11	264
12	362
13	280
14	400

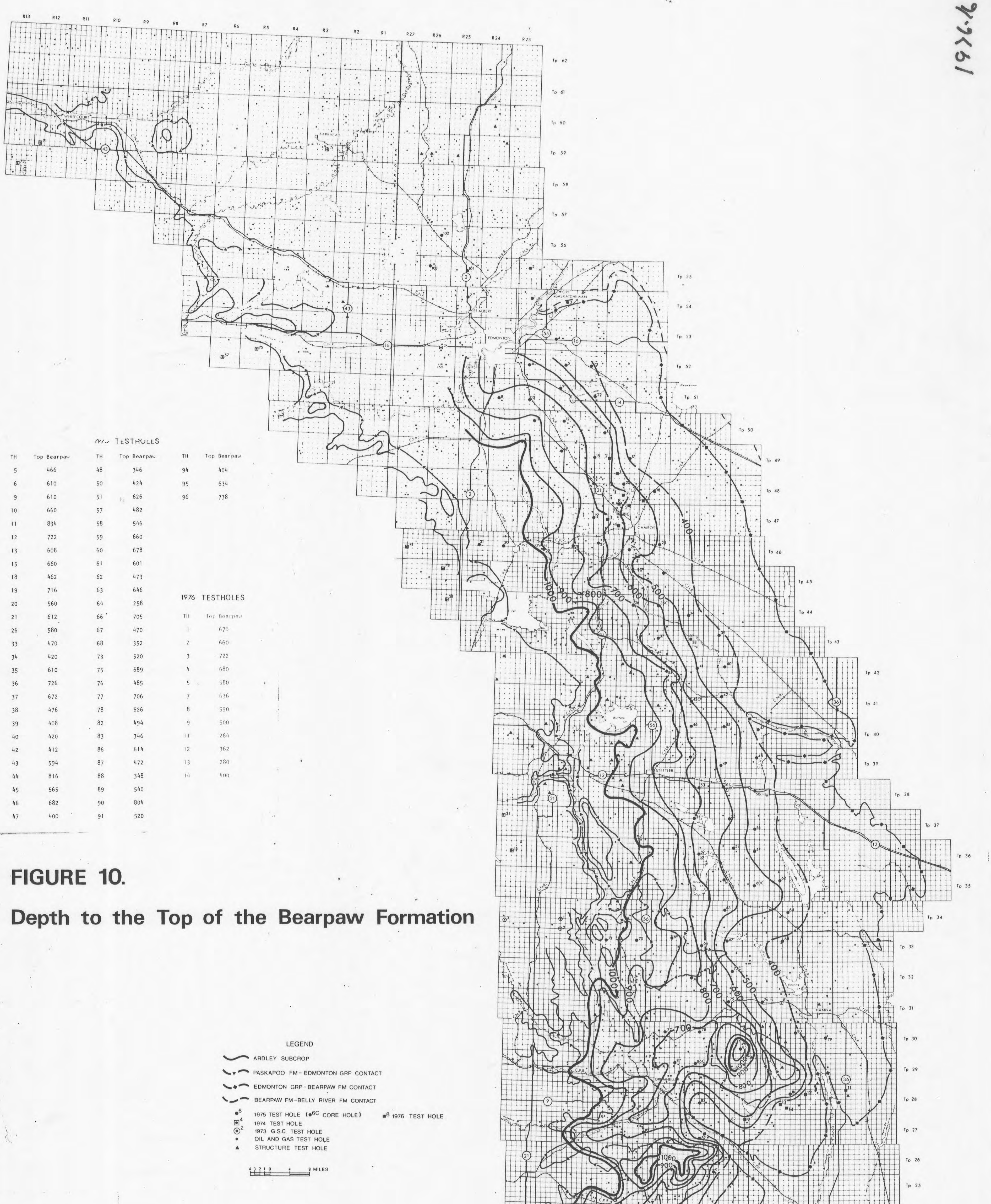

FIGURE 10.

Depth to the Top of the Bearpaw Formation

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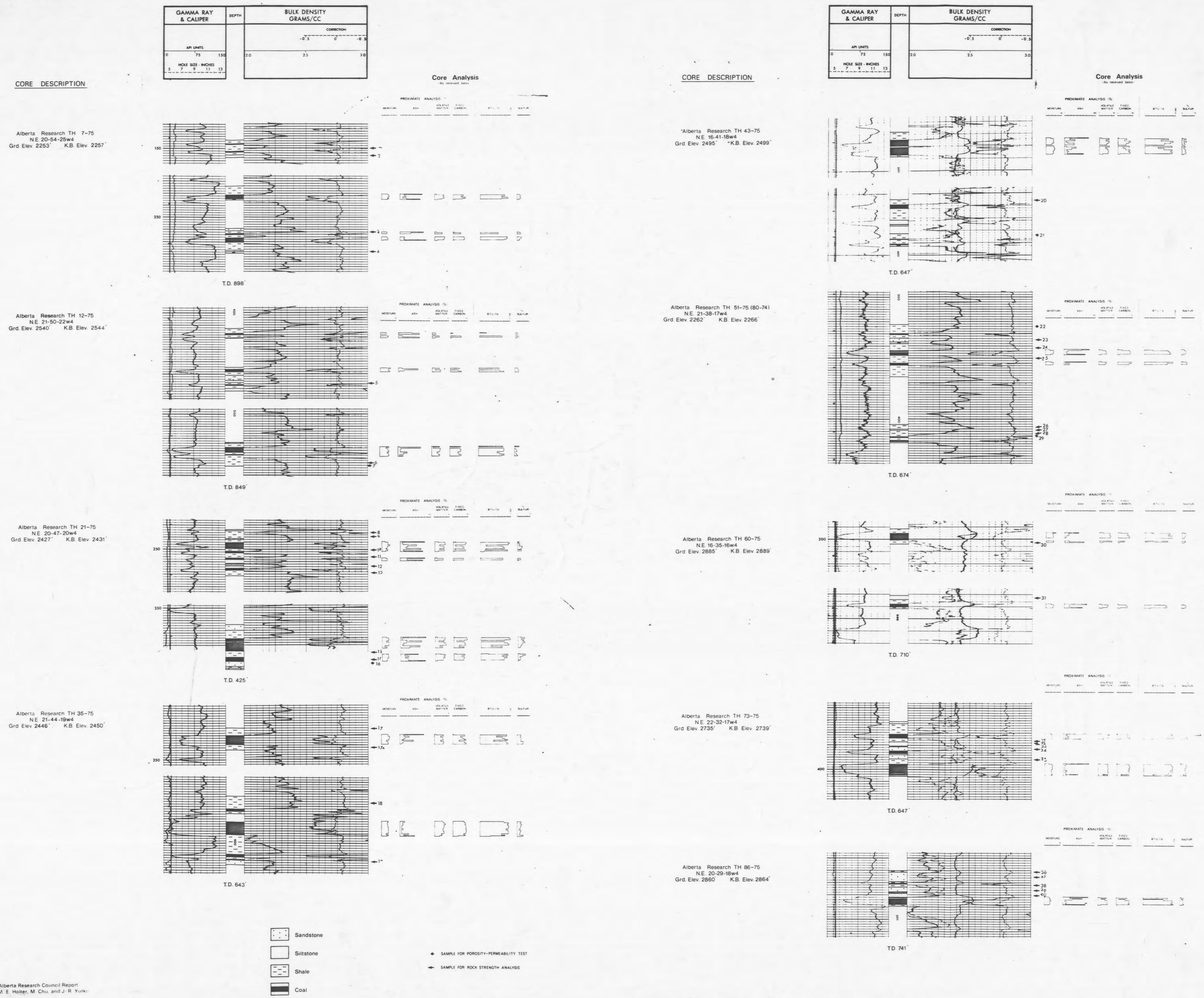

To accompany Alberta Research Council Report by M. E. Holter, M. Chu, and J. R. Yurko

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FIGURE 11. Core Descriptions

FIGURE 12.

Section A – B

DATUM: GROUND LEVEL

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FIGURE 13.

Section B-C

DATUM: GROUND LEVEL

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FIGURE 14.

Section C-D

DATUM: GROUND LEVEL

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FIGURE 15.

Structural Cross Section 1 - 2

To accompany Alberta Research Council Report by M. E. Holter, M. Chu, and J. R. Yurko.

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FIGURE 16.

Structural Cross Section 3 - 4

To accompany Alberta Research Council Report by M. E. Holter, M. Chu, and J. R. Yurko.

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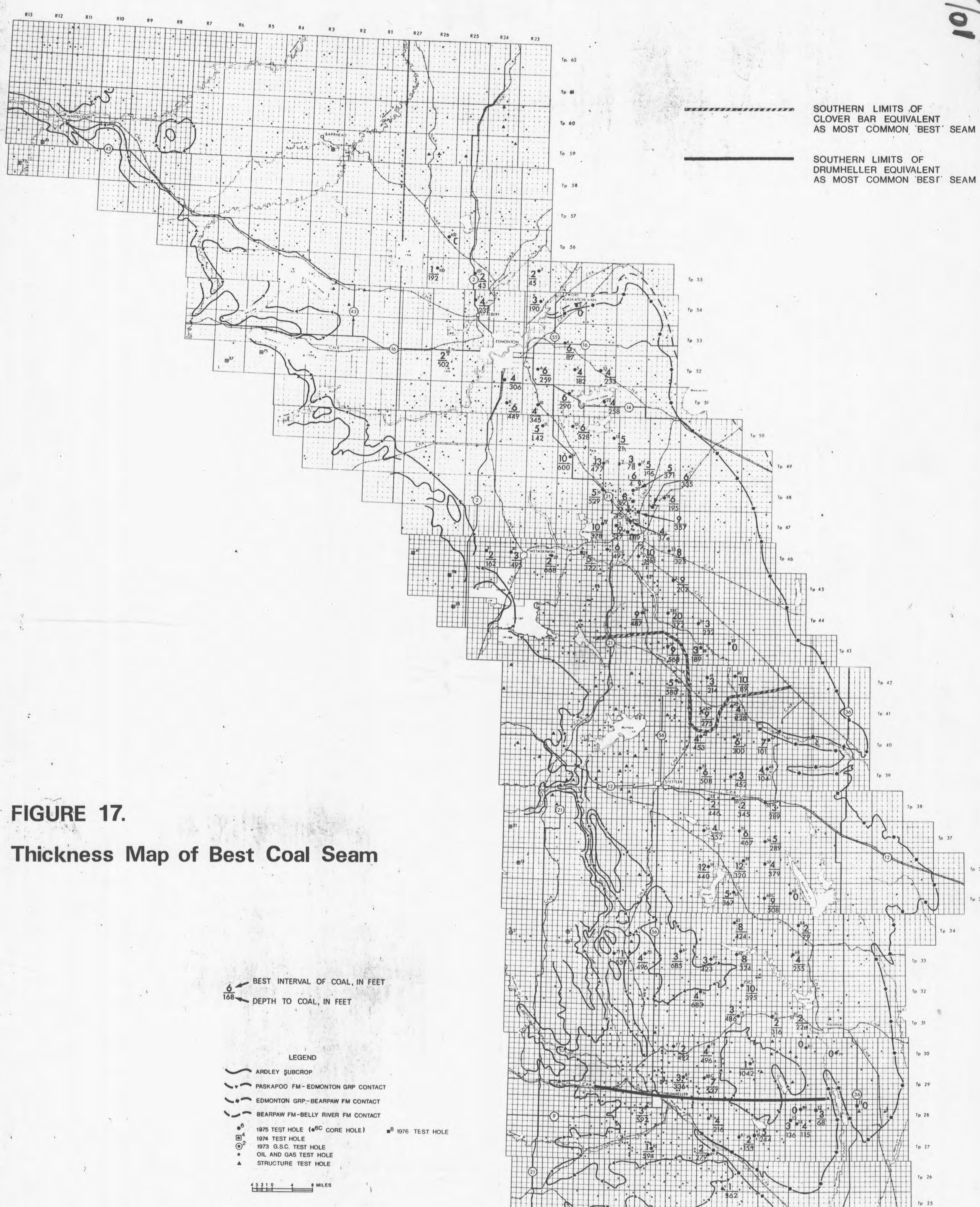

FIGURE 17.

Thickness Map of Best Coal Seam

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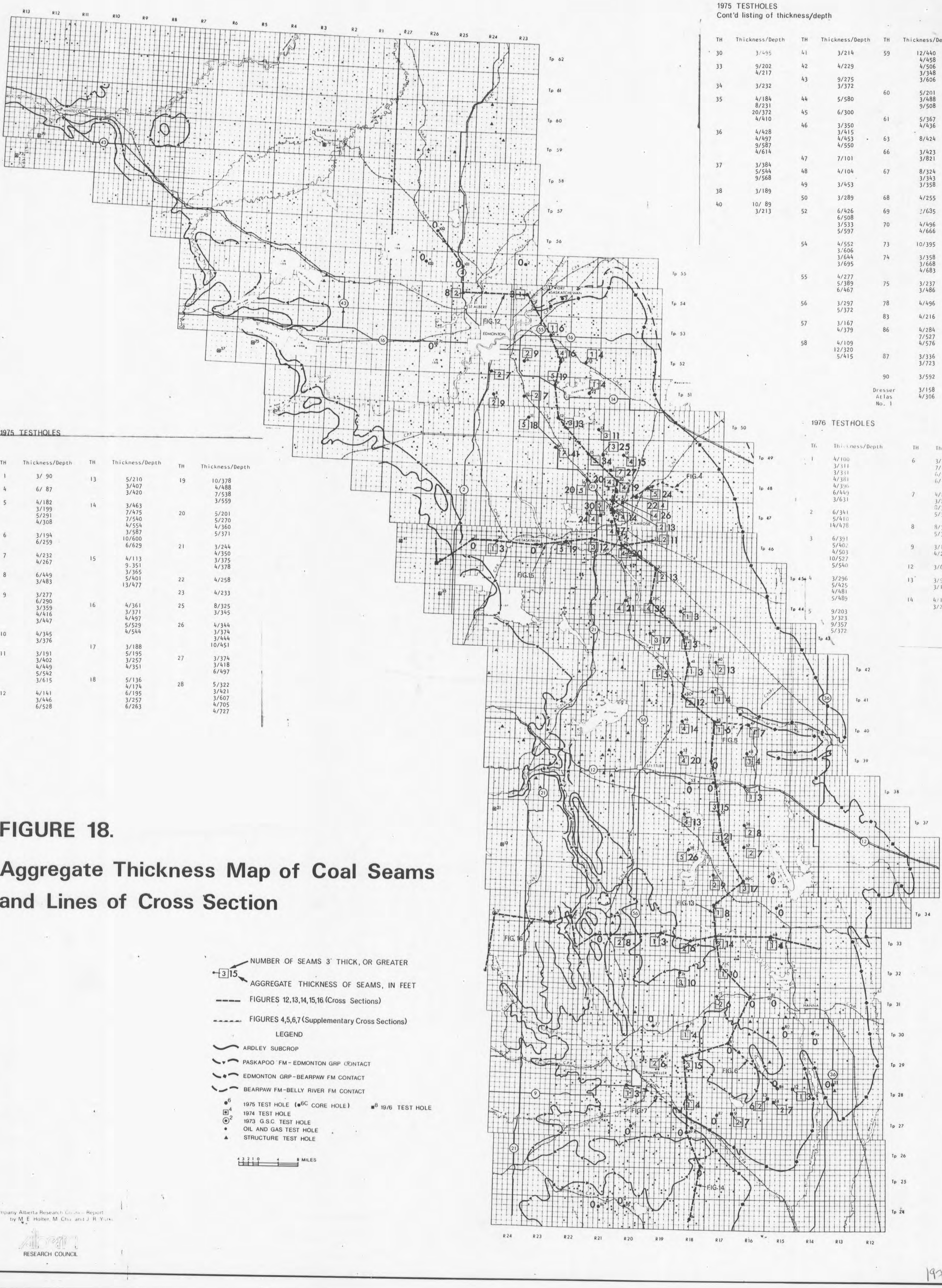

1975 TESTHOLES
Cont'd listing of thickness/depth

TH	Thickness/Depth	TH	Thickness/Depth	TH	Thickness/Depth
30	3/495	41	3/214	59	12/440 4/458 4/506 3/348 3/606
33	9/202 4/217	42	4/229	60	5/201 3/488 9/508
34	3/232	43	9/275 3/372	61	5/367 4/436
35	4/184 8/231 20/372 4/410	44	5/580	63	8/424
36	4/428 4/497 9/587 4/614	45	6/300	66	3/423 3/821
37	3/384 5/544 9/568	46	3/350 3/415 4/453 4/550	67	8/324 3/343 3/358
38	3/189	47	7/101	68	4/255
40	10/ 89 3/213	48	4/104	69	2/635
		49	3/453	70	4/496 4/666
		50	3/289	73	10/395
		52	6/426 6/508 3/533 5/597	74	3/358 3/668 4/683
		54	4/552 3/606 3/644 3/695	75	3/237 3/486
		55	4/277 5/389 6/467	78	4/496
		56	3/297 5/372	83	4/216
		57	3/167 4/379	86	4/284 7/527 4/576
		58	4/109 12/320 5/415	87	3/336 3/723
				90	3/592
				Dresser Atlas No. 1	3/158 4/306

1976 TESTHOLES

TH	Thickness/Depth	TH	Thickness/Depth
1	4/100 3/311 3/331 4/381 4/396 6/449 3/631	6	3/266 7/290 6/335 6/344
2	6/341 5/410 14/478	7	4/225 3/272 8/360 5/372
3	6/391 5/402 4/503 10/527 5/540	8	8/375 5/389
4	3/296 5/425 4/481 5/489	9	3/188 4/244
5	9/203 3/323 9/357 5/372	12	3/68
		13	3/91 3/136
		14	4/115 3/246

1975 TESTHOLES

TH	Thickness/Depth	TH	Thickness/Depth	TH	Thickness/Depth
1	3/ 90	13	5/210 3/407 3/420	19	10/378 4/488 7/538 3/559
4	6/ 87	14	3/463 7/475 7/540 4/554 3/587 10/600 6/629	20	5/201 5/270 4/360 5/371
5	4/182 3/199 5/291 4/308	15	4/113 9.351 3/365 5/401 13/477	21	3/244 4/350 3/375 4/378
6	3/194 6/259	16	4/361 3/371 4/497 5/529 4/544	22	4/258
7	4/232 4/267	17	3/188 5/195 3/257 4/351	23	4/233
8	6/449 3/483	18	5/136 4/174 6/195 3/257 6/263	25	8/325 3/345
9	3/277 6/290 3/359 4/416 3/447			26	4/344 3/374 3/444 10/451
10	4/345 3/376			27	3/374 3/418 6/497
11	3/191 3/402 4/449 5/542 3/615			28	5/322 3/421 3/607 4/705 4/727
12	4/141 3/446 6/528				

FIGURE 18.

Aggregate Thickness Map of Coal Seams and Lines of Cross Section

[3] 15 ← NUMBER OF SEAMS 3′ THICK, OR GREATER; AGGREGATE THICKNESS OF SEAMS, IN FEET

FIGURES 12,13,14,15,16 (Cross Sections)

FIGURES 4,5,6,7 (Supplementary Cross Sections)

LEGEND

ARDLEY SUBCROP

PASKAPOO FM - EDMONTON GRP CONTACT

EDMONTON GRP - BEARPAW FM CONTACT

BEARPAW FM - BELLY RIVER FM CONTACT

1975 TEST HOLE (6C CORE HOLE)

8 19/6 TEST HOLE

1974 TEST HOLE

1973 G.S.C. TEST HOLE

OIL AND GAS TEST HOLE

STRUCTURE TEST HOLE

4 3 2 1 0 4 8 MILES

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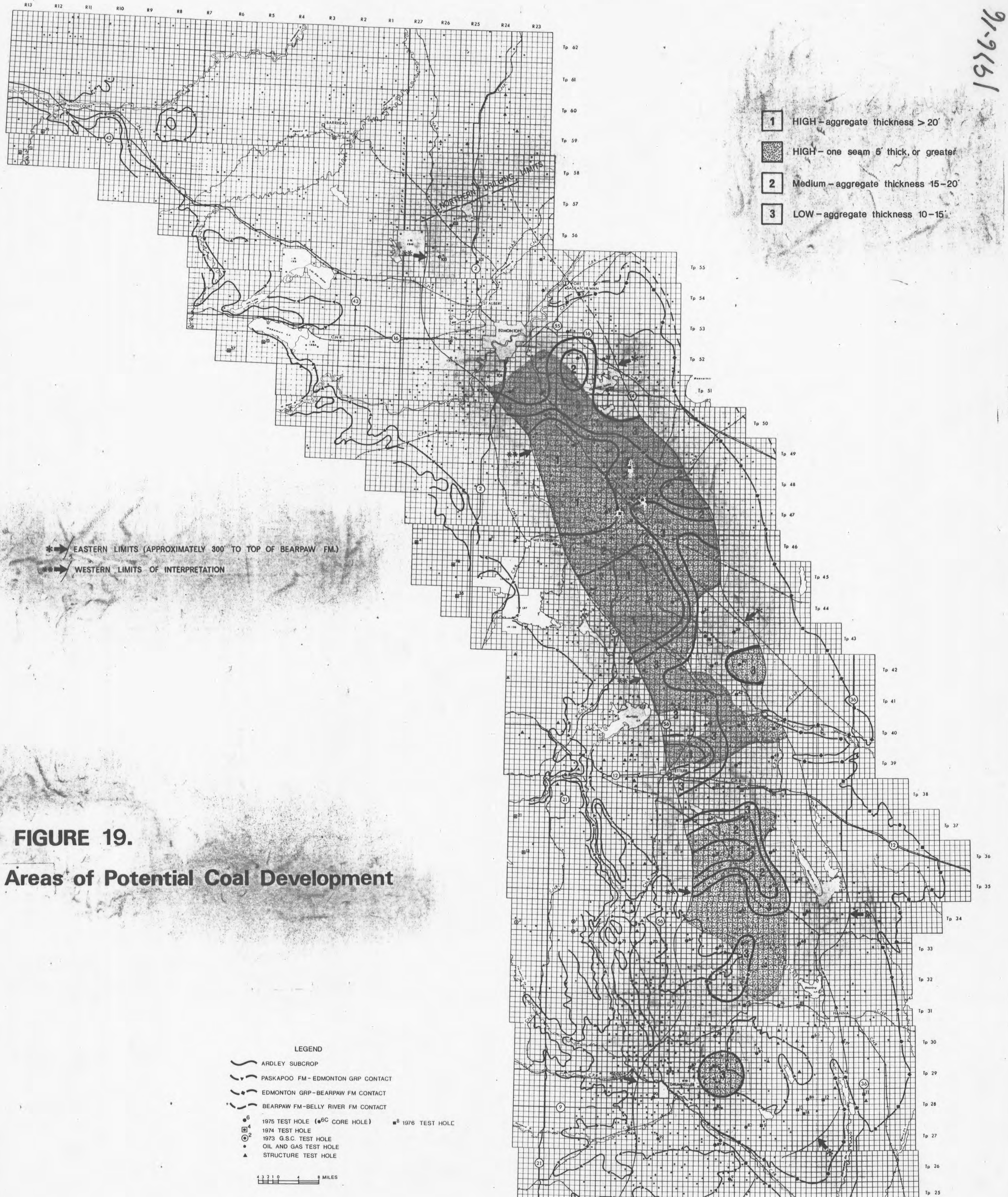

FIGURE 19.
Areas of Potential Coal Development

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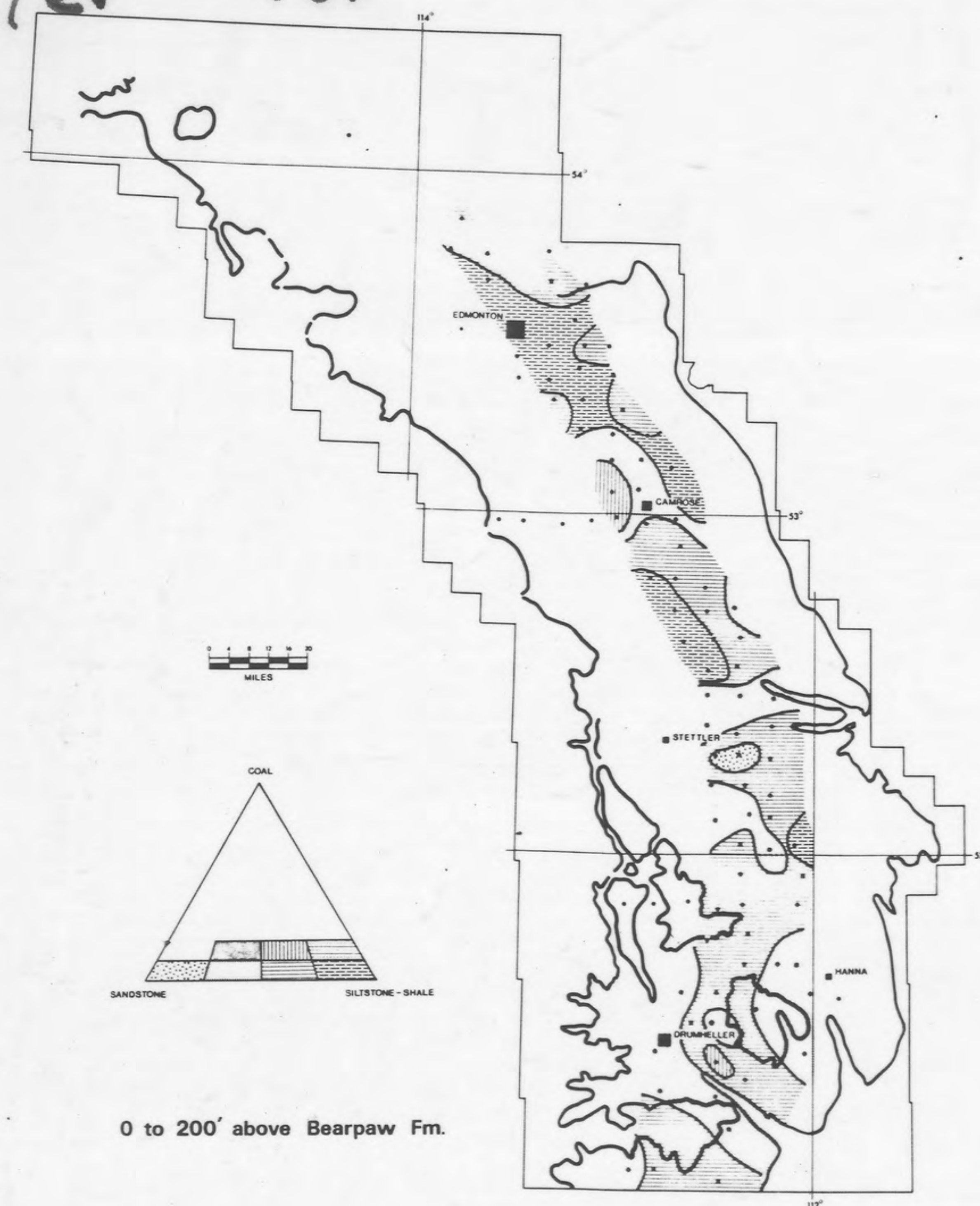
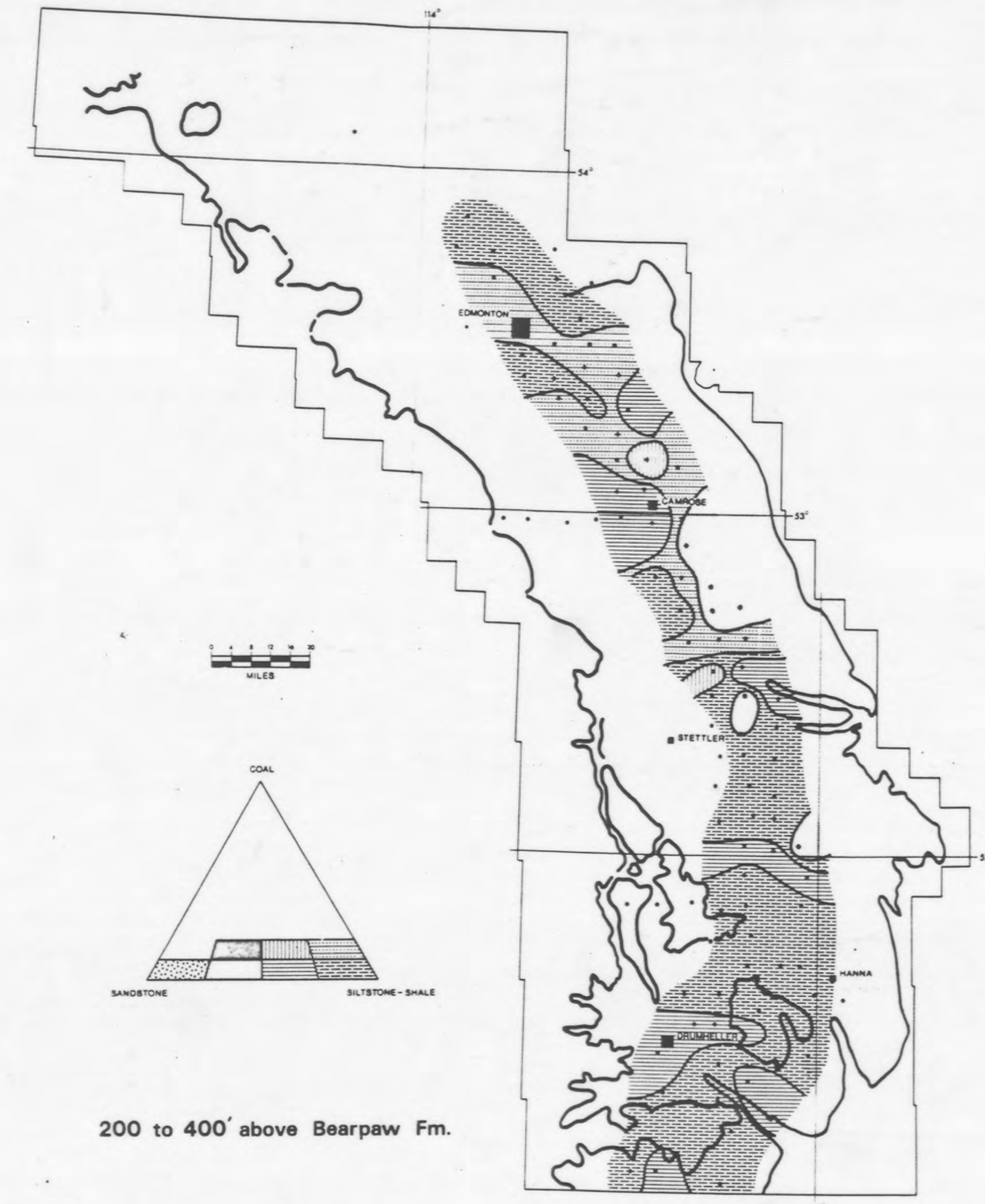


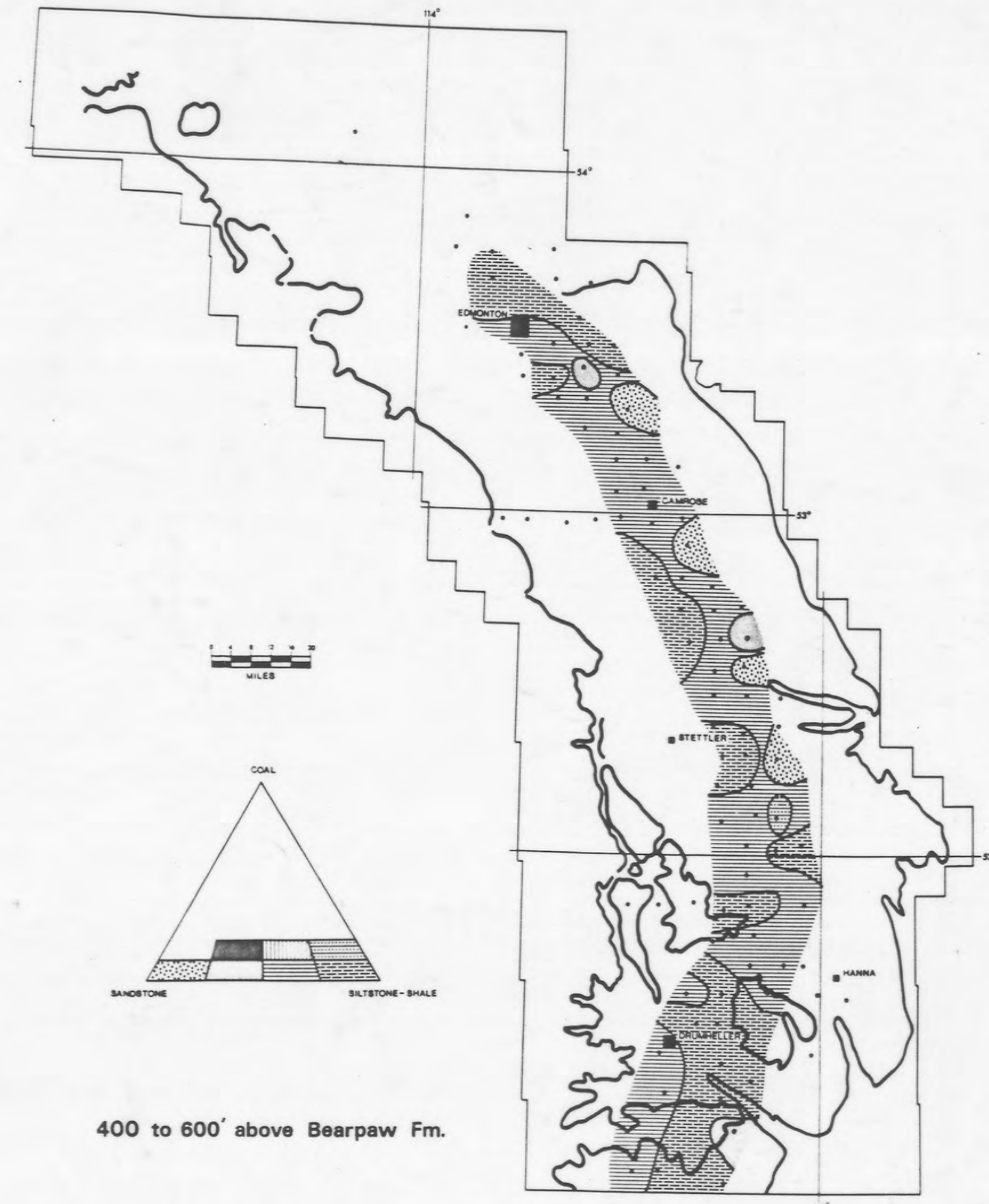
0 to 200' above Bearpaw Fm.

A.



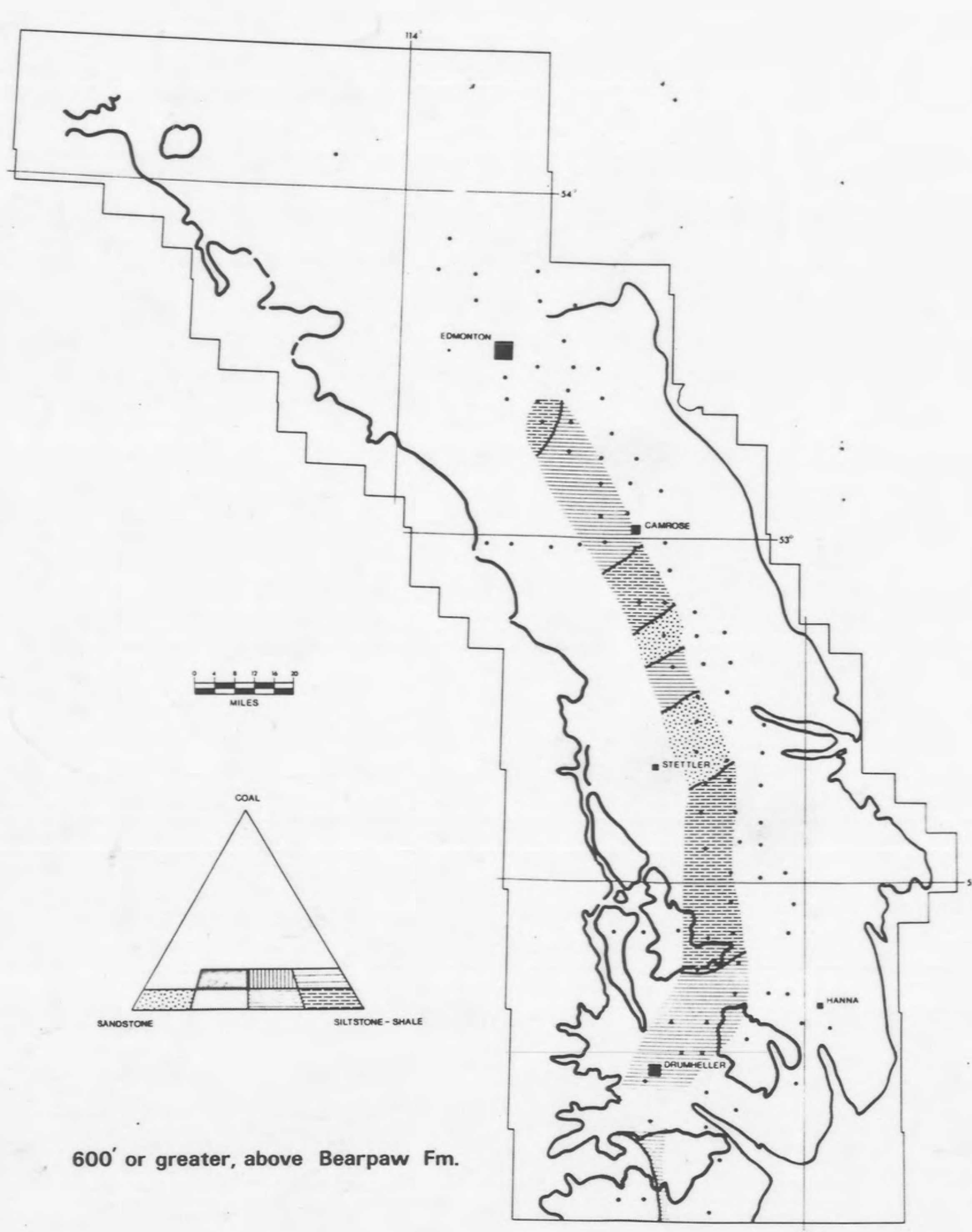
200 to 400' above Bearpaw Fm.

B.



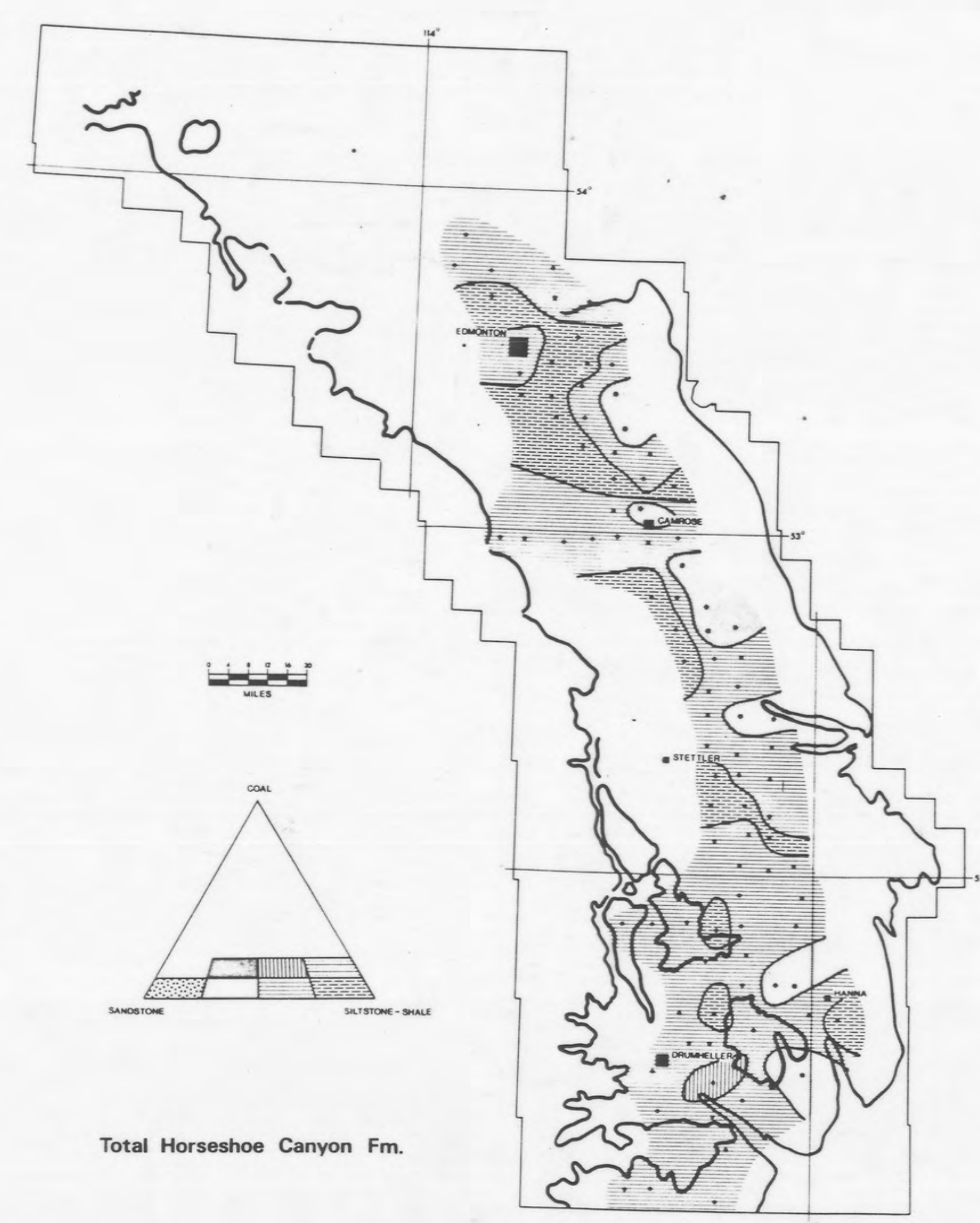
400 to 600' above Bearpaw Fm.

C.



600' or greater, above Bearpaw Fm.

D.



Total Horseshoe Canyon Fm.

E.

FIGURE 21.

Lithofacies Map of the Horseshoe Canyon Formation

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Sample No.	Average As Received H_2O Content (% Bulk Wt.)	Average Bulk Density (gm/cc)	(E_2) Young's Modulus Across Bedding	Bulk Modulus (K_2) Across Bedding	Young's Modulus (E_3) Parallel to Bedding	Bulk Modulus (K_3) Parallel	Mean Poisson's Ratio	Young's Modulus (E_1) Static Loading	Young's Modulus (E_4) Static Unloading	Failure Stress PSI (%)	(E) Strain At Failure (%)	Anisotropy Ratio=E_3/E_2	Slaking Test (Degree of Swelling - see comments) 1 hr.	Slaking Test 24 hrs.	Sample Description and Comments
			← by sonic method →												
			← PSI X 10^5 →												
1	12.5	2.19	8.9	4.2	10.0	5.0	0.16	0.53	1.17	384	0.86	1.1	D1 Medium	D1 High	Shale, carbonaceous
2	13.5	2.18	8.0	5.1	6.4	5.9	0.28	0.080	*	215	2.7	0.8	C1 Little	D1/E1 High	Siltstone, sandy
3	10.0	2.05	*	*	*	*	*	*	*	*	*	*	E1 Little	E1 Medium	Shale, carbonaceous, fractured
4	10.0	2.22	5.5	4.0	11.0	8.5	0.28	0.28	1.07	378	1.35	2.0	C1 Little	D1/E1 High	Siltstone, shaly
5	10.5	2.16	18.3	7.0	19.7	8.7	0.10	6.26	9.24	4240	1.45	1.1	B	B	Shale, silty, carbonaceous
6	13.0	2.21	7.6	5.4	13.1	9.0	0.27	0.97	2.13	930	1.1	1.7	C1 Little	C1 Medium	Siltstone, shaly, carbonaceous
7													E1 Little	D1/E1 High	Siltstone, shaly, high dry strength
8	19.0	2.01	*	*	*	*	*	*	*	*	*	*	C1 Little	C1 Little	Siltstone, shaly, very soft
9	14.5	2.16	*	*	9.1	5.0	0.20	*	*	*	*	*	C1 Medium	D1 High	Shale, very fissile
10	14.8	1.98	2.6	1.9	6.4	4.9	0.28	0.53	2.49	935	2.16	2.5	D1 Medium	E1 Medium	Shale, silty, carbonaceous
11	12.0	2.22	4.8	2.7	11.5	6.3	0.20	*	*	*	*	2.4	D2 Little	E2 Little	Shale, silty, carbonaceous
12	9.5	2.18	4.8	7.4	7.1	13.0	0.40	2.13	5.55	1940	1.02	1.5	C2 Nil	E2 Medium	Shale, silty, carbonaceous
13	14.0	2.16	1.4	2.6	2.3	5.5	0.41	*	*	*	*	1.8	C1 Little	D1 Medium	Shale, silty, thinly bedded
14	13.5	2.24	14.9	6.0	18.1	7.6	0.10	1.38	2.82	1270	1.2	1.2	C1 Medium	D1 Medium	Shale, silty, carbonaceous, hard
15	15.5	2.14	1.4	0.8	3.0	3.0	0.27	0.047	*	154	3	2.1	C1 Medium	D1 Medium	Shale, silty, sandy
16													C2 Little	D2/E2 Medium	Sandstone, carbonaceous, soft and crumbly
17	17.8	2.02	0.7	1.2	2.5	3.0	0.38	*	*	*	*	3.6	E2 Little	E2 Medium	Shale, silty, carbonaceous, soft, broken
17.A	19.5	2.01	3.0	2.0	5.4	4.2	0.28	*	*	*	*	1.8	E1 Very high	E1 Very high	Shale, silty, thinly bedded
18	13.8	2.10	5.8	5.8	7.2	8.1	0.34	*	*	*	*	1.2	C1 Little	D1 Medium	Shale, silty, desiccated sample
19	14.5	2.12	10.0	4.7	9.0	4.2	0.14	1.32	2.56	522	0.68	0.9	C1 Little	E1 Little	Sandstone, shaly
20	Variable 6-14	2.65	7.3	16.1	14.6	13.2	0.36	*	*	*	*	2.0	D1 Medium	E1 High	Shale
21													C2 Little	D1/E1 High	Shale, silty, low to medium dry strength
22													C1 Little	D1/E1 Medium	Shale, silty, carbonaceous, thinly bedded, low to medium dry strength
23	12.5	2.15	2.7	2.8	4.7	4.3	0.33	0.94	3.27	452	1.10	1.7	D2 Little	E2 Medium	Sandstone, bentonitic
24	11.0	2.16	8.8	5.1	12.0	7.7	0.23	*	*	*	*	1.4	C1 Medium	D1/E1 High	Shale, very silty
25	15.0	2.14	2.3	2.0	5.8	4.4	0.30	*	*	*	*	2.5	C1 Little	D1 Medium	Siltstone
26	9.0	2.22	11.0	7.4	11.9	6.7	0.23	*	*	*	*	1.1	C1 Little	D1 Medium	Shale, silty
27	11.0	2.29	18.2	9.1	19.5	8.6	0.15	*	*	*	*	1.1	C1 Medium	D1 Medium	Sandstone, bentonitic, silty, carbonaceous
28	4.5	2.11	14.4	4.8	11.6	7.4	0.0/0.24	1.25	2.56	1330	1.24	0.80	D1 High	E1 High	Shale, very silty, carbonaceous
29													E1 Very High	E1 Very High	Shale, very silty, carbonaceous, fissile
30	18.5	1.86	1.2	2.3	5.0	3.7	0.42/0.27	*	*	*	*	4.2	D2 Medium	D2 Medium	Shale, silty, carbonaceous
31	14.0	2.16	4.9	3.3	9.5	3.6	0.33	*	*	*	*	1.9	C1 Medium	E1 High	Siltstone, shaly, thinly bedded
32	16.5	*	*	*	*	*	*	*	*	*	*	*	E2 Nil	E2 Nil	Shale, thinly bedded, broken
33	12.5	2.16	3.6	5.4	4.4	5.4	0.38	0.50	1.71	507	1.11	1.2	D1 Medium	E1 High	Siltstone, sandy
34	12.0	2.14	7.8	4.2	7.5	3.9	0.20	*	*	*	*	1.0	C1 Medium	E1 High	Sandstone
35	9.5	2.25	11.4	5.5	11.9	9.6	0.22	*	*	*	*	1.0	C1 Medium	D1 High	Shale, silty, readily split horizontally
36	10.0	2.24	10.5	7.0	12.1	7.4	0.24	*	*	*	*	1.2	C1 Medium	D1 High	Sandstone
37	11.5	2.27	7.0	3.6	7.9	4.9	0.20	0.20	0.51	290	1.78	1.1	C1 Medium	D1 High	Sandstone, silty, shaly
38	12.0	2.17	1.2	3.8	4.5	10.0	0.44	*	*	*	*	3.8	D2 Nil	D2 Nil	Shale, very silty, sandy
39	11.0	2.29	14.5	5.8	13.5	8.0	0.16	0.63	4.0	870	1.33	0.9	C1 Little	C1 Little	Sandstone
40	12.0	2.24	8.2	6.2	10.2	7.8	0.29	0.56	3.45	890	1.79	1.2	C2 Little	D2 Medium	Siltstone, very shaly, carbonaceous

* Data impossible to obtain due to sample damage or cleavage

** These samples were subjected to permeability and porosity tests. They were completely dried and desiccated and any data would not be comparable to the other samples (except for slaking tests).

CLASSIFICATION OF SLAKING TESTS

A	No sample deterioration
B	Slight deterioraton (water clean, minor flecks or fragments)
C	Medium deterioration-original shape largely preserved-surface deteriorated 1 ... water murky 2 ... water clear
D	High amount of deterioration-original shape largely or completely destroyed-many fragments and flecks. 1 ... water quite murky 2 ... water slightly murky
E	Total Disintegration 1 ... water completely muddy 2 ... water slightly muddy

FIGURE 23

R CK Strength Propertıes,

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1976-16

FIGURE 24 Stress-Strain Diagrams

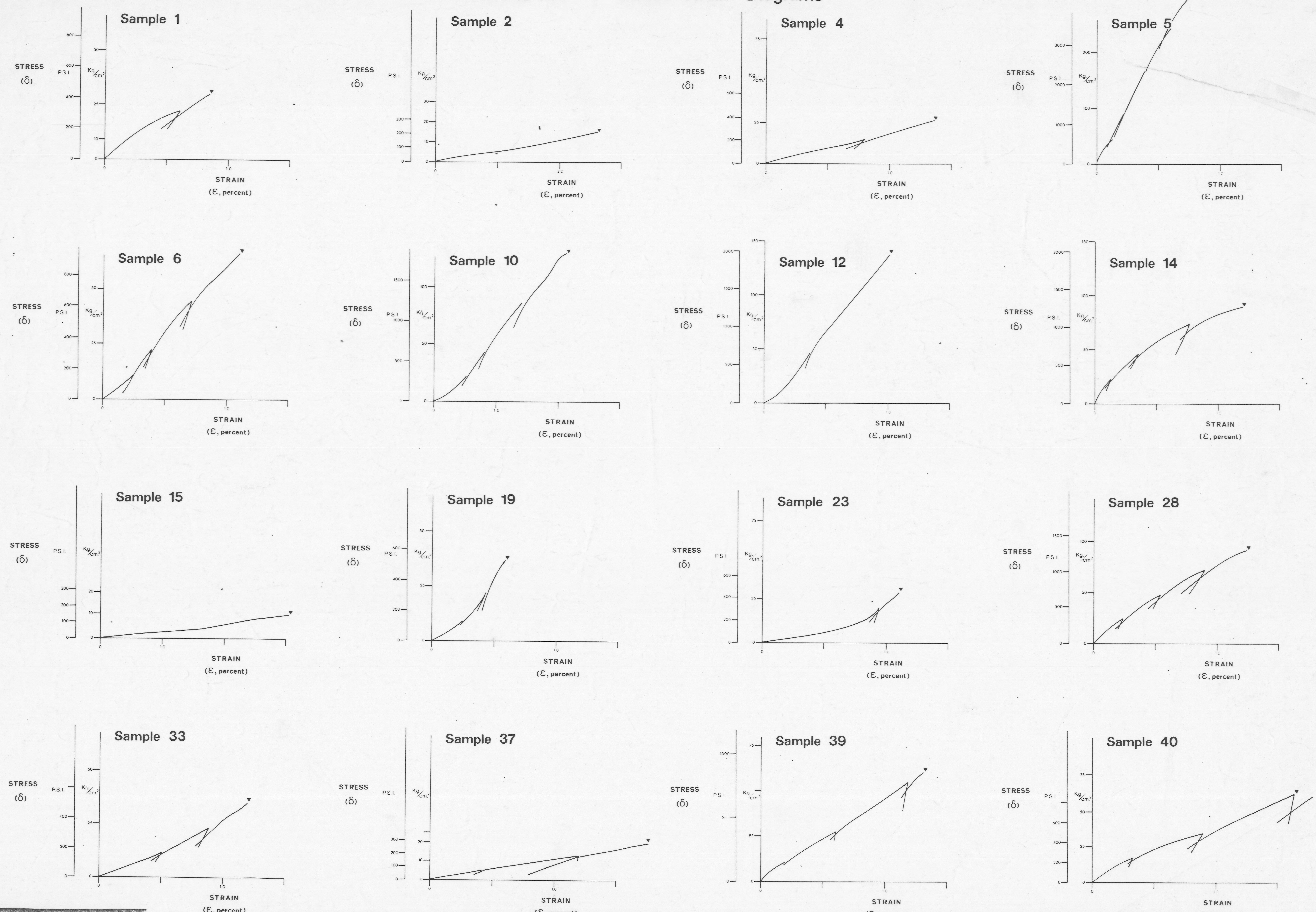

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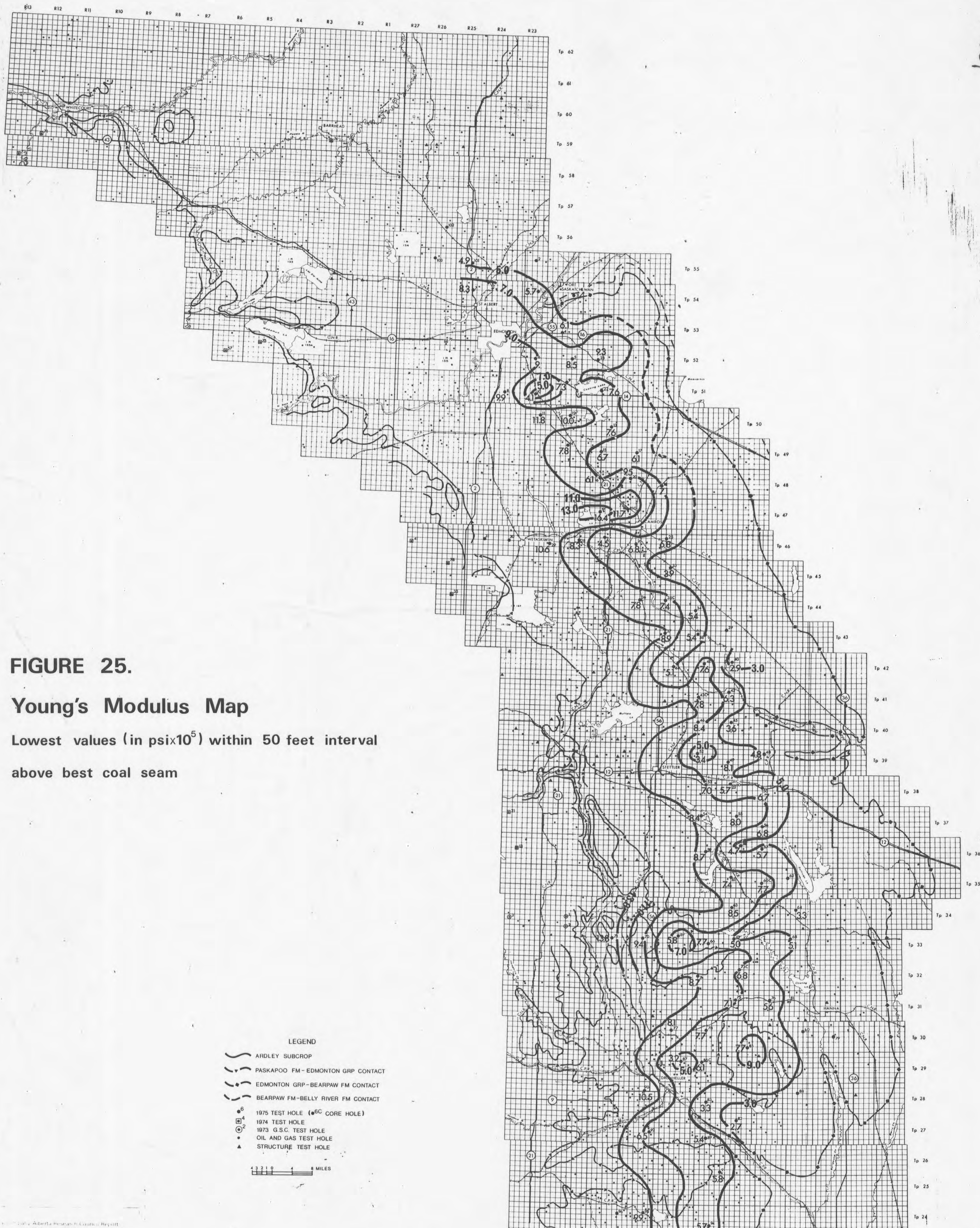
FIGURE 25.

Young's Modulus Map

Lowest values (in psi$\times10^5$) within 50 feet interval above best coal seam



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