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GEOLOGY AND COAL RESERVES OF THE ARDLEY COAL ZONE OF CENTRAL ALBERTA

M. E. Holter, J. R. Yurko and M. Chu

A report from a joint program of coal resource evaluation by
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1975

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Abstract

The Ardley coal zone is subdivided into three main units designated from base to top as the Lower Ardley 'A', Lower Ardley 'B', and Upper Ardley. The Lower Ardley 'A' is interpreted to be a split of the areally persistent and economically dominant Lower Ardley 'B' unit. Each coal unit is mapped on the basis of gross thicknesses and maximum successions of high quality coal.

Lithofacies studies are presented to indicate generalizations regarding the paleogeography of the Scollard Member and the overlying Paskapoo strata. East-west sedimentation lineaments are suggested by both isopach and lithofacies presentations.

The physical properties of the roof rock are highly variable and deserve careful study prior to mine development.

Reserves of Ardley coal between 300 and 1000 feet in depth are estimated to total 44 billion tons if developed on an in-situ basis or 17 billion tons if exploited by conventional underground methods. Areas south of Red Deer, near Pigeon Lake, southwest of Wabamun Lake, and east of Entwistle show greatest potential for future development.

INTRODUCTION

During the summer of 1974 a drilling program was carried out to evaluate the so-called Ardley Coal Zone at depths between approximately 400 and 1000 feet, between Three Hills and Whitecourt in central Alberta (Fig. 1). The area of study encompasses approximately 8,000,000 acres and one successful test hole was drilled in each of 67 townships within the outlined region. The data thus obtained is in the form of induction electric logs, gamma ray-density logs, drill cuttings and core. Drill cuttings were described during the process of drilling each test hole and coal samples were retained for analysis. The major coal intervals were cored in each of six test holes which were equidistantly spaced with respect to one another throughout the study area.

Acknowledgments

The writers acknowledge the very capable technical assistance of A. Bosman, R. J. Melin and E. J. Waterman. Supporting technical services were afforded by B. McConnell and R. Rall of Oilfield Consultants Ltd. Sedco Drilling, Dresser Industries Inc., Christensen Diamond Products (Canada) Ltd., and Chemical and Geological Laboratories Ltd. provided drilling, logging, coring and analytical services respectively. Special credit is also due to J. Kowalski of Dresser Industries Inc. for log digitization work. M. Dusseault of the University of Alberta carried out rock mechanics tests on selected core samples.

REGIONAL STRATIGRAPHY AND NOMENCLATURE

Allan and Sanderson (1945) established the first significant nomenclature for the stratigraphic interval with which the Ardley coal zone is associated (Fig. 2). The Paskapoo Formation (a term earlier used by Tyrrell, 1886) was defined as including a succession of massive sandstones, silts and shales above the coal-bearing interval. The immediate underlying coal seams and associated strata were included in the Upper Edmonton unit of the Edmonton Formation (a term first introduced by Selwyn, 1874). The top of the regionally

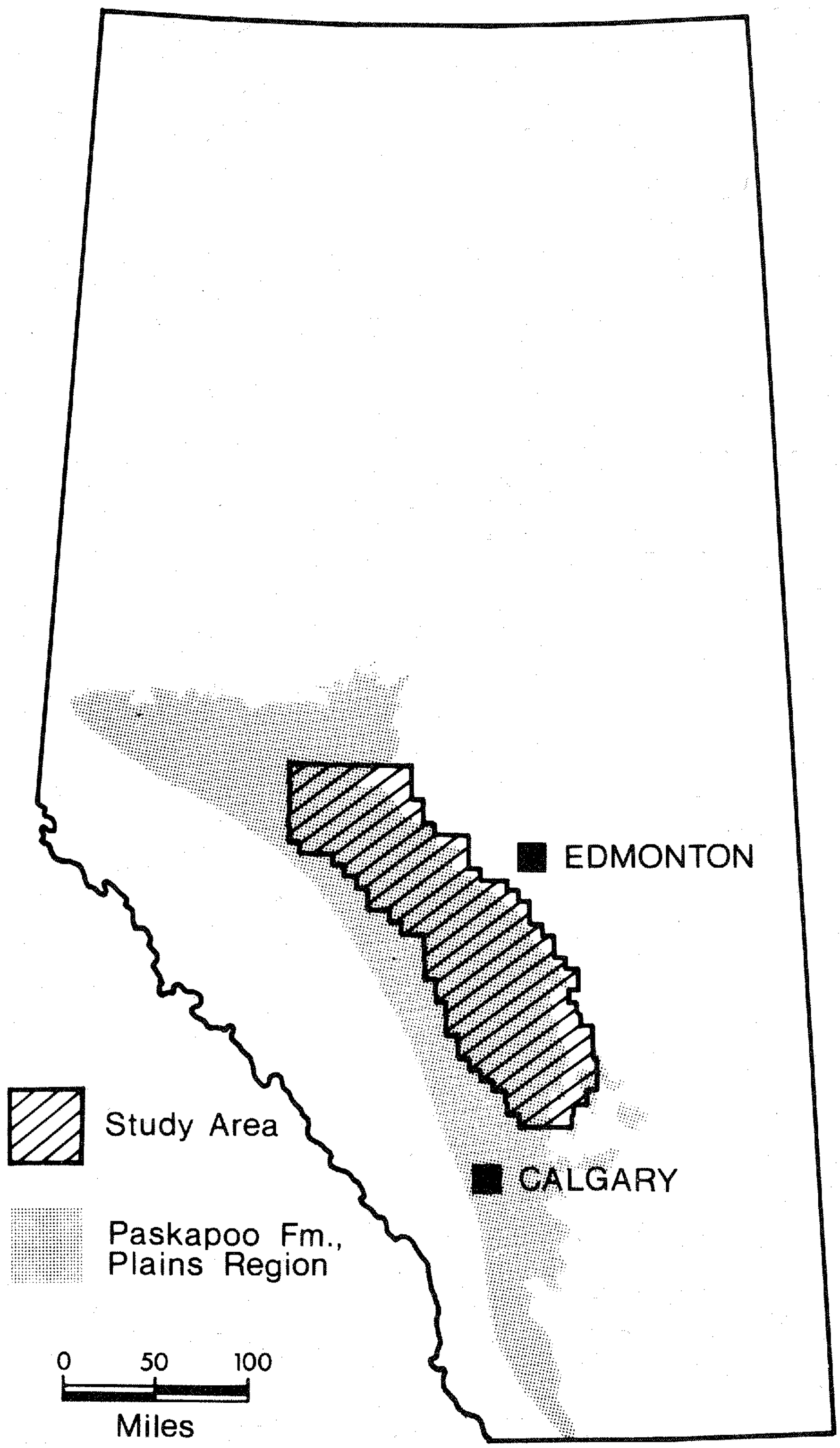


FIGURE 1. Area of study.

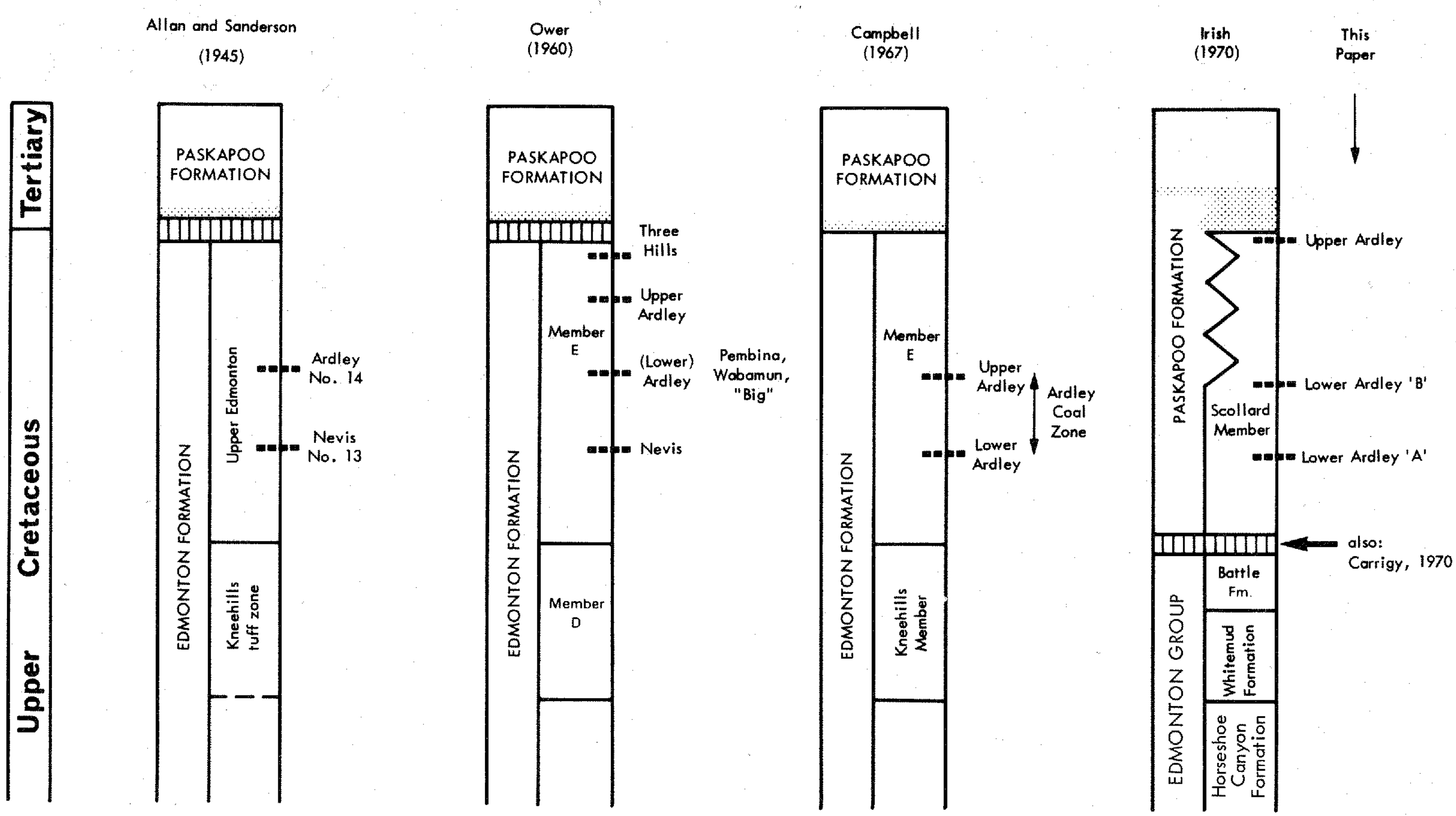


FIGURE 2. Stratigraphic table.

correlative Kneehills tuff zone defined the base of the Upper Edmonton. Two main coal zones were recognized within the Upper Edmonton including the stratigraphically lower Nevis or No. 13 seam and the overlying Ardley or No. 14 seam.

Ower (1960) subdivided the Edmonton Formation into five units which were designated, from base to top, as Members A to E. Members D and E correspond respectively to the Kneehills tuff zone and the Upper Edmonton unit of Allan and Sanderson (1945). Ower described three major coal seams within Member E in the Red Deer River area: the "Lower Ardley," "Upper Ardley" and "Three Hills" seams. Ower's interpretations appear to be in error with regard to the reported absence of the "Lower Ardley" seam (also referred to as the Ardley seam) at Scollard Canyon and at Three Hills. The "Lower Ardley" has been shown to be present at Scollard Canyon by Campbell (1967). Ower chose to regard the seam at Three Hills as stratigraphically higher than both his "Upper" and "Lower" Ardley seams because of the excessive thickness (over 300 feet) of strata between the seam and the top of Member D. However, reference to figure 3 shows Member E thins to the east and the seam at Three Hills may be correlated with some confidence to the "Lower Ardley" equivalents in neighboring test holes and outcrop. Ower's correlations for the "Lower" and "Upper" Ardley seams are valid for the Western Canadian Warren well (Lsd 2-11-37-23W4) and agree with the designations used herein. The well developed seam in the California Standard Lacombe well (Lsd 11-10-40-27W4) is probably the "Lower" Ardley, not the "Upper" Ardley. In the area of the Imperial Battle Lake well (Lsd 11-33-46-3W5) the "Upper" Ardley demonstrates unusually prominent development which led Ower to erroneously apply the term "Three Hills seam" to a stratigraphically high coal zone. Pearson (1960) disagreed with Ower's interpretation that the coal formerly mined at Wizard Lake correlates with the Upper Ardley horizon documented in the McColl Wizard Lake well (Lsd 14-14-48-27W4). A lower, well-developed seam in the Wizard Lake well was referred to as the Pembina seam.

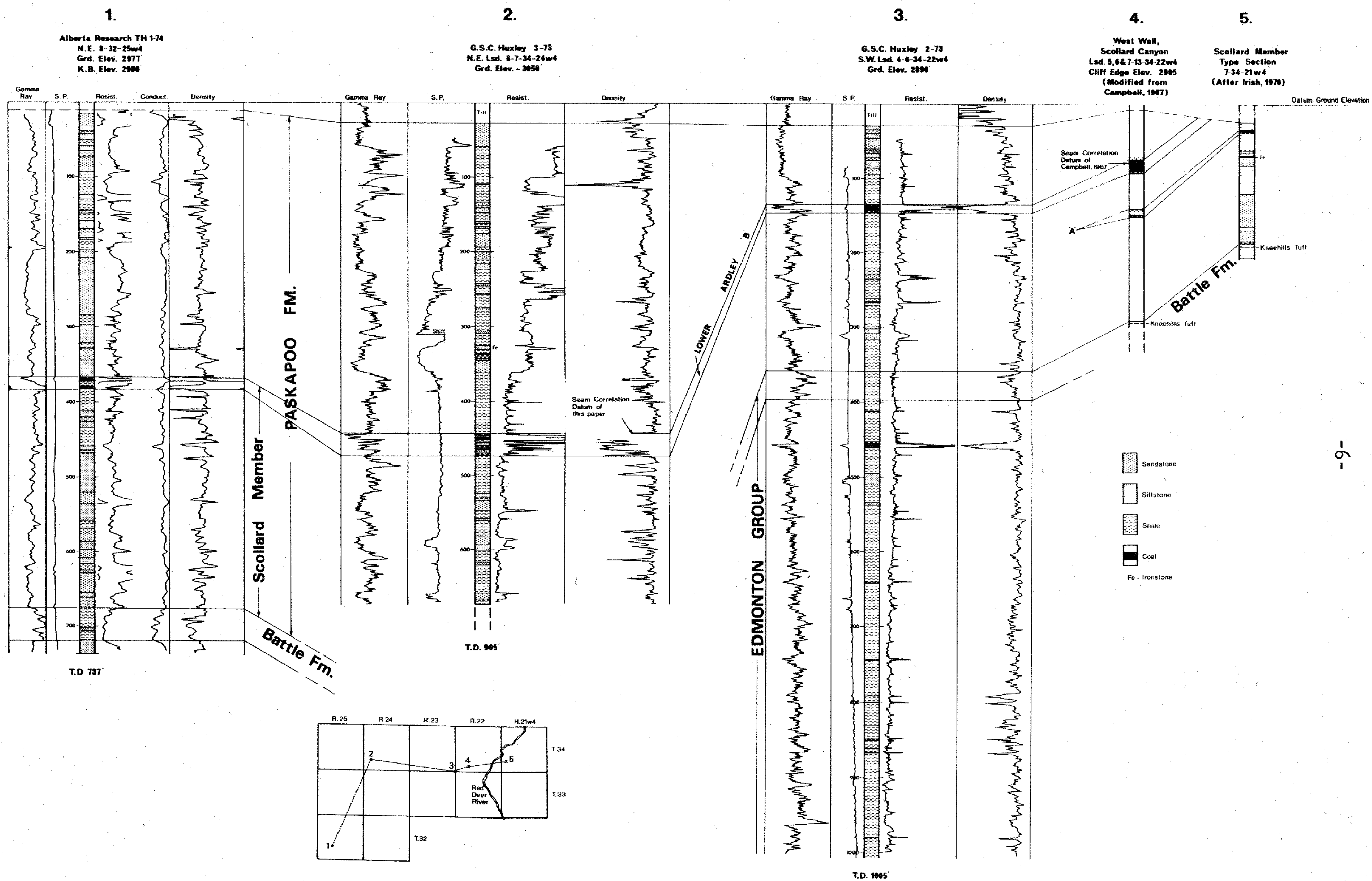


FIGURE 3. *Cross section, Kneehills to Scollard areas.*

Farther to the north in the Wabamun area, Ower regionally correlated a major seam previously referred to locally as the Pembina, Wabamun or "Big" seam. The term "Big Seam" was first applied to outcropping coal in the Red Deer River near Ardley by Tyrrell (1887).

The terminology of this paper generally relates to Ower as follows. In the south the "Lower" Ardley is more precisely defined as the Lower Ardley 'B'. The Nevis seam as used by Ower is the same as the Lower Ardley 'A' used herein. As previously noted, the Three Hills seam designation is invalid in the south. To the north in the Pigeon Lake area, the Three Hills term has been applied by Ower to a series of coal beds herein called the Upper Ardley zone. The term "Upper Ardley" is used in the same manner as designated by Ower, with the exception of those instances mentioned above. The Pembina or "Big" seam is equivalent to the Lower Ardley 'B' of this paper.

The Edmonton Formation was further subdivided by Srivastava (1968). The Kneehills tuff zone or Member D was broken into a lower unit of pale-colored beds called the Whitemud Member. This succession was correlated with the type section of the Whitemud Formation of the Cypress Hills area as established by Furnival (1946). The overlying dark-colored strata which include one or more tuff beds, were included in the newly designated Blackmud Member. The Upper Edmonton unit or Member E was subdivided into the lower Mammal-bearing Member and the upper Nevis Member.

Campbell (1967) concentrated on the study of two main seams in the Red Deer River area which he chose to collectively regard as the Ardley coal zone. The lower seam is reported to be 1 to 4 feet thick and equates to the Nevis seam of Allan and Sanderson and, in part, the Lower Ardley of Ower; this is the Lower Ardley 'A' of this paper. The upper seam is noted to be 4 to 6 feet thick and is separated by a thin but areally recognizable bentonitic clay parting (shown as Campbell's datum in Fig. 5). According to Campbell, the Ardley zone is 22 to 78 feet thick, including the interval between the upper and lower seams. The Upper Ardley of Campbell is equivalent to the Ardley or No. 14 seam of Allan and Sanderson, the Lower Ardley of Ower, and the Lower Ardley 'B' of this paper. Evidence will be presented to suggest

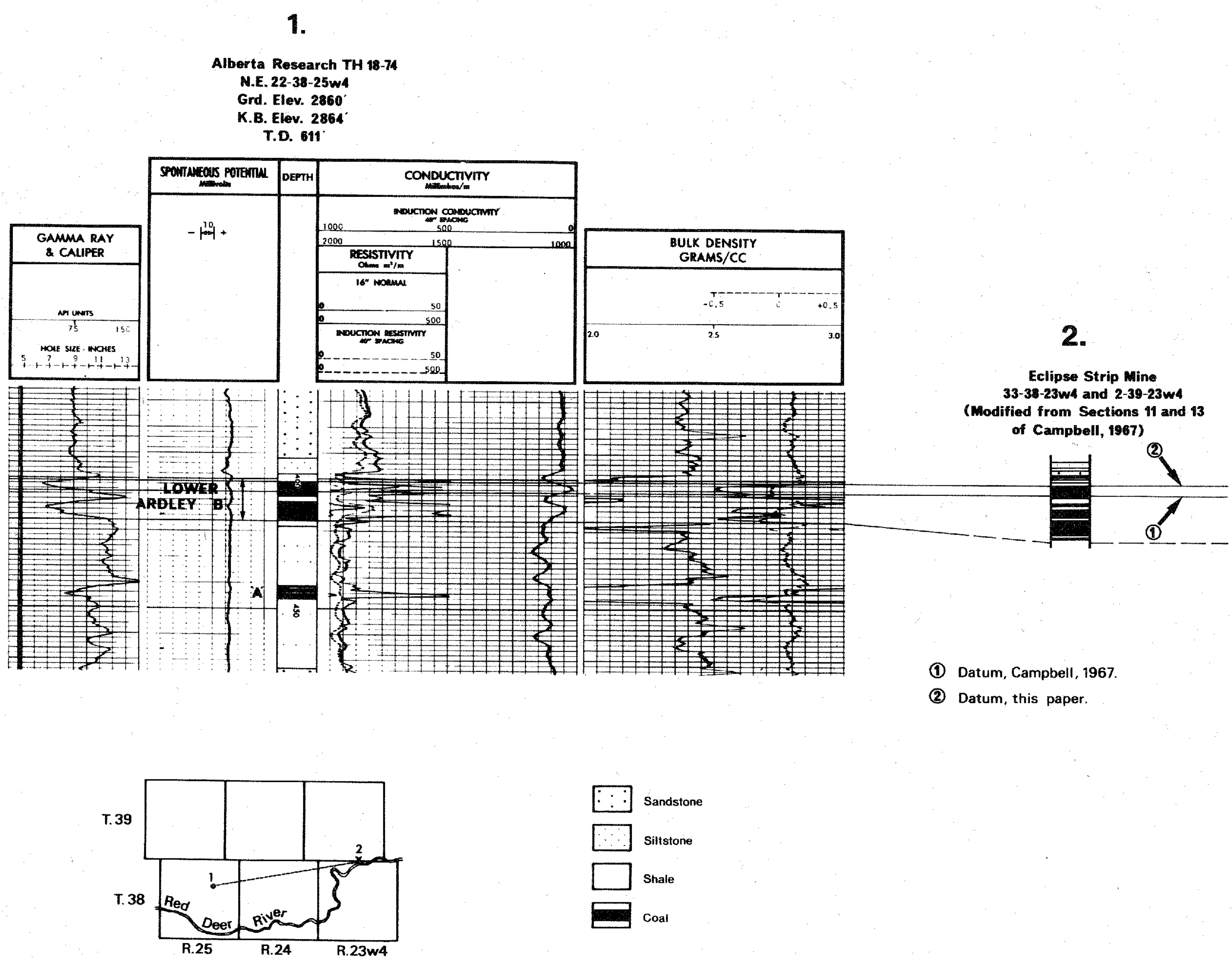


FIGURE 5. *Ardley area cross section.*

that the Lower Ardley 'A' and 'B' seams may split and recombine throughout the area, and are thus worthy of a similar or common designation.

Irish (1970) vastly modified the Upper Cretaceous-Tertiary nomenclature of central Alberta. The Edmonton Formation was given group status and the entire succession below the Whitemud unit designated the Horseshoe Canyon Formation. The Whitemud Member was given formational status and the Blackmud Member termed the Battle Formation (derived from Furnival, 1946). The reclassification of the overlying beds is of considerable importance, as it forms the basis for the nomenclature used herein. The entire succession above the top of the Battle Formation is included in the Paskapoo Formation and the coal-bearing unit previously classified as Upper Edmonton or Member E is renamed the Scollard Member. Irish established a type section for the Scollard Member in the Scollard area (Fig. 3, Sect. 5). It is the opinion of the writers that the section Campbell (1967) used (Fig. 3, Sect. 4) is a better choice as a type section, although it has not been personally studied by them. The section established by Irish (1970) is apparently incomplete due to preglacial or glacial erosion, and therefore fails to include the entire coal-bearing succession represented by outcrops to the west. In addition, it appears that the main Ardley seam (herein referred to as the Lower Ardley 'B') may not be represented due to erosion, thus eliminating one of the most important lithologic features of the succession. The coal bed present at the type section described by Irish may be correlative with a lower coal unit noted by Campbell on the west side of the Red Deer River Valley (the Nevis or Lower Ardley 'A' seam). The type section of the Scollard Member includes no strata above the Ardley coal zone to illustrate relationships between the coal-bearing succession and the massive sandstones of the overlying beds of the Paskapoo Formation.

However, for the purpose of this paper, the top of the Scollard Member is defined as the top of the uppermost coal seam of the Ardley coal zone. As will be noted, this usage results in some inconsistencies where coal seams lens out.

It is not considered within the scope of this paper to discuss in detail the controversial issue of the age relationships of Tertiary-Cretaceous units. However, a brief review of the literature is deemed necessary in order to better present the lithologic and environmental setting of the strata.

Allan and Sanderson (1945) considered the Tertiary-Cretaceous boundary to be at the base of the lowest massive sandstone above the unit now referred to as the Scollard Member. They postulated the occurrence of an unconformity at this stratigraphic level and speculated on regional truncation of Scollard Member beds. Ower (1960) considered the possibility of gradual and progressive easterly truncation of Member E beds and suggested that the base of the massive Paskapoo sandstones above the Scollard Member marked the true position of an angular disconformity. Ower accepted the possibility of continuous sedimentation, and also thought that localized channelling of the top of the Scollard Member was to be of considerable importance. Attempts by the writers to correlate sandstone lenses and to demonstrate bevelling of the top of the Scollard Member have proven fruitless.

Elliot (1960) studied the regional subsurface aspects of the problem and concluded (after noting thickening of the Edmonton Group toward the west and the basinal accumulation of Paskapoo sediments in the Alberta syncline), that a major disconformity must be present between the base of the Paskapoo and the underlying Edmonton.

Campbell (1962) found no evidence of an Edmonton-Paskapoo unconformity in outcrops; nor did the microfloral evidence suggest any significant break in sedimentation. He further observed that Paskapoo-type sandstones can be observed below significant Ardley seams.

Snead (1969) carried out microfloral studies on core from the Wizard Lake test hole (Fig. 6, Sect. 2) and was able to recognize three major floral zones. The flora from the top of bedrock to 140 feet in depth was recognized as Paleocene. Cretaceous (Maestrichtian) recoveries were made below 270 feet. Strata between these two zones have a mixed flora and thus no sharp break was found in the succession.

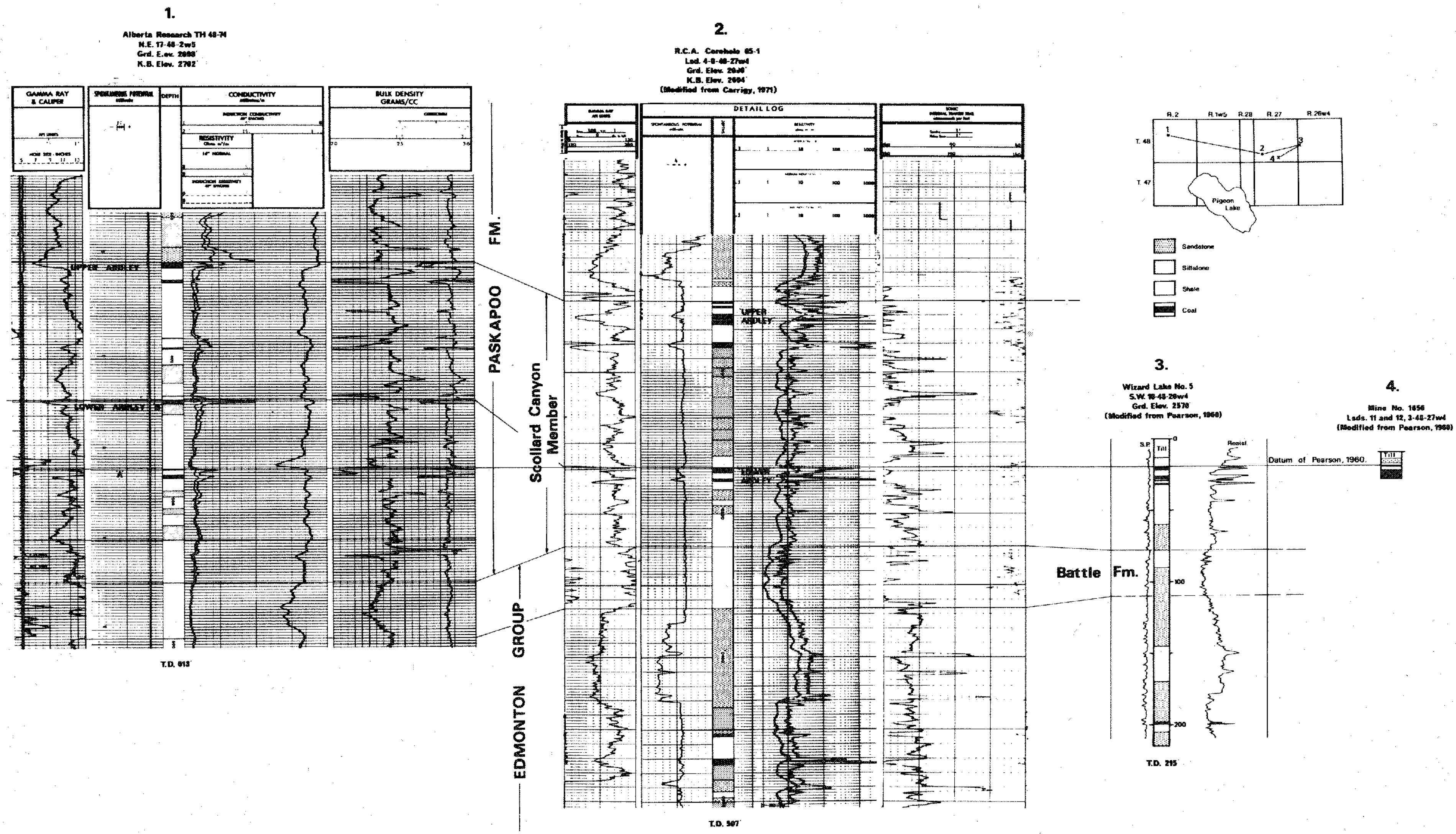


FIGURE 6. Wizard Lake area cross section.

Carrigy (1970, 1971), on the basis of lithological and compositional studies, concluded that a subdivision of the post-Battle strata into mappable units was untenable. The similarities in gross lithologies and the lack of widespread marker beds across the Edmonton-Paskapoo contact was documented and the scarcity or lack of diagnostic fossils noted. Carrigy placed the Tertiary-Cretaceous boundary at the top of the Battle Formation. Irish (1970) also supported this interpretation and cited the paleontological evidence of Sternberg (1947, 1949), Russell (1964) and Tozer (1956), which strongly suggests the correlation of the Scollard Member with strata of Lance age in southern Alberta, Montana and Wyoming. Sternberg's (1947) singular claim of having recovered dinosaurian fossils 90 feet above the Ardley seam was discounted by Campbell (1967). Campbell regarded the seam used as the datum to be, in fact, the Carbon-Thompson coal, which occurs in the upper part of the Edmonton Group.

ARDLEY COAL MINES

The Ardley coal seams have been mined to a considerable extent in the past (Fig. 4). Development has mainly been confined to four areas: Three Hills-Trochu, Ardley, Wizard Lake and Wabamun-Entwistle areas. Details of companies involved, duration and type of mining, and seam lithologies are available from Campbell (1964).

At the present time, three mines are exploiting Ardley coal. The Calgary Power Ltd. strip mines operated by Manalta Coal Ltd. at Wabamun Lake produced approximately 2.5 and 1.3 million tons from the Whitewood and Highvale operations respectively, during 1973 (Energy Resources Conservation Board, 1974). The coal was used entirely to run the two Calgary Power thermal plants in the area. The strip mine owned and operated by Sissons Mine Ltd. near Ardley, produced approximately 17,000 tons in 1973, all of which was used for domestic purposes.

Four cross sections are provided to illustrate the relationships between seams penetrated during the 1974 Alberta Research Council exploration program and those documented in the literature at or near Ardley coal mining ventures.

Figure 3 illustrates the commercial importance of the Lower Ardley 'B' zone within the Three Hills-Trochu area as documented by Campbell (1967), Alberta Research test hole 1-74 and G.S.C. test holes drilled during 1973.

A correlation between Alberta Research test hole 18-74 and Campbell's (1967) mine sections in the Ardley area establishes the Lower Ardley 'B' coal as the economic unit there (Fig. 5).

There is no production of coal in the Wizard Lake area at the present time. However, Pearson (1960) describes seam sections of former mines in the area and one such succession together with an adjacent exploration drill hole, Carrigy's (1971) Wizard Lake test and Alberta Research test hole 48-74, show the potential importance of the Lower Ardley 'B' coal in this area (Fig. 6).

Information from Pearson (1959) and Alberta Research test hole 75-74 is presented in figure 7 for the Wabamun area. The Lower Ardley 'B' is the coal interval under development.

THE ARDLEY COAL ZONES

Structure

Figure 8 indicates the nature of bed structure as defined by mapping the top of the Lower Ardley coal. The westerly dip, which averages 25 feet per mile regionally, is locally as high as 65 feet per mile and as low as 10 feet per mile. The strike of the strata is north-south in the south part of the area and approximately N25°W over much of the central region. North of Drayton Valley, the beds strike N40°W. Farther to the north (and west of the Athabasca River) the strike of the beds is nearly east-west. There are several areas of localized flexuring, the most prominent of which are documented in the Gull Lake and Drayton Valley areas. A significant anticlinal structure southeast of Drayton Valley is interpreted to be approximately 5 miles across and involves a vertical development of over 100 feet.

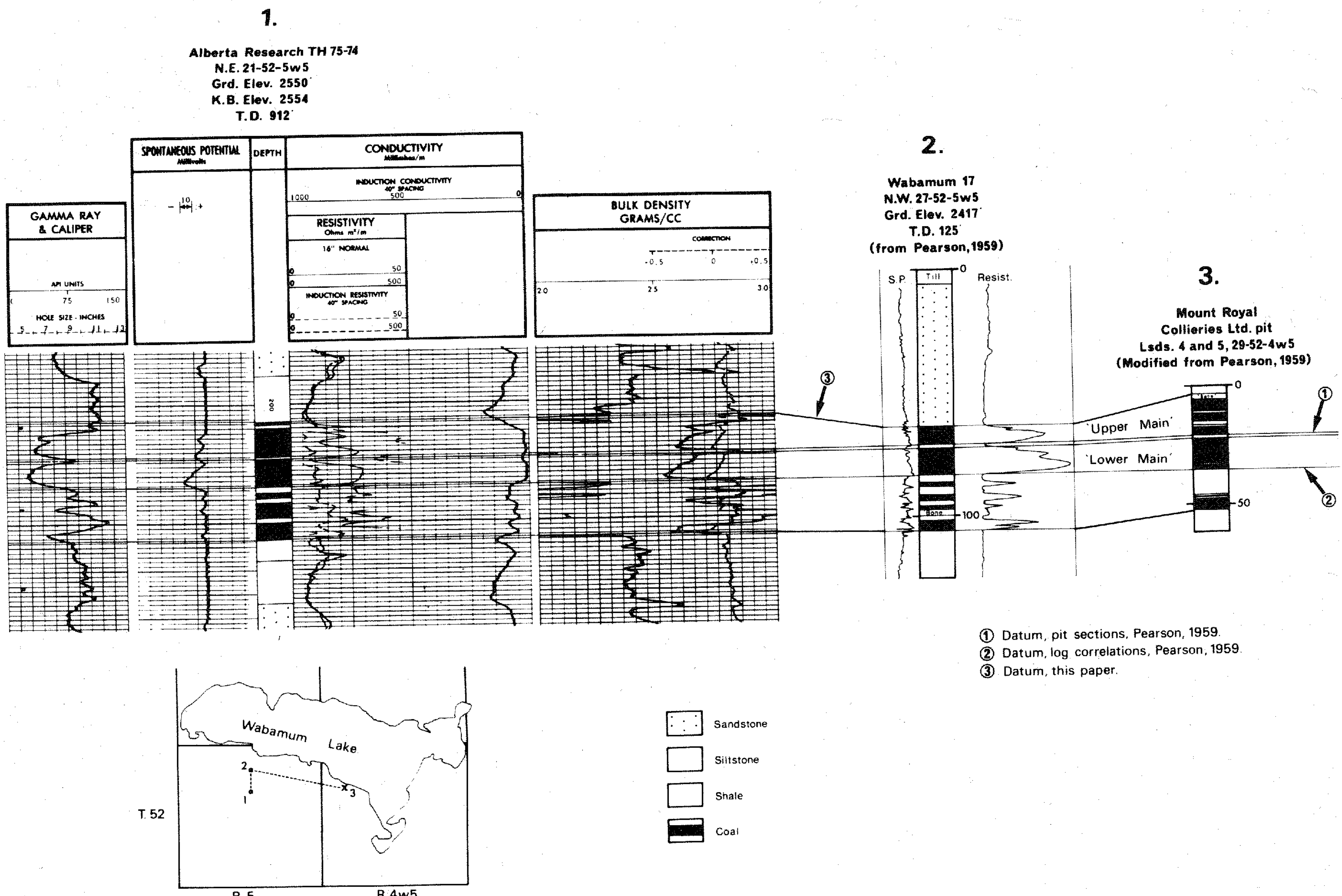


FIGURE 7. Wabamun area cross section.

Depths of Burial

The depths to the top of the Lower Ardley coal are shown in figure 9. The map presentation is understandably of a generalized nature considering the unevenness of the plains surface and the localized occurrence of river valleys. The 1974 exploration program was concentrated on those portions of the area in which the Ardley coal is encountered at less than 1000 feet. For reasons which will be elaborated later in the report, the areas in which depths of coal vary between 300 and 1000 feet are of special significance.

Stratigraphy

The core from six test holes forms the basis for standardization of log data. Visual examination of core indicates that lithologies may be determined with considerable confidence from gamma ray-density log information. Figure 10 compares core descriptions with gamma ray-density log profiles and laboratory analyses of coal. Beds which do not include coal are documented by high density values (greater than 2.0 gms/cc). Sandstones normally show gamma ray values of less than 90 API units within such successions. Siltstones with low clay contents are registered as high density log anomalies and by gamma ray readings of approximately 90 to 105 API units. Gamma ray readings and shale contents increase proportionally up to maximum readings of about 150 API units. Visual determinations of coal from core show a correspondence between the coal and density values of less than about 2.0 gms/cc. Analytical results indicate the higher quality coal (greater than, say 8000 BTU/lb, as received basis) is confined to successions recorded by density readings of less than about 1.75 gms/cc. Shaly coal beds are recognized by relatively high gamma ray values in combination with relatively low density readings. More complex lithologies such as silty sandstone, shaly siltstone, silty shale, are difficult to ascertain. However, the knowledge of log characteristics together with reference to descriptions of drill cuttings normally provides sufficient data to closely approximate the nature of the strata.

The aforementioned log parameters were utilized to determine the lithologies in each of the test holes drilled during the 1974 exploration program. Two series of cross sections were constructed from the interpreted data. A network of sections as outlined in figure 11, shows the regional correlations of units as applied to the entire succession (Figs. 12 and 13). Ground level was chosen as datum, resulting in an approximation of bed structure. All of the core holes appear on section C-D (Fig. 12).

A second set of north-south cross sections (Fig. 14) is a more detailed presentation of the part of the succession which includes the Ardley coal zone. Approximately 280 feet of section is included from each test hole and the top of the uppermost significant coal bed of the Lower Ardley 'B' is used as a datum.

The generalized cross sections (Figs. 12 and 13) illustrate several important stratigraphic features. Correlation of units within that portion of the Paskapoo Formation which lies above the Scollard Member is extremely difficult to carry out regionally. The strata include interbedded sandstones, siltstones and shales with highly localized occurrences of coal and shaly coal seams up to 6 feet thick (Fig. 12, test hole 40-74, 243'). Sandstone successions vary from a few inches to over 100 feet in thickness and are typically fine-grained and medium brown to grey (salt and pepper) in color. Shales and siltstones show a wide variation in color and texture. In a few areas shale beds are useful as marker beds particularly below Paskapoo-type sandstones which occur immediately above the Scollard Member (above prominent Ardley coal seams). In such cases the shales typically possess a greenish hue and the coloration darkens with depth to the highest Ardley coal beds due to increasing carbonaceous content.

As previously noted, a maximum of three major coal units are recognized in the Scollard Member. The cross sections provided illustrate the manner in which the top of the Lower Ardley 'B' may be traced with reasonable confidence. The underlying coal beds, collectively termed the Lower Ardley 'A', are not laterally persistent and in some areas appear to constitute a single unit which is a split of the Lower Ardley 'B'. The Upper Ardley is difficult to define as an individual coal seam or series of coal seams. It is more convenient to regard this unit as a series of seams (which may be correlated with varying degrees of success) occurring within the 50 to 150 feet of succession above the Lower Ardley 'B'. The top of the highest significant coal seam is considered to be the top of the Upper Ardley.

A number of test holes penetrated the Upper Cretaceous Battle Formation, thus establishing the Scollard Member to be between approximately 120 and 300 feet thick. The interval between the top of the Lower Ardley 'B' and the Battle Formation thins toward the north. No positive identification of tuff was made from sample cuttings collected from the Battle Formation.

The cross sections provided in figure 14 illustrate details of coal zone correlations. Some attempt is made to show shale and shaly coal beds as determined from higher density log characteristics (>1.75 gms/cc) and relatively high gamma ray counts. The definition of shales and shaly coal interbedded with coal strata lends greater definition to the units. For example, in section C-D (Fig. 14) shale beds "x" and "y" within the Lower Ardley 'B' unit demonstrate the detailed relationships between coal successions in neighboring test holes. These marker beds may be traced for distances in excess of 40 miles.

A number of correlation anomalies are apparent from the cross sections. In figure 14 (section A-B) it is noted that test hole 39-74 contains very little coal at the Lower Ardley stratigraphic level. Post-Scollard channelling may account for this phenomenon. The lateral termination of the Lower Ardley 'A' is often accompanied by an unusually prominent development of sandstone in its place. This is effectively shown in figure 14 between test holes 29-74 and 78-74. Local channelling is again considered to be the responsible factor.

The Upper Ardley is moderately well developed in the area covered by the south portion of figure 14 (section E-F). However, farther to the north in test hole 41-74 this unit is unusually well developed. In the same well the Lower Ardley 'B' is extremely thin and the lower Ardley 'A' is anomalously thick. As a result, the correlations are less confidently established in this area. Farther north in test holes 45-74 and 43-74 the Upper Ardley is also well developed. In the latter test hole the unit occurs unusually high in the stratigraphic section and the correlations are correspondingly less obvious.

Resources

Gross Isopach Studies

Variation of seam thicknesses may be presented in map form utilizing numerous types of arbitrary controls. The two isopach formats included in this study are designed to respect the following criteria:

(1) define units of coal bedding which are economically producible by reasonably well known technologies;

(2) define coal sections uninterrupted by excessively thick, non-coaly beds;

(3) define units which are correlative over reasonably extensive areas.

The technique of gross isopach mapping used herein is based on the premise that in situ gasification of coal is one recovery method applicable to the Ardley zone. It is assumed that such a process would involve combustion of coal over a considerable succession except where intervening non-coaly strata impede the vertical advance of the combusting zone. Following from these basic parameters, each Ardley coal unit is mapped individually and isopaching is confined to the thickest succession of coal bounded above and below by non-coaly beds greater than 2 feet thick.

The limitations of the above approach are apparent. For instance, a shale bed 3 feet thick which occurs between two thick coal seams would prevent the possibility of mapping both seams for the same Ardley coal unit, but in practice this situation seldom arises. Shale beds less than 3 feet thick are not included in the isopach values if the thicknesses are definable from log characteristics. There are doubtless many shale laminae which are not documented by the log profiles or which can only be vaguely delineated by weak log responses.

Gross isopach maps of the Lower Ardley 'A', Lower Ardley 'B' and Upper Ardley are presented in figure 15. East of Red Deer the Lower Ardley 'A' isopach unit attains a thickness in excess of 5 feet over a relatively small area. North of Ponoka the best seam development varies between 2 and 12 feet in thickness. High isopach values are located east of Pigeon Lake and north of Drayton Valley. The Lower Ardley 'A' merges with the Lower Ardley 'B' at several locations, as shown in figure 15, and no attempt is made to map the unit within such areas. The thickness trends plotted on the isopach map show a generalized east-west orientation.

The Lower Ardley 'B' is the most prominently developed Ardley coal unit. The isopach section exceeds 5 feet in thickness throughout the study region with the exception of areas centered in Tp. 47, R. 2W5 and Tp. 44, R. 1W5 (Fig. 15). The thickness trend lines are normal to the regional strike of the strata. Maximum thicknesses within each of the seven areas through which the trend lines pass exceed 15 feet.

Figure 15 indicates the limits of the mappable Upper Ardley seams. The area bordered to the north by Tp. 42 and to the south by Tp. 49 is underlain by seams greater than 5 feet thick. A line delineating a trend of thickness is drawn with an east-west orientation across the study area, south of Pigeon Lake. Throughout this trend, the isopach unit is greater than 10 feet thick.

Resource calculations for each major coal zone are based on the usage of the gross isopach maps and the following limiting factors:

(1) areas north of Tp. 32 and south of the Athabasca River underlain by a thickness of 5 feet or greater of coal at depths of between 300 and 1000 feet;

(2) an average specific gravity of 1.5 for Ardley coal;

(3) a 15 percent loss factor due to such things as density differences, shale partings.

The Lower Ardley 'A', Lower Ardley 'B' and Upper Ardley contain approximately 9.4, 28.5, and 6.3 billion tons of coal respectively. The total tonnage available for exploitation by means of methods outlined previously is thus about 44.2 billion tons.

Isopach Studies of High Quality Coal

A second approach is taken with regard to isopach studies in an effort to evaluate high quality coal available for more selective mining approaches. The results of digitization work are employed to delineate continuous vertical successions of coal exceeding 40 percent fixed carbon or approximately 8500 BTU/lb. Standardization of digitized analyses is based on proximate analysis of core. A cross plot of analytical data establishes the relationship between fixed carbon percentages and heating values. A number of selected samples were subjected to ultimate analysis to provide further details of coal quality.

The thickest high quality coal seam within each of the three Ardley units is presented in figure 16 and, as before, the isopach unit within each is limited above and below by non-coaly beds or coal beds of inferior quality which are greater than 2 feet thick. Intervening low quality beds less than 2 feet thick are not included in the isopach values.

The highest quality succession of the Lower Ardley 'A' coal averages 5 feet thick within a small area south of Pigeon Lake (Fig. 16). Similar quality development is also documented between Drayton Valley and Chip Lake.

The Lower Ardley 'B' is poorly developed as a source of quality coal south of Warburg with the exception of three included areas where it achieves moderate development. These three areas, shown in figure 16 occur south of Pigeon Lake, east of Gull Lake, and south of Red Deer. North of Warburg, good to excellent representation of the unit is noted. A small area north of Chip Lake is underlain by a thin bed of low quality coal.

High quality coal is rare in the Upper Ardley and successions exceeding 5 feet in thickness are only to be found in a small area between Warburg and Pigeon Lake (Fig. 16).

Tonnages of high quality coal are determined as in the case of the gross isopach studies with the exception that a recovery factor of 50 percent is applied to calculations rather than a 15 percent loss factor. As a result it is estimated that the units contain the following amounts:

Lower Ardley 'A'	2.2 billion tons
Lower Ardley 'B'	14.6 billion tons
Upper Ardley	0.5 billion tons.

The total amount of coal available for conventional mining is thus approximately 17.3 billion tons.

An attempt was made to determine the distribution of maximum quality coal and figure 17 summarizes the results of these efforts. Analyses of cuttings for the Lower Ardley 'A' coal are plotted and no distinct pattern of distribution is noted. The heating values (determined on a dry basis) range from 6700 to 11,900 BTU/lb. Core analyses show maximum heating values of approximately 11,500 BTU/lb (dry basis) thus establishing the maximum Ardley rank values as those of subbituminous A coal.

Anticipated Areas of Development

Areas of possible development are summarized in figure 18. There are few areas which are not of medium to high potential either by applying mass mining (i.e., in situ gasification) or selective (conventional underground)

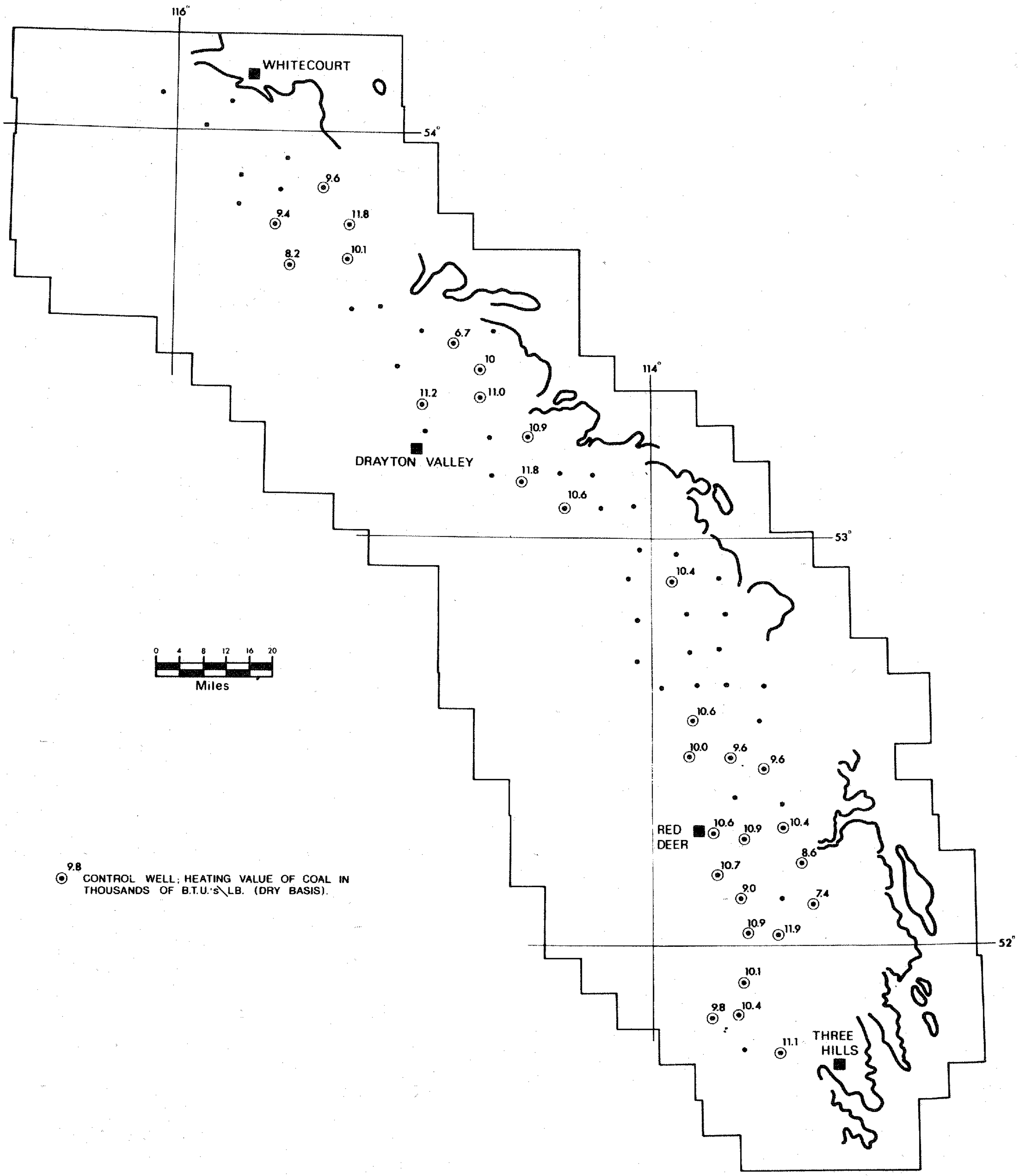


FIGURE 17. Distribution of highest quality coal.

mining methods. The region north of Gull Lake to Winfield appears to be the only large low potential area definable from the present data. High quality seams are lacking in the Red Deer area and south of Tp. 31. On the basis of the generalized distribution of coal, future development could be anticipated south of Red Deer, near Pigeon Lake, southwest of Wabamun Lake and east of Entwistle.

LITHOFACIES STUDIES

Reference to isopach thickness trends as shown in figure 15 suggests that coal deposition was concentrated along linear features oriented normal to the present regional strike. There appears to be no obvious repetition of these trends with the exception of an area south of Pigeon Lake.

Figure 19 summarizes the lithofacies analysis of the Scollard Member as determined from lithologies shown on the detailed cross section (Fig 14). For the purpose of map presentation, the analysis is based on 25 percent groupings of ratios of sandstone to siltstone-shale. The ratio of coal to clastics is divided into two main groups: 0 to 10 percent and 10 to 20 percent. The higher concentrations of coal (represented by vertical hatching and fine stipple patterns) are largely coincident with isopach trend lines previously noted. In other words, areas north of Red Deer, south of Whitecourt and surrounding Pigeon Lake and Drayton Valley are underlain by greater amounts of coal. The coal concentrations are seldom associated with a succession predominated by either sandstone or siltstone-shale. In fact, the clastic strata in such regions are of a highly variable nature. Mixed lithologies are also distinctive of areas in which the coal constitutes less than 10 percent of the succession.

Linear trends normal to the regional strike are apparent from the lithofacies presentation. The paleoenvironmental condition envisioned for the Scollard Member is a complex of broad, swampy flood plains across which easterly and northeasterly flowing drainage systems traversed and, at times, coalesced.

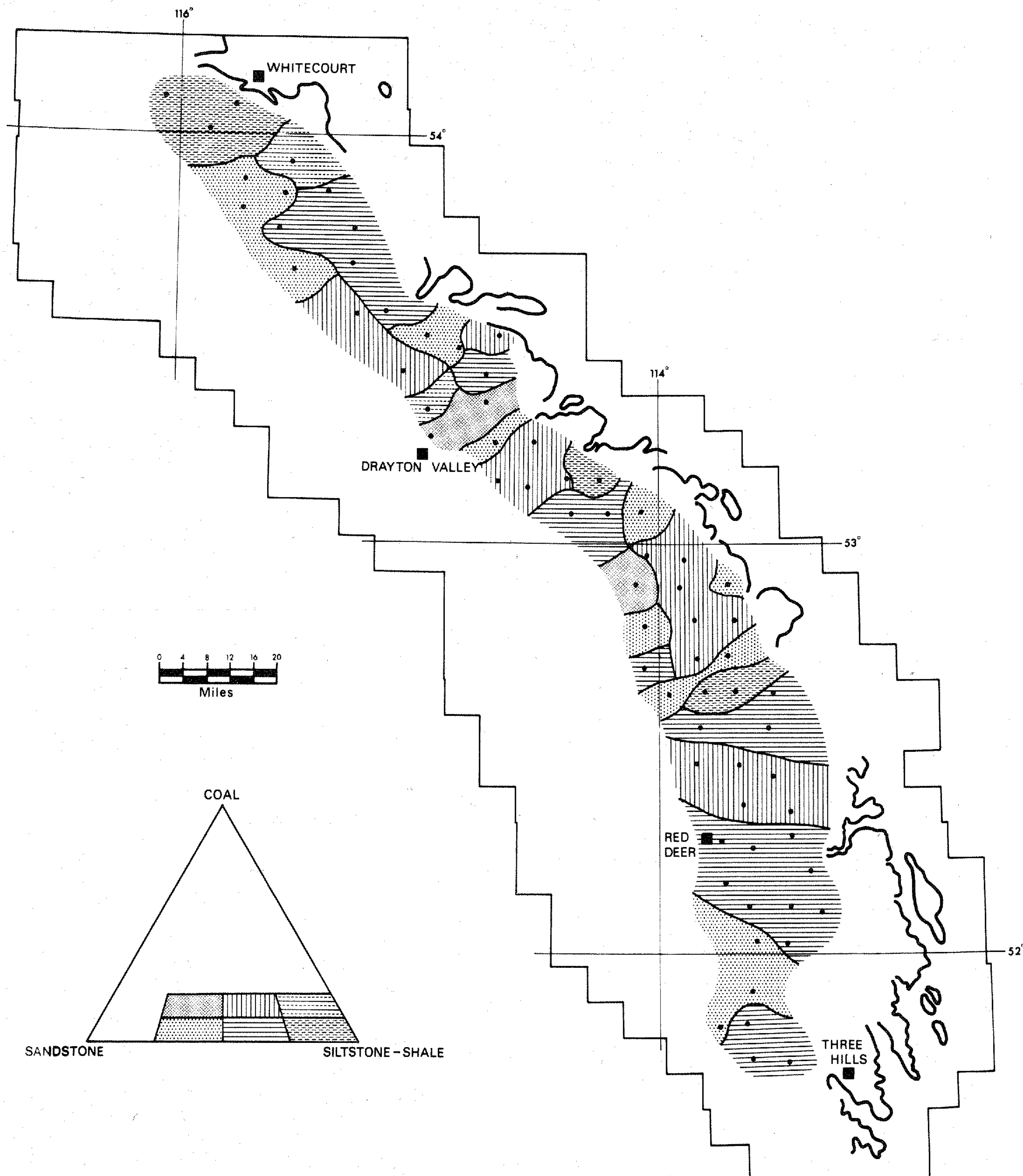


FIGURE 19. Lithofacies map of the Scollard Member.

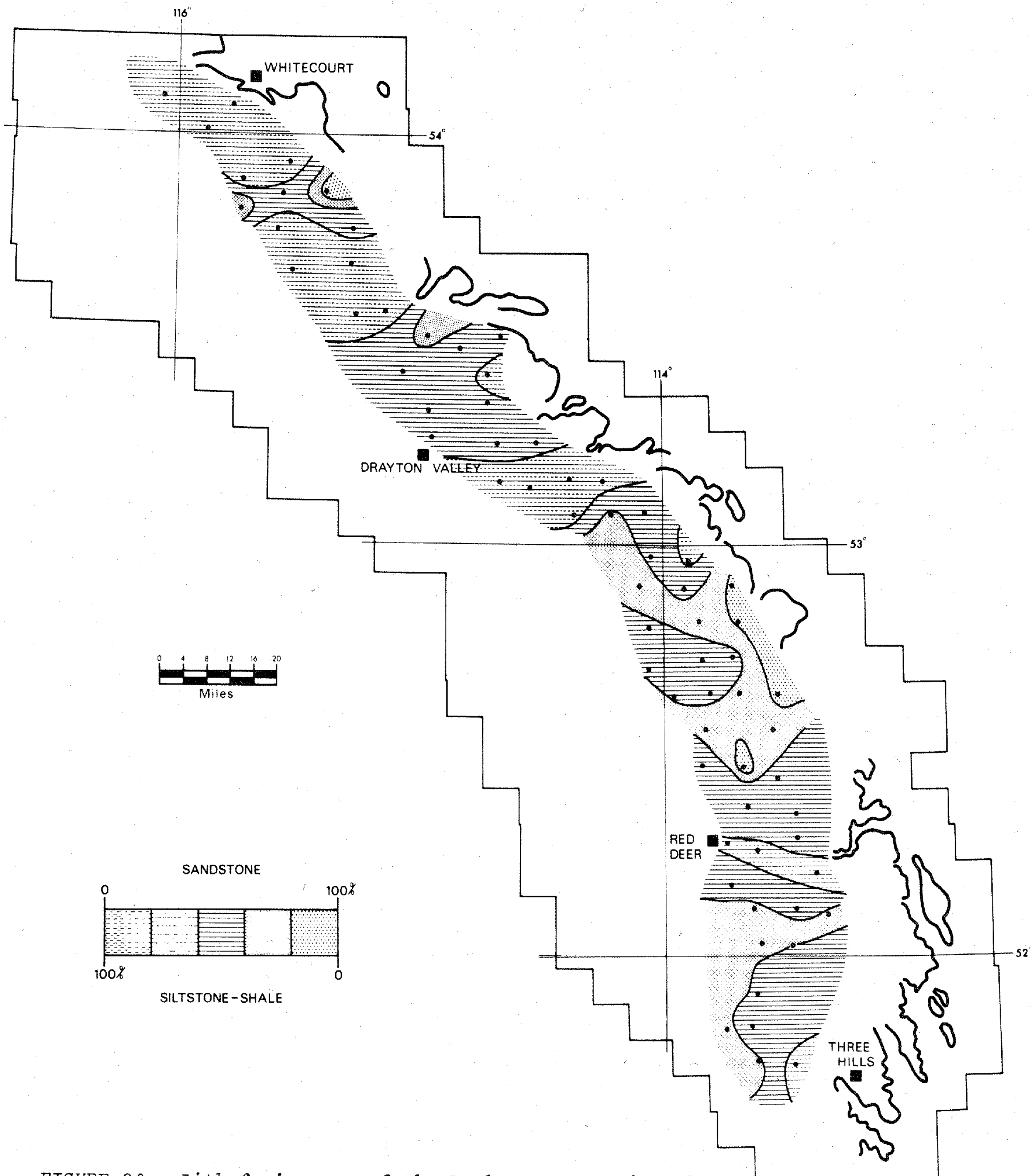


FIGURE 20. Lithofacies map of the Paskapoo Formation above the Scollard Member.

Lithologic sections were evaluated in figures 12 and 13 above the uppermost significant Ardley coal seam, to determine lithofacies characteristics of that part of the Paskapoo Formation above the Scollard Member (Fig. 20). Significant percentages of sandstone occur in successions north and south of Red Deer. Siltstone and shale predominate in the upper part of the Paskapoo immediately adjacent to Red Deer and southwest of Whitecourt. An east-west orientation of facies groups is noted, suggesting the continuance of alluvial systems responsible for Ardley coal deposition into post-Scollard time. In some areas there is a progressive change in facies along east-west axes; however, there appear to be few generalizations that can be made with regard to these changes. For example, Paskapoo clastics become finer textured in an easterly direction in the Three Hills area, whereas north of Red Deer the strata become increasingly coarse-textured as the subcrop edge is approached. The absence of coal in Paskapoo strata above the Scollard Member is interpreted to indicate the development of steeper stream gradients, higher velocity river flow and less expansive flood plain development than was prevalent during Scollard deposition. The initial stages of the Laramide orogeny may have effected sedimentologic patterns at this stage. Uplifting to the west served to alter the earlier quiescent depositional conditions and resulted in a greater supply of coarse clastics. The increased erosion capabilities of the river systems led to localized channelling of Scollard Member strata.

ROCK PROPERTIES

In an effort to evaluate the non-coaly strata for mine roof conditions, seven representative samples of core were selected for study of physical properties. The stratigraphic position of each is indicated in figure 10. Five of the samples are from beds less than 10 feet above the Lower Ardley 'B' in test holes 12-74, 20-74, 37-74 and 67-74. One sample was obtained from a core section 8 feet below the base of the Lower Ardley 'B' in test hole 59-74. Tests were run on a shale sample obtained from core cut in test hole 47-74 above a main Upper Ardley coal seam.

The specimens varied texturally from shales to medium-grained sandstones. Generalized petrographic properties of each sample are outlined in plates 1 to 4 at the end of the report. X-ray analyses were run on all the materials at laboratories of the Alberta Research Council and the resultant patterns are shown in figure 21. Analysis of clay mineral contents indicates that montmorillonite commonly predominates (refer to Table 1 for relative clay mineral percentages). Kaolinite and illite normally comprise less than 50 percent of the clay minerals. Contents of illite are unusually high in the shale sample from test hole 47-74 in which minor coal partings are also present. High percentages (40 percent) of kaolinite were recorded in a sandstone below the Lower Ardley 'B' coal in test hole 59-74.

Table 1. Relative percentages of clay minerals in roof rock

Test Hole	Depth	% Montmorillonite	% Kaolinite	% Illite
12-74	546'	70	10	20
20-74	603' 6"	95-100	trace	--
37-74	819'	85	5	5
47-74	515'	35	15	50
59-74	554' 6"	55	40	5
67-74	702'	95-100	trace	--
67-74	704' 6"	50	20	30

Quartz and plagioclase feldspar are common to all the materials tested. The sandstones in test holes 20-74 and 67-74 contain calcite as a grain cementing medium. Traces of dolomite are recognized in the latter sample as well as in the silty shale obtained from test hole 37-74.

Table 2 summarizes the results of mechanical testing of core samples by M. Dusseault of the University of Alberta. Determinations of failure stress and strain by unconfined uniaxial compressive strength tests could only be obtained on coarse clastic samples from test holes 20-74, 59-74 and 67-74. The well-cemented sandstone from test hole 67-74 is a highly competent rock. Testing pressures in excess of 8000 psi were required to initiate failure (Fig. 22). Bentonitic sandstones from test holes 20-74 and 59-74 are considerably weaker and stress failures of slightly less than 4000 psi and 3000 psi respectively were registered for these materials.

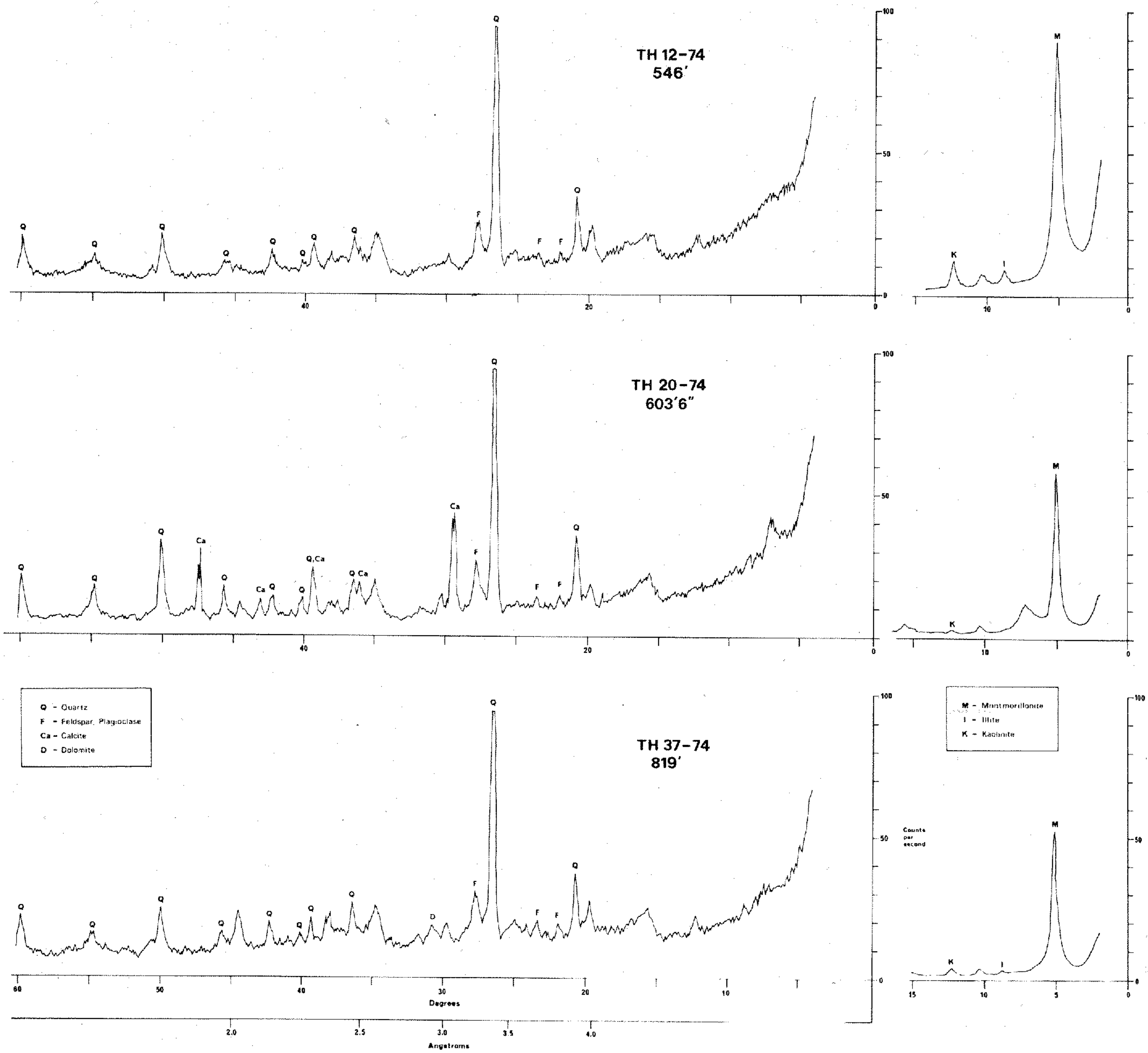
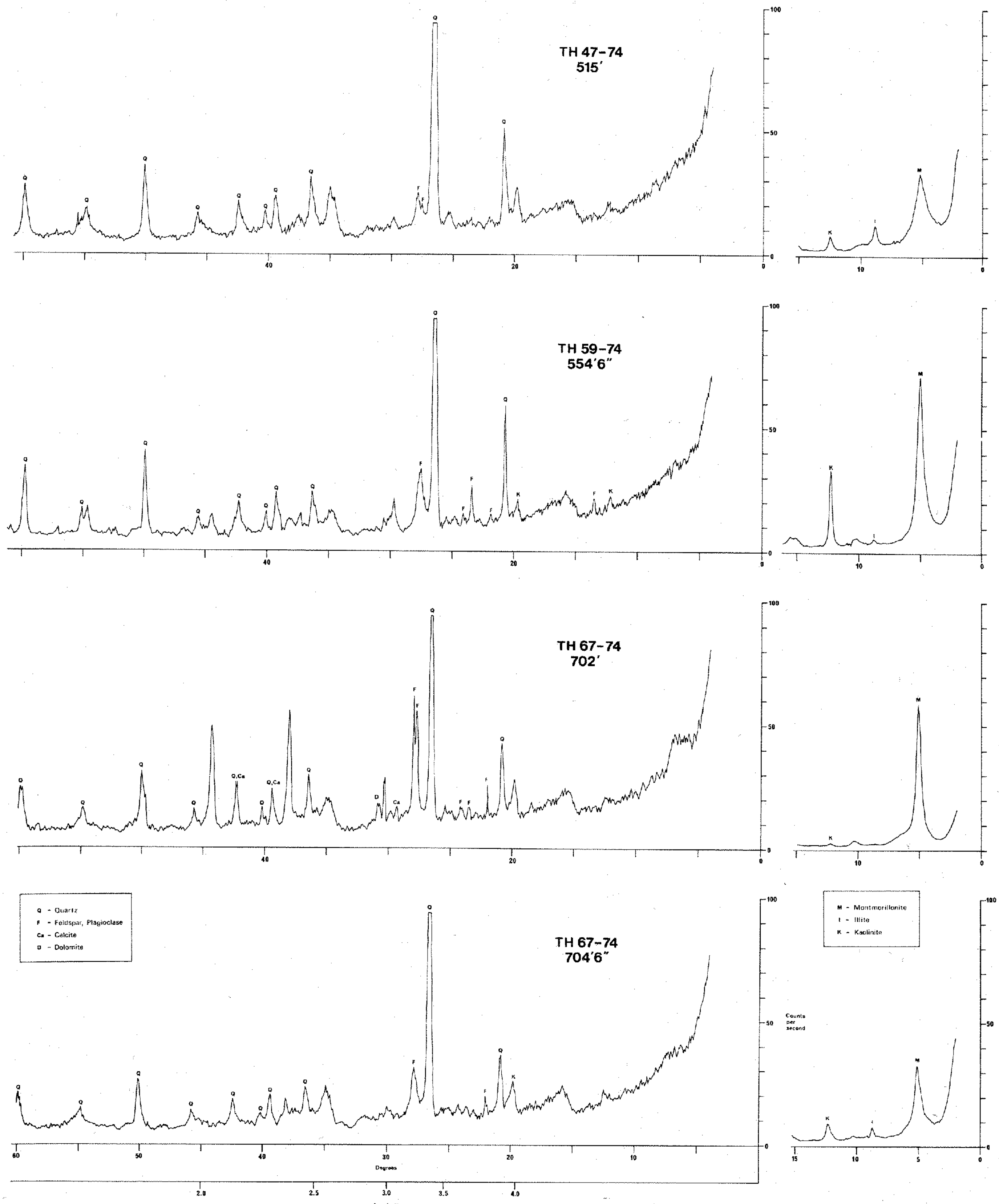


FIGURE 21. X-ray diffraction patterns of representative core from test holes.


TH 47-74
515′
TH 59-74
554′6″
TH 67-74
702′
TH 67-74
704′6″
Q - Quartz
F - Feldspar, Plagioclase
Ca - Calcite
D - Dolomite
M - Montmorillonite
I - Illite
K - Kaolinite
Counts per second
Degrees
Angstroms

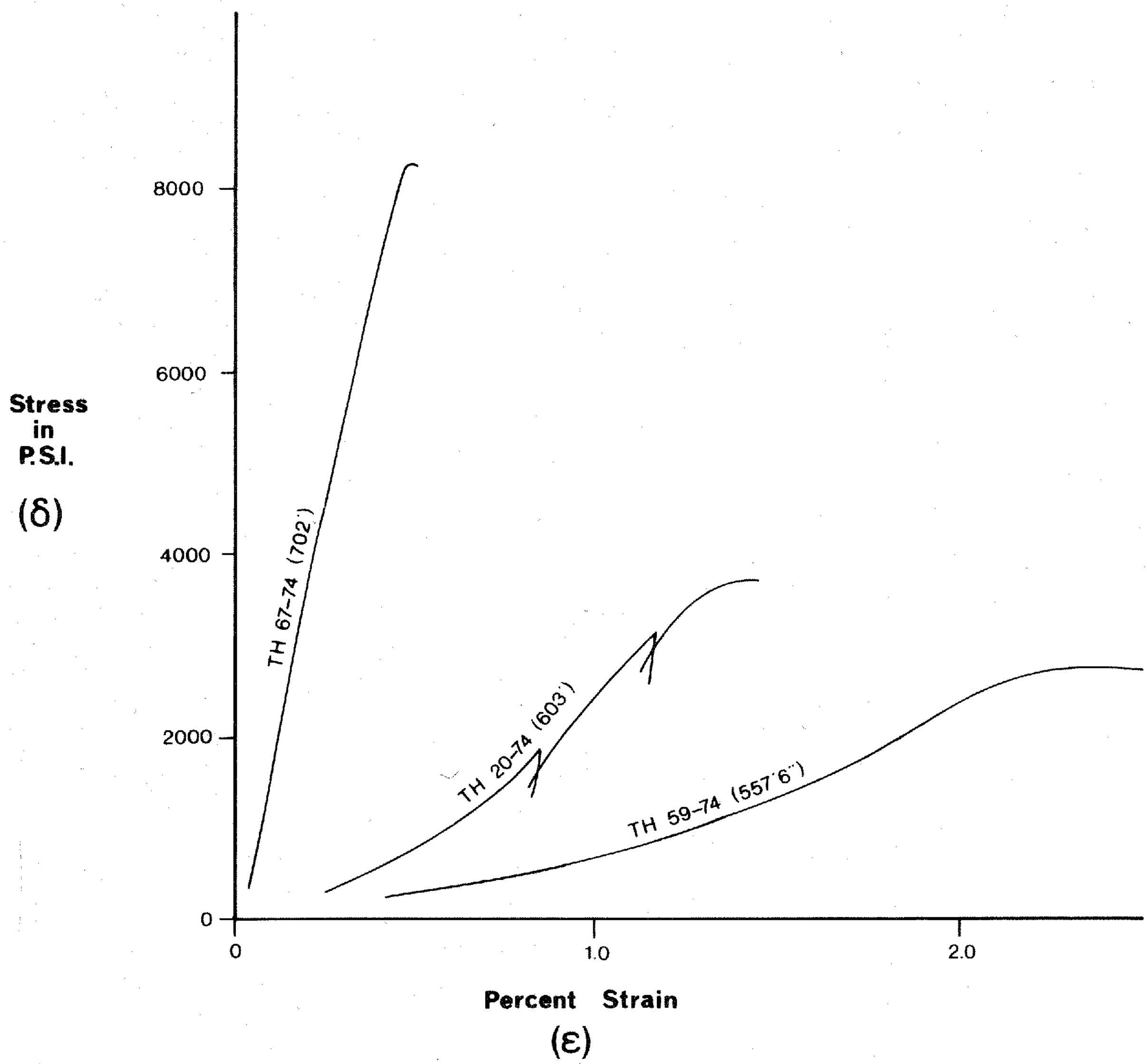


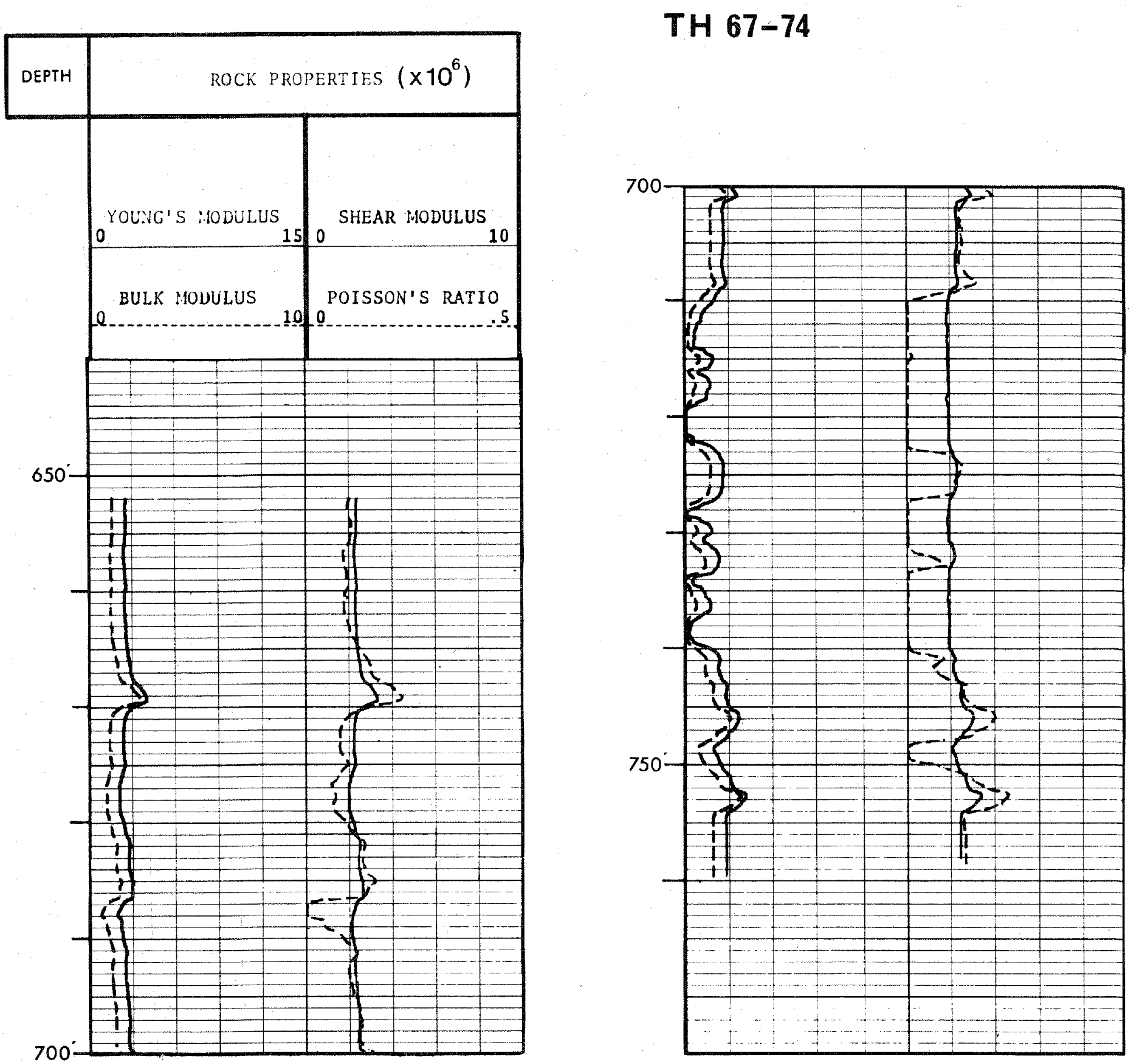
FIGURE 22. Stress strain results of core sample tests.

Elastic properties were obtained using a sonic-pulse transmitter and an oscilloscope registering mechanism. The times of travel of compressional and shear waves were thus obtained and elastic strength characteristics were then calculated. An Acoustilog (sonic log) was run on test hole 67-74 and both manual and computerized computations were arrived at by J. Kowalski of Dresser Industries (Fig. 23). On the basis of one sample the results of core testing are related to geophysical logging methods in the following

Table 2. Rock strength properties

Sample No.	gm/cc Bulk Density	Young's Modulus Across Bedding (Sonic)	Young's Modulus Parallel to Bedding (Sonic)	Bulk Modulus (K) Across (Sonic)	Bulk Modulus (K) Parallel (Sonic)	Poisson's Ratio Average (Sonic)	Young's Modulus Static Loading	Young's Modulus Static Unloading	Failure Stress	Failure Strain	Slaking Test (24 hr)	Sample Description	Anistropy Ratio = E_2/E_3
TH-12-74 546'3"	*	*	*	*	*	*	*	*	*	*	Complete Slaking into very thick mud	Very fine grained clay shale; dessication cracks; coaly partings	-
TH-20-74 603'	2.22	11×10^5	21×10^5	3×10^5	6.5×10^5	0.26	3.65×10^5	15.4×10^5	3754	1.44	Minor	Crumbly bentonitic sandstone; light grey, medium grained	1.91
TH-37-74 819'	2.54	16×10^5	26×10^5	8.5×10^5	18.0×10^5	0.21	*	*	*	*	Complete Slaking into mud	Clay shale with some silt; dense, dark grey	1.63
TH-47-74 515'	2.38	4.6×10^5	19.0×10^5	3.3×10^5	15.0×10^5	0.28	*	*	*	*	Breaks into fragments but water clear	Clay shale with coaly partings; competent	4.10
TH-59-74 554'6"	2.03	2.0×10^5	3.6×10^5	0.8×10^5	1.6×10^5	0.17	2.09×10^5	4.5×10^5	2766	2.30	Minor	Crumbly bentonitic sandstone; grey, fine grained	1.80
TH-67-74 702'	2.51	15×10^5	31.0×10^5	13×10^5	19×10^5	0.28	17.9×10^5	25.3×10^5	8334	0.48	-	Dark grey sandstone; 10° bedding dip; very competent	2.07
TH-67-74 704'6"	*	*	*	*	*	*	*	*	*	*	Breaks into fragments, water slightly murky	Silty dark grey clay shale; coaly partings; dessicated and fractured	-

*Data too difficult or impossible to obtain.



COMPUTATION PARAMETERS											
DEPTH INTERVAL		ρ_{ma}	ρ_{clay}	ΔT_{clay}	ΔT_{ma}	GR_{sd}	GR_{sh}	R_w at FT	a	m	n
FROM	TO										
652	760	2.65	2.60	122	55.5	45	135	.6	.62	2	2

FIGURE 23. Acoustilog calculations of rock properties.

manner: bulk modulus across bedding, as determined in the laboratory, is approximately equal to the value calculated from the Acoustilog. Young's modulus (tested across the bedding by the sonic-pulse transmitter method) proves to be approximately one half as great and the average Poisson's ratio is slightly more than two times greater than results obtained from logs.

Dusseault (pers. comm.) observes that there are wide variations in strength and elastic parameters of the tested materials. He notes that the strata are highly anisotropic and concurs with Locker (1973) that the strengths are dependent on many factors. Dusseault makes the following generalized observations with regard to the core examined:

(1) In sandstones, strength and elastic parameters will increase as calcite cementation increases.

(2) As the montmorillonite increases in sandstones, strength and elastic values decrease.

(3) Strength and elastic parameters increase with increasing density.

(4) In shales, strength and elastic characteristics decrease with increasing moisture contents.

(5) The elastic moduli are low in shales possessing high swelling properties. Slaking tests prove to be useful in determining the relative tendency of shales to swell.

SUMMARY

Three stratigraphic units are recognizable within the Ardley coal zone. The lowest, the Lower Ardley 'A' unit, is erratically developed and in places, constitutes a split of the overlying Lower Ardley 'B' unit. The Lower Ardley 'B' is the most prominently developed unit and is extremely widespread. The Upper Ardley is composed of a number of thin seams which are of economic interest only in the Pigeon Lake area.

On the basis of isopach mapping of maximum quality and gross thicknesses the distribution and reserves of each unit are delineated. The total resources, as determined from gross isopach studies, are 44 billion tons of which 28.5 billion tons is contained within the Lower Ardley 'B'. Clearly, the Lower Ardley 'B' will be of greatest interest for future development. Several areas between Red Deer and Entwistle are considered to have high potential for mining ventures.

Sedimentation patterns show east-west lineations as determined from paleogeographic and coal isopach maps. This is regarded to be an expression of easterly-flowing alluvial systems which initiated Paskapoo deposition and constitutes an important factor for understanding the lateral extension of coal seams.

Rock strength characteristics of strata overlying the major coal seams show wide variations. Unconfined uniaxial compression tests document stress failures of core samples between 3000 and 8000 psi.

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APPENDIX

Microphotographs of some core samples from representative wells in the study area

PLATE 1

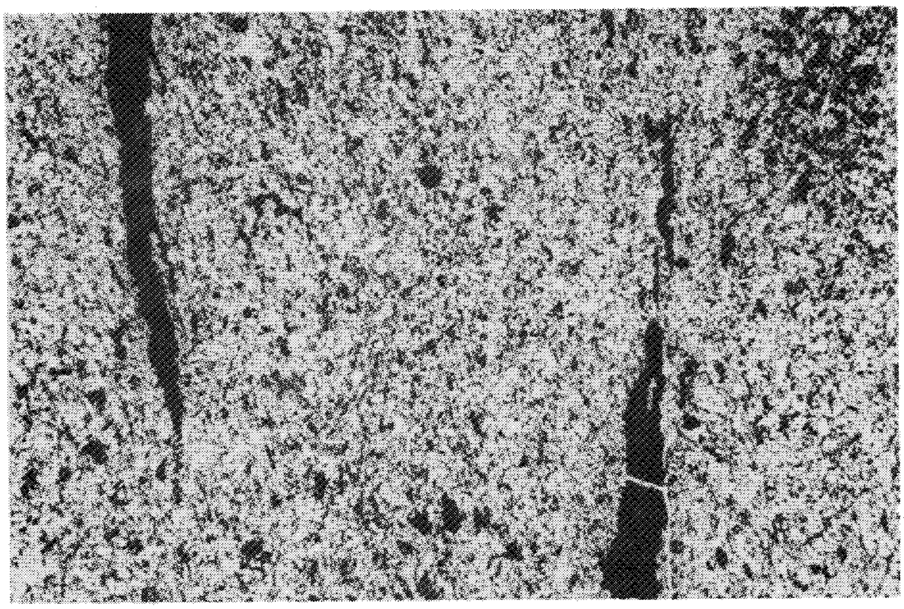

FIGURE 1. Silty shale with subparallel fractured coal laminae, TH 12-74, 546', 40X.

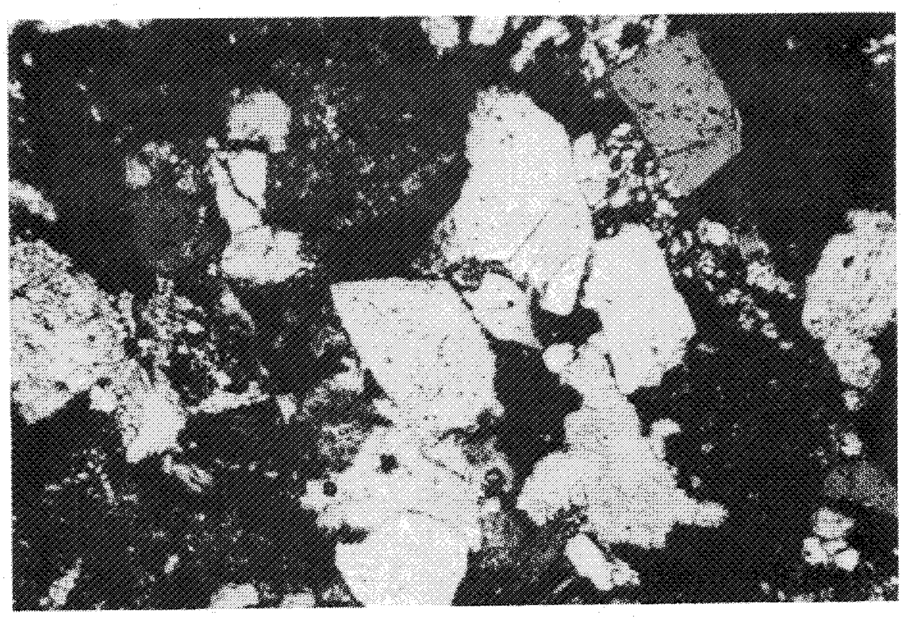

FIGURE 2. Bentonitic sandstone, angular quartz and chert grains in a matrix of silty and calcareous montmorillonite, crossed nicols, TH 20-74, 603'6", 40X.

PLATE 2

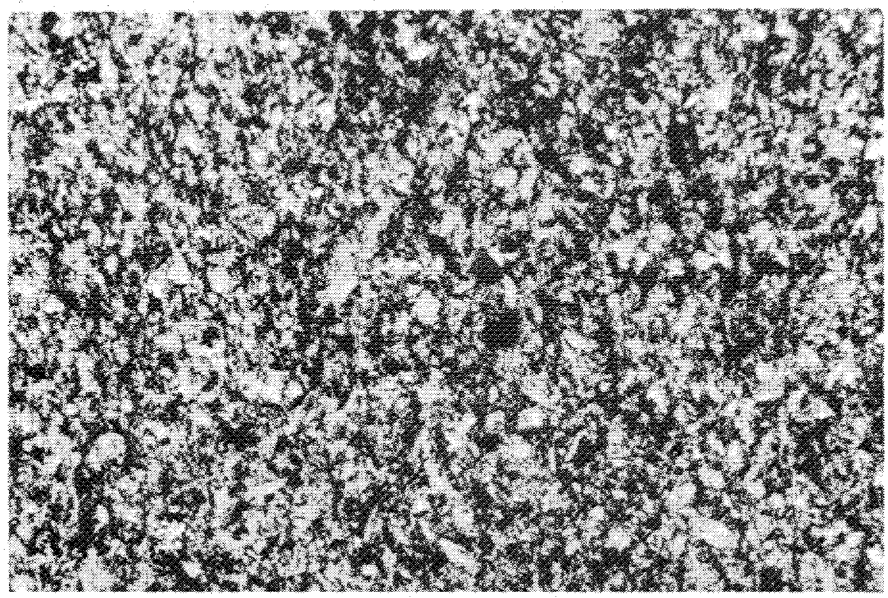

FIGURE 1. Silty shale, highly angular silt grains, TH 37-74, 819', 40X.

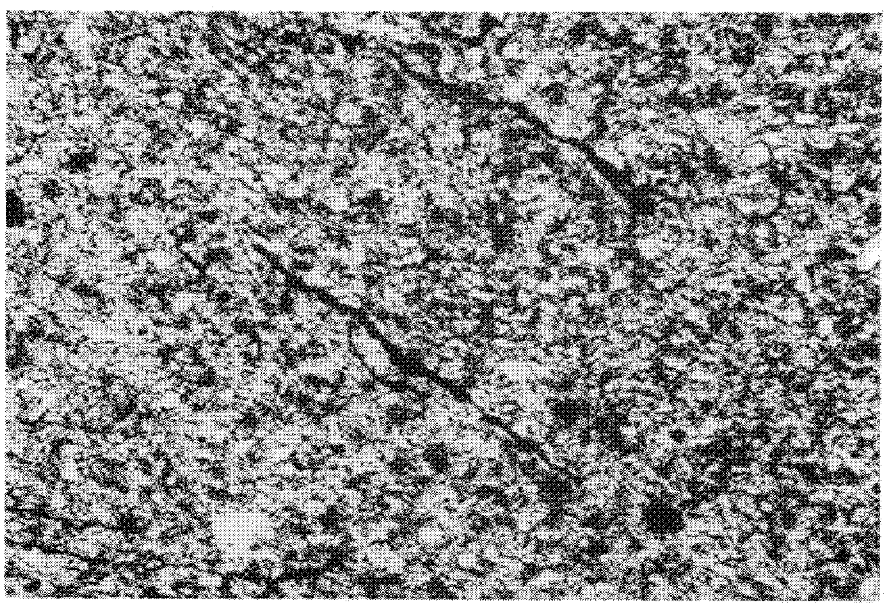

FIGURE 2. Silty shale with irregular laminae and blebs of coaly material, TH 47-74, 515', 40X.

PLATE 3

FIGURE 1. Soft bentonitic sandstone. Angular quartz, chert and feldspar (F) grains in a matrix of montmorillonite and kaolinite, TH 59-74, 554'6", 40X.

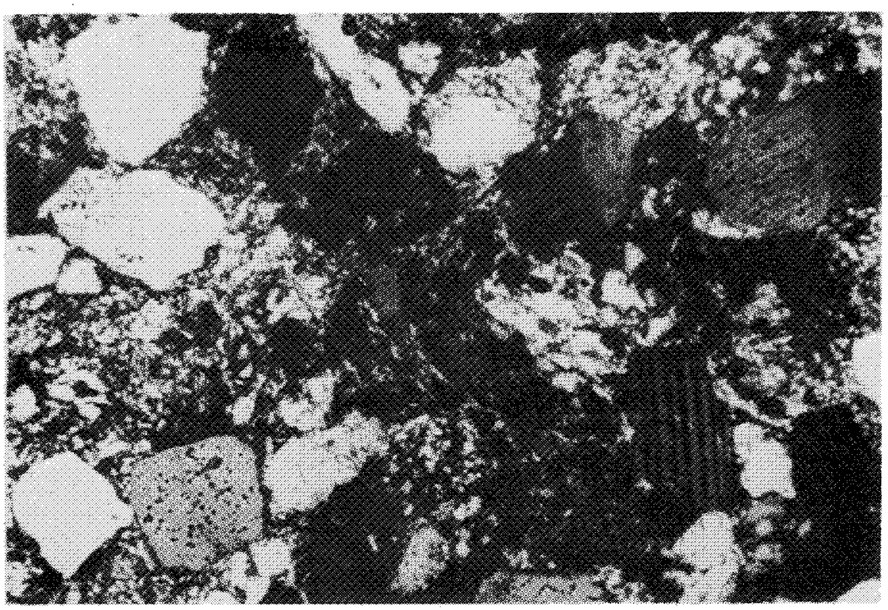

FIGURE 2. As above, crossed nicols.

PLATE 4

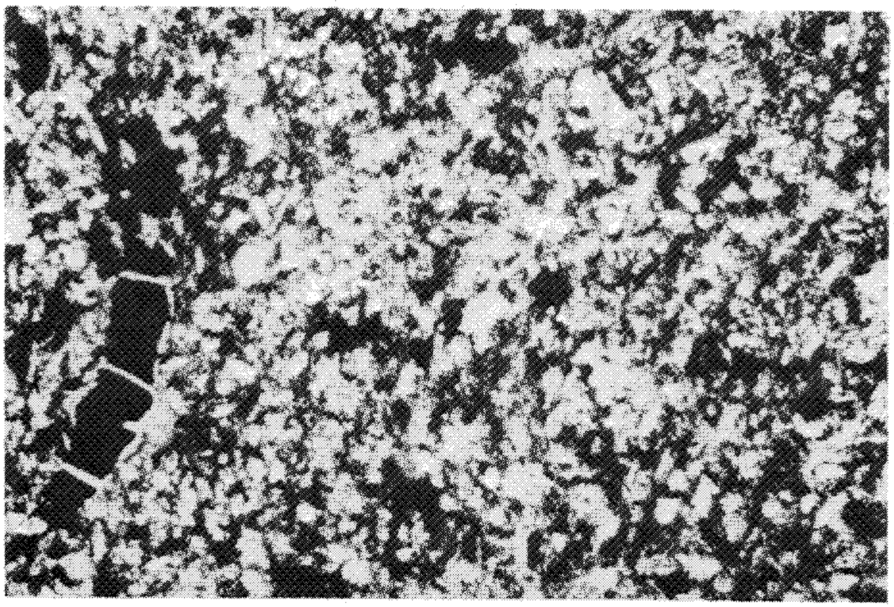

FIGURE 1. Kaolinitic silty shale, fragmented carbonaceous parting, TH 67-74, 704'6", 40X.

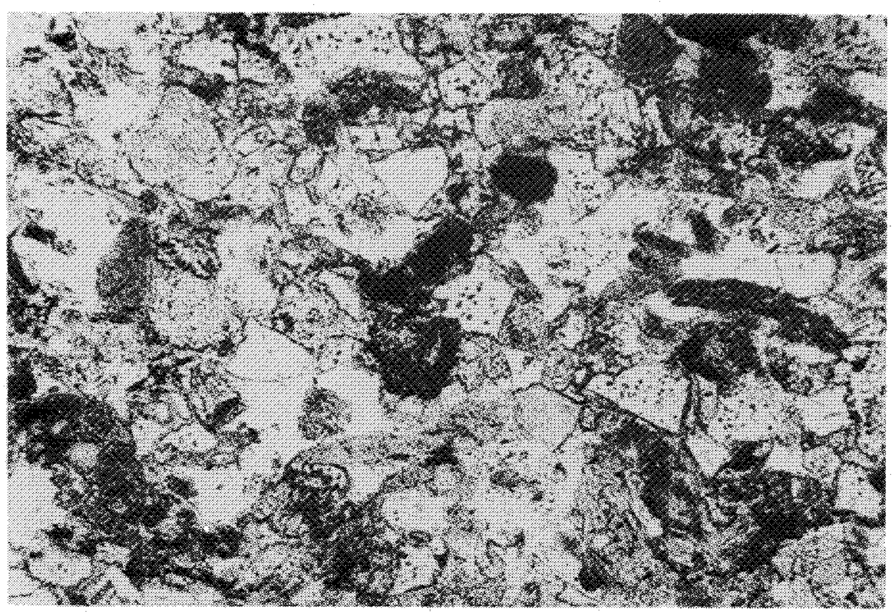

FIGURE 2. Hard sandstone comprised of angular quartz and chert grains, calcite and dolomite cemented in part, montmorillonite matrix, TH 67-74, 702', 40X.

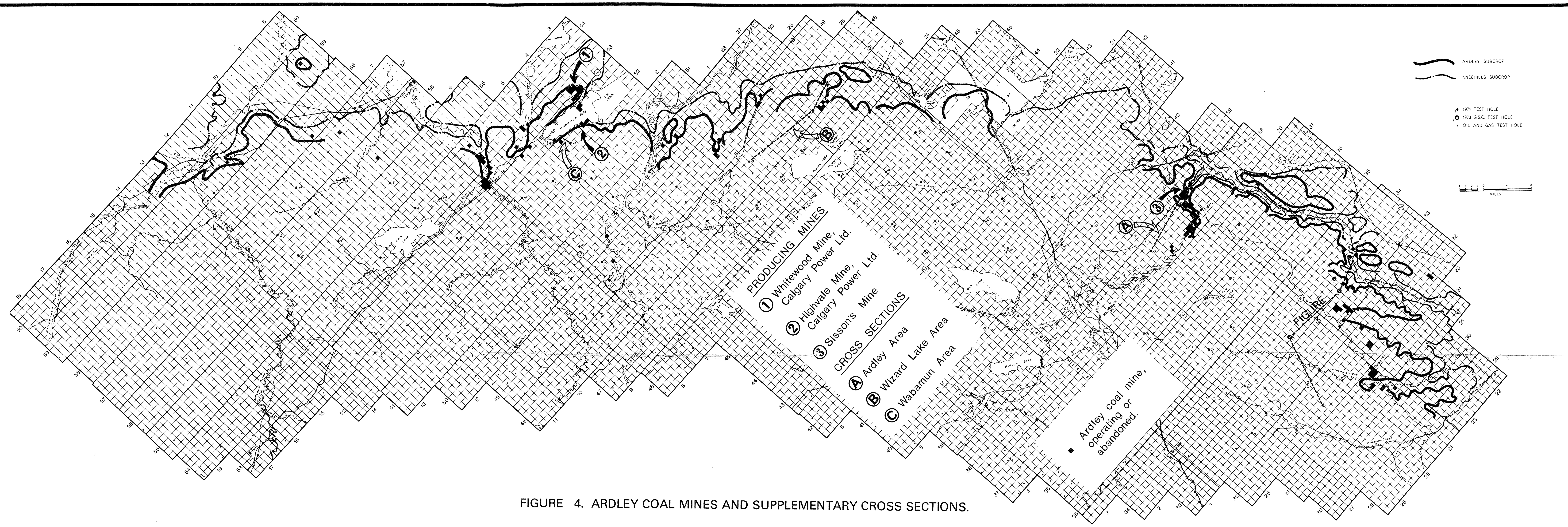

FIGURE 4. ARDLEY COAL MINES AND SUPPLEMENTARY CROSS SECTIONS.

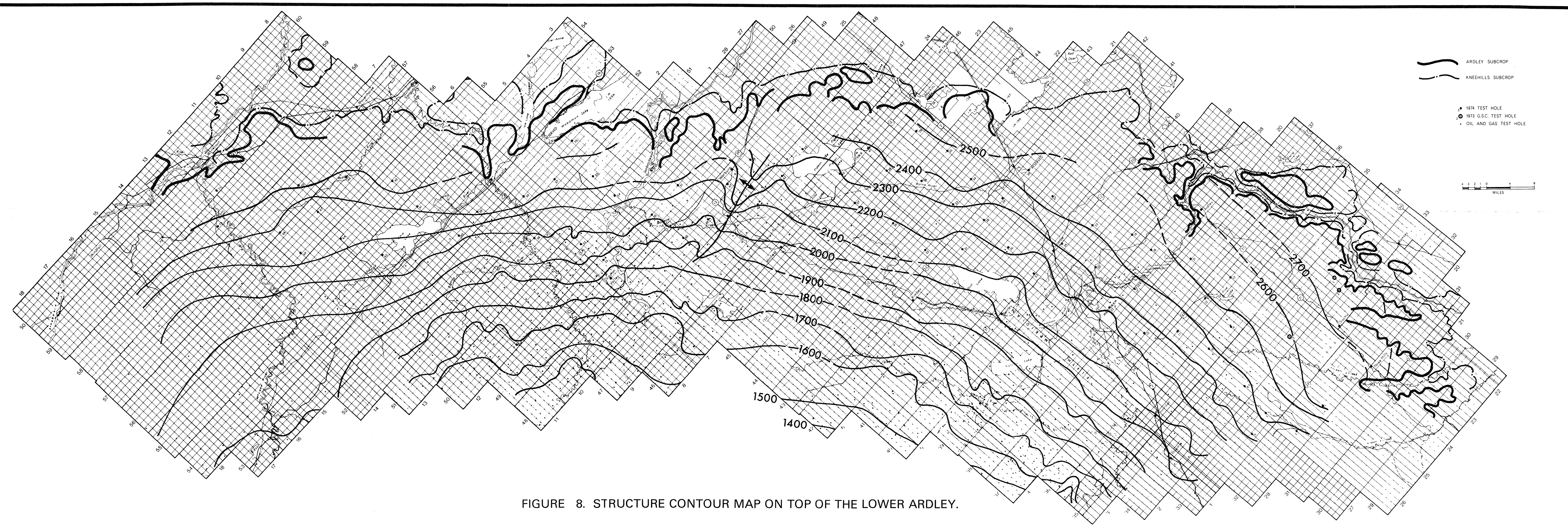

FIGURE 8. STRUCTURE CONTOUR MAP ON TOP OF THE LOWER ARDLEY.

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FIGURES 4, 8

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FIGURE 9. DEPTH OF THE TOP OF THE LOWER ARDLEY.

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FIGURE 10. CORE DESCRIPTIONS, TEST HOLES 12-74, 20-74, 37-74, 47-74, 59-74, 67-74.

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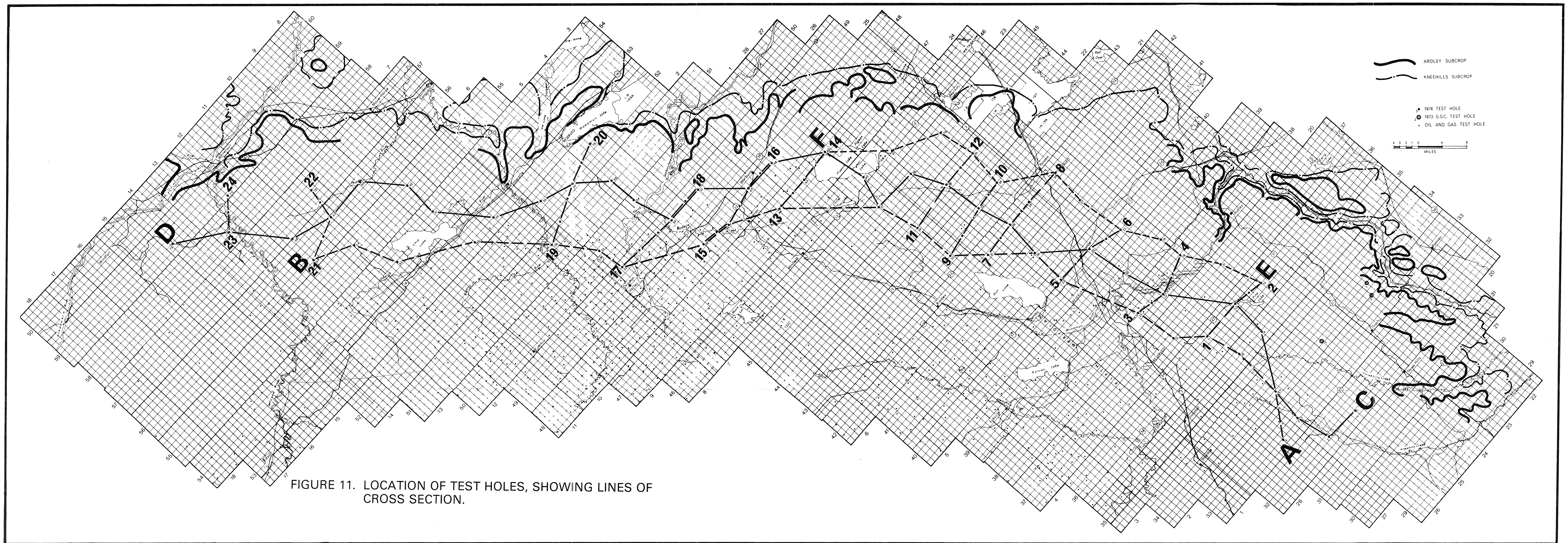

FIGURE 11. LOCATION OF TEST HOLES, SHOWING LINES OF CROSS SECTION.

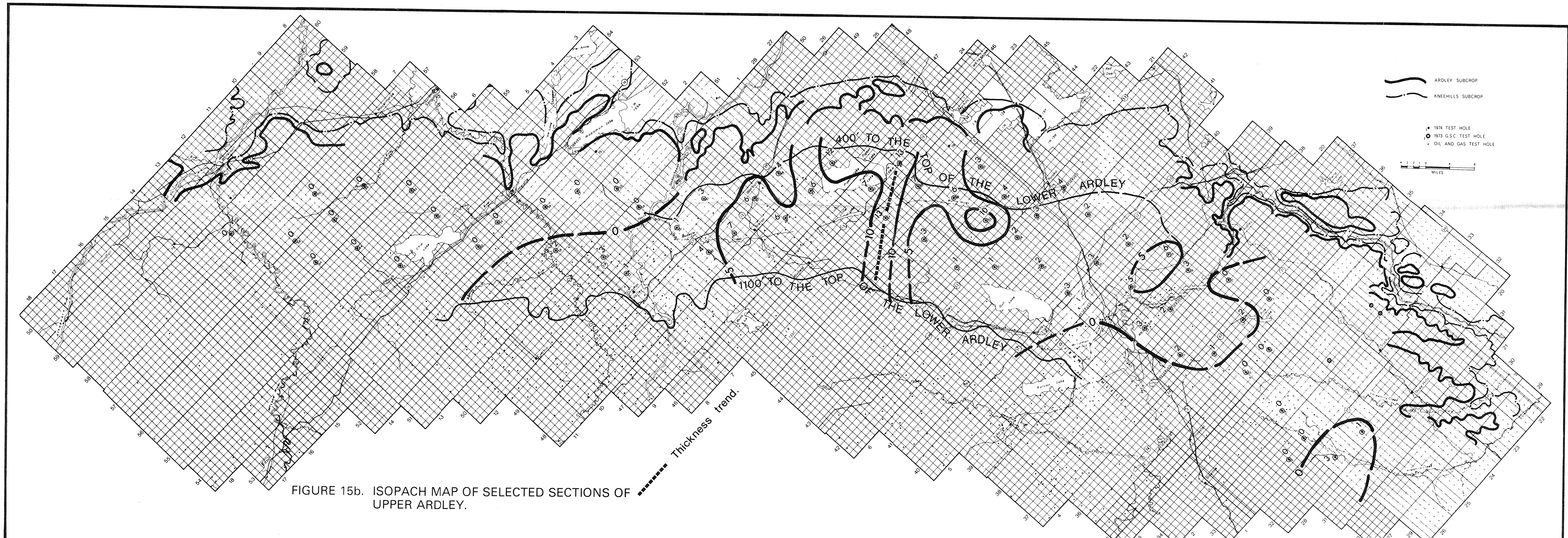

FIGURE 15b. ISOPACH MAP OF SELECTED SECTIONS OF UPPER ARDLEY.

FIGURES 11, 15b.

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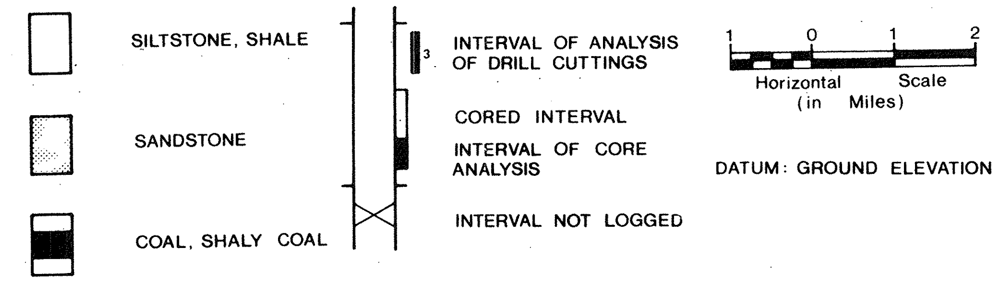
FIGURE 12a. SCHEMATIC CROSS SECTION, A-B.



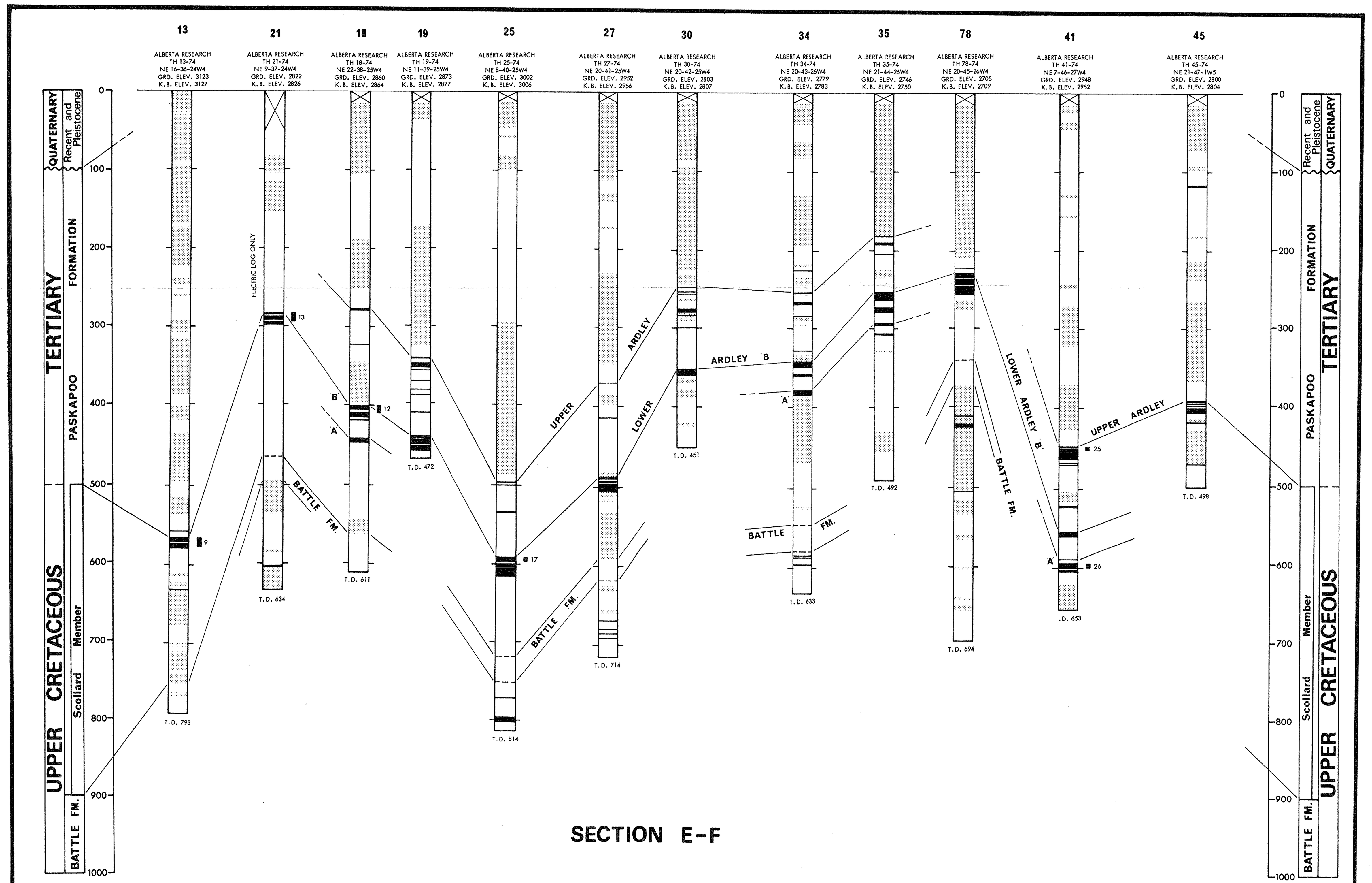
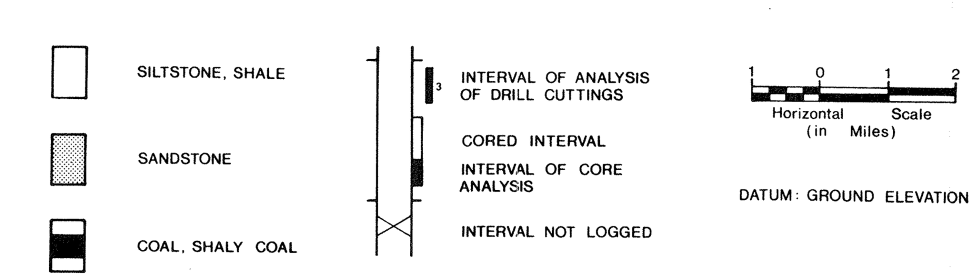


FIGURE 12b. SCHEMATIC CROSS SECTIONS, C-D, E-F.



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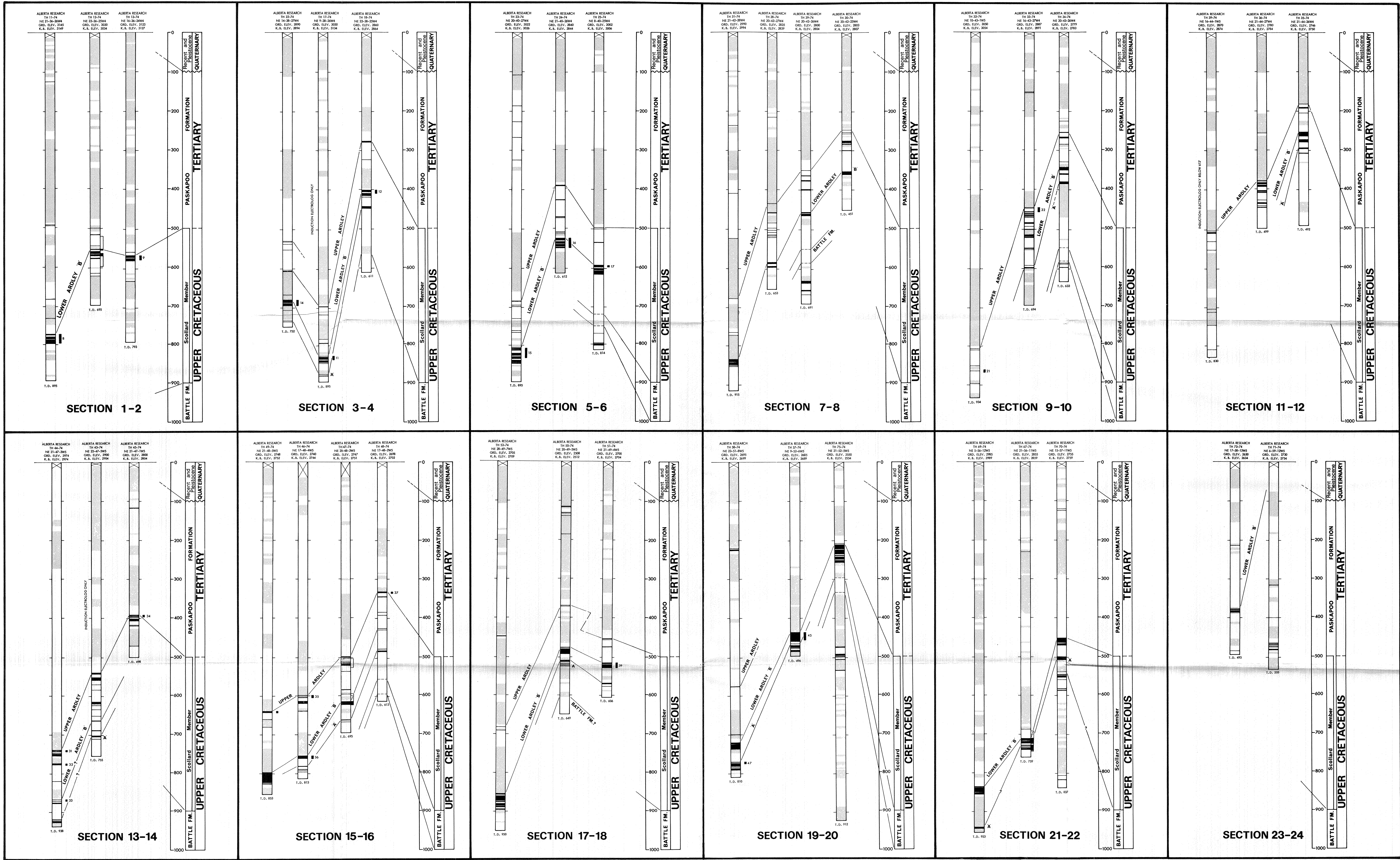

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FIGURE 13. SCHEMATIC CROSS SECTIONS OF TEST HOLES.

SILTSTONE, SHALE

SANDSTONE

COAL, SHALY COAL

INTERVAL OF ANALYSIS OF DRILL CUTTINGS

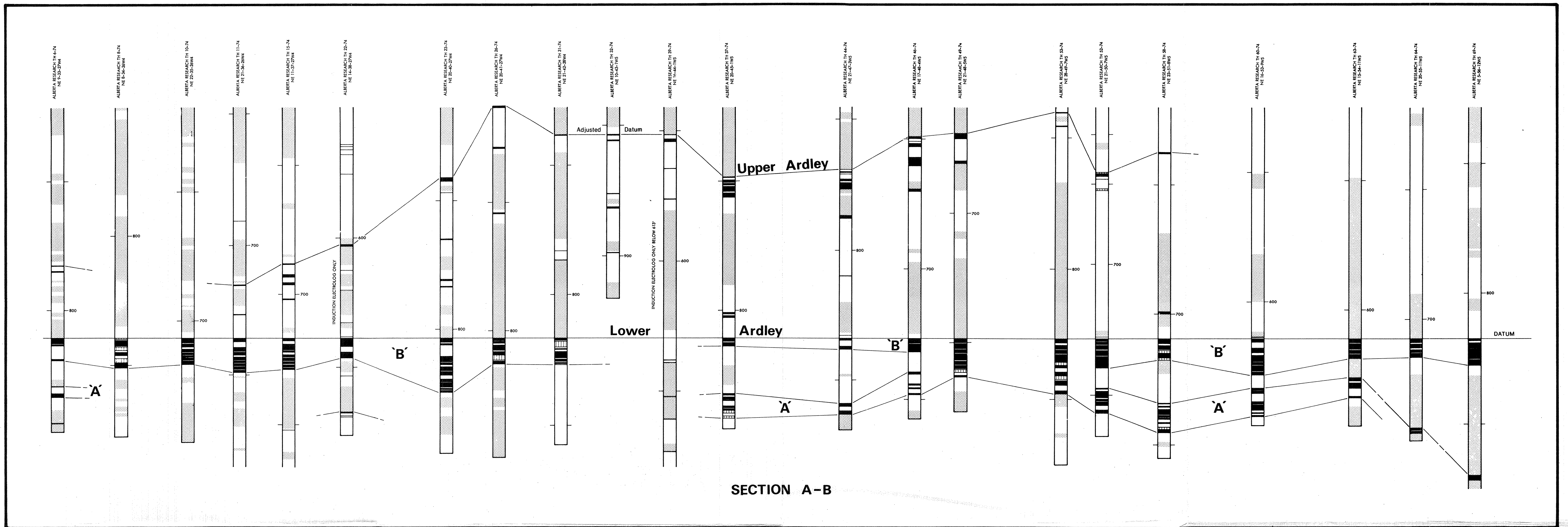
CORED INTERVAL

INTERVAL OF CORE ANALYSIS

INTERVAL NOT LOGGED

Horizontal Scale (in Miles)

DATUM: GROUND ELEVATION



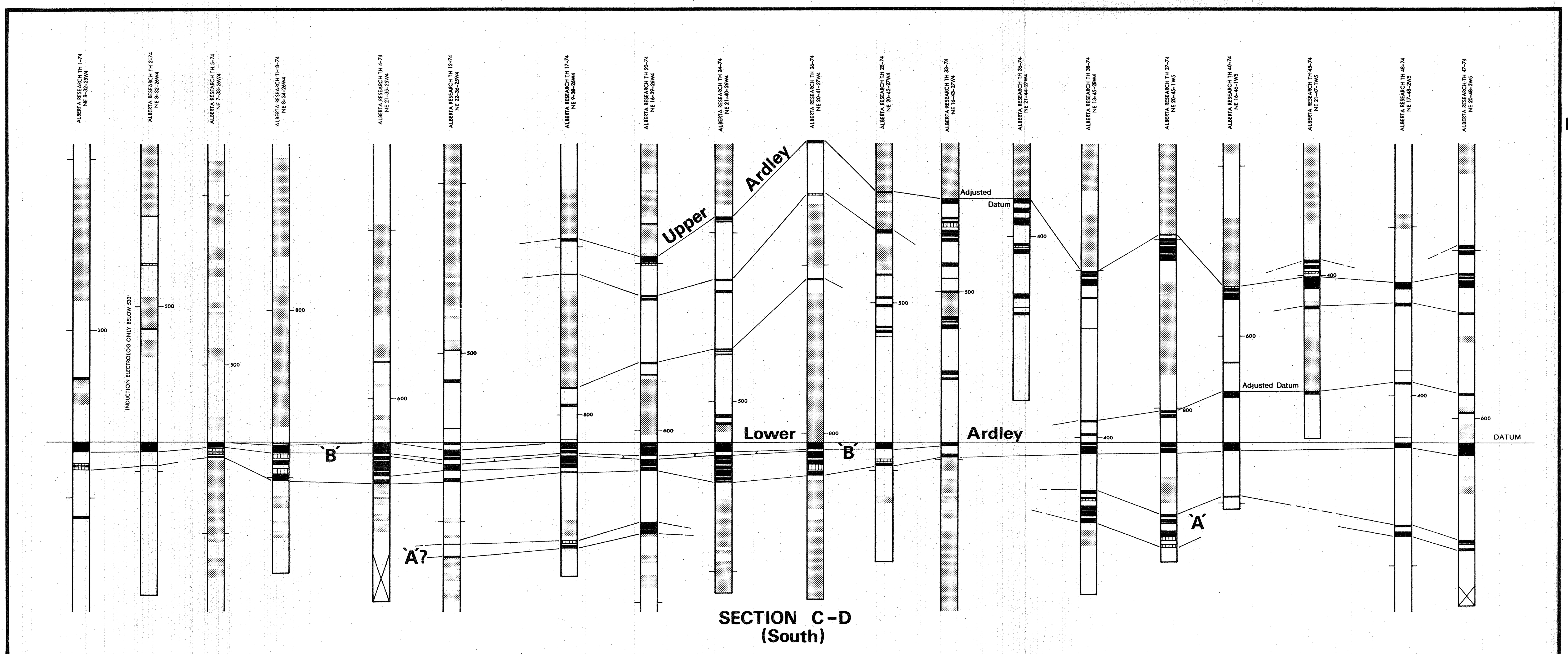
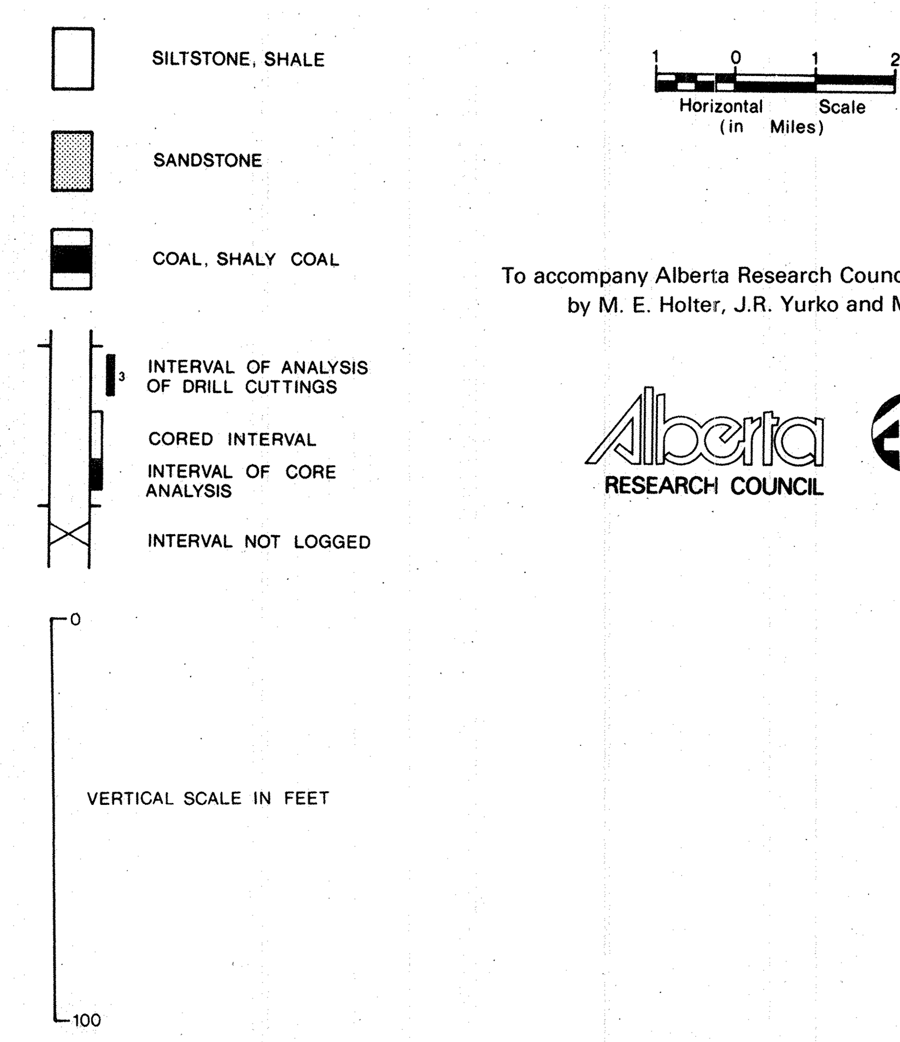


FIGURE 14a. DETAILED SECTIONS, A-B, C-D (SOUTH HALF).



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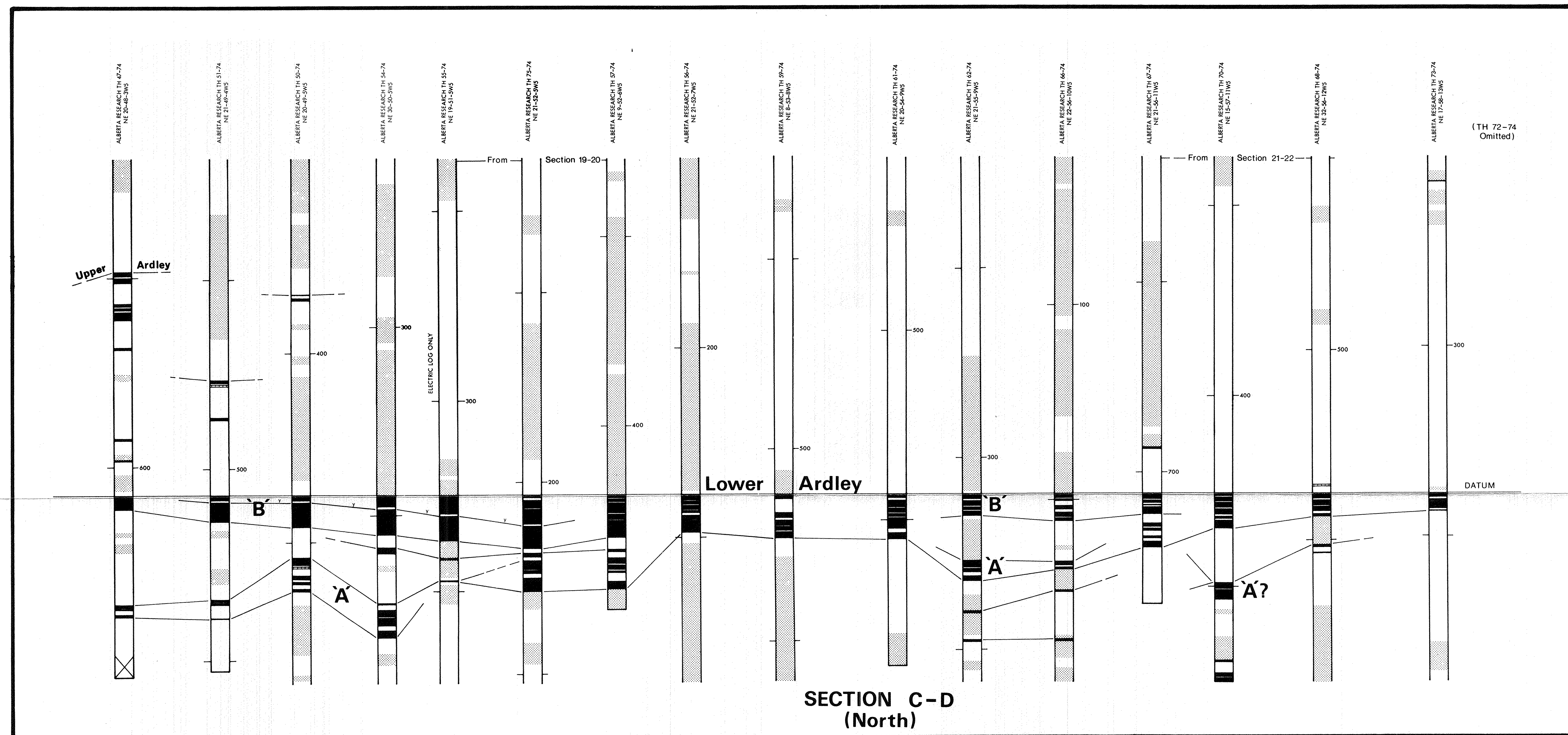

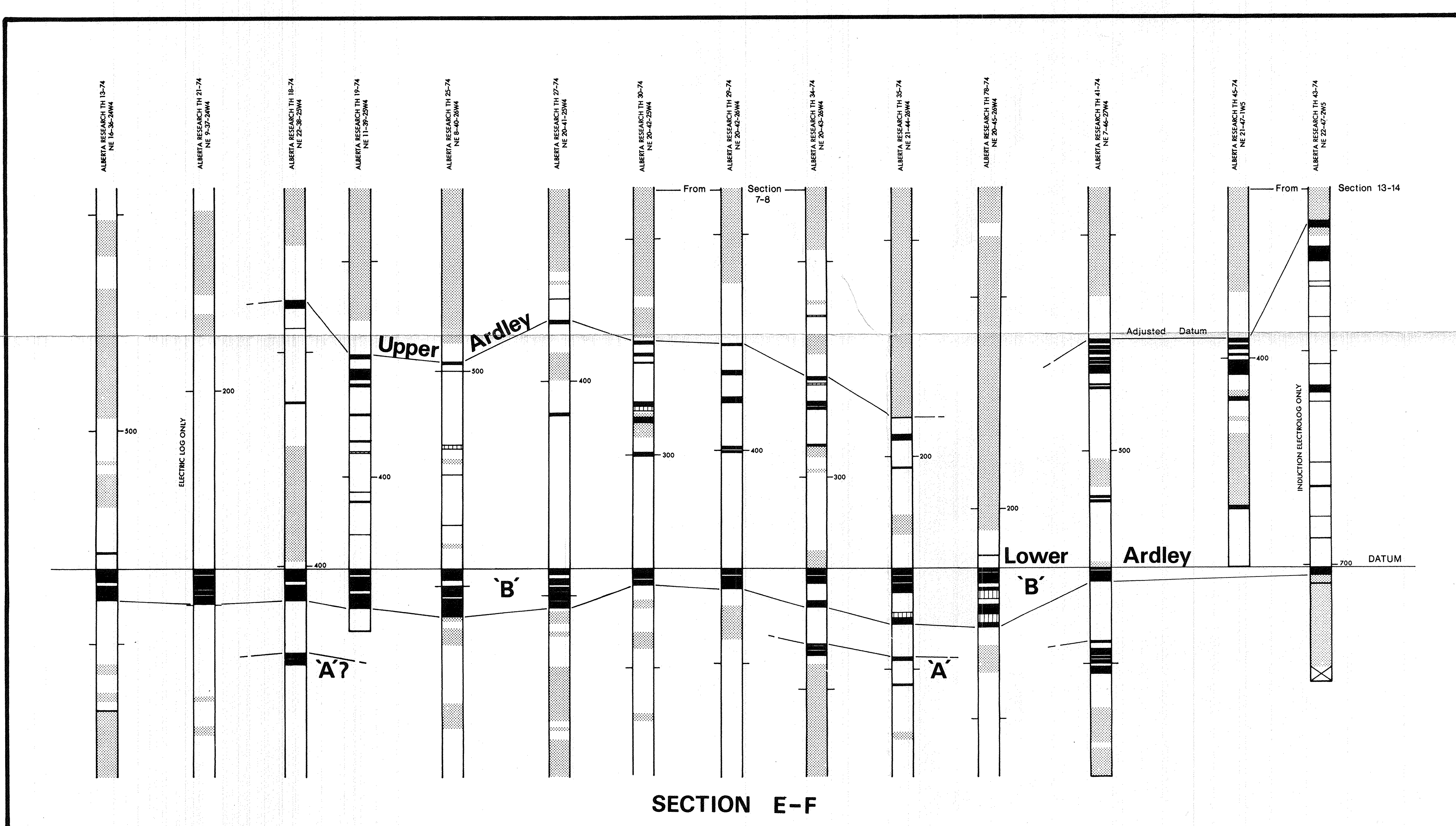

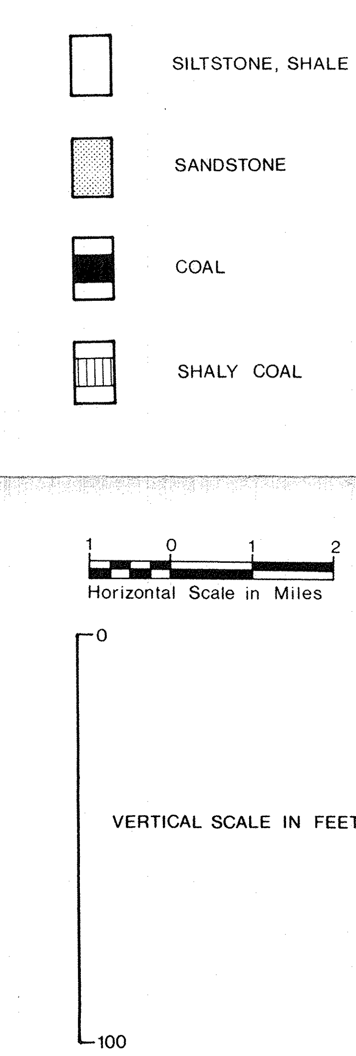

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FIGURE 14b. DETAILED SECTIONS, C-D (NORTH HALF), E-F.

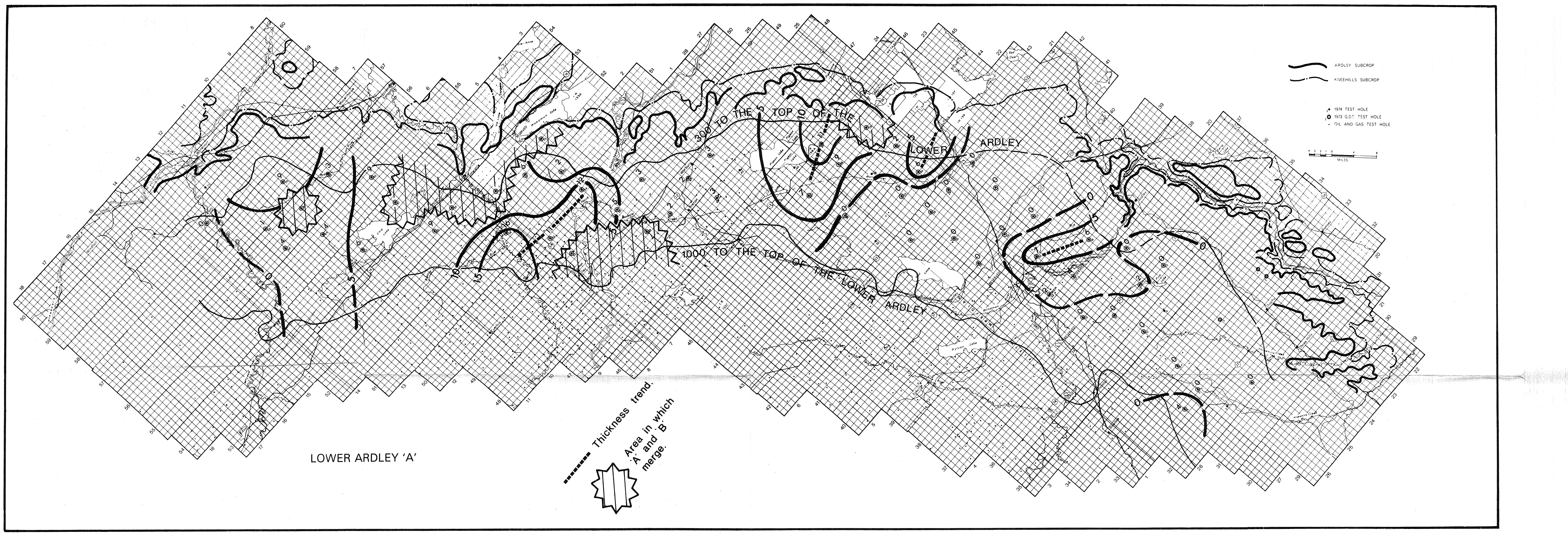

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FIGURE 15a. ISOPACH MAPS OF SELECTED SECTIONS OF LOWER ARDLEY 'A' AND LOWER ARDLEY 'B'.

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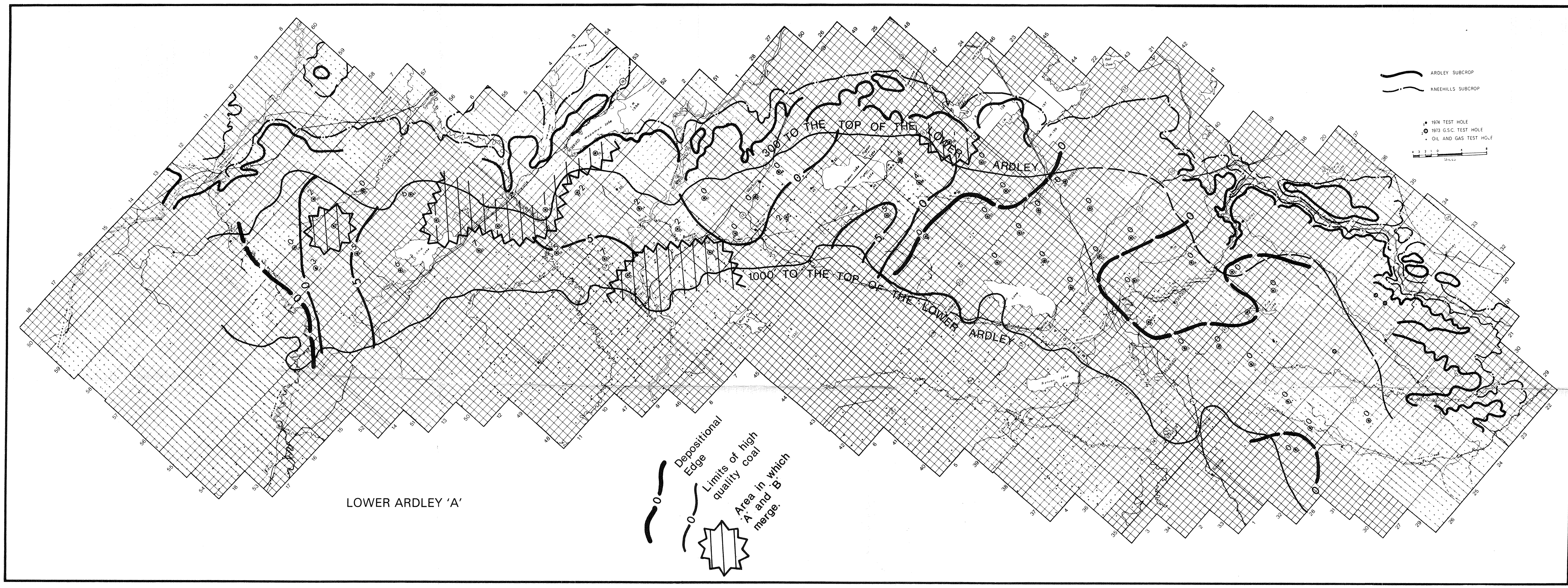

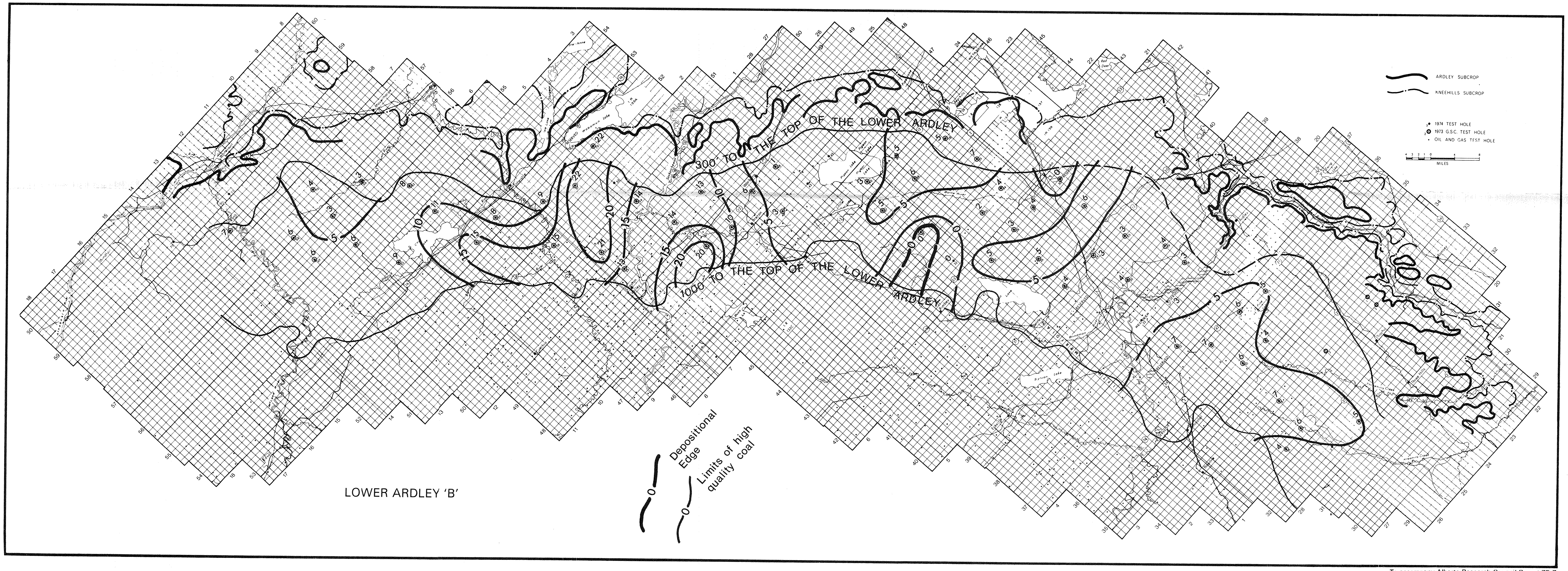

To accompany Alberta Research Council Report 75-7
by M. E. Holter, J.R. Yurko and M. Chu.

FIGURE 16a. ISOPACH MAPS OF HIGH QUALITY SECTIONS OF LOWER ARDLEY 'A' AND LOWER ARDLEY 'B'.

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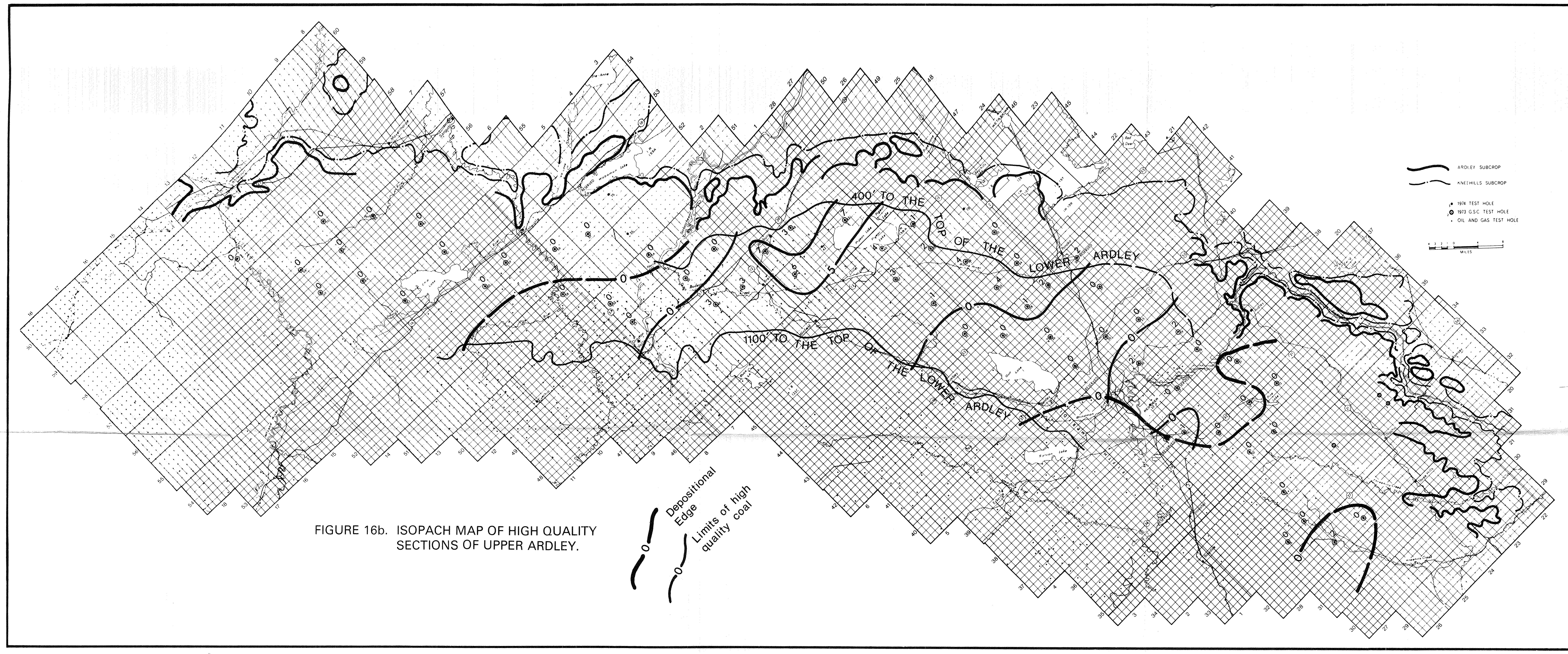

FIGURE 16b. ISOPACH MAP OF HIGH QUALITY SECTIONS OF UPPER ARDLEY.

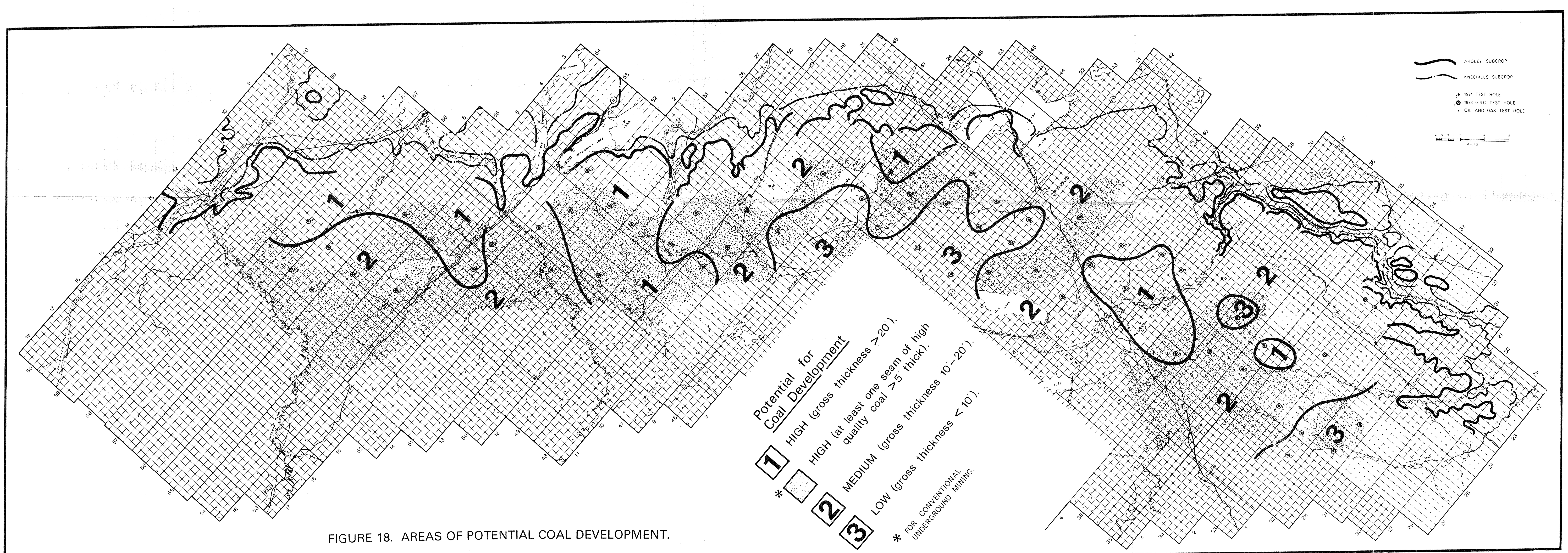

FIGURE 18. AREAS OF POTENTIAL COAL DEVELOPMENT.

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FIGURES 16b, 18.

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