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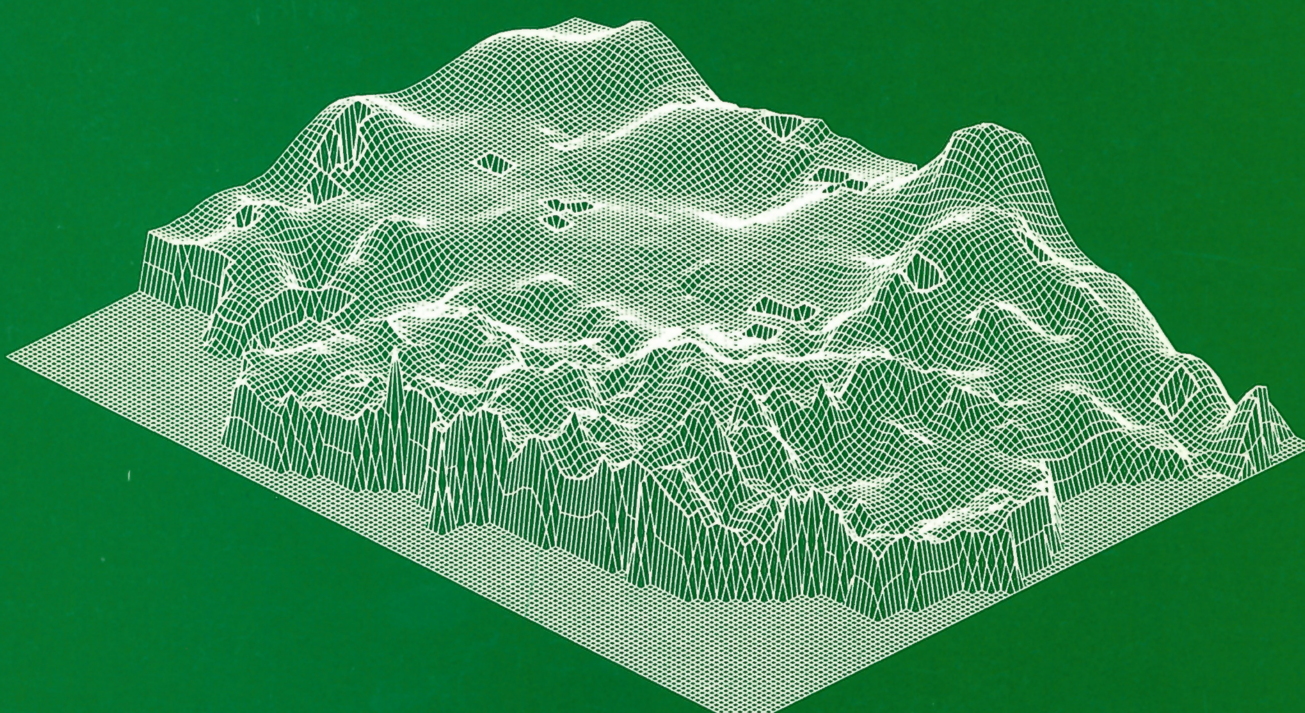
BULLETIN 361

GEOLOGY AND DEPOSITIONAL SETTING OF THE LATE CRETACEOUS, UPPER BEARPAW AND LOWER HORSESHOE CANYON FORMATIONS IN THE DODDS-ROUND HILL COALFIELD OF CENTRAL ALBERTA - A COMPUTER-BASED STUDY OF CLOSELY-SPACED EXPLORATION DATA

J.D.HUGHES



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PREFACE

Canada's coal deposits have been explored and exploited for more than a century. Until relatively recently, however, only a limited amount of geologic information on coal deposits has been available. Renewed interest in coal as a thermal and metallurgical feedstock over the past one and a half decades has produced a more comprehensive data base, collected primarily by private industry, from some 60,000 boreholes, several thousand adits and trenches, and several hundred thousand surface exposures. Development and application of geophysical logging techniques during the same period has provided abundant information both on the characteristics of many coal seams and on the nature and relationships of interseam clastic sediments. Concurrent development of computer hardware and software has provided a powerful tool to manipulate and display these data to determine resource and reserve quantities and to illuminate the geological processes involved in the formation of coal deposits.

This report is based on an application of computer-based methods and current sedimentologic principles to the study of a well explored coalfield in central Alberta. The author has endeavored to relate lateral and vertical relationships within interseam clastic sediments to coal seam geometry and to depositional processes. This is the first such computer based, detailed analysis of a large amount of high-quality subsurface data, and it is hoped that the principles defined herein may assist future interpretations in other coalfields where lesser amounts of data are available.

Data for this study were provided to the National Coal Inventory by private industry. Studies such as this should facilitate a continuation of the excellent cooperation the Geological Survey of Canada has enjoyed with private industry in the past.

OTTAWA, May 1984

R.A. Price
Director General
Geological Survey

PRÉFACE

Au Canada, l'exploration et l'exploitation des dépôts houillers se poursuivent depuis plus d'un siècle. Néanmoins, on n'a eu accès qu' à une quantité restreinte d'information géologique de bonne qualité sur ces dépôts jusqu'à date. Le renouveau de l'intérêt envers le charbon comme charge d'alimentation thermique et métallurgique au cours des 15 dernières années a produit une masse de données plus compréhensives prélevées surtout par le secteur privé de quelques 60,000 sondages, plusieurs milliers de galeries et de tranchées et plusieurs centaines de milliers coupes à ciel ouvert. La mise au point et l'utilisation des méthodes de diagraphie géophysique au cours de la même période ont fourni une abondance de données sur les caractéristiques des filons houillers recoupés et sur la nature et les rapports des sédiments clastiques entre les filons. En même temps, la mise au point de matériel et de logiciel a produit un outil utile qui permet la manipulation et la visualisation des données en vue d'évaluer les ressources et les réserves et de déterminer les processus géologiques qui mènent à la formation des gîtes de charbon.

Le présent rapport se base sur l'utilisation des méthodes informatisées et des principes sédimentologiques courants pour l'étude d'un bassin houiller bien exploré dans le centre de l'Alberta. L'auteur tente de relier les liens verticaux et latéraux au sein des sédiments clastiques entre les filons à la géométrie des filons houillers et aux processus de sédimentation connexes. Il s'agit de la première analyse détaillée traitée par ordinateur d'une grande quantité de données de haute qualité de la subsurface et l'auteur espère que les principes définis aideront à interpréter des couches houillères pour lesquelles il existe moins de données.

Les données utilisées ont été fournies par le secteur privé dans le cadre du Programme national d'inventaire des ressources charbonnières. De telles études permettront de maintenir l'excellente collaboration qui existe depuis longtemps déjà entre la Commission géologique du Canada et le secteur privé.

OTTAWA, mai 1984

R.A. Price
Directeur général
Commission géologique du Canada

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Abstract

Coal-bearing strata of the Late Cretaceous upper Bearpaw and lower Horseshoe Canyon formations in the Dodds-Round Hill area of central Alberta are examined in this report, using exploration data comprising geophysical logs, driller's logs and analytical information from 1349 boreholes drilled on 400 to 1600 m centres, throughout an area of 440 km^2. These data were manipulated by computer to determine the subsurface distribution and geometry of coal seams, marker units, and lithologic units within interseam intervals.

The succession at Dodds-Round Hill grades upward from shallow marine and brackish strata of the upper Bearpaw Formation to predominantly nonmarine strata of the lower Horseshoe Canyon Formation. Deposition of the lower part of the succession occurred within northeasterly-prograding, fluvially-dominated delta complexes along the western margin of the Bearpaw Sea. Overlying nonmarine strata were deposited in fluvial-alluvial plain settings as these delta systems migrated farther northeast and east. The succession has been subdivided into several depositional subenvironments based on the geometry, lithologic composition and vertical and lateral lithologic relationships within specific stratigraphic intervals. Shallow marine, prodelta, distributary mouth bar, distributary channel, interdistributary bay, beach, fluvial channel, floodplain and swamp-marsh subenvironments are recognized. Deltaic complexes comprise distributary mouth bar and channel sandstone units, which grade downward into prodelta and shallow marine deposits, upward into swamp-marsh or interdistributary bay deposits, and laterally into prodelta or interdistributary bay deposits. These sandstone units comprise northeast-trending, linear bodies five to ten metres thick, three to six kilometres wide and more than twenty-five kilometres in length. Fluvial-alluvial plain deposits comprise linear, fining-upward sandstone units deposited within meandering fluvial channels and, laterally adjacent, finer grained floodplain deposits which accumulated during overbank flood events. Fluvial channel sandstones comprise northeast- and east-trending units five to ten metres thick, 500 to 2000 m wide and more than 15 km in length.

Coal seams within the succession accumulated within interdistributary and interchannel areas in swamp-marsh subenvironments that were removed from active sedimentation by overbank flooding. Individual seams are variable in thickness and may coalesce laterally with other seams or pinch out. Seams with coal thicknesses of more than two metres are restricted to areas of 100 km^2 or less. Groups of coal seams, or coal zones, cover areas in excess of 400 km^2. Interseam strata within coal zones commonly comprise wedge-shaped partings, interpreted as overbank-floodplain deposits derived from source channels located in their direction of thickening. Other partings, which are thin, bentonitic and laterally very extensive, may represent altered volcanic ash deposits. Silicification associated with the alteration of volcanic ash to bentonite may be related to a laterally extensive concretionary horizon within the Round Hill Coal Zone.

The geometry of interseam clastic sediments and hence the configuration of bounding coal seams is strongly related to the orientation and position of depositional subenvironments, which in turn are related to paleoslope direction. Paleoflow in the study area was to the northeast and east. Differential compaction between laterally adjacent subenvironments has, in several instances, greatly influenced sedimentation patterns and the distribution of subenvironments in overlying stratigraphic intervals, and also has influenced the present configuration of coal seams. These effects are most pronounced between the linear, distributary mouth bar and fluvial channel sandstones, and laterally adjacent, finer grained, more compactible strata.

Cyclicity is evident on several scales within the succession. Small-scale vertical lithologic cycles related to specific subenvironments may reflect phenomena with periodicities of days to several hundred years. Larger scale cycles, representing considerably longer time periods, comprise groups of subenvironments. These larger cycles include three constructional-destructional phases of delta development.

Knowledge of the geometry, distribution and vertical and lateral lithologic relationships associated with depositional subenvironments in the succession has implications for coal exploration in laterally equivalent strata. For example, borehole control necessary to adequately define the geometry of coal seams separated by fluvial channel deposits may have to be 400 m or less, whereas seams separated by more tabular, overbank-floodplain or interdistributary bay-fill deposits may be adequately defined with a much broader spacing. This knowledge is also important later in the development process for mining feasibility, geotechnical and environmental considerations.

Résumé

Le présent rapport traite des couches houillères de la partie supérieure de la formation de Bearpaw et de la partie inférieure de la formation de Horseshoe Canyon du Crétacé supérieur dans la région de Dodds-Round Hill, en Alberta. Il se fonde sur des données d'exploration, notamment des diagraphies géophysiques, des diagraphies de forage et des renseignements analytiques, prélevés de 1349 sondages de 400 à 1600 m sur une superficie de 440 km^2. Ces données ont été traitées par ordinateur afin de déterminer la répartition et la géométrie en subsurface des filons houillers, des unités repères et des unités lithologiques dans les intervalles entre les filons.

La succession à Dodds-Round Hill se transforme vers le haut des couches de la partie supérieure de la formation de Bearpaw, déposées en milieu marin et saumâtre peu profond, aux couches d'origine principalement non marine de la partie inférieure de la formation de Horseshoe Canyon. La mise en place de la partie inférieure de la succession s'est produite dans des complexes deltaïques de nature principalement fluviale qui progressaient vers le nord-est le long de la marge ouest de la mer Bearpaw. Les couches non marines susjacentes ont été mises en place dans des plaines fluviales-alluviales à mesure que ces deltas se déplaçaient vers le nord-est et l'est.

La succession se divise en plusieurs sous-milieux de sédimentation qui se fondent sur la géométrie, la composition lithologique et les liens lithologiques verticaux et horizontaux au sein d'intervalles stratigraphiques particuliers. On y reconnaît les sous-milieux suivants: mer peu profonde, zone prodeltaïque, bras, flèche à l'entrée d'un bras, baie de front de delta, plage, chenal fluvial, plaine d'inondation et marécage-marais. Les complexes deltaïques se composent d'unités de grès accumulées à l'entrée des bras et dans les chenaux qui se transforment vers le bas en dépôts prodeltaïques et en dépôts caractéristiques d'un milieu marin peu profond, vers le haut en dépôts de marécage-marais ou de baie de front de delta, et latéralement en dépôts prodeltaïques ou en dépôts de baie de front de delta. Ces grès forment des masses linéaires orientées nord-est, dont l'épaisseur varie de 5 à 10 m et la largeur de 3 à 6 km, et dont la longueur dépasse 25 km. Les dépôts de plaines fluviales-alluviales se composent d'unités de grès dont la mise en place a un lien dans des chenaux fluviaux sinueux dont la granulométrie devient plus fine vers le haut, et de dépôts de plaine d'inondation plus fins latéralement contigus, qui se sont accumulés au cours d'inondations. Les grès de chenaux fluviaux forment des unités orientées nord-est et est de 5 à 10 m d'épaisseur, larges de 500 à 2000 m et longues de plus de 15 km.

Les filons houillers au sein de la succession se sont accumulés entre les bras et les chenaux dans un sous-milieu de marécage-marais situé loin des zones de sédimentation active dûe aux inondations. Les filons, à épaisseur variable, peuvent s'unir latéralement à d'autres filons ou disparaître progressivement en biseau. Les filons dans lesquels les couches de charbon ont plus de 2 m d'épaisseur sont limités à des zones de 100 km^2 ou moins. Les groupes de filons houillers, auxquels on donne le nom de zone houillère, couvrent plus de 400 km^2. Les couches entre les filons dans les zones houillères comprennent normalement de minces couches en coin qui se seraient accumulées dans des plaines d'inondation lors des crues; elles sont dérivées de chenaux situés dans la direction d'épaississement. D'autres couches minces contiennent de la bentonite et sont latéralement très étendues; elles pourraient représenter des dépôts de cendres volcaniques altérées. La silicification, associée à l'altération de la cendre volcanique et bentonite, pourrait être liée à un horizon latéralement vaste de concrétions au sein de la zone houillère de Round Hill.

La géométrie des sédiments clastiques entre les filons, et donc la configuration des filons houillers limitants, est étroitement liée à l'orientation et à la position des sous-milieux de sédimentation qui, à leur tour, sont liés à la direction du paléotalus. Le paléoécoulement dans la zone étudiée se faisait vers le nord-est et l'est. Le tassement différentiel de sous-milieux latéralement contigus a souvent fortement influé sur les modèles de sédimentation et sur la répartition des sous-milieux dans les intervalles stratigraphiques susjacents. Il a également influé sur la configuration actuelle des filons houillers. Ces effets sont les plus prononcés entre les grès déposés en bancs linéaires à l'entrée des bras et dans les chenaux fluviaux et les couches latéralement contigues, plus fines et plus susceptibles de tassement.

L'existence de cycles est évidente à plusieurs échelles au sein de la succession. Des cycles lithologiques verticaux de petite échelle liés à des sous-milieux particuliers peuvent refléter des phénomènes dont la périodicité varie de quelques jours à plusieurs centaines d'années. Les cycles plus importants, qui représentent des intervalles de temps beaucoup plus longs, forment des groupes de sous-milieux, notamment les trois phases de construction/destruction de l'évolution deltaïque identifiées au sein de la succession.

Les connaissances de la géométrie, de la répartition et des liens lithologiques verticaux et latéraux associés aux sous-milieux de sédimentation dans la succession ont de l'importance pour l'exploration du charbon dans les couches latéralement équivalentes. Par exemple, le contrôle des sondages rendu nécessaire par le besoin de bien définir la géométrie des filons houillers séparés par des dépôts de chenaux fluviaux pourrait être de 400 m ou moins, tandis que les filons séparés par des dépôts plus tabulaires de plaine d'inondation ou de baie de front de delta pourraient être suffisamment bien définis à l'aide d'intervalles beaucoup plus grands. Ces connaissances pourraient également servir à la mise au point éventuelle de méthodes en vue d'étudier la faisabilité de l'exploitation minière et les questions géotechniques et environnementales.

INTRODUCTION

The Dodds-Round Hill coalfield described in this report constitutes a 440 km^2 area, centred about 60 km southeast of Edmonton, which is underlain by the coal-bearing, lower part of the Horseshoe Canyon Formation (Fig. 1). The coalfield was explored between 1969 and 1976 by Fording Coal Limited, TransAlta Utilities Limited and a consortium of Shell Canada Limited and PanCanadian Oil Company Limited, to define large resources of surface-mineable coal in the area. Thirteen hundred and forty-nine boreholes, with an aggregate length of 42,626 m, were drilled in the area during this exploration, and all data obtained from these exploration programs have been incorporated into the present study. Raw data, comprising geophysical and driller's logs, as well as analytical information from these boreholes, were provided on a confidential basis to the Geological Survey of Canada by these companies, as a contribution to Canada's National Coal Inventory.

Lithologic, coal thickness, and correlation information interpreted from geophysical logs was entered, together with the analytical data, into a computer-processable data base. These data were then manipulated and displayed using the methodologies outlined briefly below and described in more detail by Hughes (in prep.) This report summarizes non-economic aspects of the study of these exploration data, as they relate to the geology and depositional setting of the Dodds-Round Hill coalfield, and attempts to relate the observed geometry and distribution of coal seams and bounding lithologic units to the causative depositional processes. Economic aspects of this study are not discussed herein in order to protect the confidentiality of the data. However, coal resource quantities calculated will be reported in an aggregated form in subsequent reviews of Canadian coal resources.

Acknowledgments

This study provided a testing ground for methodologies now in use in coal deposit evaluation at the Geological Survey of Canada and involved the efforts of several people over the course of several years.

The author gratefully acknowledges Fording Coal Limited, PanCanadian Oil Company Limited, Shell Oil Company Limited and TransAlta Utilities Limited for providing the subsurface data on which this study is based and subsequently allowing publication of this report; B.A. Latour and J.A. Irvine, formerly of the Geological Survey of Canada, who initiated the study and provided the environment in which it was allowed to grow; C.F. Stevens, also formerly of the Geological Survey, who wrote many of the computer programs used for data manipulation; K.N. Nairn, of the Geological Survey, for his assistance and advice in solving numerous computing difficulties, and K.E. Mottershead, also of the Geological Survey, who provided modifications and enhancements to several of the computer programs utilized.

Data entry, verification and lithologic interpretations for many of the Fording boreholes were performed by Carol Boonstra, Jim Bamber, Brian Cormier, Karen Hall and Dave Herron. Cathy Lutzak, of Summus Resource Evaluations Limited, provided lithologic interpretations for the Shell-PanCanadian boreholes. Assistance in preparing many of the figures was provided by Carol Boonstra and Dave Herron. Donna Smith typed several drafts of the text. D.W. Gibson and B.D. Ricketts critically read the manuscript and suggested improvements. To all of the above mentioned individuals the author is most grateful.

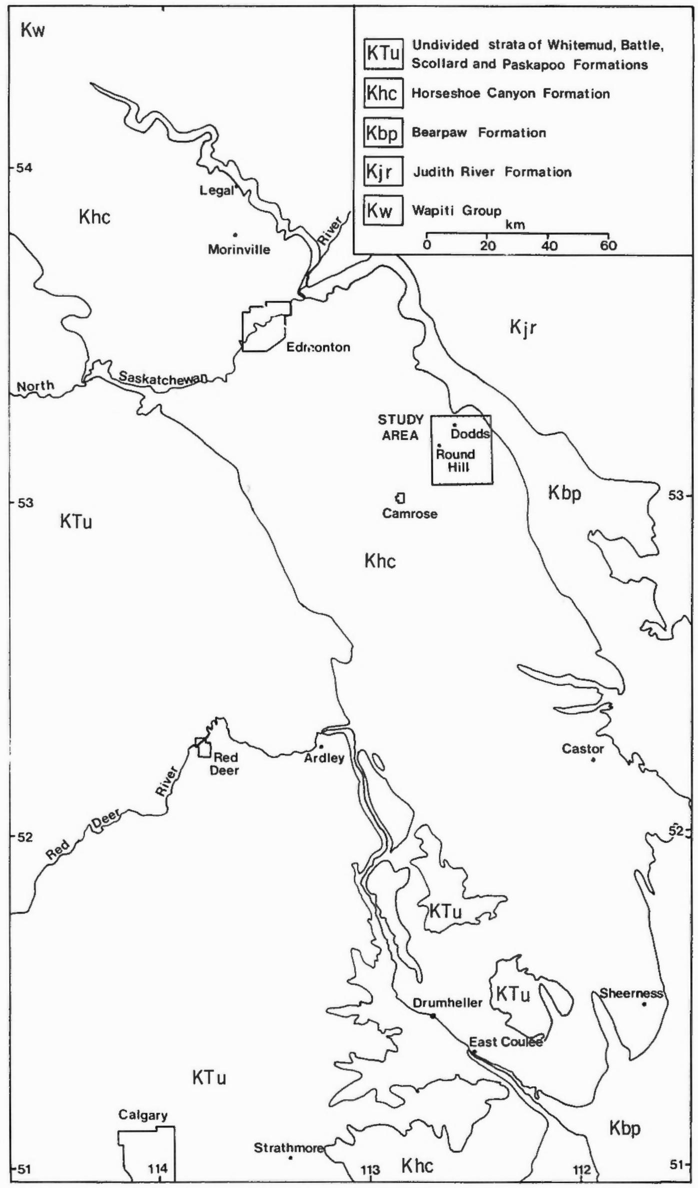


Figure 1. *Location of Dodds-Round Hill coalfield showing distribution of Late Cretaceous and Early Tertiary formations in south-central Alberta. Bearpaw Formation contacts north of latitude 53° from Feniak (1944) and Rutherford (1939). All remaining formation boundaries from Green (1970).*

Geological overview

Coal seams in the Dodds-Round Hill coalfield are contained within the lowermost 100 m of the Horseshoe Canyon Formation, a predominantly nonmarine, interbedded succession of siltstone, shale, sandstone, coal and concretionary horizons, which is of Late Campanian to Maestrichtian age. This formation is the lowermost unit of the Edmonton Group, which is recognized from the U.S.A.-Canada boundary on the south to the Athabasca River on the north. The Edmonton Group grades into laterally equivalent and older nonmarine strata of the Wapiti Group to the north, and the Brazeau Formation (Jerzykiewicz and McLean, 1980) to the west (Fig. 2).

<table>
<tr><th>Age</th><th colspan="2">South-central Plains[1]</th><th colspan="2">Northwest-central Plains[2]</th><th colspan="2">West-central Foothills[3]</th></tr>
<tr><td>Paleocene</td><td colspan="2">Paskapoo Fm.</td><td colspan="2">Paskapoo Fm.</td><td colspan="2">Paskapoo Fm.</td></tr>
<tr><td rowspan="6">Late Cretaceous</td><td rowspan="4">Edmonton Group</td><td>Scollard Fm.</td><td rowspan="6">Wapiti Group</td><td>Upper</td><td rowspan="6">Saunders Group</td><td>Coalspur Beds</td></tr>
<tr><td>Battle Fm.</td><td rowspan="4">Middle</td><td rowspan="5">Brazeau Fm.</td></tr>
<tr><td>Whitemud Fm.</td></tr>
<tr><td>Horseshoe Canyon Fm.</td></tr>
<tr><td colspan="2">Bearpaw Fm.</td></tr>
<tr><td colspan="2">Judith River Fm.</td><td>Lower</td></tr>
</table>

[1]Gibson (1977)
[2]Kramers and Mellon (1972)
[3]Jerzykiewicz and McLean (1980)

Figure 2. *Nomenclature of Late Cretaceous strata in south-central and western Alberta.*

Horseshoe Canyon Formation strata within the coalfield dip to the southwest at about three metres per kilometre, and are erosionally beveled, so that the lower boundary of the formation subcrops on the east side of the coalfield (Fig. 1). To the southwest, where a complete section is present, the formation attains a maximum thickness of about 260 m (Gibson, 1977).

The Horseshoe Canyon Formation lies conformably on marine siltstones, shales and minor sandstones of the Bearpaw Formation, which is of Campanian age and is recognized throughout central and southern Alberta and southern Saskatchewan. Laterally extensive sandstone units commonly form the contact between these formations throughout much of central Alberta. The Bearpaw Formation is about 60 m thick beneath the Dodds-Round Hill area, and lies conformably on nonmarine strata of the Judith River Formation (McLean, 1971). To the southeast, in southeastern Alberta and southwestern Saskatchewan, the Bearpaw Formation attains a thickness of more than 250 m. The above stratigraphic relationships are summarized in Figure 2.

Six major coal zones have been defined in the Dodds-Round Hill coalfield. These are termed, in ascending order, the Ryley, Dodds, Round Hill, Dusty, Burnstad and Demay coal zones. Of these, the Dodds, Round Hill and Burnstad are the thickest and most laterally persistent and, therefore, are of the greatest economic importance. A coal zone in this study is defined as one or more coal seams or beds which occur at about the same stratigraphic position. Individual coal beds within each coal zone have been assigned letter modifiers in the manner described by Irvine et al. (1978) and outlined in a later section. Because of the laterally variable nature of coal beds within the lower part of the Horseshoe Canyon Formation, it was necessary to define up to eleven individual seams within certain coal zones. In addition to the coal zones, several laterally persistent bentonitic shale units were also used for correlation. These marker units persist throughout the coalfield and are termed, in ascending order, Marker 1, Marker 2, Marker 3 and Marker 4. Figure 3 is a composite lithologic section showing the stratigraphic position and thickness of the coal zones, marker units and commonly occurring groups of coal beds, as well as the response of these units and bounding strata on the geophysical logs available for the coalfield.

The Dodds-Round Hill coalfield is mantled by a layer of unconsolidated silt, sand and till ranging in thickness from 0 to 30 m. This material has infilled irregularities in the bedrock surface, which has somewhat more relief than the present flat to gently rolling topographic surface in the area. At some locations within the coalfield there is considerable deformation of bedrock strata near the till-bedrock interface, attributed to ice movement across the area. Coal-bearing strata beneath this surficial cover dip regionally to the southwest, as previously mentioned, at about three metres per kilometre. The dip of individual coal zones and marker units is variable, however, with occasional dip reversals that usually can be related to differential compaction in bounding strata. Figure 4 shows the distribution of boreholes within the coalfield and the intersection of major coal seams and marker units with the bedrock surface. The stratigraphically lowest horizons are present throughout the coalfield, whereas the uppermost horizons are restricted to the extreme west-central portion. Figure 5 contains a series of cross-sections through the coalfield, drawn both parallel and perpendicular to regional dip, and illustrating the lateral continuity and undulatory nature of individual coal seams and marker units, as well as the lenticularity of some of the interseam rock units.

AVAILABLE DATA

Coal exploration in the Dodds-Round Hill area commenced in 1910 with the development of an underground mine near Camrose, southwest of the coalfield (Fig. 1). Since that time, thirteen shallow, surface and underground mining operations have existed within the study area, in addition to numerous others in the surrounding region. All of these mines ceased production by 1965, with the exception of the Dodds Mine, in the northeastern part of the coalfield. This mine still operates intermittently and produces about 10 000 short tons per year.

In 1969, TransAlta Utilities (formerly Calgary Power Ltd.) and Century Coals Limited drilled 102 boreholes on 800 to 1600 m centres throughout the central part of the coalfield. Although no geophysical logs were run on these boreholes, detailed logs of cuttings were made and proved quite accurate when compared to adjacent, geophysically logged boreholes. Consequently, 98 of these boreholes were included in the data base used in this study.

Between 1972 and 1975, TransAlta Utilities Limited and Fording Coal Limited drilled 1177 boreholes on 400 to 800 m centres over the central and eastern parts of the coalfield. The majority of these boreholes have a complete suite of natural gamma, resistance and gamma-gamma density geophysical logs, although only about 20 per cent have caliper logs. These logs were run at a scale of 1:120.

Between 1973 and 1975, a consortium of Shell Canada Limited and PanCanadian Petroleum Limited drilled 74 boreholes in the central and western parts of the coalfield on 800 to 1600 m centres. Natural gamma, resistance, gamma-gamma density and caliper geophysical logs, at a scale of 1:120, are available for most of these boreholes. In addition, geophysical logs at 1:24 scale are available for the thicker coal intersections. These expanded-scale geophysical logs include natural gamma and long- and short-spaced density logs for most boreholes, and neutron, natural gamma, resistance, and long-, medium-, and short-spaced density logs for boreholes which were continuously cored.

The majority of boreholes were drilled using normal rotary drilling equipment with air or water as a circulating fluid. Although descriptions of cuttings made by the driller are available for most of the boreholes, they are commonly of limited value when compared to geophysical logs, and were, therefore, used only when geophysical logs were not available. Samples of coal for analytical work were obtained from 29 reverse circulation boreholes in 1972, from cored intersections of seams in 120 normal rotary holes, and from several continuously cored holes drilled during the Shell-PanCanadian exploration program. Geologists' descriptions of core from these holes provided an opportunity to correlate geophysical log responses to specific lithologies and to the position of coal contacts.

Table 1 summarizes the data available from each of these exploration programs and Figure 4 illustrates the locations of boreholes with respect to the subcrop positions of major correlated units within the coalfield. In total, 1349 boreholes with an aggregate length of 42 626 m were included in this study. Over 90 per cent of this drilling (39 000 m) had a complete suite of natural gamma, resistance and gamma-gamma density geophysical logs. Sixteen per cent of the drilling (6887 m) had caliper geophysical logs available.

In addition to these subsurface data, topographic maps at 1:4800 scale, with 1.5 m contour intervals, were available for most of the central and eastern portions of the area. Outside this area, National Topographic System 1:50 000 scale maps, with 8 m contour intervals, were used. Surveyed location and elevation co-ordinates were also available for most of the boreholes.

METHODOLOGY

All data collected during the exploration of the Dodds-Round Hill coalfield were interpreted and stored in a computer-accessible data base on an HP3000 computer. Once in a computer-processable format, relationships within and between large numbers of spatially distributed variables could be rapidly examined, utilizing contour maps, cross-sections and other procedures that are outlined below. Basic steps in this process include: (1) the interpretation of the position of coal and other lithologic units from the geophysical logs; (2) correlation of all laterally persistent rock and coal units between boreholes; (3) entry of location, lithologic and analytical data into a computer data base; and (4) manipulation and display of data to determine coal resource quality and quantity, and to determine the geometry and distribution of lithologic units in interseam rock intervals. The basic components of each of these steps are outlined briefly below. For a more detailed discussion of computer-based procedures utilized by the Geological Survey of Canada for coal deposit assessment, the reader is referred to Hughes (in prep.).

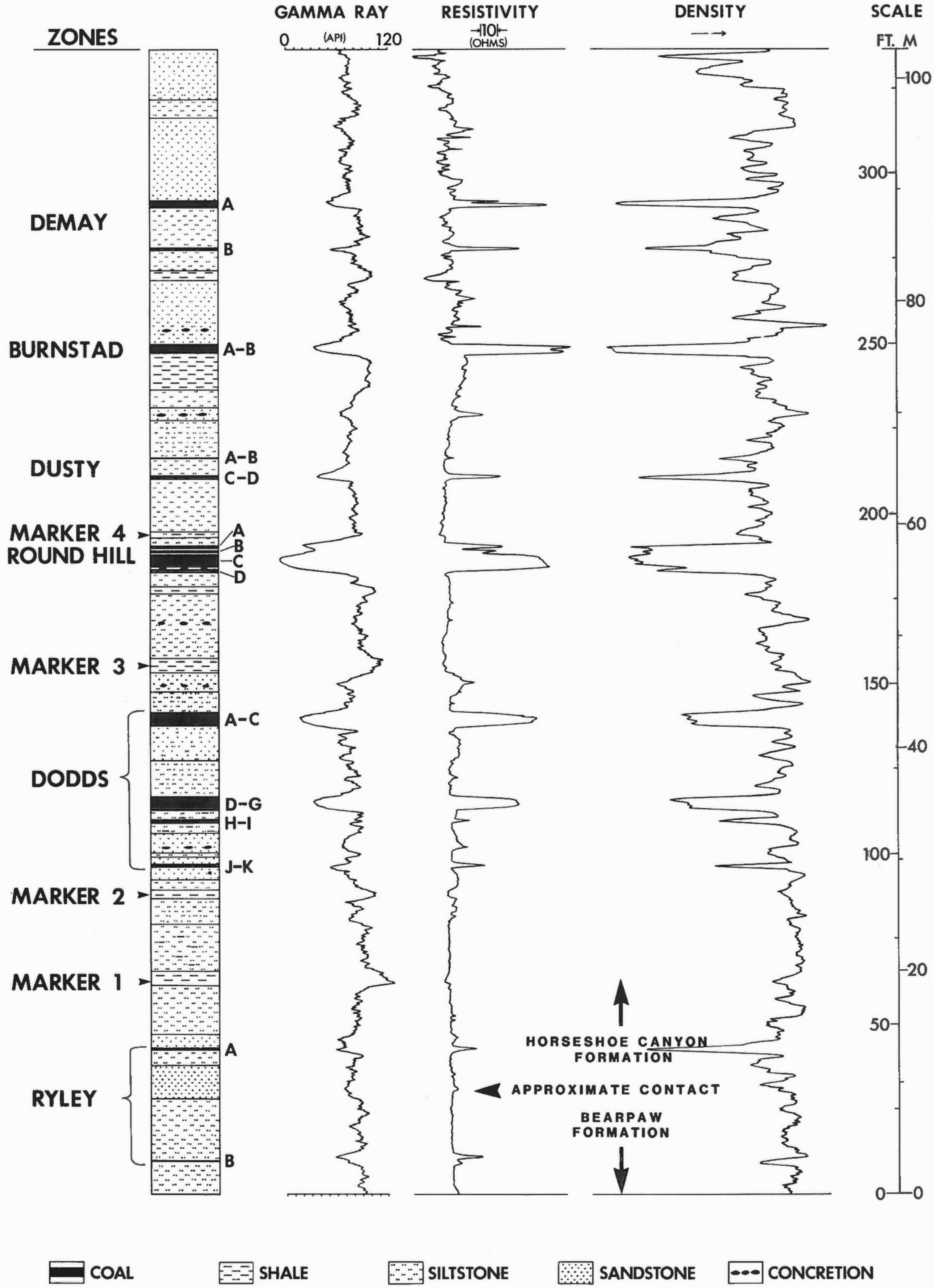


Figure 3. *Composite lithologic section of strata within the Dodds-Round Hill area, showing nomenclature of coal zones and marker units and typical geophysical log responses. Letters on right margin of lithologic column are "zone modifiers" (see text).*

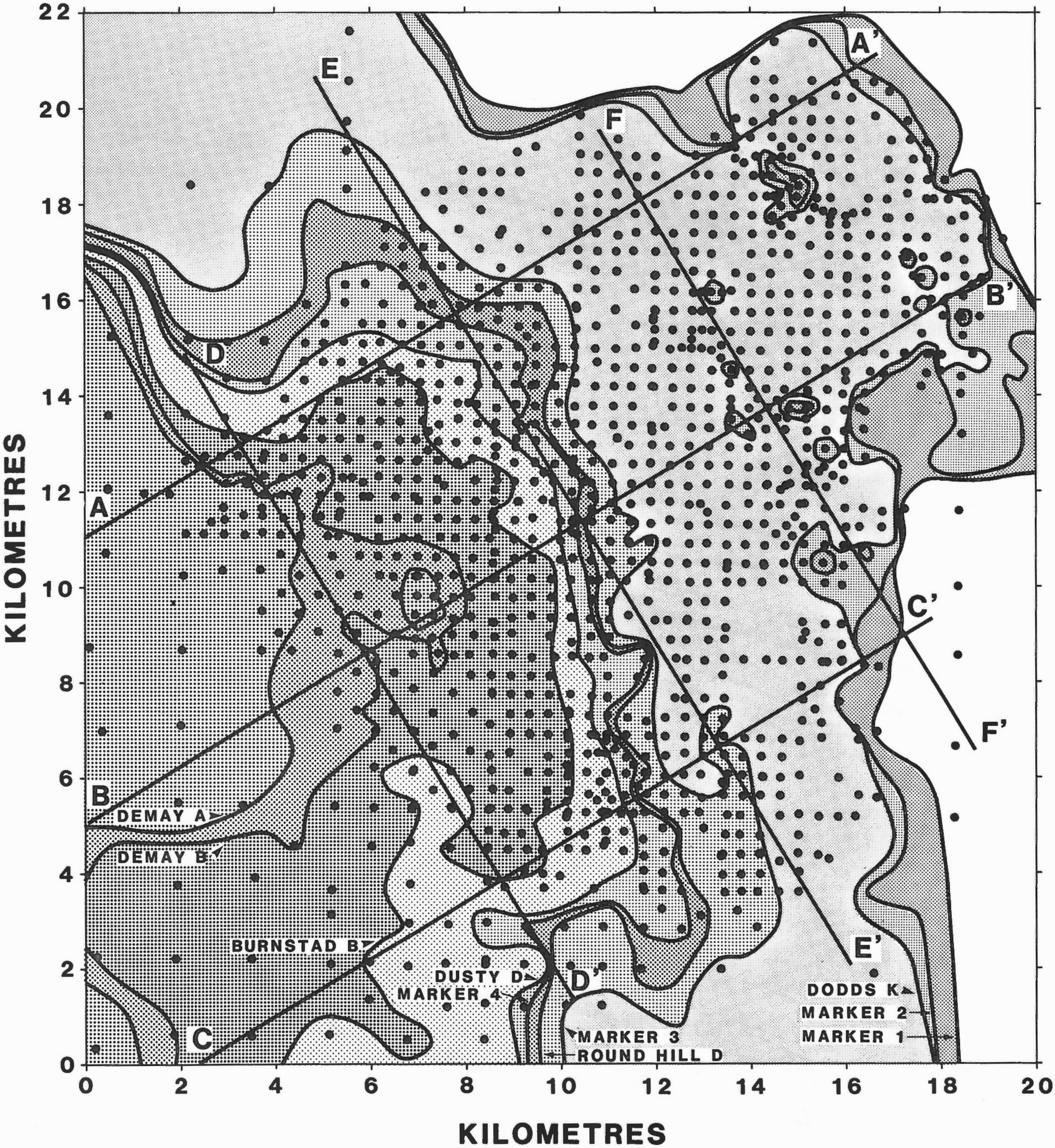
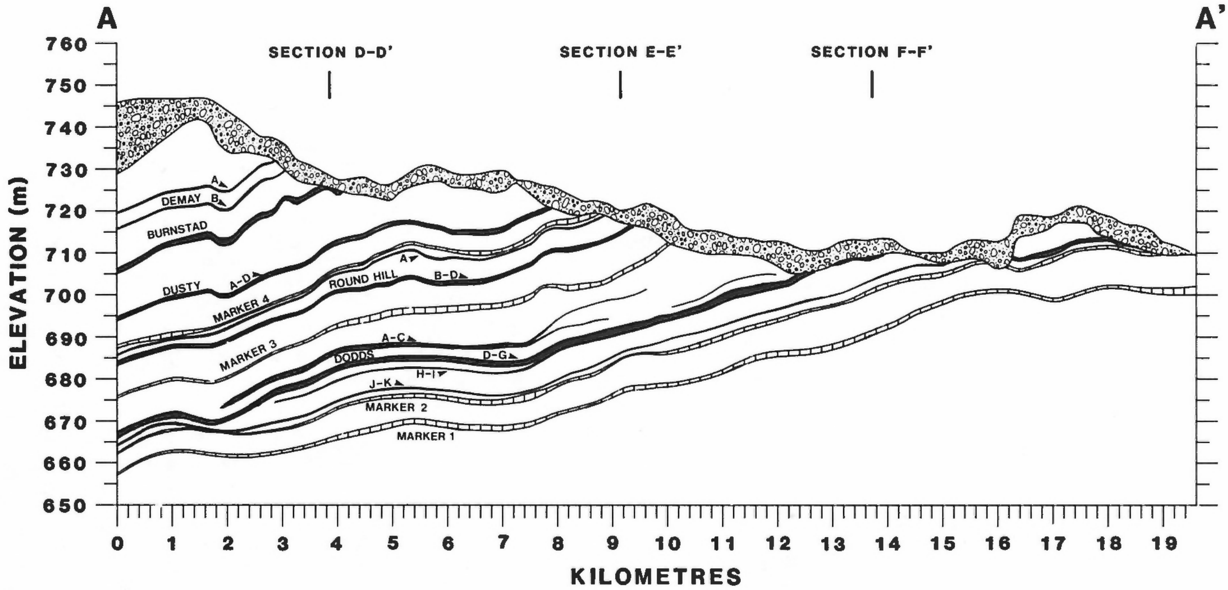
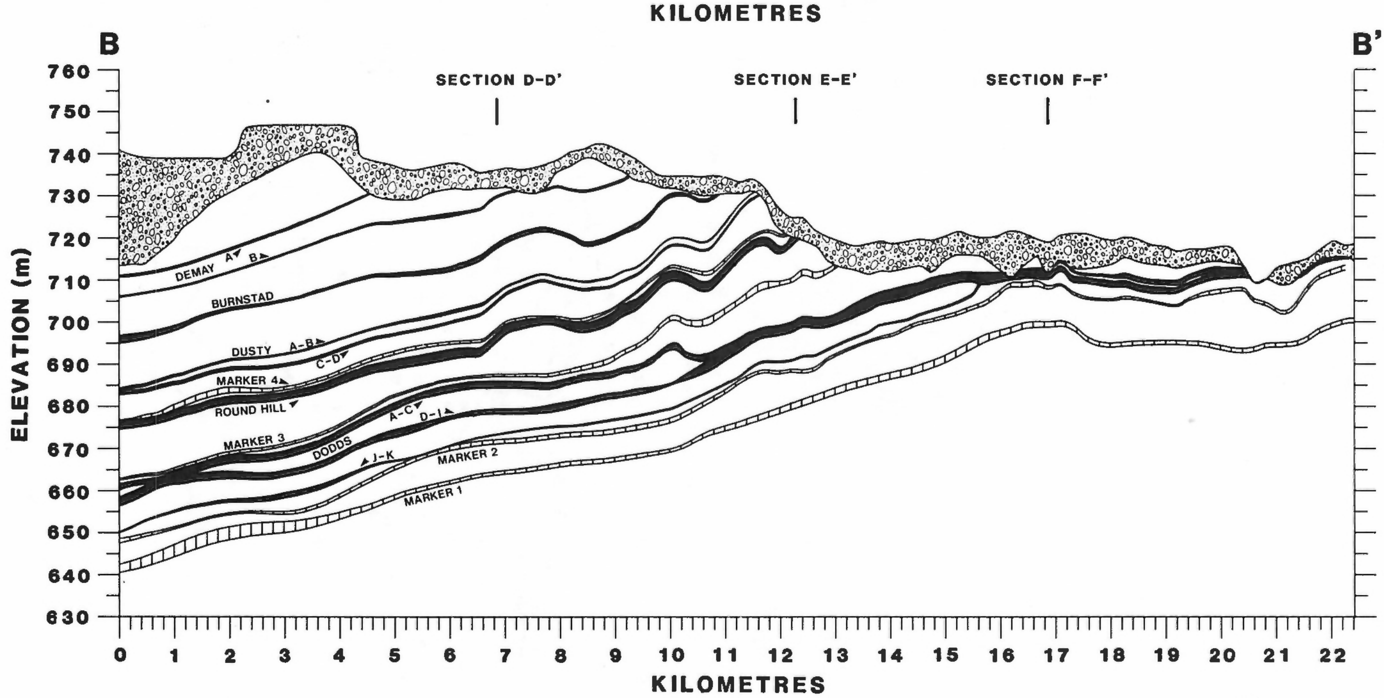
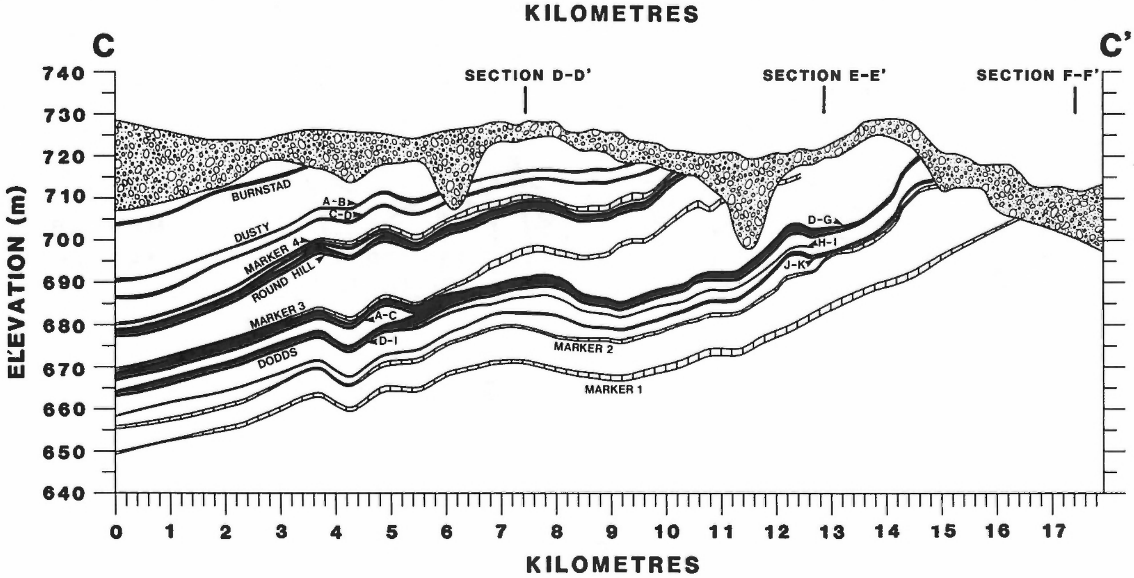


Figure 4. Dodds-Round Hill coalfield, showing location of boreholes, subcrop positions of major correlated units and location of cross-sections illustrated in Figure 5.


A
A'
SECTION D-D'
SECTION E-E'
SECTION F-F'
ELEVATION (m)
760
750
740
730
720
710
700
690
680
670
660
650
DEMAY
BURNSTAD
DUSTY
MARKER 4
ROUND HILL
MARKER 3
DODDS
MARKER 2
MARKER 1
A
B
A-D
A
B-D
A-C
D-G
H-I
J-K
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
KILOMETRES


B
B'
SECTION D-D'
SECTION E-E'
SECTION F-F'
ELEVATION (m)
760
750
740
730
720
710
700
690
680
670
660
650
640
630
DEMAY
BURNSTAD
DUSTY
MARKER 4
ROUND HILL
MARKER 3
DODDS
MARKER 2
MARKER 1
A
B
A-B
C-D
A-C
D-I
J-K
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
KILOMETRES


C
C'
SECTION D-D'
SECTION E-E'
SECTION F-F'
ELEVATION (m)
740
730
720
710
700
690
680
670
660
650
640
BURNSTAD
DUSTY
MARKER 4
ROUND HILL
MARKER 3
DODDS
MARKER 2
MARKER 1
A-B
C-D
A-C
D-I
D-G
H-I
J-K
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
KILOMETRES

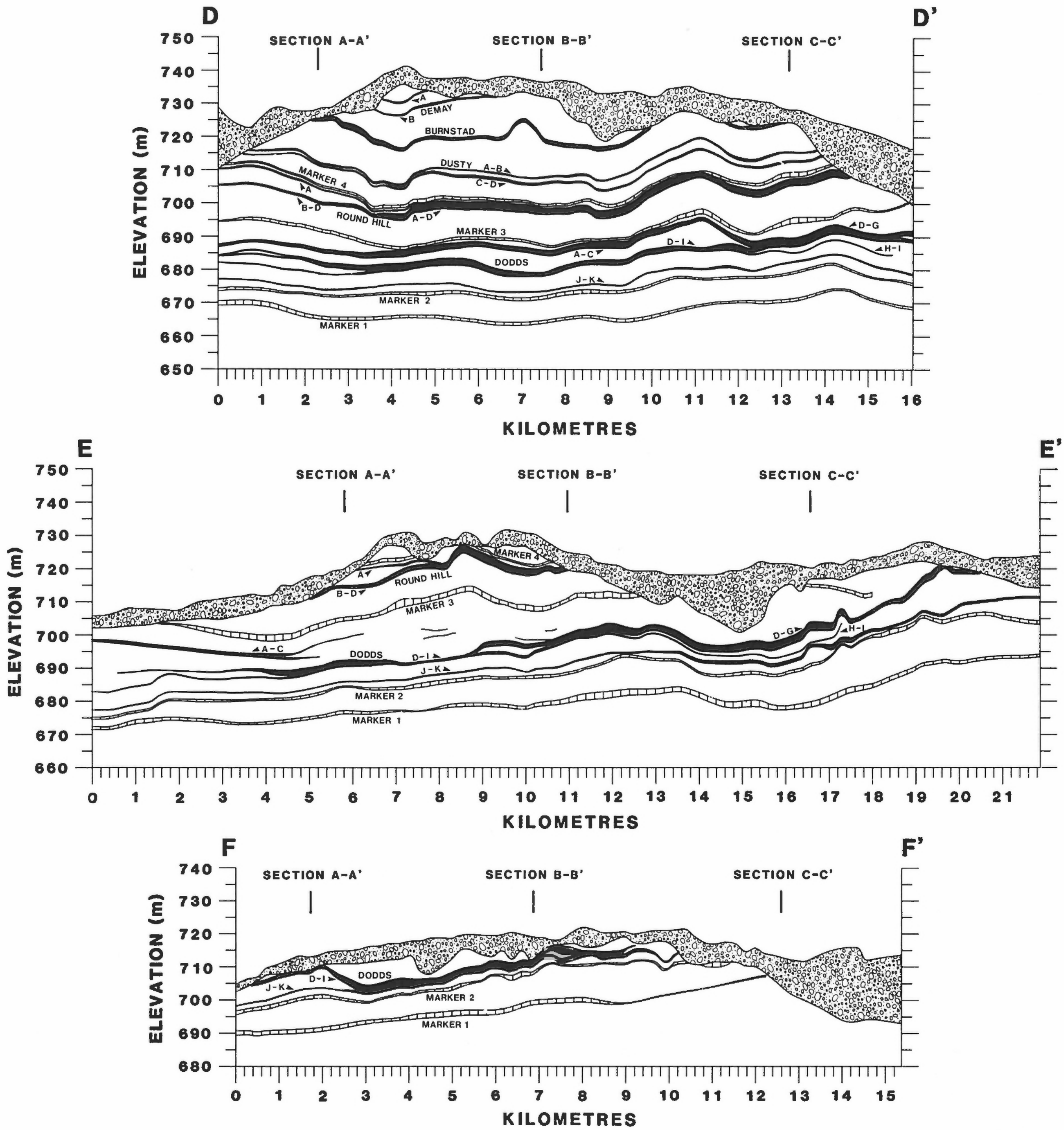


Figure 5. *Structural cross-sections, constructed parallel and perpendicular to regional dip, illustrating subsurface configuration of correlated units within Dodds–Round Hill coalfield. See Figure 4 for locations. Vertical exaggeration: 75 x.*

Table 1

Summary of borehole data for Dodds-Round Hill coalfield

Company	Year Drilled	No. of Holes	Metres Drilled	Number of boreholes with geophysical logs[5] GAM[1]	RES[2]	DEN[3]	CAL[4]	Cumulative borehole interval (metres) covered by geophysical logs[6] GAM[1]	RES[2]	DEN[3]	CAL[4]
Fording-TransAlta	1969	98	2,125	0	0	0	0	0	0	0	0
Fording-TransAlta	1972	80	3,014	79	79	77	56	2,993	2,993	2,919	2,317
Fording-TransAlta	1973	722	23,846	706	704	700	128	23,456	23,365	23,315	529
Fording-TransAlta	1974	293	7,201	260	250	259	0	6,719	6,502	6,544	0
Fording-TransAlta	1975	82	1,521	82	82	82	40	1,521	1,521	1,521	890
Fording-TransAlta	All years	1,275	37,707	1,127	1,115	1,118	224	34,689	34,381	34,299	3,736
Shell-PanCanadian	1973	17	1,187	14	17	15	0	984	1,187	1,068	0
Shell-PanCanadian	1974	4	225	4	4	4	0	225	225	225	0
Shell-PanCanadian	1975	53	3,507	53	53	53	47	3,507	3,507	3,507	3,151
Shell-PanCanadian	All years	74	4,919	71	74	72	47	4,716	4,919	4,800	3,151
All companies	All years	1,349	42,626	1,198 (88.8)	1,189 (88.1)	1,190 (88.1)	271 (20.1)	39,405 (92.4)	39,300 (92.2)	39,099 (91.7)	6,887 (16.2)

[1]Natural gamma
[2]Resistivity
[3]Gamma-gamma density
[4]Caliper
[5]Number in brackets on last line indicates percentage of all holes with various geophysical logs
[6]Number in brackets on last line indicates percentage of total meterage with various geophysical logs

Interpretation of geophysical logs

Of utmost importance in a study of this nature is the consistent interpretation of the position and character of coal and rock units from the geophysical logs. As previously mentioned, the most commonly available suite of geophysical logs included natural gamma, resistance, and gamma-gamma density. Because none of these geophysical logs were precisely calibrated against known standards, similar lithologies in adjacent holes may not have the same geophysical response in terms of log units. Therefore, the interpretation of a suite of geophysical logs for a hole required the establishment of response levels for specific lithologic types, based on a consideration of the relative responses of all available logs. In order to make this interpretation process as consistent as possible, boreholes were interpreted in geographic order, so that units with similar log responses in adjacent holes were assigned equivalent lithologic identifiers.

The interpretation of geophysical logs proceeded in the following sequence:

1. Determination of the position and thickness of all coal, shaly coal and carbonaceous units, using a combination of all available logs;

2. Determination of the position of all lithologic units requiring a combination of geophysical logs for identification (primarily concretionary horizons);

3. Determination of the type and position of all remaining rock units in the borehole, primarily utilizing the natural gamma log and secondarily utilizing the resistance and other available logs.

Although the presence of coal was determined from an examination of all available logs, the depths of coal contacts were determined from the gamma-gamma density log, where available, in order to minimize the effect of small depth shifts sometimes present between logs. In some cases, however, resistance logs resolve thin rock partings within coal seams better than the long-spaced density log, and in these cases the thickness of rock partings was determined from the resistance log.

The positions of coal/rock contacts on the density logs were determined in the following manner. A background density value for non-coal lithologies for each borehole was first determined (Fig. 6). Recognizing that the density curve was generated by a sonde moving upward in the borehole, the lower contact of a coal seam was positioned just above the point at which the density curve crossed the background density value, and the upper contact just above the point where the density curve began to swing back to values typical for non-coal lithologies, as illustrated in Figure 6. Good agreement was observed when intersections, derived by using this procedure on long-spaced density curves, were compared to intersections measured from cores and determined from detail-scale medium- and short-spaced density logs.

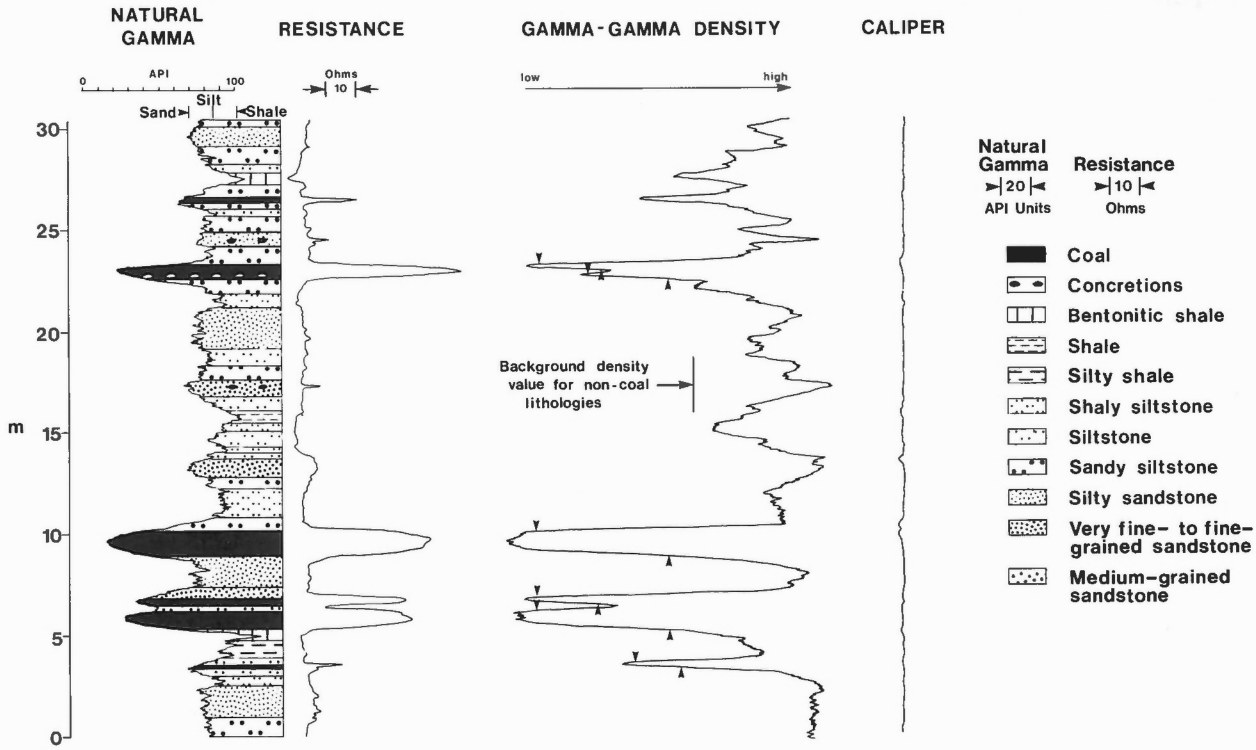


Figure 6. *Interpretation of a typical suite of geophysical logs for Dodds-Round Hill area (see text). Arrows on gamma-gamma density log indicate interpreted position of coal seam boundaries.*

Non-coal lithologies requiring a combination of geophysical logs for identification include concretionary horizons and carbonaceous shale units. Concretionary horizons respond very much like coal on the natural gamma and resistance logs, but can be differentiated by their high density response. Carbonaceous units may resemble sandstone on natural gamma and resistance logs but can be distinguished by their abnormally low density.

All remaining non-coal lithologies were defined primarily on the natural gamma logs and secondarily on the resistance logs. This was done by first examining the entire length of the natural gamma curve and determining response levels for the coarsest- and finest-grained lithologic units in a borehole. Sandstones were identified by their relatively low natural gamma and high resistance responses, and shale and bentonitic units by their high natural gamma and low resistance responses. Threshold values were then established for sandstone and shale on the natural gamma curve, and threshold values for intervening lithologies were established between these limits in the manner illustrated in Figure 6. The natural gamma curve was then subdivided into units of reasonably uniform response with a minimum thickness of about 0.5 m, and each of these units was assigned a lithologic type by comparing its response to the previously determined threshold responses. A further measure of consistency in assigning lithologic types was achieved by interpreting holes in geographic sequence, so that equivalent lithologies in adjacent holes could be assigned the same lithologic identifiers.

Correlation of coal seams and marker units

Coal seams and lithologic units that could be traced laterally between boreholes were assigned correlations using the following process. Photographic reductions of the geophysical logs at a scale of 1:600 were produced for each borehole, along with a computer generated graphic display at a similar scale showing elevation above sea level and the lithologic units interpreted from the geophysical logs. These reduced logs were then posted in geographic sequence, so that information from all boreholes could be accessed quickly in determining correlations between boreholes. Correlation nomenclature utilized the naming conventions employed by Irvine et al. (1978). Coal intersections were first grouped into "zones", which are defined as a group of coal or carbonaceous beds that occur at about the same stratigraphic position. The location in the coalfield where a particular zone comprises a maximum number of beds was then determined, and bed-by-bed correlation within the zone proceeded from this point. Each correlatable bed within a

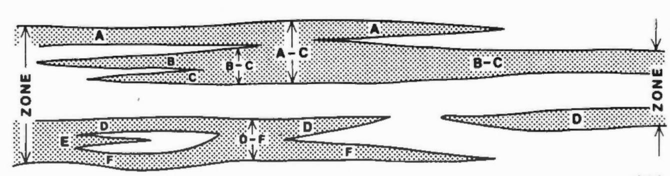


Figure 7. *Nomenclature utilized in correlation of "zones" and "modifiers" (see text). From Irvine et al. (1978).*

Identification

ITEMS:
URN,
HOLE-ID,
NTS-PRIM,
NTS-SEC,
NTS-TERT,
LSD,
LSD-MOD,
SECTION,
TWP,
RANGE,
MERIDIAN,
LATITUDE,
LONGITUDE,
UTM-ZONE,
NORTHING,
EASTING,
LOC-UNCERTAINTY,
TOTAL-DEPTH,
BOTTOM-HOLE,
DATE-DRILLED,
ELEVATION,
ELEV-UNCERTAINTY,
DRILLING-CO,
GEOLOGIST,
DRILL-TYPE,
MUD-COND,
WATER-COND,
RESISTANCE,
SP,
DENSITY,
GAMMA,
CALIPER,
NEUTRON,
NORMAL,
LATERAL,
FOCUS,
INDUCT,
SONIC,
COMPILED-ON,
SOURCE-OF-DATA,
CORNER,
XOFFSET,
E-W,
YOFFSET,
N-S,

Lithology

ITEMS:
HOLE-ID,
LITHOLOGY,
FORMATION,
ZONE-NAME,
ZONE-MOD,
TOP-DEPTH,
TOP-ELEV,
BOTTOM-DEPTH,
BOTTOM-ELEV,
THICKNESS,
CALCAREOUS,
HUE,
VALUE,
CHROMA,
SAMPLED,
DRESISTANCE,
DSP,
DDENSITY,
DGAMMA,
DCALIPER,
DNEUTRON,
DNORMAL,
DLATERAL,
DFOCUS,
DINDUCT,
DSONIC,
SEQ#,

Analysis

ITEMS:
HOLE-ID,
LAB#,
ZONE-NAME,
ZONE-MOD,
TOP-DEPTH,
BOTTOM-DEPTH,
SG-HOG,
SG-AIR,
D-VOLM%,
D-FIXC%,
D-ASH-P%,
D-ASH-U%,
D-SULPHUR-P%,
D-SULPHUR-U%,
D-PHOSPHORUS%,
D-HEAT,
D-CARBON%,
D-HYDROGEN%,
D-NITROGEN%,
D-OXYGEN%,
S-SULPHATE%,
S-PYRITE%,
S-ORGANIC%,
RO%,
RANK-RO,
RANK-ASTM,
HAR-GRIND,
FSI,
SIO2%,
AL2O3%,
FE2O3%,
CAO%,
MGO%,
NA2O%,
K2O%,
SO3%,
P2O5%,
TIO2%,
ASH-SOFT,
INITIAL-O,
HEMI-SPH-O,
SPHERE-R,
FLUID-O,
INITIAL-R,
HEMI-SPH-R,
FLUID-R,
SEQ#,
SAMPLE-ID,
SAMPLE-METHOD,
TOP-ELEV,
BOTTOM-ELEV,
THICKNESS,
INCL-PTG,
ULT-BASIS,
SPHERE-O,
UNDET%,
MERC-PPB,
REC%,
M-MMF-HEAT,
D-MMF-HEAT,
UMBASIS,
PMBASIS,
UMOIST%,
PMOIST%,

Figure 8. *Data items within Identification, Lithology and Analysis data sets.*

Identification

HOLE ID: 1455

URN: 40 NTS: 83H2

LAND SURVEY SYSTEM: NW/7/29/48/18W4 CORNER AND OFFSETS: 0(0) 0(0)

LAT-LONG: 53.17043 112.59800 UTMS: 12 5892205N 393180E

ELEVATION: 733.20M 2405.51FT
TOTAL DEPTH: 79.25M 260.01FT

UNCERTAINTY OF LOCATION: 0M UNCERTAINTY OF ELEVATION: 0M

COMPANY: MCAULEY DRILL: NR GEOLOGIST: UNKNOWN

LOGS RUN RES: Y S-P: N DEN: Y GAM: Y
CAL: Y NEU: N NOR: LAT:
IND: FOC: SON:

SOURCE OF DATA: FORDING LAST EDIT DATE: 09/24/82

Lithology

BOREHOLE: T-64

NO.	LITHOLOGY	FORM	ZONE	MOD	S	DEN	CAL	GAM	NEU	RES	S-P	SON	NOR	IND	FOC	LAT	C	DEPTH (METRES)	THICK	B-DEPTH	T-ELEV	B-ELEV
1	SNDY CLAY	GLCL			N	N	N	N	N	N	N	N	N	N	N	N	N	.00	6.74	6.74	736.79	730.05
2	SAND	GLCL			N	N	N	N	N	N	N	N	N	N	N	N	N	6.74	2.37	9.11	730.05	727.68
3	SNDY CLAY	GLCL			N	N	N	N	N	N	N	N	N	N	N	N	N	9.11	2.29	11.40	727.68	725.39
4	SHLY COAL	EDMN	DEMAY	A-A	N	N	N	N	N	N	N	N	N	N	N	N	N	11.40	.58	11.98	725.39	724.81
5	COAL	EDMN	DEMAY	A-A	N	N	N	N	N	N	N	N	N	N	N	N	N	11.98	.36	12.34	724.81	724.45
6	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	12.34	2.53	14.87	724.45	721.92
7	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	14.87	3.45	18.32	721.92	718.47
8	COLY SHLE	EDMN	DEMAY	B-B	N	N	N	N	N	N	N	N	N	N	N	N	N	18.32	.43	18.75	718.47	718.04
9	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	18.75	2.22	20.97	718.04	715.82
10	FG SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	20.97	.73	21.70	715.82	715.09
11	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	21.70	3.08	24.78	715.09	712.01
12	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	24.78	.52	25.30	712.01	711.49
13	SHLY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	25.30	1.19	26.49	711.49	710.30
14	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	26.49	.61	27.10	710.30	709.69
15	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	27.10	2.19	29.29	709.69	707.50
16	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	29.29	.85	30.14	707.50	706.65
17	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	30.14	1.35	31.49	706.65	705.30
18	COAL	EDMN	BURNSTAD	A-B	N	N	N	N	N	N	N	N	N	N	N	N	N	31.49	.48	31.97	705.30	704.82
19	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	31.97	.43	32.40	704.82	704.39
20	CNCR	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	32.40	.18	32.58	704.39	704.21
21	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	32.58	.61	33.19	704.21	703.60
22	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	33.19	.80	33.99	703.60	702.80
23	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	33.99	2.89	36.88	702.80	699.91
24	FG SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	36.88	2.90	39.78	699.91	697.01
25	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	39.78	2.01	41.79	697.01	695.00
26	FG SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	41.79	.70	42.49	695.00	694.30
27	CNCR	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	42.49	.43	42.92	694.30	693.87
28	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	42.92	2.74	45.66	693.87	691.13
29	CNCR	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	45.66	.12	45.78	691.13	691.01
30	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	45.78	3.02	48.80	691.01	687.99
31	COAL	EDMN	DUSTY	A-B	N	N	N	N	N	N	N	N	N	N	N	N	N	48.80	.43	49.23	687.99	687.56
32	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	49.23	2.25	51.48	687.56	685.31
33	CNCR	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	51.48	.09	51.57	685.31	685.22
34	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	51.57	.95	52.52	685.22	684.27
35	COAL	EDMN	DUSTY	C-D	N	N	N	N	N	N	N	N	N	N	N	N	N	52.52	.73	53.25	684.27	683.54
36	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	53.25	.97	54.22	683.54	682.57
37	SHLY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	54.22	.61	54.83	682.57	681.96
38	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	54.83	3.05	57.88	681.96	678.91
39	SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	57.88	1.37	59.25	678.91	677.54
40	SHLY COAL	EDMN	ROUNDHILL	A-B	N	N	N	N	N	N	N	N	N	N	N	N	N	59.25	.06	59.31	677.54	677.48
41	COAL	EDMN	ROUNDHILL	A-B	N	Y	N	Y	N	N	N	N	N	N	N	N	N	59.31	.55	59.86	677.48	676.93
42	SLTS	EDMN			N	Y	N	Y	N	N	N	N	N	N	N	N	N	59.86	.83	60.69	676.93	676.10
43	COAL	EDMN	ROUNDHILL	C-D	N	Y	N	Y	N	N	N	N	N	N	N	N	N	60.69	.33	61.02	676.10	675.77
44	SLTS	EDMN			N	Y	N	Y	N	N	N	N	N	N	N	N	N	61.02	4.36	65.38	675.77	671.41
45	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	65.38	1.37	66.75	671.41	670.04
46	SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	66.75	1.25	68.00	670.04	668.79
47	SNDY SLTS	EDMN			N	Y	N	Y	N	N	N	N	N	N	N	N	N	68.00	.58	68.58	668.79	668.21
48	SLTY SHLE	EDMN			N	Y	N	Y	N	N	N	N	N	N	N	N	N	68.58	.30	68.88	668.21	667.91
49	BENT SHLE	EDMN	MARKER	A	N	Y	N	Y	N	N	N	N	N	N	N	N	N	68.88	.74	69.62	667.91	667.17
50	SHLY COAL	EDMN	DODDS	A-A	N	Y	N	Y	N	N	N	N	N	N	N	N	N	69.62	.48	70.10	667.17	666.69
51	COLY SHLE	EDMN			N	Y	N	Y	N	N	N	N	N	N	N	N	N	70.10	.16	70.26	666.69	666.53
52	COAL	EDMN	DODDS	B-C	N	Y	N	Y	N	N	N	N	N	N	N	N	N	70.26	1.49	71.75	666.53	665.04
53	SHLY SLTS	EDMN			N	Y	N	Y	N	N	N	N	N	N	N	N	N	71.75	.76	72.51	665.04	664.28
54	SLTS	EDMN			N	Y	N	Y	N	N	N	N	N	N	N	N	N	72.51	1.53	74.04	664.28	662.75
55	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	74.04	.33	74.37	662.75	662.42
56	CNCR	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	74.37	.15	74.52	662.42	662.27
57	SNDY SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	74.52	.52	75.04	662.27	661.75
58	SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	75.04	.52	75.56	661.75	661.23
59	COAL	EDMN	DODDS	D-G	N	N	N	N	N	N	N	N	N	N	N	N	N	75.56	.98	76.54	661.23	660.25
60	SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	76.54	.57	77.11	660.25	659.68
61	COLY SHLE	EDMN	DODDS	H-I	N	N	N	N	N	N	N	N	N	N	N	N	N	77.11	.28	77.39	659.68	659.40
62	SLTY SHLE	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	77.39	.67	78.06	659.40	653.73
63	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	78.06	2.16	80.22	658.73	656.57
64	FG SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	80.22	.98	81.20	656.57	655.59
65	SLTY SNDS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	81.20	.52	81.72	655.59	655.07
66	SLTS	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	81.72	.58	82.30	655.07	654.49
67	COAL	EDMN	DODDS	J-K	N	N	N	N	N	N	N	N	N	N	N	N	N	82.30	.30	82.60	654.49	654.19
68	MISSING	EDMN			N	N	N	N	N	N	N	N	N	N	N	N	N	82.60	1.22	83.82	654.19	652.97

***Figure 9.** Data stored within Identification and Lithology data sets for a typical borehole.*

zone was assigned a letter "modifier", beginning at the stratigraphically highest bed. In this way, individual beds could be traced laterally to locations where they coalesce with other beds or pinch out, as illustrated in Figure 7. In the present study, four bentonitic shale units with greater lateral continuity than many of the coal seams were also assigned zone names and proved to be very valuable marker units. Figure 3 summarizes the zone names and commonly occurring modifiers recognized in the Dodds-Round Hill area.

Data storage

All geophysical log interpretations and correlations were stored, together with site identification and analytical data, within an IMAGE data base on an HP3000 computer. This data base comprises three data sets containing identification, lithology and analytical data. The identification data set contains general information about a borehole, including its location in three co-ordinate systems, the types of geophysical logs run, drilling company etc.; the lithology data set contains the type, correlation, presence or absence of detail-scale geophysical logs, depth, thickness and elevation information for each interpreted lithologic unit in a borehole; and the analytical data set contains information on each analysed sample in a borehole. Data items within each of these data sets are illustrated in Figure 8. The identification data set occurs once for each borehole, whereas the lithology and analytical data sets contain entries for each lithologic unit or each sample respectively.

Several data input and display routines have been written for this data base to allow automatic checks of the data being input against a dictionary of valid names or numeric ranges, and interactive updating, editing, and display of all data items in the data base. An example of the contents of the identification and lithology data sets for a typical borehole is given in Figure 9.

Data retrieval

Retrievals from the data base can be made on an ad hoc basis, using a query language that allows a highly specific output, or by using specialized retrieval routines, which build sequential files containing frequently used subsets of the data base. These files can then be input into other computer programs for data manipulation and display.

Specialized retrieval routines can be grouped into those that retrieve information on specific correlated units; those that retrieve information on lithologic units, between or within a specified distance of a correlated unit; and those that retrieve analytical data for specified correlated units. The first group includes routines that retrieve location, elevation, depth and thickness information for all occurrences of a specified formation, zone, or zone modifier. The second group includes routines that retrieve location, lithology, elevation, depth, and thickness information for all lithologic units between two correlated surfaces or within a specified distance above or below a correlated surface. The third group retrieves location, elevation, depth, thickness and analytical data for specified correlated units. All of these retrievals can be done on a geographic basis by retrieving data within or outside a user-specified polygon. In addition to these specialized retrieval routines, sequential files of the contents of the identification, lithology, and analysis data sets can be generated to allow transfer of the data to other computer systems.

Data manipulation and display

Several computer programs were utilized to display the data in this data base as posting or contour maps, cross-sections and block diagrams, and for various data manipulation procedures. These include commercially available software packages such as the Generalized Posting Routine (GPR) (Proudfoot and Lam, 1980), the Surface II graphics display system (Sampson, 1978), CROSEC (DeSouza and Stevens, 1980) and Terraplot (Terradata, 1981), as well as several more specialized computer programs which were written inhouse by C.F. Stevens and K.E. Mottershead. The function and utilization of these programs in the present study are outlined briefly below.

Grid interpolation

Fundamental to many of the procedures used for manipulation and display of data in this study is the interpolation of values on a regularly spaced grid from the typically irregularly spaced borehole data. Once all surfaces are represented by a common set of grid nodes, surface-to-surface comparisons and manipulations are possible, and are utilized in many aspects of the assessment process.

Several strategies are available for the interpolation of values at grid nodes from surrounding data points. These can be grouped into simple distance weighted averaging schemes, which take no account of the distribution of surrounding data points; distance weighted average techniques, which require data points to have a relatively uniform distribution about the grid node to be estimated; triangulation methods, which first triangulate between all data points and then calculate a grid from the triangulated surface; and geostatistical techniques, which first analyse and model the spatial variability of the data using semivariograms or autocorrelation functions (e.g. Journel and Huijbregts, 1978), and then utilize kriging and these functions to estimate values at grid nodes, as well as the error associated with these estimates.

In the present study, grid nodes were interpolated at 200 m intervals from the irregularly spaced borehole data, creating a grid with 111 rows and 101 columns covering an area 22 km by 20 km. All grid node values were determined utilizing the following estimating procedure available in Surface II (Sampson, 1978). In the first phase of this procedure, a search is performed around each data point in the area to be gridded. Data points which meet the requirements of the parameters specified for this search are used to calculate the slope of a plane passing through the data point under consideration. The parameters specified for this search in this study were that three out of four quadrants must contain at least one data point, and that the four nearest data points within each quadrant would be used. Quadrant boundaries were tilted at 22½ degrees from due north because of the predominantly north-south orientation of lines of boreholes, in order to maximize the number of valued nodes in the resultant grid. In the second phase of this procedure, values are estimated for all grid nodes by performing a similar search around each grid node, projecting the slopes calculated during the first phase from each of the qualifying data points to the grid node, and then performing an inverse distance weighted average of these slope projections to estimate a value for the grid node in question. The inverse distance weighting function used in this study is given by the following formula from Sampson (1978):

$$W = \left(1 - \frac{D}{1.1 \times D_{max}}\right)^2 \Big/ \left(\frac{D}{1.1 \times D_{max}}\right)^2$$

where: W = weight,

D = distance to sample point,

D_{max} = distance to most distant sample point used in estimation.

If a data point or a grid node does not meet the requirements of the search parameters used, a Surface II "blank" value of -1×10^{30} is inserted at that grid node. Contour lines do not extend across blank valued cells when grids are displayed as contour maps and appear as zero thickness cells when grids are displayed as block diagrams.

Surface II has facilities for assessing the accuracy of the gridding process by comparing original data values with the estimated values within a grid; for blanking grid cells inside or outside of a user-defined polygon; for performing arithmetic operations on or between grids; and for scaling, rotating or translating grids, among other features. For a complete description of these facilities, the interested reader is referred to Sampson (1978).

Grid manipulation

The ability to arithmetically manipulate grids and to perform arithmetic operations between grids is extremely useful in the evaluation of the geology and resource potential of a coalfield. Although most of the commonly used grid manipulation procedures are available in Surface II, a separate set of routines to perform these procedures has been written by C.F. Stevens, formerly of the Geological Survey of Canada. The following steps illustrate how grid manipulation is used in the evaluation of a coalfield. Some of these procedures have been discussed elsewhere by Irvine et al. (1978), Irvine and Williams (1978), and Irvine (1981):

1. The best available topographic maps for an area are digitized. A grid is generated from this digitized surface using a cell size in the order of one third to one half of the average borehole spacing. The choice of a grid cell size is a compromise between resolution of the surface and available computer resources for grid generation, as resource usage is proportional to the number of cells in the grid.

2. A grid with equivalent node positions is generated containing the elevation of the top of the bedrock surface in all boreholes.

3. Grid nodes in the bedrock surface elevation grid that exceed the value of corresponding nodes in the topographic grid, are set to the value of the topographic grid. This commonly occurs in topographic lows that do not have borehole control. The resulting grid is termed the modified bedrock surface.

4. Grids containing the elevations of the upper and lower boundaries of all correlated units are generated. These grids are then compared with the modified bedrock surface, and all grid nodes that exceed the value of the corresponding node in the modified bedrock surface are set to the Surface II "blank" value. Valued nodes in the resultant grids define the areal distribution of the correlated surfaces.

5. Grids containing the thickness of the interval between correlated surfaces and the modified bedrock surface are created by subtracting the elevation grid for each correlated surface from the modified bedrock surface. The subcrops or lines of intersection between correlated surfaces and the modified bedrock surface are defined by nodes with zero-thickness values in the resultant grids.

6. Isopach grids are then created between all pairs of adjacent correlated surfaces. These grids can be displayed as contour maps, and are very useful in checking for errors in the correlation framework of an area. Correlation errors are highlighted by rapid thickness changes or "bull's-eyes" on these contour maps.

7. Once the areal distribution and geometry of all correlated units have been satisfactorily defined, other grids useful in determining the geology and resource potential of an area can be generated.

Other procedures

Several other computer programs and procedures utilized in this study are outlined briefly below.

Display of lithology data. In addition to obtaining listings of lithology data associated with specific boreholes or groups of boreholes, lithology data may be displayed as strip logs, or gridded and displayed in map form utilizing two computer programs known as LITHLOG and PERCENT, both written inhouse by C.F. Stevens.

LITHLOG displays a lithologic strip log of geophysical log interpretations stored in the data base. These logs can be displayed at any scale with a unique colour and symbol pattern for each lithologic type, as well as the depth, elevation, thickness and correlation of each lithologic unit. They are very useful in assessing the consistency and input accuracy of geophysical log interpretations.

PERCENT is a computer program that accepts, as input, files of lithologic data retrieved between two correlated surfaces or within a specified distance of a correlated surface. This program combines the interpreted lithologic units in these files into five user-specified groups, calculates the net thickness and percentage of each of these groups within each borehole, and outputs these values into a sequential file, which can be input to gridding and contouring programs. These aggregated lithologic groups may contain as many or as few specific lithologies as the user wishes. In the present study, all lithologies including and coarser grained than silty sandstone were grouped as sandstone; lithologies between shaly siltstone and sandy siltstone were grouped as siltstone; lithologies between silty shale and bentonitic shale were grouped as shale; concretionary units were assigned to a single group; and coal, shaly coal and carbonaceous beds were grouped as coal. Contour maps, block diagrams and cross-sections, showing the distribution of these lithologic groups within stratigraphic intervals in the Dodds-Round Hill area, are illustrated in a following section.

Markov analysis. MARKOV is a computer program for performing first-order Markov analysis on files of lithologic data. A Markov process is one "...in which the probability of the process being in a given state at a particular time may be deduced from knowledge of the immediately preceding state..." (Harbaugh and Bonham-Carter, 1970, p. 98). Markov analysis has been applied to many stratigraphic successions, in order to detect the presence of vertical sequences of lithologies that occur more commonly than would be expected given similar proportions of each lithologic state and completely random depositional processes. Reviews of Markov analysis, as applied to stratigraphic successions, can be found in Gingerich (1969), Harbaugh and Bonham-Carter (1970), Doveton (1971), and Miall (1973), among others. The computer program used in this study is based on one written by Doveton (1971), and performs an "embedded Markov chain analysis", in which only transitions between lithologic units, and not the thickness of individual units, are considered. The program first groups the interpreted lithologic units in the input file into a maximum of ten user-specified groups. Upward transitions between each of these aggregated lithologic groups are compiled into a transition count matrix. A transition probability matrix is then computed by dividing each entry in the transition count matrix by the sum of all transitions in that entry's row. An independent trials probability matrix is also calculated, which contains the probabilities of specific transitions, based only on the abundance of each lithologic state in the succession, and thus reflects the expected probabilities if the depositional processes are completely random. A difference matrix can then be computed by subtracting each entry in the transition probability matrix from the corresponding entry in the independent trials probability matrix. Positive values in the difference matrix indicate transitions that occur more frequently than would be expected in a random succession, and allow the determination of preferred vertical sequences of lithologies.

A chi-square test can be applied to the results of these analyses to determine their level of significance (Anderson and Goodman, 1957; Billingsley, 1961; Gingerich, 1969). The chi-square test statistic utilized in this study was calculated using the following formula from Gingerich (1969, p. 331):

$$\chi^2 = \sum_{ij} (f_{ij} - f_i e_{ij})^2 / f_i e_{ij}$$

where: f_{ij} is the number of transitions between states i and j from the transition count matrix,

f_i is the total number of occurrences of state i, and

e_{ij} is the probability of a transition between state i and state j from the independent trials probability matrix.

The number of degrees of freedom for this test is given by the total number of positive entries in the independent trials probability matrix, minus the rank of the matrix.

A fundamental assumption in Markov analysis is that the processes under consideration are stationary, that is, that the depositional processes responsible for the observed transitions are uniformly distributed in space and time. In order to maximize the stationarity of lithologic data used in Markov analysis in this study, analyses were restricted to specific stratigraphic intervals, and in some cases to portions of stratigraphic intervals that have relatively uniform lithologic composition, reflecting deposition within uniform depositional subenvironments.

Also of great importance is the number of lithologic states differentiated. If too many lithologic states are recognized, the number of degrees of freedom in the chi-square test is very large, and the resulting significance of the analysis very small. If the number of states is too few, the significance of the chi-square test is high but resolution of the cyclic processes operating is correspondingly small, because many individual lithologies have been grouped. After considerable experimentation, six discrete lithologic states were differentiated for Markov analysis in the present study. The interpreted lithologic units in the data base that were grouped to form these six states are listed in Table 2.

Table 2

Grouping of interpreted lithologic units used in Markov analysis

Interpreted lithologic units in data base	Lithologic identifier used in Markov analysis
Medium grained sandstone Very fine- to fine-grained sandstone	Lithology 1
Silty sandstone Sandy siltstone	Lithology 2
Siltstone Shaly siltstone	Lithology 3
Silty shale Shale Bentonitic shale	Lithology 4
Concretions	Lithology 5
Coal Shaly coal Carbonaceous shale	Lithology 6

Cross-sections. CROSEC (DeSouza and Stevens, 1980) is a computer program that constructs cross-sections through gridded surfaces. As presently configured, the program will construct cross-sections in any direction through up to 50 grids at a time. The user has control of horizontal and vertical scales, labelling, and line type and colour for each gridded surface. This program is extremely useful for correlation verification and display of the geometry and lithologic variations between correlated surfaces. All cross-sections in this report have been constructed directly from output of CROSEC.

Resource estimation. TOTAL is one of two computer programs used to calculate coal resource quantities of a coalfield. TOTAL aggregates coal intersections for a specified coal zone, according to user-specified criteria for the minimum extractable parting thickness and minimum mineable coal seam thickness. The program outputs two sequential files; one containing the location, top and bottom elevation of qualifying coal intersections, extractable rock parting thickness and recoverable coal thickness for each occurrence of the specified zone in the coalfield; and another containing the correlation designation for all qualifying coal intersections. The net coal thickness and overburden depth for each coal zone are then gridded for input into the second program, TONS, which calculates resource tonnages.

TONS accepts as input for each coal zone a net coal thickness grid, an overburden depth or overburden ratio grid, a distance grid (this contains the distance of each grid node from the nearest control point) and the specific gravity of the coal. Resource quantities are calculated and subdivided by coal zone, depth from surface, overburden ratio, seam thickness and distance from control points, into resource categories designated in Energy, Mines and Resources Report ER 79-9. The interested reader is referred to Hughes (in prep.) for a complete discussion of these resource calculation procedures, as the present report addresses only the geological aspects of the Dodds-Round Hill coalfield.

Data verification

In order to ascertain that the initial log interpretations, correlations and subcrop positions accurately reflect the borehole data, several data verification procedures were utilized.

Verification of geophysical log interpretations

Geophysical log interpretations are verified following data input by using LITHLOG to generate a graphic log of the interpretations at the scale of the original geophysical logs. By aligning the interpreted geophysical log and the computer-generated lithology log, data input errors can be readily detected and modified. The consistency of lithologic assignments between boreholes can be checked by posting computer-generated lithology logs with the photographically reduced geophysical logs, when all boreholes are posted for correlation purposes (see previous discussion). If sufficiently distinct colour and symbol patterns are used for each lithologic type on the computer-generated lithology logs, boreholes with anomalous lithologic interpretations can be readily detected.

Subcrop determination and verification

The determination of the line of intersection of a given horizon with the bedrock surface is critical in defining the geometry, areal distribution, and hence resource quantities of coal seams. The initial subcrop position generated by plotting the zero-thickness contour of the isopach grid between the surface in question and the modified bedrock surface, seldom honours all of the subsurface data. This is because only boreholes that penetrated the correlated surface in question are utilized in the construction of its elevation grid, and boreholes that did not penetrate the surface are not considered. In order to modify the subcrop position, so that it does not enclose boreholes that did not penetrate the surface, it is necessary to overlay maps showing the locations of all borehole data, the locations of borehole data penetrating the surface in question, and the position of the computer-generated subcrop line (in order to identify boreholes not penetrating the surface but which are enclosed by its subcrop line). "Dummy" elevation values for the surface can then be inserted for these boreholes, in order to control grid estimation in the subcrop area. After one or two iterations of this process, it is possible to derive a subcrop line that honours all of the borehole data.

Correlation verification

Generation of the best possible correlation framework is also critical to the geological analysis and resource assessment of a coalfield, and also is an iterative process. Isopach grids are initially generated between elevation grids of all correlated surfaces and displayed as contour maps. Rapid variations in thickness or "bull's eyes" on these contour maps identify boreholes that may have erroneous correlations. Correlations can then be modified and a new set of isopach maps generated until an acceptable correlation framework has been created.

Correlated beds may pinch out laterally, or may coalesce with other correlated beds. To accurately define the area encompassed by a correlated bed that pinches out, it is necessary to overlay posting maps of boreholes that penetrated the correlated bed in question and boreholes that penetrated a more widespread, immediately underlying correlated bed. A polygon can then be constructed which separates boreholes that penetrated both units from boreholes that penetrated only the lower unit. This polygon is then used to blank all grid nodes outside the area encompassed by the correlated bed in question. This process was necessary in the present study for the "A", "C", "H" and "I" beds of the Dodds Coal Zone.

GEOMETRY AND DISTRIBUTION OF LITHOLOGIC UNITS

The following discussion examines lateral and vertical lithologic relationships in the Dodds-Round Hill coalfield within the stratigraphic interval extending from 15 m below Marker 1 to 5 m above the Demay "A" bed (Fig. 3). These relationships were defined utilizing isopach, lithology-thickness and lithology-per cent maps, cross-sections and Markov analysis. Although references to possible depositional environments are made in the following discussion, a more complete consideration of the depositional processes responsible for these lithologic relationships is included in a later section.

After a satisfactory correlation framework had been created and verified utilizing the methodology already described, the following procedures were used to determine lateral and vertical lithologic relationships within interseam intervals:

1. Lithologic units between all pairs of adjacent, correlated surfaces were retrieved from the data base, along with lithologic units in the interval 5 m above the Demay "A" bed and the intervals to 5, 10 and 15 m below Marker 1. Data for each stratigraphic interval were stored in separate sequential files.

2. All lithology data files generated in the previous step were processed using PERCENT (see methodology section). Sandstone, siltstone and shale thickness and percentage grids were then generated for each stratigraphic interval and displayed as contour maps.

3. From examination of isopach, lithology thickness and percentage maps of each stratigraphic interval, various sedimentological features were defined. Polygons surrounding boreholes penetrating these sedimentological features were constructed, so that lithology data within and outside each feature could be analysed separately for Markov processes.

4. Grid manipulation was then utilized to build grid models for specific stratigraphic intervals that contain the positions of correlated units and the aggregate lithologic composition of inter-unit rock intervals. These grid models were constructed utilizing both specified correlated surfaces and sea level as datums. The stratigraphic datums chosen were correlated surfaces immediately above or below sedimentological features of interest. Cross-sections through grid models with a stratigraphic datum emphasize lateral lithologic relationships, whereas cross-sections through grid models with a sea level datum emphasize the effect of these lithologic relationships on the present geometry of the correlated surfaces. Grid models were created for the interval from 15 m below Marker 1 to the Dodds "A" bed, using the base of Marker 1 as a datum; for the interval between the Dodds "K" bed and Marker 4, using the top of the Dodds "D" bed as a datum; for the interval from Marker 3 to a level 5 m above the Demay "A" bed, using the base of the Round Hill "D" bed as a datum; and for the interval between

the Round Hill "D" bed and a level 5 m above the Demay "A" bed, using the top of the Dusty "A" bed as a datum (Fig. 3).

5. Within these grid models, longitudinal and transverse cross-sections were constructed through features of sedimentological interest. These cross-sections, together with the lithology-distribution and isopach maps, were very useful in assessing the lateral lithologic relationships of these features, and the effect of these relationships on the geometry of bounding correlated surfaces and on the distribution of lithologies in adjacent stratigraphic intervals.

6. Markov analyses were then performed on sedimentologic features and stratigraphic intervals of interest.

Cross-sections utilized in the following discussion illustrate the position of correlated surfaces relative to a stratigraphic datum and to sea level. They also show the aggregate lithologic composition of the rock intervals between correlated surfaces. The vertical sequence of lithologies shown for any given rock interval on these cross-sections is arbitrary, and was chosen to reflect the predominant character of the interval as determined from Markov analysis (i.e. fining- or coarsening-upward). Rock intervals between zero and 5 m, 5 and 10 m and 10 and 15 m below Marker 1; between Marker 1 and Marker 2; and between the Round Hill Coal Zone and Marker 3, are depicted as coarsening upward. All remaining rock intervals are shown as fining upward. Cross-sections constructed relative to a stratigraphic datum have a vertical exaggeration of 1:190, whereas those constructed relative to sea level have a vertical exaggeration of 1:152.

Interval below Marker 1

The stratigraphic interval below Marker 1 has, because of its depth, less borehole control than any other part of the succession in the coalfield. One hundred and eighty-one boreholes penetrated Marker 1 (Fig. 10), whereas only 23 boreholes penetrated more than 15 m below Marker 1.

The interval from zero to 5 m below Marker 1 is dominated by a linear, northeast-trending sandstone body at least 25 km long and 3 to 5 km wide (Fig. 10). This sandstone caps a coarsening upward sequence in the order of 15 m thick, and grades laterally into an interbedded sequence of siltstone, shale, minor sandstone, thin coal, and concretionary beds. The lateral distribution of sandstone, siltstone and shale associated with this sandstone body is indicated by the three perspective diagrams illustrated in Figure 11. From these diagrams, it can be seen that sandstone comprises nearly 100 per cent of this interval along the axis of the sandstone body, whereas off-axis areas are predominantly siltstone with lesser amounts of shale and from 10 to 30 per cent sandstone.

Geophysical log traces for several boreholes penetrating strata on and off the axis of this sandstone body are illustrated in Figure 12. Boreholes 1, 2 and 3, which penetrated the on-axis area, show a gradational, coarsening-upward sequence grading from shale through interbedded siltstone, shale and minor sandstone to a well defined sandstone, which is abruptly overlain by the bentonitic shales of Marker 1. Strata in off-axis boreholes (boreholes 4, 5, 6; Fig. 12) are characteristically much finer grained, comprising interbedded shales, siltstones and minor sandstones, which commonly show less pronounced coarsening-upward sequences.

Lateral and vertical lithologic relationships along and across this sandstone unit, and within underlying and overlying stratigraphic intervals, are illustrated on the cross-sections shown in Figure 13. From the longitudinal section (cross-section A-D, Fig. 13), it can be seen that the sandstone body is consistently about 5 m thick throughout the central and northeastern portions of the coalfield, where it is underlain predominantly by siltstone. To the southwest, however, this unit thickens to 10 m, and is underlain predominantly by shale and siltstone. On the transverse cross-sections (E-E', F-F', G-G'; Fig. 13), the sandstone body is well defined in the interval from zero to 5 m below Marker 1. Underlying and laterally adjacent strata are predominantly siltstone and shale. On cross-section E-E', however, a second prominent sandstone unit can be seen to have developed in a 5 to 10 m thick interval on the west side of the coalfield. This unit may represent deposits of a distributary that migrated laterally through time and subsequently deposited the sandstone body in the zero to 5 m interval or, alternatively, may have been deposited by a separate, older distributary.

Differential compaction between the relatively uncompactible sandstone along the axis of this unit and the more compactible siltstones and shales in the off-axis areas has resulted in structural drape over the axis in the northeast and southwest portions of the coalfield. A structural relief of up to 7 m over a 5 km interval is apparent on cross-sections E-E' and G-G' (Fig. 13). Sedimentation patterns in overlying stratigraphic intervals, as far upsection as the Dodds "D" bed (see following discussion), suggest that differential compaction associated with this sandstone body also may have influenced sedimentation during later deposition.

Markov analysis was conducted on all lithologic data between zero and 5, zero and 10, and zero and 15 m below Marker 1. Initially, data from each of these stratigraphic intervals were divided into on-axis and off-axis subareas. However, these analyses had a very low significance because of the small number of boreholes involved, and, therefore, all data from each interval were combined. Preferred vertical lithologic transitions and their probabilities, as determined from the difference matrix (see previous discussion), and the total number of beds of each lithologic type are illustrated for each of these stratigraphic intervals in Figure 14. Coarsening-upward trends from shaly siltstone (lithology 3), through sandy siltstone (lithology 2), to medium grained sandstone (lithology 1) are indicated in all intervals. Fining-upward and interbedded trends within the siltstone and shale lithologies (lithologies 2, 3, 4) are also evident, particularly within the zero to 10 and zero to 15 m stratigraphic intervals. Concretions (lithology 5) and coal (lithology 6) are associated with the coarsest grained lithologies (lithologies 1, 2). Markov analysis thus confirms the coarsening-upward and interbedded character observed on the geophysical logs (Fig. 12) for this part of the succession.

Interval between Marker 1 and Marker 2

Marker 1 and Marker 2 are laterally very extensive units that can be recognized in all boreholes that penetrate this part of the section (Fig. 3). They range in composition from bentonitic shale, with a very high response on the natural gamma log, to shale, shaly and, more rarely, silty siltstone. Marker 1 ranges in thickness from 0.5 m to 2.0 m, with an average thickness of 1.16 m (figs. 12, 13). Marker 2, which has an average thickness of about 0.7 m (ranging from 0.2 m to 2.0 m; figs. 12, 13), is separated from Marker 1 by 5 to 8 m of shale, siltstone and minor sandstone throughout the

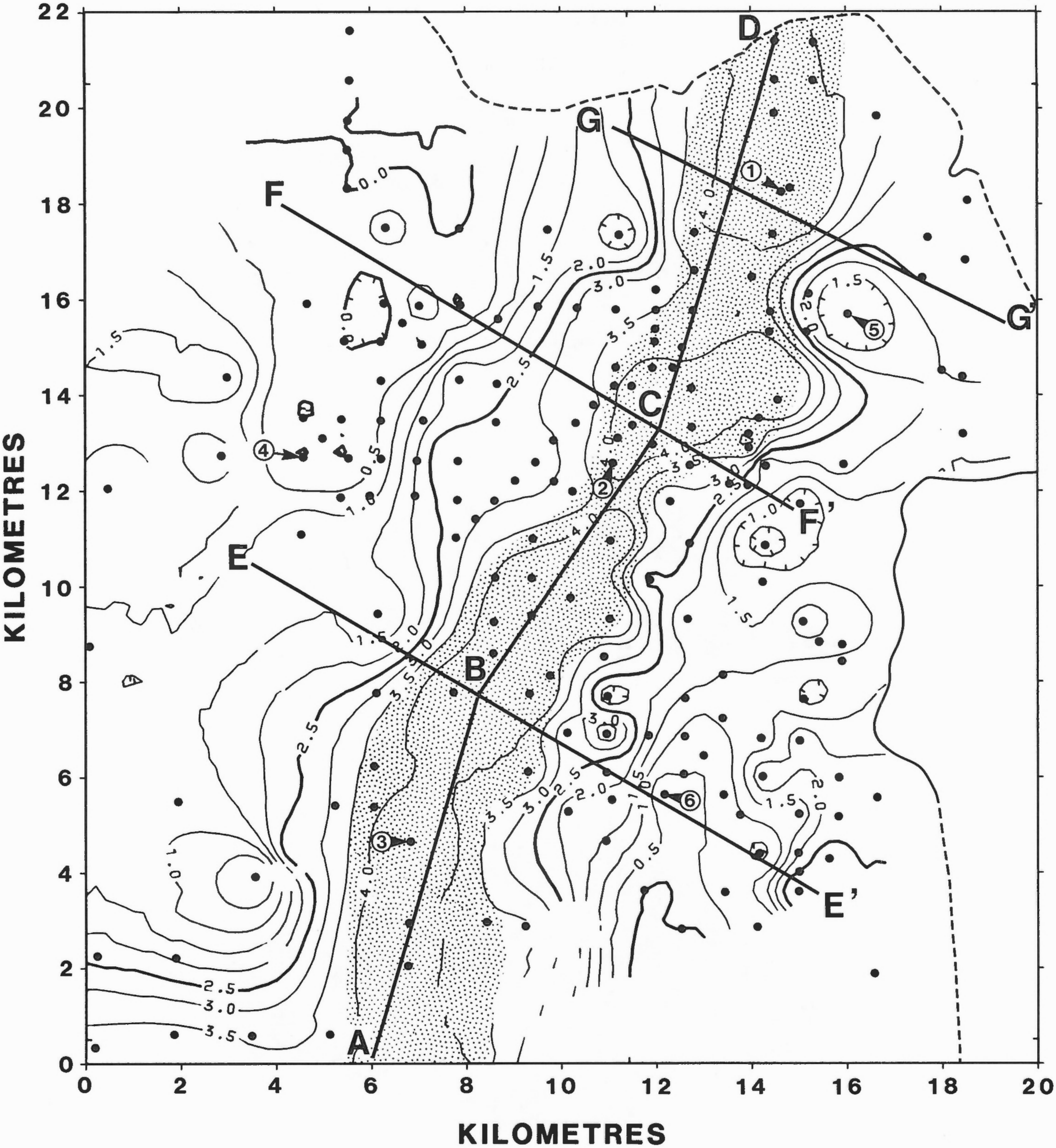


Figure 10. *Aggregate sandstone thickness and borehole control for the interval 0 to 5 m below Marker 1. Stippled area indicates axis of major sandstone body referred to in text. Locations of cross-sections in Figure 13 and boreholes in Figure 12 (numbers) are indicated. Contour interval is 0.5 m.*

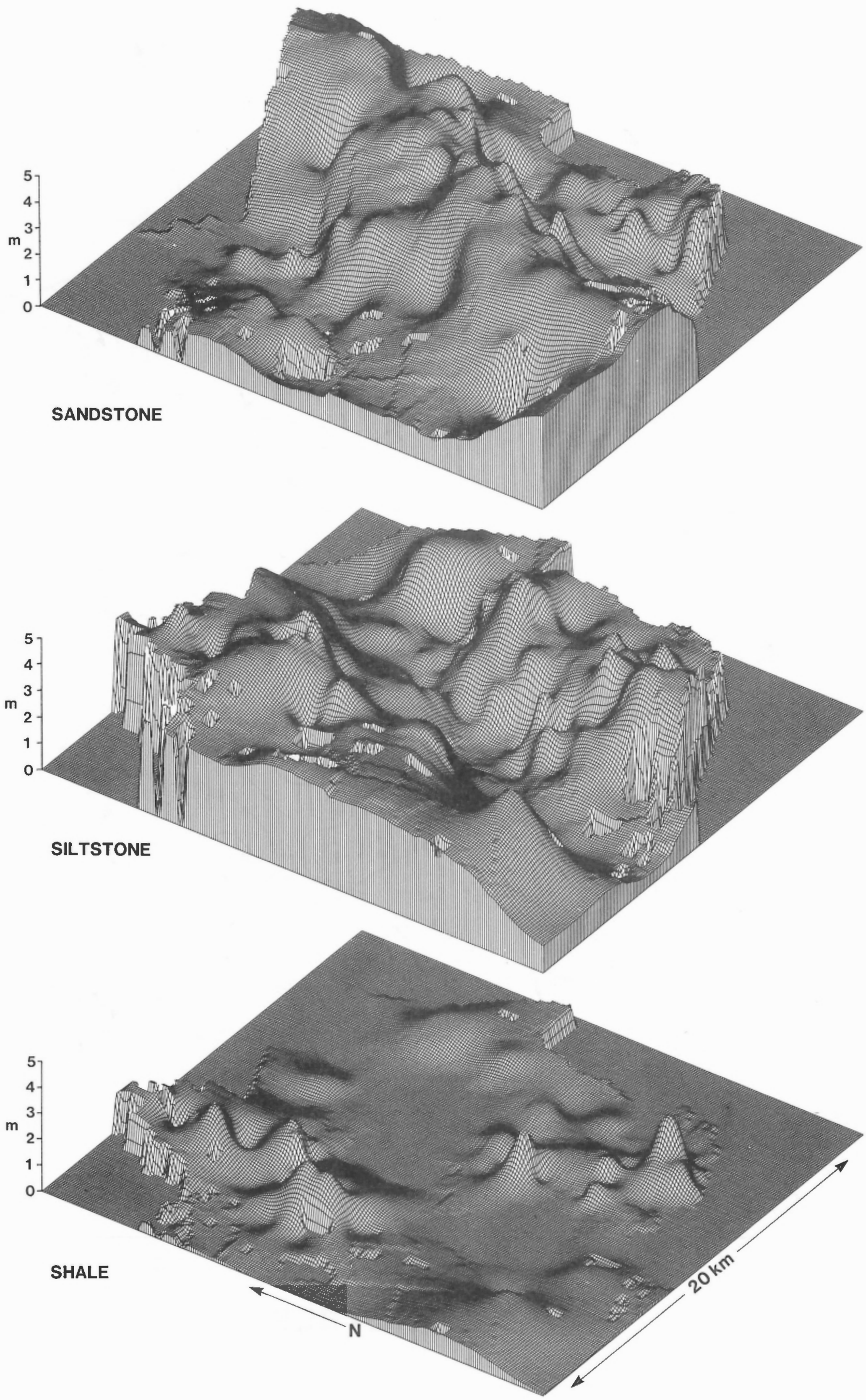


Figure 11. *Perspective diagrams viewed from southwest, illustrating distribution and thicknesses of sandstone, siltstone and shale for the interval 0 to 5 m below Marker 1. Note high concentration of sandstone in on-axis areas and inverse relationship with siltstone and shale between on- and off-axis areas (see text).*

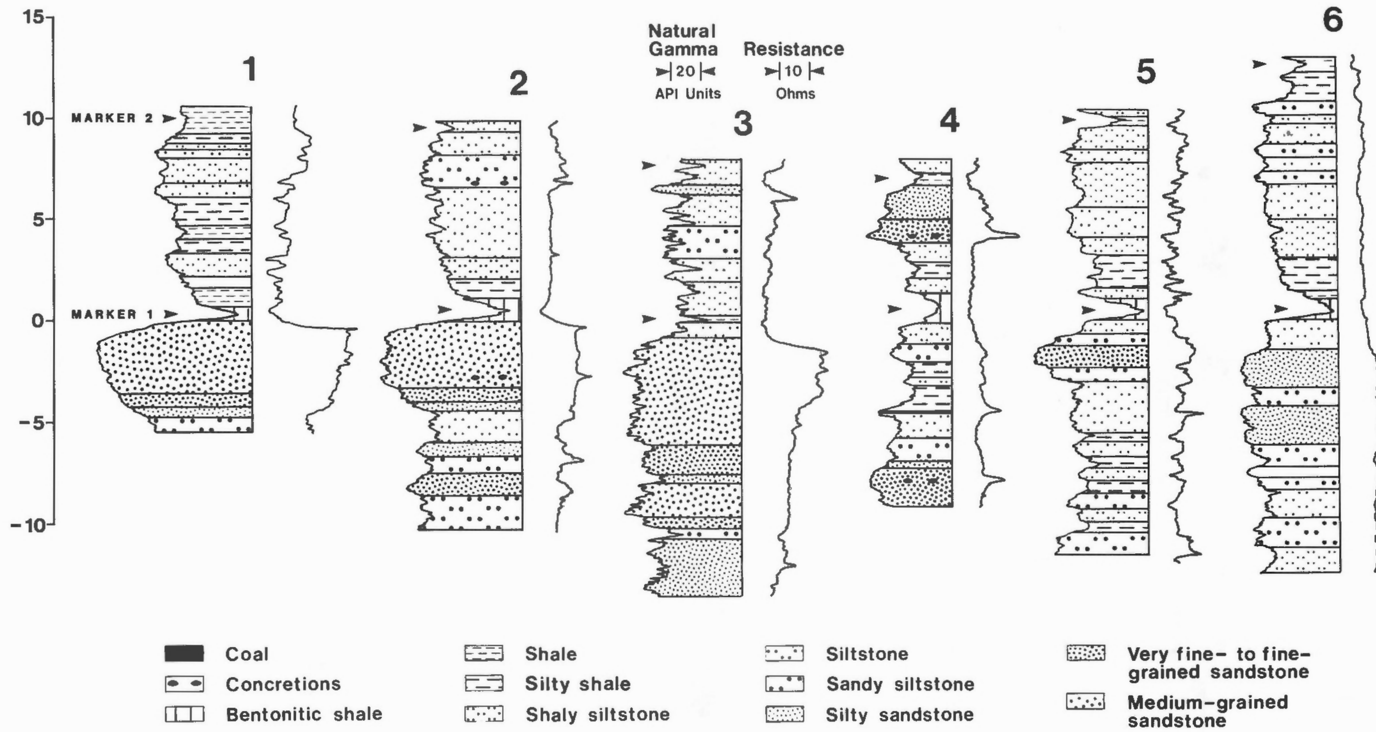


Figure 12. *Geophysical log responses and interpretations below Marker 2 for boreholes located on-axis (1, 2, 3) and off-axis (4, 5, 6) of the sandstone body below Marker 1. 0 m = base of Marker 1. See Figure 10 for borehole locations.*

central and western portions of the coalfield (Fig. 15). This interval increases to more than 17 m in thickness along a linear, north- to northeasterly-trending area about 15 km long and one to two kilometres wide in the eastern portion of the coalfield (Fig. 15).

The sandstone component of this interval is restricted almost entirely to the western part of the coalfield. The sandstone per cent map illustrated in Figure 16 shows a linear north- and northeasterly-trending area of high sandstone concentration, 2 to 4 km wide, which extends for more than 15 km across this part of the coalfield. The eastern limit of this area of high sandstone concentration roughly corresponds to the western edge of the sandstone body underlying Marker 1 (stippled pattern on Fig. 16). Strata in the area immediately above this sandstone body contain almost no sandstone. This suggests that differential compaction may have created a topographically high area over the axis of the sandstone body which limited the southeastward migration of the small channel or distributary system that elsewhere may have deposited the sandstone within the Marker 1 to Marker 2 interval. The interrelationship of sandstone distribution between these intervals can also be seen on cross-sections E-E', F-F' and G-G' in Figure 13.

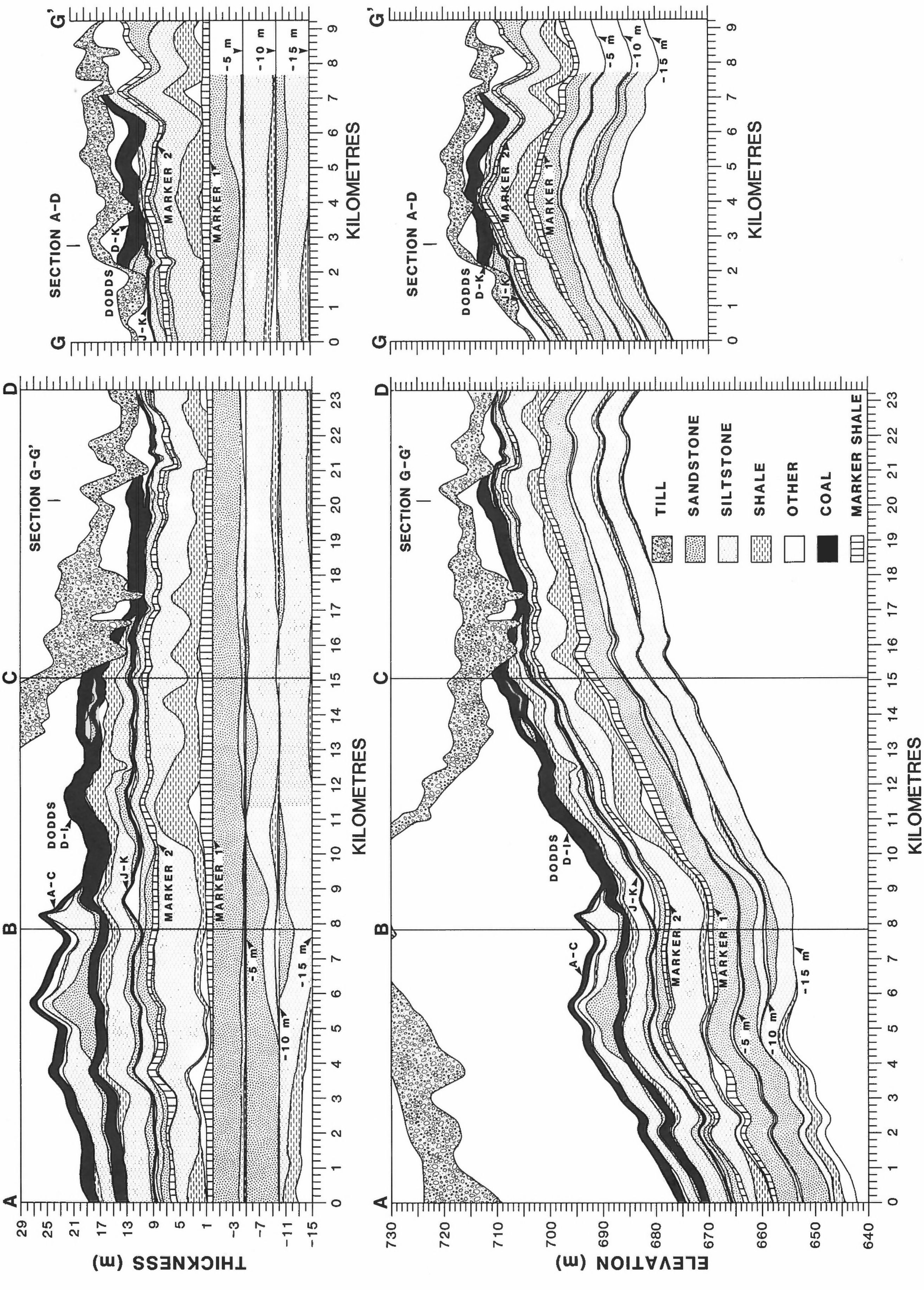
Lithologic relationships along and across the linear zone of thickening within this stratigraphic interval in the eastern part of the coalfield are illustrated on the cross-sections in Figure 17. Perspective diagrams of isopach and lithology-thickness data for this feature and immediately surrounding areas are illustrated in Figure 18. Although boreholes providing lithologic data on this feature are sparse, and resolution is hindered by its close proximity to the subcrop of Marker 2 (Fig. 16), several characteristics are evident:

1. Lithologic composition is predominantly siltstone with lesser amounts of shale and only minor amounts of sandstone.

2. The feature exerts strong control on the present structural geometry of Marker 2 and the overlying Dodds Coal Zone (cross-sections F-F', G-G', H-H'; Fig. 17).

3. The feature may have controlled sedimentation patterns during deposition of the overlying Dodds Coal Zone and intervening strata, as partings within this interval pinch out over its axis on cross-sections G-G' and H-H' (Fig. 17). This control appears to have been limited to the area between A and C on Figure 15 and cross-section A-E (Fig. 17), as a large rock parting exists within the Dodds Coal Zone over this feature between points C and E.

Preferred vertical lithologic transitions and their probabilities were determined from Markov analysis of all lithologic data within this interval. In Figure 19, a predominant coarsening-upward trend from shaly siltstone (lithology 3) through sandy siltstone (lithology 2) to sandstone (lithology 1) is indicated, as is a fining-upward trend between shaly siltstone (lithology 3) and shale (lithology 4). Concretionary units (lithology 5) and the few coal beds (lithology 6) in this sequence are associated with the coarsest grained lithologies (lithologies 1, 2). The coarsening-upward character of this interval is indicated also by most geophysical log traces (e.g. Fig. 12), and its predominantly shaly and silty lithologic composition is apparent from the relative abundance of each lithology, as illustrated in Figure 19.


A
B
C
D
G
G'
THICKNESS (m)
ELEVATION (m)
KILOMETRES
SECTION G-G'
SECTION A-D
A-C
DODDS
D-I
D-K
J-K
MARKER 2
MARKER 1
-5 m
-10 m
-15 m
TILL
SANDSTONE
SILTSTONE
SHALE
OTHER
COAL
MARKER SHALE

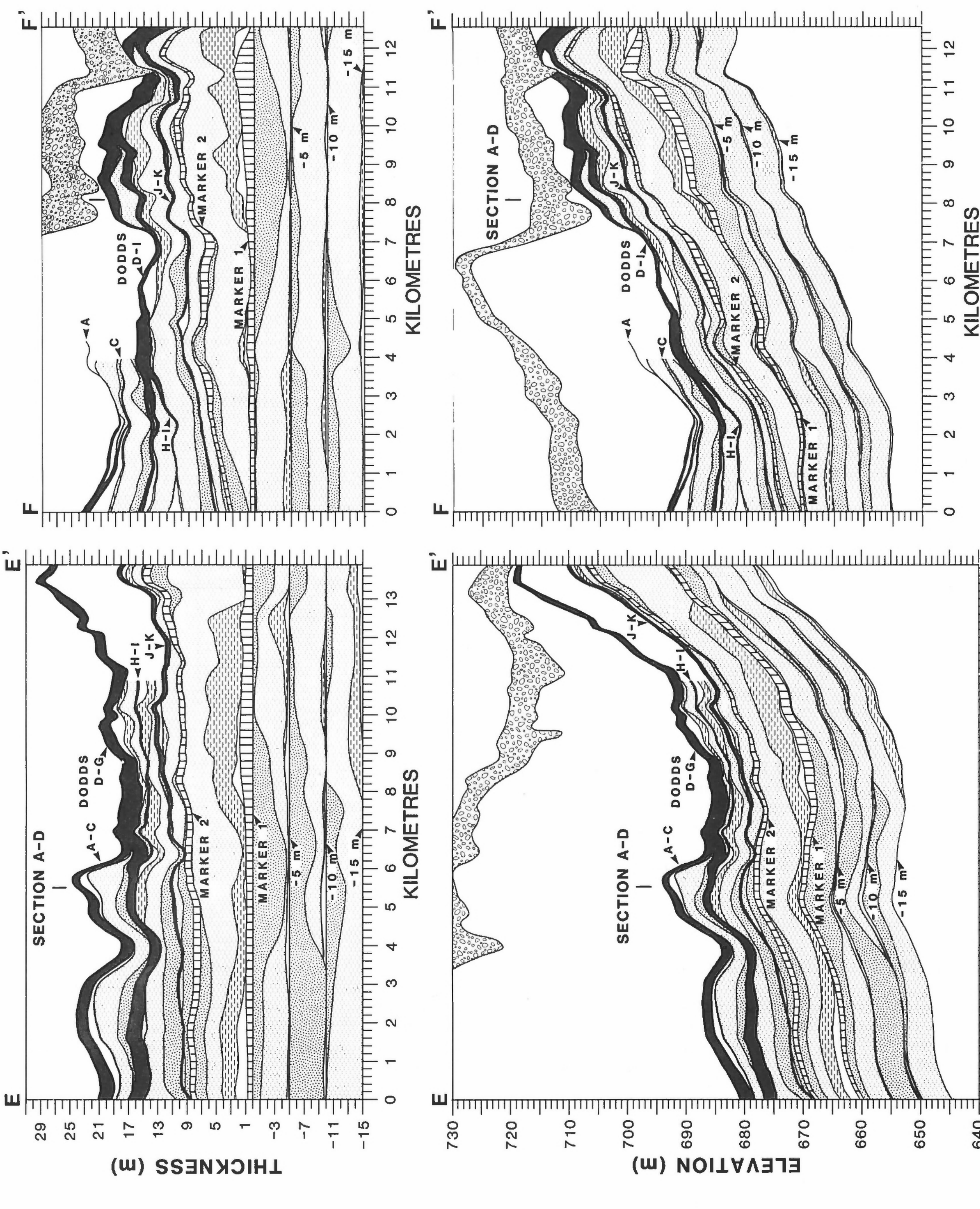


Figure 13. *Cross-sections constructed parallel (A-D) and perpendicular (E-E', F-F', G-G') to the axis of the sandstone body below Marker 1 (see text). Correlated surfaces between 15 m below Marker 1 and the top of Dodds "A" bed and the aggregate lithologic composition of intervals between surfaces are shown. See Figure 10 for locations. Note prominent structural drape over sandstone body on traverse, structural (lower) cross-sections. The base of Marker 1 is used as a datum for the upper cross-sections.*

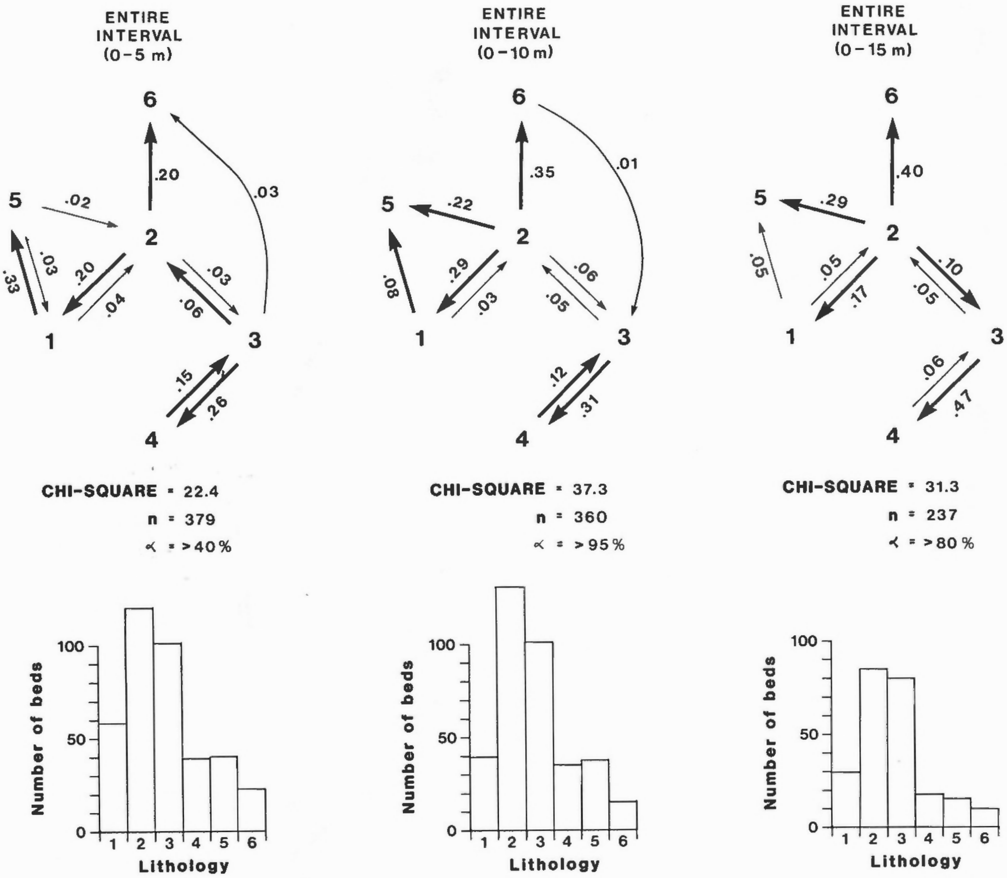


Figure 14. Markov analysis and lithologic composition of intervals between 0 and 5 m, 0 and 10 m, and 0 and 15 m below Marker 1. See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).

Interval between Marker 2 and Dodds Coal Zone

Marker 2 is separated from the Dodds Coal Zone by one to four metres of predominantly silty and shaly sediments throughout most of the coalfield (figs. 3, 13, 17). Northeasterly trending, linear zones of thickening do occur in the northeastern part of the field, however, and the interval thins to less than one metre in the extreme southeastern part of the field (cross-section A-E; Fig. 17).

The aggregate sandstone thickness map for this interval, shown in Figure 20, defines a linear concentration of sandstone that trends north to northeast in the southwestern and west-central portions of the coalfield, and east to northeast in the north-central portion. This pattern of sandstone distribution is similar to that in the underlying Marker 1 to Marker 2 interval (Fig. 16), as sandstone accumulations are restricted to the area west of the axis of the sandstone body beneath Marker 1 (stippled area in Fig. 20). This suggests that the sandstone body below Marker 1 also may have exerted some control on sedimentation patterns within this interval.

Preferred vertical lithological transitions for this stratigraphic interval (Fig. 21) include a strong coarsening-upward tendency from shaly siltstone (lithology 3), through sandy siltstone (lithology 2), to sandstone (lithology 1), and a predominantly fining upward tendency between shaly siltstone and shale (lithology 4). Concretionary horizons (lithology 5) are associated with the coarsest grained lithologies. The overall abundance of each lithology, as indicated in Figure 21, illustrates the predominantly silty character of this interval.

Dodds Coal Zone

The Dodds Coal Zone comprises the thickest and most widespread coal zone in the coalfield. The zone contains up to 11 separate seams over a stratigraphic interval of between 2 and 17 m in thickness. Over much of the western and central parts of the coalfield the zone is represented by three major seams, termed "A-C", "D-I", and "J-K". In the northeastern part of the field, seams "D-I" and "J-K"

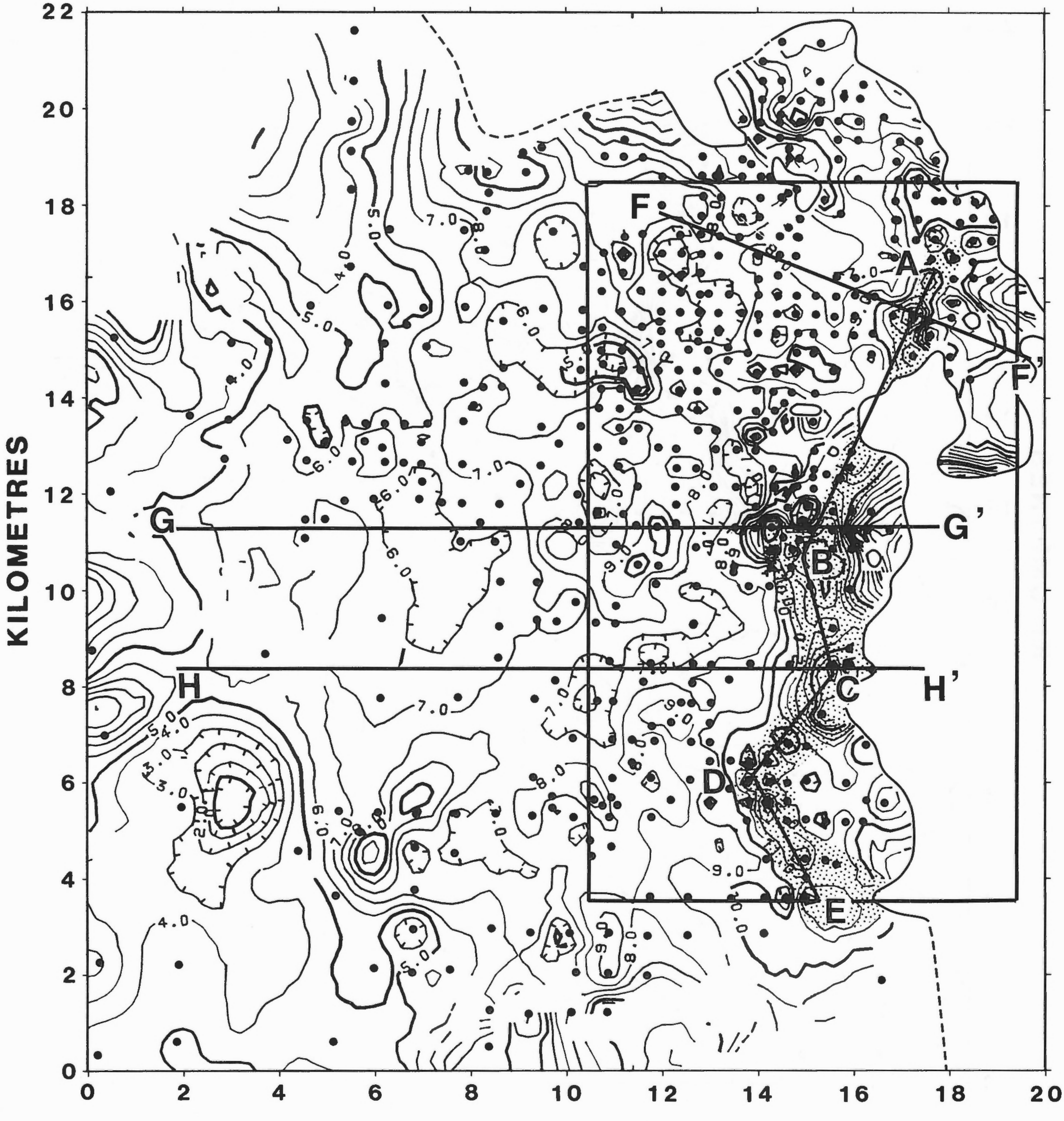


Figure 15. *Isopach map of the interval between Marker 1 and Marker 2. Boreholes penetrating Marker 2 are posted. Stippled area indicates location of zone of thickening discussed in text. Also shown are the locations of cross-sections illustrated in Figure 17 and perspective diagrams (rectangle) in Figure 18. Contour interval is 1 m.*

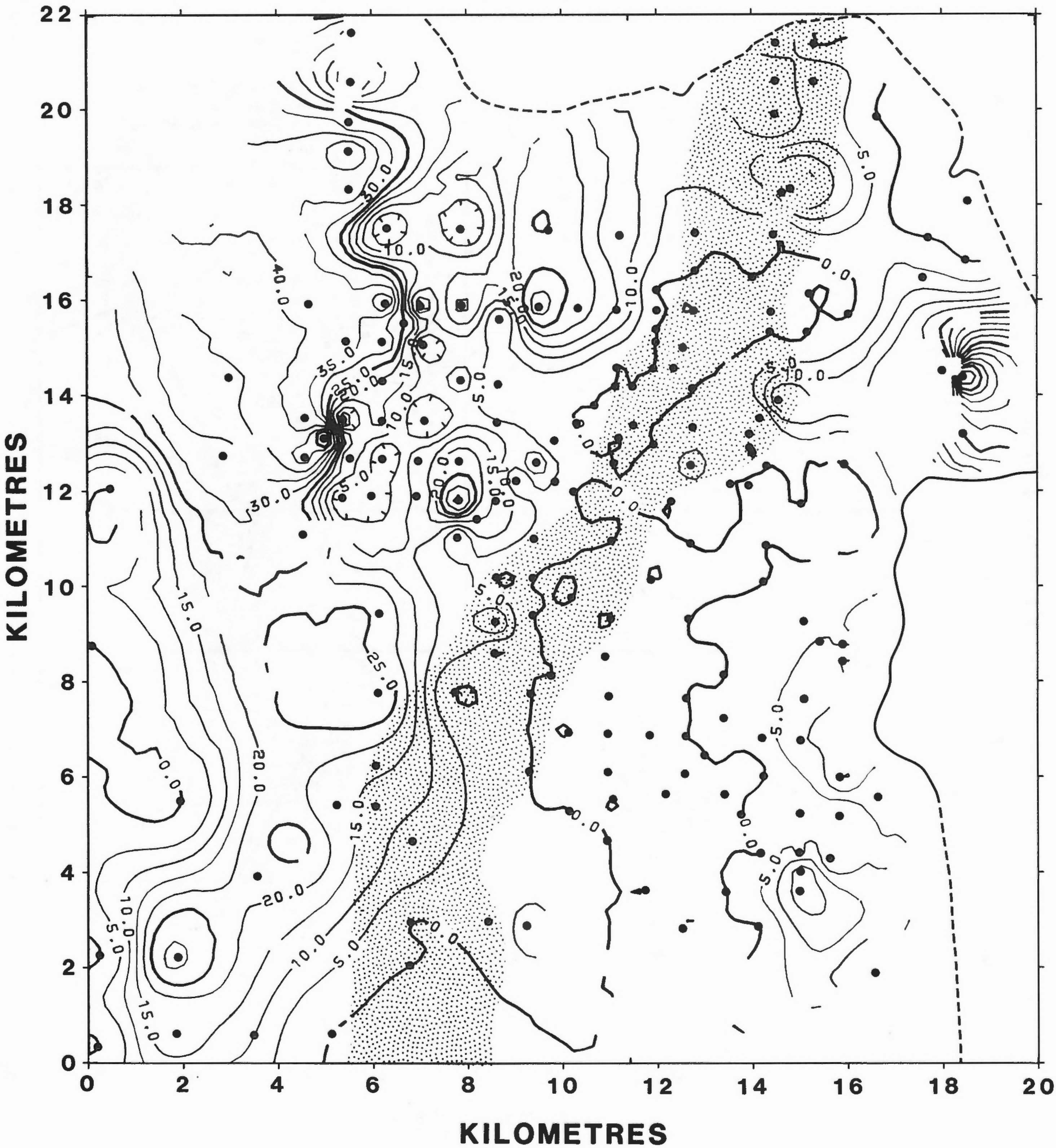


Figure 16. Aggregate sandstone percentage map for the interval between Marker 1 and Marker 2. Boreholes penetrating Marker 1 are posted. Stippled area indicates position of sandstone body below Marker 1 (see text). Contour interval 5 per cent.

coalesce, forming a single coal seam from 2 to 3 m thick (cross-sections A-A', B-B', F-F'; Fig. 5). In the central and southern parts of the field, seams "A-C" and "D-I" coalesce to the east forming a single seam up to 3 m thick (cross-sections B-B', C-C', D-D'; Fig. 5). To the north, however, seams "A-C" is split by an eastward-thickening rock parting and pinches out several metres above the "D-I" seam (cross-sections A-A', E-E'; Fig. 5). The regional interrelationships and thickness variation of coal seams within the Dodds Coal Zone are illustrated on cross-sections in figures 5, 13, and 17, as well as on cross-sections included later in this section.

The geometry and lithologic relationships within the major rock partings between Dodds "I" and "J" beds, "G" and "H" beds and "C" and "D" beds, are discussed in more detail below. Other rock partings that occur within the Dodds Coal Zone in various parts of the coalfield are thin, predominantly fine grained (shale and siltstone), and laterally discontinuous and, therefore, were not studied in detail, although their lithologic composition and geometry can be seen on several of the above-mentioned cross-sections.

"I-J" rock parting

The rock parting between Dodds "I" and "J" beds is present throughout all but the northeastern portion of the coalfield, where it abruptly pinches out along a north-trending line (Fig. 22). In the southeastern part of the coal-field, the "H-I" coal bed defining its upper limit pinches out to the east, and this rock parting becomes part of a thicker unit between Dodds "G" and "J" beds.

The "I-J" parting ranges between 4 and 6 m in thickness over much of the central and western parts of the coalfield and thins, over a distance of 1 to 3 km, to its pinch-out in the northeast and east (Fig. 22). In the east-central part of the field, the position of this pinch-out appears to be controlled by the linear zone of thickening in the underlying Marker 1 to Marker 2 interval, as can be seen on cross-sections G-G' and H-H' in Figure 17. Farther north, however, the position of the pinch-out lies 4 to 5 km west of the underlying feature and, there, is apparently unrelated to it (cross-section F-F'; Fig. 17).

The overall lithologic composition of this stratigraphic interval is predominantly siltstone with lesser amounts of shale and sandstone. The lateral distribution of these lithologies can be seen on the cross-sections in figures 13 and 17 and on the aggregate sandstone thickness map shown in Figure 24. This map indicates that sandstone within the "I" to "J" parting is restricted primarily to the west-central and western parts of the coalfield, in a pattern similar to that observed in the underlying Marker 1 to Marker 2 interval. A linear zone of relatively thick sandstone, which trends north in the southwestern part of the coalfield and east to northeast in the north-central portion, can be seen also in Figure 24. The eastern limit of this zone of thick sandstone corresponds approximately with the western limit of the sandstone body underlying Marker 1 (stippled area in Fig. 24). This relationship is illustrated also on cross-sections E-E' and F-F' in Figure 13. In the north-central part of the coalfield, both the eastern limit of this sandstone concentration and the pinch-out of the "I-J" rock parting coincide with the western limit of the underlying sandstone body (Fig. 24; cross-section G-G', Fig. 13). These relationships suggest that differential compaction between the sandstone body below Marker 1 and laterally adjacent sediments may have created a topographic high, which exerted some control on sedimentation patterns during deposition of the "I-J" parting.

Markov analysis of this interval (Fig. 23) indicates fining-upward tendencies from sandy siltstone (lithology 2), through shaly siltstone (lithology 3), to shale (lithology 4) and coal (lithology 6), and coarsening-upward tendencies between sandy siltstone and sandstone. Concretions (lithology 5) are predominantly associated with fine grained lithologies (lithologies 2, 3).

"G-H" rock parting

The rock parting between the Dodds "G" and "H" coal beds is restricted primarily to the northwest and southeast portions of the coalfield, as illustrated in figures 25 and 26. The parting in both areas has a distinctly wedge-shaped geometry, thickening from northeast-trending pinch-out lines to more than 6 m in thickness (figs. 25-26). The "H-I" coal bed, which defines the parting's lower limit, pinches out to the southeast, and the "G-H" parting becomes part of a thicker unit between Dodds "G" and "J" beds.

The distribution and geometry of the "G-H" parting in the southeastern portion of the coalfield appears to have been controlled in part by the distribution of the sandstone body underlying Marker 1 (stippled area on Fig. 25), as the pinch-out line of this parting coincides with the axis of the underlying sandstone body in the central and southern parts of the field.

The overall lithologic composition of the "G-H" rock parting (Fig. 27) is more shaly than the underlying "I-J" parting. Its lithologic composition tends to become coarser grained in the direction of thickening, as illustrated on cross-section E-E' in Figure 13, and on cross-sections H-H', J-J', and K-K' in Figure 28. Preferred vertical lithologic transitions illustrated in Figure 27 include considerable interbedding between lithologies. Concretions are associated with shaly siltstone (lithology 3) and the few coal beds present are preferentially underlain by shale (lithology 4).

"C-D" rock parting

The Dodds "C-D" parting is restricted to the western part of the coalfield, where it ranges from 2 to 6 m in thickness (Fig. 29). In the central and southern parts of the field this parting abruptly pinches out to the east, and coal beds "C" and "D" coalesce (cross-sections I-I', J-J', K-K', Fig. 28; Fig. 29). In the north-central part of the field, coal beds "A", "B" and "C" are separated by rock partings and pinch out several metres above the Dodds "D" bed (cross-sections A-G, H-H'; Fig. 28), and the "C-D" parting is, therefore, not mappable in that area.

A prominent, north-trending, linear zone of thickening is evident within the Dodds "C-D" parting immediately west of the pinch-out line that marks its eastern limit (Fig. 29). The cross-sections in Figure 28 have been constructed along and perpendicular to this linear feature to illustrate lateral relationships in lithology and geometry associated with it, and with adjacent stratigraphic intervals. The perspective diagrams in Figure 30 illustrate the aggregate thickness and lateral distribution of lithologies within and adjacent to this linear feature. From these figures, it is evident that there is a large concentration of sandstone and siltstone along the axis of this feature relative to off-axis areas to the west. Geophysical logs from boreholes that penetrated on- and off-axis areas are illustrated in Figure 31. On-axis boreholes comprise predominantly fining-upward sequences grading from medium- to coarse-grained sandstone to sandy siltstone and siltstone, whereas off-axis boreholes comprise a thinner, interbedded sequence of shale, siltstone and minor sandstone.

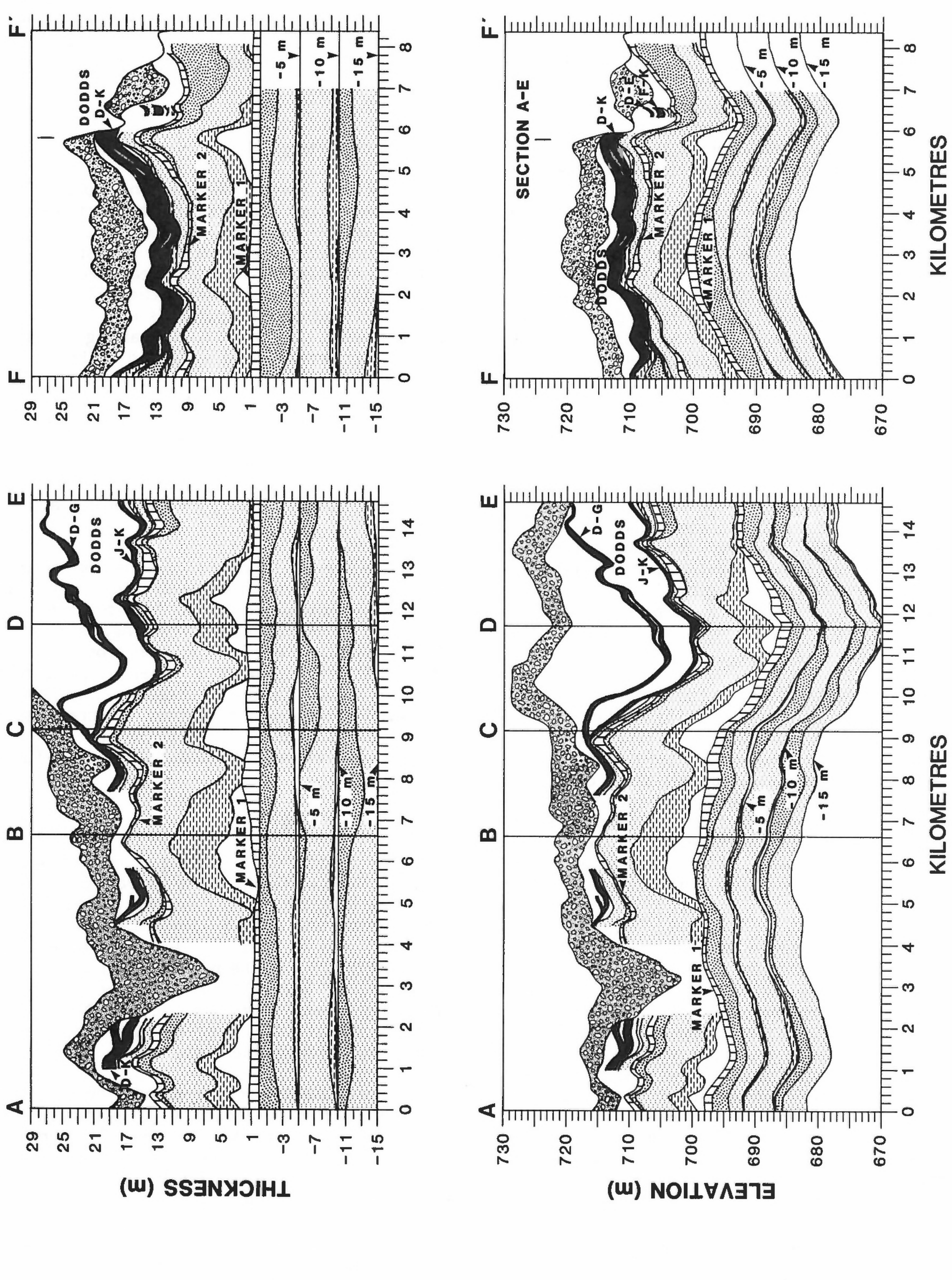
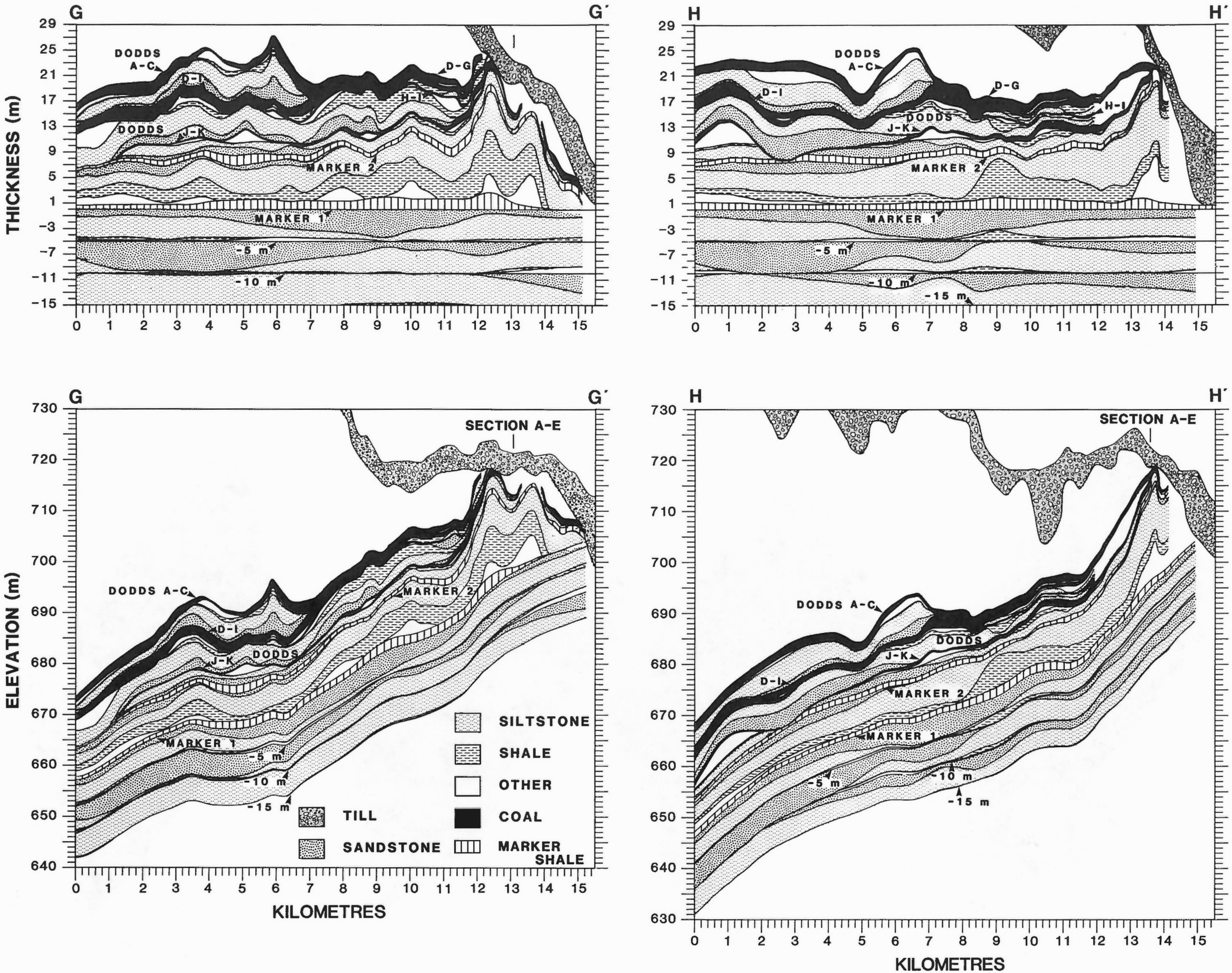


Figure 17. Cross-sections constructed parallel (A-E) and perpendicular (F-F', G-G', H-H') to the axis of the zone of thickening between Marker 1 and Marker 2 (see text). Correlated surfaces for the interval from 15 m below Marker 1 to the Dodds "A" bed, and the aggregate lithologic composition between surfaces are shown. See Figure 15 for locations. The base of Marker 1 is used as a datum for the upper cross-sections.


G
G′
H
H′
THICKNESS (m)
ELEVATION (m)
DODDS A-C
D-I
D-G
H-I
DODDS
J-K
MARKER 2
MARKER 1
-5 m
-10 m
-15 m
SECTION A-E
SILTSTONE
SHALE
OTHER
COAL
MARKER SHALE
TILL
SANDSTONE
KILOMETRES

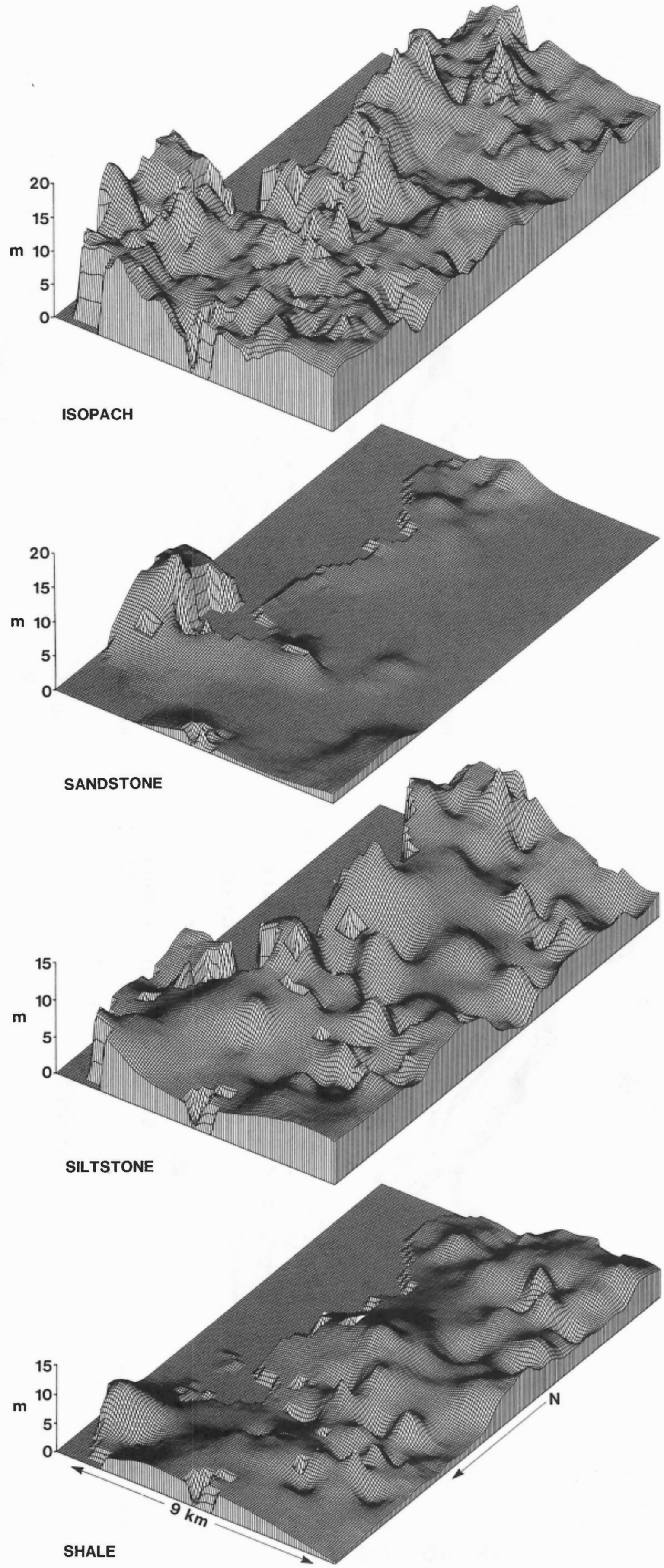


Figure 18. *Perspective diagrams viewed from northwest, illustrating variations in total thickness and aggregate sandstone, siltstone and shale thickness associated with the linear zone of thickening between Marker 1 and Marker 2 (see text). See Figure 15 for location.*

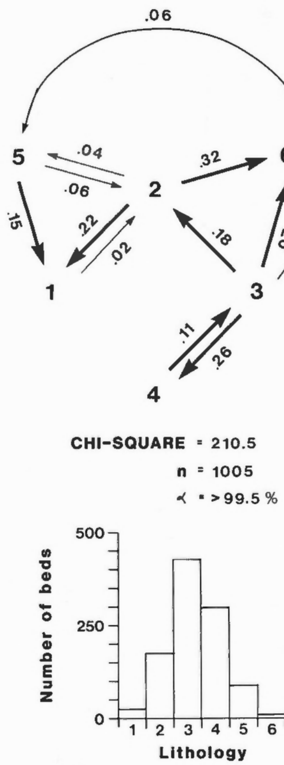


Figure 19. *Markov analysis and lithologic composition of the interval between Marker 1 and Marker 2. See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).*

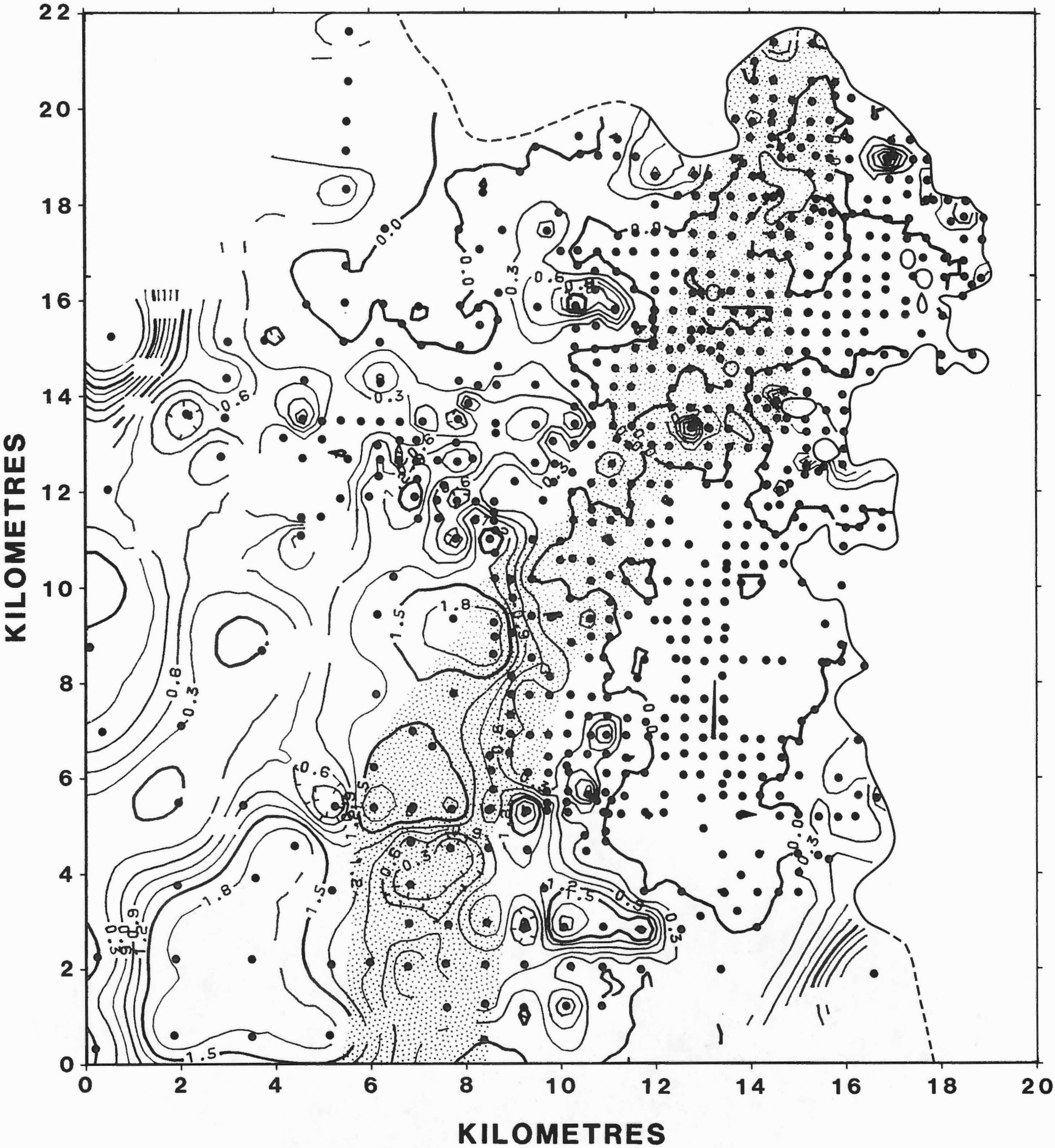


Figure 20. *Aggregate sandstone thickness and borehole control for the interval between Marker 2 and the Dodds Coal Zone. Stippled area indicates location of sandstone body below Marker 1 (see text). Contour interval is 0.3 m.*

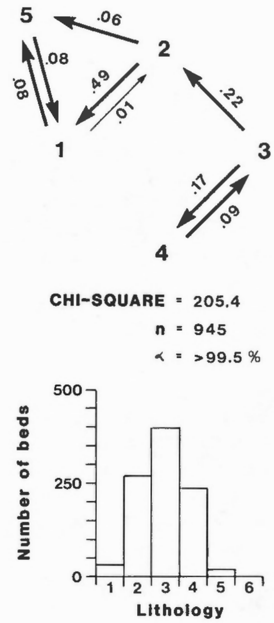


Figure 21. *Markov analysis and lithologic composition of the interval between Marker 2 and the Dodds Coal Zone. See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).*

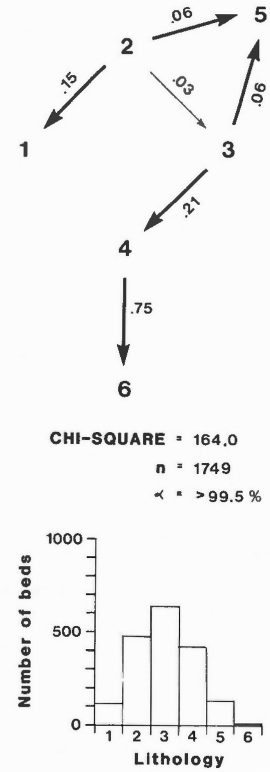
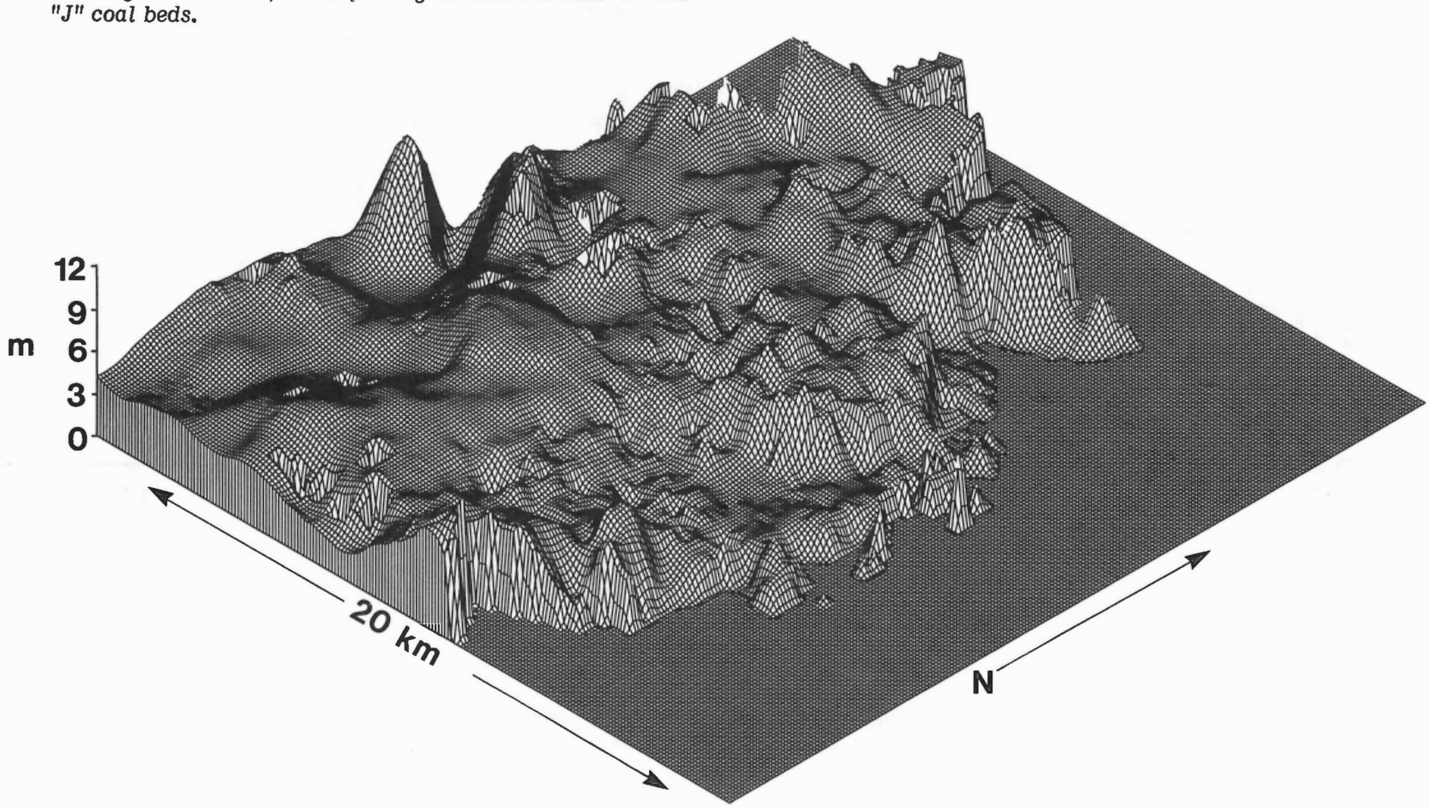


Figure 23. *Markov analysis and lithologic composition of the rock parting between the Dodds "I" and "J" coal beds. See Table 2 for lithologic units represented by each lithologic identifer. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).*

Figure 22. *Perspective diagram viewed from southeast showing thickness of rock parting between Dodds "I" and "J" coal beds.*



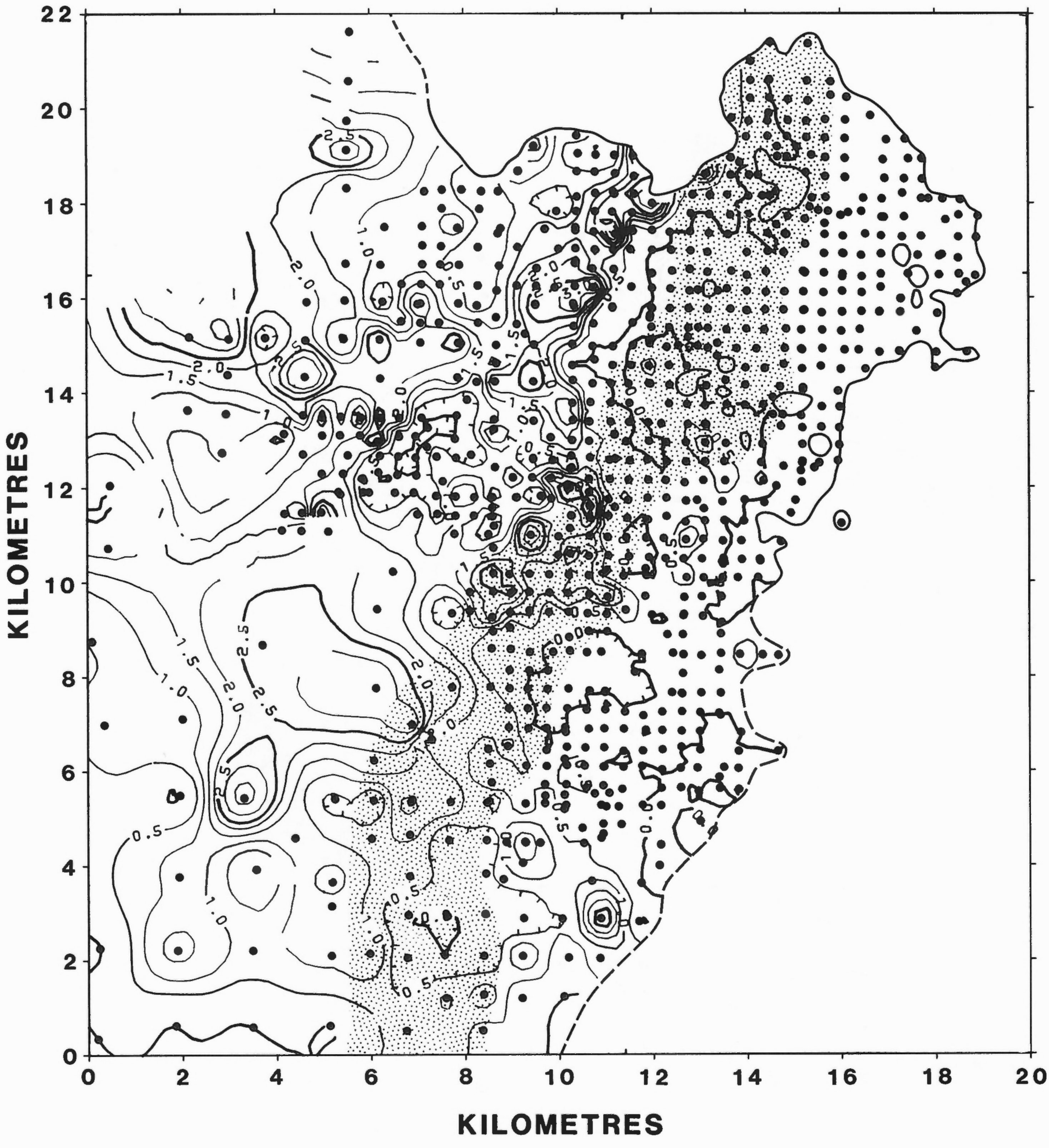


Figure 24. Aggregate sandstone thickness and borehole control within the rock parting between the Dodds "I" and "J" coal beds. Stippled area indicates location of sandstone body below Marker 1 (see text). Contour interval is 0.5 m.

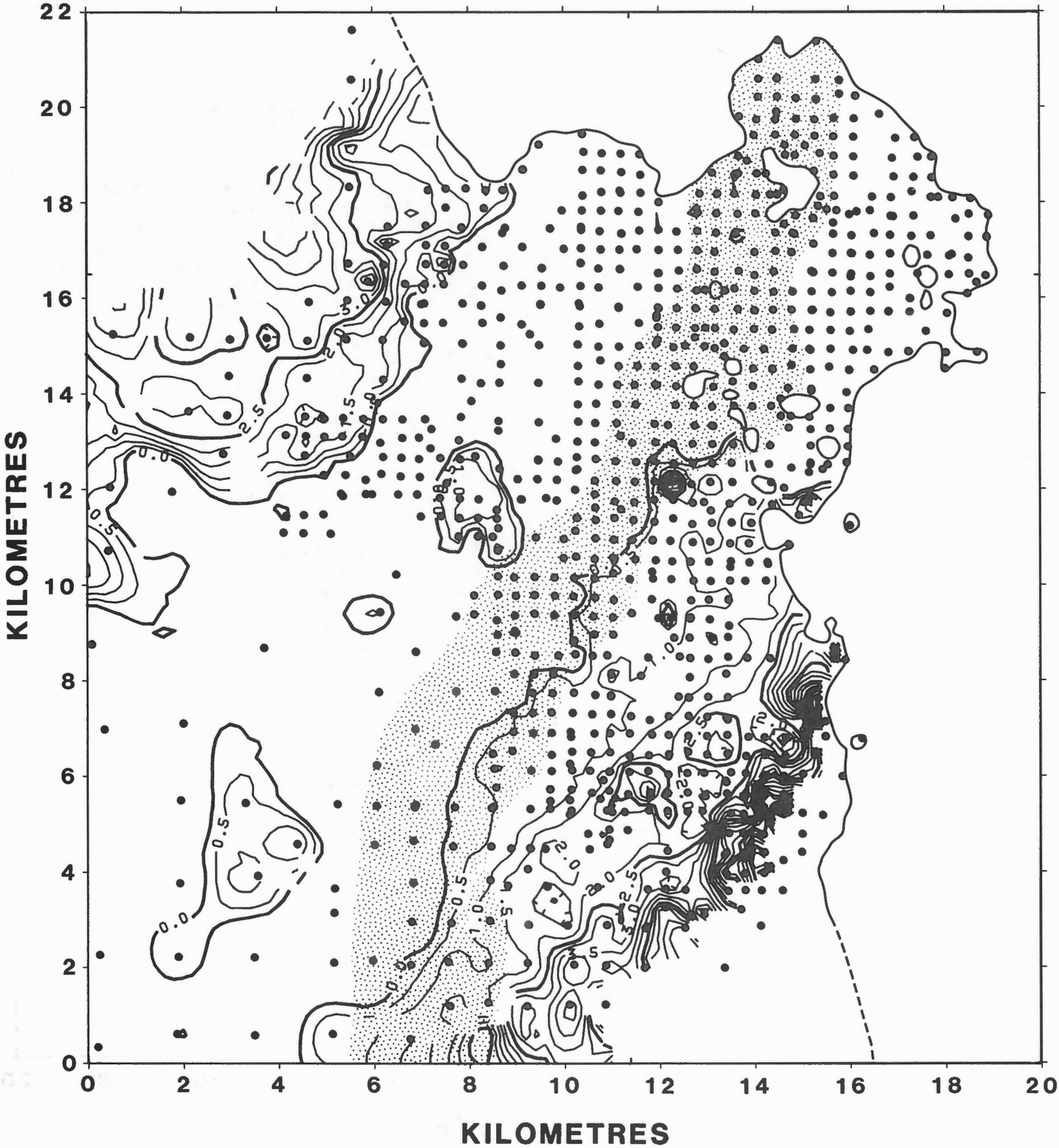


Figure 25. Isopach map of rock parting between the Dodds "G" and "H" coal beds. Stippled area indicates location of sandstone body below Marker 1. Contour interval is 0.5 m.

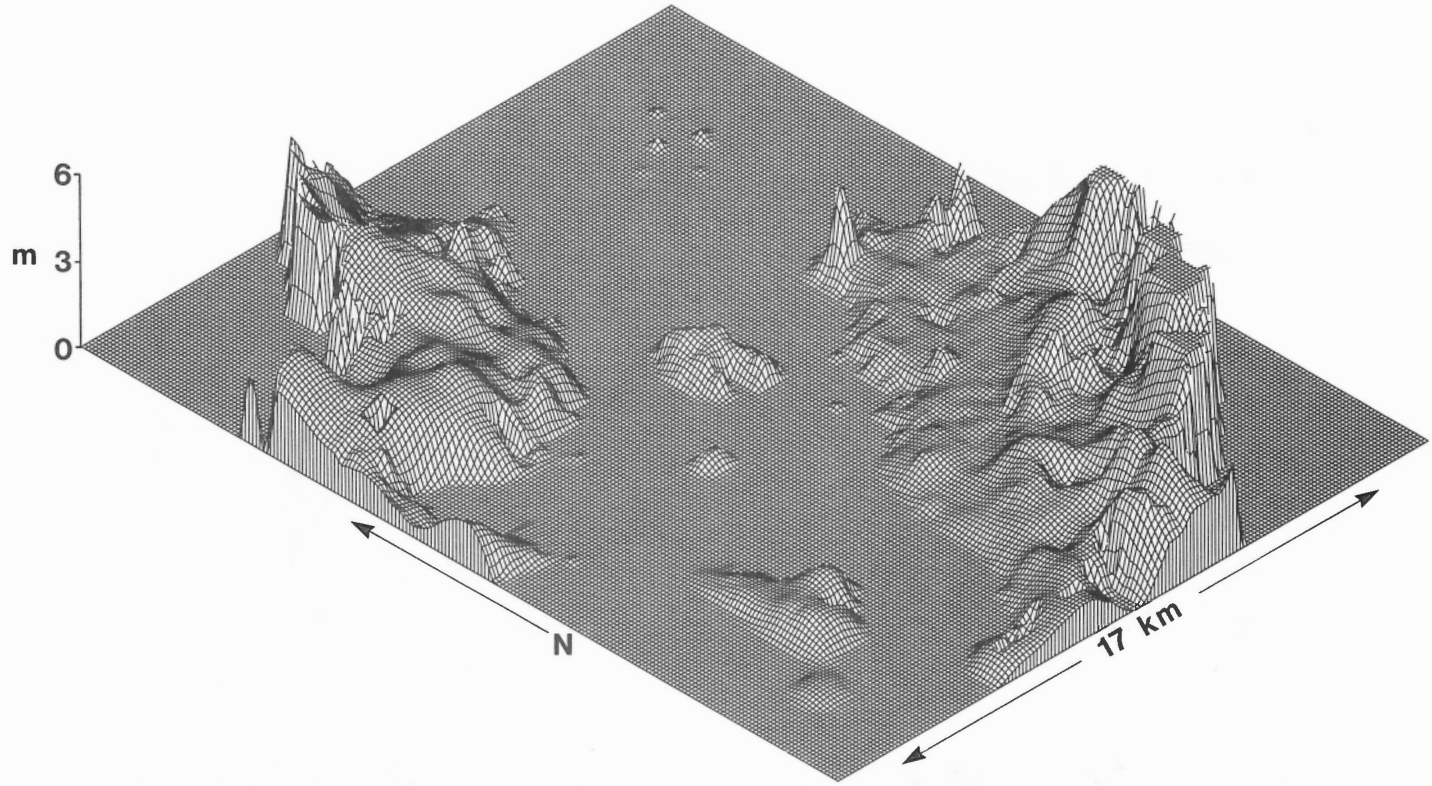


Figure 26. Perspective diagram viewed from southwest of the thickness of the rock parting between Dodds "G" and "H" coal beds. Note wedge-shaped geometry and linear character of pinch-out lines.

Differential compaction between on-axis areas of high sandstone concentration and adjacent, off-axis, finer grained areas is reflected by structural drape over the on-axis areas. A structural relief of more than 5 m is evident on overlying surfaces as high as Marker 4 on cross-section J-J' in Figure 28, and as high as the Burnstad Coal Zone on cross-section D-D' in Figure 5. In the southern part of the field, where there is less contrast in the sandstone concentration between on- and off-axis areas, there is relatively little structural drape over this feature (cross-section K-K', Fig. 28).

Markov analysis was performed separately for boreholes penetrating the axis of this linear feature (stippled area on Fig. 29) and for boreholes penetrating the off-axis areas. The analysis for the on-axis boreholes has a relatively low significance because of the small number of transitions involved (Fig. 32). A fining-upward tendency is apparent, however, between sandy siltstone (lithology 2), shaly siltstone (lithology 3) and shale (lithology 4), and a coarsening-upward tendency is evident between sandy siltstone (lithology 2) and sandstone (lithology 1). Off-axis boreholes show a similar fining-upward tendency between sandy siltstone and shale, but show no interrelationships between silty sandstone and sandstone (Fig. 32). Concretionary units in the case of both analyses are associated primarily with silty sandstone (lithology 2). The coarser grained character of on-axis as compared to off-axis areas is indicated by the relative abundance of lithologies in each area illustrated in Figure 32.

The geometry, distribution and lithologic relationships within the Dodds "C-D" parting bear no apparent relationship to underlying sedimentological features, as was noted in the discussion of some of the underlying stratigraphic intervals.

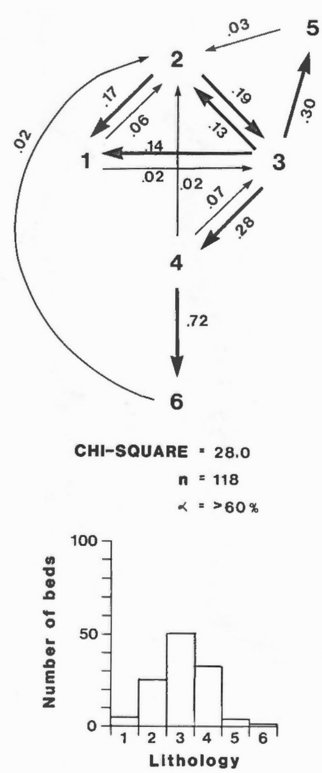
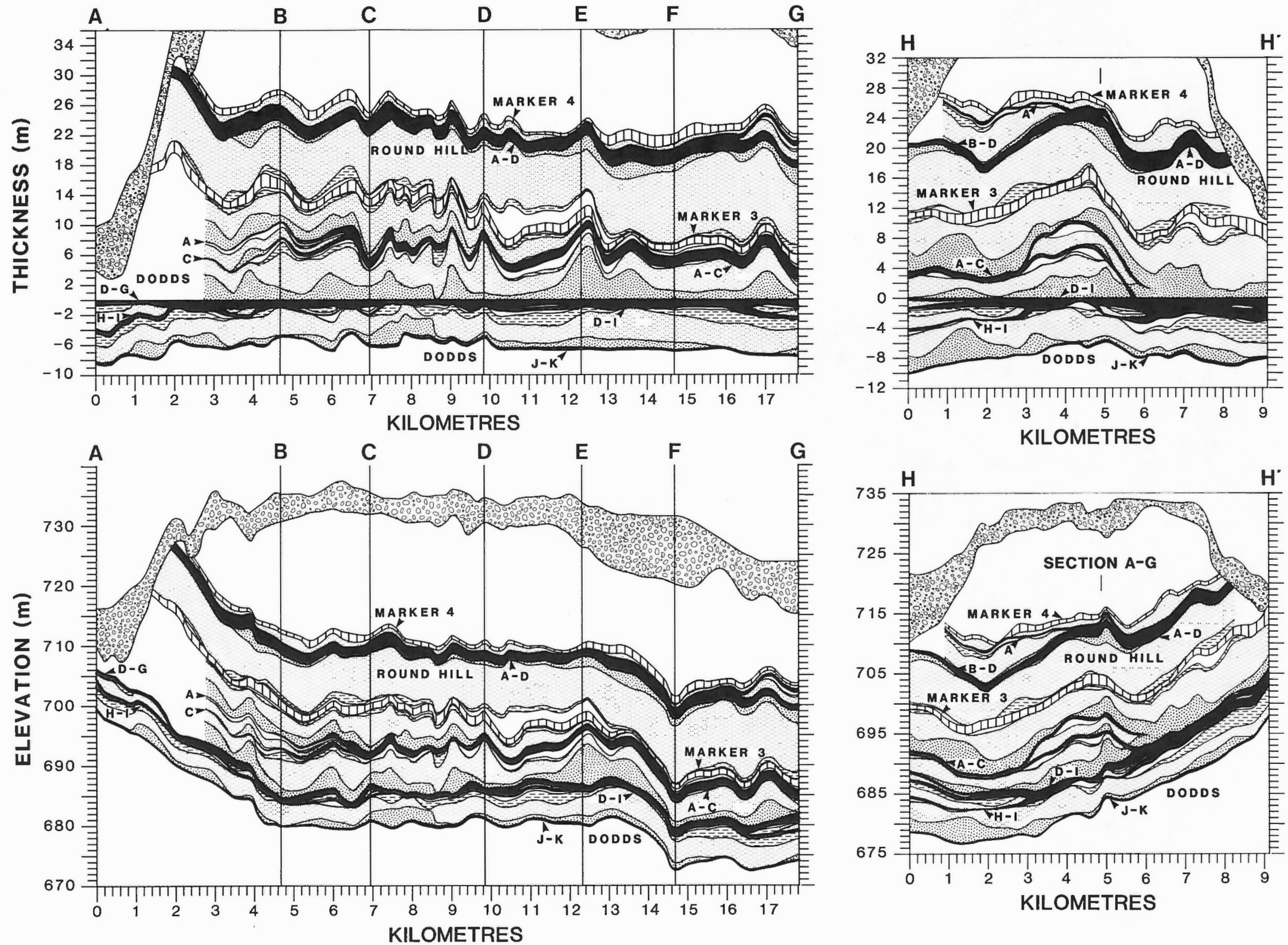


Figure 27. Markov analysis and lithologic composition of the rock parting between Dodds "G" and "H" coal beds. See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).



A
B
C
D
E
F
G
THICKNESS (m)
MARKER 4
ROUND HILL
A-D
A
C
DODDS
D-G
H-I
MARKER 3
A-C
D-I
J-K
KILOMETRES
ELEVATION (m)
H
H'
B-D
SECTION A-G

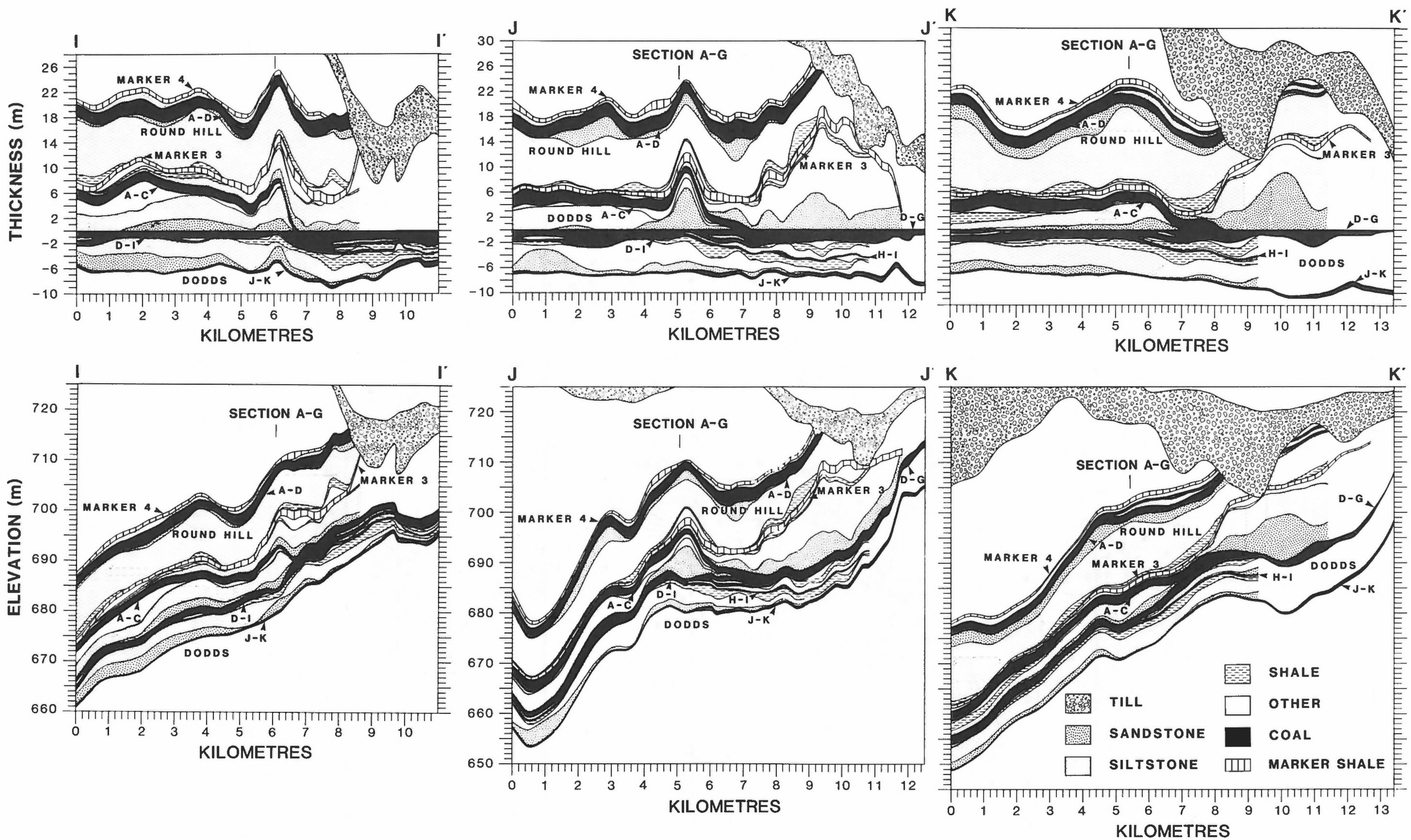


Figure 28. *Cross-sections constructed parallel (A-G) and perpendicular (H-H', I-I', J-J', K-K') to axis of linear zone of thickening between Dodds "C" and "D" coal beds. Correlated surfaces between the base of Dodds "K" coal bed and the top of Marker 4 and the aggregate lithologic composition of intervals between surfaces are shown. See Figure 29 for locations. See text for discussion of individual cross-sections. The top of Dodds "D" coal bed is used as a datum, for the upper cross-sections.*

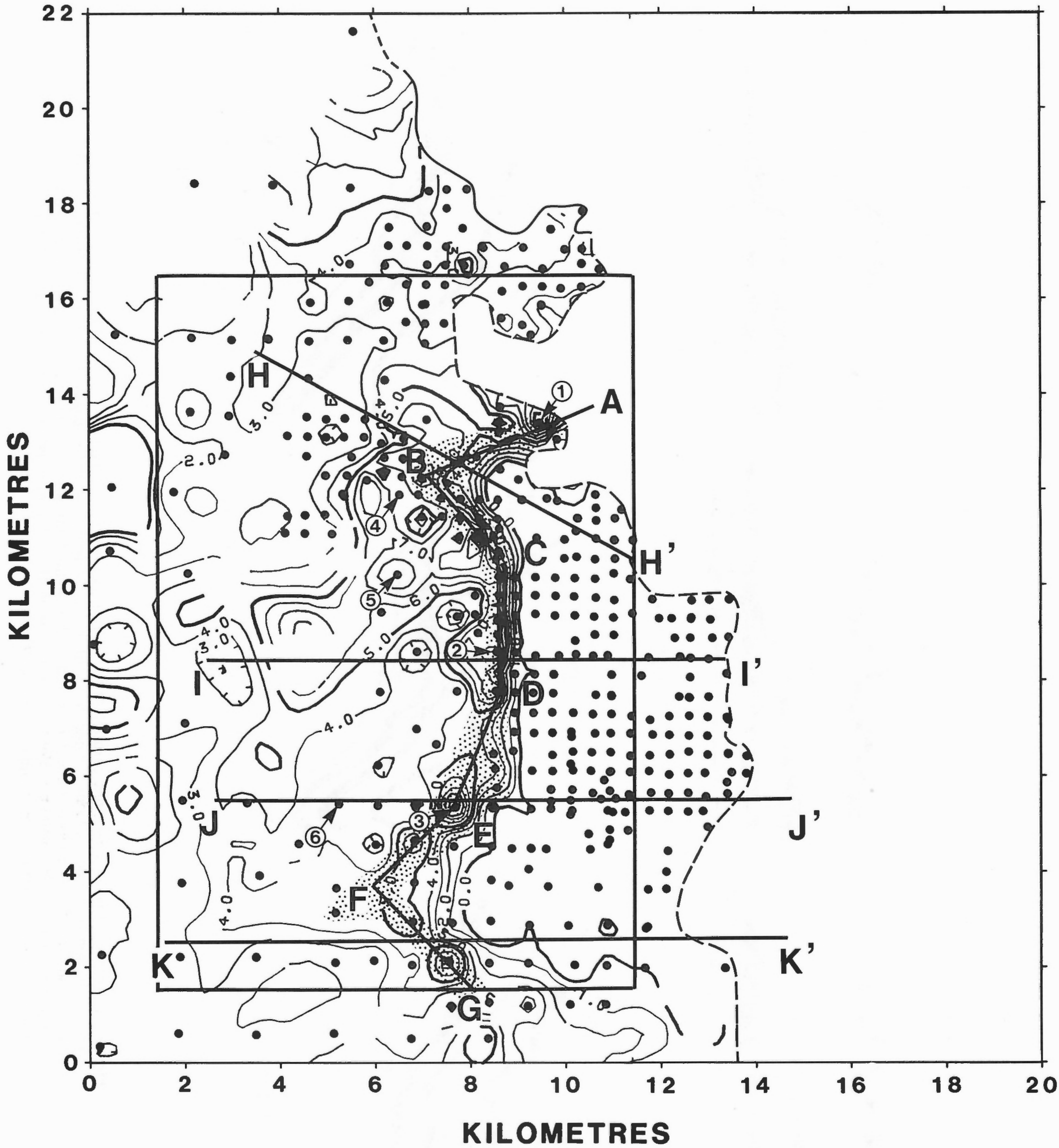


Figure 29. Isopach map (and borehole location) for the interval between Dodds "C" and "D" coal beds. Stippled area outlines linear zone of thickening discussed in text. Markov analysis was performed separately for boreholes within and west of this stippled area. Also shown are the locations of cross-sections in Figure 28, perspective diagrams (rectangle) in Figure 30, and boreholes (numbers) in Figure 31. Contour interval is 1 m.

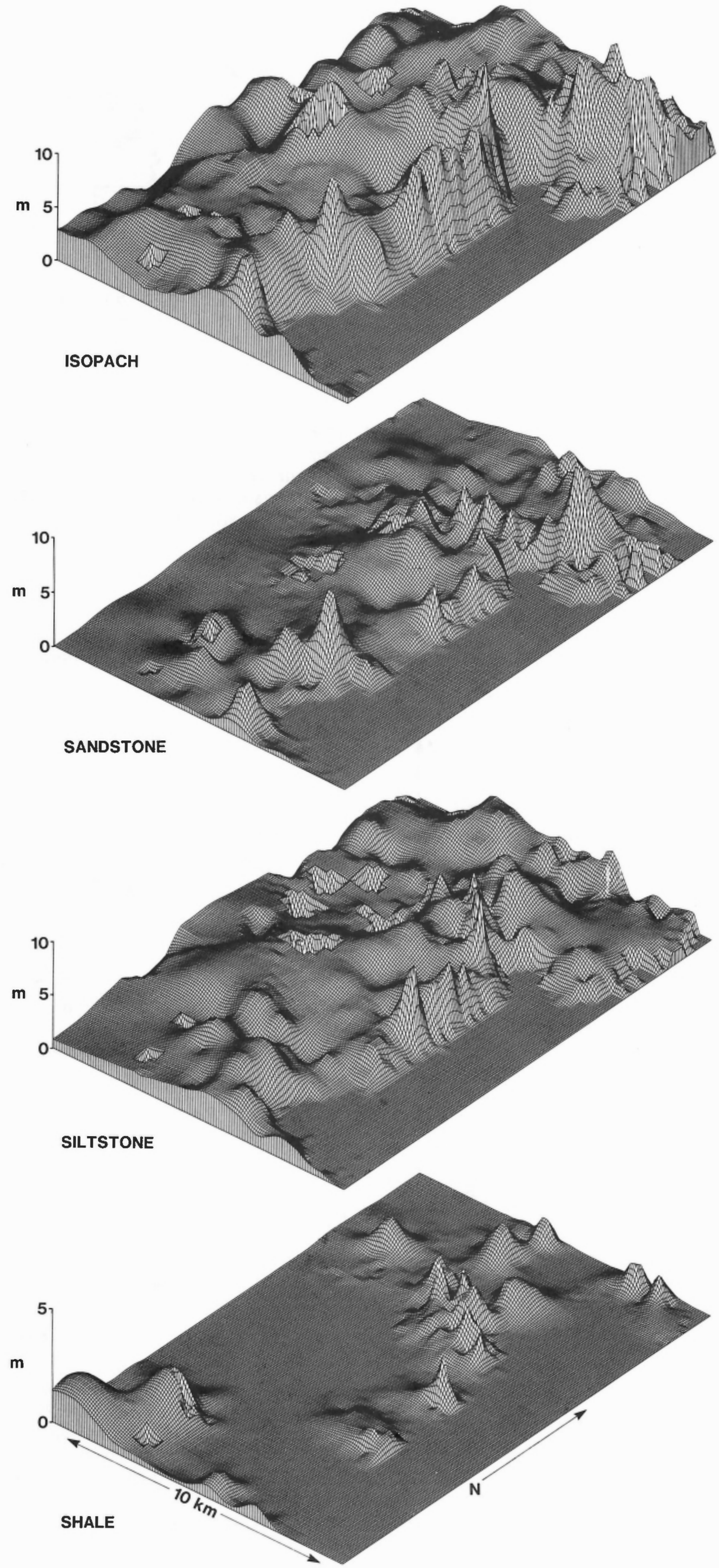


Figure 30. *Perspective diagrams viewed from southeast, illustrating variations in total thickness and aggregate sandstone, siltstone and shale thickness associated with the linear zone of thickening within the interval between Dodds "C" and "D" coal beds. See Figure 29 for location.*

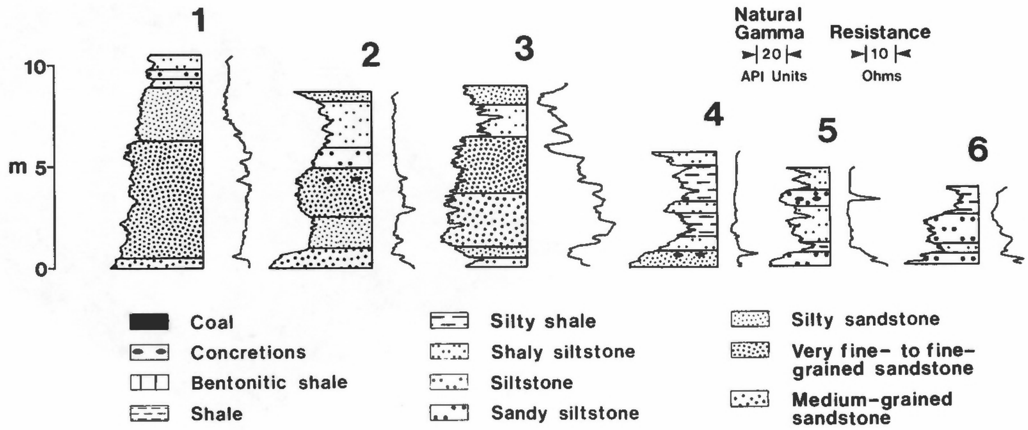


Figure 31. *Geophysical log responses and interpretations for boreholes penetrating on-axis (1, 2, 3) and off-axis (4, 5, 6) areas associated with the linear zone of thickening in the interval between Dodds "C" and "D" coal beds (see text). See Figure 29 for locations. "0" m = top of the Dodds "D" coal bed.*

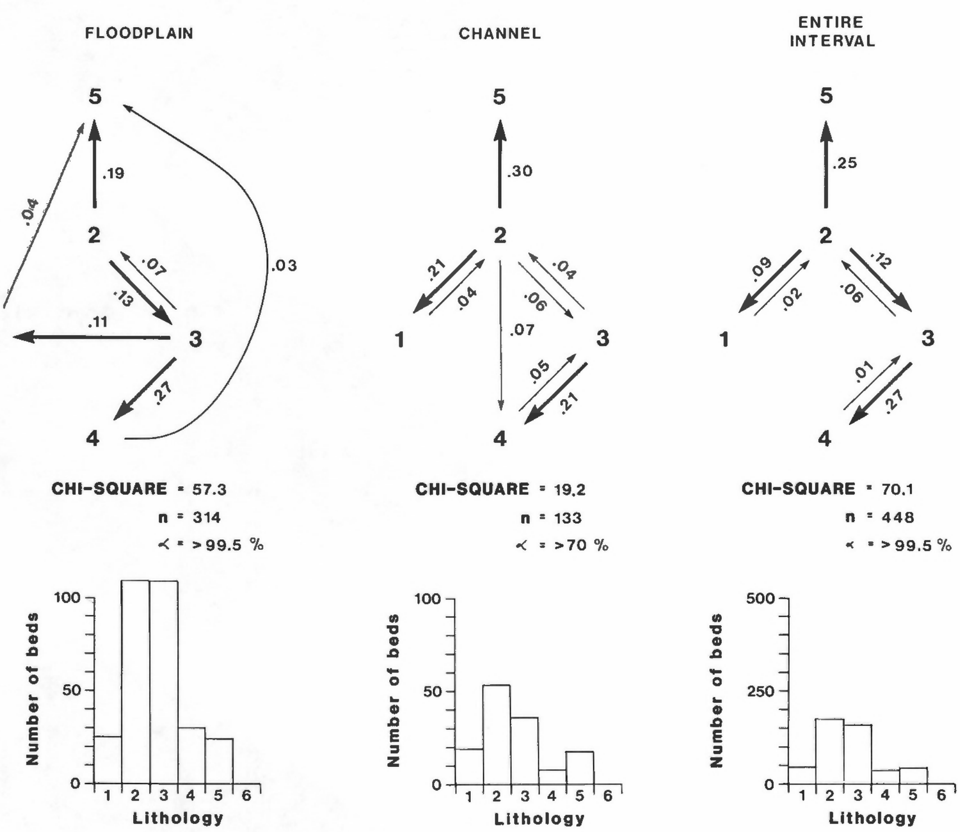


Figure 32. *Markov analysis and lithologic composition of on-axis ("channel" - stippled area in Figure 29) and off-axis ("floodplain") areas associated with the linear zone of thickening between Dodds "C" and "D" coal beds, and of these areas combined. See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).*

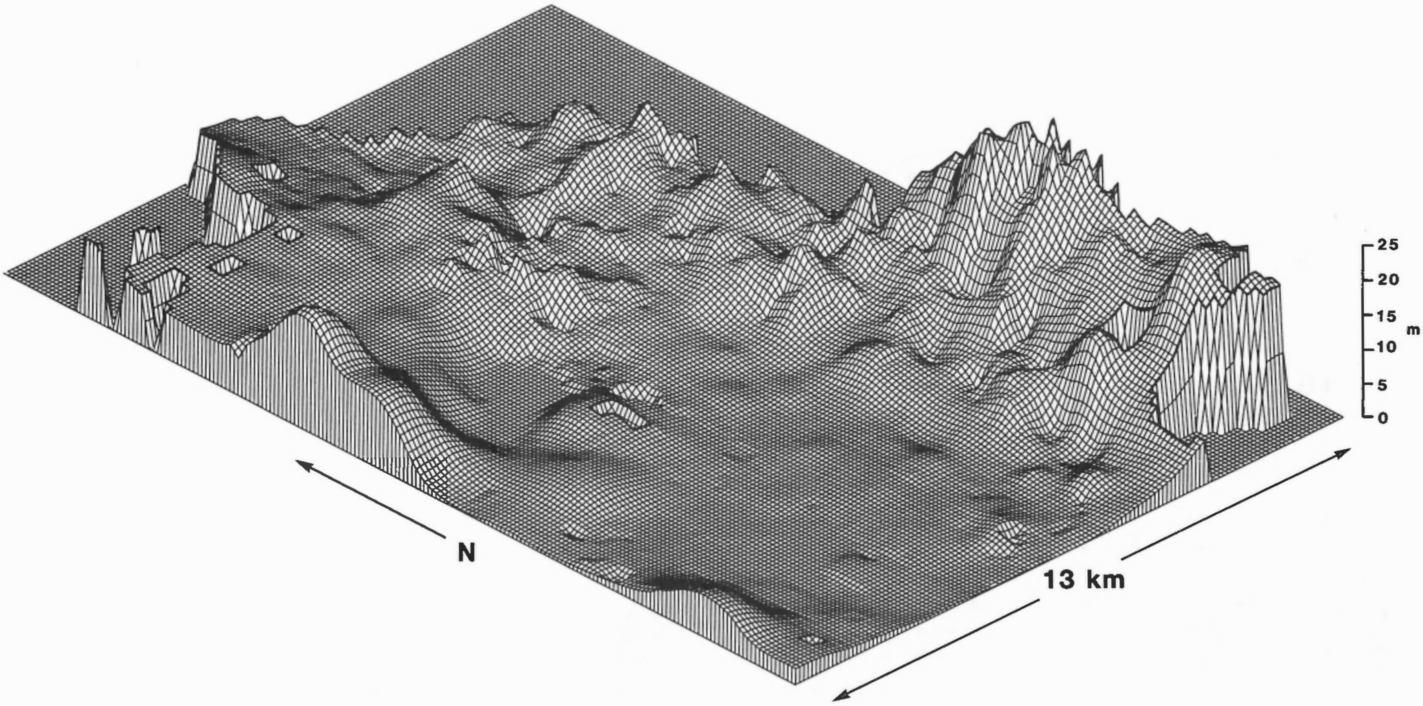


Figure 33. *Perspective diagram viewed from southwest, illustrating variations in thickness of the interval between the top of the Dodds Coal Zone and Marker 3.*

Interval between Dodds Coal Zone and Marker 3

The stratigraphic interval between the top of the Dodds Coal Zone and Marker 3 ranges from a few centimetres in thickness in the southwestern part of the coalfield to 18 m in thickness along a linear, north-trending area near the subcrop of Marker 3 in the south-central part of the field (Fig. 33). Over most of the northwestern part of the coalfield this interval ranges from four to seven metres in thickness (Fig. 33). In the southern part of the coalfield, the geometry of this interval appears to be strongly controlled by the position of the linear feature within the underlying Dodds "C-D" parting, as the interval thins to a few centimetres along a line which roughly corresponds to the position of the axis of the underlying linear feature (left-hand stippled area in Fig. 34). These relationships are illustrated on cross-sections J-J' and K-K' in Figure 28.

The north-trending linear feature in the southern part of the coalfield is well defined by isopach (Fig. 33) and aggregate sandstone thickness (Fig. 34) maps. Figure 35 illustrates the lateral distribution of lithologies within and adjacent to this feature. These figures indicate a large concentration of sandstone within on-axis as compared to off-axis areas. Geophysical log responses in boreholes penetrating on-axis areas (Fig. 36) show high proportions of sandstone and sandy siltstone, which generally occur within a fining-upward sequence. Off-axis boreholes commonly show an interbedded succession grading upward to a thin sandstone bed immediately underlying Marker 3 (Fig. 36).

Separate Markov analyses were performed for boreholes penetrating on-axis (stippled area in Fig. 34) and off-axis areas (Fig. 37). Preferred vertical trends within on-axis boreholes include interbedding between the coarsest grained lithologies (lithologies 1, 2) with a strong fining-upward tendency from sandy siltstone (lithology 2) to shaly siltstone (lithology 3) to shale (lithology 4). Concretions are predominantly associated with shaly siltstone. In the off-axis area there is a strong coarsening-upward tendency between sandy siltstone (lithology 2) and sandstone (lithology 1) and a fining-upward tendency, much less predominant than in the on-axis area, from sandy siltstone (lithology 2) through shaly siltstone (lithology 3) to shale (lithology 4). Concretionary units are predominantly associated with shaly siltstone (lithology 2) in the off-axis areas. Although the proportion of the coarsest lithology (lithology 1) is greater in the on-axis as compared to off-axis areas (Fig. 37), the predominant lithologies in off-axis areas are coarser grained than in off-axis areas of previously discussed stratigraphic intervals. Differential compaction between on- and off-axis areas has resulted in a structural relief of greater than 5 m on overlying surfaces as high as Marker 4 (see cross-sections J-J', K-K'; Fig. 28) in some areas.

Interval between Marker 3 and Round Hill Coal Zone

The interval between Marker 3 and the Round Hill Coal Zone is relatively uniform in thickness and lithologic composition across the area. It ranges from 7 to 9 m in thickness within the central and western parts of the coal-field, and thins to 6 m over the axis of the previously discussed linear feature within the underlying Marker 3 to Dodds Coal Zone stratigraphic interval. These relationships are well defined on cross-sections J-J' and K-K' in Figure 28.

From 70 to 80 per cent of this interval is composed of siltstone throughout most parts of the coalfield, as illustrated in Figure 38 and the cross-sections in Figure 28. The overall lithologic composition of the interval, determined from the relative abundance of each lithology (Fig. 39), confirms this relationship. Geophysical logs of individual boreholes commonly show a coarsening-upward profile, from the bentonitic shales of Marker 3, through interbedded shales and siltstones, to sandy siltstones below the Round Hill Coal

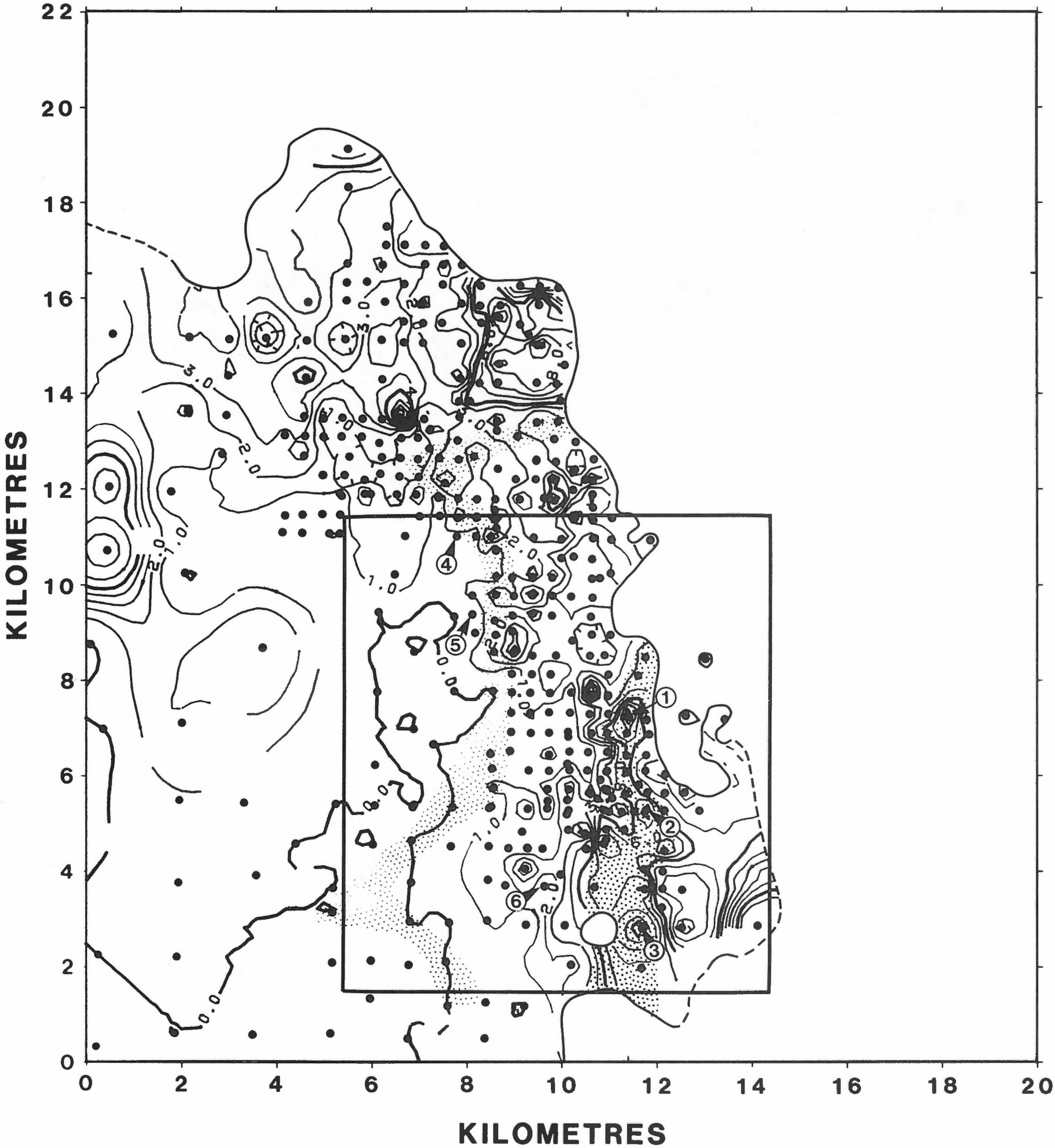


Figure 34. Aggregate sandstone thickness and borehole control for the interval between Dodds Coal Zone and Marker 3. Stippled area on right indicates on-axis area of linear zone of thickening discussed in text. Stippled area on left indicates position of underlying linear zone of thickening between Dodds "C" and "D" coal beds. Note correspondence of area of thinning with position of the underlying feature (see text). Also shown are the locations of the perspective diagrams in Figure 35 (rectangle) and the boreholes (numbers) illustrated in Figure 36. Contour interval is 1 m.

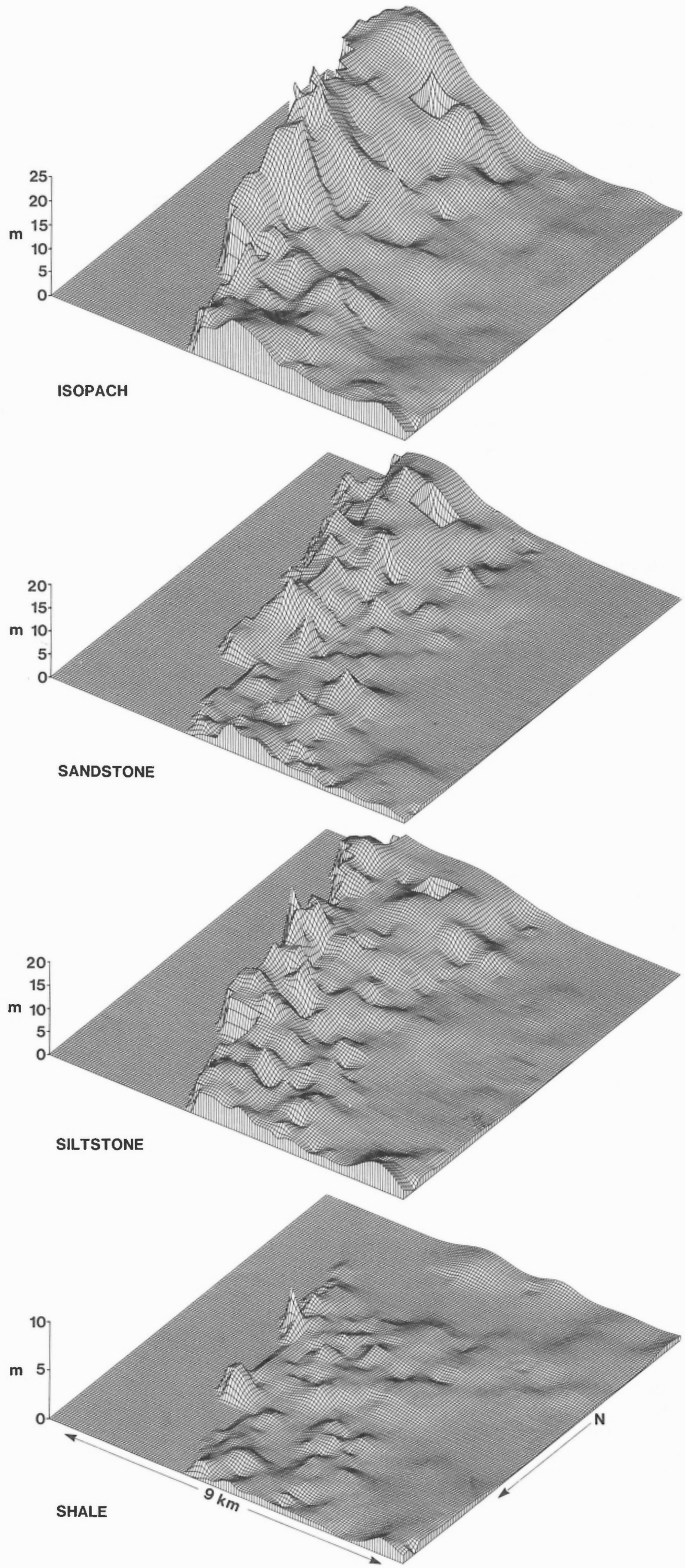


Figure 35. *Perspective diagrams viewed from northwest, illustrating variations in total thickness and aggregate sandstone, siltstone and shale thickness associated with linear zone of thickening in the interval between Dodds Coal Zone and Marker 3. See Figure 34 for location.*

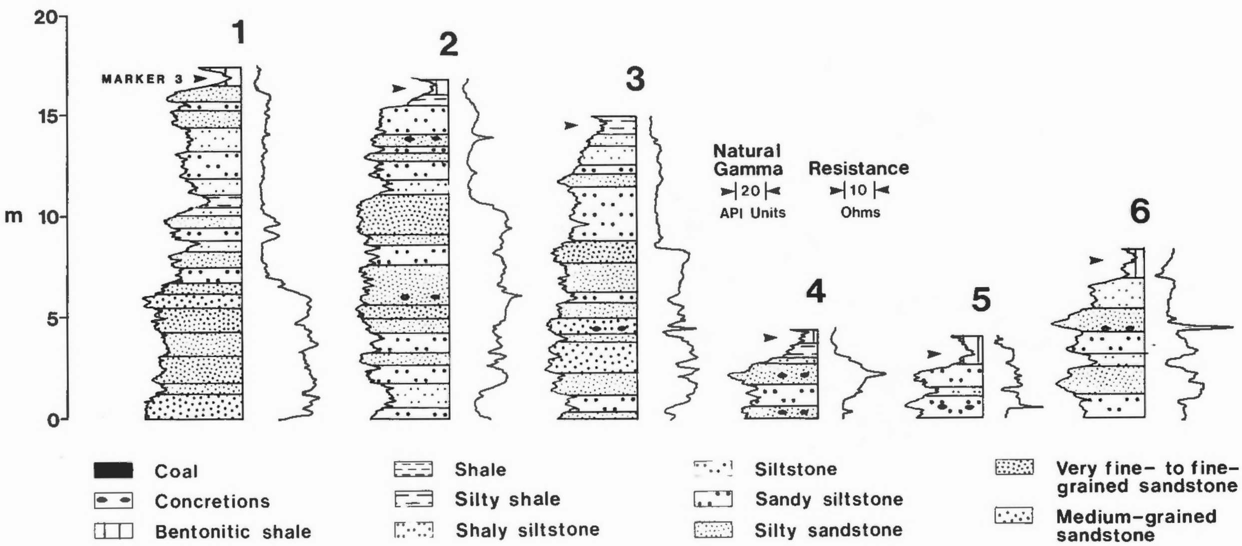


Figure 36. *Geophysical log responses and interpretations for boreholes penetrating on-axis (1, 2, 3) and off-axis (4, 5, 6) areas associated with the linear zone of thickening between Dodds Coal Zone and Marker 3. See Figure 34 for locations. 0 m at top of Dodds Coal Zone.*

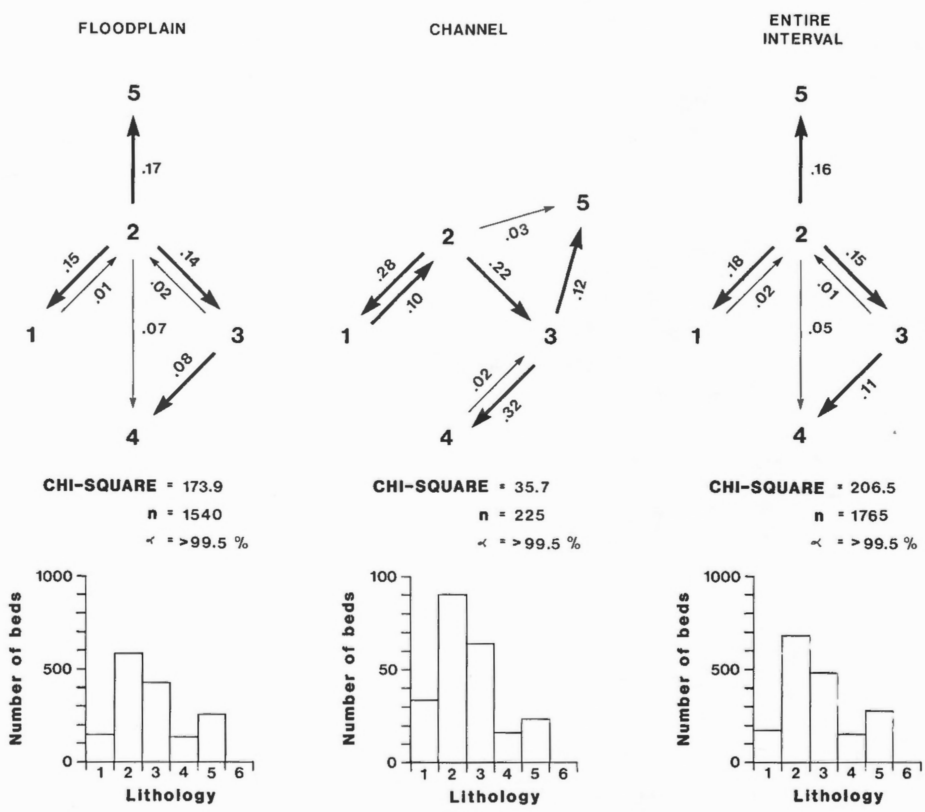


Figure 37. *Markov analysis and lithologic composition of on-axis ("channel"-stippled area in Figure 34) and off-axis ("floodplain") areas associated with linear zone of thickening between the Dodds Coal Zone and Marker 3, and of entire interval combined. See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).*

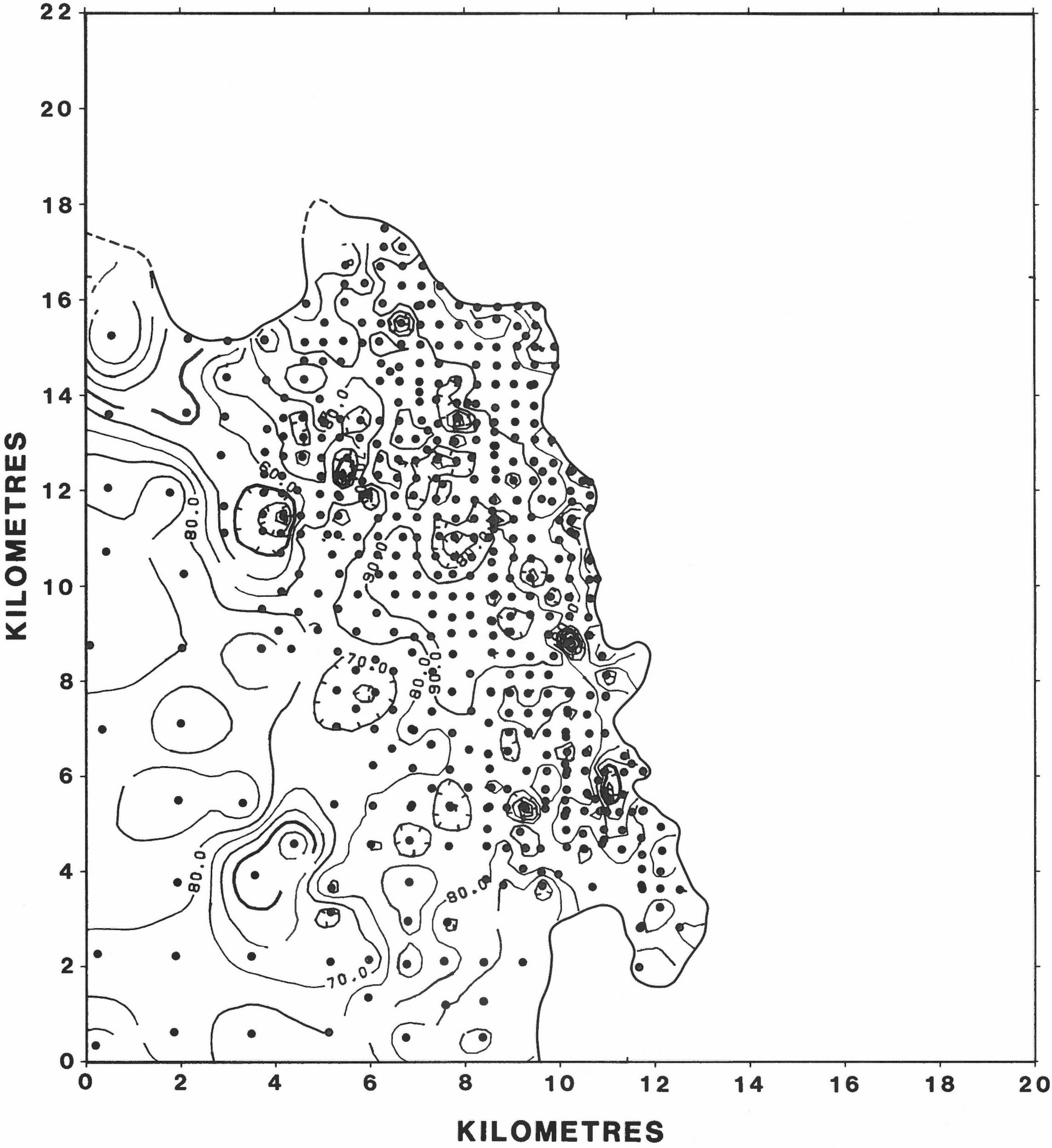


Figure 38. Aggregate percentage of siltstone and borehole control for the interval between Marker 3 and Round Hill Coal Zone. Contour interval is 10 per cent.

Zone. This coarsening-upward trend is evident also from Markov analysis, as illustrated in Figure 39. Preferred vertical transitions include a coarsening-upward tendency from shaly siltstone (lithology 3) to sandy siltstone (lithology 2) to sandstone (lithology 1), and a fining-upward tendency between shaly siltstone (lithology 3) and shale (lithology 4). The three coal beds in the succession are always underlain by the finest grained lithology (lithology 4), and concretions are preferentially associated with shaly siltstone (lithology 3).

Round Hill Coal Zone

Over much of the southwestern part of the coalfield, the Round Hill Coal Zone comprises a single seam with minor partings between 1.2 and 1.8 m in thickness. To the north, the zone is split by a northward thickening, wedge-shaped rock parting and the aggregate coal thickness thins to less than 0.5 m. To the south, a rock parting of small areal extent separates beds of the coal zone by as much as 2 m.

Rock partings between the "A", "B", "C" and "D" beds of the Round Hill Coal Zone each have distinct characteristics. The parting between the Round Hill "C" and "D" beds is a concretionary layer that occurs at the same position with respect to the floor of the coal zone in about 20 per cent of the boreholes penetrating the interval. This concretionary layer may form a more or less continuous horizon in some areas, as reported by an operator of a shallow surface mine in the region, who encountered a concretionary layer within a seam which covered a five acre area (Fording Coal Ltd., internal report by J.Y. Wright, 1976). Concretionary units recovered from core have been examined by L. Jory for Montreal Engineering Limited, who reported the concretions to be partially coalified material with about 60 per cent silica and minor amounts of carbonate and pyrite. The cell walls of the woody material in these samples had been coalified, whereas the internal portion of the cells had been replaced by silica.

The parting between the Round Hill "B" and "C" beds is a discontinuous layer, rarely more than 30 cm in thickness, that is present throughout the southern and central parts of the coalfield, and is composed predominantly of shale and siltstone. To the north, where the overall thickness of the coal zone decreases, this parting is absent.

The parting between the Round Hill "A" and "B" beds is similar in thickness and lithologic composition to the "B-C" parting in the central part of the coalfield, but thickens to more than 5 m to the north, and to more than 2 m in the extreme southern part of the coalfield (Fig. 40). The wedge-shaped geometry of this parting in the northern part of the field is indicated by the block diagrams in Figure 41. The geometry and lithologic relationships within this parting can be seen also on cross-sections H-H', I-I' and J-J' in Figure 42. The lithologic composition of this parting is predominantly siltstone and shale, with the proportion of coarser grained lithologies increasing in the direction of thickening. There is no apparent relationship between the distribution and thickness of partings within the Round Hill Coal Zone and lithologic relationships in underlying stratigraphic intervals.

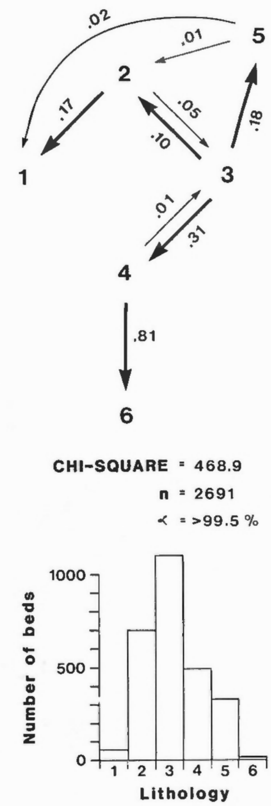


Figure 39. *Markov analysis and lithologic composition of the interval between Marker 3 and Round Hill Coal Zone. See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).*

Interval between Round Hill and Dusty Coal zones

The stratigraphic interval between the Round Hill and Dusty Coal zones can be subdivided into two units, separated by Marker 4 (Fig. 3). The interval between the top of the Round Hill Coal Zone and Marker 4 ranges from zero thickness, where Marker 4 rests directly on the Round Hill Coal Zone, to more than one metre in thickness in the northeast part of the coalfield. This interval has a mean thickness of 78 cm and is composed predominantly of siltstone.

Marker 4 is a shale and bentonitic shale unit which is present above the Round Hill Coal Zone throughout the coalfield. It ranges from a few centimetres to 2 m in thickness, and has an average thickness of 70 cm. The character of this unit, as compared to the underlying and overlying strata, can be seen on the geophysical logs illustrated in Figure 44. Lateral variations in thickness and position with respect to the Round Hill Coal Zone can be seen on the cross-sections in figures 28 and 42.

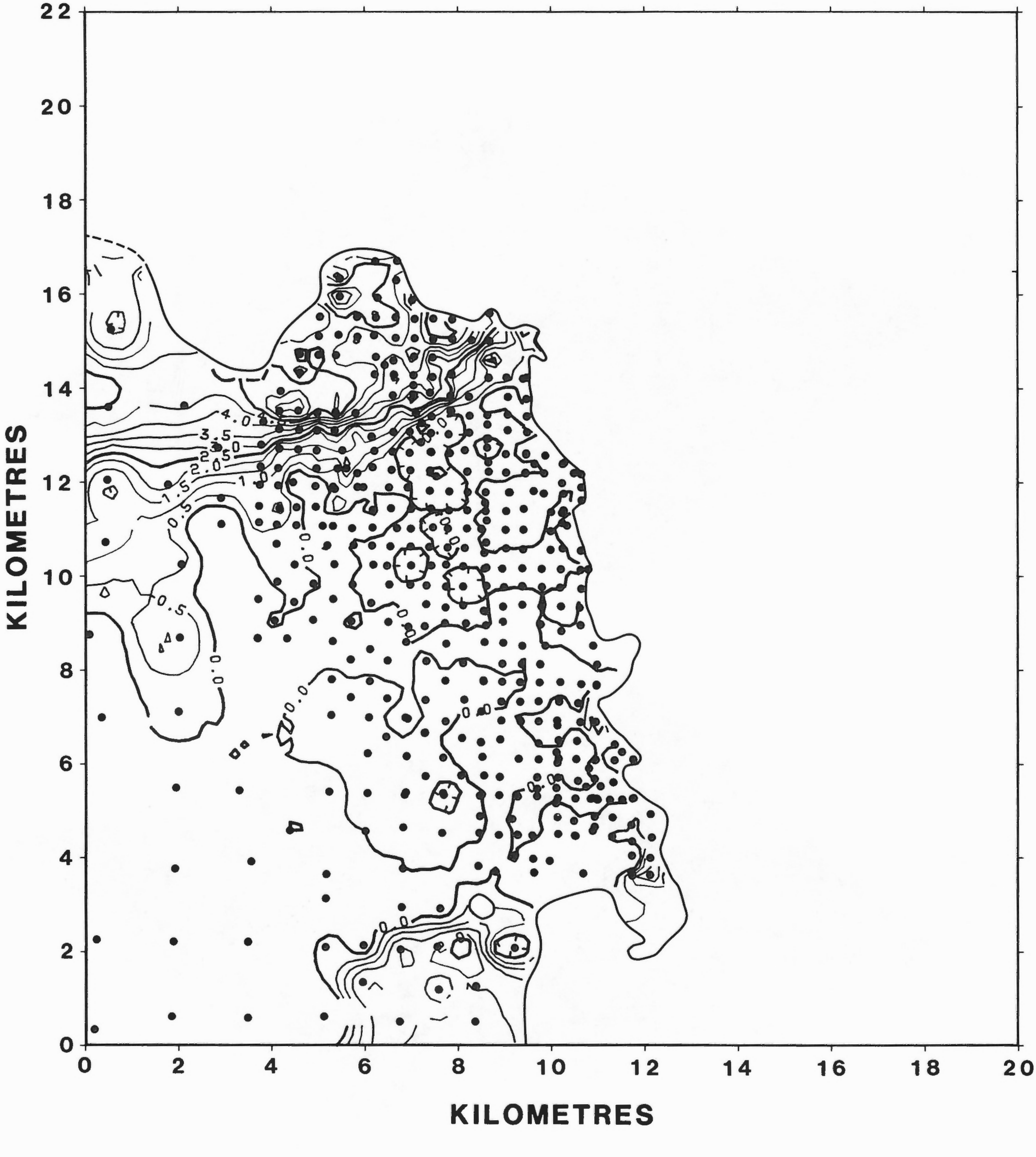


Figure 40. *Isopach map and borehole control for the interval between Round Hill "A" and "B" coal beds. Contour interval is 0.5 m.*

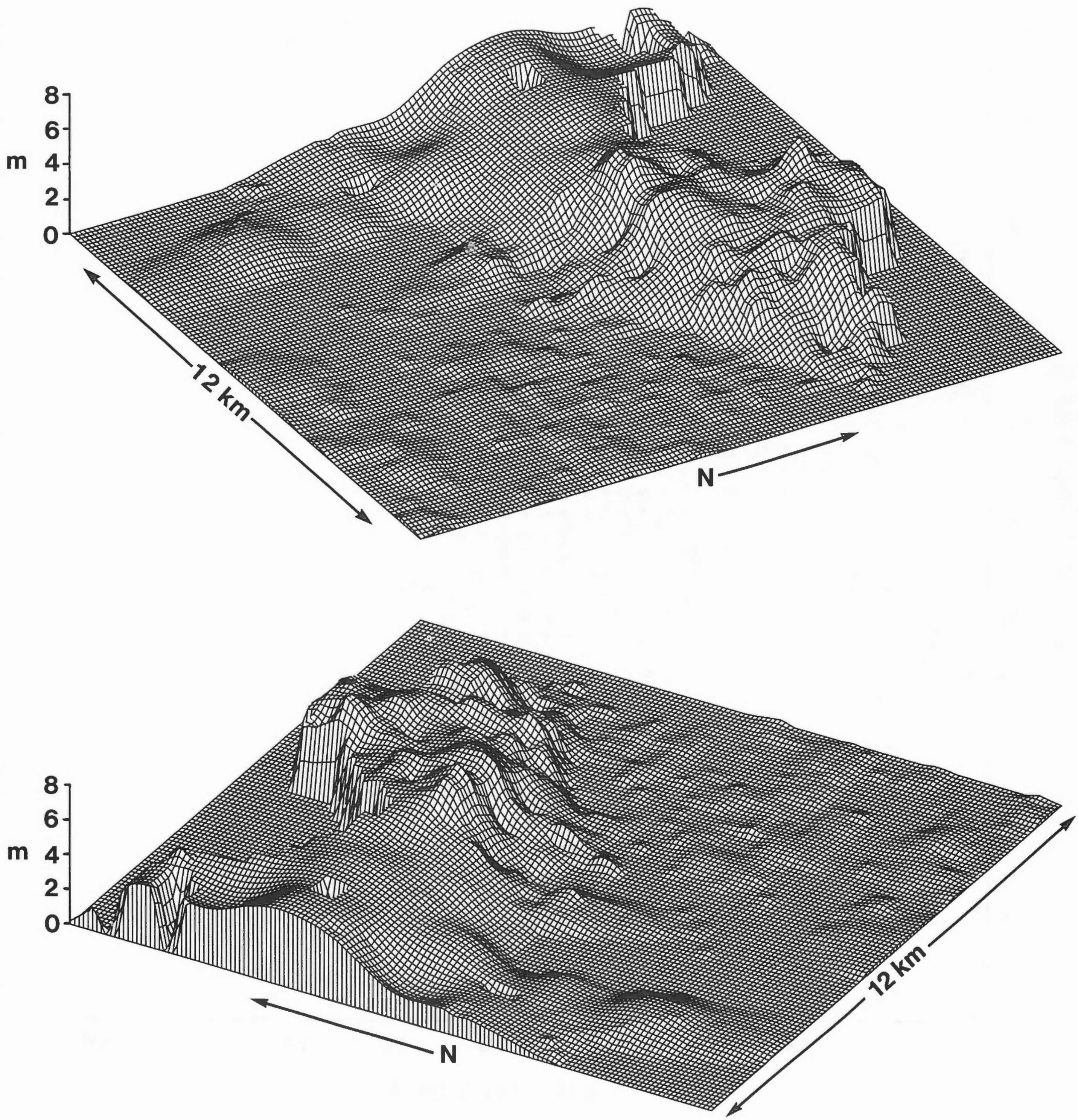


Figure 41. Perspective diagrams viewed from southeast and southwest, illustrating total thickness of the rock parting between Round Hill "A" and "B" coal beds.

The interval between Marker 4 and the Dusty Coal Zone ranges from 4 to 6 m in thickness over much of the southwestern part of the coalfield, and increases to more than 9 m in thickness along a linear, easterly-trending, one to two kilometre wide zone that extends across the north-central part of the area (Fig. 43). North of this area, the interval thins to less than 4 m near the subcrop of the Dusty Coal Zone (Fig. 43). The cross-sections in Figure 42 were constructed along and perpendicular to this linear zone of thickening to illustrate the internal relationships in geometry and lithology associated with it. Borehole control on the western portion of this feature is very sparse, and has resulted in some anomalous lithologic relationships on the western part of cross-section A-G in Figure 42. The block diagrams in Figure 45 illustrate lateral variations in thickness and lithology within and adjacent to this feature in the densely drilled, northeastern part of the coalfield. Areas on the axis of this feature are marked by a linear zone of high sandstone concentration, 500 to 1500 m wide and 9 km long. Off-axis areas are composed predominantly of siltstone with minor sandstone and shale. Geophysical log responses from boreholes penetrating on- and off-axis areas are illustrated in Figure 44. They verify lithology distribution patterns observed on the previously discussed figures: on-axis boreholes contain a thick succession of relatively coarse grained, interbedded to fining-upward lithologies; whereas off-axis boreholes contain a thinner succession predominantly composed of siltstone and shale.

Markov analysis was performed separately for boreholes penetrating on-axis and north and south off-axis subareas, and for all subareas combined (Fig. 46). On-axis boreholes show strong fining-upward tendencies between sandy siltstone (lithology 2) and shale (lithology 4), and between shaly siltstone (lithology 3) and shale. A coarsening-upward tendency is indicated between sandy siltstone and sandstone (lithology 1). Both off-axis subareas show fining-upward tendencies from sandy siltstone through shaly siltstone to shale. A coarsening-upward tendency, less pronounced than in the on-axis subarea, is indicated in the north off-axis subarea. Concretionary units in all three subareas are underlain by shaly siltstone. The proportions of lithologies within north and south off-axis subareas shown in Figure 46 are similar, and are composed predominantly of sandy and shaly siltstone, with a higher relative abundance of shale in the north subarea as compared to the south. Boreholes penetrating the on-axis area have the highest proportion of coarse lithologies (lithologies 1, 2).

Differential compaction between the relatively thick sandstones within this linear feature and the finer grained lithologies of the off-axis areas has resulted in structural relief of more than 5 m over its axis on surfaces as high as the Burnstad Coal Zone (cross-sections H-H', I-I', J-J'; Fig. 42).

Dusty Coal Zone

In the central and southern parts of the coalfield, the Dusty Coal Zone comprises two beds, termed "A-B" and "C-D", each about 0.5 m thick. To the north, these beds coalesce into a single seam up to one metre thick. The parting separating Dusty "B" and "C" beds is wedge-shaped, increasing in thickness southward to greater than 3 m in some areas (Fig. 47). The pinch-out line of this parting coincides very closely with the axis of the underlying linear feature in the Marker 4 to Dusty interval (stippled area in Fig. 47). This suggests that the linear feature may have been topographically high during deposition of the Dusty "B" to "C" parting and, therefore, exerted some influence on sedimentation patterns. The relationship of the geometry of this parting to that of the underlying Marker 4 to Dusty interval is illustrated by the block diagrams in Figure 48.

The overall lithologic composition and preferred vertical lithological transitions for the Dusty "B" to "C" parting are illustrated in Figure 49. The parting is composed predominantly of shaly and sandy siltstone, with minor amounts of sandstone and shale. Markov analysis shows a fining-upward tendency from sandy siltstone (lithology 2) through shaly siltstone (lithology 3) to shale (lithology 4), with some interbedding between sandy and shaly siltstone, and a slight coarsening-upward tendency between shaly siltstone and sandstone (lithology 1). Concretions are predominantly associated with sandy siltstone. Lateral thickness and lithologic relationships within this parting and adjacent intervals can be seen on the cross-sections in figures 42 and 50.

Interval between Dusty and Burnstad Coal zones

The stratigraphic interval between the Dusty and Burnstad Coal zones ranges from 8 to 11 m in thickness over much of the coalfield, but increases to more than 15 m along a linear, northeasterly-trending, 500 to 2000 metre-wide zone, which extends for more than 12 km across the central part of the field (figs. 51, 52).

The cross-sections in Figure 50 have been constructed along and perpendicular to the axis of this linear feature to illustrate lateral lithologic relationships associated with it and with adjacent stratigraphic intervals. The interrelationships between interval thickness and lithology distribution across this feature, within the densely drilled northeastern part of the field, are illustrated by the perspective diagrams in Figure 53. On-axis areas are characterized by a large sandstone concentration relative to adjacent off-axis areas, a pattern similar to that associated with linear features observed in underlying stratigraphic intervals. Geophysical logs from boreholes that penetrated the axis of this linear feature (boreholes 1, 2, 3; Fig. 54) display an interbedded to fining-upward sequence that grades from sandstone to minor amounts of siltstone, shaly siltstone and shale. Boreholes in adjacent, off-axis areas (boreholes 4, 5, 6, 7; Fig. 54), are characterised by a thinner sequence of interbedded siltstone, shale and minor sandstone, also commonly arranged within a fining-upward succession. At one location in the southern part of the coalfield the Dusty "A-B" coal bed is absent and the sandstone body rests directly on the Dusty "C-D" coal bed, suggesting the presence of an erosion surface beneath the on-axis sandstone, which cuts through the underlying coal bed at some localities. At most other locations, however, the on-axis sandstone rests directly on or very close to the Dusty "A-B" coal bed, suggesting that the peat material in this seam was relatively resistant to erosion in comparison to adjacent unconsolidated clastic sediments.

Separate Markov analyses were performed on boreholes that penetrated the axis of the linear feature and these boreholes that penetrated the adjacent subareas on the west and east, as well as for the stratigraphic interval as a whole (Fig. 55). Boreholes penetrating the on-axis subarea (stippled in Fig. 51) show a strong fining-upward tendency from sandstone (lithology 1), through sandy siltstone (lithology 2) and shaly siltstone (lithology 3) to shale (lithology 4). Concretionary units are associated with the coarsest grained lithologies (lithologies 1, 2). Both the east and west off-axis subareas show similar vertical successions, with a

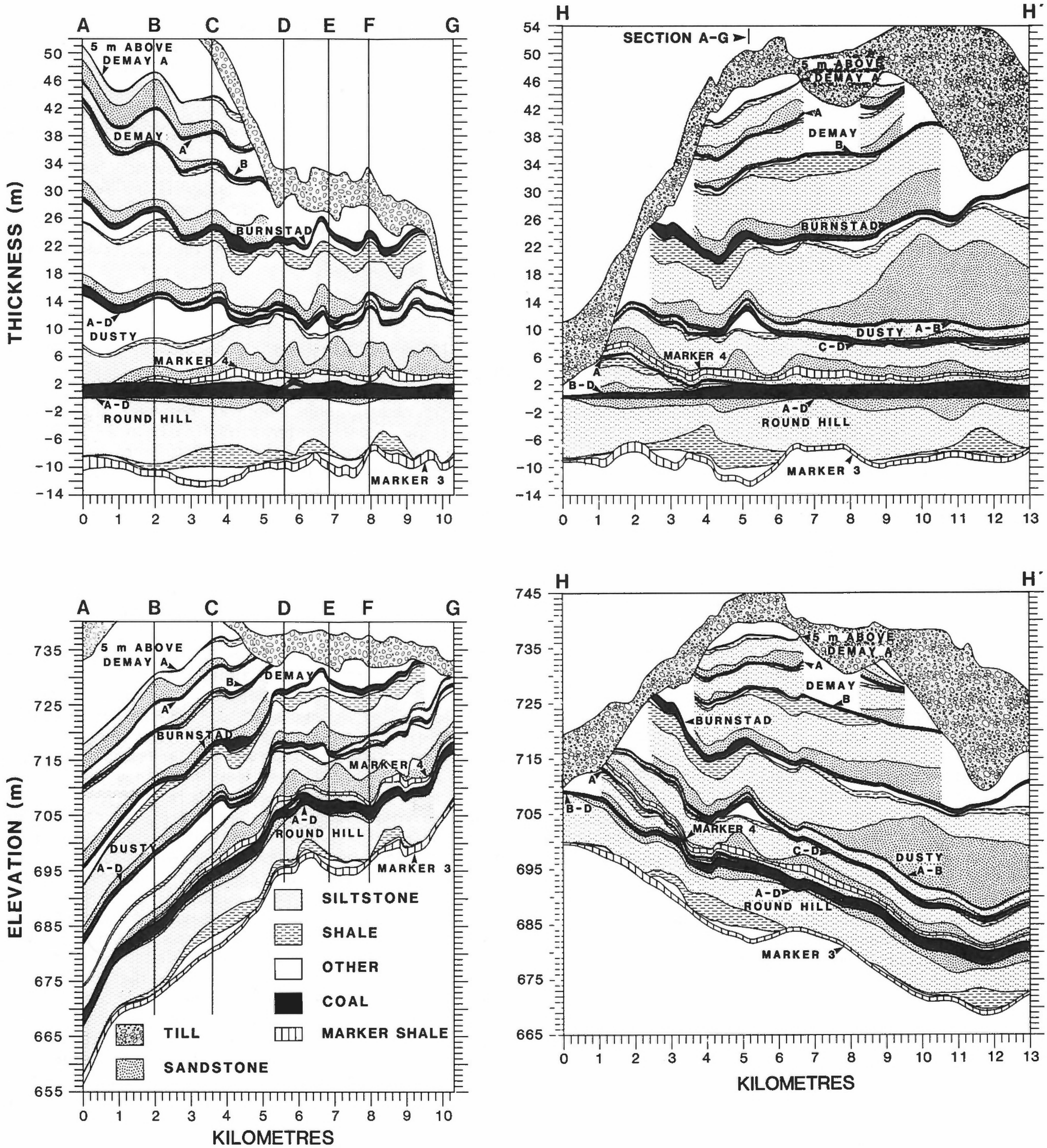
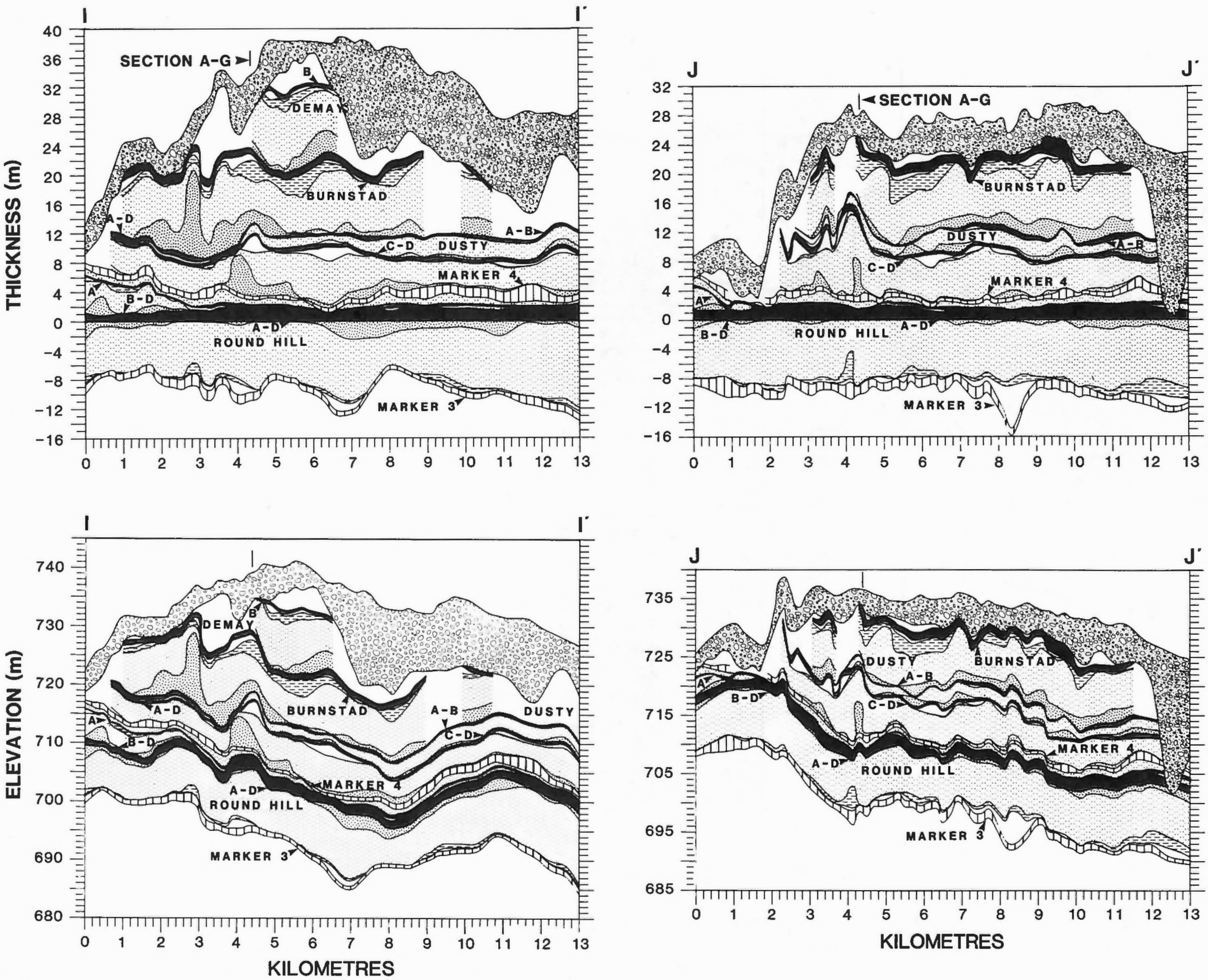


Figure 42. Cross-sections constructed parallel (A-G) and perpendicular (H-H', I-I', J-J') to axis of linear zone of thickening in the interval between Marker 4 and the Dusty Coal Zone. Correlated surfaces between the base of Marker 3 and 5 m above Demay "A" coal bed and the aggregate lithologic composition between surfaces are shown. See Figure 43 for locations. See text for discussion of individual cross-sections. The base of Round Hill "D" coal bed is used as a datum for the upper cross-sections.


I
I′
THICKNESS (m)
SECTION A-G
B
DEMAY
BURNSTAD
A-D
A-B
C-D
DUSTY
MARKER 4
A
B-D
ROUND HILL
MARKER 3
J
J′
ELEVATION (m)
KILOMETRES

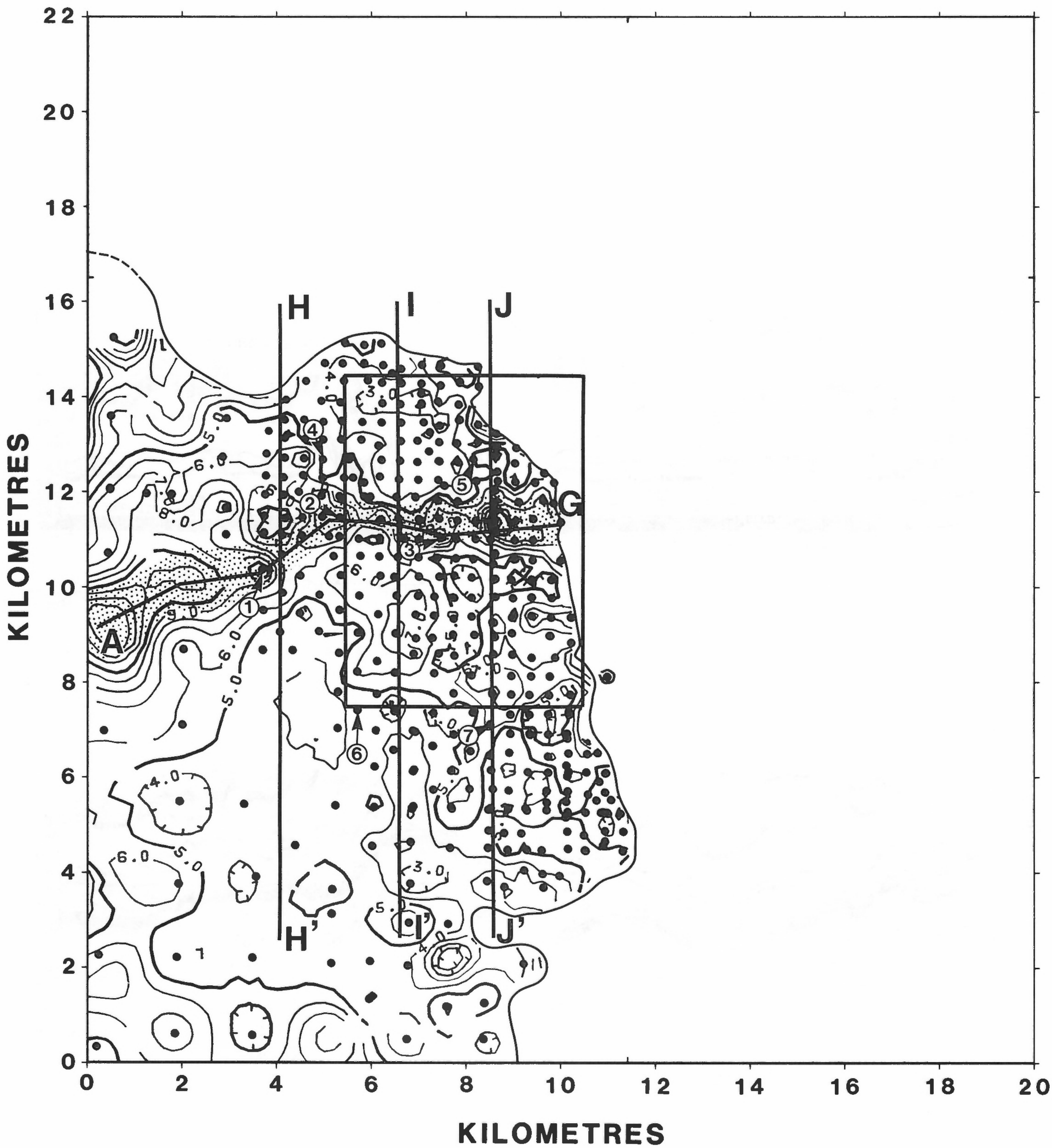


Figure 43. *Isopach map and borehole control for the interval between Marker 4 and Dusty Coal Zone. Stippled area indicates linear zone of thickening discussed in text. Markov analysis was performed separately on stippled area and on areas to the north and south. Also shown are the locations of cross-sections in Figure 42, perspective diagrams in Figure 45 (rectangle), and boreholes (numbers) in Figure 44. Contour interval is 1 m.*

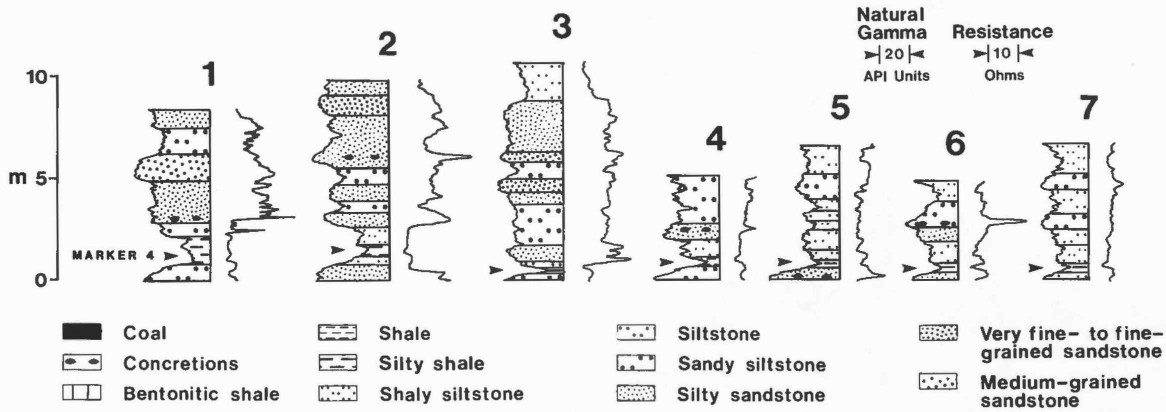


Figure 44. *Geophysical log responses and interpretations for boreholes penetrating on-axis (1, 2, 3) and off-axis (4, 5, 6) areas associated with linear zone of thickening within interval between Marker 4 and the Dusty Coal Zone (see text). See Figure 43 for locations. "0" m = top of Round Hill "A" coal bed.*

fining-upward tendency from sandy siltstone (lithology 2), through shaly siltstone (lithology 3) to shale (lithology 4), and a coarsening-upward tendency between sandy siltstone and sandstone. Concretionary horizons in both east and west subareas are predominantly associated with sandy siltstone. The overall lithological composition of each of these subareas (Fig. 55) confirms the relationships illustrated in figures 50, 51, 52 and 53; that is, large relative proportions of coarse grained lithologies within the on-axis subarea and finer grained lithologies in the adjacent off-axis areas.

Differential compaction between on- and off-axis areas has resulted in distortion of both overlying and underlying beds adjacent to this linear feature. Overlying surfaces as high as the Demay "B" coal bed have a relief of several metres over the on-axis area on cross-sections I-I' and J-J' (Fig. 50), whereas, on cross-section K-K' (Fig. 50), underlying surfaces at least as far down as the Round Hill "D" coal bed have a similar structural relief, and overlying surfaces are not affected.

Burnstad Coal Zone

Throughout most of the coalfield the Burnstad Coal Zone comprises a single seam which ranges in thickness from 0.5 m to 2.4 m, with a mean thickness of 0.98 m. It is generally thickest in the northern part of the coalfield and is split by a thin parting at some localities. In the northern and eastern parts of the coalfield the Burnstad Coal Zone lies near or immediately adjacent to the bedrock-till interface, and some of the thicker values for the coal zone in these areas are probably related to deformation by ice movement.

Although the thickest portions of the Burnstad Coal Zone overlie the western, off-axis subarea of the underlying Burnstad to Dusty interval, there is no obvious relationship between the thickness of the coal zone and the position of the underlying on-axis area of thickening. This suggests that there was little interrelationship between these two depositional events. Lateral thickness variations within the Burnstad Coal Zone are illustrated on the cross-sections in figures 42 and 50.

Interval overlying Burnstad Coal Zone

The stratigraphic interval overlying the Burnstad Coal Zone was penetrated by relatively few holes in the extreme west-central part of the coalfield (Fig. 4). This interval contains the Demay "A" and "B" coal beds and a small amount of overlying strata.

The interval between the Burnstad and Demay Coal Zones thickens from about 5 m in the northwestern part of the field to more than 12 m to the southeast (Fig. 56). The interval is composed predominantly of siltstone, sandy siltstone and shale (Fig. 57). The aggregate sandstone thickness increases to the east and southeast, in the direction of overall thickening (cross-sections H-H', I-I', Fig. 42; K-K', Fig. 50). Markov analysis of the interval (Fig. 57) indicates a fining-upward tendency from sandy siltstone (lithology 2), through shaly siltstone (lithology 3) to shale (lithology 4), and a coarsening-upward tendency from sandy siltstone to sandstone. Coal and carbonaceous beds (lithology 6) are predominantly underlain by shale, and concretionary units (lithology 5) are associated with sandy- and shaly-siltstone.

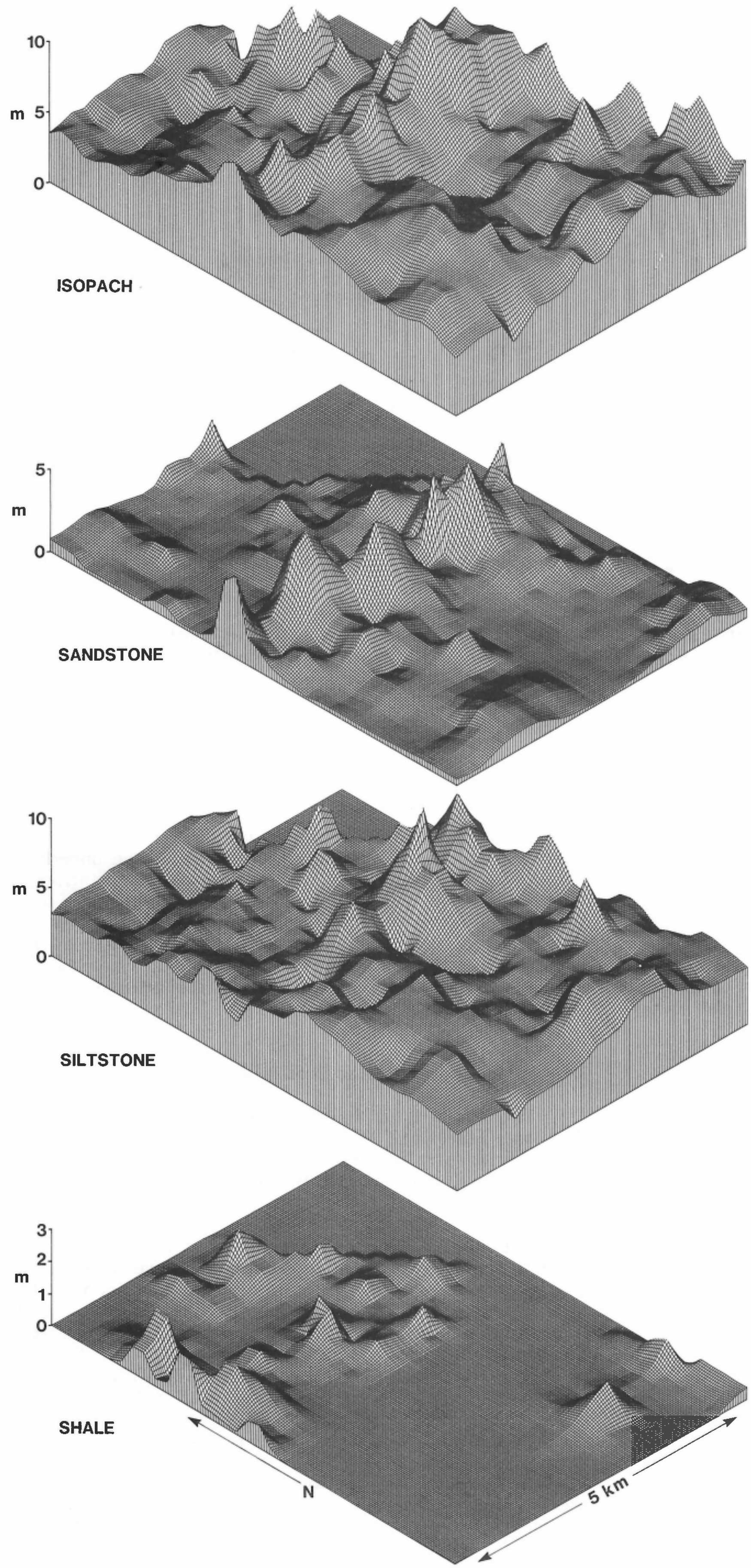


Figure 45. *Perspective diagrams viewed from southwest, illustrating variations in total thickness and aggregate sandstone, siltstone and shale thickness associated with the linear feature between Marker 4 and the Dusty Coal Zone. See Figure 43 for location. Note linear nature of sandstone concentration associated with this feature and its effect on the overall thickness of the interval.*

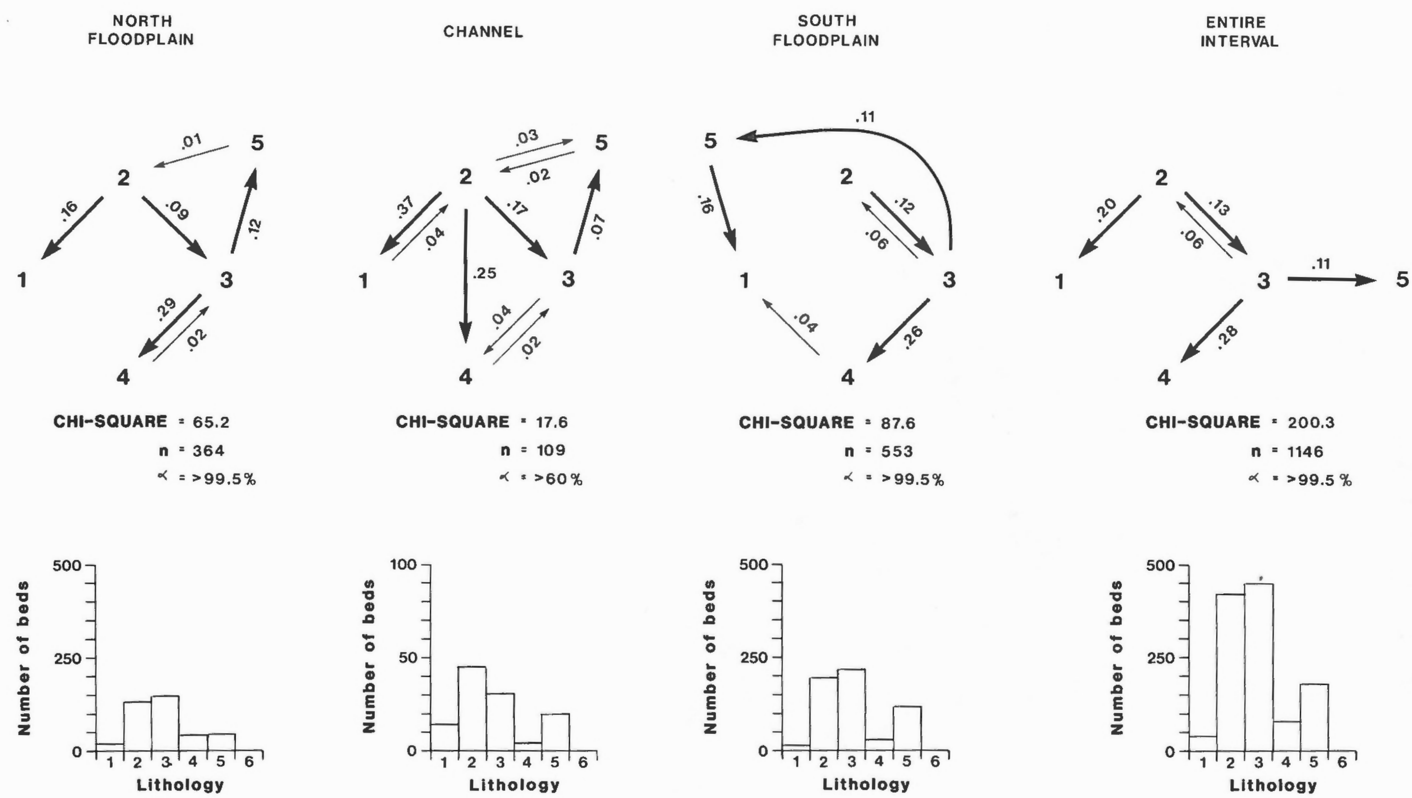


Figure 46. *Markov analysis and lithologic composition of on-axis ("channel"-stippled area in Figure 43) and north and south off-axis ("floodplain") areas associated with linear zone of thickening within the interval between Marker 4 and the Dusty Coal Zone, and of entire interval combined. See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).*

The Demay Coal Zone comprises two thin coal beds, termed "A" and "B" (Fig. 3), neither of which commonly exceeds 0.5 m in thickness. These coal beds are separated by a rock parting which ranges in thickness from 2 m in the west-central part of the field, to more than 6 m in the southeast, as illustrated in figures 58 and 59. The overall lithologic composition and preferred vertical transitions within the interval (Fig. 60) are similar to those observed in the underlying Burnstad to Demay interval. Preferred transitions include a fining-upward tendency from sandy siltstone (lithology 2), through shaly siltstone (lithology 3) to shale (lithology 4), and a coarsening-upward tendency from sandy siltstone to sandstone. Concretions are associated primarily with sandstone and shaly siltstone. The aggregate sandstone thickness within this interval increases to the southeast in the direction of overall thickening (cross-sections H-H', I-I', Fig. 42; J-J', K-K', Fig. 50), as in the underlying Burnstad-Demay interval.

The strata above the Demay "A" bed lie relatively close to the bedrock-till interface, except in the extreme western part of the field, and afforded too few data for a complete evaluation. The sandstone per cent map for the interval 0 to 5 m above the Demay "A" bed shows a linear, northeasterly-trending zone of high sandstone concentration crossing the centre of the area (Fig. 61). Markov analysis was not performed on this interval because of the small number of lithologic transitions present.

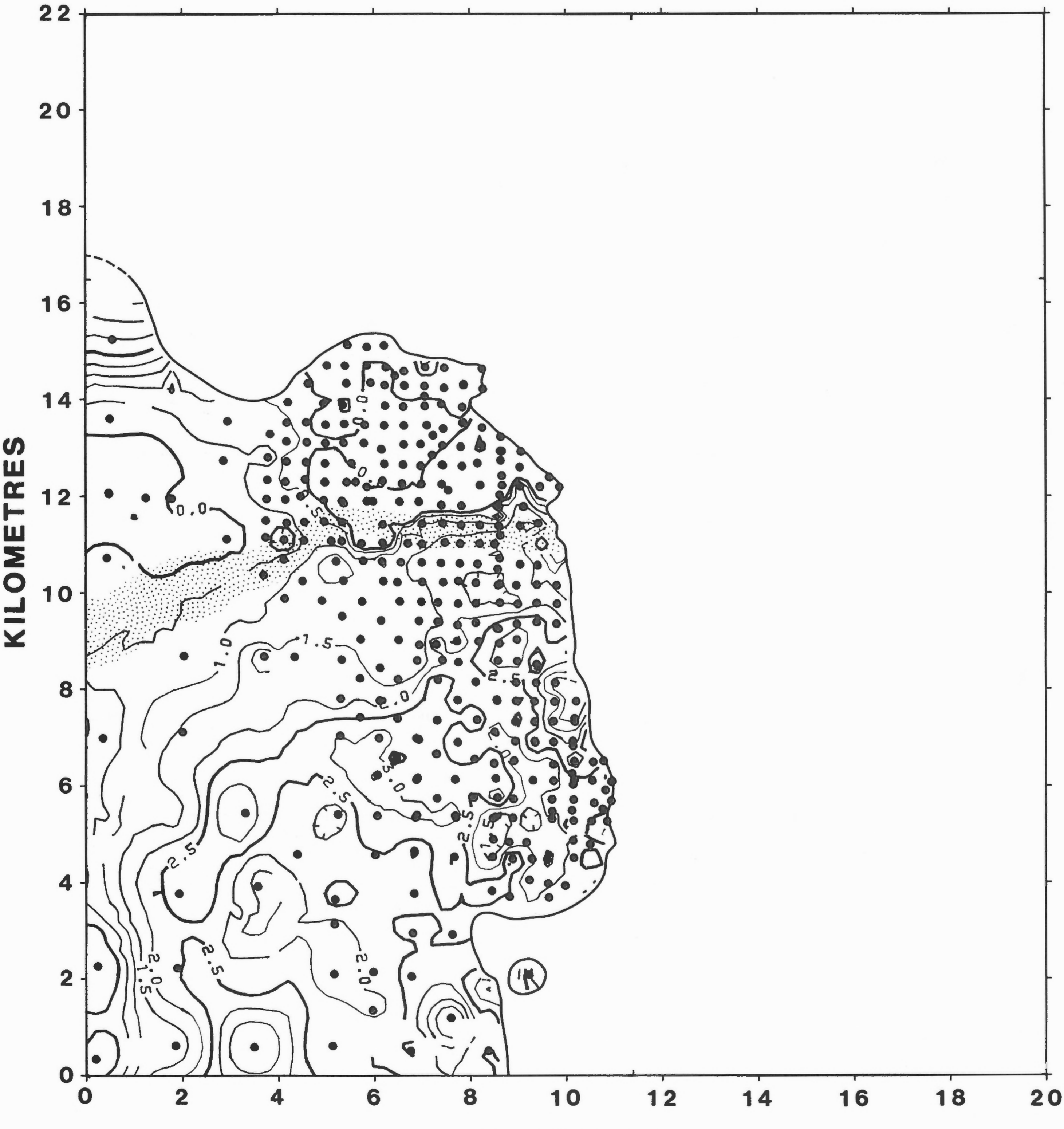


Figure 47. Isopach map and borehole control for the interval between Dusty "B" and "C" coal beds. Stippled area indicates location of linear zone of thickening in underlying Marker 4 to Dusty Coal Zone interval. Note correspondence of pinch-out line with this underlying feature. Contour interval is 0.5 m.

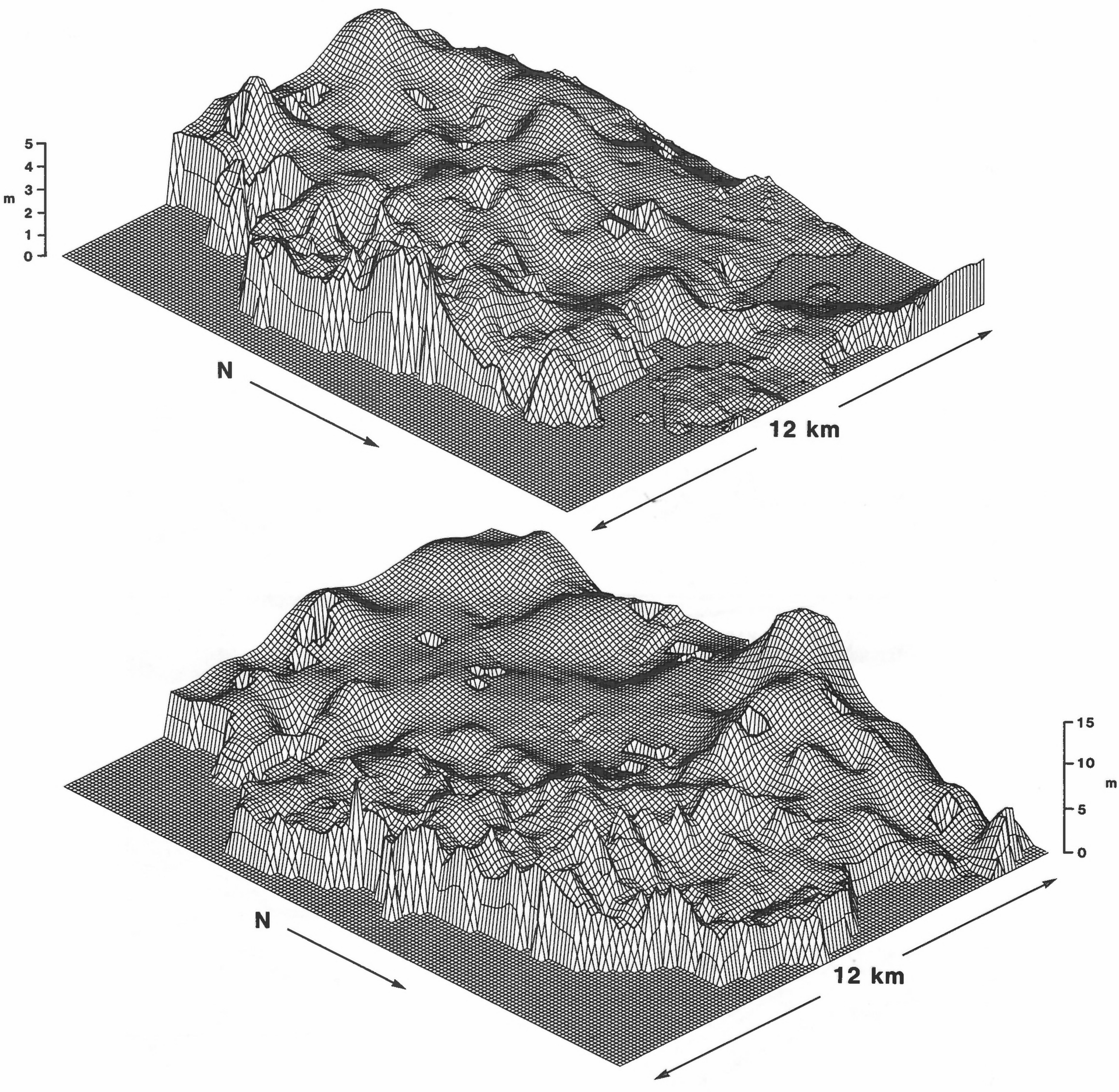


Figure 48. Perspective diagrams viewed from northeast, illustrating variations and interrelationships between total thicknesses of Marker 4 to Dusty Coal Zone (lower diagram) and Dusty "B" to "C" (upper diagram) intervals.

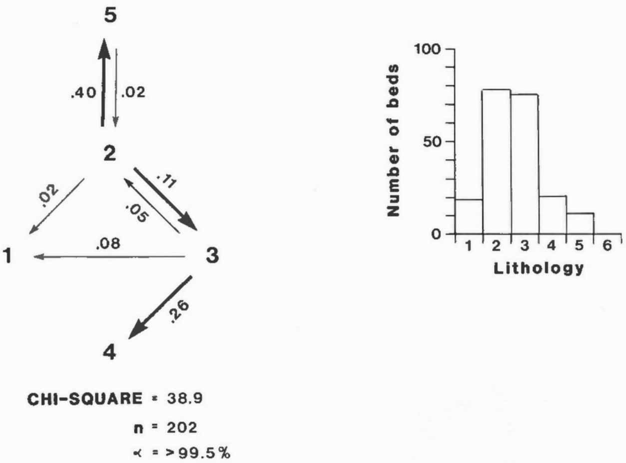
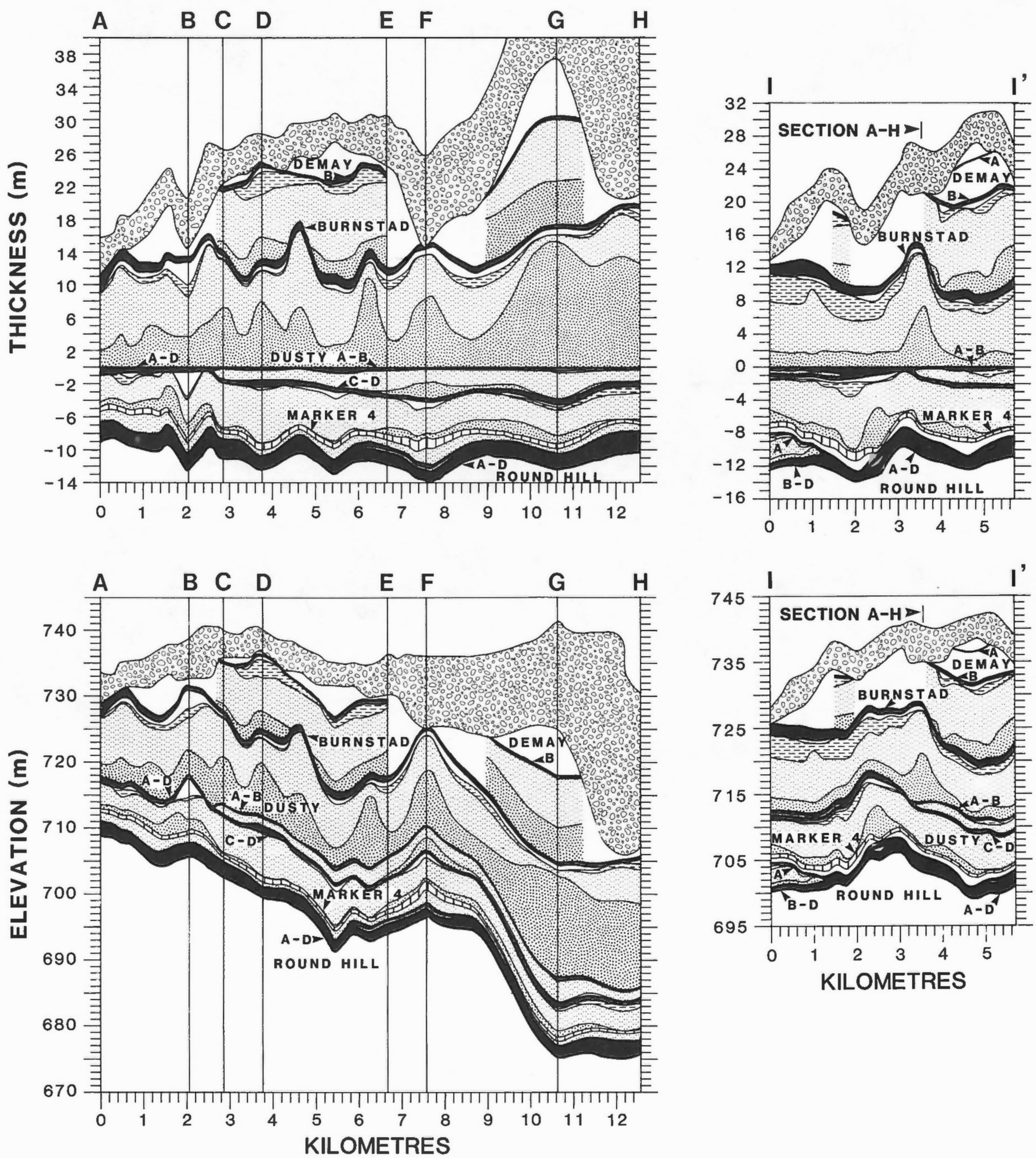


Figure 49. *Markov analysis and lithologic composition of the interval between the Dusty "B" and "C" coal beds. See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of anlaysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).*



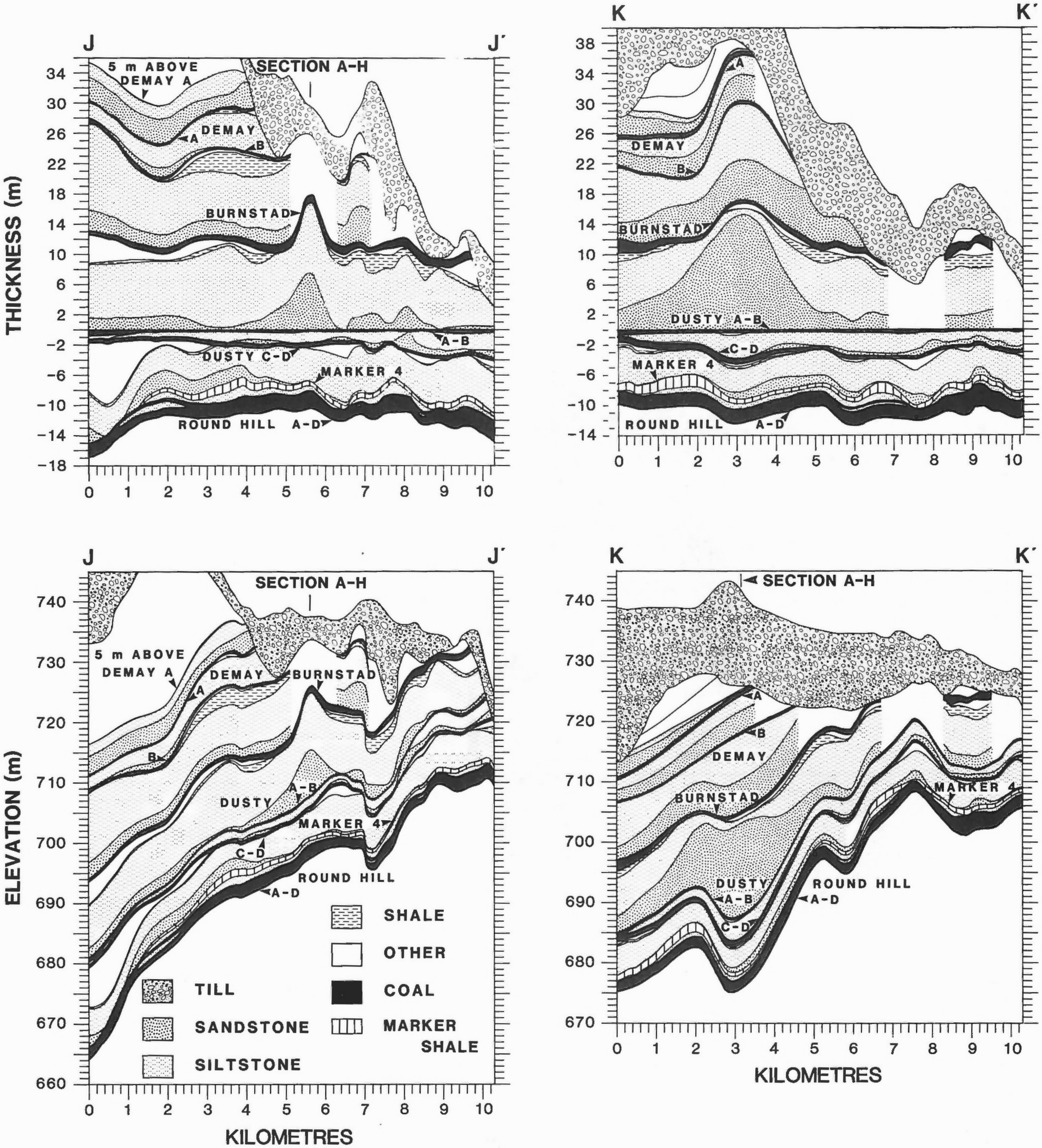


Figure 50. Cross-sections constructed parallel (A-H) and perpendicular (I-I', J-J', K-K') to the axis of the linear feature between Dusty and Burnstad Coal zones (see text). Correlated surfaces between the base of Round Hill "D" coal bed and 5 m above the Demay "A" coal bed, and the aggregate lithologic composition of intervals between surfaces are shown. See Figure 51 for locations. See text for discussion of individual cross-sections. The top of Dusty "A" coal bed is used as a datum for the upper cross-sections.

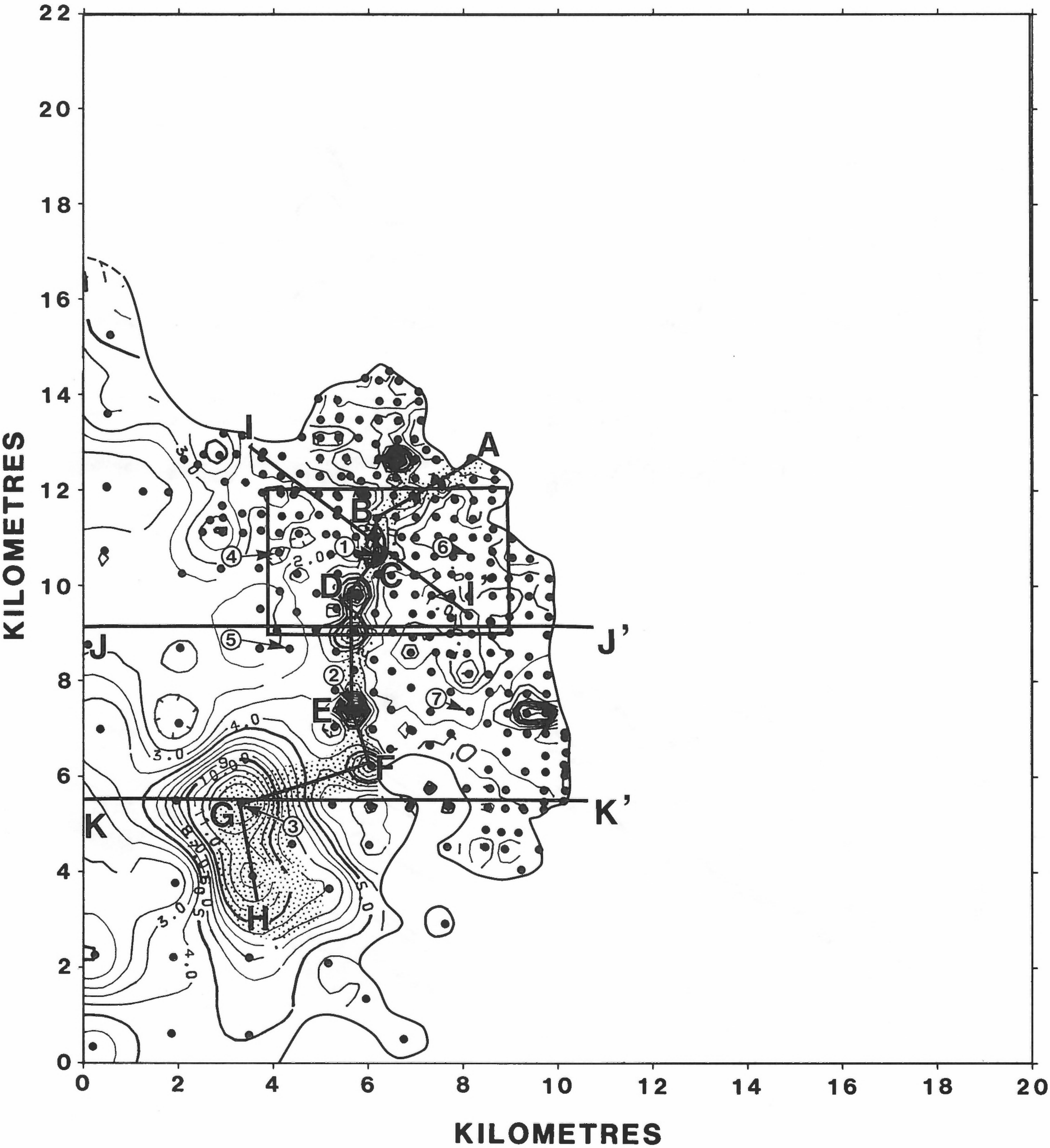


Figure 51. Aggregate sandstone thickness map and borehole control for the interval between the Dusty and Burnstad Coal zones. Stippled area indicates linear zone of thickening discussed in text. Markov analysis was performed separately on stippled area and on west and east off-axis areas. Also shown are the locations of cross-sections in Figure 50, perspective diagrams in Figure 53 (rectangle), and boreholes in Figure 54. Contour interval is 1 m.

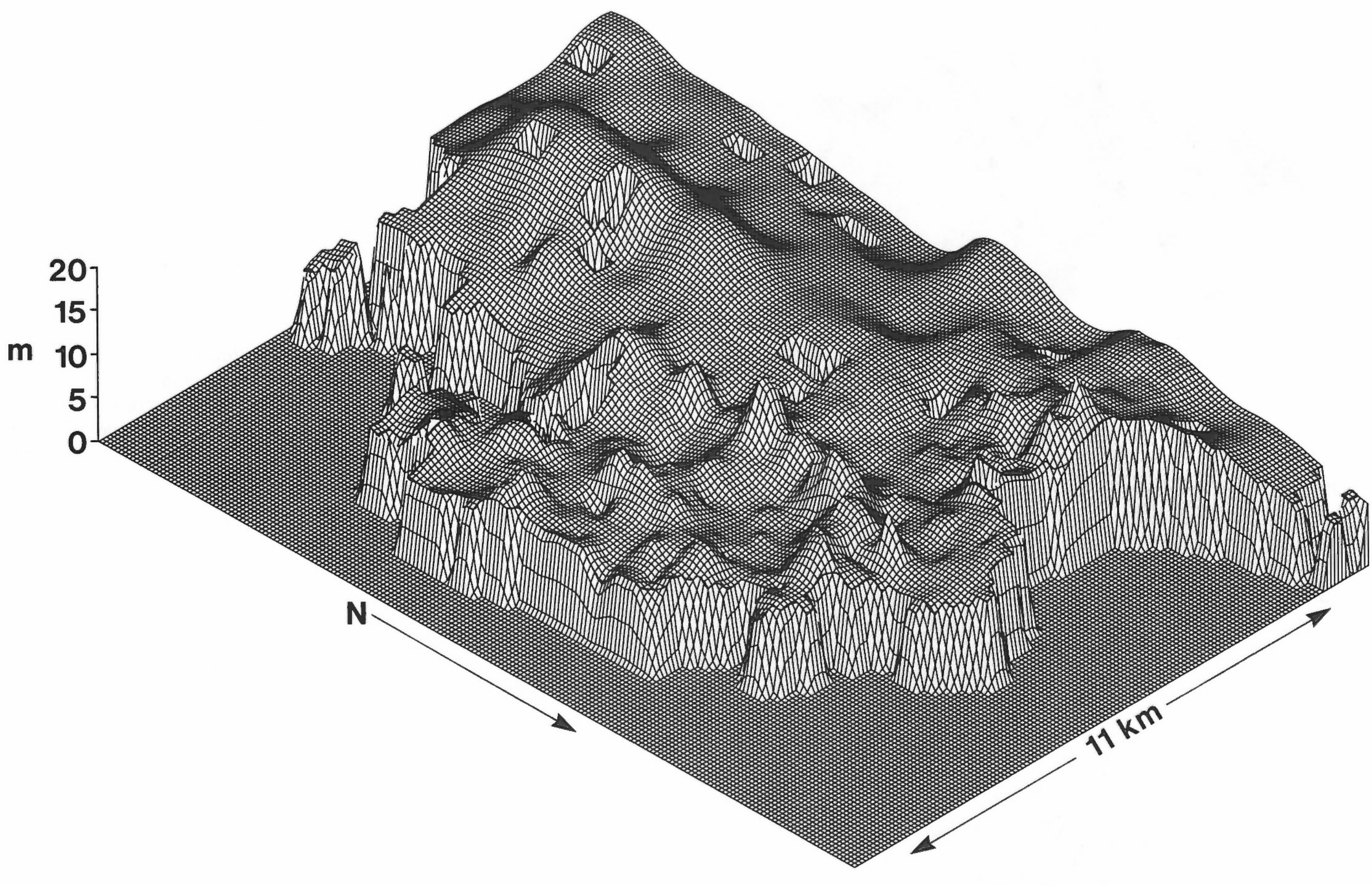


Figure 52. *Perspective diagram viewed from northeast, illustrating variations in total thickness within the interval between Dusty and Burnstad Coal zones.*

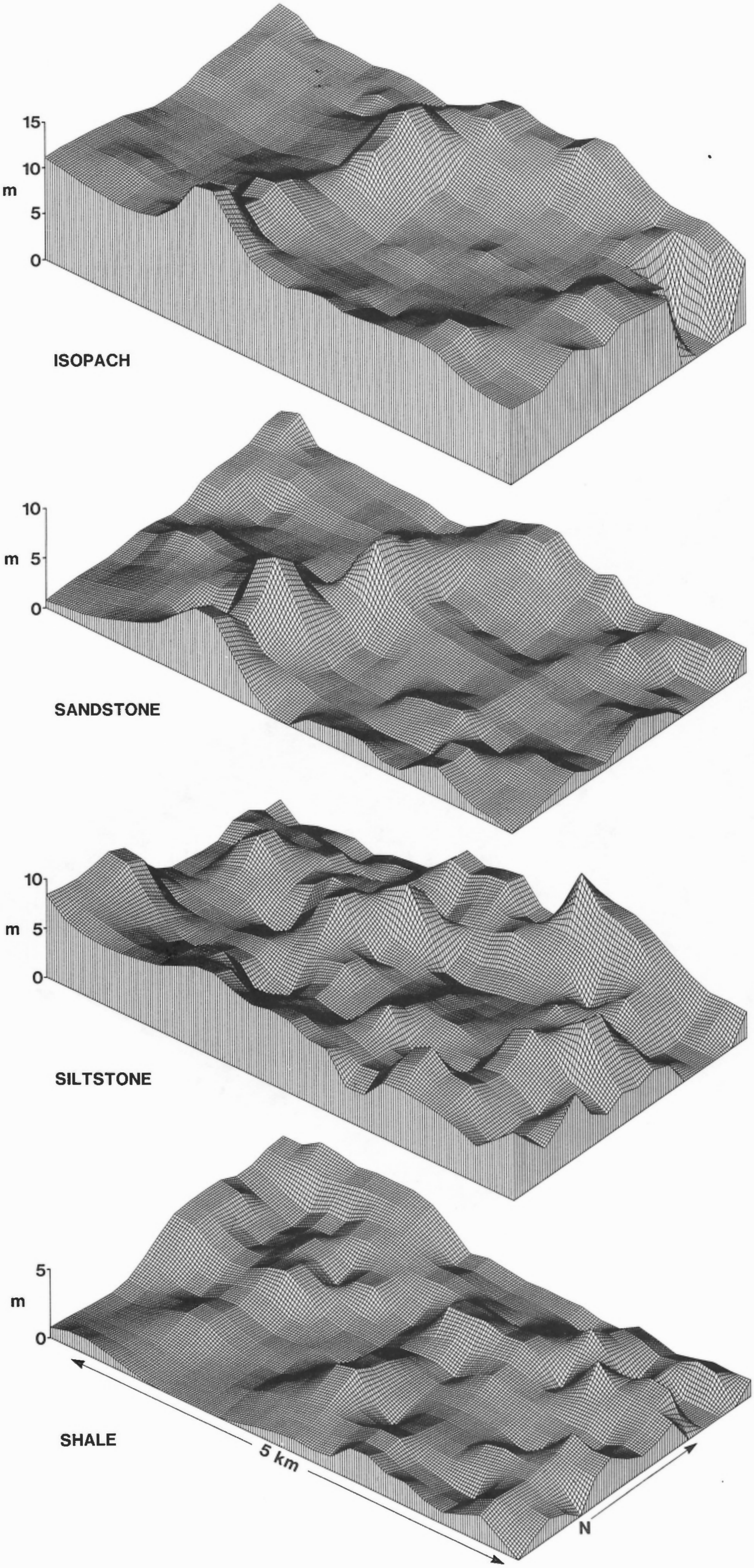


Figure 53. *Perspective diagrams viewed from southeast, illustrating variations in total thickness, and sandstone, siltstone and shale thickness associated with the linear feature between Dusty and Burnstad Coal zones (see text). See Figure 51 for location.*

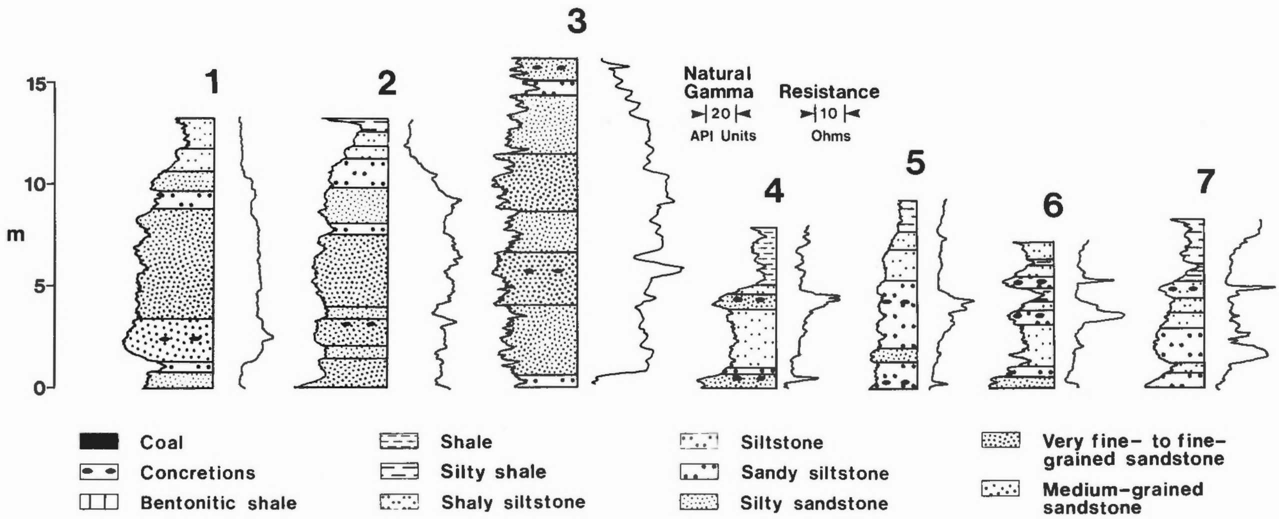


Figure 54. Geophysical log responses and interpretations for boreholes penetrating on-axis (1, 2, 3) and off-axis (4, 5, 6, 7) areas associated with the linear zone of thickening between Dusty and Burnstad Coal zones (see text). See Figure 51 for location. "0" m = top of Dusty Coal Zone.

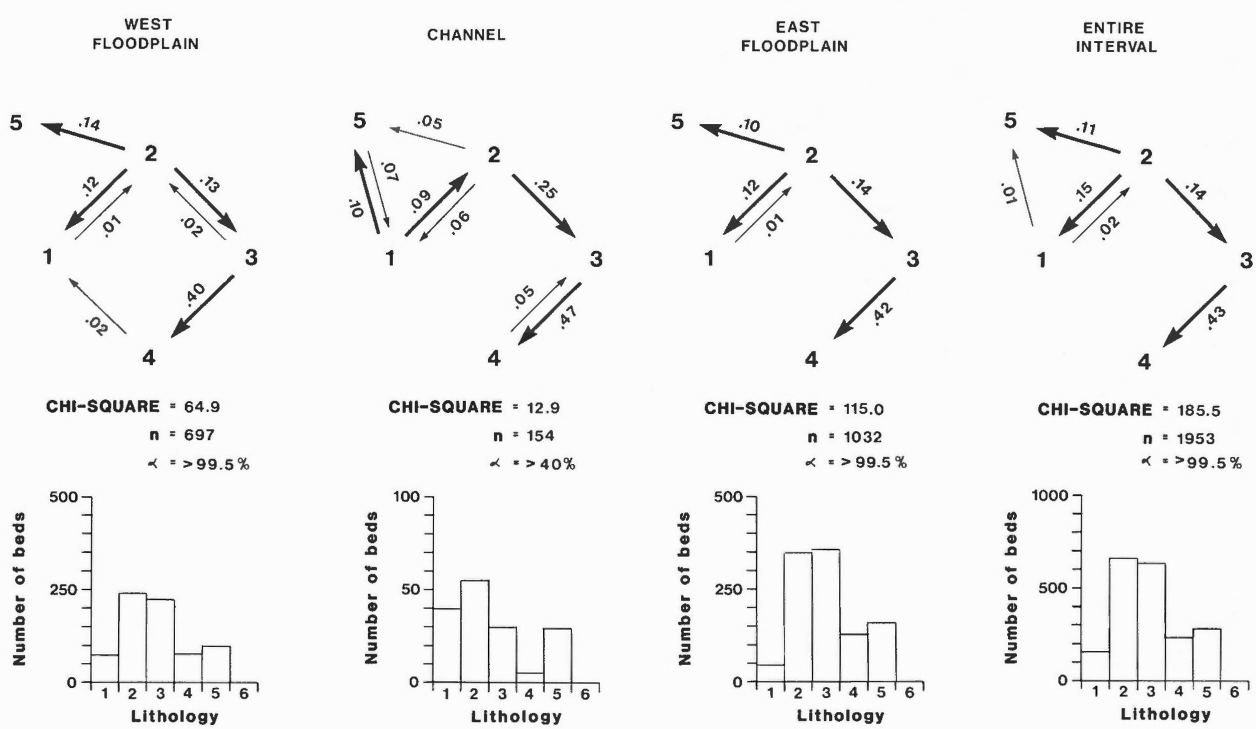


Figure 55. Markov analysis and lithologic composition of on-axis ("channel" - stippled area in Figure 51) and west and east off-axis ("floodplain") areas associated with the linear zone of thickening between Dusty and Burnstad Coal zones, and of entire interval combined (see text). See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).

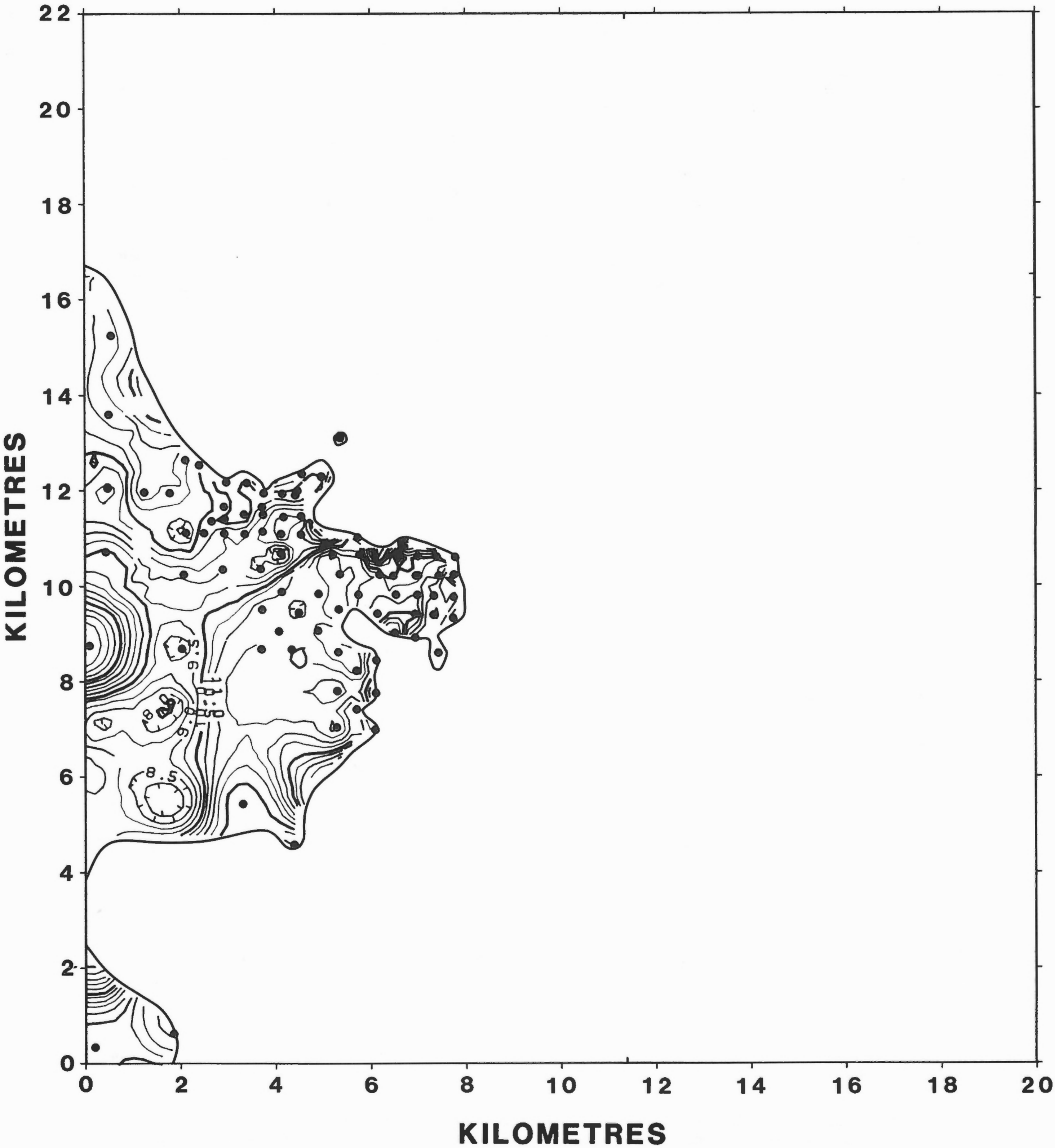


Figure 56. Isopach map and borehole control for the interval between Burnstad and Demay Coal zones. Contour interval is 0.5 m.

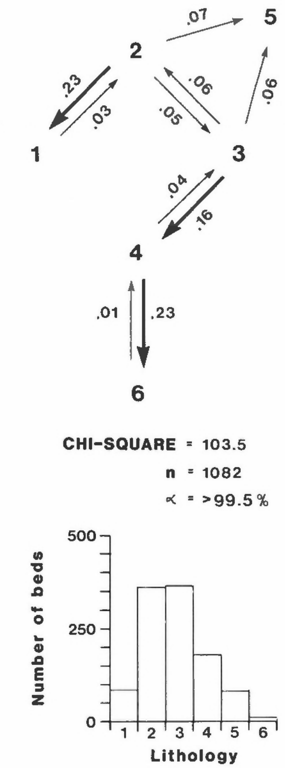


Figure 57. *Markov analysis and lithologic composition of the interval between Burnstad and Demay Coal zones. See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).*

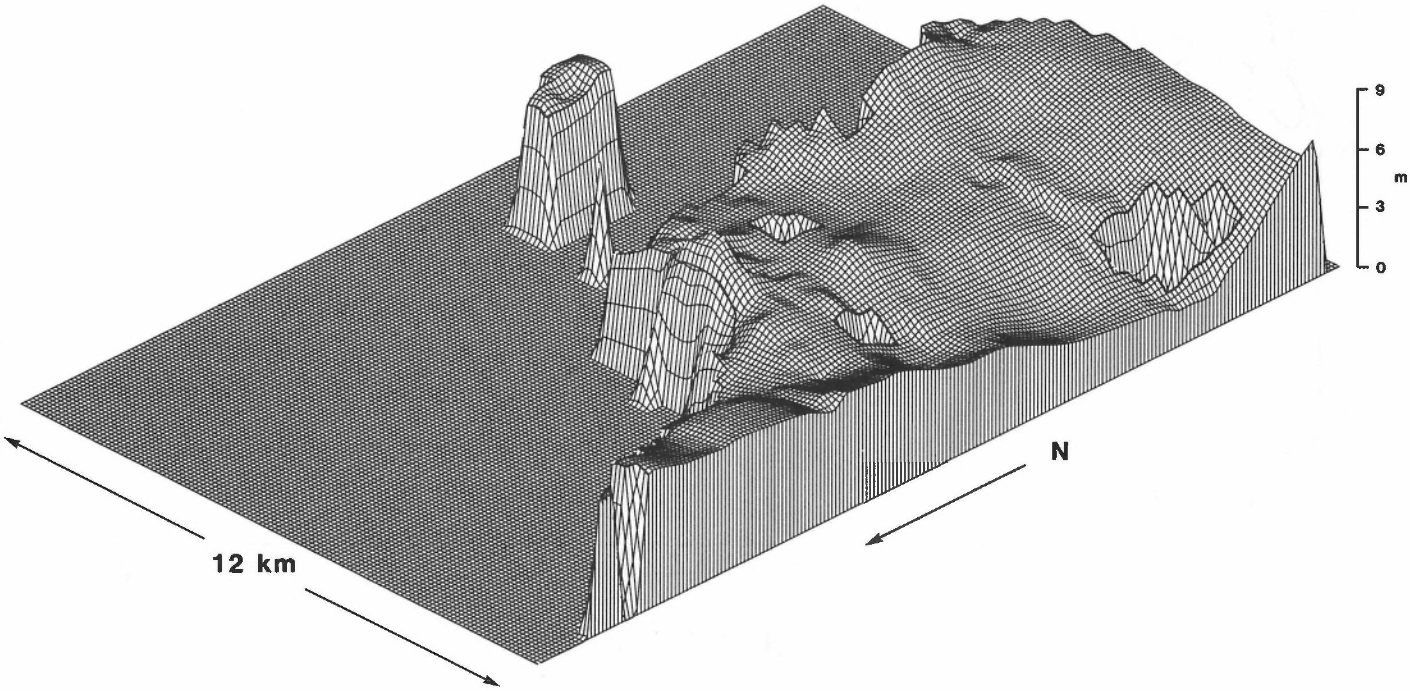


Figure 58. *Perspective diagram viewed from northwest, illustrating thickness variations within the interval between Demay "A" and "B" coal beds.*

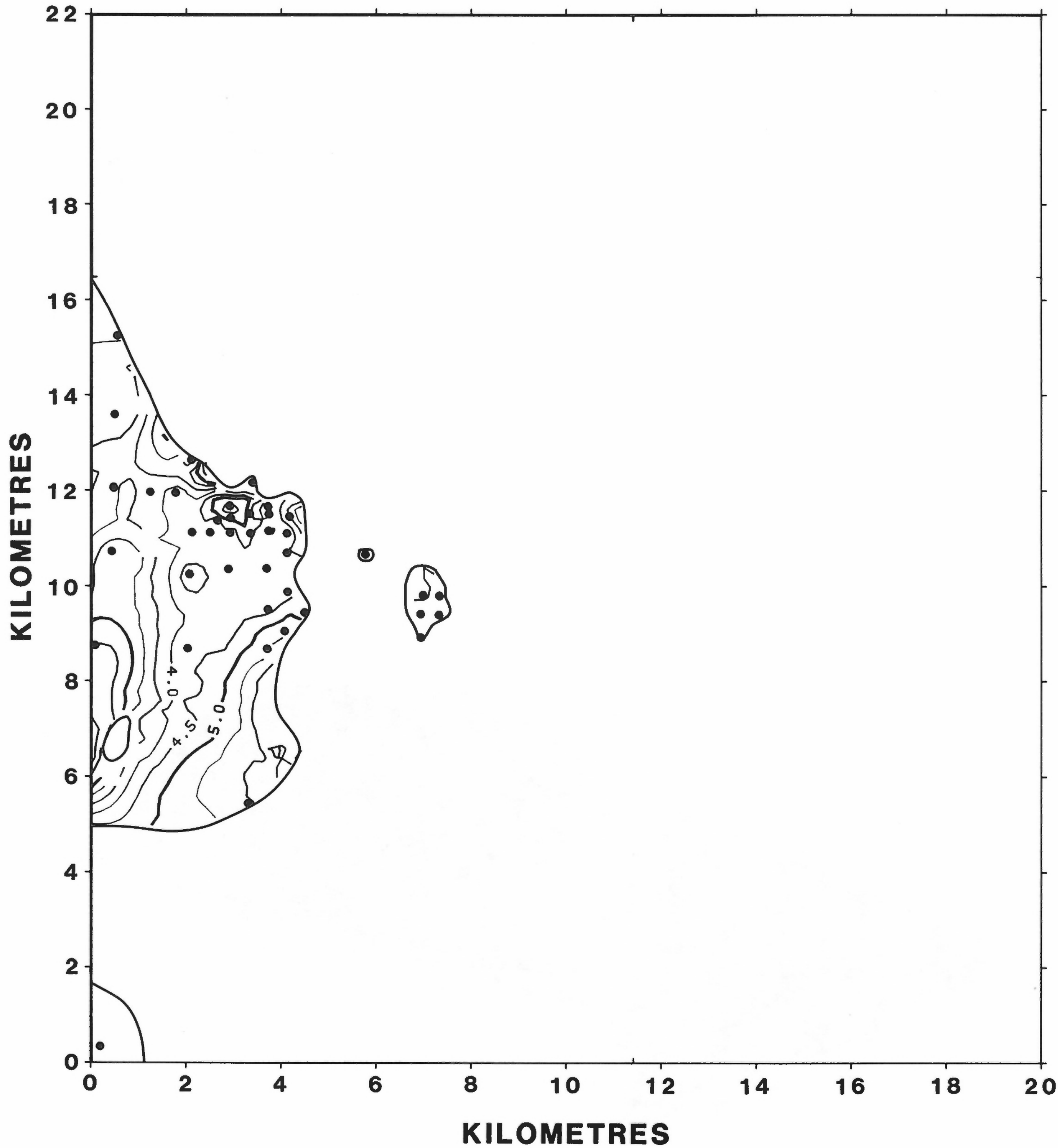


Figure 59. *Isopach map and borehole control for the interval between Demay "A" and "B" coal beds. Contour interval is 0.5 m.*

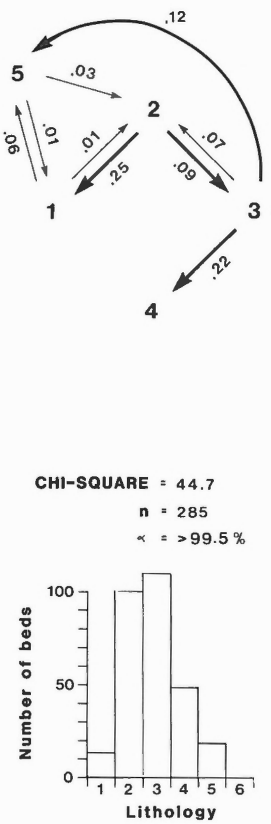


Figure 60. Markov analysis and lithologic composition of interval between Demay "A" and "B" coal beds. See Table 2 for lithologic units represented by each lithologic identifier. n = number of beds analysed; α = significance level of analysis from chi-square test; numbers on preferred transition diagram are probabilities from difference matrix (see text).

DEPOSITIONAL SETTING OF TRANSITIONAL BEARPAW-HORSESHOE CANYON STRATA

Previous work

Interpretation of the depositional setting of transitional strata between the Bearpaw and lower part of the Horseshoe Canyon formations has been addressed in varying degrees of detail by several authors. Given and Wall (1971) examined microfauna-microflora and paleoecological relationships within the Bearpaw Formation in surface and subsurface sections in southcentral Alberta. Havard (1971), Wall et al. (1971), Hills and Levinson (1975), and Wall (1976) examined lithologic, microflora-microfauna, and paleoecological relationships within the Bearpaw and lower Horseshoe Canyon formations in core from a well drilled near Strathmore, about 30 km east of Calgary (Fig. 1). Habib (1981) examined lithologic relationships within the Bearpaw Formation in the subsurface of the Calgary-Drumheller area, using oil and gas well data. Regional studies of the Edmonton Group, some of which contain brief discussions of depositional environments, include those of Elliott (1960), Ower (1960), Williams and Burk (1964), Irish and Havard (1968), and Irish (1970).

Several detailed studies of lithologic and sedimentological relationships in transitional Bearpaw-Horseshoe Canyon strata have been based on examinations of excellent surface exposures along Red Deer River near Drumheller. These include studies by Allan and Sanderson (1945), Shepheard (1969), Shepheard and Hills (1970), Gibson (1977), and Rahmani (1981, 1982). The major conclusions of these workers, as they relate to the depositional setting of the Dodds-Round Hill coalfield, are outlined briefly below.

Bearpaw Formation

The Bearpaw Formation can be traced in surface exposures from southern Alberta to Athabasca River, northwest of Edmonton, where it pinches out within nonmarine sediments of the Wapiti Group (figs. 1, 2). Regional subsurface studies indicate the Bearpaw Formation pinches out to the west in the subsurface along a north-trending line located approximately 100 km west of Edmonton and 30 km west of Calgary (Williams and Burk, 1964). North of Edmonton, Williams and Burk (*op. cit.*) suggested this pinch-out line curves to the northeast to intersect the present land surface near the Athabasca River (see Wall et al., 1971, their Figure 1).

In the Dodds-Round Hill area, the Bearpaw Formation is about 60 m thick. At Castor, about 100 km farther southeast, it is 140 m thick (Given and Wall, 1971). In the subsurface at Strathmore, Wall et al. (1971) included 27 m of strata within the Bearpaw Formation, which there is overlain by a transition zone 80 m thick. Habib (1981, his Figure 20) reported 140 m of Bearpaw strata at Strathmore and over 100 m northwest of Calgary, which suggests he may have included strata belonging to the transition zone of Wall et al. (1971) in his definition of the Bearpaw Formation.

Most workers recognize a series of gradational coarsening-upward cycles within the Bearpaw Formation. These cycles grade upward from shale through interbedded siltstone and shale to sandstone, in some cases with minor carbonaceous interbeds. Microfauna-microflora associations suggest that the shaly parts of these cycles accumulated in shallow, brackish or marine environments. Overlying sandstone and minor carbonaceous beds may represent a shallow brackish water habitat or, in some cases, subaerial exposure. Given and Wall (1971, p. 52) concluded that although several episodes of deepening are represented, all of the Bearpaw sediments they examined in south-central Alberta were deposited in "...quite shallow water...". Wall, et al. (1971, p. 697) suggested "...a shallow, inner-neritic environment with average water depth probably under 20 feet..." for Bearpaw sediments in the Strathmore core. Habib (1981) related these transgressive-regressive sequences to the successive, eastward progradation of deltaic complexes across the area.

The orientation of the western shoreline of the Bearpaw Sea is important in determining the regional paleoslope direction, and hence the progradation direction of the distributaries that deposited much of the sediment within the Bearpaw Formation. Williams and Burk (1964) indicate a north-south orientation of this shoreline south of Edmonton, and a northeast orientation farther north. Williams and Stelck (1975, p. 17) show an embayment in southeastern Alberta with an east-trending, northern shoreline on their paleogeographic map of early Maestrichtian time, which was somewhat later than the maximum extent of the Bearpaw Sea in the Late Campanian.

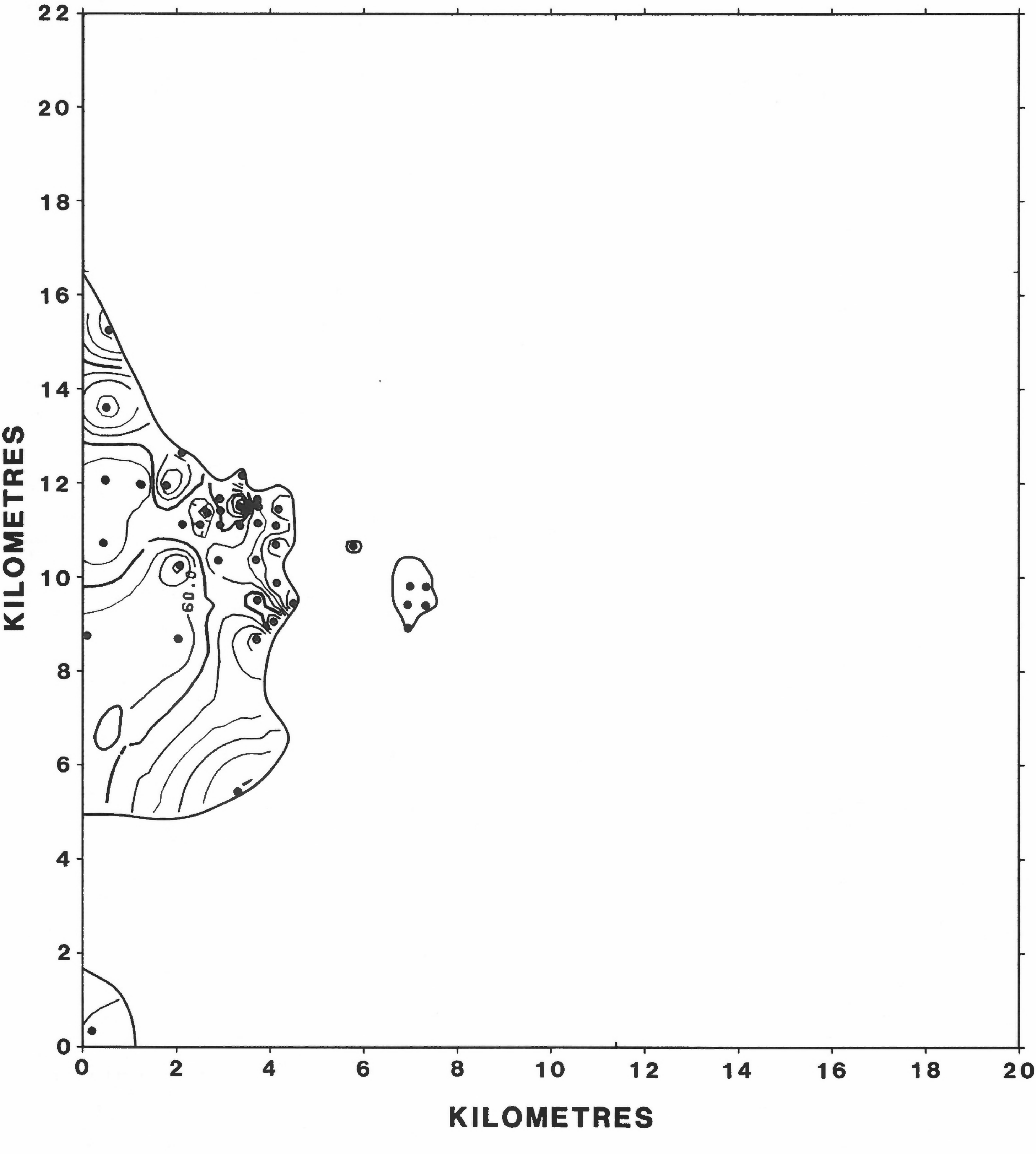


Figure 61. *Aggregate sandstone percentage and borehole control for the interval 0 to 5 m above the Demay "A" coal bed. Contour interval is 10 per cent.*

The absence, due to erosion, of Bearpaw strata in east-central and northeastern Alberta makes the orientation of the western limit of the Bearpaw Sea north of Edmonton impossible to establish. However, given the present distribution of Bearpaw strata in the subsurface, the orientation of the shoreline south of Edmonton appears to have been roughly north-south.

Transitional Bearpaw-Horseshoe Canyon strata

In the subsurface near Strathmore, transitional Bearpaw-Horseshoe Canyon strata display two prominent coarsening-upward sequences, overlain by coal-bearing strata of the Horseshoe Canyon Formation. A 1.5 m thick coal bed occurs at the base of the transitional interval at this locality (Wall et al., 1971). Microflora-microfauna relationships suggest an alternating sequence of transgressive marine and regressive brackish to freshwater environments, with the youngest marine phase represented by shales at the base of the uppermost coarsening-upward sequence (Wall et al., 1971).

Depositional models developed from examination of the surface exposures along Red Deer River near Drumheller (Allan and Sanderson, 1945; Shepheard and Hills, 1970; Gibson, 1977; Rahmani, 1981, 1982) generally agree on the following points:

1. The transitional strata are the result of sedimentation within fluvial-deltaic complexes along the western margin of the Bearpaw Sea.

2. Although marine or brackish strata recur above the lowermost coal seams in the Horseshoe Canyon Formation, there is an overall upward progression from predominantly brackish or marine to freshwater fluvial environments.

These authors differ, however, in their interpretations of the overall morphology and depositional subenvironments within these delta systems, and on their direction of progradation. As the succession along Red Deer River near Drumheller is laterally equivalent and lithologically similar to the succession in the Dodds-Round Hill coalfield, it is instructive to consider each of these previous studies in more detail.

Allan and Sanderson (1945) studied the entire Edmonton Group, utilizing exposures along Red Deer River between Red Deer and East Coulee (Fig. 1). They estimated the overall lithologic composition of the group as 30 per cent clay, 50 per cent silt and 10-15 per cent sand, with a slight predominance of silts and clays in the lower part of the group. They also identified two varieties of concretionary units: calcite cemented units associated with coarse grained lithologies; and sideritic, clay-ironstone units associated with the finest grained lithologies. In some cases, concretions with a sand matrix had dinosaur bones or wood fragments within their cores, which they interpreted as evidence of subaerial exposure. They suggested that the transitional deposits of the lower Edmonton Group were deposited in delta systems of low relief (*op. cit.*, p. 74), within which occurred channel, swamp and floodplain subenvironments. Although they suggested the source area for clastics in the Edmonton Group was to the west, they did not specify the progradation direction of these delta systems.

Shepheard and Hills (1970) studied 32 stratigraphic sections covering an interval of about 120 m of transitional Bearpaw-Horseshoe Canyon strata, measured along Red Deer River and Willow Creek near Drumheller (Fig. 1). They interpreted the laterally extensive sandstone units, which gradationally or abruptly overlie interbedded siltstones and shales of the Bearpaw Formation, as mouth bar and channel deposits of major distributaries, prograding in easterly and northeasterly directions. Overlying these sandstone units, they recognized an interval containing marginal swamp, levee, and marsh subenvironments, represented by siltstones, shales and coal deposited adjacent to major distributaries in flood basin settings on a lower delta plain. Overlying this interval they recognized a succession of marginal marine subenvironments, including interdistributary bay-fill, beach, barrier, marsh, open and restricted bay, and mud flat. They attributed the uppermost part of the succession to deposition by entirely nonmarine, fluvial processes on a lower delta plain. On the basis of limited paleocurrent data, the same writers suggested that the shoreline was oriented north-south during this period, with distributaries and fluvial channels prograding in an easterly and northeasterly direction. They also suggested that although these strata contain features that do not correspond with the deposits of any one modern delta system, they most closely resemble the deposits of the present Mississippi River Delta.

Gibson (1977) studied the entire Edmonton Group, utilizing stratigraphic sections measured at 55 localities along Red Deer River and its tributaries between Ardley and East Coulee (Fig. 1). He interpreted the laterally extensive sandstone units at the base of the Horseshoe Canyon Formation as the deposits of "...large and small braided streams flowing across a rapidly prograding delta..." (*op. cit.*, p. 16). Overlying, thinner, laterally less extensive sandstone units were interpreted as the deposits of smaller braided channels. He suggested that interbedded siltstone, claystone and fine grained sandstone may represent possible crevasse splay, interdistributary bay and flood basin deposits. Oyster-bearing black shale and sandstone units in the lower part of the formation were attributed to deposition within shallow marine or brackish water lagoons, bays or salt marshes. Coal seams represented accumulations of vegetal material in flood basin marsh or swamp areas. Gibson (*op. cit.* p. 16, 17) suggested the delta of the present Brahmaputra River of Bangladesh as a possible modern analogue for the deposits of the transitional Bearpaw-Horseshoe Canyon interval. Although he did not suggest a progradation direction for these deltaic complexes, the mean orientation of 28 paleocurrent readings collected over the transitional Bearpaw-Horseshoe Canyon interval (Gibson, pers. comm., 1983) is azimuth 087 degrees, suggesting paleoflow to the east with a north-south oriented shoreline.

Rahmani (1981, 1982) conducted a detailed study of 28 stratigraphic sections measured along Red Deer River in the study areas of Shepheard and Hills (1970) and Gibson (1977). Rahmani interpreted the basal sandstone units as the products of deposition within a distributary channel-estuarine complex. Above these basal sandstones, he recognized swamp, tidal flat, tidal channel, beach, bay-lagoon, and barrier island subenvironments. At the top of the section, he recognized fluvial strata deposited "...in the upper to lower delta plain..." (Rahmani, 1982, p. 22). Although his interpretation of the section in terms of interbedded marine, nonmarine and brackish sediments deposited within a deltaic environment is similar to the interpretations of previous workers, Rahmani differs from them in his interpretation of paleoflow directions and of the energy regimes and morphology of the depositing delta systems. Paleocurrent data collected by Rahmani from the basal sandstone unit (his unit E1) show a mean orientation of about azimuth 050 degrees (*op. cit.*, p. 8, his Fig. 8), and data from the unit immediately overlying the basal sandstone (his unit E2) have a mean orientation of about azimuth 060 degrees (*op. cit.*, p. 14, his Fig. 11). Rahmani suggested that paleoflow during deposition of the basal sandstone was from north and northeast toward the south and southwest, in an opposite direction to his paleocurrent data, and that paleoflow in the overlying unit was from "...east-northeast to west-southwest..." (*op. cit.*, p. 21). To account for this apparent contradiction of the paleocurrent data, Rahmani suggested these units were deposited in a tidally-dominated delta system, and that the directional structures measured were produced during the flood phase of tides, when currents were directed in a landward direction, and that ebb phase structures were rarely if ever preserved. In order to account for the presence of macro- to meso-tidal regimes and the existence of apparently anomalous southwestward-directed paleoflow, Rahmani postulated the existence of a local embayment in the area. He concluded that regionally, the ancient shoreline had an orientation of west-southwest to east-northeast with regional transport to the southeast. Rahmani suggested the tidally-dominated delta of the present Ord River in western Australia as a modern analogue for transitional Bearpaw-Horseshoe Canyon strata.

Present interpretations

Criteria for the interpretation of depositional setting in the Dodds-Round Hill coalfield of this report include:

1. The overall geometry of stratigraphic intervals and interrelationships with the geometries of adjacent intervals, as determined from isopach maps.

2. The lithologic composition of all or portions of stratigraphic intervals determined from the abundance of lithologic types.

3. Lateral interrelationships between lithologic units in terms of their geometry and distribution both within and between specific stratigraphic intervals, as determined from lithology-thickness and lithology-per cent maps and cross-sections.

4. Vertical lithologic relationships within all or portions of stratigraphic intervals as determined from Markov analyses and geophysical logs.

By comparing the above relationships with those observed in modern and ancient delta systems, an understanding of the depositional processes and overall morphology of the fluvial and deltaic systems within which these strata accumulated can be achieved.

Systematic studies of modern delta systems (Fisk, 1961; Allen, 1965b; Wright and Coleman, 1973; Wright, Coleman and Erickson, 1974; Coleman and Wright, 1975; Galloway, 1975; and numerous others) reveal that delta morphology is a result of the complex interaction between fluvial and marine processes. Variables affecting fluvial processes include type of sediment and the rate and annual variation in the discharge of distributaries which, in turn, are largely a function of climate, source rocks, and the size and geometry of the drainage basin. Variables affecting marine processes include tidal range, wavepower, longshore currents and the tectonics and geometry of the depositional basin. The relative energies of fluvial, wave and tidal forces are of primary importance in the determination of delta morphology and hence the geometry and distribution of lithologic units within it. Galloway (1975) constructed a threefold delta classification scheme based on the relative contributions of fluvial, wave and tidal forces. Characteristics of modern deltas that represent end members of this classification scheme, as well as those in which more than one process dominated, are discussed by Galloway (*op. cit.*), Coleman and Wright (1975) and Coleman and Pryor (1980), among others.

Several factors limit possible interpretations of transitional Bearpaw-Horseshoe Canyon strata:

1. The Bearpaw Formation accumulated in a shallow, epeiric sea under conditions ranging from shallow marine to brief periods of subaerial exposure. This suggests that wave energy would have been relatively unimportant in the delta-forming process, since high wave energies are associated with steep offshore slopes.

2. The source area for sediments within this succession was probably uplifted highlands, 150 km or more to the southwest, which were undergoing deformation at the commencement of the Laramide Orogeny. Contemporaneous volcanism associated with this deformation is indicated by the laterally extensive bentonitic shale and bentonite seams within these strata that may represent altered volcanic ash deposits. The size of the drainage basin for any one delta complex may have been relatively small compared to the drainage basins of major deltas such as that of the present Mississippi River.

3. The western limit of the Bearpaw Sea apparently lay along a north-south trending line extending from the Foothills area of southwestern Alberta to the Athabasca River northwest of Edmonton (see previous discussion), where Bearpaw and adjacent strata are truncated by the present erosion surface (Williams and Burk, 1964; Wall et al., 1971). There is little evidence for major deflections of this western limit, such as the embayment postulated by Rahmani (1981, 1982), since Bearpaw sediments are known to extend at least as far west as the Pembina Oil Field (Williams and Burk, 1964). Extreme tidal ranges, such as those postulated by Rahmani (*op. cit.*), are favored if elongate embayments or estuaries oriented at a high angle to the shoreline are present. Lack of evidence for such embayments in the subsurface distribution of the Bearpaw Formation, coupled with the probable shallow, epeiric nature of the Bearpaw Sea, suggest that tidal forces were probably of relatively minor importance in the delta-forming process.

These constraints and the vertical and lateral lithologic relationships observed in the Dodds-Round Hill coalfield, suggest that deposition by northeastward and eastward prograding, fluvially-dominated delta systems may be the most appropriate model. Strata above the Round Hill Coal Zone are considered to have been deposited within fluvial-alluvial plain settings. This interpretation is similar to that proposed by Shepheard and Hills (1970) for transitional strata in the Drumheller area. A northeastward and eastward progradation direction is consistent with the distribution and geometry of lithologic units in the Dodds-Round Hill coalfield and the paleocurrent data collected in the Drumheller area by Shepheard and Hills (1970), Rahmani (1981, 1982) and Gibson (pers. comm., 1983). Jerzykiewicz and McLean (1980) also reported northeasterly paleocurrent directions for the laterally equivalent Brazeau Formation in the western foothills of central Alberta, and Lerbekmo (1963) and McLean (1971) reported northeasterly paleoflow for the Judith River Formation of southern Alberta and Saskatchewan, which immediately underlies the Bearpaw Formation. The following discussion attempts to relate the observed vertical and lateral lithologic relationships within the Dodds-Round Hill coalfield to specific depositional subenvironments within these deltaic and fluvial systems.

Interval below Marker 1

The linear, northeast-trending sandstone body that immediately underlies Marker 1 (figs. 10, 11, 12) is interpreted as the proximal mouth bar deposit of a major distributary, prograding in a northeasterly direction into the Bearpaw Sea. At some localities in the Dodds-Round Hill coalfield and in the Drumheller area, the contacts at the base of this and equivalent sandstone bodies are sharp and apparently erosional, and at these localities may represent deposition within major distributary channels. Underlying, finer grained siltstones and shales represent deposition farther offshore in prodelta and distal mouth bar settings. Interbedded siltstone, shale and thin sandstone beds, which are laterally adjacent to this sandstone body, represent deposition between major distributaries in interdistributary bay, subaerial and subaqueous levee and, rarely, in subaerial marsh and swamp subenvironments (represented by the Ryley Coal Zone).

These major distributary mouth bar sandstone bodies may be arranged en echelon in the subsurface, as suggested by cross-section E-E' in Figure 13, where a second sandstone body is developed in the interval from 5 to 10 m below Marker 1 in the northwest part of the coalfield. Alternatively, this second sandstone body may represent an older part of the first, having been deposited by a distributary which migrated laterally to the southeast through time as it prograded northeastward down the paleoslope.

This interval is characterized by a coarsening-upward vertical profile with coal, carbonaceous beds and concretionary units associated with the coarsest grained lithologies (Fig. 14). This reflects the progradation of a major distributary into the area and deposition within subenvironments successively more proximal to its mouth, with eventual subaerial exposure and the development of carbonaceous and/or concretionary horizons.

Linear, distributary mouth bar sandstone deposits with similar vertical profiles have been reported by numerous workers in modern fluvially-dominated delta systems. Fisk (1961), Wright and Coleman (1973), Coleman and Wright (1975), Coleman and Pryor (1980) and numerous others, report that linear sandstone bodies up to 80 m thick and 8 km wide, which are oriented at high angles to the shoreline, are associated with major distributaries in the Mississippi River delta system. Lateral progradation rates of distributaries in the Mississippi Delta are high, in some cases more than 100 m per year (Scruton, 1960). Individual delta complexes within the Mississippi Delta system lasted from several hundred to more than 1000 years before major avulsion events caused lateral shifts in sedimentation to new areas (Kolb and Van Lopik, 1965). The succession of coarsening-upward sequences within transitional Bearpaw-Horseshoe Canyon strata suggests that similar processes were operating, with the establishment of a major distributary in an area marked by a coarsening-upward sequence capped by sandstone. This was followed by an avulsion event, a lateral shift of active sedimentation away from the area, subsidence, and a gradual return to brackish or marginal marine conditions, represented by shales and interbedded shales and siltstones at the base of overlying coarsening-upward sequences.

Marker 1 to Dodds Coal Zone

The stratigraphic interval extending from below Marker 1 to the Dodds Coal Zone contains Marker 1 and Marker 2, two laterally persistent bentonite and bentonitic shale units separated by predominantly fine grained, coarsening-upward strata. Marker 2 is overlain by fine grained clastic sediments (figs. 3, 17, 18, 19). The bentonitic character and lateral continuity of Marker 1 and Marker 2 suggest that they may represent altered volcanic ash deposits, similar to those reported by other workers in laterally equivalent strata (e.g. Allan and Sanderson, 1945; Shepheard and Hills, 1970). As the preservation and alteration of volcanic ash to bentonite is favored by deposition in shallow water, low-energy conditions (Grimm and Güven, 1978), the presence of these laterally extensive bentonite units, together with the predominantly fine grained, coarsening-upward character of the intervening sediments, suggest deposition within a low energy, brackish, interdistributary bay subenvironment. Similar lithologic associations have been reported by several workers (e.g. Coleman and Wright, 1975) within interdistributary bay-fill deposits of modern fluvially-dominated delta systems. The lateral continuity and overall uniform lithological composition of the interval suggest that this interdistributary bay extended for at least 15 km in a northwest-southeast direction, and for more than 20 km in a northeast-southwest direction.

The linear, north-trending, siltstone- and shale-filled feature in the eastern part of the coalfield may have been the source channel system for much of the sediment within this interval, since the overall interval thickness decreases to the west away from it (figs. 15, 18). This feature is similar to the clay-filled channel noted by Shepheard and Hills (1970) in their unit E-3 in the Drumheller area, and to the "tidal mud plug" facies of Rahmani (1981, 1982). Shepheard and Hills (*op. cit.*) reported an erosional contact below this channel unit and also noted a decrease in thickness of their unit E-3 away from it.

The concentration of sandstone in the northwestern part of the coalfield may represent local beach development on the margins of the interdistributary bay or, alternatively, result from a small, northeasterly prograding channel or distributary. The correspondence of the southeast edge of this sandstone concentration with the northwest edge of the sandstone body underlying Marker 1, suggests that differential compaction between this sandstone body and adjacent finer grained sediments may have created a topographic high that influenced sedimentation patterns during deposition of Marker 1 to Marker 2 strata (Fig. 16). A similar concentration of sandstone in the northwestern part of the coalfield between Marker 2 and the Dodds Coal Zone (Fig. 20) suggests that differential compaction below Marker 1 also may have influenced sedimentation patterns in this interval. The Marker 2 to Dodds Coal Zone interval represents the final stages of bay filling prior to the establishment of subaerial conditions and the marsh-swamp subenvironments of the Dodds Coal Zone.

Dodds Coal Zone

Coal seams within the Dodds Coal Zone represent the accumulation and preservation of vegetation within swamp and marsh subenvironments on the subaerial part of the lower delta plain, whereas rock partings separating the coal seams represent in-channel and overbank sedimentation by fluvial processes. Where the Dodds Coal Zone is thick and comprises essentially a single seam, as in the northeastern part of the coalfield, accumulation of peat was uninterrupted by overbank flooding from adjacent fluvial channels. Over much of the rest of the field, seams within the zone are split by lenticular or wedge-shaped partings, indicating periodic flooding of the swamps and resultant interruption in the accumulation of peat.

Relatively long periods of time are required to accumulate and preserve plant materials for a thick coal seam as compared, for example, to the progradation and abandonment of an individual delta lobe, such as the one represented by the sandstone body beneath Marker 1. Modern peat accumulation rates range from one-half to one millimetre per year for temperate climate peats, to four millimetres per year in tropical climate forested swamps (Stach et al., 1975, p. 17). If a subtropical climate is assumed for the Dodds-Round Hill area during the Late Cretaceous, peat accumulation rates in the order of 1.5 mm per year would be expected. If a peat to subbituminous coal compaction ratio of 5:1 is assumed, the thickest parts of Dodds Coal Zone represent at least 10 000 years, if peat accumulation and preservation were continuous; and may represent considerably more time, if peat accumulation and preservation were intermittent.

The parting between the Dodds "I" and "J" beds is wedge-shaped, thickening to the west (Fig. 22). It pinches out along the axis of the underlying zone of thickening between Marker 1 and Marker 2 in the southeastern part of the coalfield and along the western margin of the sandstone body underlying Marker 1 in the northeastern part of the field (figs. 17, 23). Throughout most of the area this parting is predominantly fine grained, comprising interbedded shale, siltstone and minor sandstone, which are interpreted as overbank-flood basin deposits from a fluvial channel located to the west and northwest of the coalfield. Other evidence for a major channel in this direction includes the thinning of most Dodds' coal beds and the thickening of intervening rock partings to the northwest, as illustrated on cross-sections D-D' and E-E' in Figure 5. Deposition within a tributary of this major fluvial channel may be represented by the linear zone of high sandstone concentration in the western part of the coalfield (Fig. 23). Some control on sedimentation patterns within this interval, by differential compaction associated with the sandstone body below Marker 1, is indicated, as the pinch-out line in the north-central part of the field, and the southeast edge of the sandstone concentration in the western part of the field, correspond with the northwest edge of the underlying sandstone body (Fig. 23). Similarly, in the southeast part of the field, the pinch-out of this parting is related to the position of the zone of thickening between Marker 1 and Marker 2 (Fig. 17).

The parting between Dodds "G" and "H" beds comprises two wedge-shaped units that thicken to the southeast and northwest from northeast-trending lines of pinch-out (figs. 25, 26). The interbedded, predominantly fine grained character of the sediments within these partings, coupled with their wedge-shaped geometry, suggests that they were deposited in floodplain subenvironments, during periods of overbank flooding from fluvial channels located to the northwest and southeast of the coalfield. The coarsest grained sediments within these partings represent relatively high-energy, current-laid, crevasse splay and possibly levee deposits, whereas the finer grained shales and silty shales represent deposition from suspension in very slow-moving, or standing, bodies of water on the floodplain. The northeastward orientation of the pinch-out lines of these partings suggests that the source channels also may have been oriented in a northeast direction. The previously discussed correspondence between the position of the sandstone body below Marker 1 and the pinch-out line of the southeastern rock parting between Dodds "G" and "H" beds (Figure 25), suggests that differential compaction may have created a topographic high over this sandstone body, which limited the northwest advance of floodwaters into the Dodds "coal" swamp.

The rock parting between the Dodds "C" and "D" beds is thought to contain both in-channel and associated overbank-flood basin deposits of a meandering fluvial channel system that flowed north and northeastwards through the west-central part of the coalfield. In-channel deposits comprise the relatively thick, fining-upward sandstone units penetrated along the axis of the linear zone of thickening illustrated in figures 29, 30 and 31 (boreholes 1, 2, 3; Fig. 31). Overbank-flood basin deposits comprise relatively thin, interbedded shale and siltstone flanking these in-channel deposits on the west.

Fining-upward sequences, similar to those observed within the in-channel parts of the Dodds "C" to "D" rock parting, have been reported by numerous workers (e.g. Allen, 1965a, 1970, 1971; Jackson, 1976) in modern and ancient meandering stream deposits. The coarsest grained, basal portion of these sequences represents in-channel deposition in relatively high energy settings. Overlying, finer grained strata represent deposition in lower energy settings on point bars, as the main channel migrates laterally and downstream. Sediments deposited on the adjacent floodplain comprise levee and proximal crevasse splay deposits near the channel, and finer grained, crevasse splay and suspension-laid deposits in more distal locations. The rather variable lithologic composition along the axis of the channel (Fig. 30) suggests that, at some localities, in-channel deposits comprise finer grained sediments, as observed in the meander cutoffs and oxbow lakes of present-day meandering fluvial systems. Alternatively, borehole control along the axis may not be sufficiently concentrated to intersect on-axis deposits at all locations, since the meander belt width of this channel system and, hence, the width of resultant channel deposits, appears to have been in the order of 500 to 1500 m (Fig. 29).

The area to the east of the fluvial channel within the Dodds "C" to "D" interval apparently was not subject to overbank flooding, as the "A-I" seam in this area is unbroken by partings and, therefore, may have been topographically high relative to the area to the west. The period of time represented by strata in the "C" to "D" rock parting was probably relatively short in comparison to the time represented by the Dodds "coal" swamp immediately to the east, as the aggregate thickness of the "A-C" and "D-I" coal seams above and below this parting (Fig. 28) is similar to the thickness of the equivalent "A-I" seam to the east, where no "C-D" parting exists. If peat accumulation and preservation were continuous during deposition of these coal beds, the "C-D" rock parting could have been deposited within a period of one thousand years or less.

Other partings within the Dodds Coal Zone are thin, lenticular, and cover relatively small parts of the coalfield. The parting between the Dodds "E" and "F" beds is composed primarily of siltstone and shale, and is considered to represent low energy floodplain deposits. The parting between the Dodds "A" and "C" beds in the north-central part of the coalfield (cross-sections A-G, H-H'; Fig. 28) has a wedge-shaped geometry, thickening to the east, and is composed predominantly of siltstone and shale. This parting also is interpreted as an overbank-flood basin deposit from a channel system in the east-central part of the field. Both the "A" and "C" coal beds pinch out in the direction of thickening of this parting in this area. The source channel for these deposits may have been the channel between Dodds "D" and Marker 3 farther east (see following discussion). If this is the case, the Dodds "A" and "C" coal beds are diachronous, being somewhat younger in the northern part of the coalfield.

Dodds Coal Zone to Marker 3

The linear, north-trending zone of thickening in the interval between the Dodds Coal Zone and Marker 3 contains predominantly coarse grained, fining-upward sediments, which are interpreted as in-channel and point bar deposits of a northerly-flowing, meandering, fluvial channel system (figs. 33, 34, 35; boreholes 1, 2, 3, Fig. 36). Although data required to define the orientation and eastern edge of this channel system are limited because of the subcrop of Marker 3 (Fig. 34), its dimensions are in the order of 700 to 1500 m in width, and more than 8 km in length. The thinner, generally finer grained sediments adjacent to this channel on the west and northwest represent overbank-flood basin deposits derived from it. In the northern part of the coalfield, a thin, laterally persistent sandstone unit underlies Marker 3 (Fig. 36). This unit is thought to represent sand reworked by wave and current action during a destructional phase of the delta complex. These sands may have been derived, at least in part, from the fluvial channel complex to the southeast, and mark the initiation of a period when the locus of sedimentation shifted laterally away from the Dodds-Round Hill area, and subsidence produced a shallow, possibly brackish, interdistributary bay.

In the southwestern part of the field, this interval pinches out along the axis of the underlying Dodds "C" to "D" channel complex (cross-sections I-I', J-J', K-K'; Fig. 28). This suggests that differential compaction created a topographic high over the axis of this channel complex, which limited the westward advance of floodwaters and hence restricted deposition to the area east of its axis, in the Dodds to Marker 3 stratigraphic interval.

Marker 3 to Round Hill Coal Zone

The interval between Marker 3 and Round Hill Coal Zone is uniform laterally in lithologic composition and thickness, comprising a predominantly fine grained, interbedded to coarsening upward sequence (figs. 28, 38, 39, 42). Marker 3, the laterally persistent bentonitic shale unit at the base of this interval, is interpreted to be altered volcanic ash, deposited in shallow water on reworked fluvial sediments of the underlying Marker 3 to Dodds Coal Zone interval. Lateral variations in the thickness and apparent bentonite content of Marker 3 suggest there may have been some reworking of the ash by wave-action and low-velocity currents after deposition. Overlying, predominantly silty sediments are considered to be the products of deposition under very low energy conditions in a shallow, probably brackish, interdistributary bay subenvironment. The gradual progradation of a distributary or main channel into the vicinity is indicated by the coarsening-upward character of the interval. Coals of the Round Hill Coal Zone mark the re-establishment of subaerial marsh-swamp subenvironments in the area. Some control on sedimentation patterns within this interval by differential compaction associated with the underlying fluvial channel in the Marker 3 to Dodds Coal Zone interval is indicated, because the interval above Marker 3 thins and becomes finer grained over the axis of the underlying channel (cross-sections J-J', K-K'; Fig. 28).

The lateral uniformity of this stratigraphic interval and the absence of any major channels or distributaries, or systematic changes in thickness, suggests that its overall dimensions during deposition may have been more than 25 km in a northwest-southeast direction. Therefore, these sediments record a period of low energy sedimentation following the abandonment of fluvial channels in the underlying interval between Marker 3 and the base of the Dodds Coal Zone. Major distributaries were probably ten or more kilometres distant from the area during this period.

Round Hill Coal Zone

The Round Hill Coal Zone marks the establishment of subaerial swamp-marsh subenvironments on the bay-fill sediments of the underlying Marker 3 to Round Hill interval. The thickness and lateral continuity of this zone in the central and southern parts of the coalfield suggest that major fluvial channels or distributaries were distant from this area for a period of more than 6000 years (see discussion of peat accumulation rates in Dodds Coal Zone section). To the northwest, however, the Round Hill coal swamps were subject to overbank sedimentation from a fluvial channel located northwest of the coalfield, which resulted in deposition of the northwestward thickening, wedge-shaped parting between the Round Hill "A" and "B" coal beds (figs. 40, 41). Both the "A" and "B-D" coal beds thin to the north toward this channel (cross-sections B-B', C-C', Fig. 5; H-H', I-I', Fig. 42). The northeasterly-trending pinch-out line of the Round Hill "A" to "B" rock parting suggests a similar orientation for the source channel.

The parting between the Round Hill "C" and "D" coal beds is unique in that it constitutes a discontinuous, concretionary, silicified zone of plant material, which always occurs at the same position with respect to the base of the coal zone. The silicified character and laterally extensive nature of this parting suggests to the author that it is related to an ash fall on the Round Hill coal swamps. Grimm and Güven (1978) noted that there is a release of silica during the alteration of volcanic ash to bentonite and that, at several localities, silicification of beds underlying bentonites has been observed. Further, Allan and Sanderson (1945, p. 69) reported a very high silica content within unaltered tuffs of the Battle Formation near Drumheller, and Grimm and Güven (*op. cit.*, p. 51) indicated these Late Cretaceous ashes were dacitic to rhyolitic in composition, with an associated high silica content. It is suggested, therefore, that the "C-D" parting may be related to the release of silica during alteration of a thin volcanic ash bed deposited on the Round Hill coal swamp, which caused selective silification rather than coalification of the underlying plant material. A similar origin may be responsible for the zone of silicified tree trunks that occur in apparent growth position near the top of the No. 1 coal seam in the Drumheller area (Shepheard and Hills, 1970; Gibson, 1977), since thin bentonite beds are reported to occur within and immediately above this coal seam.

Round Hill to Dusty Coal zones

Strata above the Round Hill Coal Zone are interpreted to be nonmarine in the Dodds-Round Hill area. Fine grained sediments between the top of the Round Hill Coal Zone and Marker 4 indicate the termination of growth in the "coal" swamps through subsidence and renewed sedimentation. This renewed sedimentation may have taken place within a lacustrine setting, since the widespread bentonitic shales of Marker 4 suggest deposition and subsequent alteration of volcanic ash within a low energy, subaqueous environment.

The interval between Marker 4 and the Dusty Coal Zone is thought to contain in-channel and overbank deposits associated with a major meandering fluvial channel. Channel deposits are contained within the 500 to 1500 m wide linear zone of thickening within this interval (figs. 43, 45), and are characterized by a high sandstone concentration and an interbedded to fining-upward vertical profile (figs. 44, 46). These strata are interpreted to represent in-channel and point bar deposition within an easterly-flowing meandering fluvial channel system. The remainder of the sediments within this interval are considered to represent overbank-flood basin deposits derived from this channel. These sediments are characterized by a thinner, interbedded to fining-upward sequence composed primarily of siltstone and shale, which becomes coarser grained and thicker near the channel (cross-sections H-H', I-I'; Fig. 42). These strata probably represent levee and proximal crevasse splay deposits near the channel, and distal crevasse splay and suspension-laid sediments farther into the flood basin.

A major avulsion event occurred at the end of deposition of this stratigraphic interval, and the locus of sedimentation shifted laterally away from the area, resulting in a quiescent period suitable for the establishment, accumulation and preservation of plant material within swamp-marsh subenvironments of the overlying Dusty Coal Zone.

Dusty Coal Zone

The Dusty Coal Zone comprises a single seam up to one metre thick in the northern part of the coalfield, and two thinner seams, split by a wedge-shaped, southeastward-thickening rock parting in the central and southern parts of the field. This coal zone indicates a period of at least 3000 years (see discussion of peat accumulation rates in Dodds Coal Zone section) in which, with the exception of the parting between the Dusty "B" and "C" beds, major fluvial channels and active sedimentation were distant from the area. The predominantly fine grained parting within the Dusty Coal Zone is interpreted as overbank deposits derived from an easterly flowing fluvial channel located to the south of the coalfield, in the direction of thickening of this parting (figs. 46, 47). The correspondence between the line of pinch-out of this rock parting and the axis of the channel complex in the underlying Dusty to Marker 4 interval suggests that differential compaction created a topographic high over this channel. This high limited the northward advance of floodwaters into the coal swamp during deposition of the Dusty Coal Zone (cross-sections H-H', I-I', J-J', Fig. 42; figs. 47, 48). Floodwaters apparently topped this high in places, however, resulting in the presence of a thin parting between the Dusty "B" and "C" beds in the northern portion of the field (figs. 47, 48).

Interval between Dusty and Burnstad Coal zones

Strata within the interval between the Burnstad and Dusty Coal Zones are interpreted as channel and overbank-flood basin deposits of a northeastward-flowing, meandering fluvial channel system. Channel deposits are confined to the linear zone of thickening, between 700 and 2000 m wide, which crosses the area in a northeast-trending direction (figs. 48, 51). These deposits are characterized by fining-upward sequences grading from fine- to medium-grained sandstone to siltstone and shale (figs. 54, 55), and are interpreted as in-channel and point bar deposits of a meandering fluvial channel. Overbank-flood basin deposits adjacent to this channel complex are thinner, finer grained, and are characterized by an interbedded to fining-upward sequence which becomes coarser grained and thicker in proximity to the channel system. These overbank sediments are thought to be levee and proximal crevasse splay deposits immediately adjacent to the channel, and lower energy, current- and suspension-laid sediments farther into the flood basin.

Although the in-channel deposits within this and other intervals undoubtedly rest on an erosion surface, similar to those reported by many authors from comparable ancient and recent deposits (e.g. Allen, 1965a, 1971, 1978), erosion has removed the underlying Dusty "A-B" bed at only one locality, in the southern part of the coalfield. This suggests that the original peat of the Dusty "A-B" coal bed was relatively resistant to erosion, and that the overlying channel cut down to the top of the Dusty Coal Zone, but in most instances did not erode through it. Similar observations have been made by other workers (e.g. Horne and Ferm, 1978; Horne et al., 1978) in comparable geological settings.

Interval above Burnstad Coal Zone

The stratigraphic interval overlying the Burnstad Coal Zone accumulated in an upper delta plain or alluvial plain setting, entirely removed from marine influence. These strata are characterized by thin coal seams and lenticular, intervening rock intervals, predominantly composed of siltstone and sandy siltstone, which occur within interbedded and fining-upward vertical sequences (figs. 56-61).

Strata between the Demay and Burnstad coal zones thicken and become coarser grained to the southeast, and probably represent overbank-flood basin deposits derived from a northeast-trending fluvial channel located to the southeast of the coalfield. Strata within the rock parting between the Demay "A" and "B" coal beds also are interpreted as overbank-flood basin deposits, derived from a channel located southeast of the coalfield, because this parting also increases in thickness and sand content in this direction (Fig. 58). The Demay "A" and "B" coal beds represent brief periods of peat accumulation in swamp-marsh subenvironments during which major overbank flood events did not occur. The thinness of the Demay coal beds, relative to underlying coal zones, suggests that flood basin areas suitable for the accumulation and preservation of peat existed for shorter periods of time and probably were of smaller areal extent than those associated with underlying coal zones.

The linear, northeasterly-trending zone of high sandstone content (Fig. 61) in the interval overlying the Demay "A" coal bed may represent in-channel and point bar deposits of a northeasterly-flowing fluvial channel. Finer grained sediments adjacent to this channel may represent overbank-flood basin deposits derived from it.

CHARACTERISTICS OF DEPOSITIONAL SUBENVIRONMENTS

Transitional Bearpaw-Horseshoe Canyon strata in the Dodds-Round Hill coalfield have, in the previous discussion, been subdivided into genetic units according to a combination of criteria, including geometry, lithology, and vertical and lateral lithologic relationships, and the comparison of these characteristics with those observed in deposits of other ancient and modern depositional environments. Shallow marine, prodelta, distributary mouth bar and channel, interdistributary bay, beach, swamp-marsh, fluvial channel and floodplain depositional subenvironments have been recognized. The following section summarizes characteristics observed for the deposits of each of these subenvironments in the Dodds-Round Hill area.

Shallow marine and prodelta subenvironments

Shallow marine and prodelta subenvironments are represented at the base of the succession in the Dodds-Round Hill coalfield by interbedded and coarsening-upward shale and siltstone units, which underlie the prominent sandstone body below Marker 1. These strata grade laterally and vertically upward into distributary mouth bar and channel deposits, and may abruptly overlie older distributary complexes. The geometry of the deposits of these subenvironments is controlled by the proximity and lateral spacing of delta lobes along the coastline. In the Dodds-Round Hill area, shallow marine and prodelta deposits have lateral continuities of more than 20 km, and from regional studies by Given and Wall (1971) and Habib (1981), lateral continuities of several tens of kilometres are indicated.

Sedimentation rates within these subenvironments are a function of proximity to major distributaries within delta lobes. In shallow marine areas proximal to distributary mouths, sedimentation rates are high, and several metres of sediment may accumulate during the time a particular distributary is active. In more distal areas, sediment supply and sedimentation rates are correspondingly lower, and one or two metres of sediment may represent an equivalent or much longer time period.

Distributary mouth bar and distributary channel subenvironments

Distributary mouth bar and channel deposits are restricted also to the lowest part of the succession in the Dodds-Round Hill area. These deposits comprise linear, northeasterly-trending sandstone bodies 5 to 10 m thick, three to six kilometres wide, and more than 25 km long, which may be arranged en echelon in the subsurface. Habib (1981), on the basis of rather sparse well control, suggested that the deposits of some distributary mouth bar complexes may extend for more than 100 km parallel to the paleoslope. Distributary mouth bar deposits accumulate in shallow marine environments adjacent to the mouths of major distributaries (e.g. Coleman and Pryor, 1980). They grade laterally into subaqueous levee, interdistributary bay or shallow marine deposits, and downward into prodelta and shallow marine deposits. Distributary channel deposits are formed at the mouths of and within distributary channels, and are recognizable within distributary mouth bar sands by their sharp, probably erosional, lower contacts. Distributary mouth bar and channel sandstones are commonly associated with concretionary units, and may grade laterally into, or be overlain by, thin coal seams, suggesting subaerial exposure. By analogy with the present Mississippi River Delta, the period of time represented by an individual distributary mouth bar and channel complex may be in the order of several hundred to one or two thousand years.

Interdistributary bay subenvironments

Interdistributary bay-fill deposits are interpreted to occur between Marker 1 and the base of the Dodds Coal Zone, between Marker 3 and the base of the Round Hill Coal Zone, and in areas laterally adjacent to the distributary mouth bar sandstone below Marker 1 (Fig. 3). These deposits are composed predominantly of siltstone and shale with minor sandstone, and display an interbedded to coarsening-upward vertical profile. They are commonly overlain by marsh-swamp deposits in the Dodds-Round Hill area and may grade laterally into levee, beach, or distributary mouth bar and channel deposits. They are characterized by lateral uniformity in thickness and lithologic composition over distances of more than 20 km in the Dodds-Round Hill area. Because the distribution and geometry of these deposits are controlled by proximity to, and distance between, major distributaries, distributary spacings of greater than several tens of kilometres along the paleoslope are indicated.

The lithologic composition and sedimentation rates within interdistributary bay-fill deposits are a function of proximity to major distributaries. Proximal to distributaries, deposition occurs within higher energy settings on subaerial and subaqueous levees, sediments are relatively coarse grained, sedimentation rates are high, and several metres of sediment may accumulate over the life span of a distributary. In distal areas, deposition occurs in lower energy settings, sedimentation rates are relatively low, and a thinner, finer grained sequence may represent an equivalent or longer time period. The linear, shale and siltstone filled feature within the Marker 1 to Marker 2 interval may represent a tidal channel within an interdistributary bay subenvironment (e.g. Coleman and Pryor, 1980).

Beach subenvironments

Although criteria utilized in this study are not particularly suitable for identification of beach subenvironments, two lithologic units have been tentatively identified as beach deposits by virtue of their coarse grained character and lateral proximity to interdistributary bay-fill sequences. These include the sandstone concentrations in the western part of the coalfield between Marker 1 and the Dodds Coal Zone, and the thin sandstone unit that immediately underlies Marker 3 in the northwestern part of the field. These units comprise coarse grained sediments which, if their interpretation as beach deposits is correct, have been reworked by wave action, and extend over areas of more than 100 km^2. The possible beach deposits between Marker 1 and the Dodds Coal Zone are part of a regressive sequence overlain by swamp-marsh subenvironments, whereas the deposits underlying Marker 3 are overlain by low energy interdistributary bay-fill strata, suggesting a transgressive period of net subsidence, during which previously deposited fluvial sediments were reworked by wave action.

Fluvial channel subenvironments

Fluvial channel deposits are present between Dodds "C" and "D" coal beds, between the Dodds Coal Zone and Marker 3, between Marker 4 and the Dusty Coal zone, and between the Dusty and Burnstad Coal zones. They are coarse grained relative to laterally adjacent strata, and commonly display a fining-upward vertical profile. They grade laterally into floodplain sediments and commonly grade vertically upward into swamp-marsh subenvironments. Channel deposits comprise between 10 and 20 per cent of the total volume of nonmarine, fluvial sediments in the succession.

Channel deposits are composed of in-channel sediments, the coarsest grained of which accumulate on erosion surfaces in the highest energy settings; and lower energy point bar deposits that form on the inside of meander bends adjacent to the main channel. Although sedimentation rates within and adjacent to fluvial channel systems are relatively high, considerable erosion of in-channel deposits occurs through lateral and downstream migration of meanders, and sediments deposited just prior to an avulsion event have the highest potential for preservation. The period of time between the initiation of a channel within an area and an avulsion event causing channel abandonment is uncertain, but appears to be relatively short in comparison to the time taken to accumulate a thick coal seam, as the Dodds Coal Zone encloses an entire fluvial channel-floodplain complex. This suggests that several metres of channel and laterally equivalent floodplain strata may represent an interval in the order of several hundred to one or two thousand years.

Floodplain subenvironments

The deposits of floodplain subenvironments comprise 80 to 90 per cent of the total volume of nonmarine, fluvial sediments in this succession. Sedimentation within floodplain subenvironments occurs during periods of overbank flooding from adjacent fluvial channels. These deposits display a wide variety of lithologies and vertical sequences, reflecting the wide range of energy conditions under which they accumulated, although they are generally finer grained and thinner bedded than laterally adjacent fluvial channel deposits. Preferred vertical sequences include both fining- and coarsening-upward units and interbedding between lithologies. Fining-upward sequences reflect a gradation to lower energy settings, perhaps during the waning phases of floods, whereas coarsening-upward sequences indicate deposition within progressively higher energy settings, which may occur during the waxing phases of floods. Interbedding between lithologies may reflect high and low energy deposits of separate flood events. The common occurrence of concretionary units and carbonaceous horizons within floodplain deposits suggests subaerial exposure between flood events.

Floodplain deposits are characteristically wedge-shaped in overall geometry, and thicken and become coarser grained toward the source channel. They may grade in their direction of thinning into swamp-marsh sediments. Deposition under the highest energy conditions occurs adjacent to the main channel, where proximal crevasse splay and levee deposits accumulate. Farther into the flood basin, deposition occurs under lower energy conditions from low velocity currents or from suspension within standing bodies of water.

Several units interpreted as floodplain deposits within the succession appear to have been derived from a single source channel, as they pinch out laterally. Other units, with more tabular, less wedge-shaped geometries, may have been derived from more than one source channel. The width of floodplain areas affected by overbank sedimentation from individual fluvial channels is at least 15 km in the case of floodplain deposits within the Dodds Coal Zone, and is greater than 10 km in floodplain strata above the Round Hill Coal Zone.

Swamp-marsh subenvironments

Peat accumulation and preservation occurs within swamps or marshes on floodplains in interchannel areas. As previously discussed, coal seams represent peat accumulation over relatively long periods compared to the probable time represented by individual fluvial channel or delta lobe deposits. The thickest coal seams in the area reflect a delicate balance between peat accumulation rates and subsidence rates for periods in excess of 10 000 years.

Coal seams accumulate within floodplain areas removed from the effects of overbank flooding and sedimentation from adjacent fluvial channels. Within the Dodds-Round Hill coalfield, the proportion of floodplain areas suitable for accumulation of thick coal seams was apparently relatively small. Coal zones are characterized by thin coal seams separated by wedge-shaped floodplain deposits, which cover areas of more than 400 km^2 in the case of the Dodds Coal Zone. Thick seams within the Dodds zone are restricted to much smaller areas, however, in the order of 50 to 100 km^2. Within the succession at Dodds-Round Hill, there is an overall upward decrease in thickness of coal seams, which suggests that floodplain subenvironments became progressively less stable, with correspondingly shorter periods for peat accumulation. This may reflect an overall change in environment from a lower delta plain setting, during deposition of the Dodds Coal Zone, to a fluvial-alluvial plain setting during deposition of the uppermost strata.

Bentonitic shale horizons within and adjacent to coal seams provide, if their interpretation as altered volcanic ash deposits is correct, time lines that can be used as an indication of the relative ages of bounding strata. Bentonitic beds within and immediately overlying the Round Hill Coal Zone suggest that these coals are approximately isochronous throughout the field. Coal beds in the Dodds Coal Zone, while broadly isochronous, may vary in age by several hundred to one or two thousand years across the coalfield (see discussion of Dodds "A-C" coal beds in previous section).

CYCLIC PATTERNS IN DEPOSITIONAL PROCESSES – INFERENCES

Although transitional Bearpaw-Horseshoe Canyon strata represent, in a general sense, a regressive sequence, grading from strata of shallow marine origin within the Bearpaw Formation through strata of deltaic to fluvial-alluvial plain origin within the lower part of the Horseshoe Canyon Formation, the vertical repetition of lithologic sequences suggests sedimentation was controlled, at least in part, by cyclic depositional processes. Lithologic cycles observed during this study range in scale from characteristic vertical cycles in sequences associated with specific depositional subenvironments, through vertical and lateral interrelationships between subenvironments, to vertical repetitions of groups of subenvironments within the constructional and destructional phases of delta development.

Large scale cycles within transitional Bearpaw-Horseshoe Canyon strata are indicated by stacked coarsening-upward sequences, reported in the subsurface of south-central Alberta by Havard (1971), Wall et al. (1971) and Habib (1981). Each of these cycles grades upward from shallow marine deposits, represented by the finest grained shales and siltstones, through progressively more proximal and coarser grained prodelta deposits, to sandstones representing distal to proximal distributary mouth bar and distributary channel deposits. The development of coals on top of the sandstones in some of these cycles (Habib, 1981) suggests subaerial exposure.

Each of these coarsening-upward sequences may be attributed to deposition within a single delta lobe prograding eastward and northeastward into the Bearpaw Sea. High sedimentation rates near major distributaries would eventually have built these lobes above local base level, making them susceptible to avulsion and a shift in active sedimentation laterally to a topographically lower location along the shoreline. Such avulsion events would be followed by subsidence and the re-establishment of shallow marine conditions. Similar processes are operating in the delta of the present Mississippi River, where seven such constructional-destructional phases of delta development over the past 6000 years have been recognized (Kolb and Van Lopik, 1965).

In the Dodds-Round Hill area, large-scale cycles are represented by alternating constructional and destructional phases of delta development. Constructional phases include the coarsening-upward interval below Marker 1, and the less pronounced coarsening-upward intervals between Marker 1 and the Dodds Coal Zone, and between Marker 3 and the Round Hill Coal Zone. Destructional phases are indicated by the abrupt return to shallow water conditions represented by Marker 1, Marker 3, and immediately overlying strata.

Under conditions of uniform sediment supply, a factor controlled by the size, geometry and discharge regimes of the drainage basin, the progradation rate and the geometry of sand deposits related to a given distributary is dependent on the subsidence rate of the receiving basin. If subsidence rates equal sedimentation rates, no progradation occurs and a relatively thick sand body is formed. If sedimentation rates are substantially higher than subsidence rates, and the receiving basin is relatively shallow, progradation rates of distributaries would be relatively high, and the thickness of sand deposits associated with a distributary considerably thinner. In the Bearpaw-Horseshoe Canyon interval, subsidence rates appear to have been relatively low in comparison to sedimentation rates at the mouths of major distributaries, resulting in rapid progradation of these distributaries into the shallow Bearpaw Sea. This has resulted in relatively thin sandstone bodies that are laterally extensive in the direction of the paleoslope. Sedimentation rates within interdistributary areas may have been much closer to subsidence rates, resulting in slow aggradation or maintenance of water depths.

The period of time represented between the initial progradation of a distributary and the avulsion event that ended its sedimentation may have been in the order of several hundred to one or two thousand years, by analogy to the modern Mississippi River delta (Kolb and Van Lopik, 1965, p. 23). The time represented by shallow marine, prodelta and interdistributary sediments deposited between progradational events may have been much longer, in the order of several thousands or tens of thousands of years. The overall sequence of events in forming these cycles appears to be as follows:

1. Progradation of a major distributary into an area, with deposition of prodelta, distributary mouth bar, distributary channel and overlying subaerial deposits.

2. Aggradation of areas proximal to the distributary channel above local base level.

3. Avulsion and establishment of a new distributary in a laterally adjacent, topographically lower area.

4. Subsidence and re-establishment of shallow water marine conditions in the area.

Following an avulsion event, new distributaries would be preferentially established in former interdistributary areas, where sedimentation rates and net sediment accumulation would have previously been relatively low. In this way, an en echelon arrangement of sand bodies is developed in the subsurface, and the overall succession, comprising groups of these large-scale cycles, is laterally relatively uniform in thickness. The shallow marine deposits of one cycle may thus be the contemporaneous, lateral equivalents of the prodelta, distributary mouth bar, distributary channel, and subaerial deposits of another.

Smaller scale cycles and lateral interrelationships between subenvironments are apparent mainly in the nonmarine, fluvial portion of the succession. A fundamental characteristic is for subenvironments with high sedimentation rates and high energy to grade vertically and laterally into subenvironments with low sedimentation rates and lower energy. Thus, channel subenvironments grade laterally to floodplain deposits and vertically to floodplain or swamp-marsh deposits. Channel deposits within adjacent stratigraphic intervals rarely overlie one another. Instead, they are arranged in an en echelon fashion, so that if a large enough stratigraphic interval is considered, net sedimentation and interval thickness are relatively uniform across a large area.

Differential compaction between subenvironments with high and low sediment accumulation rates appears to be a principal mechanism controlling the lateral distribution of subenvironments in overlying intervals. The degree to which overlying sedimentation patterns are affected by the presence of a given subenvironment is dependent on the geometry, type and distribution of its deposits. Major linear features, such as the sandstone body below Marker 1, have affected sedimentation patterns as far upsection as the Dodds "G" coal bed (see previous discussion), which may represent a time interval of several tens of thousands of years. Smaller scale feaures, such as the fluvial channel systems in the Dodds "C" to "D" rock parting, between Marker 3 and the Dodds Coal Zone, and between Marker 4 and the Dusty Coal Zone, all exert strong control on sedimentation within immediately overlying intervals (see previous discussion). However, their effect is restricted to smaller stratigraphic intervals and correspondingly shorter time periods.

IMPLICATIONS FOR COAL EXPLORATION

The lower Horseshoe Canyon interval is an important coal-bearing unit for more than 400 km along strike, between the Bow and Athabasca rivers (Fig. 1), and for an unknown but probably substantial distance downdip. Coal exploration drilling along the part of this trend underlain by coal at surface mineable depths, varies from relatively wide spacing, in the order of five or more kilometres, to very dense drilling near existing and proposed mines, as in the Sheerness, Paint Earth and Dodds-Round Hill coalfields (Fig. 1). Coal exploration programs conducted by private companies along this trend tend to be iterative processes. Initial drilling occurs on relatively widely spaced centres to define the presence of coal and the general configuration of seams. Infill drilling refines this correlation framework and provides additional information on coal quality and geotechnical parameters of coal and interseam strata. Of fundamental importance in these exploration programs is the establishment of the most accurate correlation framework possible, as such a framework forms the basis of all subsequent engineering and mining feasibility studies.

The present study indicates that these transitional strata can be subdivided into several depositional subenvironments, each with unique geological characteristics. A knowledge of these characteristics allows the probable geometry of interseam rock units to be estimated, and hence constrains possible interpretations during the correlation process. The geometry of interseam strata ranges from relatively tabular bodies, comprising shallow marine, prodelta and interdistributary bay-fill sediments, through wedge-shaped features, comprising overbank-floodplain sediments, to narrow, linear, sand-filled features deposited within fluvial channel and distributary mouth bar subenvironments.

Bentonitic partings provide extremely useful marker units which, although thin, extend over areas of several hundreds of square kilometres and may represent time lines. Although individual coal seams are quite variable laterally, with seams more than two metres thick being restricted to relatively small areas, groups of coal seams, such as the Dodds Coal Zone, extend over much larger regions.

The presence of specific subenvironments has ramifications concerning the amount of drilling required to adequately define coal seam configuration. Coal seams separated by fluvial channel deposits may require borehole spacings of 400 m or less to adequately define their geometry, whereas seams separated by overbank-floodplain or interdistributary bay-fill subenvironments can be adequately defined with a much broader spacing. The geometry and orientation of interseam rock intervals, and of areas of thick coal accumulation, is strongly related to the orientation of major channels and distributaries, which is in turn a function of regional paleoslope direction. Paleocurrent measurements from transitional strata at Drumheller (Shepheard and Hills, 1970; Rahmani, 1982; Gibson, pers. comm., 1983) and the geometry and distribution of lithologic units in the Dodds-Round Hill area suggest that the regional paleoslope was to the northeast and east during deposition. The present study also demonstrates that differential compaction associated with specific subenvironments, particularly the linear distributary mouth bar and fluvial channel sandstones, has, in some cases, had a profound effect on the present geometry of adjacent coal seams, and also influenced sedimentation patterns during deposition of overlying strata.

Preliminary studies of subsurface data from the Sheerness, Paint Earth and Morinville-Legal coalfields, all within the lower Horseshoe Canyon Formation, suggest that the depositional framework in these areas may be similar to that at Dodds-Round Hill. Application of knowledge gained from this study of the geometry, lithologic composition and lateral and vertical lithologic inter-relationships within specific depositional subenvironments may, therefore, aid in the interpretation of less densely explored, laterally equivalent areas.

Fundamental to studies such as this one is the construction of a consistently defined database of all available exploration information. Computer-based methods are ideally suited to the collection and subsequent manipulation of the typically large volumes of data that are available for many coalfields. Validity checks on data entry, and the ability to display and manipulate data in a variety of ways, allow a large proportion of errors to be identified and corrected. Once an error-free state is achieved, a variety of displays suitable for the assessment of the geology, depositional setting, resource and reserve quantities and geotechnical properties can be rapidly generated.

CONCLUSIONS

Coal-bearing strata within the Dodds-Round Hill coalfield comprise a regressive sequence grading from shallow marine deposits of the upper Bearpaw Formation, through deltaic deposits to fluvial-alluvial plain sediments within the lower Horseshoe Canyon Formation. Deltaic deposits accumulated in several subenvironments within fluvially-dominated delta complexes prograding in a northeasterly direction. Constructional phases of delta development occurred when distributaries or fluvial channels were within or immediately adjacent to the area, and include most of the deltaic sediments in the succession. Destructional phases of delta development are represented by an abrupt upward transition from subaerial to subaqueous deposits, which suggests subsidence following a lateral shift of active sedimentation away from the area. Destructional phases are indicated by strata at the base of the Marker 1 to Marker 2 interval and by Marker 3 and immediately overlying strata.

Shallow marine, prodelta, distributary mouth bar, distributary channel, interdistributary bay, beach, swamp-marsh, fluvial channel and floodplain subenvironments have been interpreted within the succession at Dodds-Round Hill. Each of these subenvironments has unique attributes in terms of lithologic composition, vertical and lateral lithologic interrelationships and geometry. Differential compaction between the deposits of laterally adjacent subenvironments appears to have influenced sedimentation patterns during the deposition of overlying intervals, and strongly influenced the present configuration of overlying and/or underlying coal seams. Bentonite and bentonitic shale horizons, which probably represent altered volcanic ash deposits, form very valuable marker horizons that may be isochronous throughout the area. A laterally extensive concretionary unit within the Round Hill Coal Zone may represent silicification of plant material, related to the alteration of volcanic ash within a swamp-marsh subenvironment.

The accumulation and preservation of peat within the thickest coal seams of the Dodds-Round Hill area involved relatively long periods of time as compared to thicker clastic sequences deposited within other subenvironments. Coal seams within individual zones are separated by lenticular rock partings, predominantly of overbank-floodplain origin. Although the Dodds Coal Zone extends over an area of more than 400 km^2, portions of these coal zones, where thick seams are preserved, cover much smaller areas. These areas were probably topographically high during deposition, or distant from active channels and, therefore, were removed from overbank sedimentation.

Knowledge of the characteristics of depositional subenvironments within and adjacent to coal zones allows the prediction of probable seam geometries during exploration, and can indicate borehole densities required to adequately define seam geometry. Knowledge of the distribution of lithologies in interseam strata also is important later in the development process to determine the presence of aquifers, mineability of overburden, and other geotechnical and environmental considerations.

Large volumes of surface and subsurface exploration data are available for Canadian coalfields, many of which are of good quality and are ideally suited to the types of analyses discussed herein. Through the National Coal Inventory, the Geological Survey of Canada is endeavouring to compile these data into a consistently defined, computer-processable format, from which a comprehensive understanding of the geology, resource and reserve quantities and quality of Canada's coal deposits may be derived.

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