At Coal Valley there appear to be two generations of southwest-dipping faults. The older structures are low-angle, bedding-plane thrusts which glide within some of the coal, carbonaceous mudstone and bentonite horizons of the coal zone and which are commonly the bounding thrusts of duplexes (see below). The younger faults are higher-angle thrusts which cut up-section through both competent and incompetent horizons as well as through the duplexes. Some appear to be imbricates which merge with bedding plane thrusts at depth. They tend to make 30° angles with bedding, but the actual dip of some of the faults can be very steep because they have rotated along younger underlying listric thrusts.

Duplexes

A duplex consists of two thrusts, both essentially parallel to bedding, separated by a series of more steeply dipping imbricate thrusts that have thickened the intervening stratigraphic succession. The term *duplex* was first applied to a fault zone in southwestern Alberta. In this area the Lewis and Mount Crandell thrusts are the floor and roof thrust boundaries of "a suite of more steeply dipping minor thrusts that thicken and shorten an intervening panel of rock" (Dahlstom 1970). This type of structure was documented by Peach *et al.* (1907) in the Scottish Caledonides but was termed "schuppen" or "imbricate" structure, neither term implying the existence of a roof thrust. Duplexes have subsequently been documented in the southern Appalachians (Boyer 1976), southeastern British Columbia (Fermor and Price 1976) and in the Scottish Caledonides (Elliott and Johnson 1980).

In the Canadian Rockies thrusts tend to have staircase geometries, with bedding-plane glide zones or 'flats' connected by footwall longitudinal 'ramps', that make angles of less than 35° to bedding. Boyer (1978) believes that duplexes form from the progressive breakdown of the footwall ramp connecting two flats. The outcome of the breakdown of a ramp is the stacking of a panel of rock called a 'horse', due to movement of the panel along the floor thrust flat and up

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STRUCTURAL GEOLOGY NEAR COAL VALLEY, ALBERTA.

University — Université

Univ. OF ALBERTA

Degree for which thesis was presented — Grade pour lequel cette thèse fut présentée

M. Sc. GEOLOGY

Year this degree conferred — Année d'obtention de ce grade

Spring 1982

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Structural Geology of the Luscar-Sterco Mine, Coal Valley, Alberta

by

© Lawrence G. Gagnon

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF Master of Science

IN

Geology

Department of Geology

EDMONTON, ALBERTA

Spring 1982

THE UNIVERSITY OF ALBERTA

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Structural Geology of the Luscar-Sterco Mine, Coal Valley, Alberta submitted by Lawrence G. Gagnon in partial fulfilment of the requirements for the degree of Master of Science in Geology.

H. A. K. Charlesworth

Supervisor

Date April 20, 1982

Abstract

In a 55 km² area in the outer Rocky Mountain Foothills of west-cen-
Alberta, data from some 260 outcrops and 1900 drillholes were analyzed
systems for collecting both data types proved to be very efficient. The
data were stored, retrieved and processed using a Fortran computer pac... for
structural analysis.

Strata at Coal Valley belong to the Coalspur beds of uppermos... etace...
to Paleocene age which lie between the Brazeau and Paskapoo Formatic... the
Saunders Group. Structural analysis was restricted to a 300 m thick co... the
the upper portion of the Coalspur beds. The zone contains seven coal seams and
five other traceable marker horizons of which the most important are the Mynheer
and the Val D'or coal seams.

Regionally the study area lies just southwest of the Alberta Syncline. Strata
in the coal zone lie in duplexes between bedding plane thrusts, are cut by
southwest and northeast-dipping thrusts and transverse ramps, and are gently
folded.

Northeast-verging bedding plane thrusts within the Mynheer, Wee and
Val D'or coal seams are believed to have developed contemporaneously: the
Mynheer thrust occurs on one side of a transverse ramp and the Wee and
Val D'or thrusts on the other. Imbrication between bedding plane roof and floor
thrusts at the tops and bottoms of the Mynheer and Val D'or seams has formed
duplexes and increased the seam's thickness up to twenty times. Younger
southwest-verging folds and thrusts altered the geometry of the duplexes. The
largest of the thrusts, the Halfpenny Creek thrust, is believed to cut up-section
from the Mynheer to the Val D'or duplex and to have had a major effect on the
thickness of the Mynheer duplex. Deformation at Coal Valley concluded with

movement along the Beaverdam transverse ramp and contemporaneous southwest-dipping thrusts. These thrusts have cut the Val D'or duplex, juxtaposing older and older strata to the southwest and are believed to merge with a bedding plane thrust below the Mynheer coal seam. Folding in the area is predominantly gentle and the result of bending above thrust-related thickening at depth.

Acknowledgements

I would like to express my gratitude to Dr. Henry Charlesworth for his guidance, encouragement and criticism throughout the course of this study. To the geological staff at Luscar Exploration Company Ltd. appreciation is extended for suggesting this project, for providing access to all drillhole data and internal maps and reports, for accommodation while in the field and for drafting the figures in this thesis. In particular I would like to thank Gordon Shewchuck, Merv Rogan, Bob Engler, Ron Ronaghan and Gary Johnson for their assistance and for many useful discussions. Bob Allan, the mine geologist at Coal Valley, obtained security clearances and a telephone line for data entry. Frank Dimitrov assisted with some drafting and photography. Desmond Wynne's assistance with computer programming and systems use is gratefully acknowledged and appreciation for help with coding of geophysical logs goes to Jim Lee, Wendy Zwickel, Gordon Bailey and Bruno Wiskel.

The Alberta Research Council paid the author's salary during the summer of 1981. Other financial support was provided by an American Association of Petroleum Geologists Grant-In-Aid, the University of Alberta by means of a graduate teaching assistantship and spring bursary to the author and a Natural Sciences and Engineering Research Council of Canada operating grant to Dr. Charlesworth.

I would especially like to thank my wife, Andrea, for her constant encouragement and care during this struggle.

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I. Introduction

The Rocky Mountain stratigraphic succession at latitude 53° is divisible into an older miogeoclinal sequence, Precambrian to Middle Jurassic in age and a younger clastic wedge sequence of Late Jurassic to Paleocene age. The older sequence, dominated by Paleozoic carbonates, is well exposed in the Main and Front Ranges. The more recessive clastic wedge sequence underlies much of the Foothills. During orogenesis both sequences were thickened vertically and shortened horizontally, partly as a result of folding but mainly by movement along thrust faults that dip southwest and merge at depth with a basal detachment zone. Excellent exposures of Paleozoic rocks in the Main and Front Ranges and good seismic reflections from near the top of the Paleozoics beneath the Foothills have resulted in good documentation of the characteristics of thrusts in the miogeoclinal sequence. In contrast, poor exposures and seismic reflections for most of the Mesozoic rocks of the Foothills have prevented thrusts in the clastic wedge sequence from becoming as well known.

Recent coal exploration and production in the Foothills have generated vast quantities of drillhole data enabling structural studies to circumvent the scarcity of outcrop data. The purpose of this study was threefold:

(1) to build outcrop and drillhole data bases for a 56 km^2 area in the outer Foothills comprising the Luscar-Sterco Coal Valley mine,

(2) to retrieve and process these data with a software package for structural analysis and

(3) to determine the structure of Upper Cretaceous and Paleocene coal measures in this area, including the nature and origin of the coal pods.

In the process it was hoped that the efficiency of computer-based techniques could be demonstrated and our knowledge of Foothills structure improved.

The Luscar-Sterco mine is located in west-central Alberta 48 km southwest of Edson and 200 km west-southwest of Edmonton. The area lies just northeast of Highway #40 (Nordegg branch of the Forestry Trunk Road), 30 km southeast of Coalspur (Fig. 1). Topographic relief is moderate in the northeast to low in the southwest. Although sparse, the best natural exposures are found along the Lovett River and on ridges in the northeast. Four abandoned and three active open pits and three trenches provide good exposure and there are over 2500 geophysically logged drillholes. Access to all open pits and trenches and to most outcrops is provided by numerous mine and exploration roads.

Vegetation is typical of a medium-relief, sub-boreal climactic zone. String bogs with grasses, moss and black spruce are numerous in the southwest. Alders and willows predominate along the banks of creeks and rivers. Elsewhere a mature coniferous forest predominates, except in the north where there are large stands of trembling aspen. The regions around abandoned and active open pits are disturbed sites.

Coal has been mined in the area since the early 1900's and the present Coal Valley mine lease now encompasses the former coal mining communities of Lovettville, Reco, Foothills, Coal Valley and Sterco. The end of steam-driven locomotion in the early 1950's forced closure of these mines, but new markets for thermal coal in Ontario resulted in renewed exploration in the mid 1970's and the opening of the Luscar-Sterco mine in 1978. The yearly production is now about 3.35 million tonnes of cleaned, high volatile C bituminous coal.

The lack of exposure in the Coal Valley area reflects a similar deficiency of published geologic literature. Early reports by Dowling (1909, 1922), Stewart (1916), Allan (1920) and Allan and Rutherford (1924) introduced the stratigraphy and economic potential of the area. MacKay (1943, 1947, 1949) produced a preliminary geologic map of the Foothills belt of central Alberta and examined the stratigraphy in more detail. Much later, the Athabasca River regional geology map

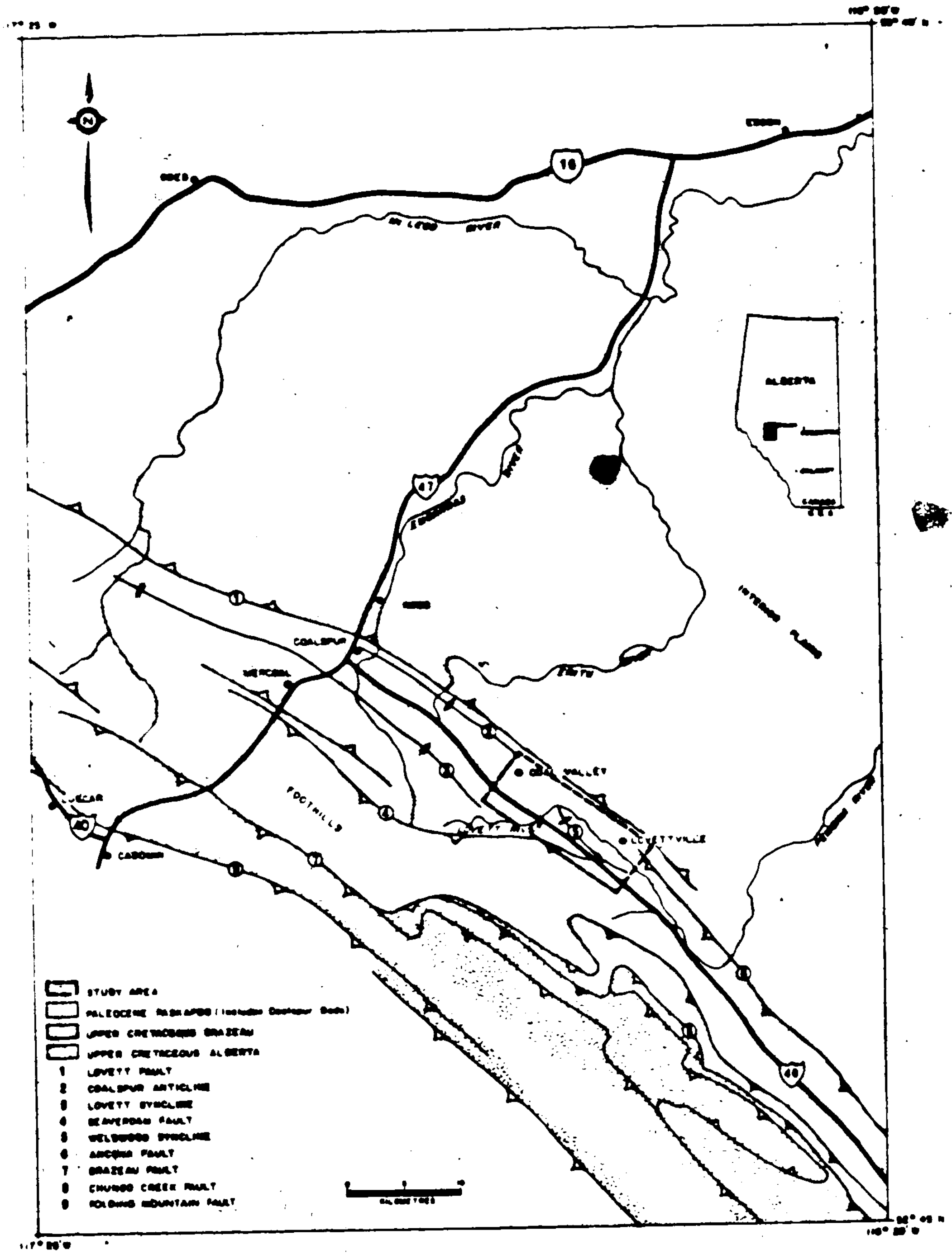


Fig. 1. Rocky Mountain Foothills in the Coal Valley area (after Price et al. 1977).

(Price *et al.* 1977), which displays structural features for the central Foothills, was completed. The configuration of the Mynheer coal seam in part of the study area was researched by Alexander (1977), and most recently the lithologic and sedimentological aspects of Coal Valley strata have been studied by Jerzykiewicz and McLean (1977, 1980) and McLean and Jerzykiewicz (1978).

II. Data Collection

A. Field Data

During the summer of 1981 six weeks were spent collecting field data from open pits, trenches and outcrops within the Coal Valley mine lease. A four-wheel-drive truck was used to reach open pits and trenches and a trail bike to reach remote outcrops. Of the 260 data stations established, most were in the open pits.

The positions of data stations were obtained from maps prepared by Luscar-Sterco and Western Photogrammetry Ltd. Up-to-date topographic maps of the four active open pits have a scale of 1:1200. These were used directly (without aerial photographs) in pit mapping. In mapping the abandoned open pits topographic maps prepared in 1977 at a scale of 1:4800 were also used directly. Most outcrops were mapped using 1:33,000 aerial photographs in conjunction with 1:4800 topographic maps. Five northeastern outcrops not covered by the 1:4800 maps were located using aerial photographs and 1:12,000 topographic maps.

Field sheets

At each data station certain positional, lithologic-stratigraphic and structural data were recorded on field sheets (Fig. 2). The format of the lithology section of the A field sheets is after Kilby (1978) except that lithologic and stratigraphic data have been coded. Most of the variables and associated codes for the A field sheets are listed in Appendix 1; the others are described in Charlesworth (1981) and will not be discussed here. The stratigraphic and lithologic coding system (Appendix 2) was based on a geophysically logged columnar section made available by Luscar Exploration Ltd. In the field the system was learned rapidly and with less time spent writing, efficiency increased. A field notebook was used to record general observations and interpretive ideas and to sketch mesoscopic features.

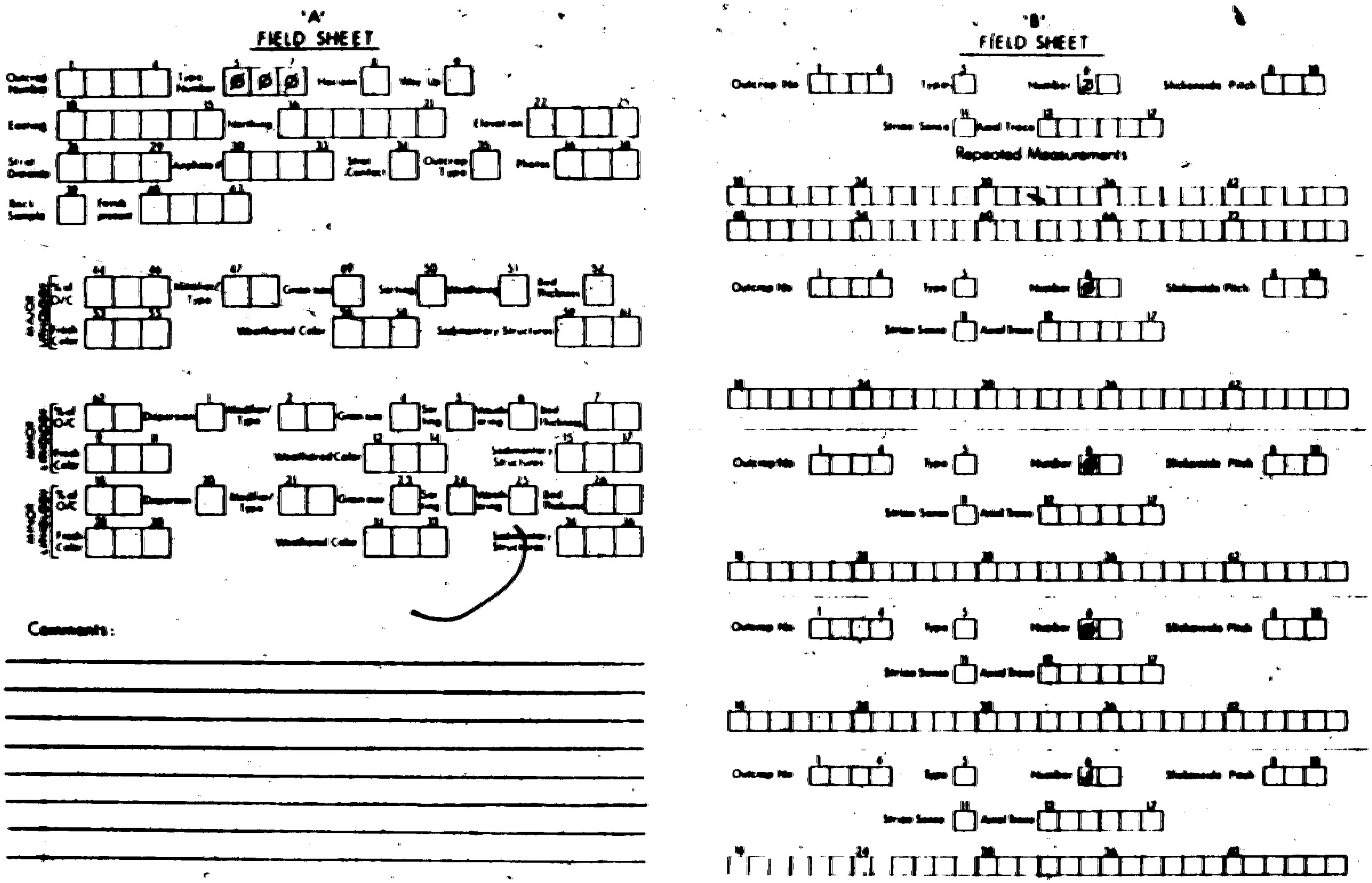


Fig. 2. Format of the A and B field sheets.

The mine grid, oriented 46° clockwise from true north, was used to specify the eastings and northings of data stations (Appendix 3). The likely error of an outcrop's recorded position depends upon the scale of the map. Positions from the 1:1200 maps should have errors of less than 2 m, from the 1:4800 maps less than 6 m, from the 1:4800 maps in conjunction with the aerial photographs less than 40 m and from the 1:12,000 maps less than 60 m. Elevations were determined by interpolating between contours on the topographic maps and should have errors of approximately half the errors in horizontal position.

Orientation measurements were made with a Freiberger structural compass and were recorded in terms of dip-direction and dip or trend and plunge with respect to true north. At each outcrop up to seven planar bedding orientations were taken, up to five readings for each joint set and as many readings as possible on fault planes and mesoscopically folded bedding.

B. Drillhole Data

An active drilling program at Coal Valley has been carried out by Luscar Exploration Ltd. since 1973. By mid-November 1981 approximately 2770 drillholes had been drilled. Data from some 1900 of these with 'picked', reliable geophysical logs were recorded. The remaining 870 drillholes were not used for one or more of the following reasons:

(1) the drillhole was not geophysically logged,

(2) the geophysical logs were unreliable, or,

(3) the drillhole collar position was unavailable or unreliable.

The first two reasons applied to some 800 of the older exploration drillholes. Recorded drillhole collar positions were unavailable or considered to be incorrect for the remaining 70 drillholes.

Most logs are gamma, caliper, density and single-point resistance curves on a scale of 1 in to 10 ft. This combination enables reliable lithologic interpretations to be made. Since the beginning of 1981 the gamma-caliper-neutron tool has been used in order to log through the drill stem in drillholes with caving problems. These logs result in less reliable lithologic interpretations.

The spacing of drillholes varies considerably. It can be as close as 8 m but in some areas no drilling has been done. The average spacing is approximately 75 m, which is sufficient in most cases to allow the structure to be estimated. The drilled depth averages 110 m with fewer than 10 holes exceeding 350 m. Most drillholes are vertical. Bottom-hole deviations are generally less than 2° for every 100 m drilled. The error in the recorded positions of drillhole marker bed intersections should therefore not exceed 5 m at the bottom of an average depth drillhole.

Drillhole sheets

Certain data from holes drilled before November 1981 were used to construct a computerized data base as follows. First, these data were written onto Drillhole A and B Sheets (Fig. 3). An alphanumeric coding system was designed for Drillhole B Sheets such that all lithologic types, stratigraphic markers, faults and even coal seam partings in each drillhole could be recorded (Appendix 2). One feature of this system is that lithologic contacts can be distinguished from stratigraphic marker horizons and faults. The stratigraphic marker codes correspond exactly to those used for the HORIZON code on the A field sheets (Fig. 2).

Once a geophysical log had been checked for reliability the header information and overburden depth were written on a Drillhole A sheet. The header data include drillhole number, orientation, collar coordinates, logged depth, mine area code and drilled depth. Next, each lithologic or stratigraphic marker and fault pick down the hole was given a code and its depth and associated drillhole number were recorded on Drillhole B sheets.

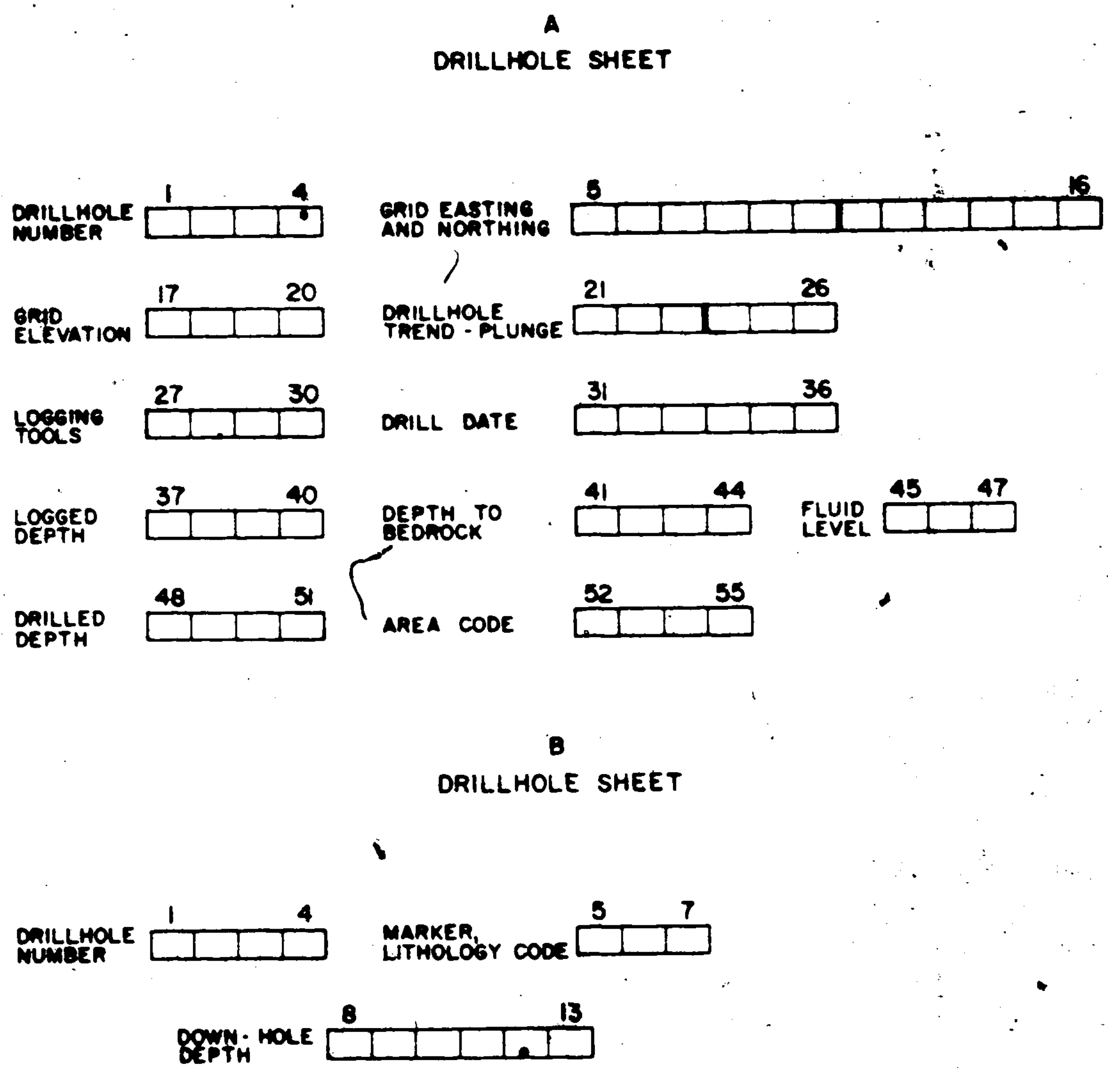


Fig. 3. Format of A and B Drillhole Sheets

III. Preliminary Data Storage and Processing

Most of the data recorded on Field and Drillhole A and B Sheets were used to construct computer files which in turn were used as input to the software package TRIPOD (Charlesworth 1981). During this procedure, some recorded data were omitted, others were reformatted, and azimuths of structural data and UTM coordinates were referred to the mine grid rather than true north. Fig. 4 is a flow diagram of the computer files and programs used for this study.

During the field season evenings were spent entering data from completed Field Sheets A and B into line files on disc at the University of Alberta Computing Centre. This was accomplished using a portable interactive terminal, acoustically coupled through a direct telephone line to Edmonton. While in Edmonton, completed Drillhole A and B sheets were keypunched, verified and entered into computer files. Files made up from completed copies of the four types of sheet comprise the *Raw Data Files*. When all outcrop and drillhole data had been stored, these files were re-formatted to *Preliminary Data Files* for use with TRIPOD (Fig. 4).

The formats of the Raw and Preliminary Data Files are found in Appendix 4 while Appendix 5 contains listings of all the processing and re-formatting programs referred to in Fig. 4.

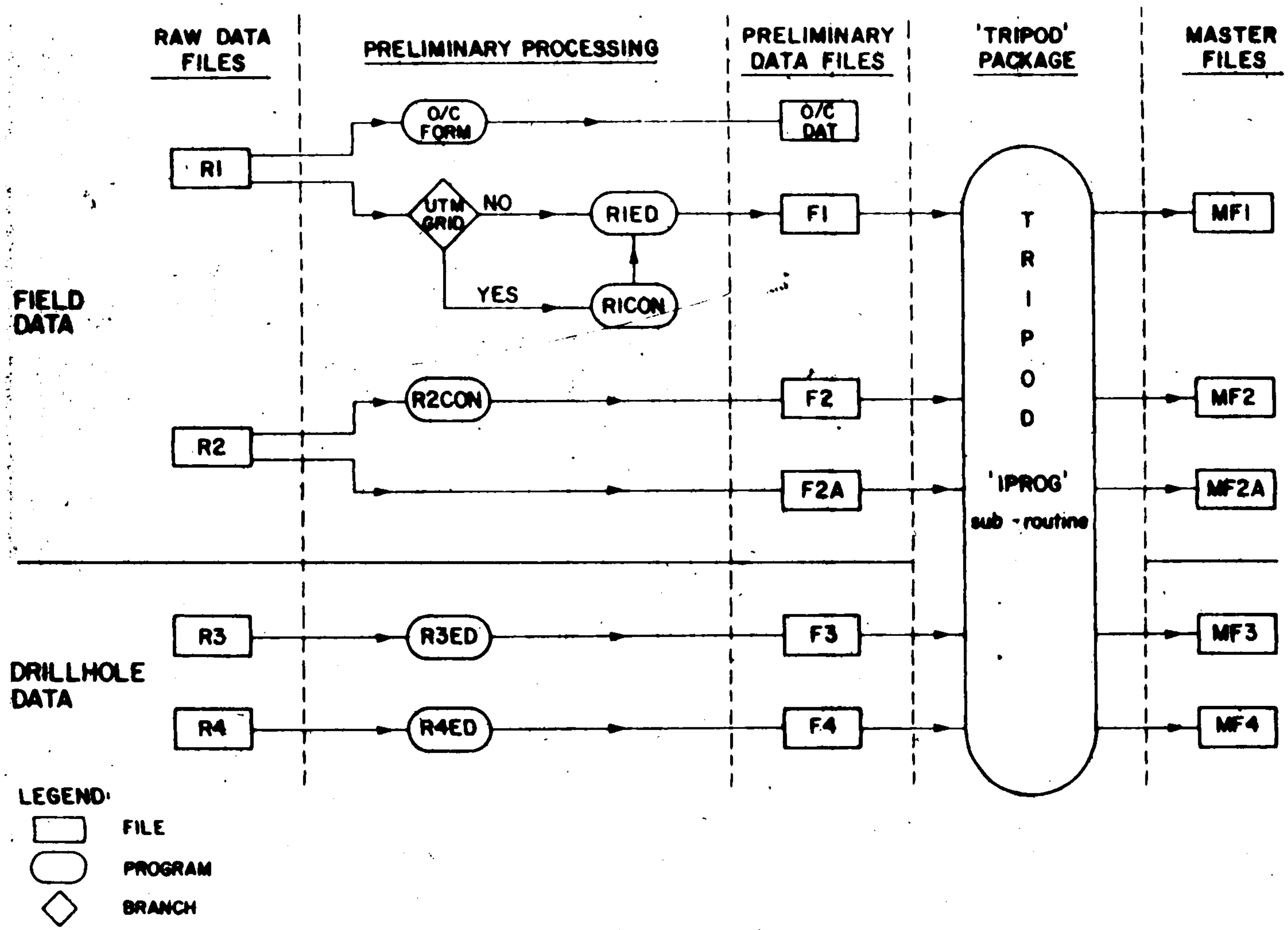


Fig. 4. Flow diagram of file management and preliminary data storage and processing

IV. Data Storage, Retrieval and Processing

A. Introduction

Outcrop and drillhole data in the preliminary data files were stored, retrieved and processed using the Fortran software computer package TRIPOD (Charlesworth 1981) which has been designed primarily for field geologists, especially those working in the sedimentary terrains of orogenic belts. The system is command-driven and interactive to the extent that the required output, whether graphical or numeric, can be verified or rejected and re-run numerous times at a single terminal session. TRIPOD was designed about a main program which is essentially a command interpreter. The interpreter accepts a number of active and passive commands. The active commands cause the interpreter to call specific subroutines for computation while the passive commands establish the output parameters and the data *retrieval filters*. These filters allow for data to be retrieved on the basis of

(1) type: whether drillhole, outcrop or both

(2) surface: a specific geologic horizon or marker

(3) outcrop or drillhole number

(4) geographic position

(5) type of structure.

All combinations of these filters are allowed.

Upon specifying an active command the appropriate subroutine performs the action. Each subroutine is built around a *pre-processor* which sets up the command and makes parameter checks, a *point-processor* which performs the action on each data point in accordance with previously specified retrieval parameters and a *post-processor* which writes out the results and returns to the main program.

The Preliminary Data Files F1–F4 were processed by a subroutine in TRIPOD upon input of the command 'READ'. The subroutine called is 'IPROG', which generates *Master Files* 1-4. These files are stored in machine language in order to save disc space. The Master Files differ in format from the Preliminary Files and contain information concerning the file position of specific data types (Charlesworth 1981). Owing to the size and variability of the data types within the master files and the necessity for retrieval filters, permanent arrays to store and sort data for each subroutine would require excessive disc space. To circumvent this the subroutine 'READIT' reads the master files when other subroutines require specific data sets.

In conjunction with plotting and printing hardware the TRIPOD system was used to produce outcrop and drillhole collar maps, delineate structural domains, draw down-plunge cross sections, rotate orientation data, produce orientation diagrams of various types and list output and statistics data.

The usual procedure for preliminary structural analysis of deformed terrains using numerically based computer techniques is to divide the study area into domains where folding is essentially cylindrical. Establishing domains is usually accomplished by performing a series of statistical tests using outcrop data, such as explained in Cruden (1968) and Charlesworth *et al.* (1976). At Coal Valley, however, these statistical tests have little value because outcrops are sparse and irregularly distributed. Drillhole data are, however, well distributed in most of the study area. The most useful structural tool is therefore the down-plunge cross section. Data processing consequently proceeded as follows. First, the entire area was divided up into 'slices' perpendicular to the regional strike. Then, using the 'SECT' command of the computer package and an interactive graphics system available at the University of Alberta, a profile plot of both drillhole and outcrop data projected along an estimated fold axis for each slice was viewed on a graphics terminal. The alignment of traces of drillhole marker bed intersections on the profile was examined. If there were no anomalies and the traces could be considered geologically workable a hard copy of the plot was obtained. Otherwise the profile was re-plotted using different fold axis orientations until the best plot was produced.

B. Cross Sections

The orientation of the fold axis varies only slightly throughout the study area and the plunge is almost horizontal. As a result, in order for there not to be an undesirable superposition of projected outcrops and drillholes, it was found that the distance of projection generally had to be less than 75 m. Accordingly, the area was divided into ninety slices most of which are 150 m wide: a few slices in areas with scant drillhole control are 300 m wide. All outcrop and drillhole data within each slice were selectively retrieved using the geographic filter of the TRIPOD system. These data were then projected parallel to the fold axis onto vertical planes oriented parallel to the Coal Valley mine grid northing, which is within a few degrees of perpendicularity to the fold axes within the slices (Appendix 3). Use of this grid facilitated verification of drillhole positions in the event of anomalies and construction of cross sections and final geological maps.

The computer-constructed down-plunge plots display outcrop and drillhole data differently. For outcrops, a short line of appropriate slope is plotted along with the geologic horizon symbol. For drillholes, a line connecting the projections of the top of the bedrock and the bottom of the logged segment of the drillhole is plotted together with a '+' sign and the geologic horizon symbol for each marker bed intersected. Geologic cross sections were constructed from these plots by connecting corresponding marker bed intersections. The cross section was then balanced in order to maintain a constant cross-sectional area for each horizon.

The down-plunge projection method requires that the planar structures under examination be cylindrically folded. At Coal Valley gently folded stratigraphic horizons and low-angle thrust faults are the dominant structural features. In order for the down-plunge profiles to portray these features accurately it is necessary that they have the same fold axis orientation and that this axis be perpendicular to the direction of displacement along the faults. At Coal Valley the strikes of most faults and stratigraphic horizons are almost parallel. Because of this, the fold axes for most faults and stratigraphic horizons can be considered coaxial. Since most thrusts move up the dip direction in their central portions (Elliott 1976) the error in displacement resulting from non-perpendicularity of the displacement direction of thrusts with respect to the profile plane is probably small. The error in measuring the amount of displacement from the profile will consequently be small as well. If the error in orientation of a profile is θ and the projection length is p the error e in the amount of displacement associated with projection is given by $p \sin \theta$ (Elliott and Johnson 1980). Because p is less than 75 m and θ is unlikely to be more than [illegible] e should never exceed 26 m.

In some areas oblique and longitudinal cross sections were constructed in order to detect oblique faults. Because these are not down-plunge profiles the true dips and displacements of the detected faults could not be ascertained from these sections.

C. Map Construction

Various types of machine-plotted maps were used during the course of this study. These maps were produced by a Calcomp Plotter in conjunction with the TRIPOD package, the SURFACE II package (Sampson 1975) and a library of plotting routines available at the University of Alberta.

Outcrop and Drillhole Maps

The command 'DRAW' in the TRIPOD package will produce outcrop or drillhole location maps depending upon the retrieval filter settings. Drillhole location maps were used to decide upon suitable cross section spacing and location and to verify the positions of questionable drillholes.

Structure Contour Maps

A facility for placing the spatial coordinates of marker horizons in a file for use with an outboard structure contouring package is available in the TRIPOD system. The contouring package used in this study is the SURFACE II software system designed by R. J. Sampson (1975). In conjunction with longitudinal cross sections, structure contour maps were employed to determine the orientation of oblique faults.

The Geological Map

The surface traces of geologic horizons, faults and axial planes of folds are key elements in the construction of a geological map. Because outcrops are so scarce at Coal Valley, geological maps were constructed by locating the intersection between the traces of these elements and the topographic surface in each cross section (Fig. 5a). The geographic position of each trace-topography intersection point was then measured from its X and Y coordinates on the cross section and placed along with a numeric identification code in the computer file TRACES (Appendix 4). Using the SURFACE II graphics system a plot of the various intersection points was obtained (Fig. 5b). Such plots greatly facilitated the construction of the geological map of the area.

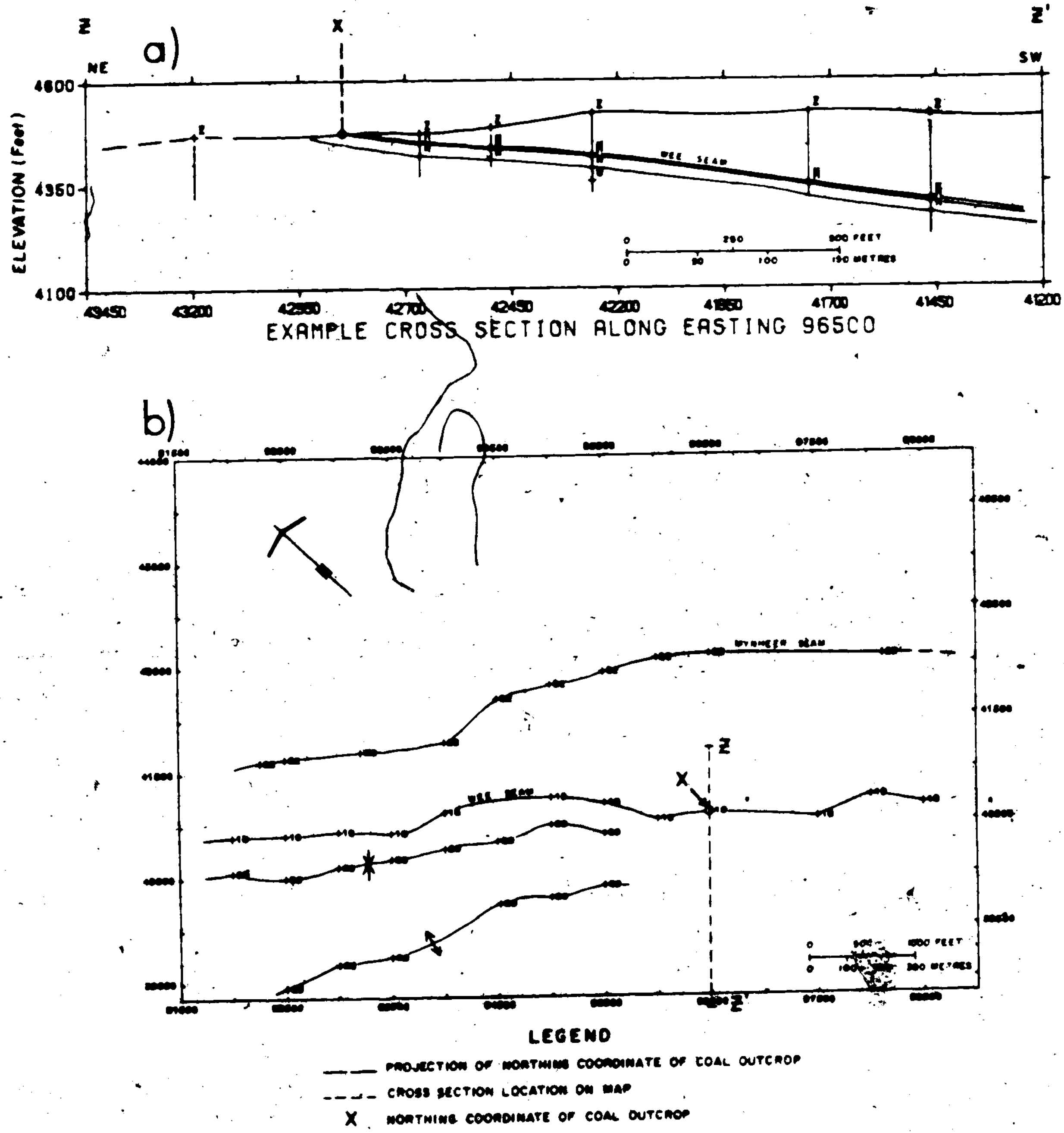


Fig. 5. Diagram illustrating the method of constructing geological maps at Coal Valley (a) sample cross section (b) sample geologic map constructed from positions in the computer file TRACES.

V. Stratigraphy

A. Introduction

Strata at Coal Valley are Upper Cretaceous to Paleocene continental clastics situated near the top of the Upper Molasse Unit of the Rocky Mountain clastic wedge sequence. Recent palynological studies have suggested that the base of the Paskapoo Formation does not coincide with the top of the Brazeau Formation in the central Foothills because the coal seams above the Brazeau Formation correlate with seams below the Paskapoo Formation in its type area (Jerzykiewicz and McLean 1980). This leaves a gap in the nomenclature between the top and bottom of the Brazeau and Paskapoo Formations, respectively. An informal name, the Coalspur beds, was assigned to these rocks by MacKay (1947,1949). All strata studied are contained within this unit.

B. Description of the Coalspur Beds

The strata at Coal Valley belong to the 'coal zone' of the Coalspur beds (Fig. 6). This zone is approximately 300 m thick and contains 7 coal seams of which the oldest, the Mynheer, is 275 m above the Entrance Conglomerate (MacKay 1943). All rocks are of continental origin as substantiated by pollen and freshwater fossil identifications and by sedimentary structures. An alluvial paleoenvironment is suggested by Jerzykiewicz and McLean (1980).

Although scarcity of exposure prevented a complete section from being measured, geophysical logs permitted some lithologic units to be traced throughout the area. Fig. 7 is the stratigraphic section for strata analyzed in this study and includes coal seam names which were assigned in the earlier part of this century.

In a broad sense the rocks at Coal Valley consist of fining upward sequences of sandstones, siltstones and mudstones interspersed with coals, carbonaceous mudstones and bentonites. A few laterally discontinuous pebble

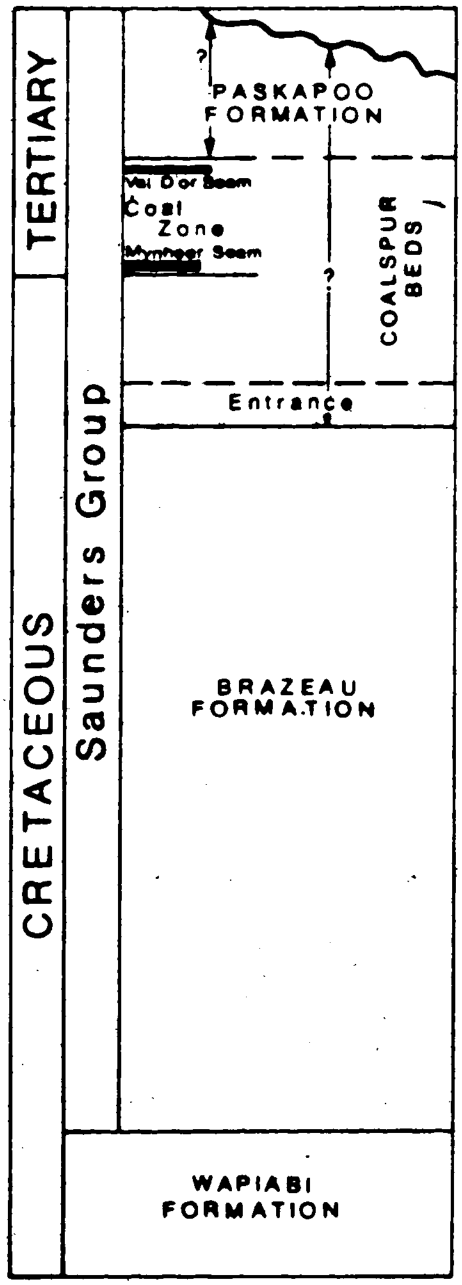


Fig. 6. Stratigraphic position of the Coalspur beds and the 'Coal Zone' (after Jerzykiewicz and McLean 1980)

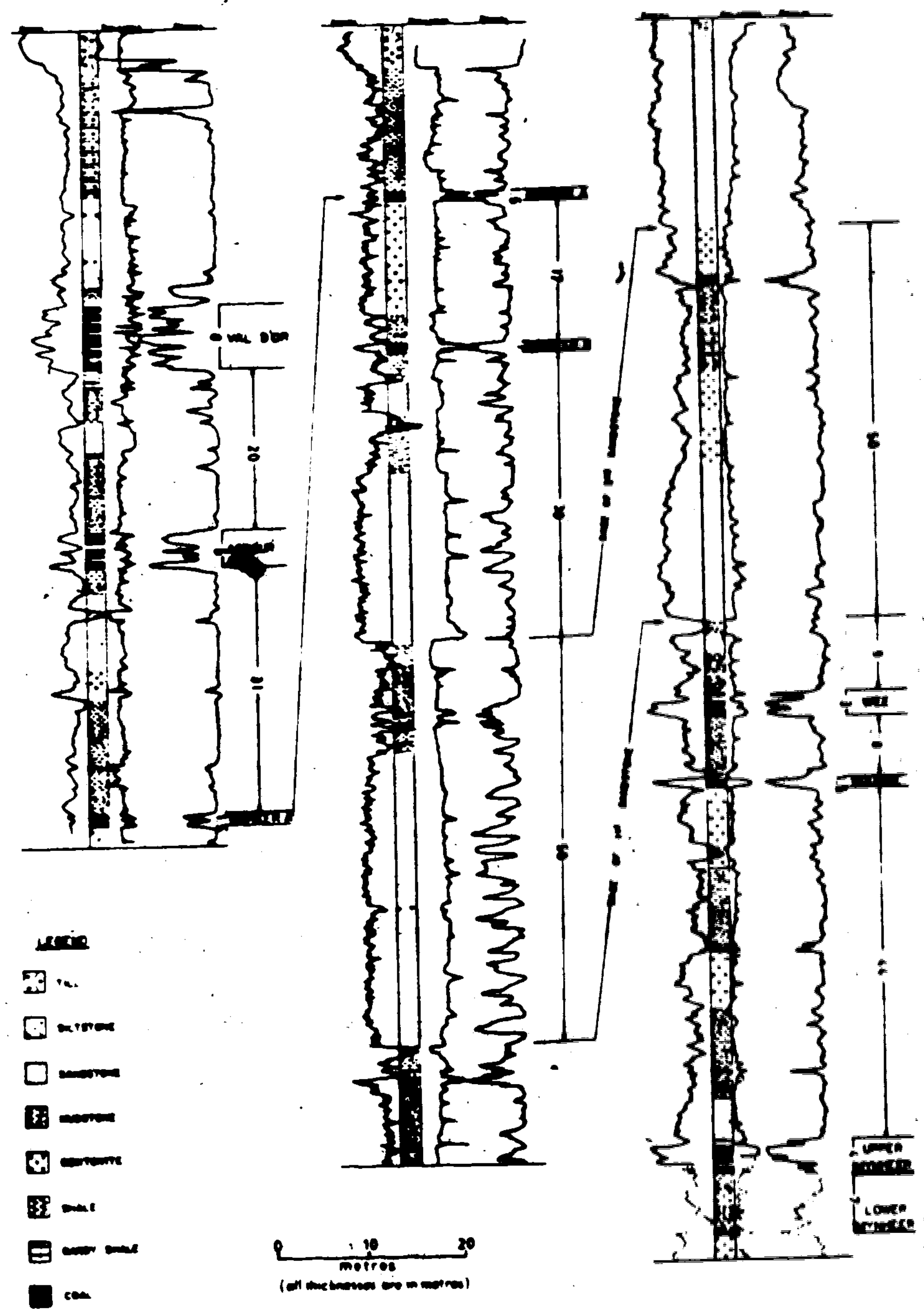


Fig. 7. Stratigraphic section of the 'Coal zone' of the Coalspur beds (after Luscar Exploration staff).

conglomerates representing channel lag deposits were observed and a siliceous tuff crops out in the northwest. The sandstones have a characteristic salt-and-pepper texture, weather to light rust or greyish olive, and contain a large proportion of clay cement. Siltstones are generally thinly bedded, greenish-grey and weather light brown; near coal seams they contain abundant plant remains. The mudstones weather rapidly to greenish grey clay with little preservation of sedimentary structure. Bentonite partings occur in a number of coal seams. They are light grey to light orange in color and are composed essentially of smectites (L. Pudsey, personal communication, 1981). A complete lithofacies analysis of the Coalspur beds can be found in Jerzykiewicz and McLean (1980).

All the coal seams and two bentonites have highly characteristic signatures on geophysical logs and can be used as marker beds for structural purposes. For instance the 'Lower Mynheer', lying immediately below the Mynheer coal seam, is a useful marker horizon containing 5 m of carbonaceous mudstones and bentonites. The lenticularity of many of the sandstone beds at outcrop and the variability of drillhole log signatures suggest that the facies of strata between marker horizons change over short distances.

VI. Structure

A. Tectonic Setting

The outer Foothills in the vicinity of the study area can be defined as lying between the northeast-dipping Lovett and the southwest-dipping Brazeau faults (Fig. 1). To the southwest lie the inner or western Foothills characterized by low-angle, folded thrust faults which cut up-section to the northeast through the Mesozoic clastic wedge sequence (see Hake *et al*. 1942; Kilby 1978; Hill 1980; Charlesworth and Kilby 1981). To the northeast lies the southwest limb of the Alberta syncline. The structure of the outer Foothills is obscure, primarily the result of poor exposures and the monotonous nature of the Upper Cretaceous-Paleocene continental clastics. The most conspicuous large-scale folds near Coal Valley are the Coalspur Anticline and the Lovett Syncline.

For the purpose of description, the study area has been divided into ten structural blocks, the largest of which are shown in Fig. 8. Within each of the blocks specific structural elements tend to occur. The geological map (Fig. 9, in pocket) and the cross sections (Figs. 10a-10o, pages 52-65) display the structure of the study area.

B. Structural Elements

Southwest-dipping Thrust Faults

The most prevalent structural element in the Foothills is the southwest-dipping thrust fault. Such thrusts generally

(1) follow a staircase trajectory composed of flats and ramps,

(2) cut up-section in the direction of hanging wall displacement,

(3) thrust older rocks over younger, and

(4) are folded by subsequent deformation of footwall strata.

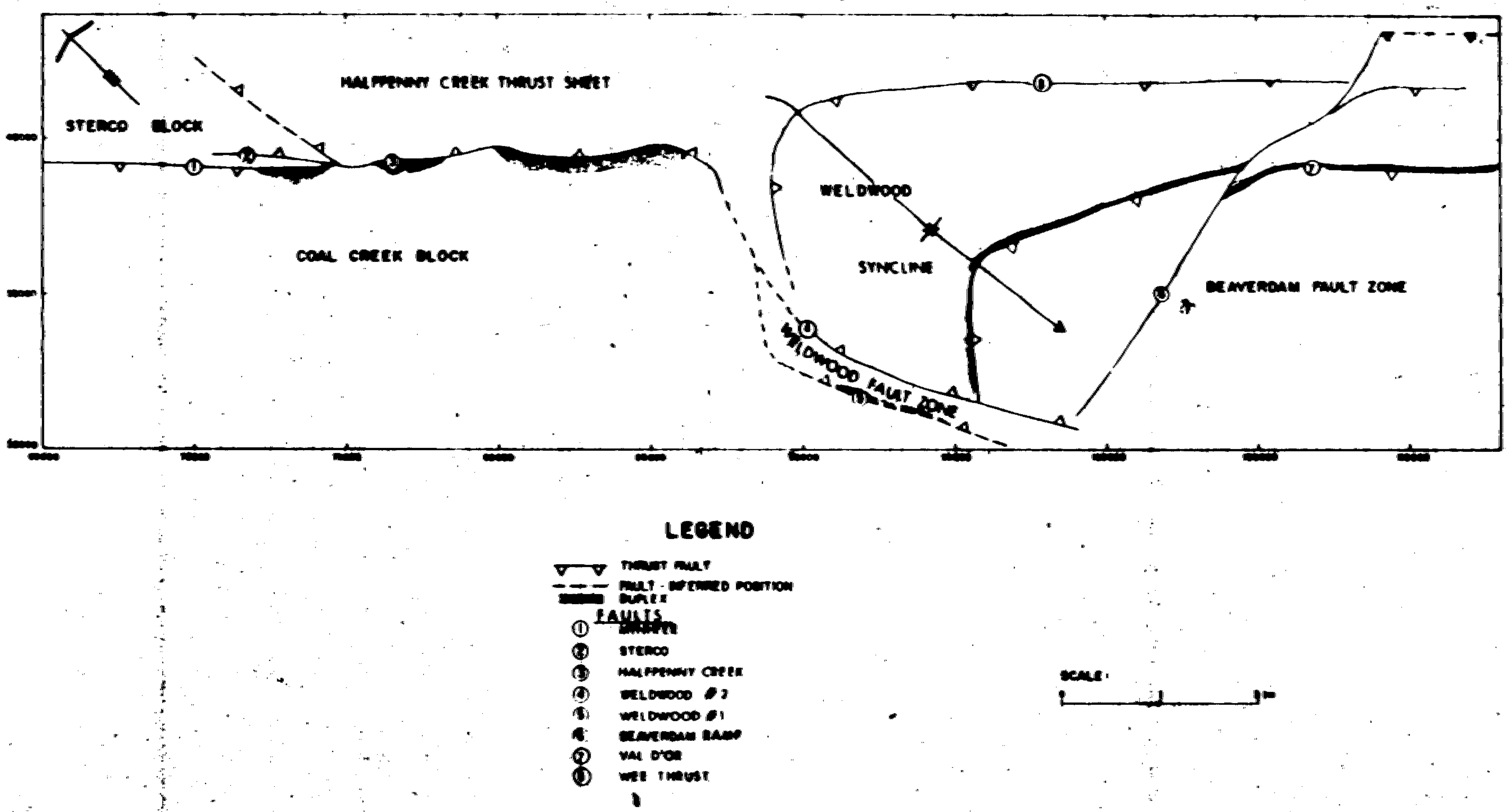


Fig. 8. Major faults and structural blocks in the study area.

At Coal Valley there appear to be two generations of southwest-dipping faults. The older structures are low-angle, bedding-plane thrusts which glide within some of the coal, carbonaceous mudstone and bentonite horizons of the coal zone and which are commonly the bounding thrusts of duplexes (see below). The younger faults are higher-angle thrusts which cut up-section through both competent and incompetent horizons as well as through the duplexes. Some appear to be imbricates which merge with bedding plane thrusts at depth. They tend to make 30° angles with bedding, but the actual dip of some of the faults can be very steep because they have rotated along younger underlying listric thrusts.

Duplexes

A duplex consists of two thrusts, both essentially parallel to bedding, separated by a series of more steeply dipping imbricate thrusts that have thickened the intervening stratigraphic succession. The term *duplex* was first applied to a fault zone in southwestern Alberta. In this area the Lewis and Mount Crandell thrusts are the floor and roof thrust boundaries of "a suite of more steeply dipping minor thrusts that thicken and shorten an intervening panel of rock" (Dahlstom 1970). This type of structure was documented by Peach *et al.* (1907) in the Scottish Caledonides but was termed "schuppen" or "imbricate" structure, neither term implying the existence of a roof thrust. Duplexes have subsequently been documented in the southern Appalachians (Boyer 1976), southeastern British Columbia (Fermor and Price 1976) and in the Scottish Caledonides (Elliott and Johnson 1980).

In the Canadian Rockies thrusts tend to have staircase geometries, with bedding-plane glide zones or 'flats' connected by footwall longitudinal 'ramps', that make angles of less than 35° to bedding. Boyer (1978) believes that duplexes form from the progressive breakdown of the footwall ramp connecting two flats. The outcome of the breakdown of a ramp is the stacking of a panel of rock called a 'horse', due to movement of the panel along the floor thrust flat and up the active ramp. The active footwall ramp connects the active segments of the roof and floor thrusts. Continued breakdown of the ramp in the direction of hanging wall transport creates a series of stacked horses separated by imbricate thrusts which merge down dip with the floor thrust at depth and up dip with the roof thrust. The mechanics are not understood but balanced restored cross sections enable the probable sequence of duplex formation to be unravelled (Fig. 11). Most duplexes are approximately tabular, although irregularly shaped duplexes with folded roof thrusts have been documented (Elliott and Johnson 1980, p.79). The geometry of a duplex enables the derivation of quantitative information. If the present cross-sectional area of a duplex is A and the original thickness of the imbricated strata is t_0, the original length L_0 of the strata in the duplex can be calculated from: $L_0 = A/t_0$. Assuming plane strain, the minimum amount of shortening S which has taken place between the roof and floor thrusts in the duplex can then be calculated by subtracting the current length of the duplex L' from L_0 (Elliott and Johnson 1980).

At Coal Valley duplexes appear to be confined to the Val D'or and Mynheer coal seams. The most intriging feature of these duplexes is that the roof and floor thrusts generally coincide with the tops and bottoms of these coal seams, resulting in greatly thickened sections of coal of considerable economic importance. Their geologic and economic significance warrants treatment of the duplexes as distinct structural units.

Transverse Faults

Most faults which are oblique or perpendicular to the regional strike of the Rocky Mountain Foothills are either (Dahlstrom 1970)

(1) tear faults which are usually confined to a thrust sheet or

(2) transverse ramps.

At Coal Valley at least two transverse or oblique ramps appear to be present. One, the Reco Fault, separates the Mynheer duplex to the northwest from

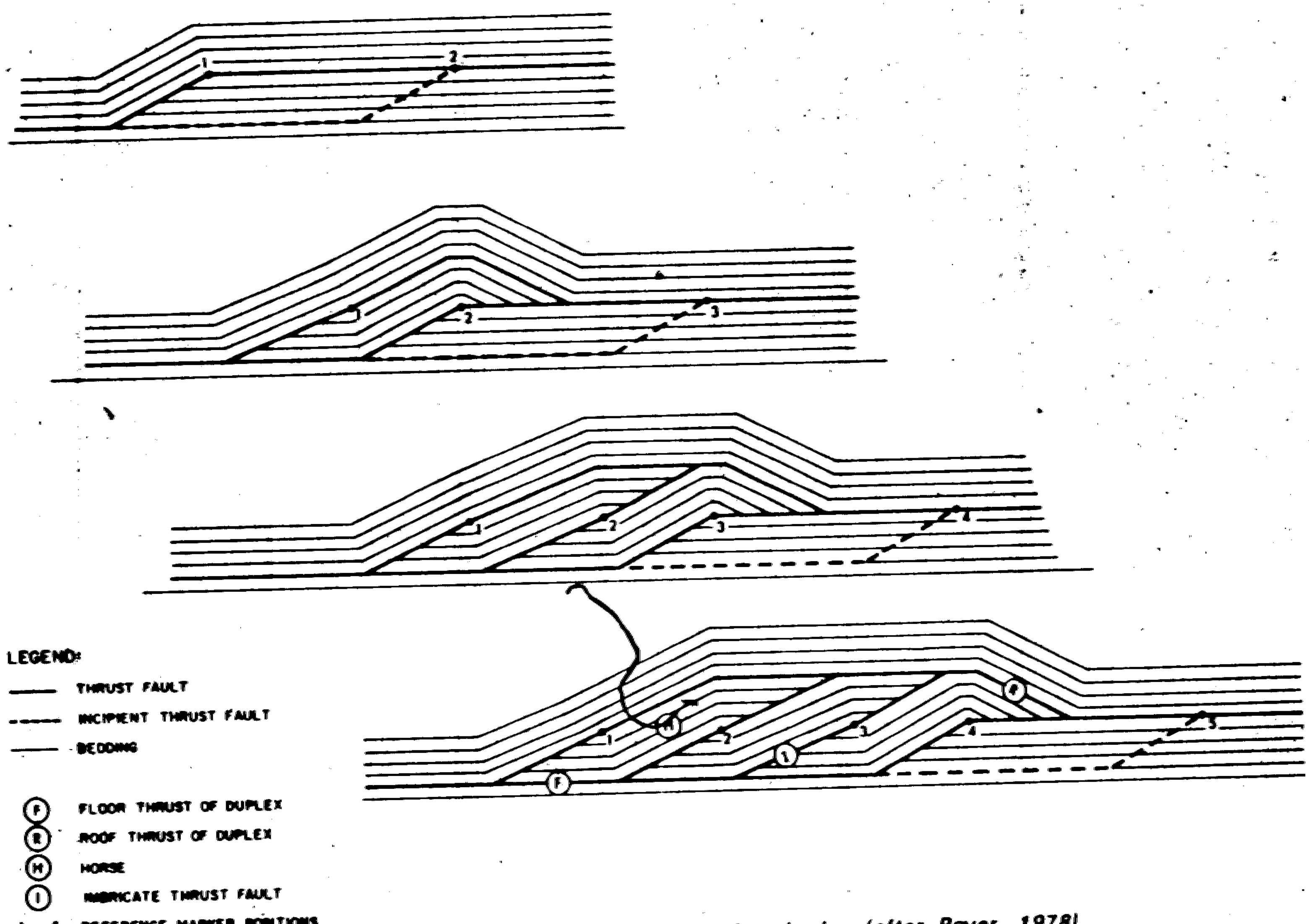


Fig. 11. Four stages in the initiation of a duplex (after Boyer, 1978).

the Wee bedding plane thrust and the Val D'or duplex to the southeast. The oblique Beaverdam ramp separates the Weldwood Syncline and Weldwood Fault Zone to the northwest from the Beaverdam Fault Zone to the southeast (Fig. 8). In addition, the Halfpenny Creek thrust and Weldwood #1 and #2 thrusts are believed to be connected by a transverse ramp (Fig. 8).

Northeast-dipping Thrust Faults

Northeast-dipping thrusts are an important structural element in the outermost Foothills, particularly near the western margin of the asymmetric Alberta Syncline. They thus form the northeastern boundary of what petroleum explorationists often call the 'triangle' or 'delta' zone. Here, northeast-dipping strata in the southwest limb of the Alberta syncline are bounded below by one or more northeast-dipping thrusts whereas on the other side of the 'triangle' most strata dip southwest above southwest-dipping thrusts. The upturning of the southwest limb of the Alberta syncline was probably the result of tectonic thickening of strata lying between the northeast-dipping thrusts and the basal detachment zone. Northeast-dipping thrusts such as the Wildhay, Pedley, Lovett, Waldron and Black Mountain faults have been documented in the southern and central outer Foothills (Hume 1931; Douglas 1950; Irish 1965; Price 1981). At Coal Valley northeast-dipping thrusts can be observed at the surface and interpreted in the subsurface. The northeast-dipping Halfpenny Creek thrust delineates the boundary between the Coal Creek Block and the Halfpenny Creek Thrust Sheet whereas the east-dipping Weldwood thrusts occur in the vicinity of the Weldwood Fault Zone (Fig. 8). Just northeast of the study area a major northeast-dipping thrust, the Lovett fault, lies in the southwest limb of the Alberta Syncline (Fig. 1).

Folds

Deformation by folding in the outer Foothills has been less intense than in the inner Foothills. Folds tend to be simple, rounded and concentric and to be less tight and less closely-spaced than folds closer to the Front Ranges. The larger folds at Coal Valley are probably bending folds where strata have behaved passively in response to deformation associated with a vertical bending moment in underlying strata, rather than buckle or kink folds which resulted from compression parallel to layering.

Most strata in the study area dip essentially homoclinally or are gently folded. These folds tend to have vertical or steeply dipping axial planes and fold axes with average trends of 162° and plunges of 3°. The Coal Creek Block contains three folds which end downwards against the Mynheer duplex. A moderately southeast-plunging anticline is contained within the Halfpenny Creek Thrust Sheet in the north-central part of the study area. In the Weldwood Syncline the Reco anticline-syncline fold pair and the Weldwood syncline are open folds with long wavelengths.

Mesoscopic Structures

Structures at the scale of an outcrop in the study area include highly contorted small-scale folds in disturbed coal seams, small-scale faults (both thrust and normal), drag folds, thrusts, joints, slickenside striae and calcite fibres associated with both fault and joint surfaces. Small scale faults and disharmonic folds are common in all coal seams which have been structurally thickened or which were glide horizons. For most of the study area, joints can be grouped into three sets, two of which are widespread. The dominant joint set has a mean orientation of 275° 87°. The second set averages 354° 84° while the third, less widespread joint set has an mean orientation of 54° 88°. Northwest of Pits 14 and 15, joint sets are poorly developed.

C. The Val D'or Duplex

The Val D'or coal seam in the southeastern part of the study area generally occurs in a duplex bounded by the Val D'or roof and floor thrusts. At all localities where the seam crops out repetition of strata within the duplex is easy to see because of the existence of sandstone and bentonite layers within the seam. The connecting imbricate faults can also be clearly observed. The existence of the duplex at depth is indicated by the seam's increased thickness – up to five times normal (as seen in Figs. 10m–10o) – and by the repetition of marker beds within the seam as seen on geophysical logs (Fig. 12). The duplex is believed to terminate to the northwest against the Reco fault and to have developed contemporaneously with the Mynheer duplex and the Wee thrust (see below). The duplex is cut by and therefore older than the Beaverdam fault, thrust faults in the Beaverdam Fault Zone, and the Weldwood thrusts. It appears to die out and be replaced by a bedding plane thrust both along strike to the southeast and down-dip to the southwest.

In the Weldwood Syncline, near the outcrop of the Val D'or seam, the roof and floor thrusts coincide with the top and bottom of the seam. Horses are well delineated by repetition of thin bentonites and the 35–40 cm thick sandstone split between the 'B' and 'C' coals of the seam (Fig. 12). . The imbricate thrusts have orientations that average 215° 30° and make angles with bedding of 20°. Displacements on these thrusts, which are some 4 m apart, average 5 m (Plate 1, page 49). Val D'or coal adjacent to the hanging wall of the Weldwood #2 thrust is nowhere exposed, but has been intersected by drillholes. Although gently dipping throughout, the thickness of the seam is up to three times normal and apparently occurs in a duplex (Fig. 10j).

In the Beaverdam fault zone the Val D'or duplex is partially exposed in Pit 24 where thickening up to 4.5 times has occurred. Within the zone thickening decreases down-dip to the southwest and also along strike to the southeast (Figs. 10m–10o).

In the Weldwood Fault Zone the Val D'or seam occurs in a duplex which has probably been rotated and repeated by younger, northeast-dipping, listric thrust faults. Although the structure of the duplex could not be ascertained, the large thickness of coal now observed is thought to be a function of imbrication of the seam between the Val D'or roof and floor thrusts and later repetition of the

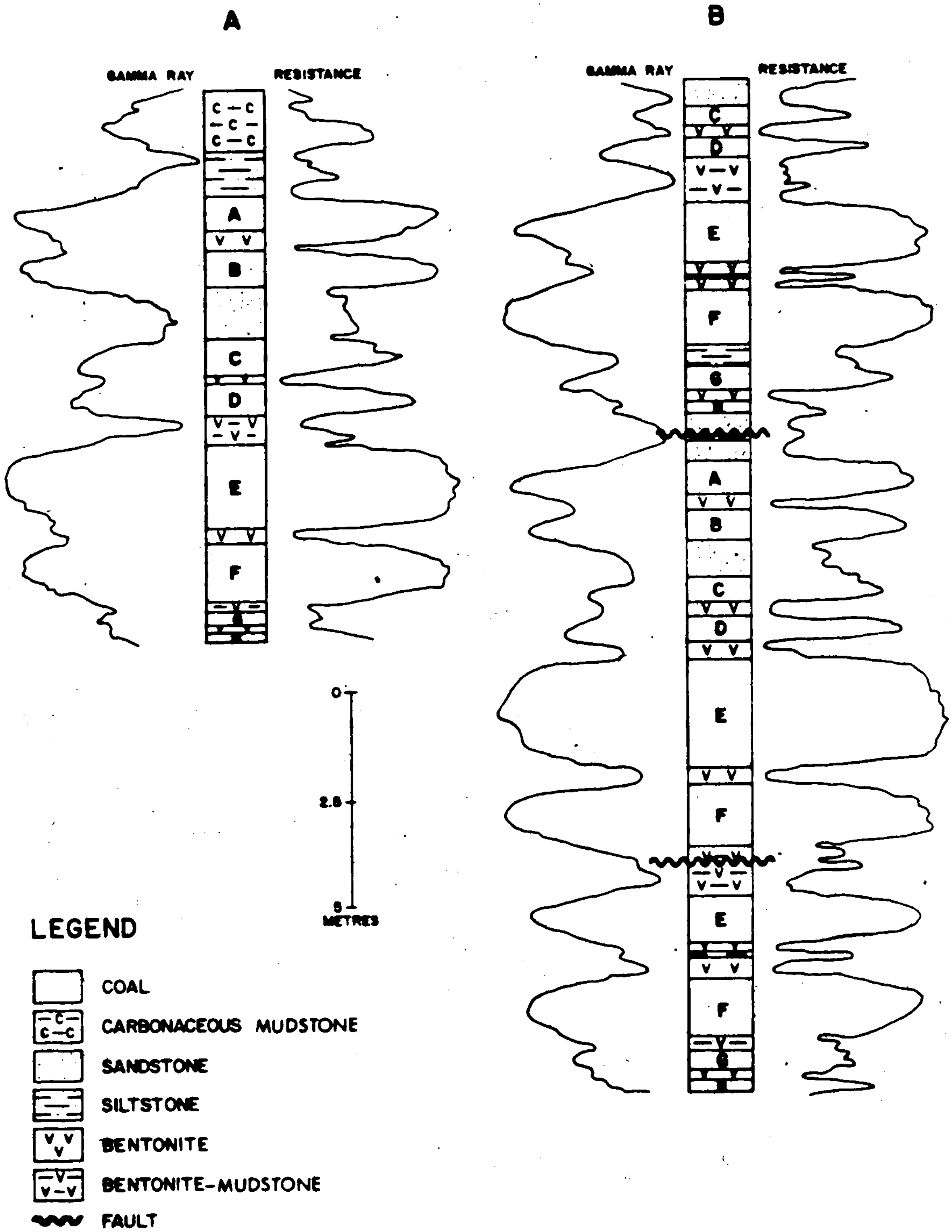


Fig. 12. The [illegible]l D'or Coal Seam: a) normal stratigraphy b) stratigraphy repeated by imbricate thrusting within a duplex.

duplex by thrust faulting (Fig. 10i).

Pit 21, located in the hinge zone of the Weldwood syncline, is the only region where the Val D'or floor thrust was not observed to coincide with the base of the coal seam. Here, a layer of coal, carbonaceous mudstone and bentonite (the uppermost unit of the Val D'or seam) has been thickened from 1.0 to 1.5 m for 250 m along the strike of the seam. Individual horses are well delineated by a light orange bentonite marker. Imbricate thrusts bounding these horses are 20-30 cm apart and make angles of 35° with bedding. The orientation of the horses suggests a relative northeasterly movement of younger over older strata (Plate 2). This thin duplex occurs only 600 m southeast of the duplex which involves the entire seam. This observation, together with the lenticularity of the thin duplex, indicates that duplexes in the Val D'or seam are lenticular and separated by zones where the seam is followed by a single bedding plane thrust.

D. Mynheer Duplex

The Mynheer coal seam in much of the northwestern part of the study area appears to occur in a duplex bounded by the Mynheer roof and floor thrusts that occur at the top and bottom of the seam, respectively. Although the occurrence of imbricate horses is difficult to see in outcrop because of the homogeneous nature of the coal seam, that a duplex is present is suggested by

1) the seam's increased thickness, up to 20 times normal, and

2) the unfolded nature of strata below the seam.

Northwest of the Reco fault, against which the duplex terminates, the thickness of the duplex decreases until 3.5 km away, the Mynheer coal seam returns to its normal thickness (Ronaghan 1977; Figs. 10a-10f). Between grid eastings 75000 and 86000 the duplex is cut by and therefore older than the Halfpenny Creek thrust. The Mynheer duplex is believed to be contemporaneous with the Val D'or duplex, the Wee thrust and the Reco fault.

Whereas the floor thrust tends to dip uniformly southwest, the roof thrust has been folded into two longitudinal anticlines and a syncline. Towards the southeast these folds become overturned to the southwest and increase in width and structural relief.

In accordance with the folded nature of the roof thrust, the thickness of the duplex varies considerably, being greatest in two anticlinal pods whose separation varies from 300 m in the northwest to 575 m in the southeast. In the more northeasterly 'main pod' the thickness is up to 20 times normal (4 m), whereas in the more southwesterly 'secondary pod' thickening up to 17 times has occurred. The few drillholes which penetrate the southwestern flank of the secondary pod suggest that the Mynheer coal seam returns to normal thickness a short distance southwest of the study area, although drillhole control is insufficient to verify this. The northeastern limit of the main pod is abrupt; Mynheer coal here returns to normal stratigraphic thickness within 10 m. A normal or slightly thickened Mynheer coal seam underlies the syncline between the main and secondary pods. An isopach map of the duplex can be seen in Alexander (1977). In the southeast the duplex is truncated by the northeast-dipping Halfpenny Creek thrust in whose footwall fault drag can be observed (Fig. 10f). Figs. 10a-10c and Figs. 10d-10f illustrate the geometry of the Mynheer duplex in the northwest and southeast, respectively.

Some mesoscopic structural features in the Mynheer duplex can be observed where portions of the main pod are exposed in Pits 5, 13, 14 and 15 (Fig. 9). Apart from its highly brecciated appearance, the most conspicuous feature is the almost vertical attitude of bedding. Northeast-verging tongues of Mynheer coal intrude roof rock just above the roof thrust of the duplex in Pit 5, apparently confirming northeast-directed movement along the Mynheer roof thrust (Plate 3). Similar features have been noted in some large thrusts in the Rocky Mountain Front Ranges and other fold and thrust terrains (Gretener 1977). Other mesoscopic structures include large roof rock xenoliths (Alexander 1977) and folds with wavelengths of 10 cm whose geometries are extremely variable (Plate 4).

Calculations to determine the minimum shortening between the roof and floor thrusts, as well as the thickening factor in the Mynheer duplex, were performed using the geometric relationships discussed on page 25 and data from 30 cross sections through the duplex. Results show that thickening in the main pod varies from 2 to 20 times the normal stratigraphic thickness with a mean of 10.5 times. In the secondary pod the range is 1.5 to 17 times with a mean of 7.6 times. The average minimum shortening (S) for the entire duplex is 10 km with a standard deviation between 30 cross section calculations of 1.7 km.

E. Wee Thrust

Southeast of grid easting 86500 (Fig. 9) the Wee coal seam is believed to contain a bedding plane thrust fault. Normally the seam is 3-4 m thick and contains two coals of approximately equal thickness separated by a 20 cm bentonitic mudstone. In the Weldwood Syncline it displays abrupt lateral variations in thickness. The variations are generally confined to the lower coal which is slightly overthickened in some localities and apparently absent in others. Core holes from the Weldwood Syncline have shown that the Wee seam (in particular the lower bed) is often highly sheared and pulverized (Shewchuk 1981). The Wee thrust is believed to be contemporaneous with the Mynheer and Val D'or duplexes and the Reco fault.

F. Reco Fault

A transverse ramp, called the Reco fault, is thought to occur in the vicinity of grid easting 86500. Although the fault is nowhere exposed, having been over-ridden by strata in the hanging walls of east-dipping thrusts continuous with the Weldwood thrusts #1 and #2 and the Halfpenny Creek thrust, an abrupt discontinuity follows the line of the fault. The Mynheer coal seam lies in a duplex northwest of the fault whereas it is undisturbed to the southeast. The Val D'or seam occurs in a duplex southeast of the fault but is undisturbed to the northwest. The Wee coal seam southeast of the Reco fault is followed by a bedding plane thrust which does not occur northwest of the ramp. The Reco fault therefore appears to mark a transverse ramp along which the 10 km of displacement associated with the Mynheer duplex has been transferred to the Val D'or duplex and the Wee thrust. Although its orientation cannot be determined by direct observation, in accordance with the characteristics of transverse ramps elsewhere in the Rocky Mountains, the ramp is probably steeply dipping and has a northeasterly strike.

G. Steroo Block

Strata beneath the Mynheer duplex lie in the footwall of the Mynheer floor thrust and are therefore autochthonous relative to those above the duplex. These footwall rocks, which consist of Lower Mynheer and older strata, are exposed northeast of the Sterco railway siding (Fig. 9). The block is bounded to the east-northeast by the Halfpenny Creek thrust but is probably continuous beneath the Mynheer coal seam elsewhere in the northwestern part of the study area.

In a few areas Lower Mynheer strata and the Mynheer floor thrust have been disrupted by faults younger than the duplex (e.g., Figs. 10b and 10f). Data were insufficient to determine whether these features are longitudinal thrusts or transverse ramps. In some areas Lower Mynheer strata beneath the duplex exhibit thinning and thickening perpendicular to strike (e.g., Fig. 10d). A small duplex in the Lower Mynheer may explain the thickening whereas thinning may have been caused by active involvment of this marker horizon in the Mynheer duplex.

Between grid eastings 73500 and 75500 (Fig. 9) the Lower Mynheer and overlying Mynheer thrust lying northeast of the termination of the main pod of the Mynheer duplex have been displaced southwestwards along a northeast-dipping fault, the Sterco thrust (Fig. 10c). The vertical separation of the displaced marker is 40 m but because the dip of the thrust is unknown its displacement could not be determined. This fault cuts up-section and merges with the overlying Halfpenny Creek thrust 150 m northwest of Pit 5 but could not be traced further northwest than Pit 1.

H. Coal Creek Block

The Coal Creek Block overlies the roof thrust of the Mynheer duplex and is therefore allochthonous with respect to the Sterco Block. To the northwest, beyond the limits of the duplex, it overlies the Mynheer thrust. Strata within the block are folded and disrupted by the southwest-dipping Bourne thrust and its splays.

Anticlines separated by a gentle syncline are observed above the southeastern portion of the Mynheer duplex (e.g., Fig. 10f). These three folds have axial planes with dip directions varying from 40° to 50° and dips from 75° to 90°. They developed contemporaneously with growth of the pods in the duplex.

A low-angle, southwest-dipping thrust, the Bourne thrust, is thought to occur in the Coal Creek Block between the Bourne coal seam and the roof thrust of the Mynheer duplex because everywhere the apparent thickness (about 58 m) of the Bourne to Mynheer interval is greater than the true thickness of 44 m. Above the southwestern flank of the main pod what appear to be a series of imbricate splays from this thrust have disrupted a 15 m thick assemblage of strata from above the Wee to below the Bourne coal seam (Figs. 10b and 10d). A bedding plane thrust may follow the Bourne seam in part of the Coal Creek Block which would account for the apparent absence of this seam in several drillholes. A sedimentological explanation for the absence of the Bourne seam is unlikely because of its continuity elsewhere in the study area. Drillhole control is insufficient to determine the dips and displacements of the Bourne thrust and its splays. The splays of the Bourne thrust do not extend along strike through the entire block but appear to be confined to the area between grid eastings 71500-78000 (Fig. 9).

Although drillhole control is poor, strata in the southwestern part of the Coal Creek Block appear to dip uniformly to the southwest at 25°.

I. Halfpenny Creek Thrust Sheet

The northern quarter of the study area contains the northeast-dipping Halfpenny Creek Thrust Sheet (Fig. 8). The Halfpenny Creek thrust cuts and is therefore younger than the Mynheer duplex. It is partially exposed on the north walls of Pits 5 and 14. Only a few drillholes have penetrated the sheet adjacent to these pits but additional data are available from scattered outcrops to the north. The thrust is thought to be continuous with the Weldwood #1 and #2 thrusts.

Strata in the thrust sheet do not correlate with those elsewhere in the study area. They appear to belong to the lower part of the Coalspur beds and possibly to the uppermost Brazeau Formation and are thus older than the Lower Mynheer seam (Fig. 6). A distinctive 10 m thick assemblage of silicified tuffs and bentonites is exposed in Pit 5 and can also be seen on logs from nearby drillholes. The tuffs also crop out 2 m above the Halfpenny Creek thrust in Pit 14, but in this location the beds are only 7 m thick. Sanderson (1931) described a 5 m thick bed of "hard unaltered tuff interbedded with thinner beds of pure bentonite" from the Coalspur and Pembina River regions, 20 km to the northwest and southeast, respectively, of the study area (Fig. 1). He named this sequence the 'Saunders tuff' and stated that it occurs 245 m below the Mynheer coal seam. The 'Saunders' and 'Coal Valley' tuff horizons are believed to be equivalent because Coal Valley lies between the two occurrences of these distinctive markers. Furthermore, Jerzykiewicz and McLean (1980) have noted that both horizons and the Kneehills Tuff in the Alberta plains contain correlatable palynomorph zones. The occurrence of older strata in the hanging wall of the Halfpenny Creek thrust implies substantial southwest-directed displacement along it.

The thrust is exposed in Pit 5 where it forms the northeastern limit of the main pod (Plate 3). Here the fault coincides with a zone of shearing in which northeast-plunging fibres of calcite in layers up to 4 cm thick have been precipitated and in which fault gouge containing unconsolidated carbonaceous, sandy and bentonitic material occurs. A similar zone of shearing occurs just above the main pod in Pit 14.

Drillhole and outcrop control are insufficient to trace the Halfpenny Creek thrust at the northwest and southeast edges of the sheet. However, aerial photograph interpretation northwest of Pit 5 suggests that the Halfpenny Creek thrust trends northward in this region (Fig. 9). Because the angle between the Halfpenny Creek thrust and bedding is unknown, displacement along the thrust could not be determined.

To the southeast the Halfpenny Creek thrust is believed to have cut up section into the Val D'or seam along a vertical or east-dipping, slightly oblique ramp which strikes 25° and to continue in the central-southwest portion of the study area as the east to northeast-dipping Weldwood thrusts (Figs. 8 and 9). That the thrust cuts up section to the southeast is consistent with the overall southeast plunge in the study area and that the age of strata in the hanging wall of the Halfpenny Creek thrust increases to the northwest. A small, subsidiary, northeast-dipping thrust has been interpreted on the basis of discontinuities of bedding orientations just above the Halfpenny Creek thrust and northeast of Pit 14. This thrust lies on the southwest flank of a broad, gentle anticline whose fold axis orientation is 100° 13° and whose steeply-dipping axial plane strikes 126° (Fig. 9). The anticline may be the result of a ramp at depth, in the Halfpenny Creek thrust or in the subsidiary thrust. The large northeast-dipping Lovett fault, which can be easily traced on aerial photographs, forms the upper boundary of the Halfpenny Creek thrust sheet. Because it lies northeast of the study area its characteristics and geometry have not been examined.

J. Weldwood Syncline

The central-southeastern part of the study area is dominated by the Weldwood syncline which is probably continuous with the Halfpenny Creek Thrust Sheet. The syncline is bounded to the west by the Weldwood #2 thrust and to the southeast by the Beaverdam transverse ramp (Fig. 8). The syncline folds and is therefore younger than the Val D'or duplex and the Wee thrust. The oldest strata to crop out in the northeast belong to those slightly older than the Lower Mynheer marker bed. Exposures are limited to Pits 21, 41 and 42 and to the banks of the Lovett River (Fig. 9). Although drillhole spacing is small, averaging 150 m, most holes are shallow and do not penetrate the entire coal zone section.

Structure is simplest in the northeastern third of the syncline where strata older than the Wee seam dip uniformly to the southwest. Elsewhere there are east to northeast-dipping thrust faults, bedding plane thrusts and broad, gentle to open folds affecting Mynheer through Val D'or strata. The Val D'or duplex extends throughout the Weldwood Syncline, so that strata above the seam are allochthonous with respect to those below.

Faults

Structure contour maps drawn on the base of the Wee seam and drillhole cross sections in the southwest part of the Weldwood Syncline have enabled detection of three east to northeast-dipping thrust faults, Weldwood thrusts #3-5. Because these thrusts strike parallel to the Weldwood #2 thrust they may be splays from it, but drillhole control is insufficient to verify this. Of these the Weldwood #3 thrust is the most extensive, striking parallel to the Weldwood #2 thrust, but it apparently flattens into a bedding plane thrust located between the Wee and Mynheer coal seams (Fig. 9). The geometry of and the displacement on the Weldwood #3 thrust can only be estimated from cross sections. The dip of the fault is probably similar to that of the Weldwood #2 thrust and the displacement is about 60 m (Fig. 10g). Weldwood thrusts #4 and #5 are small, arcuate, east-dipping thrusts which die out upwards in strata between the Wee and

Arbour coal seams and which could only be traced for 450 m in the subsurface. The Wee bedding plane thrust is also found in the Weldwood Syncline

Folds

The Mynheer coal seam near the abandoned mining town of Reco through to strata above the Val D'or seam south of Pit 21 have been very gently folded into a southeast plunging fold called the Weldwood syncline (Figs. 1, 9 and 10j). Val D'or coal in both limbs is presently being mined in Pit 21 This syncline has a vertical axial plane trending 165° and a fold axis oriented 164° 5°. The apical angle of the fold is 175°. North of Pit 21 outcrop and drillhole data reveal an anticline-syncline pair called the Reco folds, which are oblique to the Weldwood syncline but approximately parallel to the regional strike (Fig. 9) Although the anticline has been observed along the Lovett River, its geometry is better seen on drillhole cross sections (Fig. 10g). The syncline has been observed on structure contour maps drawn on the base of the Wee seam and on cross sections (e.g., Fig. 10j) The vertical axial planes of both folds strike southeast and their apical angles are about 170°. The relative ages of the Reco folds and the Weldwood syncline could not be established.

K. Weldwood Fault Zone

The Weldwood Fault Zone is a narrow structural unit bounded to the northeast by the Weldwood #2 thrust and to the southwest by the Weldwood #1 thrust (Fig. 8). In this area Val D'or coal appears to lie in a duplex which in places has been intensely disrupted by and rotated on, younger, steeply northeast-dipping listric faults including the Weldwood #1 thrust. The structure in the zone varies from northwest to southeast. In the northwest the Val D'or seam dips steeply northeast but is of normal thickness (Fig. 10h). In the central portion of the zone the coal occurs in a pod which is 915 m long, 45-60 m wide and up to 90 m thick (Johnson 1979). In the southeast the seam appears to occur in a gently southeast dipping duplex where thickening is up to four times normal (Fig. 10k).

The only exposure of the zone is in Pit 26 where the northeastern part of the pod can be observed (Plate 6). The spacing of drillholes is low nearest the pod, but the shallowness of the holes and the inability to identify units within the Val D'or seam in geophysical logs have impeded definition of the structure of this complex region.

Although the Weldwood #1 thrust cannot be traced at the surface the steep northeast dip of the Val D'or seam through most of the Weldwood Fault Zone suggests that the seam is bounded below by a listric northeast-dipping thrust which juxtaposes Val D'or against younger strata and along which the Val D'or has probably been rotated. The absence of markers across the fault prevents determination of its displacement. In the central part of the fault zone the Val D'or seam is thought to occur in a duplex which has been complicated by subsequent faulting and rotation. In a vertical core from this region bedding dips at 65°-85°. Steep bedding in some areas is also supported by the large apparent thickness exhibited by geophysical log signatures of marker beds. This suggests that the Val D'or duplex has been rotated by subsequent movement along northeast-dipping thrusts. Besides rotation it is believed that younger, northeast-dipping thrusts repeated the entire duplex. It is difficult to distinguish the faults along which the duplex was repeated using geophysical logs alone because marker beds have such exaggerated signatures and cannot be identified with any confidence. The faults must die out along strike or flatten into a bedding plane thrust because they do not appear to disrupt the Val D'or duplex in the southeastern or northwestern portions of the fault zone.

L. Beaverdam Fault Zone

The southeasternmost portion of the study area lies in the Beaverdam fault zone, consisting of Mynheer and younger strata repeated by numerous longitudinal thrusts. The fault zone is bounded to the north by the Beaverdam ramp and continues to the southwest and southeast beyond the limits of the study area.

Towards the southwest the faults in the zone bring older and older strata to the surface. Folding is apparently limited to small-scale drag features associated with thrusting. Exposures of strata are limited to Pits 24 and 25 and along the Lovett River. Drillhole control is good near the outcrop of the Val D'or, Arbour and Mynheer seams but poor elsewhere. Drillholes rarely penetrate deeper than 180 m so little is known about the zone below this depth.

Beaverdam ramp

Aerial photographs and drillhole data assisted in tracing the oblique Beaverdam ramp whose strike is 65°. Because drillholes are unevenly distributed the characteristics of the fault could be studied only near Pit 24 where drillhole spacing is low. On cross sections the fault appears as a steeply south-dipping thrust (e.g., Fig. 10I). However, the great difference in the amount of shortening between the Beaverdam Fault Zone and the Weldwood Syncline, the transverse to slightly oblique strike of the Beaverdam fault, and the counter-clockwise rotation of faults and bedding adjacent to its hanging wall suggest that the Beaverdam fault is an oblique ramp that dips steeply south. The continuation of the Beaverdam ramp to the southwest is uncertain. To the east the ramp changes strike moderately eastwards and is believed to continue past Lovettville, where it displaces the Mynheer coal seam, and to end in a bedding plane thrust below the Mynheer seam (Fig. 9).

Thrust faults

Some 11 southwest-dipping thrusts have been identified using drillhole cross sections. Linear ridges visible on aerial photographs appear to follow the outcrop of resistant sandstones repeated by these thrusts. Drillholes, however, are irregularly distributed and shallow, so the exact displacement on the faults could not be determined. Nonetheless, the individual faults appear to make angles of 30° to bedding and have been traced for up to 3 km parallel to strike.

In the northeastern half of the fault zone the thrusts disrupt the Val D'or duplex and the Arbour coal seam (Figs. 10m and 10n). Other thrusts which lie above and to the southwest of the more northeastern thrusts have brought Marker A through strata older than Mynheer northeastwards over younger Coalspur beds and have larger displacements than those thrusts to the northeast (Figs. 10m and 10n). Because the angle between the faults and bedding could not be determined, the displacements on the thrusts is unknown. The thrusts are assumed to end to the north against the Beaverdam ramp. To the northeast the Beaverdam Fault Zone appears to end in a bedding plane fault beneath the Mynheer because there is no significant separation of the Mynheer seam near the abandoned town of Lovettville (Fig. 9). This bedding plane thrust is probably the basal thrust for the entire fault zone. From this thrust splays cut up section to disrupt coal zone strata. The apparently larger displacements associated with the more southwesterly thrusts in the zone suggests that the faults decrease in age to the northeast.

VII. Structural Synthesis

Based on the aforesaid structural observations and with consideration of the geometric and temporal relationships of similar structures elsewhere in the Rocky Mountain Foothills, the author proposes the following five-stage structural evolution for the Coal Valley area.

STAGE A

Deformation in the Coal Valley area began with movement along the Bourne thrust. This fault appears to be folded along with strata above the Mynheer duplex and is therefore older than this structure.

STAGE B

Movement along the Mynheer and Val D'or thrusts resulted in the formation of essentially tabular duplexes in the Mynheer (Fig. 13, stages 1-2) and Val D'or seams. This movement seems to have occurred contemporaneously with movement along the Wee thrust and the Reco transverse ramp. Displacement leading to the Mynheer duplex seems to have been at least 10 km. Southwest of the study area, with the disappearance of the Mynheer duplex, the Mynheer roof and floor thrusts probably merge with a single thrust which must parallel bedding in the footwall for at least 10 km. The positions of the longitudinal ramps which must bound the wide Mynheer flat to the southwest and northeast are unknown (Fig. 14). Northwest of the study area, the roof and floor thrusts of the duplex appear to merge with a single bedding plane thrust located in the Mynheer seam where displacement is also probably about 10 km.

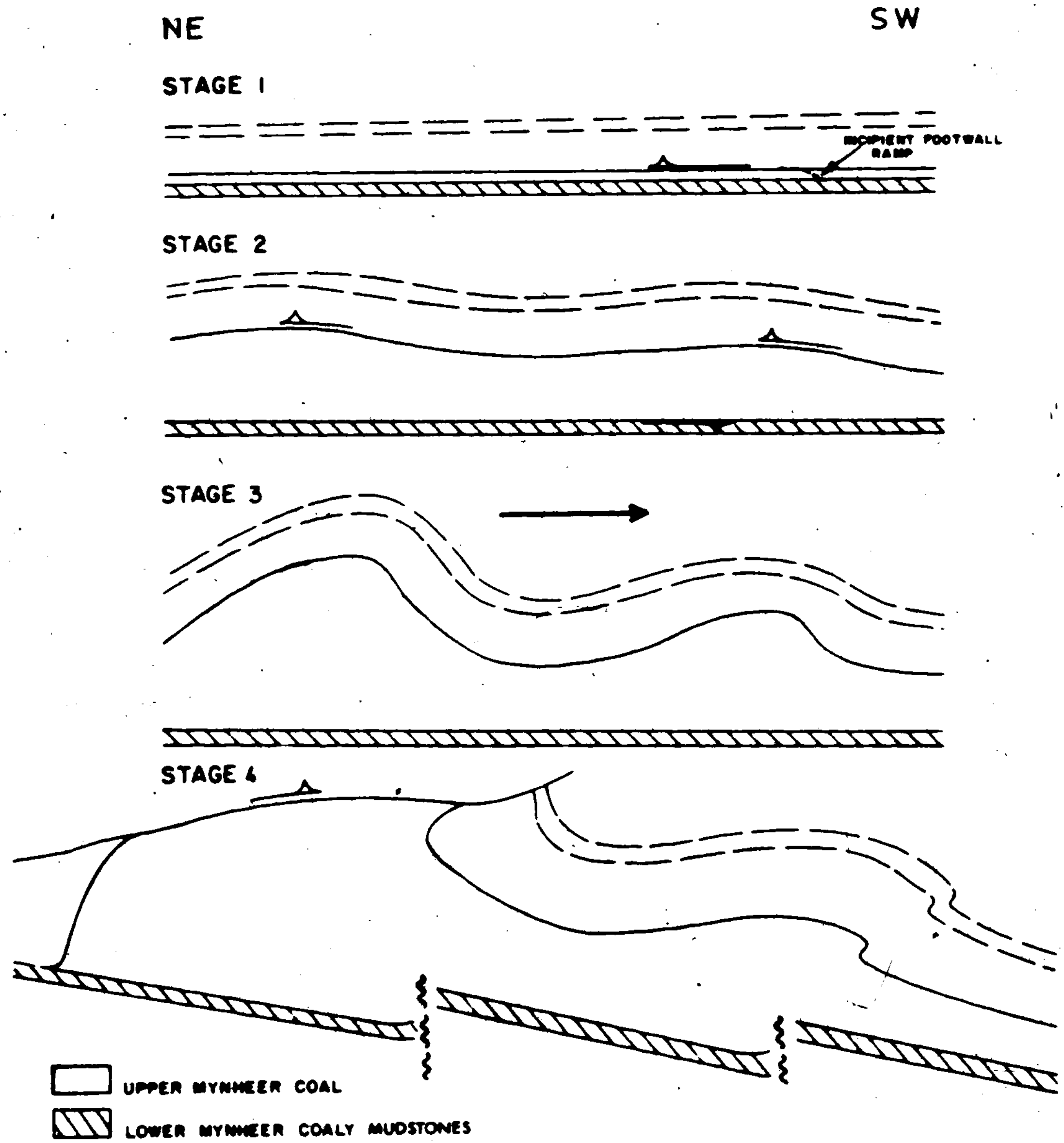


Fig. 13. Structural evolution of the Mynheer duplex.

Southeast of the Reco transverse ramp, movement along the Wee and Val D'or thrusts occurred contemporaneously with that along the Mynheer thrust. The combined displacement along the Wee and Val D'or thrusts is probably the same as that along the Mynheer thrust (Fig. 14).

STAGE C

Whereas the movements that occurred during Stage B were associated with northeast-verging structures, those that took place during Stage C produced structures where vergence is to the southwest. Where the Mynheer duplex was sufficiently thick, strata above it behaved independently of those below, i.e. the duplex behaved as a detachment zone. Gentle folds corresponding to small variations in thickness of the essentially tabular duplex at the end of Stage B (Fig. 13, stage 2), became accentuated by buckle or kink folding (Fig. 13, stage 3). Folds of this type did not develop over the Val D'or duplex because it was nowhere thick enough to permit decoupling of strata above the duplex from those below. Furthermore, the Val D'or seam contains considerable detrital material, including a thick sandstone split and is therefore more competent. Detachment of the strata above the Mynheer duplex appears to have occurred in Stage C because the folds are overturned towards the southwest (Fig. 13, stage 3). The main and secondary pods, where thickening is up to twenty times normal, developed in the cores of anticlines which were formed during this stage. It was during this stage that coal in the Mynheer duplex probably experienced small-scale deformation, resulting in its present contorted appearance.

Probably contemporaneous with folding of strata above the thicker region of the Mynheer duplex, the northeast-dipping thrust faults became active. This is suggested by the fact that both they and the folds have a southwest vergence. The Halfpenny Creek thrust and Weldwood thrusts #1 and #2 are believed to be contemporaneous and to be connected by a transverse ramp. These two Weldwood thrusts probably merge at depth. Strata in the southwest limb of the

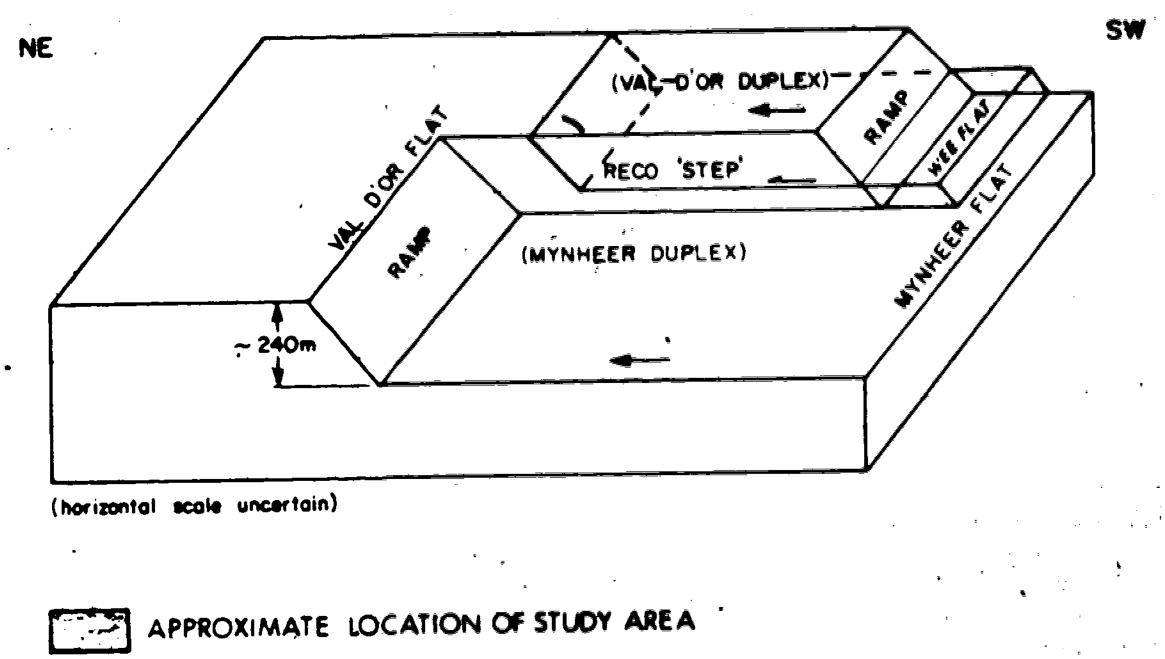


Fig. 14. Schematic block diagram of fault geometry during duplex initiation.

Weldwood syncline were rotated to their present position as a result of movement along the Weldwood #1-#3 thrusts, which appear to flatten with depth.

STAGE D

During Stage D movement occurred along southwest-dipping thrusts which end to the north against the Beaverdam ramp in the Beaverdam Fault Zone. The northeast-dipping thrusts of the Weldwood Fault Zone are truncated by the Beaverdam ramp, so movement along the Beaverdam thrusts must have occurred after the end of Stage C.

The base of the Mynheer duplex was disrupted in certain localities by faults with small displacements (Fig. 13, stage 4). These are either small transverse ramps contemporaneous with duplex formation, or younger longitudinal thrusts, in which case these structures developed during or after Stage B, respectively.

STAGE E

Movement along deep-seated southwest-dipping thrusts was probably responsible for southwest tilting of the entire Coal Valley assemblage. This tilting appears to have been the last tectonic event in the area.

VIII. Summary

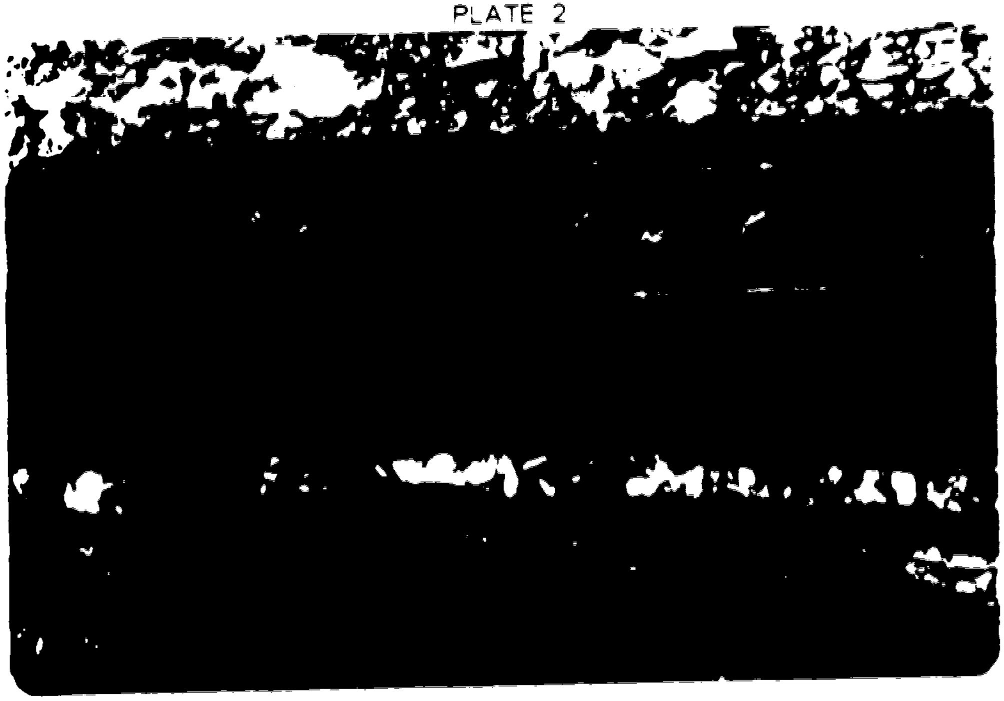
All three objectives of the thesis project were realized, namely: (1) large outcrop and drillhole data bases were constructed, (2) computer processing of the data was accomplished and proved to be effective, and (3) the structure of coal measures in the study area was analyzed and the podding of two coal seams explained. Based on this structural analysis, a scenario for the structural evolution of the area was proposed.

The most economic and structurally significant feature in the study area is the duplex, which has resulted in up to twentyfold thickening of the Mynheer coal seam and up to fivefold thickening of the Val D'or coal seam. The reason why duplexes form in specific localities may be related to the interaction between large bedding plane thrusts, oblique ramps and northeast-dipping thrust faults. The recognition of other duplexes and structures associated with them will be necessary to establish a model for their occurrence in the Foothills.

PLATE 1

The Val D'or coal seam viewed from the edge of Pit 21 looking north. Imbricate thrusts within the Val D'or duplex are designated by arrows. Depth of the cut is 8 m.

PLATE 2

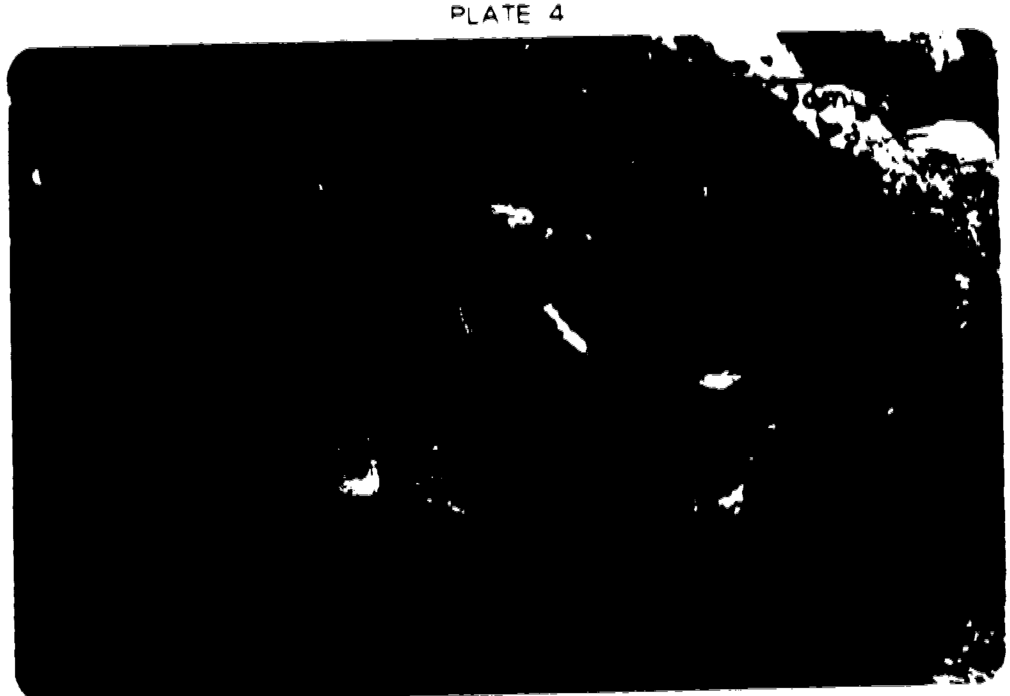


The Val D'or seam in Pit 21 looking south. The imbricated bentonite in the upper part of seam is within a duplex. Roof and floor thrusts are designated by arrows. The sandstone split is 40 cm thick.

PLATE 3

The main pod of the Mynneer duplex in Pit 8 looking southeast. The lake level to the top of the coal pod is 26 m. Thrusts are designated by arrows. B= basal tongues. T= Coal Valley tuff horizon.

PLATE 4

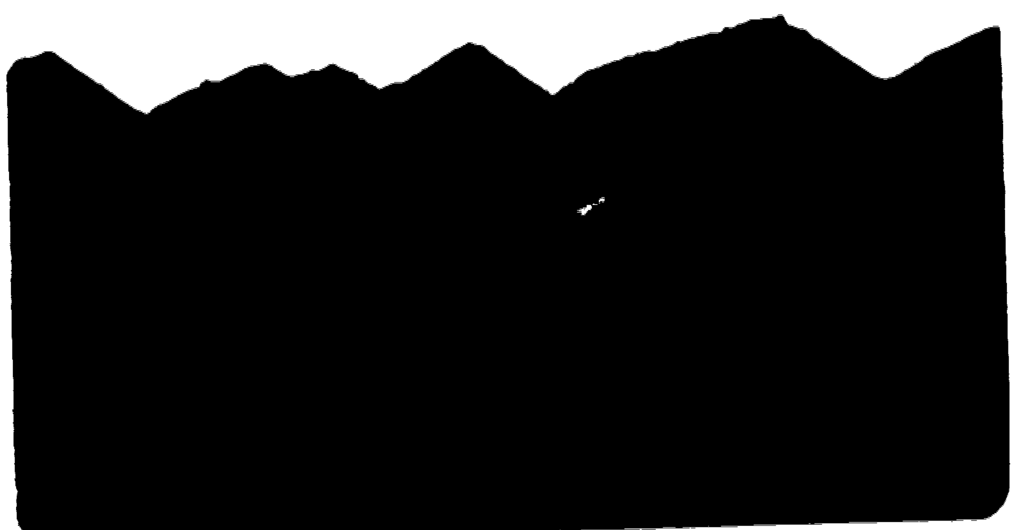


Mesoscopic folds in the Mynneer coal in Pit 15. The scale is shown.

PLATE 5

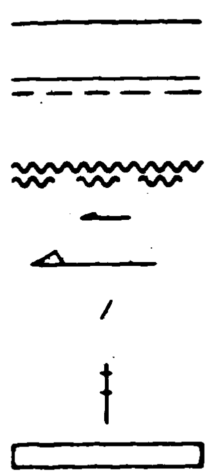
The main pod of the Mynheer duplex in Pits 13 and 14 looking northwest. Water level to dragline bench is 34 m.

PLATE 6



The Val D'Or coal on the northwest edge of the Weldwood pod looking southwest. Repetition of the 50 cm thick sandstone split is shown by arrows.

Legend for Figures 10a - 10o



TOPOGRAPHIC SURFACE

GEOLOGICAL CONTACT
(known, inferred)

FAULT (known; inferred)

SENSE OF MOVEMENT

BOUNDING FAULT OF DUPLEX (showing movement)

OUTCROP STATION PROJECTION

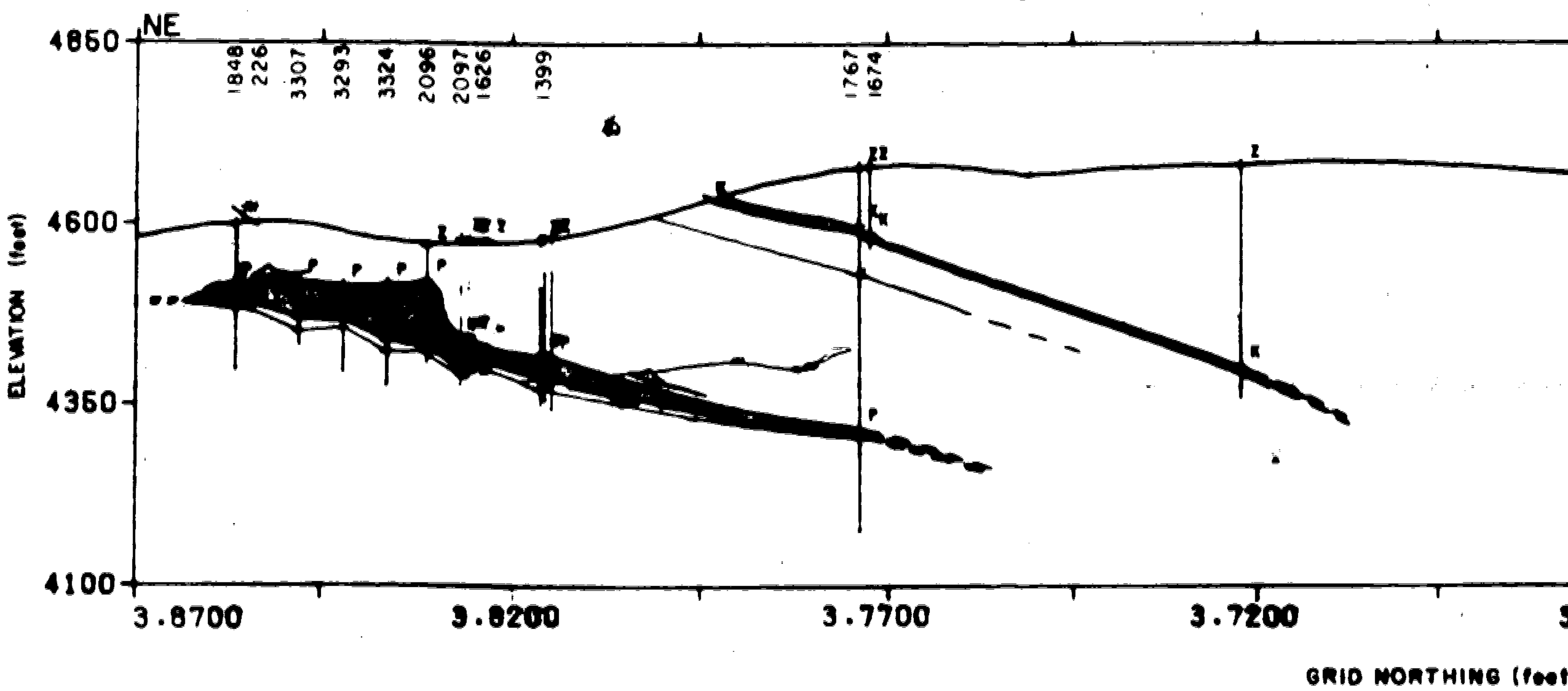
DRILLHOLE PROJECTION

COAL SEAM

A VAL D'OR TOP
C VAL D'OR BOTTOM
D ARBOUR TOP
F ARBOUR BOTTOM
G BENTONITE
H MARKER A
I MARKER B
(FOR KEY TO OTHER CODES SEE APPENDIX 1)

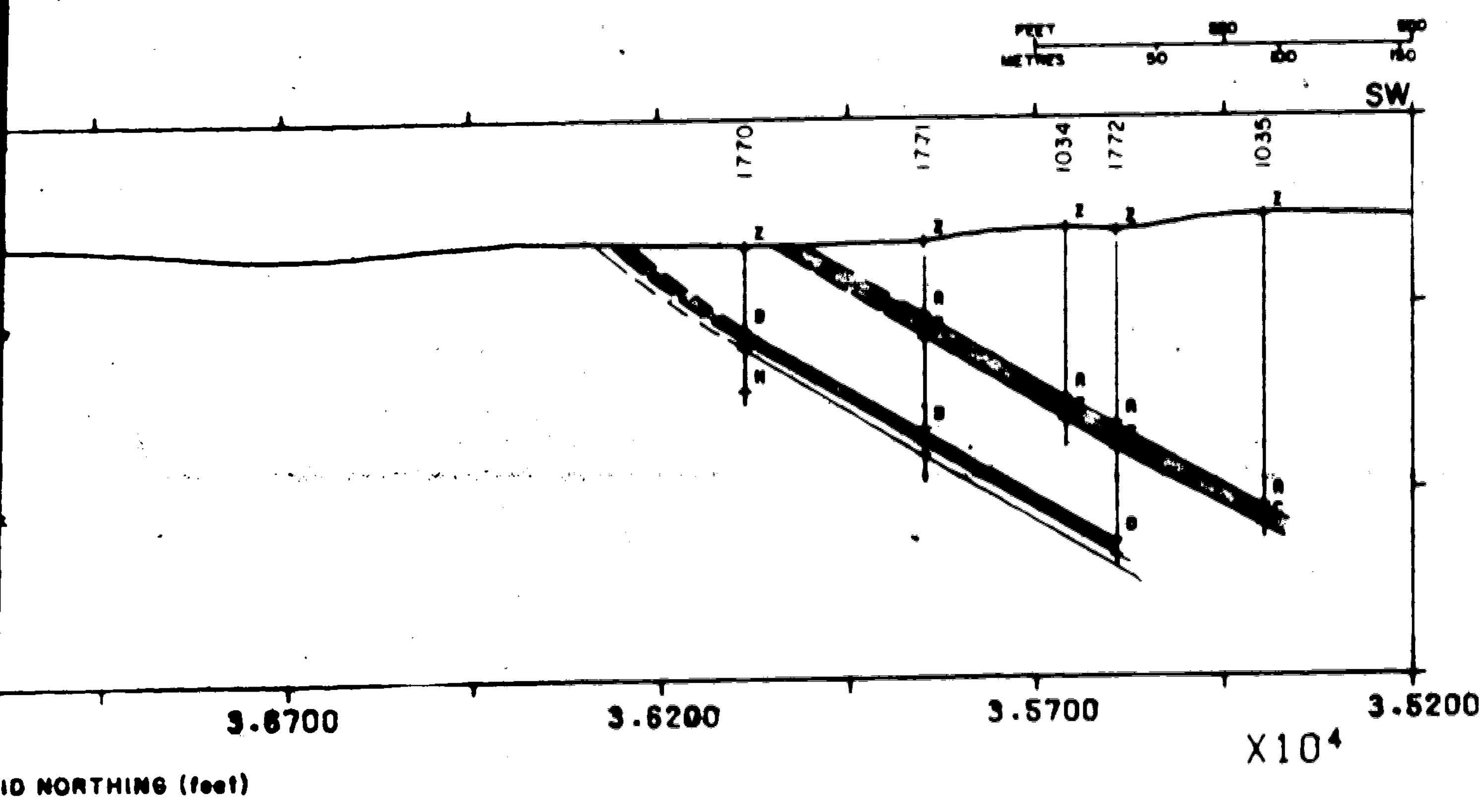
K WEE TOP
M WEE BOTTOM
N BOURNE TOP
P MYNHEER TOP
R } MYNHEER BOTTOM AND
S } LOWER MYNHEER TOP
U LOWER MYNHEER BOTTOM

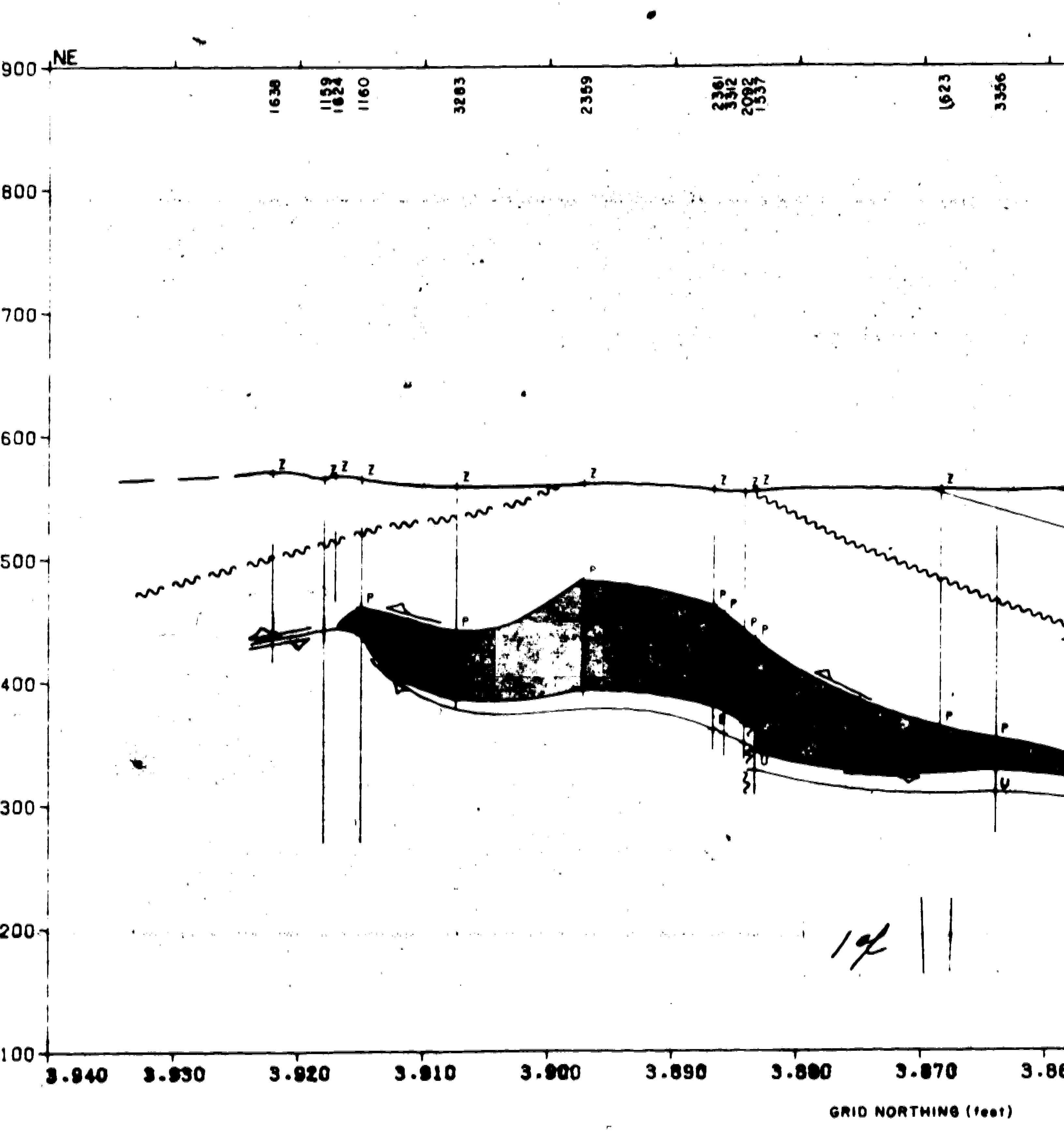
14 ||


NE
4850
4600
4350
4100
ELEVATION (feet)
1848
226
3307
3293
3324
2096
2097
1626
1399
1767
1674
3.8700
3.8200
3.7700
3.7200
GRID NORTHING (feet

2 of 2

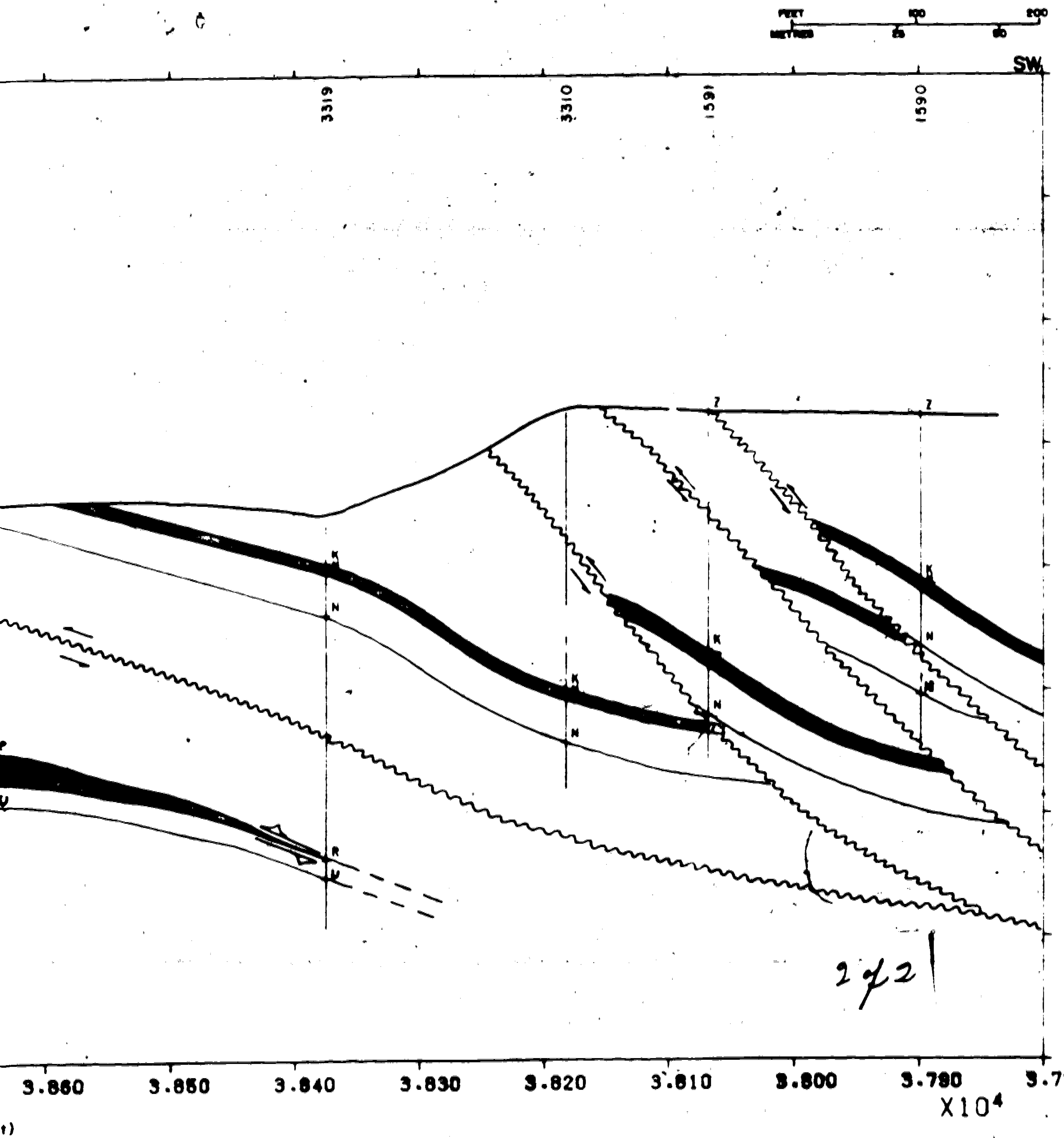
FIGURE 10a
CROSS-SECTION A-A'
GRID EASTING 70000

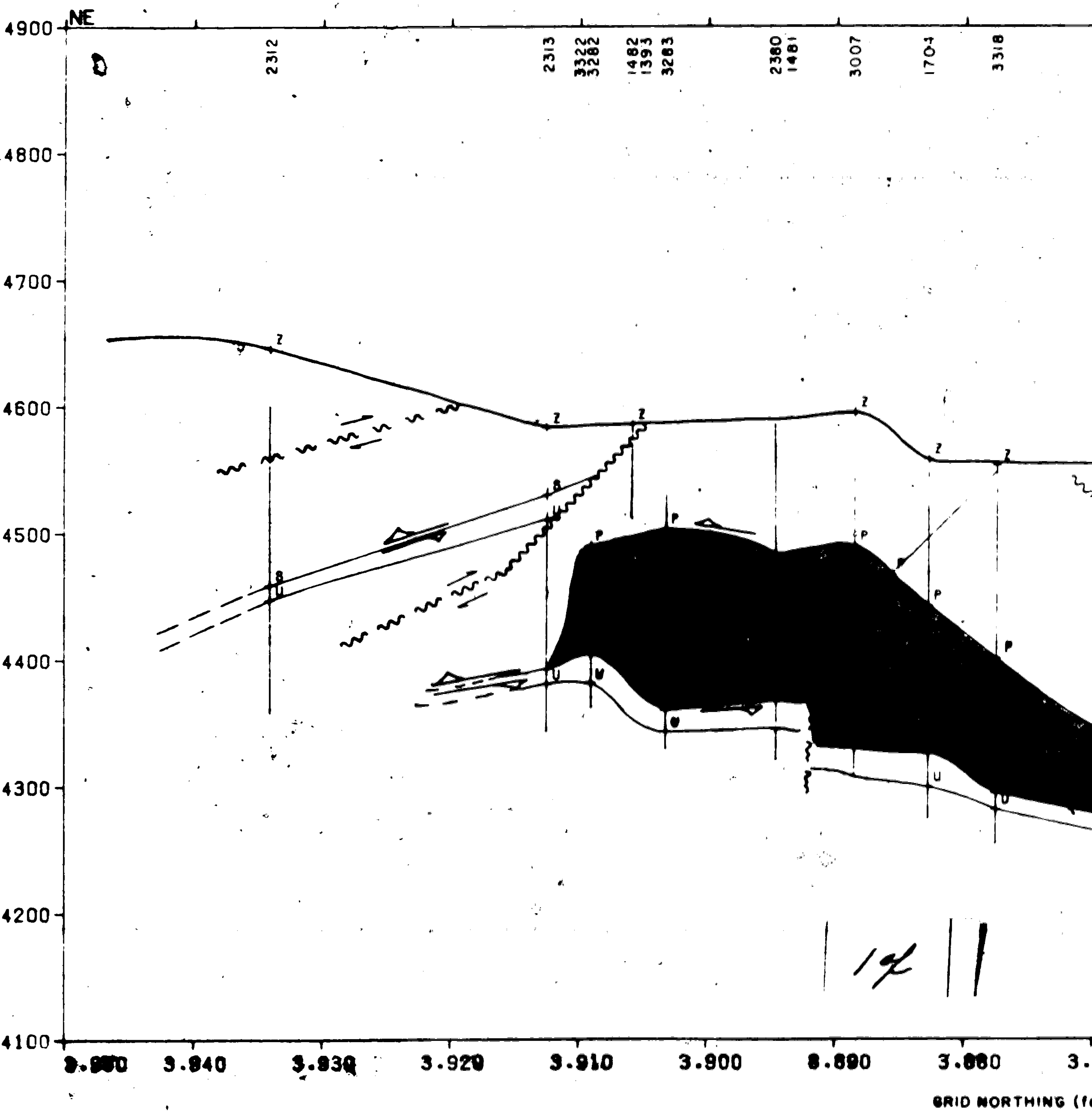




NE
900
800
700
600
500
400
300
200
100
1638
1159
1624
1160
3283
2359
2361
3312
2082
1537
1623
3356
3.940
3.930
3.920
3.910
3.900
3.890
3.880
3.870
GRID NORTHING (feet)

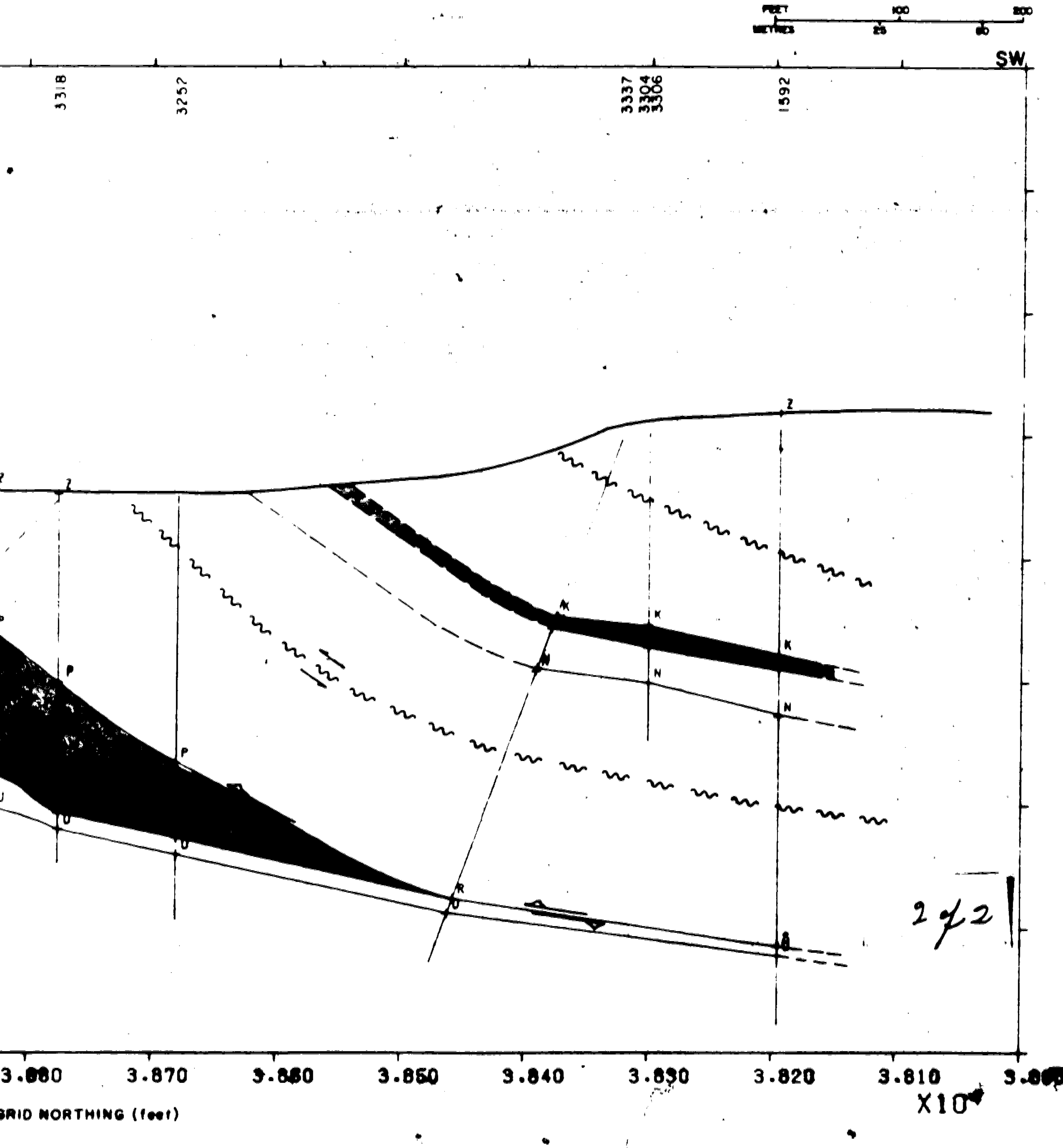
FIGURE 10b
CROSS-SECTION B-B'
GRID EASTING 74500





NE
4900
4800
4700
4600
4500
4400
4300
4200
4100
2312
2313
3322
3282
1482
1393
3283
2380
1481
3007
1704
3318
3.940
3.930
3.920
3.910
3.900
3.890
3.880
GRID NORTHING

FIGURE 10c
CROSS-SECTION C-C'
GRID EASTING 75000



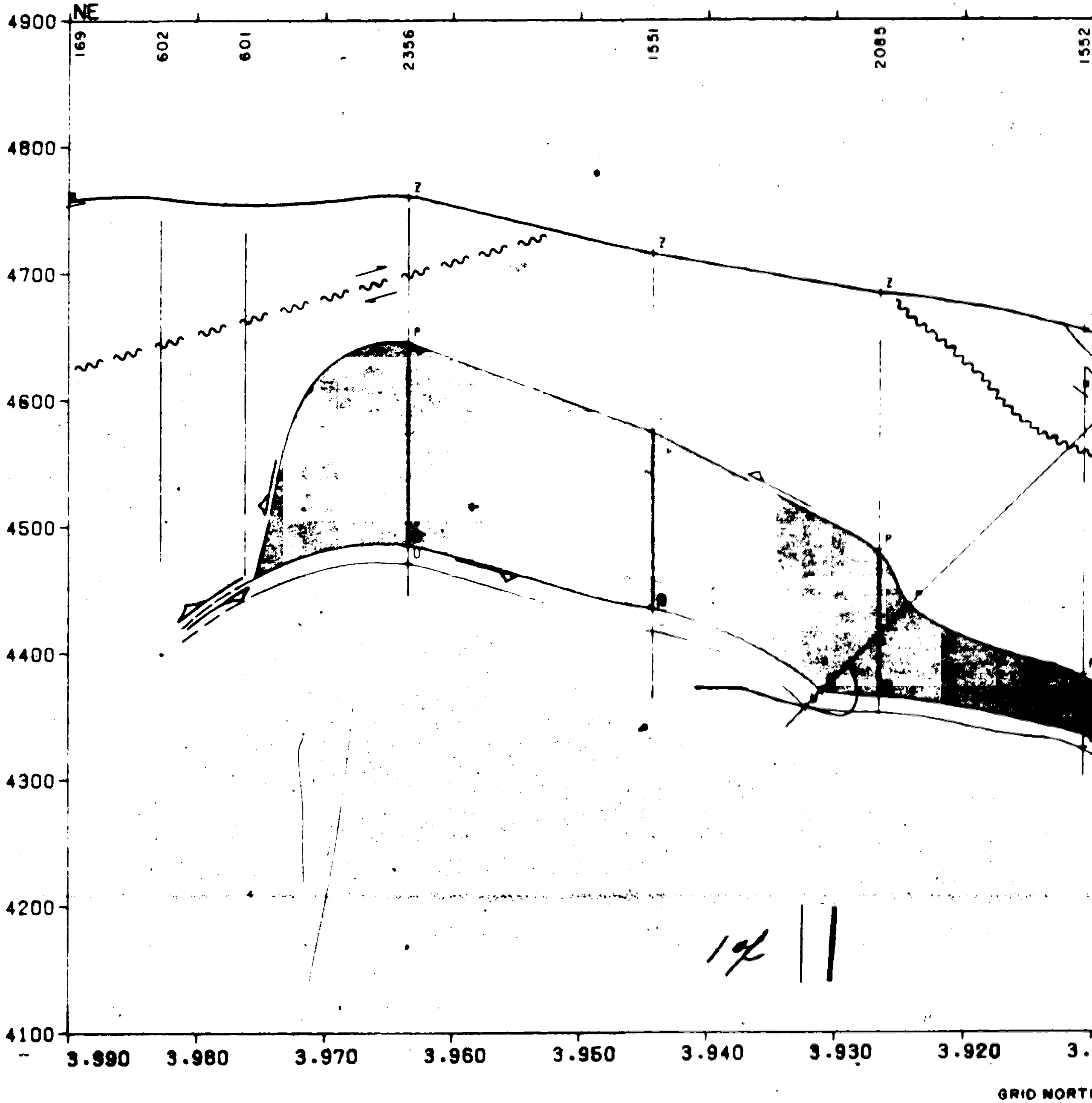
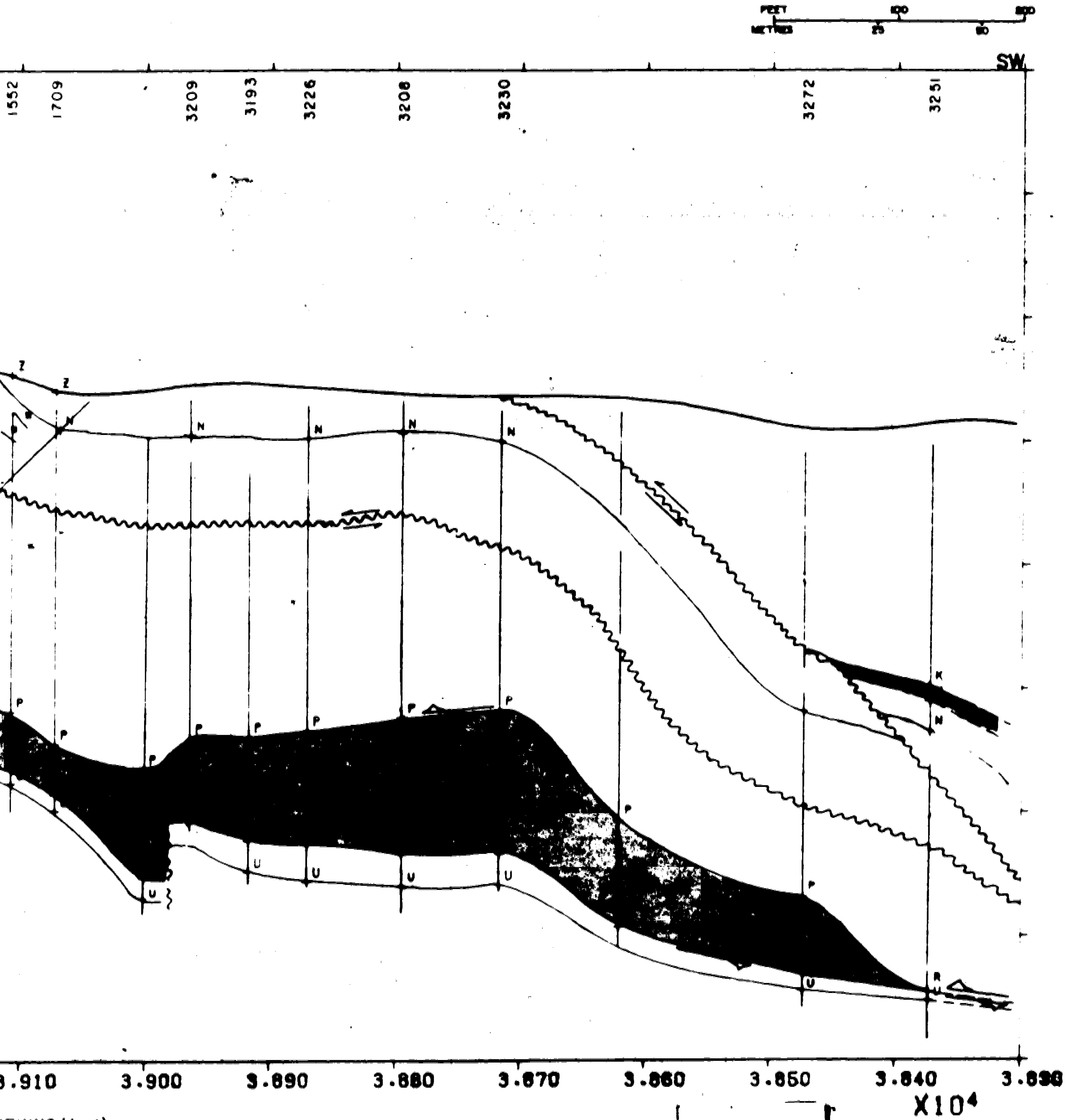
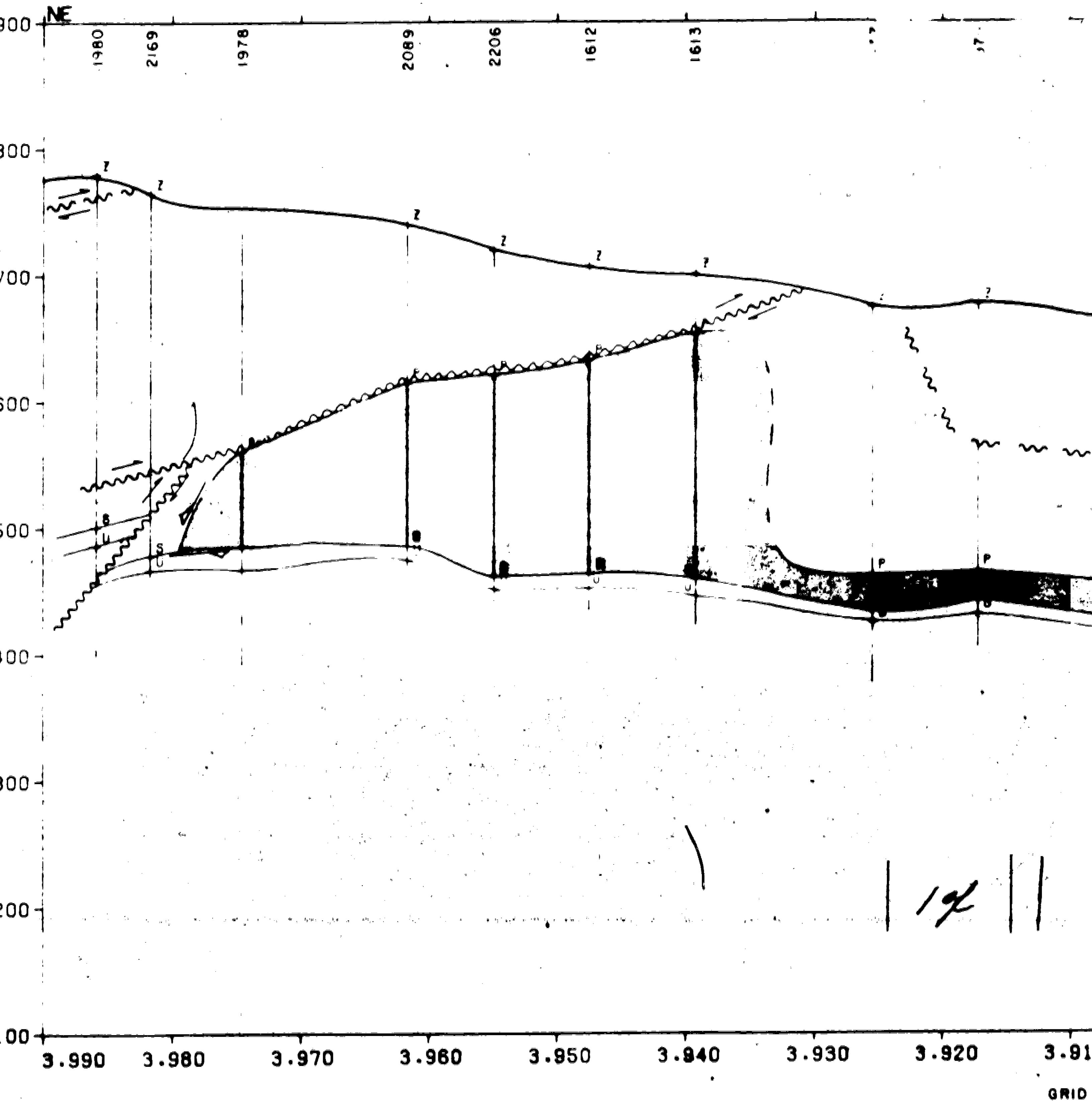

NE
4900
4800
4700
4600
4500
4400
4300
4200
4100
169
602
601
2356
1551
2085
1552
3.990
3.980
3.970
3.960
3.950
3.940
3.930
3.920
GRID NORT

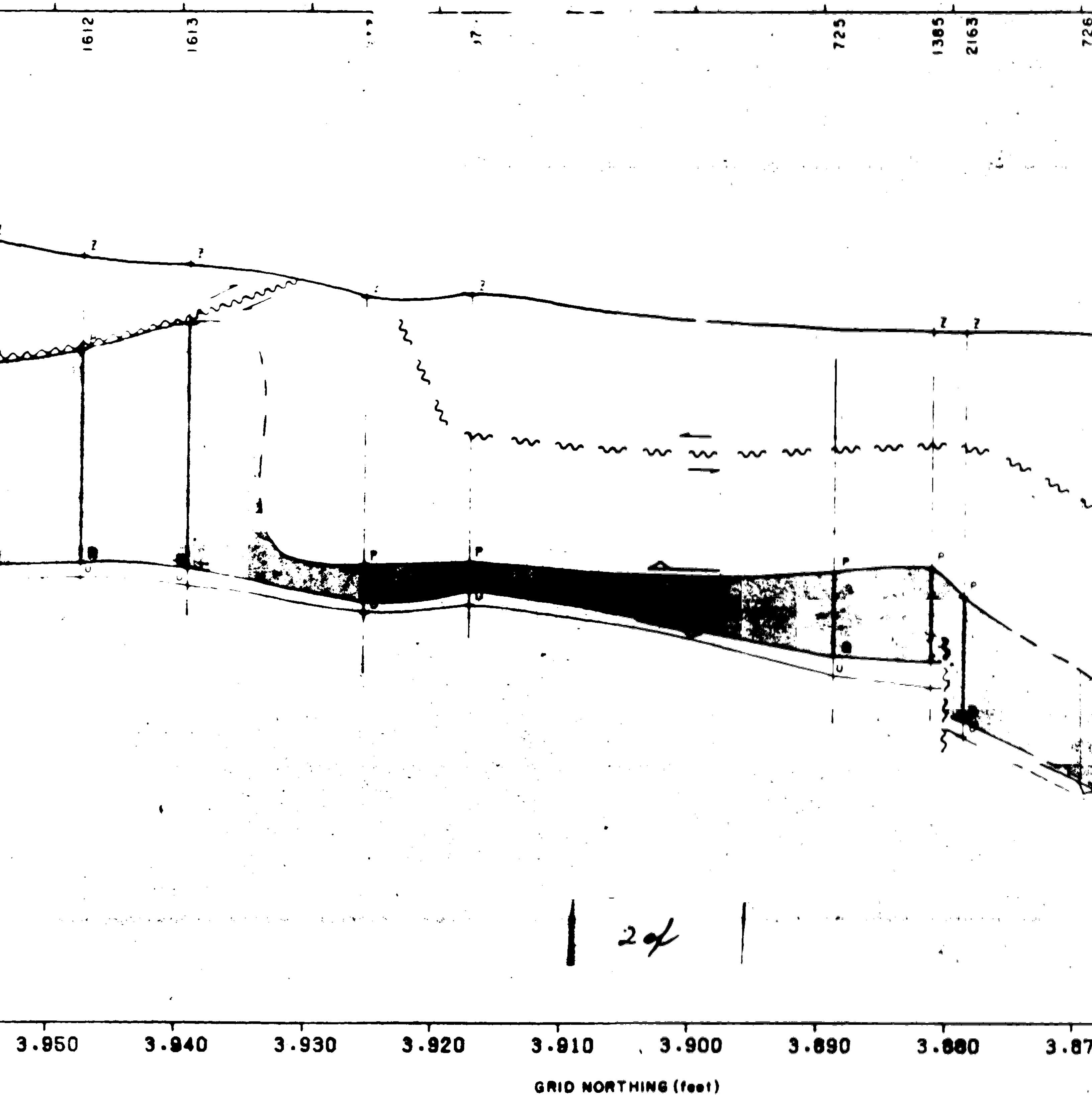
FIGURE 10d
CROSS-SECTION D-D'
GRID EASTING 77500



2 of 2



NE
1980
2169
1978
2089
2206
1612
1613
900
800
700
600
500
400
300
200
100
3.990
3.980
3.970
3.960
3.950
3.940
3.930
3.920
3.91
GRID

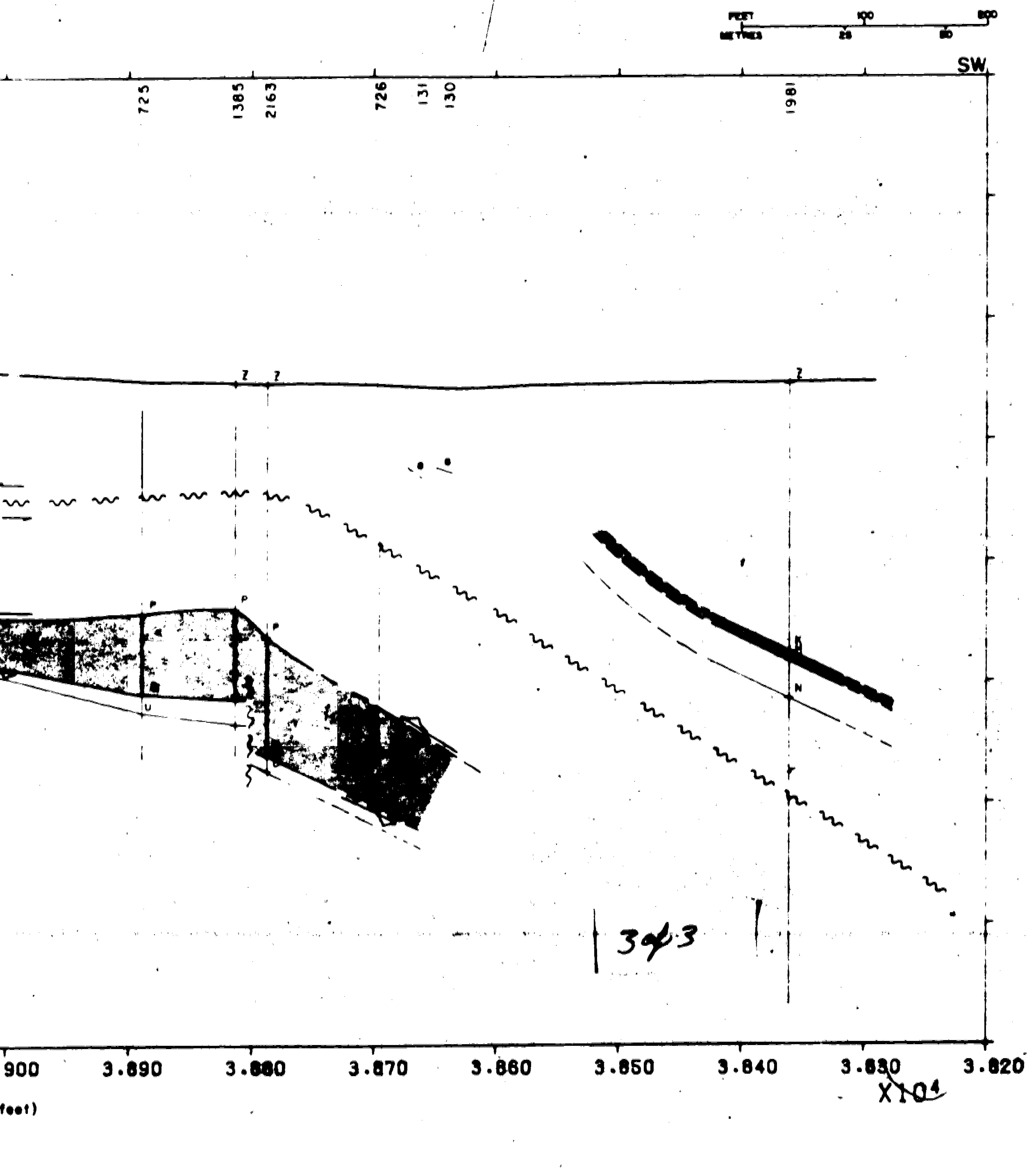


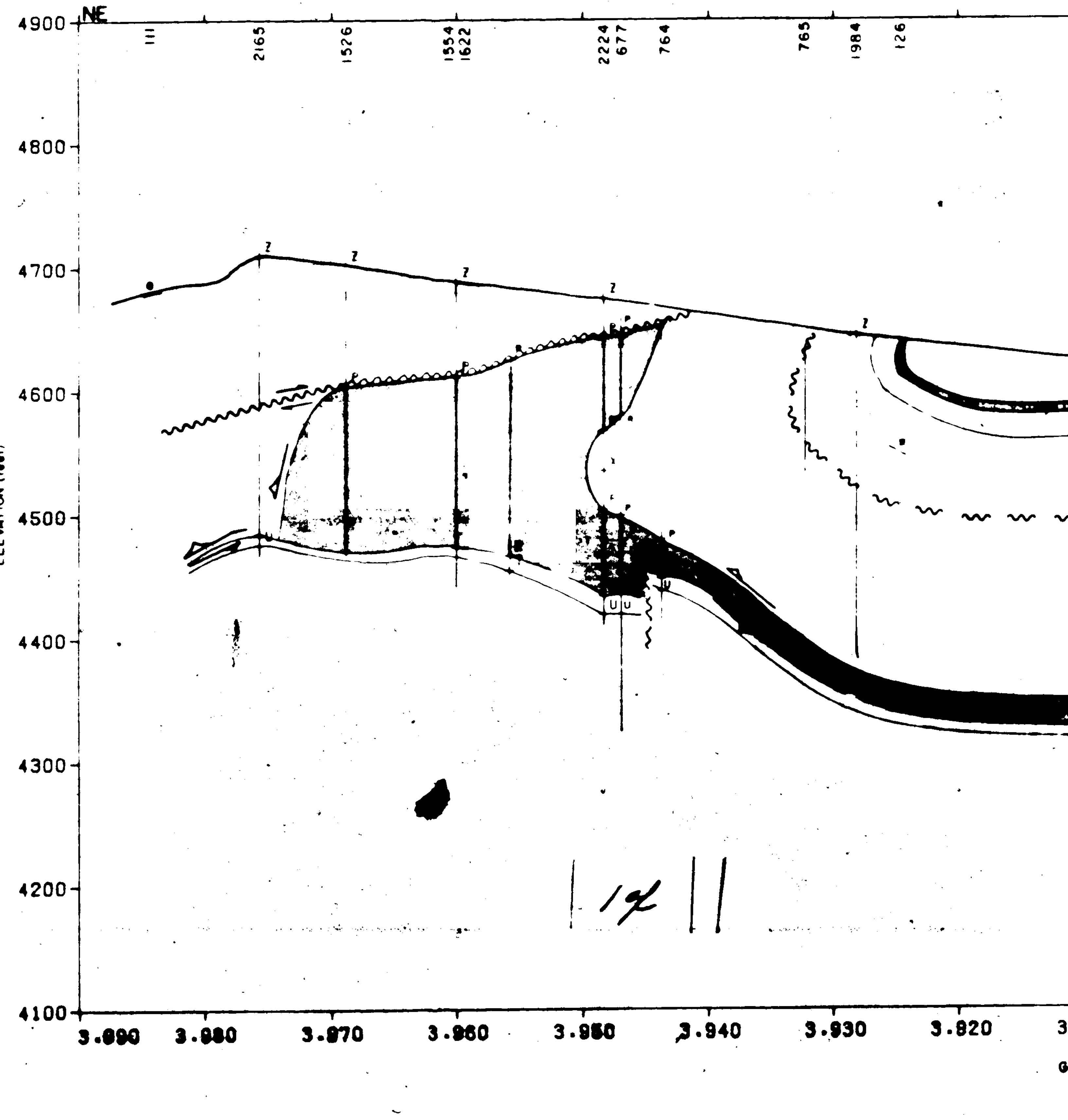
1612
1613
725
1385
2163
726
3.950
3.940
3.930
3.920
3.910
3.900
3.890
3.880
GRID NORTHING (feet)
2 of

FIGURE 10e

CROSS-SECTION E-E'

GRID EASTING 82000




NE
4900
4800
4700
4600
4500
4400
4300
4200
4100
111
2165
1526
1554
1622
2224
677
764
765
1984
126
3.990
3.980
3.970
3.960
3.950
3.940
3.930
3.920

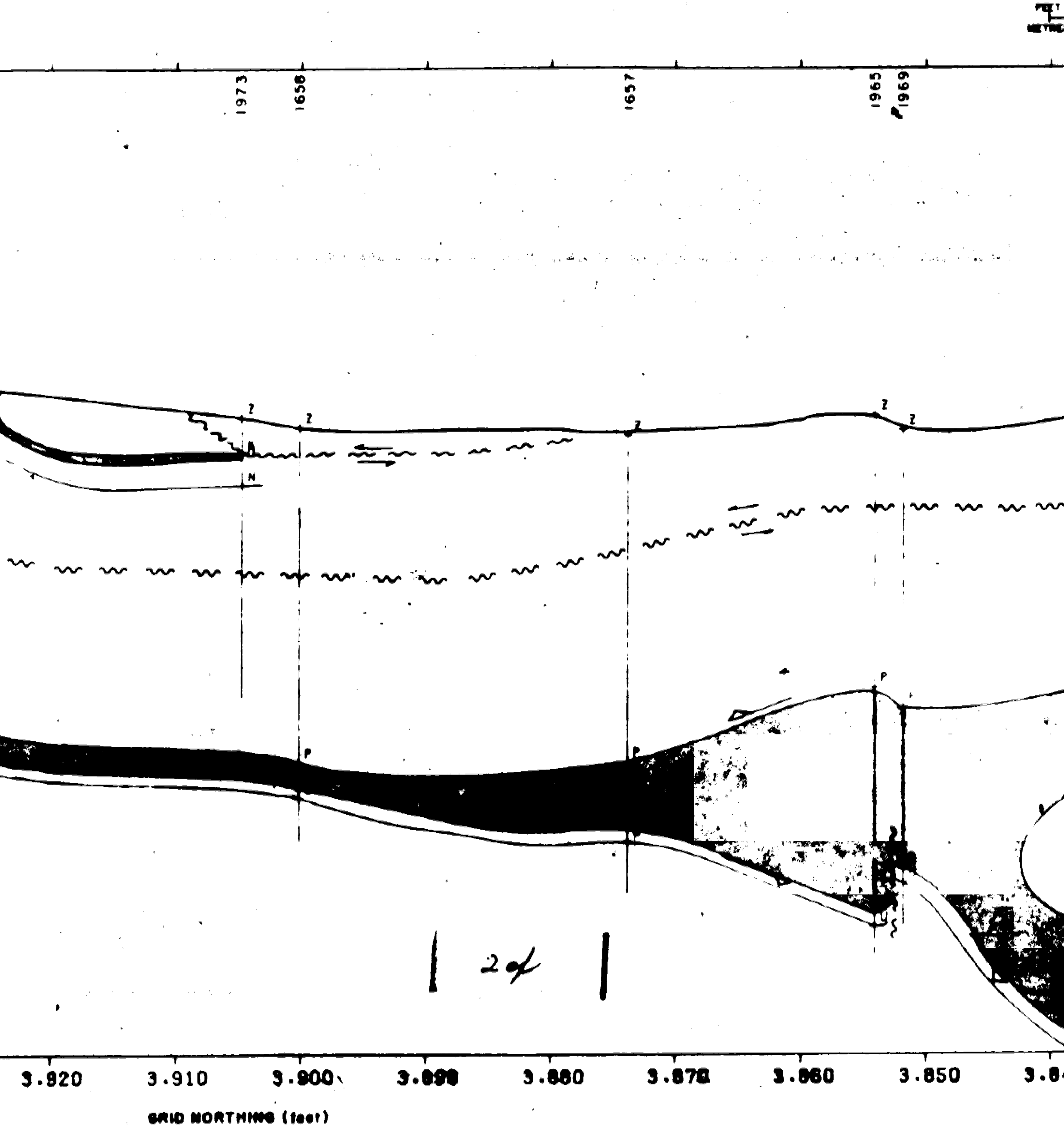
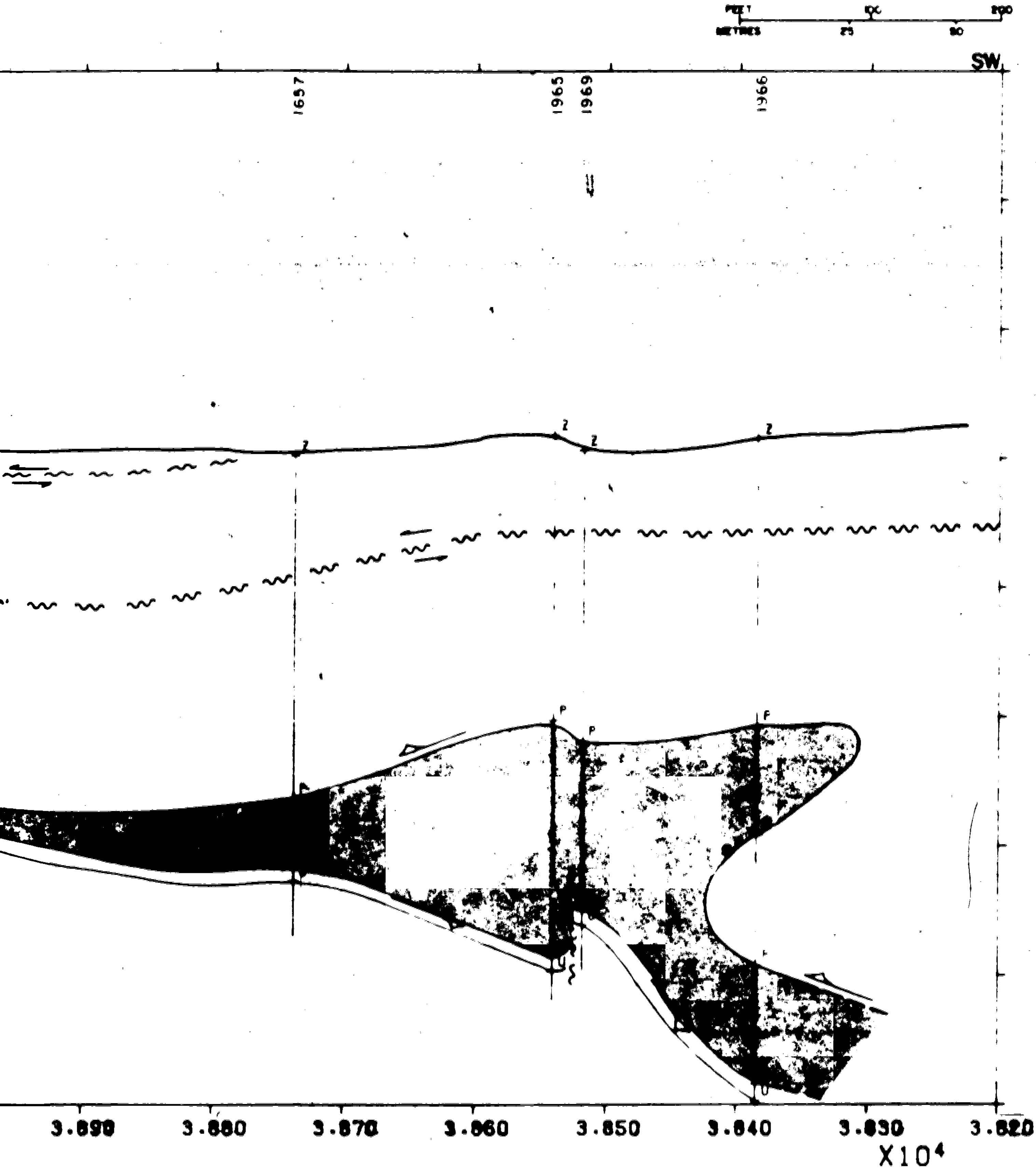
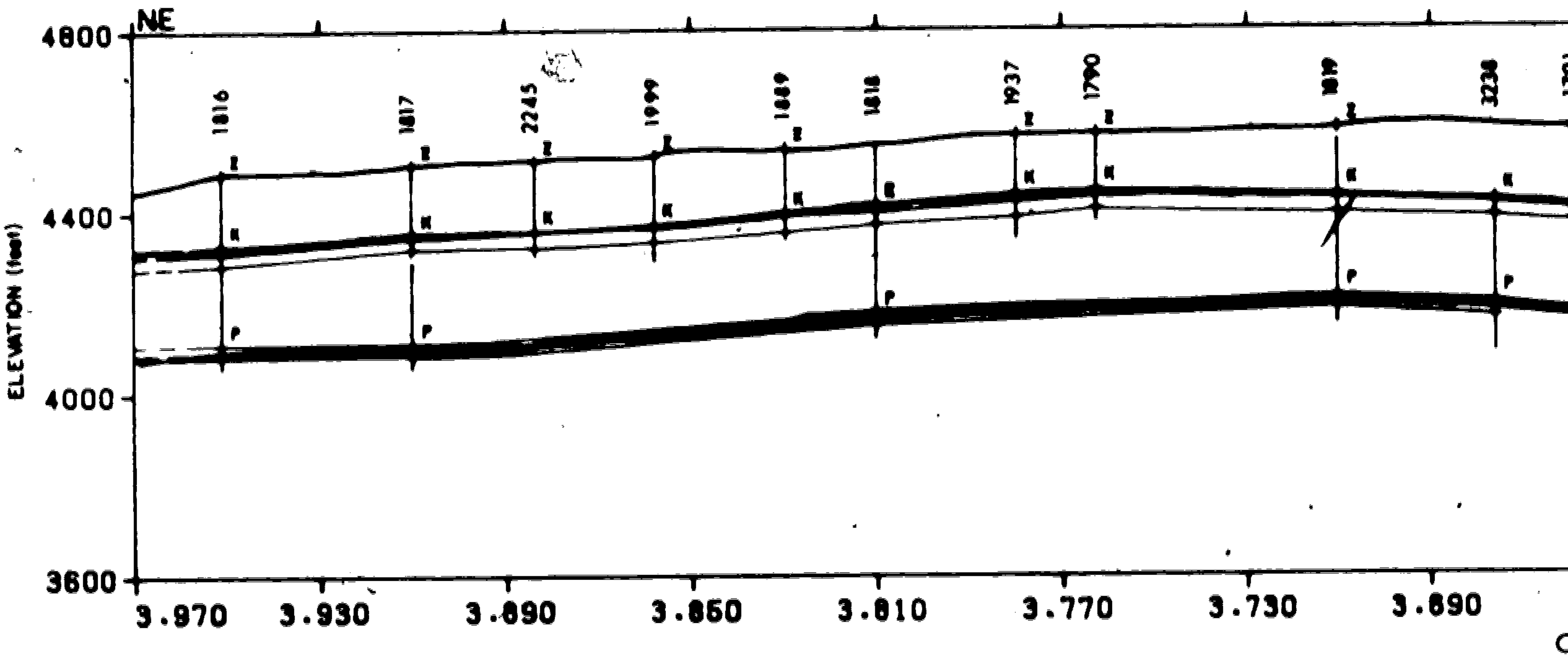

1973
1658
1657
1965
1969
3.920
3.910
3.900
3.880
3.850
GRID NORTHING (feet)

FIGURE 10f
CROSS-SECTION F-F'
GRID EASTING 83000

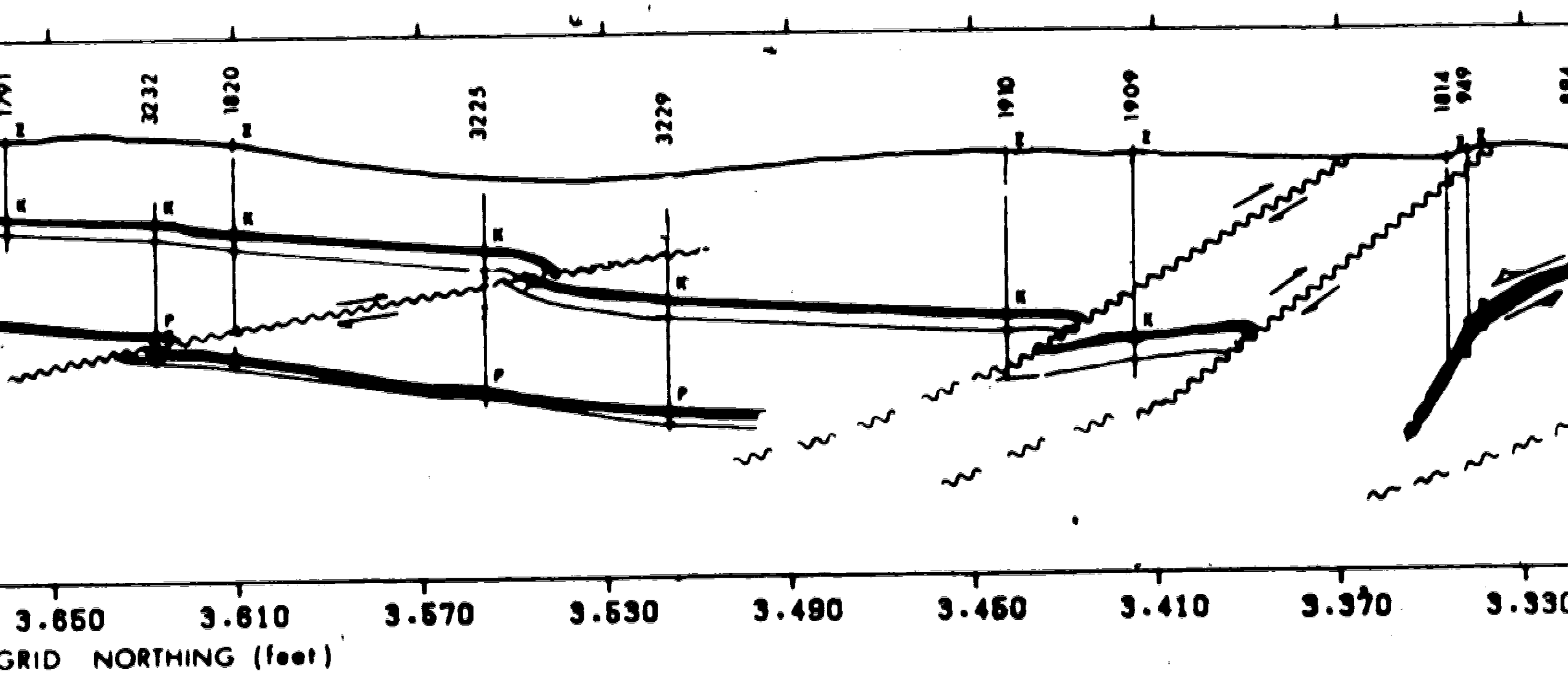


3 of 3



NE
4800
4400
4000
3600
ELEVATION (feet)
1816
1817
2245
1999
1889
1818
1937
1790
1819
3238
3.970
3.930
3.890
3.850
3.810
3.770
3.730
3.690

14



3232
1820
3225
3229
1910
1909
1814
949
3.650
3.610
3.570
3.530
3.490
3.450
3.410
3.370
3.330
GRID NORTHING (feet)

2 of

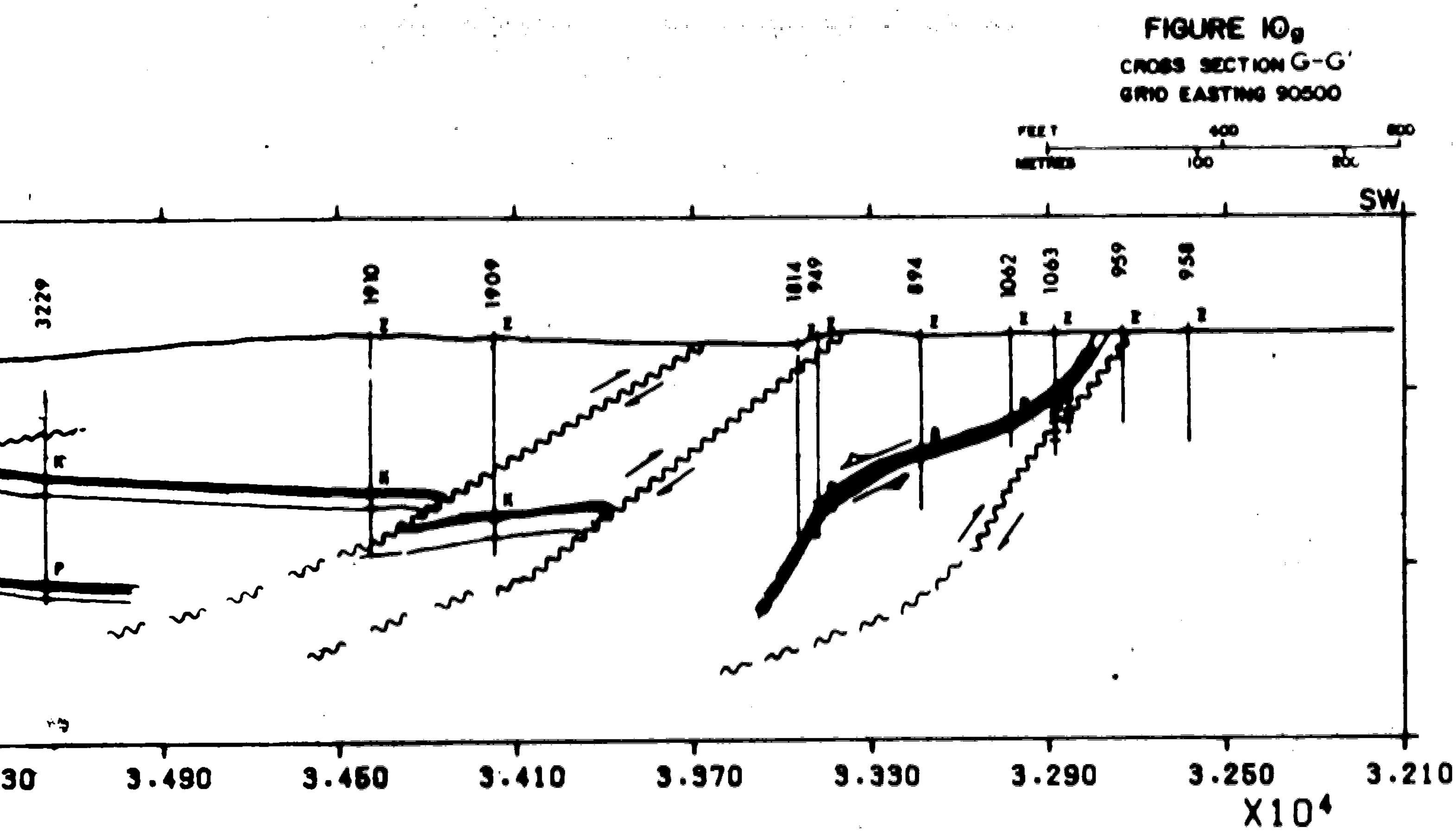
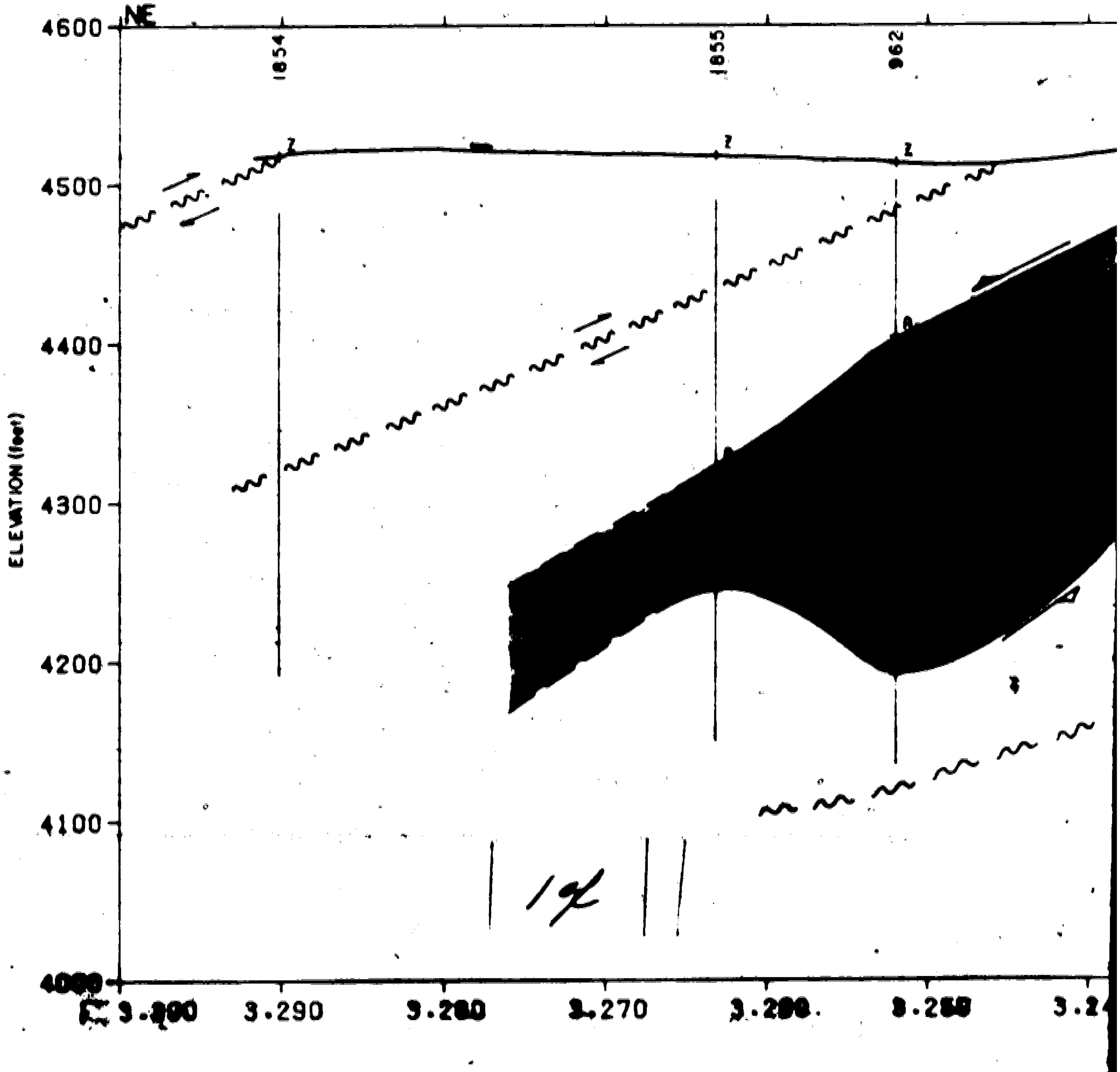
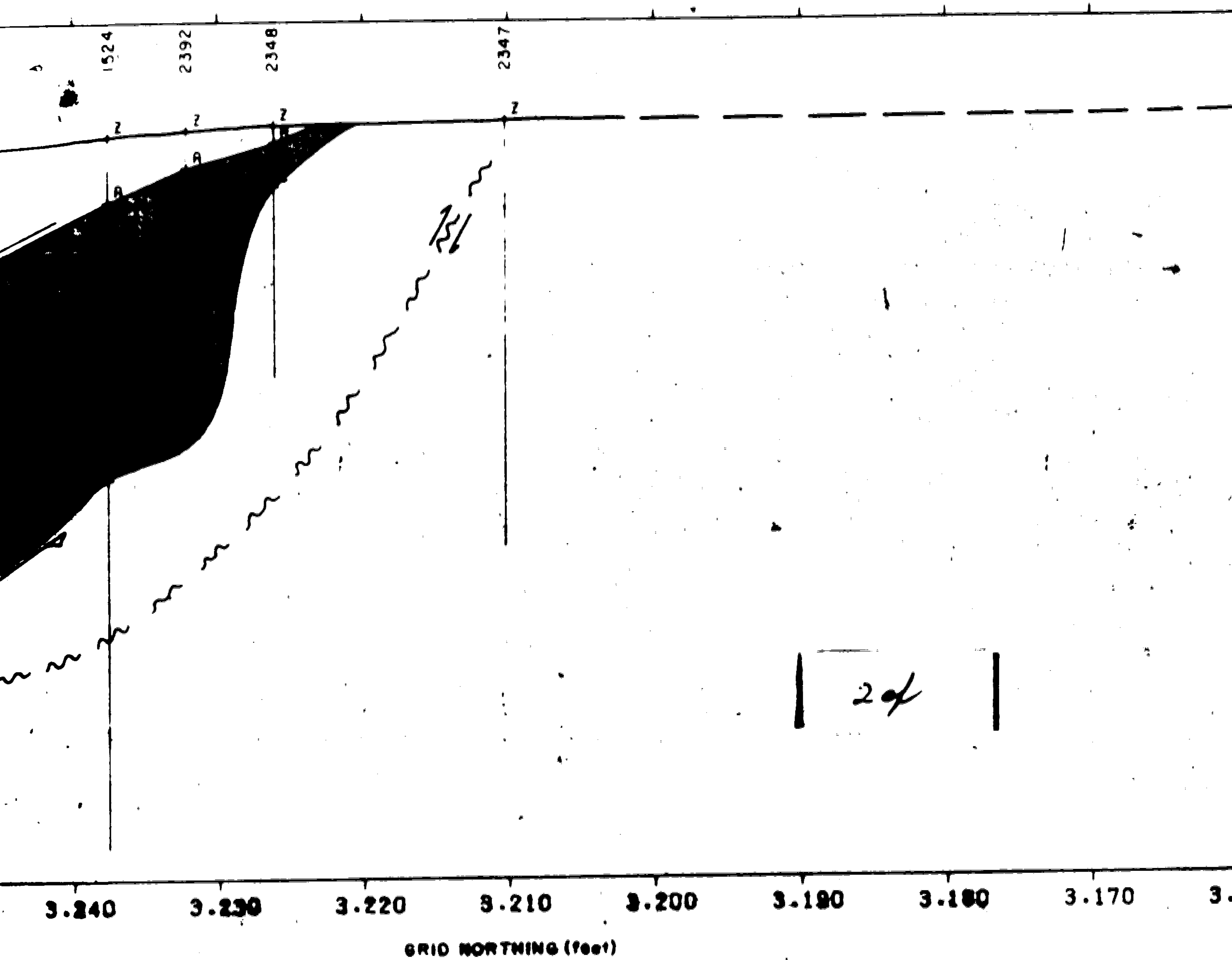


FIGURE 10g
CROSS SECTION G-G'
GRID EASTING 90500
FEET
400
800
METRES
100
200
SW
3229
1910
1909
1814
949
894
1062
1063
959
958
30
3.490
3.450
3.410
3.370
3.330
3.290
3.250
3.210
X10⁴

3 of 3



NE
4600
4500
4400
4300
4200
4100
ELEVATION (feet)
1854
1855
962
3.290
3.270

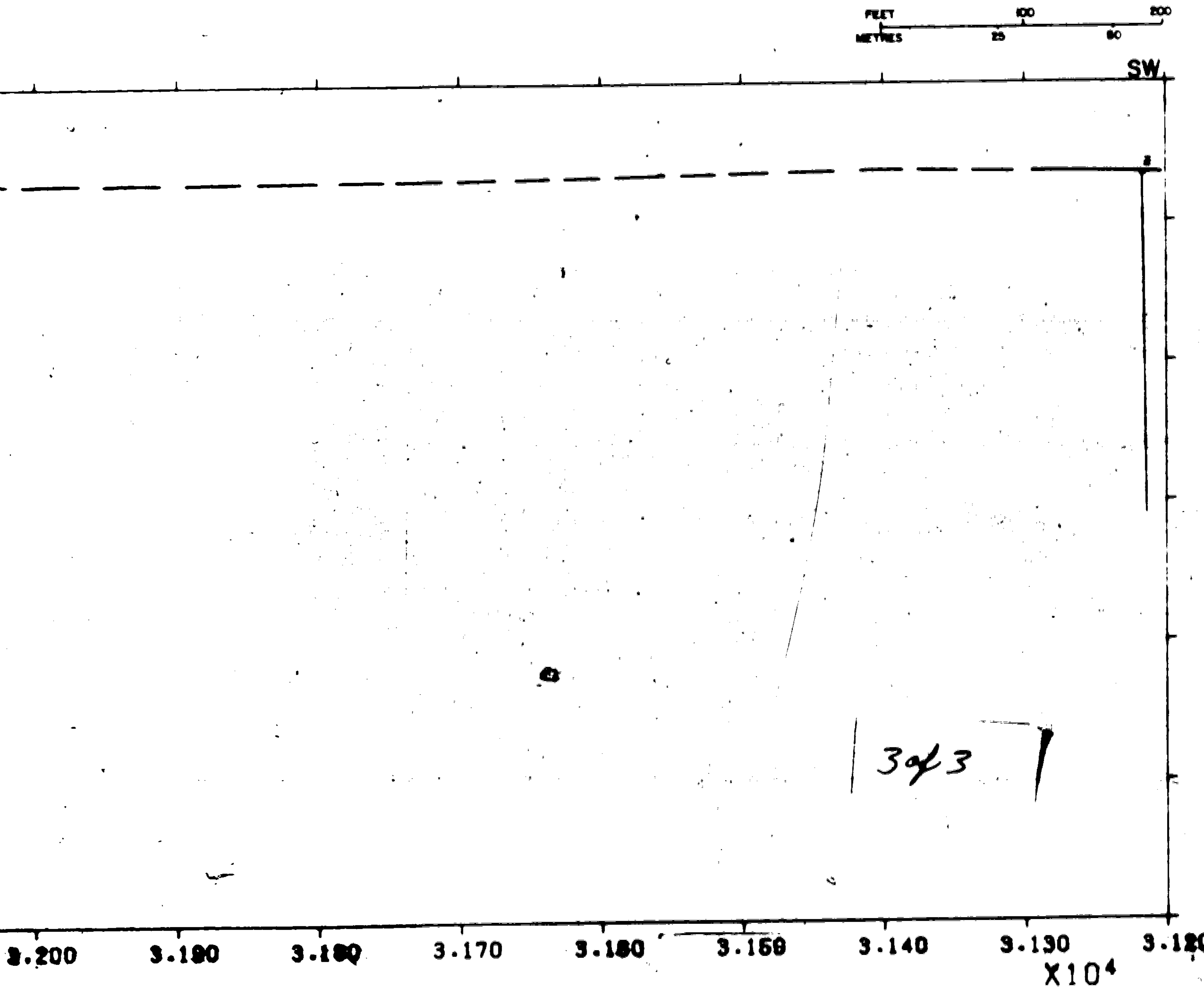


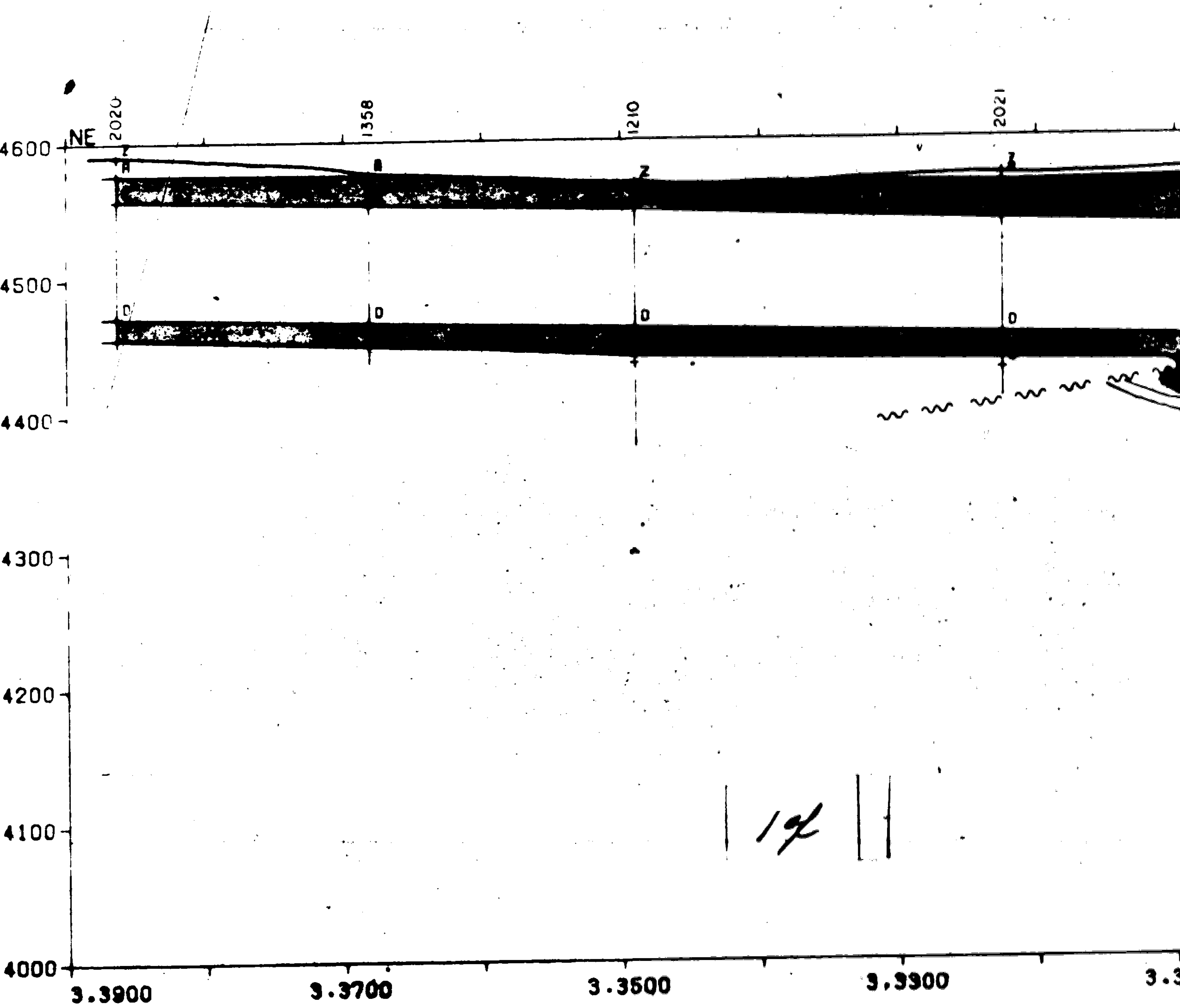
1524
2392
2348
2347
3.240
3.230
3.220
3.210
3.200
3.190
3.180
3.170
GRID NORTHING (feet)
2 of

FIGURE 10h

CROSS-SECTION H-H'

GRID EASTING 91800




4600
4500
4400
4300
4200
4100
4000
NE
2020
1358
1210
2021
Z
B
D
3.3900
3.3700
3.3500
3.3300

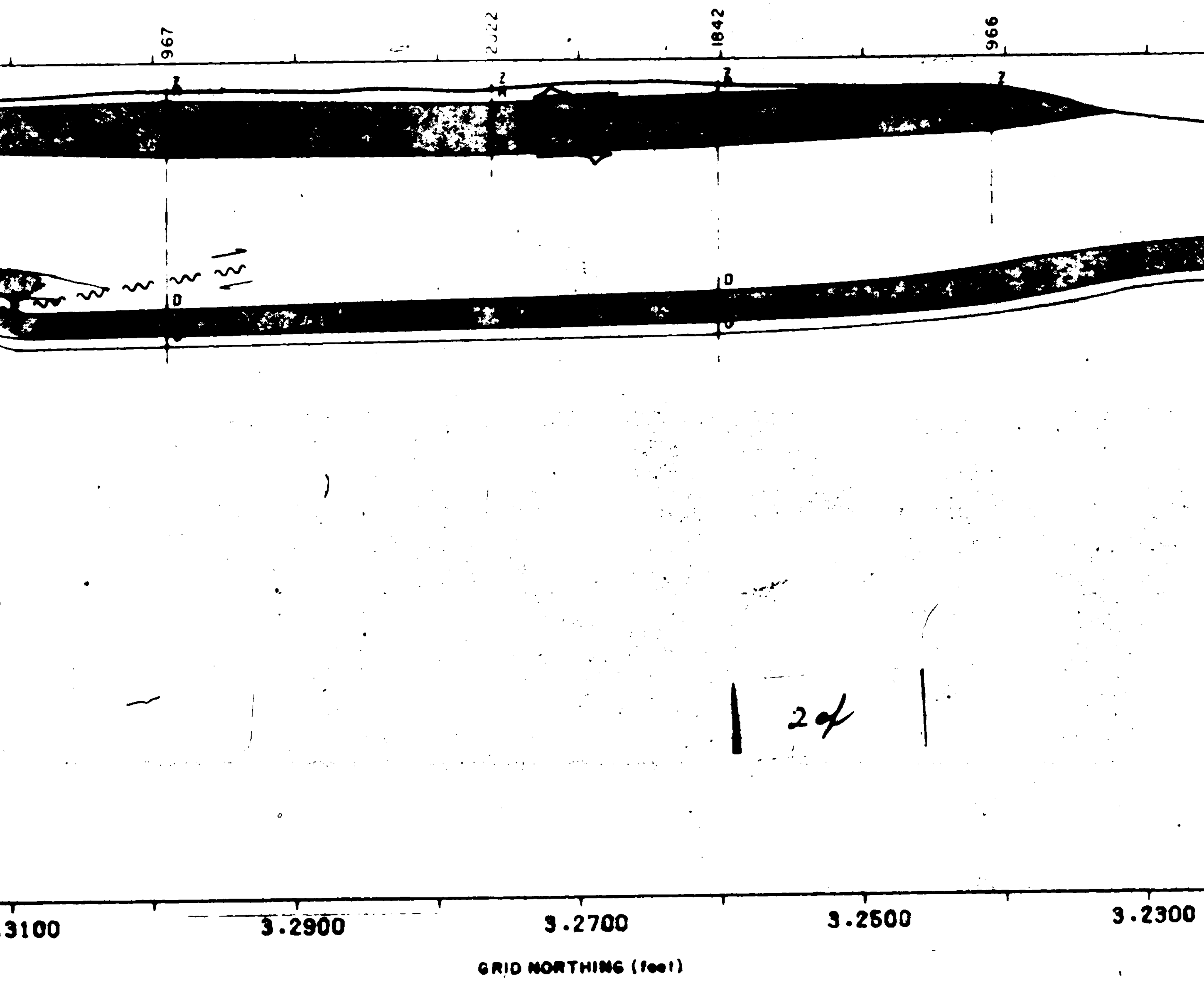
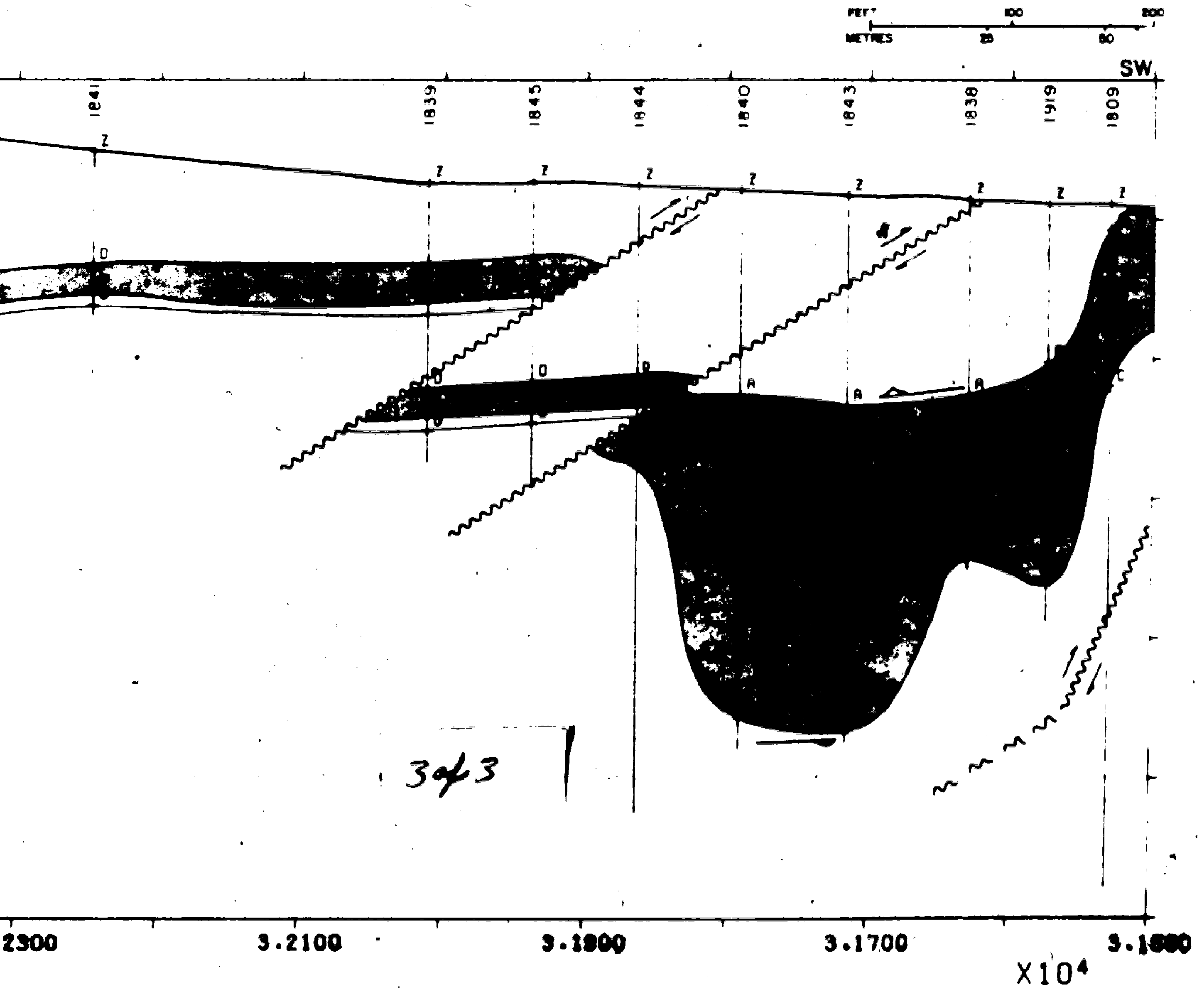
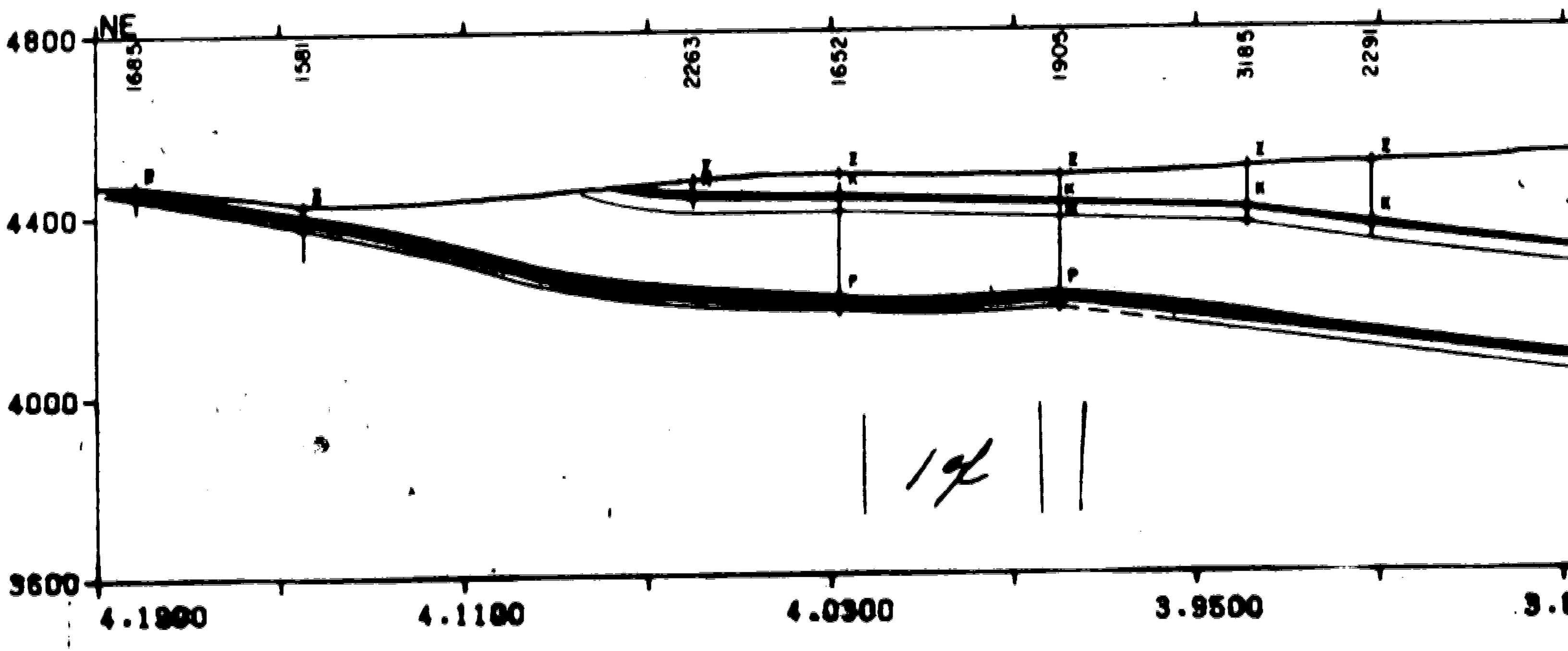
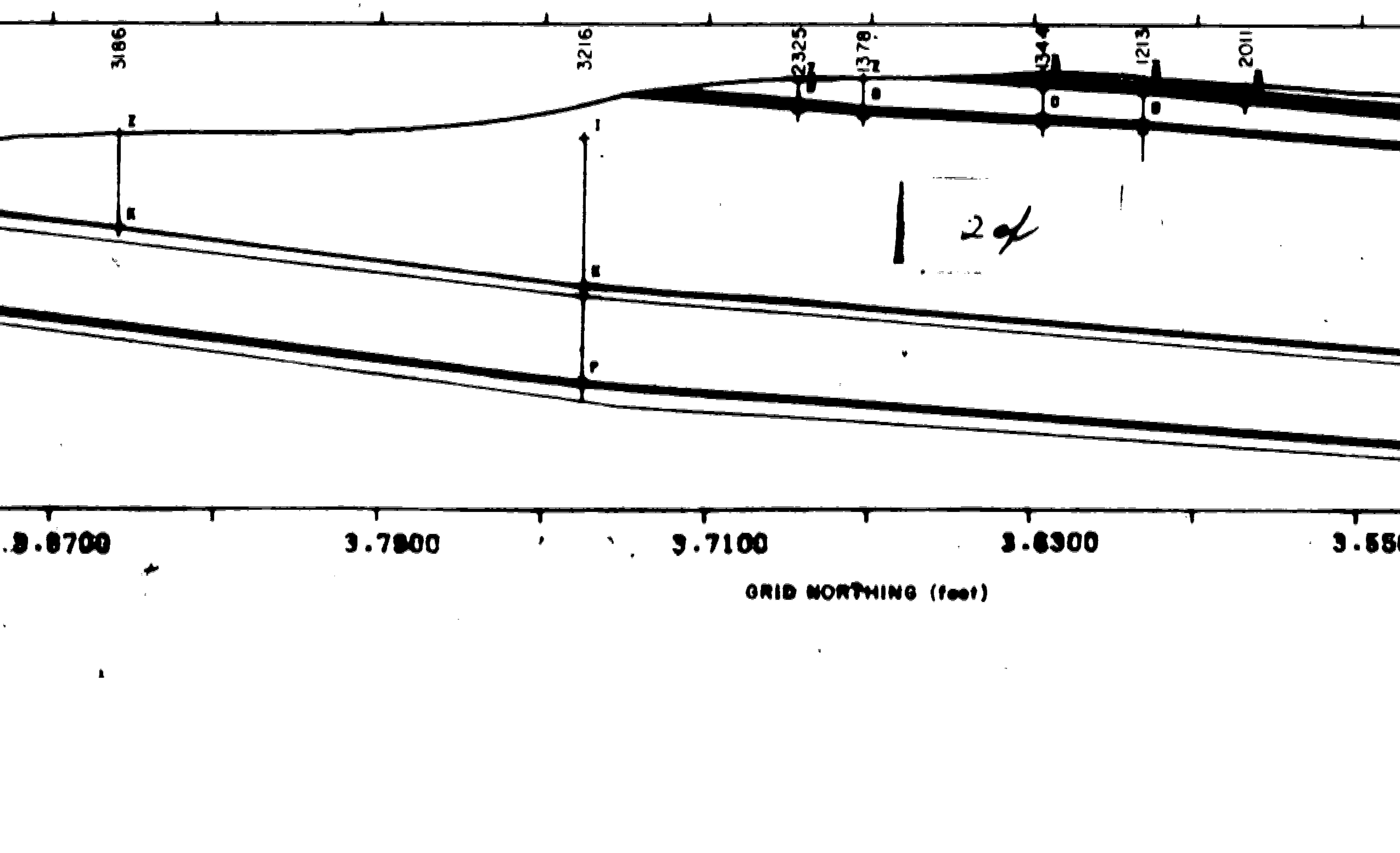

967
1842
966
D
2 of
.3100
3.2900
3.2700
3.2500
3.2300
GRID NORTHING (feet)

FIGURE 10i
CROSS-SECTION I-I'
GRID EASTING 94230

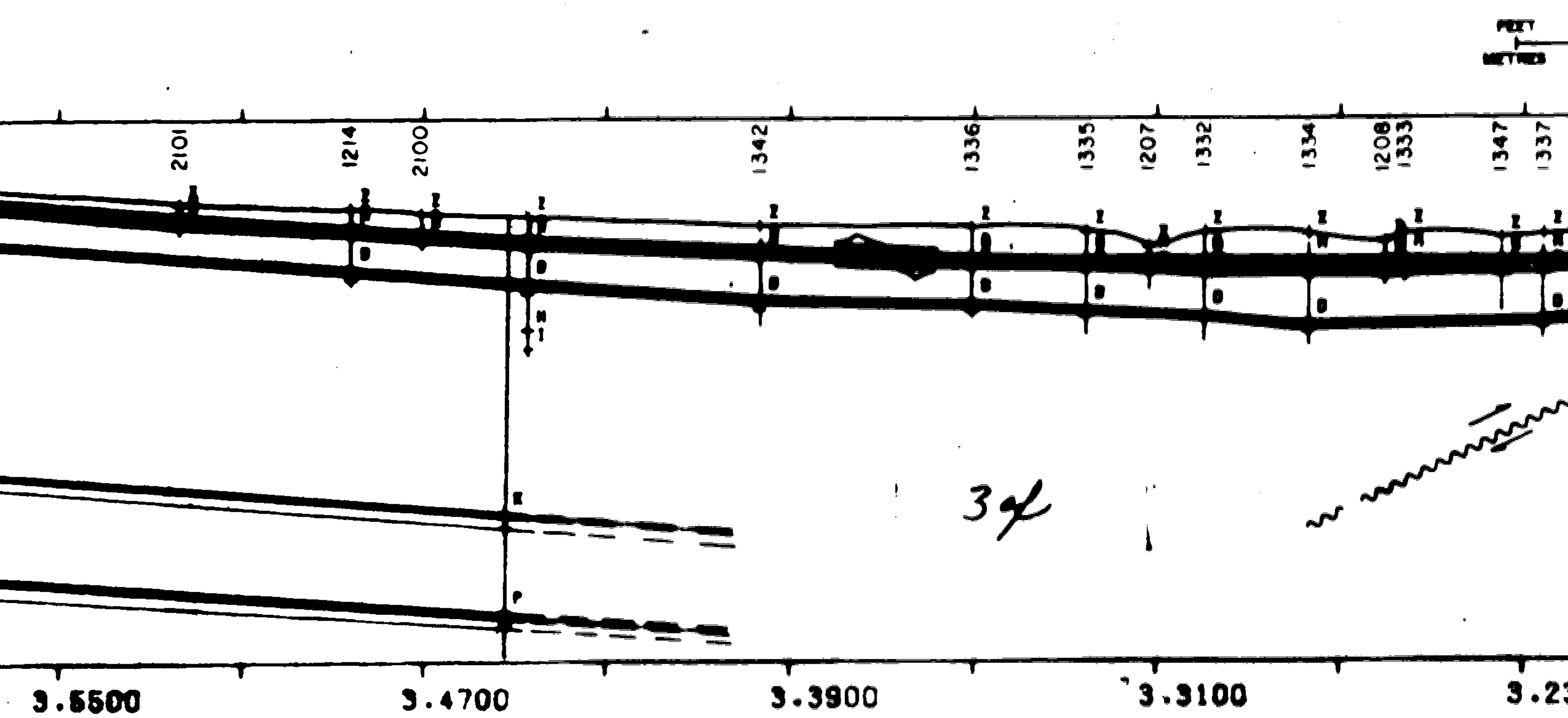




NE
4800
4400
4000
3600
1685
1581
2263
1652
3185
2291
4.1900
4.1100
4.0300
3.9500

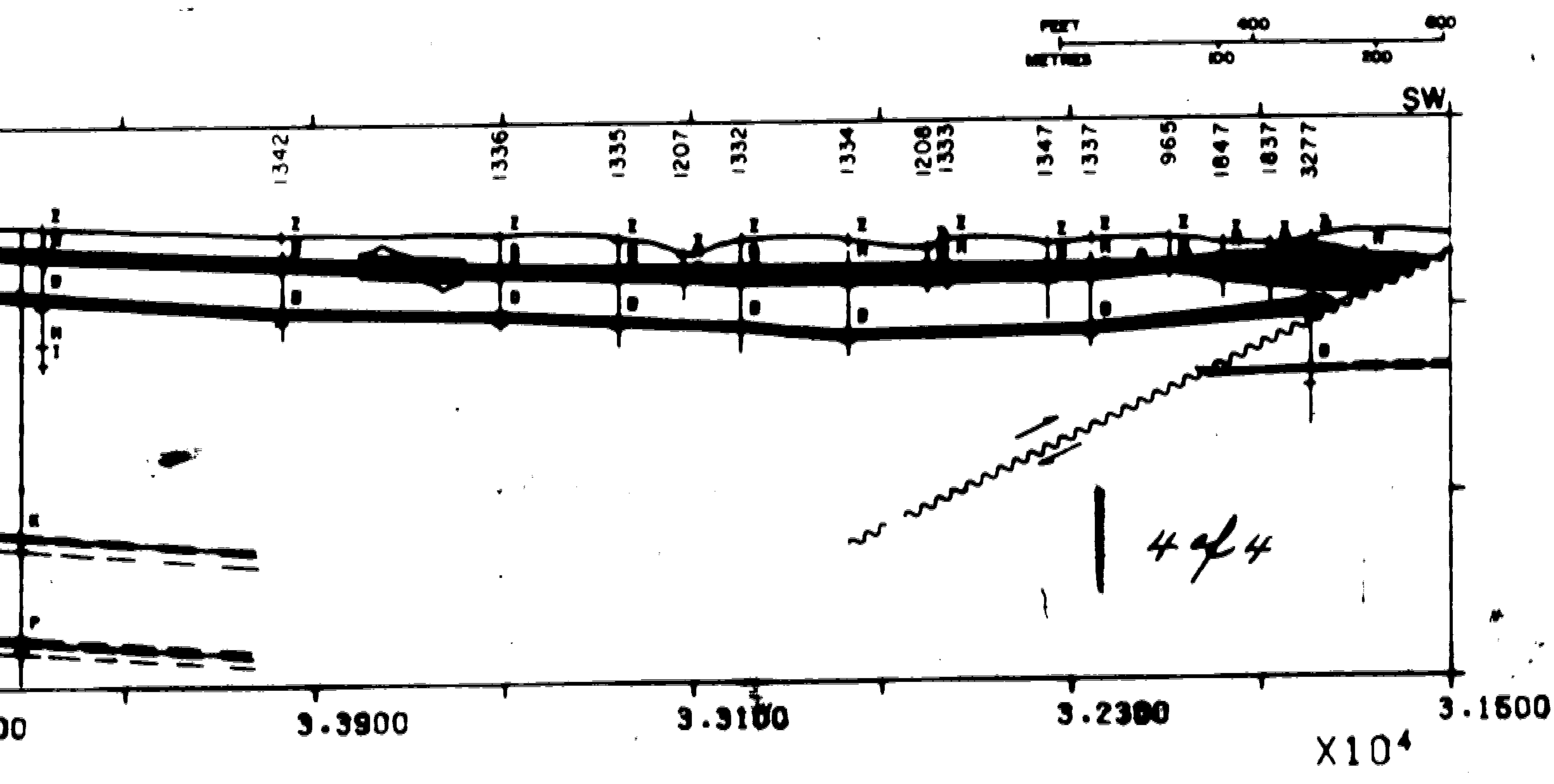


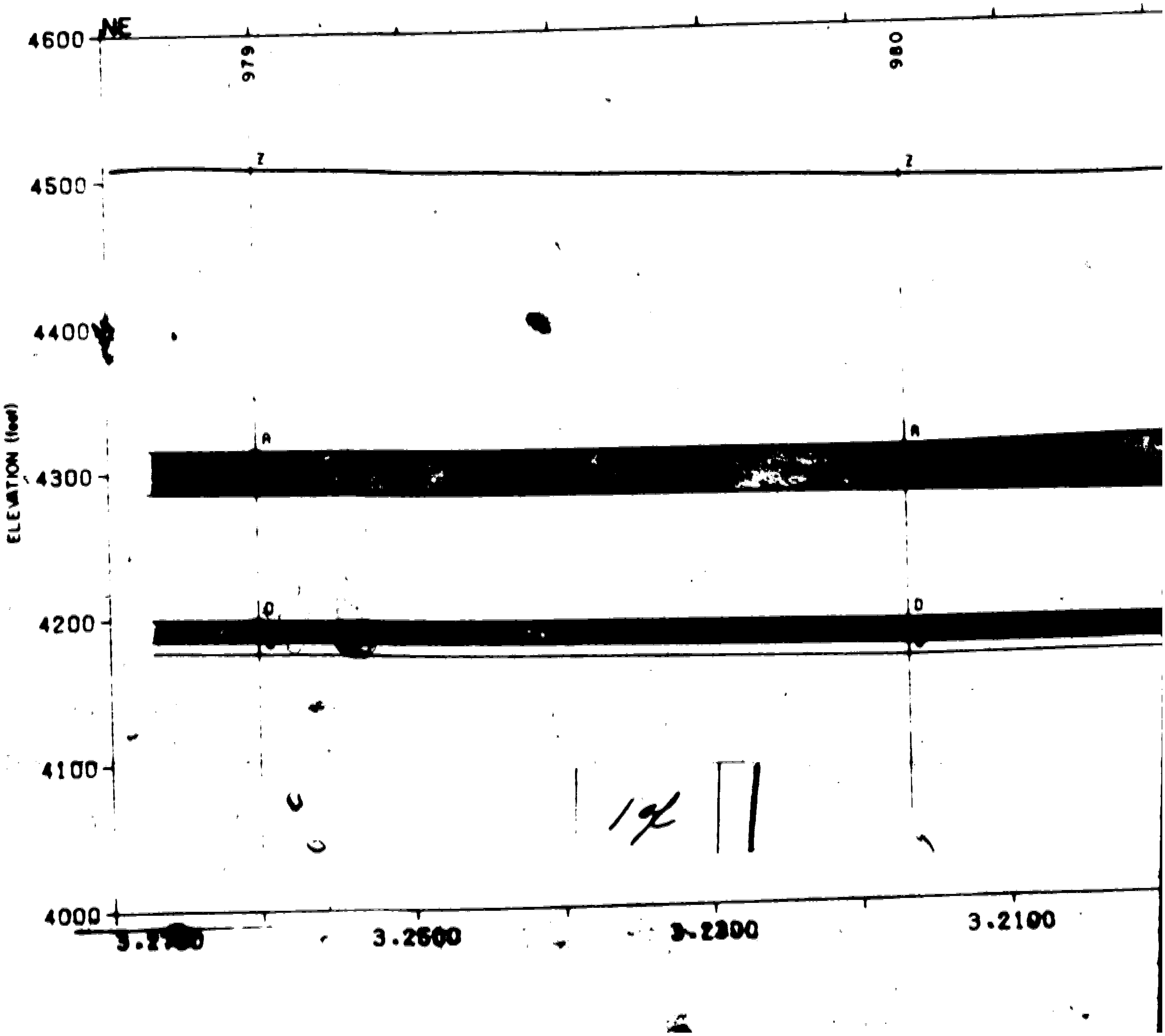
3186
3216
2325
1378
1344
1213
2011
3.8700
3.7900
3.7100
3.6300
3.55
GRID NORTHING (feet)



FEET
METRES
2101
1214
2100
1342
1336
1335
1207
1332
1334
1208
1333
1347
1337
3.5500
3.4700
3.3900
3.3100

FIGURE 10j
CROSS-SECTION J-J'
GRID EASTING 96000




NE
979
980
Z
A
D
ELEVATION (feet)
4600
4500
4400
4300
4200
4100
4000
3.2600
3.2100

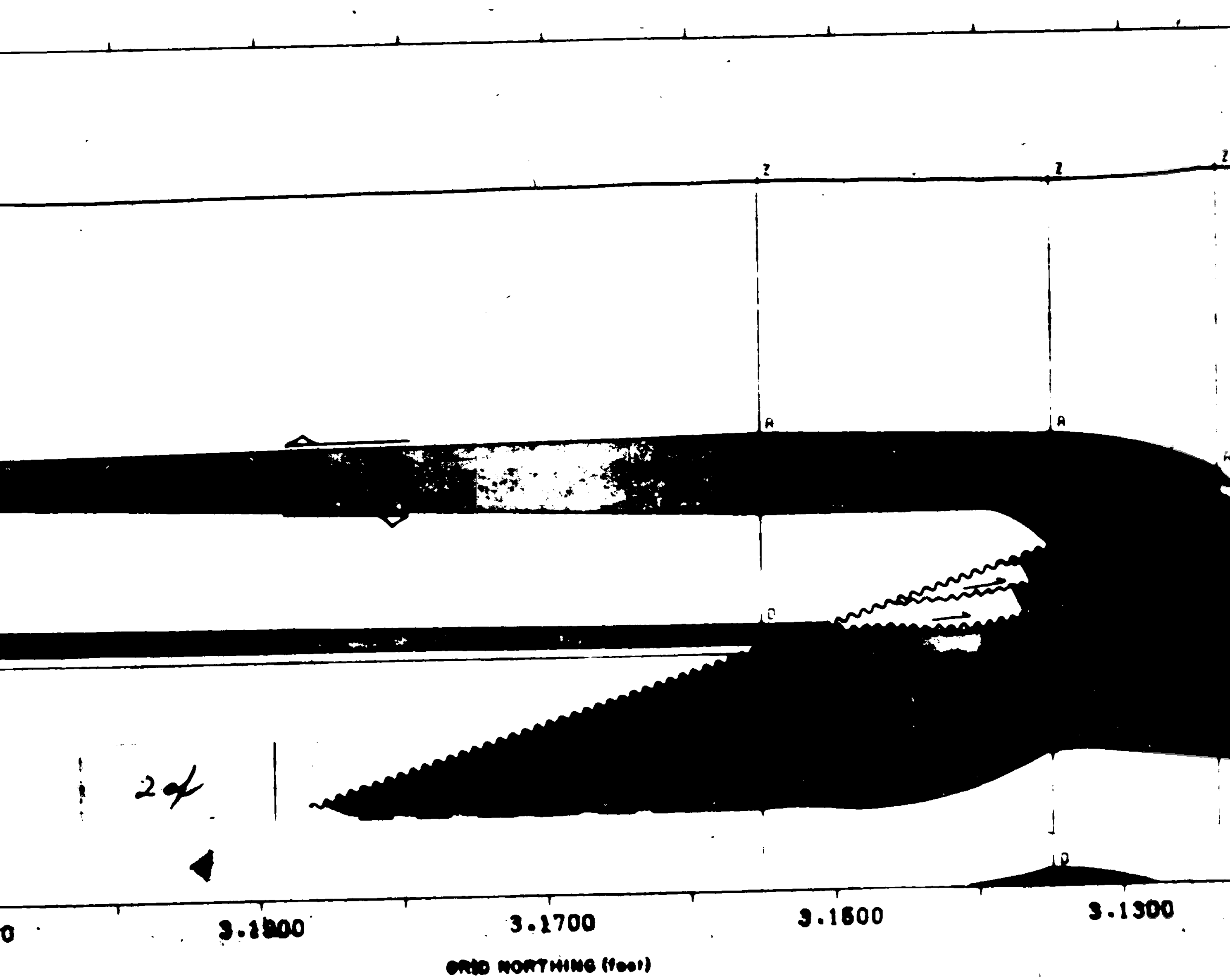
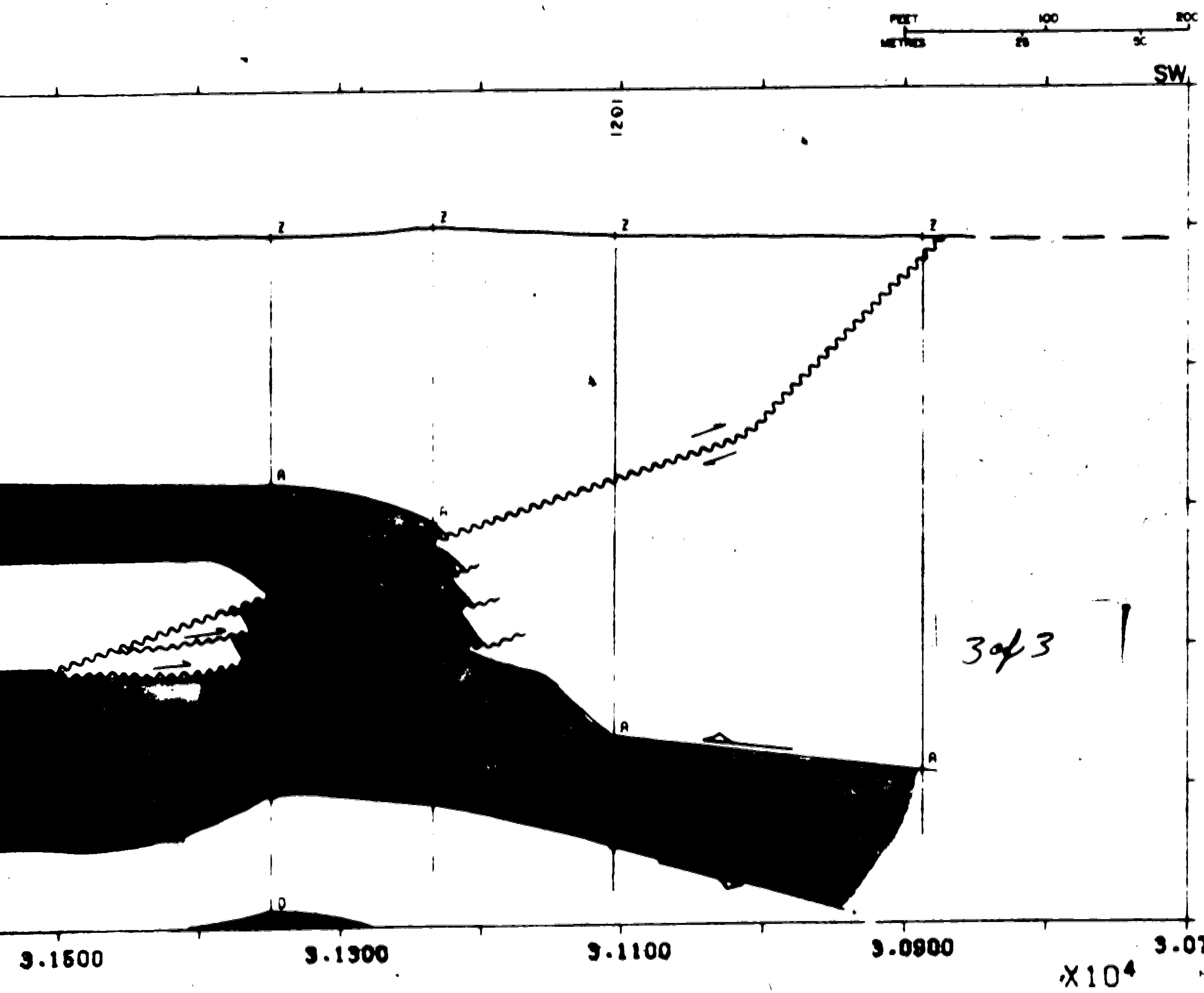
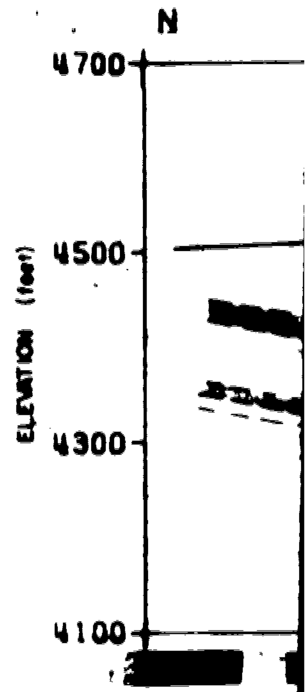

3.1700
3.1300
GRID NORTHING (feet)

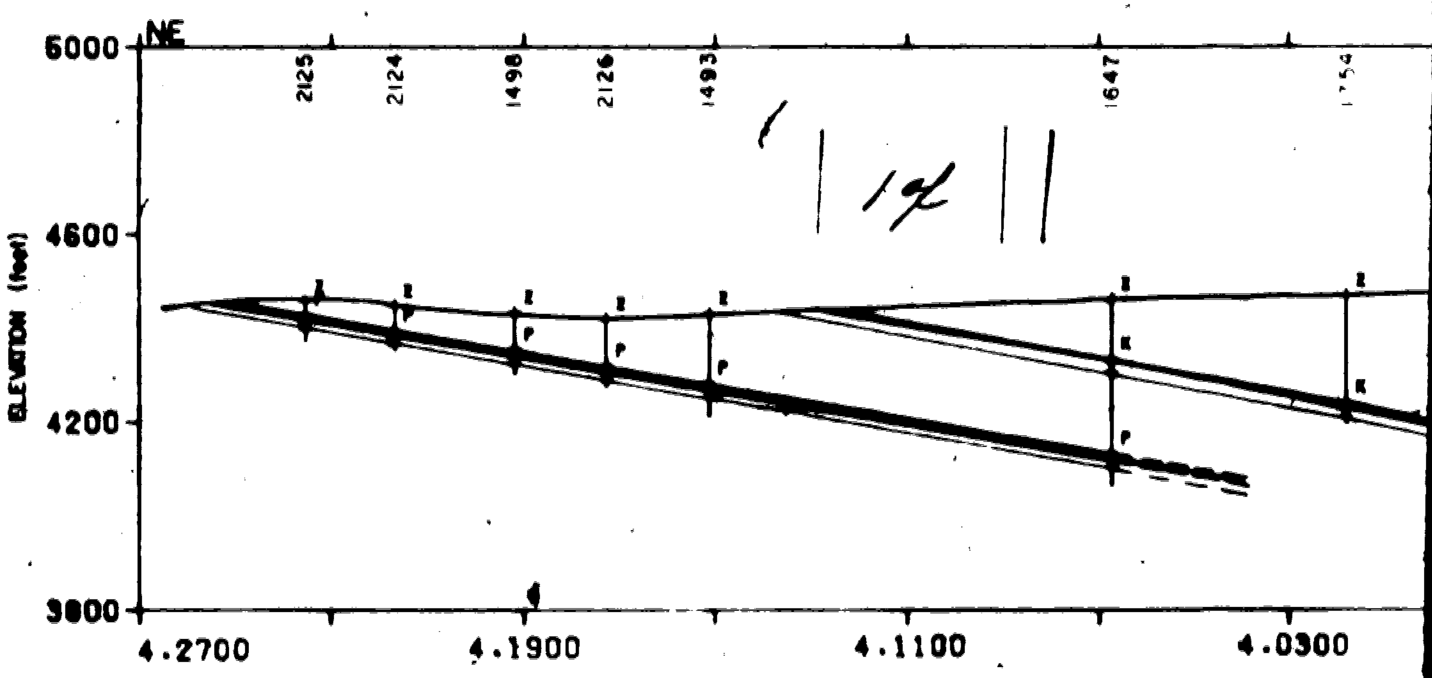
FIGURE 10k

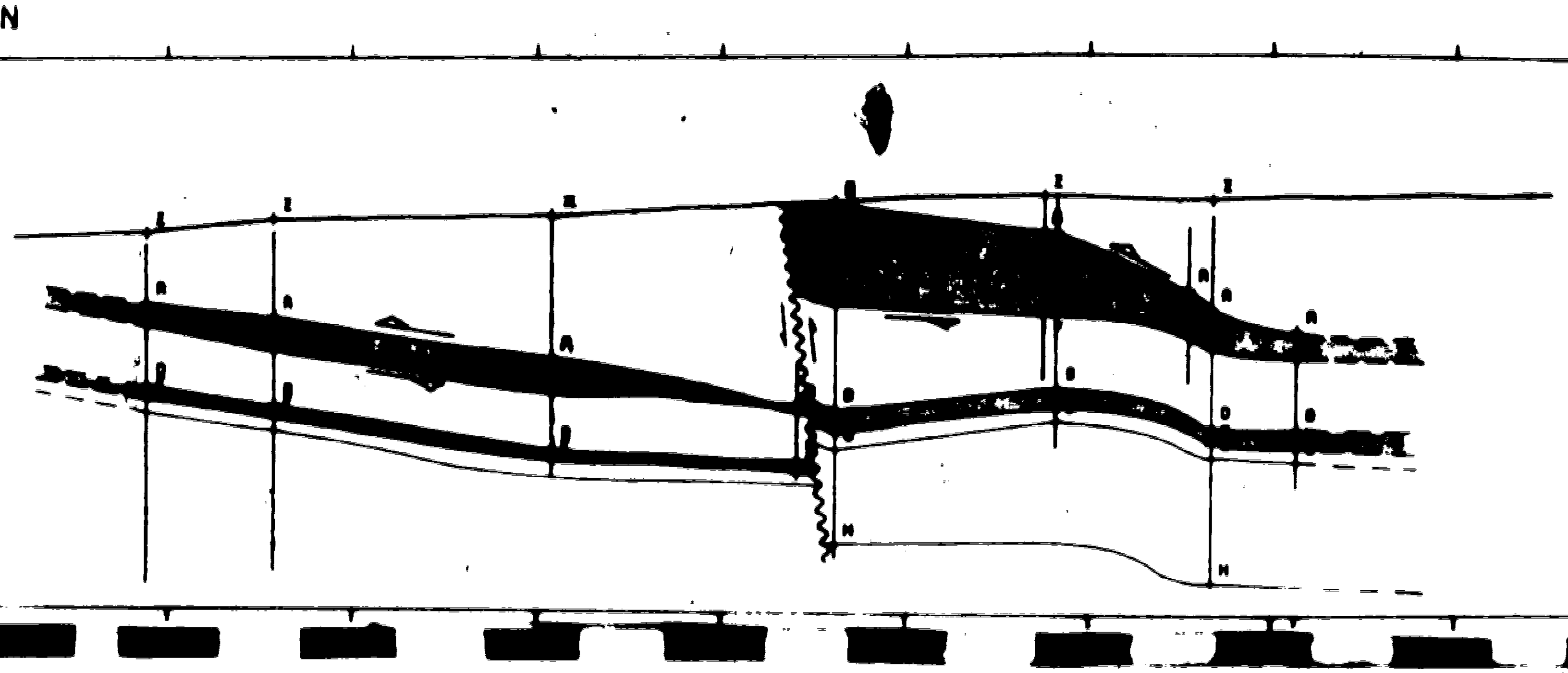
CROSS-SECTION K-K'

GRID EASTING 96780



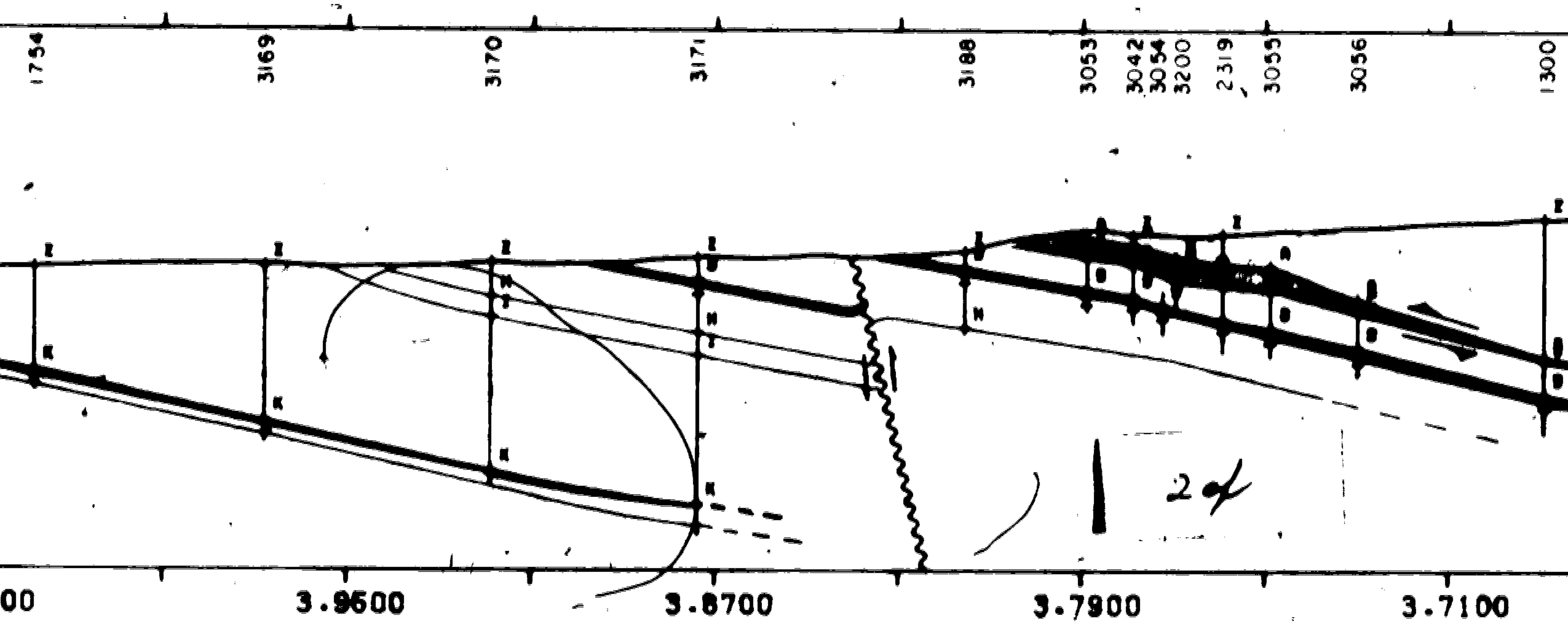

N
4700
4500
4300
4100
ELEVATION (feet)


NE
5000
4600
4200
3800
ELEVATION (feet)
2125
2124
1498
2126
1493
1647
Z
P
K
4.2700
4.1900
4.1100
4.0300

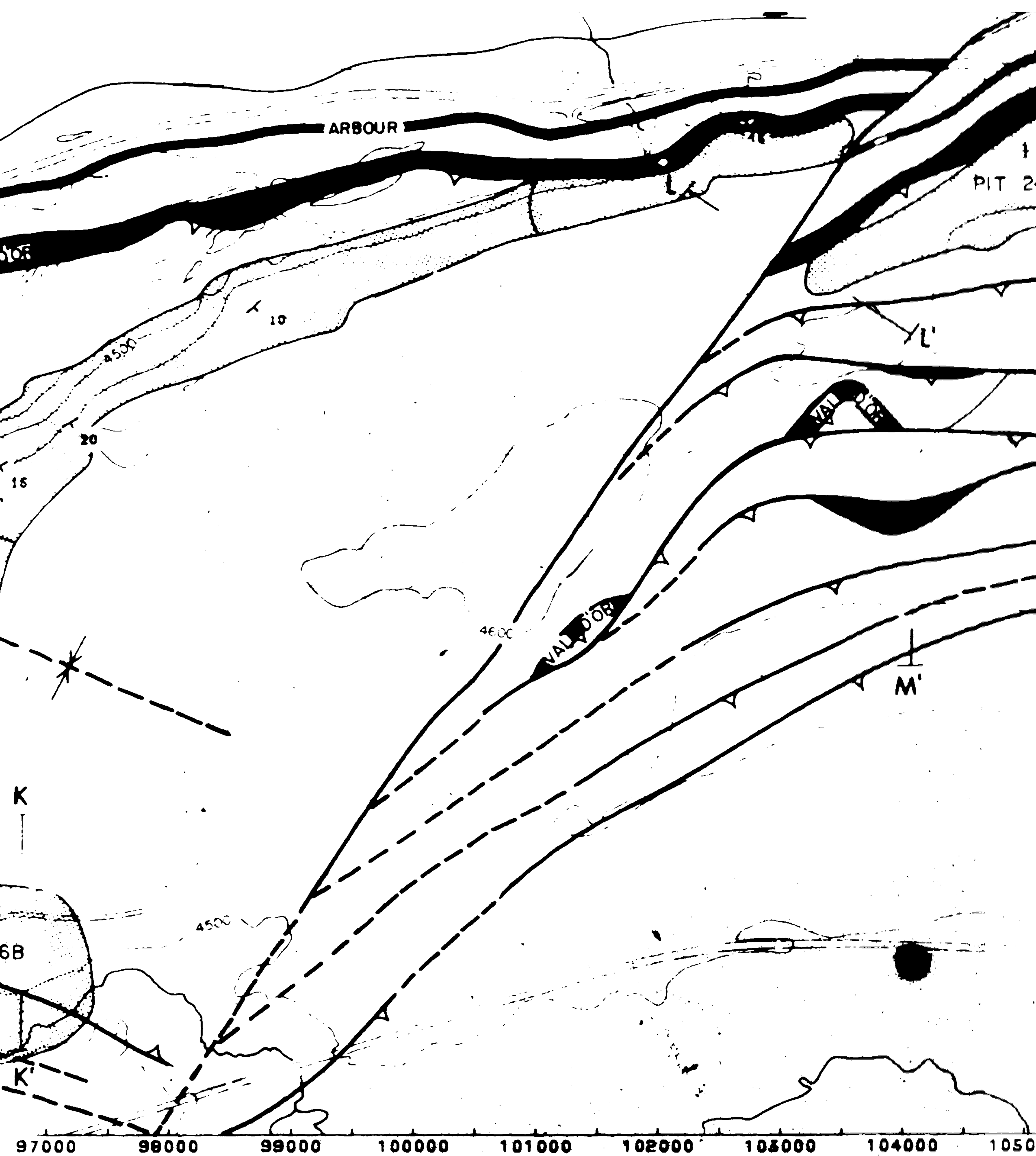


GRID NORTHING (feet)

F
CROS
GRID



GRID NORTHING (feet)


ARBOUR
VAL D'OR
PIT 2
L
L'
10
4500
20
15
4600
VAL D'OR
VAL D'OR
M'
K
K'
6B
4500
97000
98000
99000
100000
101000
102000
103000
104000
1050

11 of

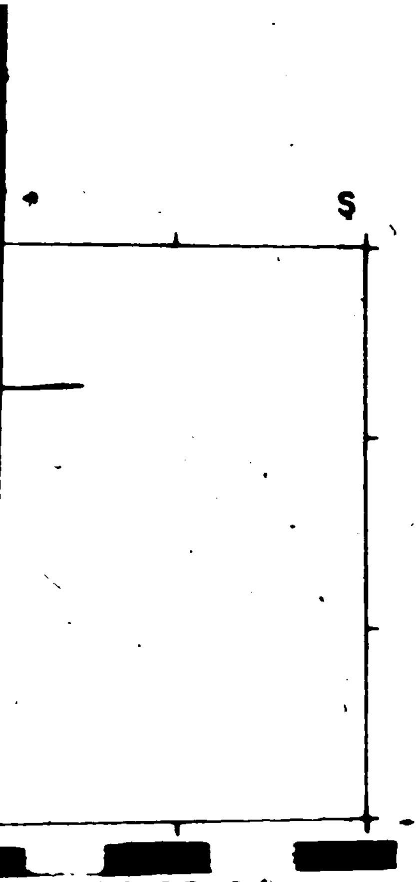


FIGURE 10 ℓ
CROSS-SECTION L-L'
GRID NORTHING 37500

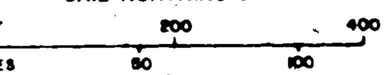
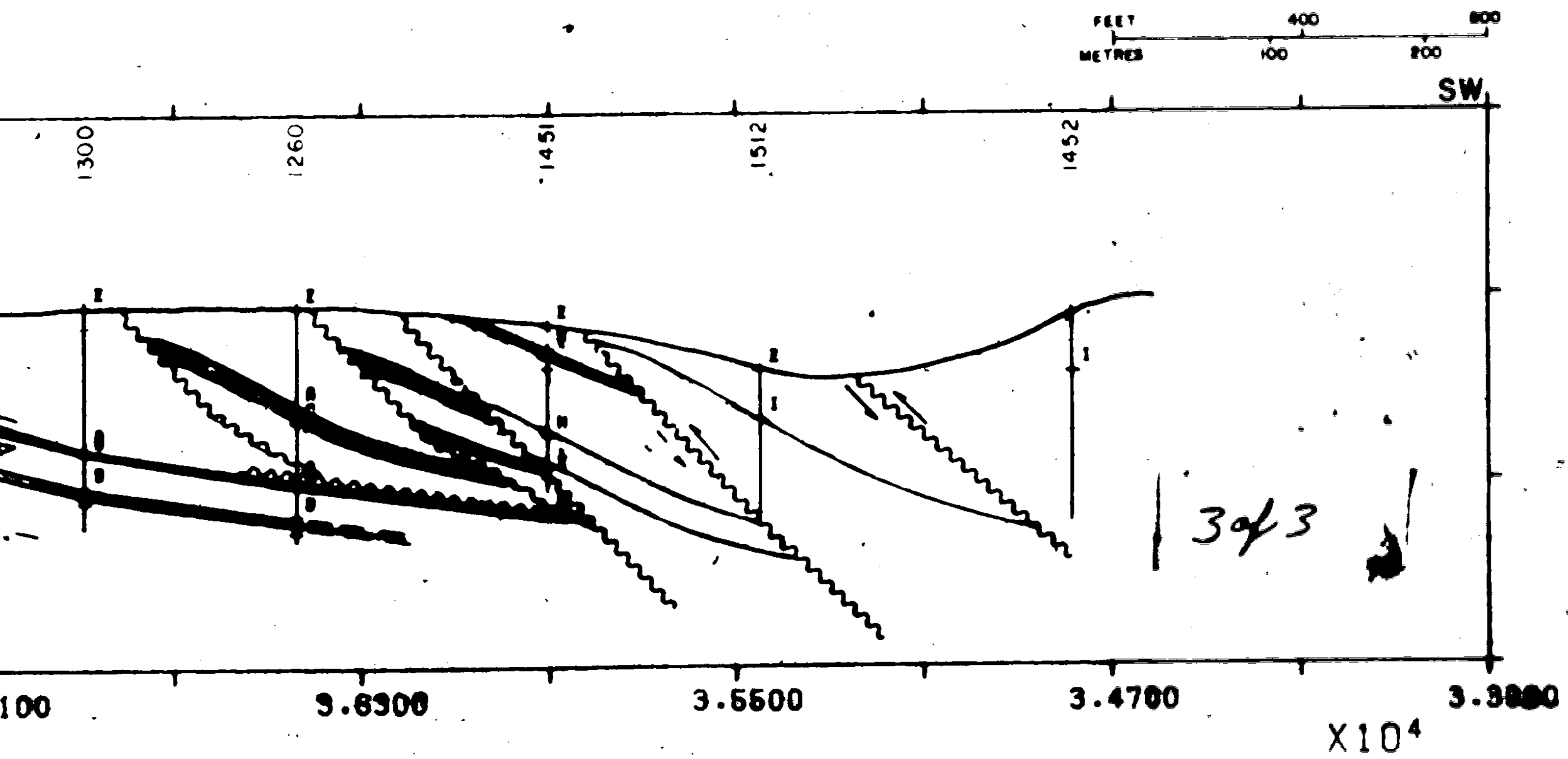
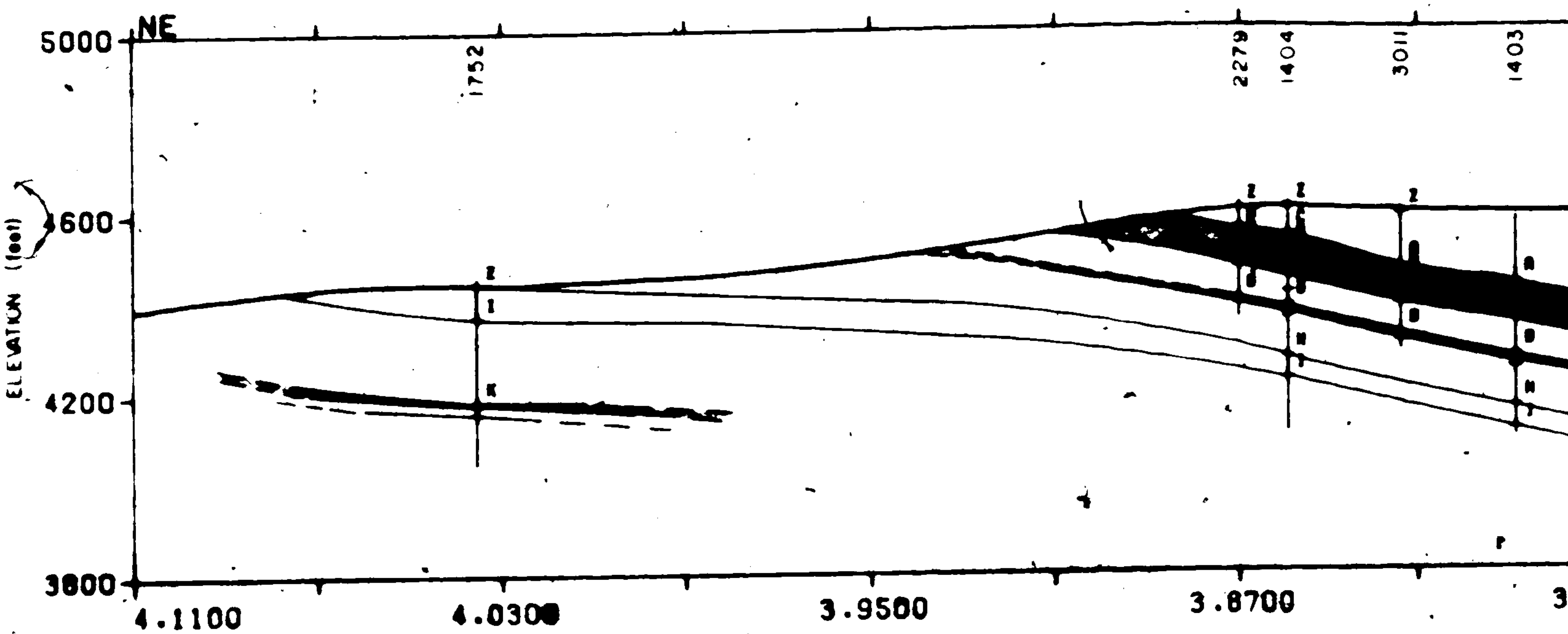
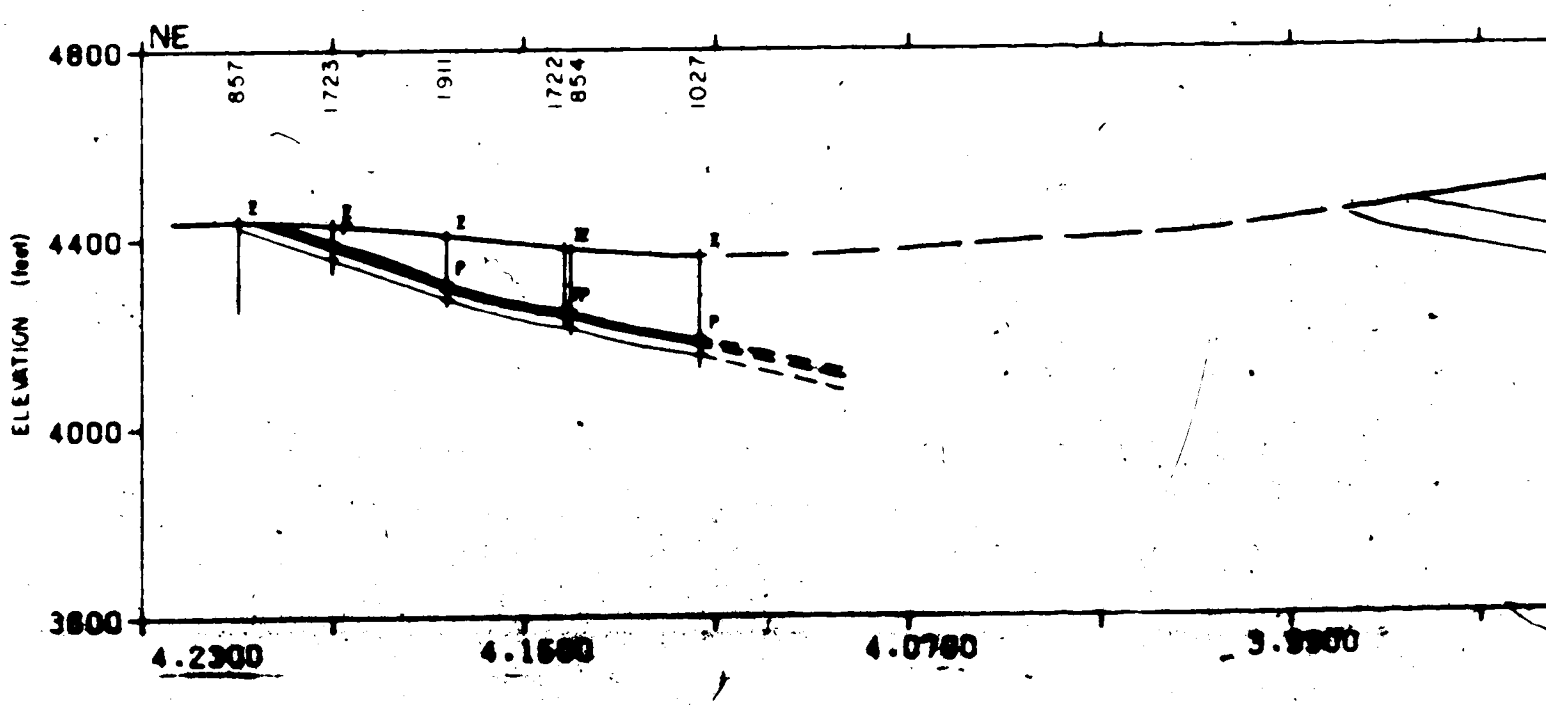


FIGURE 10m
CROSS-SECTION M-M'
GRID EASTING 104000



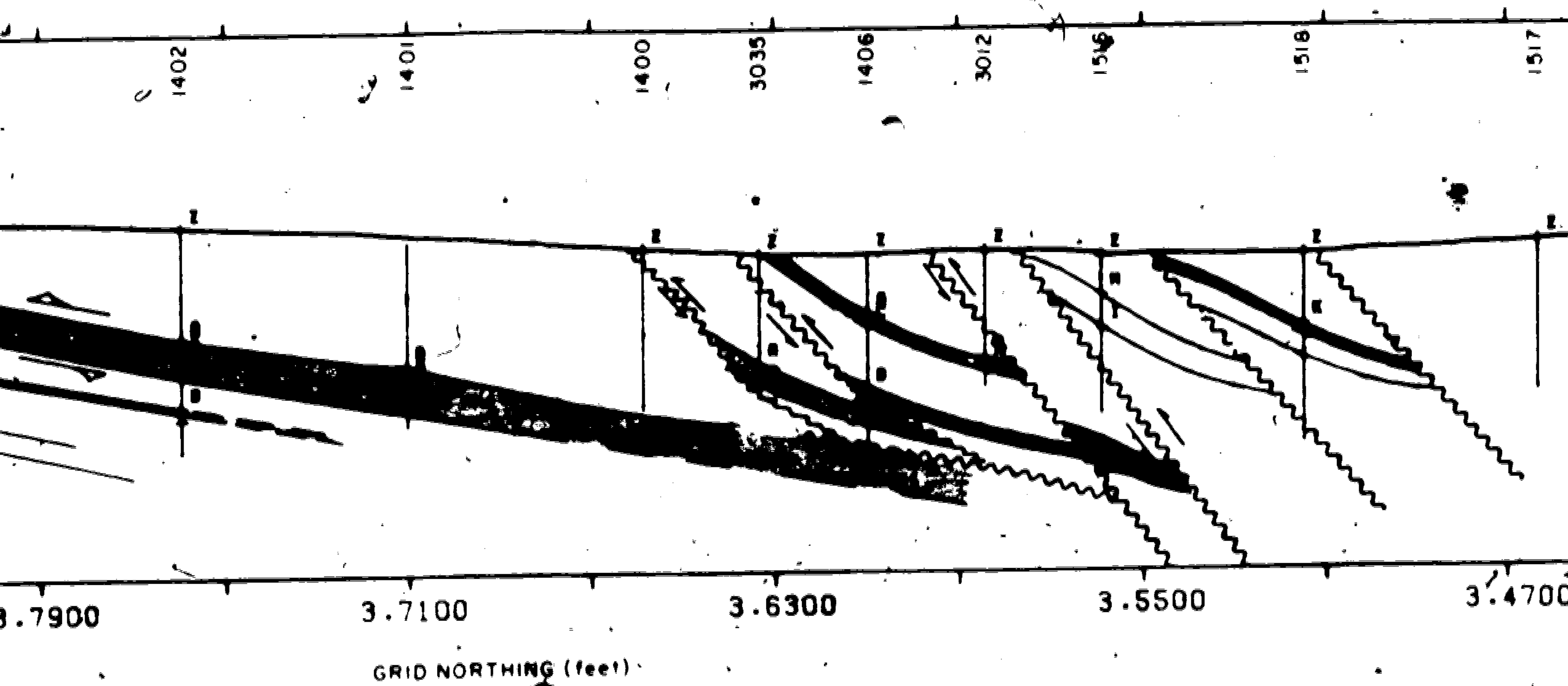


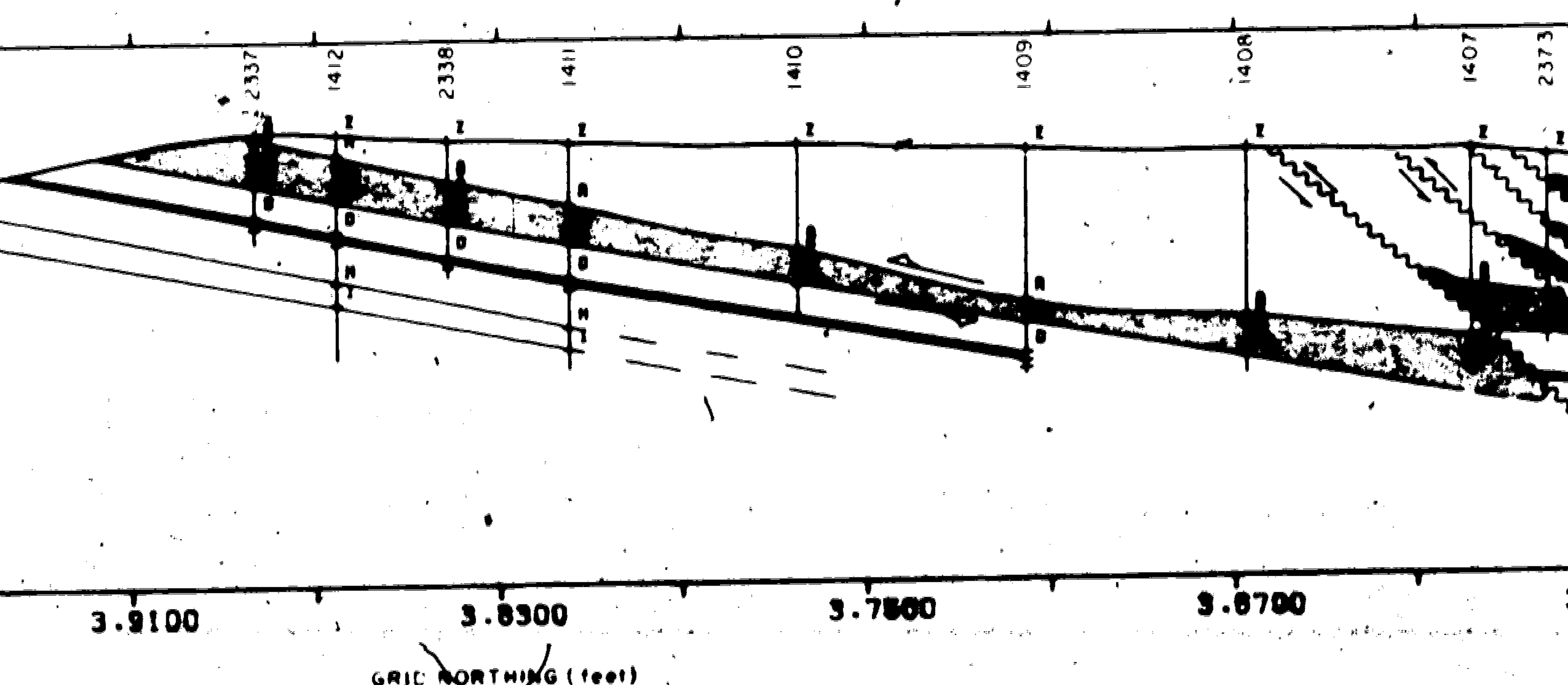
NE
5000
4600
4200
3800
ELEVATION (feet)
1752
2279
1404
3011
1403
4.1100
4.0300
3.9500
3.8700



NE
4800
4400
4000
3600
ELEVATION (feet)
857
1723
1911
1722
854
1027
4.2300
4.1500
4.0700
3.9900

1/2


1402
1401
1400
3035
1406
3012
1518
1517
.7900
3.7100
3.6300
3.5500
3.4700
GRID NORTHING (feet)


2337
1412
2338
1411
1410
1409
1408
1407
2373
3.9100
3.8300
3.7500
3.6700
GRID NORTHING (feet)

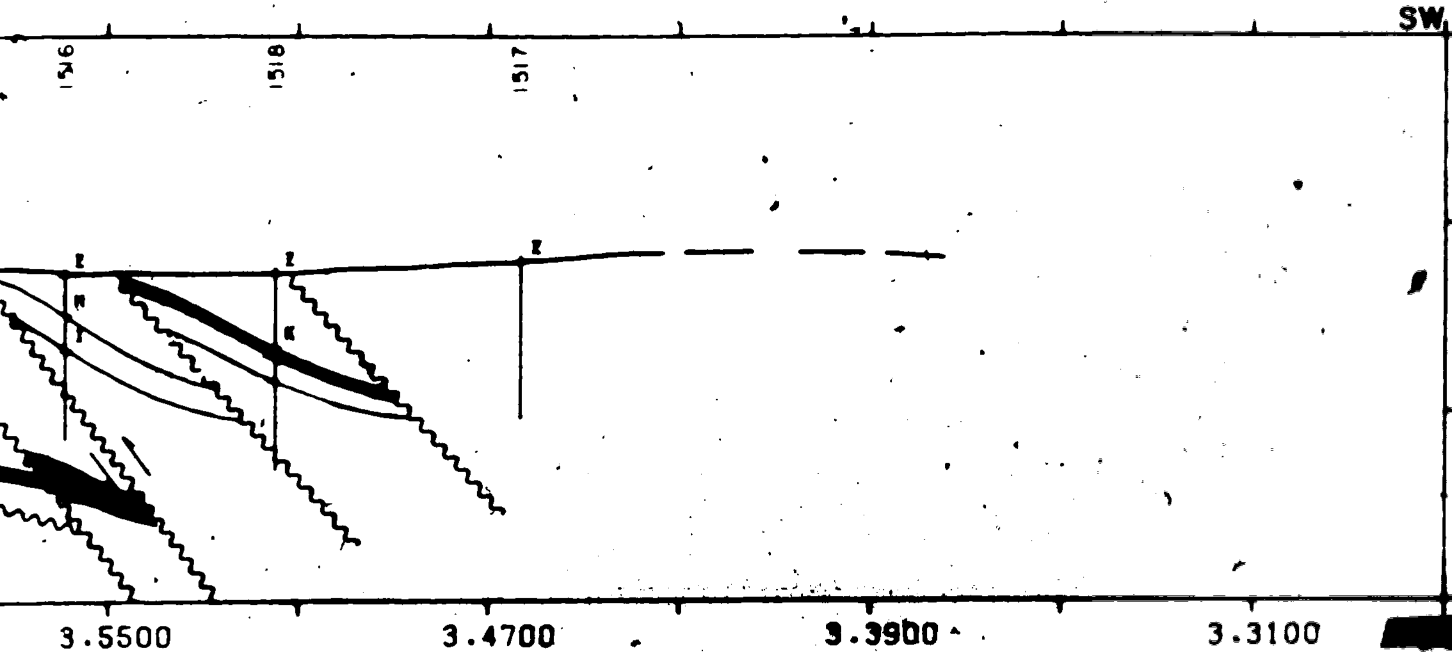


FIGURE 10n

CROSS-SECTION N-N'

GRID EASTING 108000

FEET 400 800

METRES 100 200

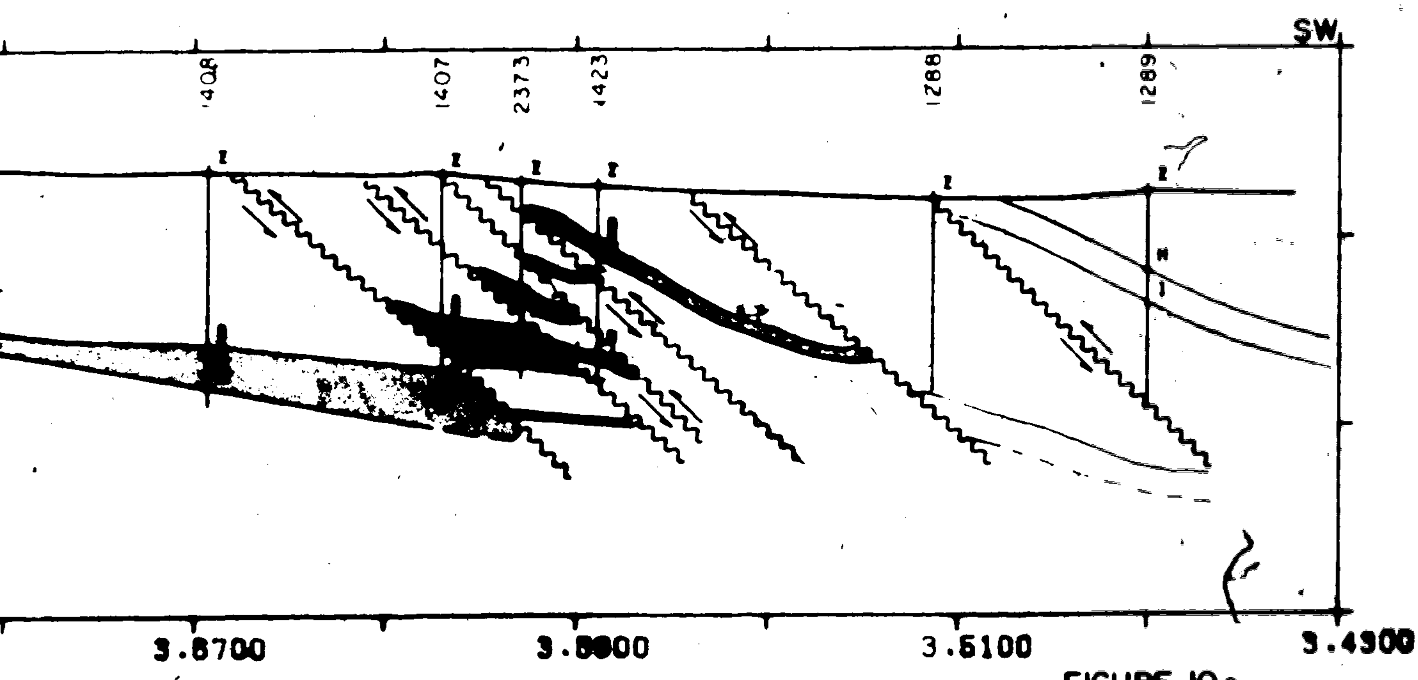


FIGURE 10o

CROSS-SECTION O-O'

GRID EASTING 109800

FEET 400 400

METRES 100 200

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Appendix 1

Field Sheet 'A' Codes

WAY-UP
0=unknown
1=right way up
2=overturned

STRAT CONTACT
0=none
1=transitional
2=abrupt
3=erosional

OUTCROP TYPE
1=outcrop
2=open pit
3=adit
4=trench

PHOTOS
0=no
1=yes
frame number

ROCK SAMPLE
0=none taken
1=yes

FOSSILS
0=none
1=molluscs
2=plant remains
3=stems
4=roots
5=trace fossils

ROCK MODIFIER
1=silty
2=sandy
3=pebbly
4=boulder
5=calcareous
6=dolomitic
7=carbonaceous
8=fossiliferous

ROCK TYPE
0=shale
1=mudstone
2=claystone
3=siltstone
4=sandstone
5=conglomerate
6=bentonite
7=coal
8=carbonate
9=ironstone

SORTING
1=poor
2=moderate
3=good

DISPERSION
1=dispersed
2=at top
3=at middle
4=at bottom
5=interbedded

GRAIN SIZE
1=very fine
2=fine
3=medium
4=coarse
5=very coarse
6=extremely coarse

WEATHERING
1=recessive
2=moderate
3=resistant

BED THICKNESS
1=thinly laminated
2=thickly laminated
3=very thinly bedded
4=thinly bedded
5=medium bedded
6=thickly bedded
7=very thickly bedded

SED. STRUCTURES
1=cross-bedding
2=graded bedding
3=contorted bedding
4=flute casts
5=ripple marks
6=flame structure
7=mud casts
8=load casts

NOTE: HORIZON codes are on the following page. Fresh and weathered COLOUR codes are based on a sequential numbering of the colours found in the Geological Society of America Rock Color Chart. A listing of the sequential order of these colours can be seen in Appendix 5 (the program O/CFORM). STRATIGRAPHIC DISTANCE is the stratigraphic distance from the outcrop station to a known geological marker horizon. It was not used in this study

HORIZON

NOTE: the alphabetic codes correspond to the drillhole primary marker codes (Appendix 2)

A= top of Val D'or coal seam
C= bottom of Val D'or coal seam
D= top of Arbour coal seam
F= bottom of Arbour coal seam
G= bentonite marker below Arbour coal seam
H= Marker 'A' coal seam
I= Marker 'B' coal seam
J= bentonite marker below Marker 'B'
K= top of Wee coal seam
M= bottom of Wee coal seam
N= top of Bourne coal seam
O= bentonite marker above Mynheer coal seam
P= top of Mynheer coal seam
R= bottom of Mynheer coal seam
S= top of Lower Mynheer coal seam
U= bottom of Lower Mynheer coal seam
X= fault location
Z= topographic surface

0= siltstones above Val D'or coal seam
1= sandstone above Val D'or coal seam
2= mudstone below Val D'or coal seam
3= sandstone above Arbour coal seam
4= mudstone above Arbour coal seam
5= mudstone above Marker 'A'
6= siltstone between Marker 'A' and Marker 'B'
7= bentonite and mudstone below Marker 'B'
8= sandstone below Marker 'B'
9= sandstone above Wee coal seam
#= mudstone between Wee and Bourne coal seams
$= mudstone and siltstone below 'O' bentonite
*= sandstone above Mynheer coal seam
&= silstone below Lower Mynheer carbonaceous mudstones
+= strata below Lower Mynheer carbonaeeous mudstones

Appendix 2

Drillhole B Sheet Code System

A coding system for use with Drillhole B sheets (Fig. 3) was devised in order to facilitate computer retrieval of depth to specific marker horizons, total seam thicknesses, individual parting thicknesses and thicknesses of various lithologic units for structural, sedimentological and coal quality analyses. The codes are entered in columns 5-7.

Column 5 contains the *lithologic code* if the marker represents only a lithology change and not a stratigraphic pick, otherwise it contains the *primary marker code*.

Column 6 contains the *secondary marker code* or is left blank if column 5 contains a lithologic code.

Column 7 contains the *top-bottom marker code* if column 6 contains a secondary marker code, otherwise it is left blank.

Lithologic Codes

This code is always numeric and appears only in column 5. If a lithologic code is entered columns 6 and 7 are blank. The depth parameter (columns 8-13) represents the bottom of the lithologic unit. The code is given below.

1= sandstone
2= siltstone
3= mudstone
4= bentonite
5= carbonaceous mudstone
6= conglomerate
7= coal
8= shale
9= bentonitic mudstone

Where a pick on a geophysical log represents the change from a specific lithology to the top of a stratigraphic marker there will be two B entries for the same depth. In this case the first B entry will represent the lithology encountered above that depth and the second B entry designates this depth as the top of the marker.

Marker Codes

The primary marker code is alphabetic. It is entered in Column 5 and is only one character in length if the marker is of negligible thickness, but if its thickness is of economic significance then a *secondary marker code* and *top-bottom code* are entered in Columns 6 and 7. These secondary codes are important for the economic evaluation of coal seams.

The Primary Marker Code

A= top of Val D'or coal seam
B= tops and bottoms of Val D'or units
C= bottom of Val D'or coal seam
D= top of Arbour coal seam
E= tops and bottoms of Arbour units
F= bottom of Arbour coal seam
G= top of bentonite below Arbour coal seam
H= Marker 'A' top
I= Marker 'B' top
J= Bentonite 30ft above Wee coal seam
K= top of Wee coal seam
L= tops and bottoms of Wee units
M= bottom of Wee coal seam
N= top of Bourne coal seam
O= bentonite 35ft below Bourne coal seam
P= top of Mynheer coal seam
R= bottom of Mynheer coal seam
S= top of Lower Mynheer carbonaceous mudstones
T= top of Lower Mynheer carbonaceous mudstones
U= bottom of Lower Mynheer carbonaceous mudstones
X= fault location
Z= topographic surface

Secondary Marker Code

This code is entered in Column 6, is alphabetic, and corresponds to the coal horizon nomenclature used by Luscar Exploration. For instance, the Val D'or seam has been divided into 9 units labelled Val D'or (A–I) and similarily for the Arbour (A–D) and the Wee (A–C). This code enables the computer to decide upon thicknesses for these coal seam units. The Mynheer coal seam and the Lower Mynheer marker bed are given a secondary code of 'A' because it has not been possible to subdivide them into specific units. In these two instances only partings in the seams or pods which are greater than 2 feet thick have been coded. These partings are given lithologic rather than marker codes.

Top-Bottom Marker Code

This code is entered in Column 7 and either a '1' or a '2'. A '1' designates the pick as being the top of a marker unit within a specific seam whereas a '2' designates the pick as being the bottom of such a unit. A computer routine designed to scan for a 2 and then a 1 and then subtract the approprate depth values associated with each will give the thickness of a parting within a seam.

Where a fault was located within a seam that repeated all or part of that seam, succesive drillhole 'B' sheet entries have repeated marker codes with only the *top-bottom code* changing from a 1 to a 2 and back again. NOTE: The bottom of the Bourne seam and other thin unnamed coal beds are coded with the lithologic code '7'.

Appendix 3

The Luscar-Sterco Coal Valley Mine Grid

The Coal Valley mine grid is oriented such that mine northings are approximately parallel to the regional strike of the strata. The grid is consistent through the entire mine lease and is in *feet* not *metres*. The bearing of the grid northing line is 45° 44' 21" east of true north.

The origin of the grid is not located within the mine lease. A reference point which is within the mine lease is the southeast corner of Legal subdivision 7- Township 47- Range 19- West of the 5th Meridian, which has a grid northing of 33,392.35 and a grid easting of 95,044.07.

Appendix 4

Format of Raw Data File R1.

Columns	Description
	First line
	OUTCROP DESCRIPTION
1-4	outcrop station number
5-7	type/number - a code for use in TRIPOD
8	horizon code
9	way-up code
10-25	easting, northing and elevation of outcrop station
26-29	stratigraphic distance from a known horizon
30-33	airphoto number
34	stratigraphic contact at outcrop?
35	outcrop type
36-38	photos taken and frame number
39	rock sample taken?
40-43	fossils present
	MAJOR LITHOLOGY DESCRIPTION
44-46	% of outcrop represented by lithology
47-48	modifier and lithology type
49	grain size
50	sorting
51	weathering characteristics
52	bed thickness
53-55	fresh colour
56-58	weathered colour
59-61	sedimentary structures
	1st MINOR LITHOLOGY DESCRIPTION
62-63	% of outcrop represented by lithology
	Second line
1	dispersion of 1st minor lithology in outcrop
2-17	same as lines 47-61 above
	2nd MINOR LITHOLOGY DESCRIPTION
18-19	% of outcrop represented by lithology
20	dispersion of 2nd minor lithology in outcrop
21-36	same as 47-61 in line 1

Format of Raw Data File R2

Columns	Description
1-4	outcrop number
5	structural type: planar or folded bedding, faults, or joints
6-7	number: given to each joint set, otherwise blank
8-10	pitch of slickenside striae
11	sense of slickenside striae: whether up or down
12-17	dip direction and dip of the axial trace of fold
18-77	up to 10 readings, in terms of dip-direction and dip of fault, joint, folded or planar bedding

Format of Raw Data File R3

Columns	Description
1-4	drillhole number
5-20	grid easting, northing and elevation of the drillhole collar
21-26	trend and plunge of the drillhole
27-30	geophysical logging tools used: 1=yes, 0=no for caliper, gamma, resistance and density, respectively
31-36	date drillhole logged (day,month,year)
37-40	logged depth
41-44	depth to bedrock
45-47	fluid level depth
48-51	drilled depth
52-55	lease area code: CV=Coal Valley Mine SB=Silkstone 'B' VA=Val D'or 'A' VB=Val D'or 'B' W=Weldwood WP=Weldwood Pod MA=Mynheer 'A' MB=Mynheer 'B'

Format of Raw Data File R4

Columns	Description
1-4	drillhole number
5-7	marker and lithologic codes (see Appendix 1)
8-13	down-hole depth of associated marker or lithology

Format of Preliminary Data File F1

Columns	Description
1-4	outcrop station number
5-7	'000', a code for use in TRIPOD
8	horizon code (see Appendix 1)
9	way-up code (see Appendix 1)
10-25	easting, northing and elevation of the outcrop station

Format of Preliminary Data File F2

The format of the preliminary data file F2 is exactly the same as that of the raw data file R2.

Format of Preliminary Data File F2A

The format of the preliminary data file F2A is the same as file F2 and file R2 except that the dip-directions and trends of structural elements have all had 46° subtracted from them in order to perform projections and rotations when referring to the Coal Valley mine grid rather than true north (see Appendix 1).

Format of Preliminary Data File F3

Columns	Description
1-4	drillhole number
5	'8', a code used in TRIPOD
6-7	null character, required in TRIPOD
8-23	mine grid easting, northing and elevation of the drillhole collar
24-29	trend and plunge of the drillhole
30-33	logged depth
34-37	depth to bedrock

Format of Preliminary Data File F4

Columns	Description
1-4	drillhole number
5	'9', a code for use in TRIPOD
6-7	a consecutive number assigned to each down-hole pick, for use in TRIPOD
8	marker code (see Appendix 3)
9-14	down-hole depth of associated marker

Format of file TRACES

Columns	Description
1-15	mine grid easting, northing and elevation of the topography-trace intersection point
16-17	not used
18-19	a numeric code which is assigned to each fault, fold and marker horizon which intersects the topographic surface

Appendix 5

The Preliminary Processing Program R1ED

```
C     INPUT
C
C     The outcrop 'A' cards of the Raw Data File R1: two
C     cards for each outcrop station.
C
C     OUTPUT
C
C     Re-formatted 'A' cards, now the Preliminary Data File F1:
C     one card or line for each outcrop station.
C
      INTEGER E,N
    5 READ(5,10,END=99) OC,TNUM,HRZN,WUP,E,N,EL,DIS
   10 FORMAT(A4,A3,A1,A1,2I6,2A4/)
      WRITE(6,20) OC,TNUM,HRZN,WUP,E,N,EL,DIS
   20 FORMAT(A4,A3,A1,A1,2I6,2A4)
      GO TO 5
   99 STOP
      END
```

The Preliminary Processing Program R1CON

```
C     INPUT
C
C     Outcrop 'A' cards of the Raw Data File R1 which have UTM
C     coordinates rather than mine grid coordinates.
C
C     OUTPUT
C
C     Outcrop 'A' cards with mine grid coordinates
C
C     PROCEDURE
C
C     A control point with known true easting, true northing, grid
C     easting and grid northing coordinates, along with the angle
C     between the grids (in grads) are used to refer and rotate the
C     true grid to the mine grid.
C
      INTEGER EL,TE,TN
      DATA THETA/.7982945/
    1 READ(5,2,END=99) TE,TN,EL
    2 FORMAT(I6,I6,I4)
      TEO=TE-45581.05
      TNO=TN-303171.58
      GEO=(TEO*COS(THETA))-(TNO*SIN(THETA))
      GNO=(TEO*SIN(THETA))+(TNO*COS(THETA))
    5 GE=GEO+76784.24
      GN=GNO+40191.47
      WRITE(6,3) GE,GN,EL
    3 FORMAT(2F12.5,2X,I4)
      GO TO 1
   99 STOP
      END
```

The Preliminary Processing Program R2CON

```
C     INPUT
C
C     Outcrop 'B' cards of the Raw Data File R2A
C
C     OUTPUT
C
C     Outcrop 'B' cards of the Preliminary Data File R2, which are
C     amenable for use with a mine grid rather than a true north grid.
C
C     PROCEDURE
C
C     46 degrees is subtracted from the trend of the axial trace and from
C     the dip-directions of bedding, joint and fault measurements. This
C     results are the grid north bearings rather than true north bearings.
C     Checks are made for no further data on the card and for no axial
C     trace data.
C
      INTEGER BRNG(22)
    5 READ(5,10,END=99) OC,TYP,NUM,PIT,SEN,(BRNG(I),I=1,22)
   10 FORMAT(A4,A1,A2,A3,A1,22I3)
      DO 20 I=1,22,2
      IF(BRNG(I).EQ.0.AND.BRNG(I+1).EQ.0.AND.BRNG(I+2).EQ.0.AND.BRNG
     &(I+3).EQ.0) GO TO 30
      IF(BRNG(I).LT.46) BRNG(I)=BRNG(I)+360
      BRNG(I)=BRNG(I)-46
   20 CONTINUE
   30 N=I-1
      IF(BRNG(1).EQ.314) GO TO 40
      WRITE(6,10) OC,TYP,NUM,PIT,SEN,(BRNG(I),I=1,N)
      GO TO 5
   40 WRITE(6,11) OC,TYP,NUM,PIT,SEN,(BRNG(I),I=3,N)
   11 FORMAT(A4,A1,A2,A3,A1,6X,20I3)
      GO TO 5
   99 STOP
      END
```

The Preliminary Processing Program R3ED

```
C     INPUT
C
C     Drillhole 'A' cards from the Raw Data File R3
C
C     OUTPUT
C
C     Drillhole 'A' cards of the Preliminary Data File F3
C
      INTEGER DHN,E,N,EL,T,P,LOG,DAT,TD,LD,WT,OB
    2 READ(5,4,END=10) DHN,E,N,EL,T,P,LOG,DAT,TD,OB,WT,LD,PC,AC
    4 FORMAT(G4,2G6,G4,2G3,G4,G6,G4,2G3,G4,A2,A2)
      WRITE(6,6) DHN,E,N,EL,T,P,LD,OB,WT,TD,LOG,DAT,AC
    6 FORMAT(G4,'B',2X,2G6,G4,2G3,G4,G3,8X,G3,G4,G5,G6,2X,A2)
      GO TO 2
   10 STOP
      END
```

The Preliminary Processing Program R4ED

```
      C        INPUT
      C
      C          The drillhole 'B' cards of the Raw Data File R4
      C
      C        OUTPUT
      C
      C         Only those 'B' cards which represent significant
      C         stratigraphic markers useful for structural studies.
      C         This output becomes the Preliminary Data File F4.
      C
      C        PROCEDURE
      C
      C         The stratigraphic markers are represented by codes
      C         (see Appendix  1  ). These codes are placed in a Data
      C         statement and are scanned for when each card is read. If one
      C         or more of these codes are found in a specific drillhole
      C         The codes are consecutively numbered and are printed
      C         in a format amenable to the TRIPOD package. Cards which
      C         do not contain the required codes are not in the output list.
               DIMENSION STRA(18)
               INTEGER DHN,NUM,D
               DATA STRA/'A','C','D','F','G','H','I','J','K','M','N',
              *'O','P','R','S','U','X','Z'/,NUM/0/,DHN/1/
            2  READ(5,4,END=20) DHN,CODE,DEP
            4  FORMAT(G4,A1,2X,F5.1)
                DO 8 J=1,17
            6   IF(CODE.EQ.STRA(J)) GO TO 10
            8  CONTINUE
               GO TO 2
           10  IF(DHN.NE.D) NUM=0
               NUM=NUM+1
               WRITE(6,12) DHN,NUM,CODE,DEP
               D=DHN
           12  FORMAT(G4,'9',G2,A1,F6.1)
               GO TO 2
           20  STOP
               END
END OF FILE
```

Format of the Field Sheet A Processing Program Q/CFORM

Written and copyright by: Desmond Wynne, Department of Geology, University of Alberta, Edmonton.

The purpose of this program is to write out a legible one page form of data concerning each outcrop station. Input to this program is the file R1 which contains the coded outcrop data from the A field sheets. The program essentially decodes and re-formats file R1. A sample output is listed on page 87.

The main FORTRAN calling program is:

```
      LOGICAL*1 INPUT(132)
   10 READ(5,30,END=20) INPUT
      CALL FORM(INPUT)
      GO TO 10
   20 STOP
   30 FORMAT(132A1)
      END
```

The IBM Assembler Language Program is:

```
FORM     CSECT
*
*        CALL FORM(DATA)
*
         USING *,12
         STM   14,12,12(13)
         LR    12,15
         LA    11,SAVE
         ST    11,8(13)
         ST    13,4(11)
         LR    13,11
*
         NI    0(1),X'7F'
         L     11,0(1)
*
         MVI   TEXT,C'1'
         MVI   LEN,X'00'
         MVI   LEN+1,X'01'
         BAL   10,OUTPUT
         MVI   TEXT,C'-'
         BAL   10,OUTPUT
*
         L     2,=F'-8'
NEXT     A     2,=F'8'
         C     2,=F'344'
         BH    FINI
*
         C     2,=F'80'
         BNE   TL2
         CLC   BLANK(2),80(11)
         BNE   TL2
         LA    2,168(2)
TL2      C     2,=F'176'
         BNE   STDATA
         CLC   BLANK(2),81(11)
         BNE   STDATA
         LA    2,88(2)
*
STDATA   MVI   DATA,X'00'
         MVC   DATA+1(15),DATA
*
         L     8,=V(INDEX)
         LA    3,0(2,8)
         MVC   DATA(8),0(3)
*
         SR    3,3
         IC    3,DATA+1
         SRL   3,7
         STC   3,DATA+8
         NI    DATA+1,X'7F'
*
         IC    3,DATA
         STC   3,DATA+9
         NI    DATA+9,X'0F'
         SRL   3,4
         STC   3,DATA
         SLL   3,2
*
         SR    4,4
         IC    4,DATA+7
         AR    4,11
         ST    4,DATA+12
*
         SR    5,5
         IC    5,DATA+1
*
*   GR3 - CONTAINS THE INDEX TO THE LINE TYPE
*   GR4 - CONTAINS THE ADDRESS OF THE DATA ITEM
*   GR5 - CONTAINS THE INDEX TO THE CSECTS
*
BRANCH   B     *(3)
         B     LINE1
         B     LINE2
         B     LINE3
         B     LINE4
         B     LINE5
         B     LINE6
         B     LINE7
         B     LINE8
         B     LINE9
         B     LINE10
*
LINE1    B     FORMAT
*
LINE2    BAL   10,SETSTR
         B     FORMAT
*
LINE3    CLI   0(4),C' '
         BE    UNKNOW
         MVI   DATA+8,X'01'
         B     FORMAT
UNKNOW   MVI   DATA+8,X'07'
         LA    4,UNKN
         ST    4,DATA+12
         B     FORMAT
*
LINE4    MVC   LDATA(5),0(4)
         B     LITHOL
*
LINE5    MVC   NUM+5(3),0(4)
         L     0,NUM+4
         O     0,=X'F0F0F0F0'
         ST    0,NUM+4
         PACK  NUM(8),NUM+4(4)
         CVB   0,NUM
         STC   0,0(4)
         B     LINE3
*
LINE6    MVI   LDATA,C' '
         MVC   LDATA+1(2),0(4)
         MVC   LDATA+3(2),3(4)
         B     LITHOL
*
LINE7    MVI   MAX+3,X'02'
LTLO     SR    6,6
         SR    7,7
         LA    8,STRING
         LR    9,8
TEST     CLI   0(4),C' '
         BE    TNEXT
         CLI   0(4),C'0'
```

```
         BE    TNEXT
         BAL   10,GETSTR
         IC    5,DATA+8
         STC   5,MOVEC+1
         L     1,DATA+16
MOVEC    MVC   0(0,8),0(1)
         LA    8,1(5,8)
TNEXT    LA    7,1(7)
         C     7,MAX
         BH    ENDLT
         LA    4,1(4)
         B     TEST
ENDLT    SR    8,9
         BZ    NO
         BCTR  8,0
         STC   8,DATA+8
         ST    9,DATA+16
         B     FORMAT
NO       CLI   MAX,X'02'
         BNE   NONEQ
         MVI   DATA+8,X'0C'
         LA    4,NOTQ
         B     FORMAT
NONEQ    MVI   DATA+8,X'0D'
         LA    4,NONEQQ
         ST    4,DATA+16
         B     FORMAT
*
LINE8    MVI   MAX+3,X'03'
         B     LTLQ
*
LINE9    CLI   0(4),C' '
         BE    NTAKN
         CLI   0(4),C'0'
         BE    NTAKN
         MVI   DATA+8,X'03'
         LA    4,1(4)
         ST    4,DATA+16
         B     FORMAT
NTAKN    MVI   DATA+8,X'09'
         LA    4,NTAKEN
         ST    4,DATA+16
         B     FORMAT
*
LINE10   CLI   0(4),C' '
         BNE   FORMAT
         MVI   DATA+8,X'07'
         LA    4,UNKN
         ST    4,DATA+16
*
LINE11   CLI   0(4),C' '
         BNE   FORMAT
         MVI   DATA+8,X'04'
         LA    4,NONE
         ST    4,DATA+16
         B     FORMAT
*
LITNUL   SR    5,5
         SR    7,7
         LA    8,STRING
         LR    9,8
         LA    4,LDATA
         CLC   0(3,4),BLANK
         BE    NOPER
         MVC   0(3,8),LDATA
         MVI   3(8),C' '
         MVI   4(8),C' '
         LA    8,5(8)
NOPER    MVI   DATA+1,X'05'
         LA    4,LDATA+3
         BAL   10,GETSTR
         IC    5,DATA+8
         BCTR  5,0
         STC   5,MOVNOD+1
         L     4,DATA+16
MOVNOD   MVC   0(0,8),0(4)
         LA    8,1(5,8)
         MVI   0(8),C' '
         LA    8,1(8)
         MVI   DATA+1,X'06'
         LA    4,LDATA+4
         BAL   10,GETSTR
         IC    5,DATA+8
         BCTR  5,0
         STC   5,MOVLIT+1
         L     4,DATA+16
MOVLIT   MVC   0(0,8),0(4)
         LA    8,1(5,8)
         SR    8,9
         STC   8,DATA+8
         ST    9,DATA+16
         B     FORMAT
*
GETSTR   STM   5,8,SAVE8
         CLI   0(4),C' '
         BNE   NOTBLNK
         LA    5,1
         B     GETS
NOTBLNK  SR    5,5
         IC    5,0(4)
         CLI   DATA+1,X'0E'
         BE    INCS
         STC   5,DATA+16
         NI    DATA+16,X'0F'
         IC    5,DATA+16
INCS     LA    5,2(5)
GETS     SR    6,6
         IC    6,DATA+1
         SLL   6,2
         LA    6,TYPES(6)
         L     6,0(6)
         S     6,=F'2'
         C     5,0(6)
         BNP   ITMNOK
         MVI   DATA+8,X'00'
         LM    5,8,SAVE8
         BR    10
ITMNOK   LA    6,2(6)
         LA    8,4(6)
         LR    7,8
         SR    8,8
NEXTC    LA    8,1(8)
TESTC    CLI   0(7),C','
         BE    FOUNDC
         LA    7,1(7)
         B     TESTC
FOUNDC   CR    5,8
         BE    ENDES
         LA    6,1(7)
         LR    7,6
         B     NEXTC
ENDES    SR    7,6
         ST    6,DATA+16
         STC   7,DATA+8
         LM    5,8,SAVE8
         BR    10
*
FORMAT   CLI   DATA+8,X'00'
         BE    LINE
         MVC   TEXT(14),FONT
         MVC   TEXT+14(6),BOLD
         MVC   TEXT+20(20),FP
         MVI   LEN,X'00'
         MVI   LEN+1,X'28'
         BAL   10,OUTPUT
*
LINE     SR    6,6
         SR    7,7
         IC    6,DATA+2
         STC   6,TEXT
         CLI   DATA+4,X'00'
         BE    TXT
         IC    6,DATA+4
         A     6,POSN
         A     6,ADRTEXT
         IC    7,DATA+8
         BCTR  7,0
         STC   7,MOVN+1
         SR    8,8
         SR    9,9
         IC    9,DATA+3
         BCTR  9,0
         M     8,=F'24'
         A     9,TYPES
MOVN     MVC   0(0,6),0(9)
*
TXT      CLI   DATA+8,X'00'
         BE    OUTL
         SR    6,6
         SR    7,7
         IC    6,DATA+5
         A     6,POSN
         A     6,ADRTEXT
         IC    7,DATA+8
         BCTR  7,0
         STC   7,MOVT+1
         L     9,DATA+16
MOVT     MVC   0(0,6),0(9)
*
OUTL     LA    6,2(7,6)
         S     6,ADRTEXT
         STH   6,LEN
         BAL   10,OUTPUT
*
         CLI   DATA+8,X'00'
         BE    NEXT
         MVC   TEXT(14),FONT
         MVC   TEXT+14(6),MEDIUM
         MVC   TEXT+20(20),FP
         MVI   LEN,X'00'
         MVI   LEN+1,X'28'
         BAL   10,OUTPUT
         B     NEXT
*
OUTPUT   LA    1,PTEXT
         L     15,=V(WRITE)
         BALR  14,15
         MVI   TEXT,C' '
         MVC   TEXT+1(128),TEXT
         BR    10
*
FINI
         L     13,4(13)
         LM    14,12,12(13)
         SR    15,15
         BR    14
*
PTEXT    DC    A(TEXT)
         DC    A(LEN)
         DC    A(MODE)
         DC    A(LNUM)
         DC    A(UNIT)
MODE     DC    F'0'
LNUM     DC    F'0'
UNIT     DC    F'6'
*
ADRTEXT  DC    A(TEXT)
LEN      DC    H'0'
*
BLANK    DC    C'   '
FONT     DC    C'$++$FONT=1200 '
BOLD     DC    C'BOLD'
MEDIUM   DC    C'MEDIUM'
FP       DC    C' 12 FIXED PORTRAIT 1'
```

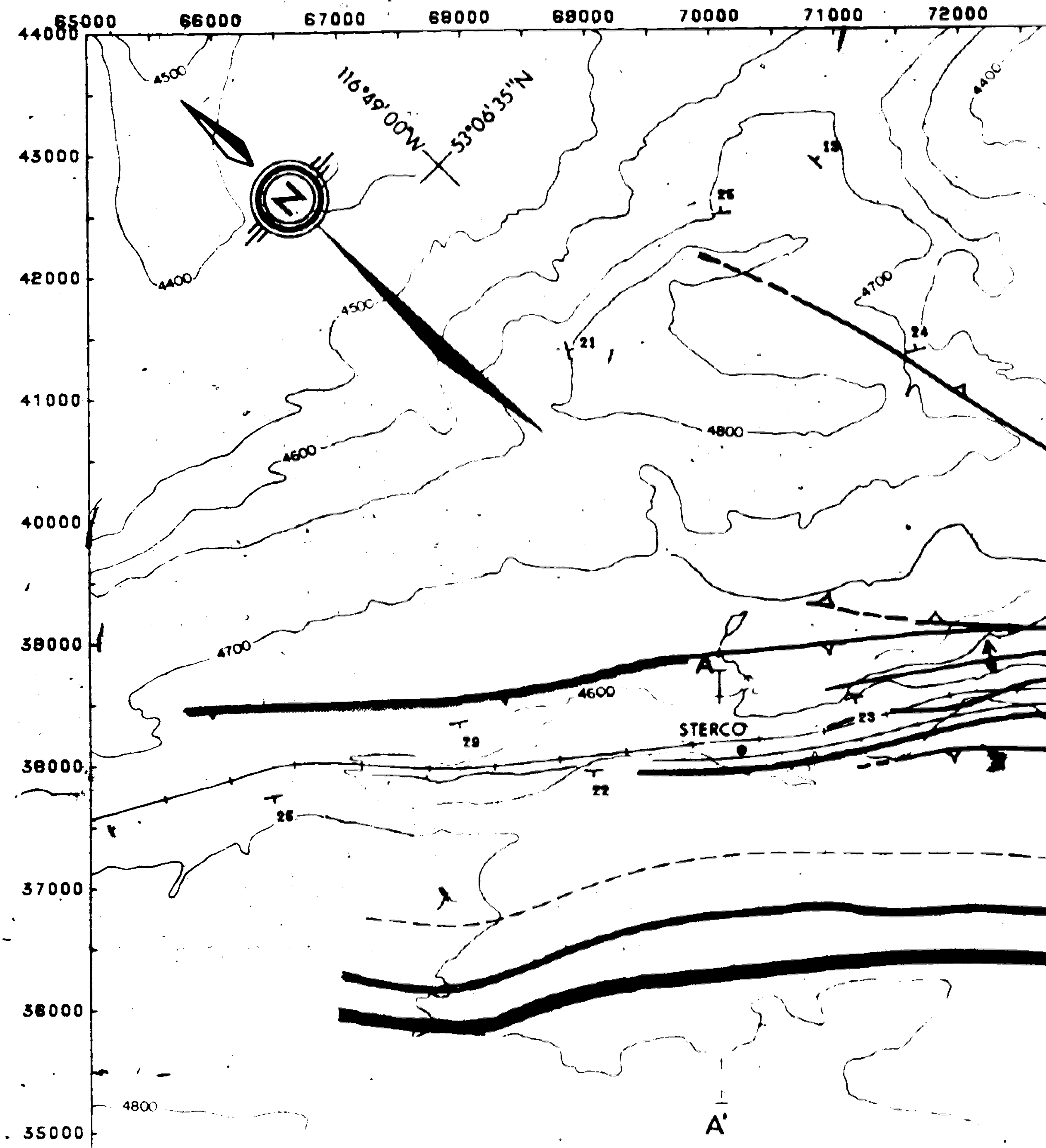
```
UNKN     DC    C'unknown'
NOTO     DC    C'not observed'
NONEOB   DC    C'none observed'
NTAKEN   DC    C'not taken'
NONE     DC    C'none'
*
MAX      DC    F'0'
NUM      DC    D'0'
         DC    F'0'
POSN     DC    F'11'
*
TYPES    DC    V(TITLES)
         DC    V(WAYUP)
         DC    V(OCTYPE)
         DC    V(SCTACT)
         DC    V(FOSILS)
         DC    V(LITHOL)
         DC    V(MDFIER)
         DC    V(SRTING)
         DC    V(WEATHR)
         DC    V(BTHKNS)
         DC    V(GRSIZE)
         DC    V(DSPRSN)
         DC    V(STRUCT)
         DC    V(SAMPLE)
         DC    V(COLORS)
*
SAVE4    DS    4F
STRING   DS    30F
LDATA    DS    2F
DATA     DS    5F
SAVE     DS    18F
TEXT     DS    33F
         END
INDEX    CSECT
         DC    X'148040010E10[illegible]00'
         DC    X'108080020100[illegible]0'
*        DC    X'30004E000000A[illegible]00'
         DC    X'1080800301001000'
         DC    X'40004E00001200[illegible]'
         DC    X'600EF0C7041C0D[illegible]4'
         DC    X'600E4008041C11[illegible]7'
         DC    X'200A4008041C08[illegible]0'
         DC    X'2007400A041C083[illegible]'
         DC    X'2008400B041C0E3[illegible]'
         DC    X'2008400C041C1832'
         DC    X'700C400D041C173A'
         DC    X'1080800401001000'
         DC    X'60004E0000120030'
         DC    X'2008F008041C083F'
         DC    X'600E4007041C0847'
         DC    X'600E4008041C114A'
         DC    X'200A4008041C0842'
         DC    X'2007400A041C0843'
         DC    X'2008400B041C0845'
         DC    X'2008400C041C1844'
         DC    X'700C400D041C1748'
         DC    X'1080800601001000'
         DC    X'60004E0000120050'
         DC    X'2008F008041C0852'
         DC    X'600E4007041C085A'
         DC    X'600E4008041C115D'
         DC    X'200A4008041C0855'
         DC    X'2007400A041C0855'
         DC    X'2008400B041C0856'
         DC    X'2008400C041C1567'
         DC    X'700C400B041C1760'
         DC    X'1080800501000000'
         DC    X'1800F0080400000F'
         DC    X'18004E0F1721000F'
         DC    X'14004E1028300A18'
         DC    X'2003F011041C1721'
         DC    X'A8004012041C1710'
         DC    X'20024013041C0027'
         DC    X'20014014041C0708'
         DC    X'B4004015041C1018'
         DC    X'80044016041C1027'
         DC    X'200B4017041C1C28'
         DC    X'80004018041C0723'
         END
TITLES   CSECT
         DC    C'OUTCROP NUMBER
         DC    C'Horizon
         DC    C'Major lithology
         DC    C'Minor lithology
         DC    C'Outcrop data
         DC    C'Dispersion
         DC    C'Fresh colour
         DC    C'Weathered colour
         DC    C'Grain size
         DC    C'Sorting
         DC    C'Bed thickness
         DC    C'Weathering character
         DC    C'Sedimentary structures
         DC    C'Easting
         DC    C'Northing
         DC    C'Elevation
         DC    C'Stratigraphic context
         DC    C'Stratigraphic distance
         DC    C Outcrop type
         DC    C'Way up
         DC    C'Airphoto number
         DC    C Fossils present
         DC    C'Rock sample
         DC    C'Photos
         END
WAYUP    CSECT
         DC    F'2'
         DC    C'unknown '
         DC    C unknown,
         DC    C'right way up '
         DC    C overturned,'
         END
OCTYPE   CSECT
         DC    F'4'
         DC    C' ,'
         DC    C' ,'
         DC    C'outcrop,'
         DC    C'open pit,'
         DC    C'adit,'
         DC    C'trench,'
         END
SCTACT   CSECT
         DC    F'3'
         DC    C' ,'
         DC    C'none,'
         DC    C'transitional,'
         DC    C'abrupt,'
         DC    C'erosional,'
         END
FOSILS   CSECT
         DC    F'5'
         DC    C'none observed,'
         DC    C'none observed,'
         DC    C'molluscs,'
         DC    C'plant remains,'
         DC    C'stems,'
         DC    C'roots,'
         DC    C'trace fossils,'
         END
LITHOL   CSECT
         DC    F'8'
         DC    C' ,'
         DC    C'shale,'
         DC    C'claystone,'
         DC    C'mudstone,'
         DC    C'siltstone,'
         DC    C'sandstone,'
         DC    C conglomerate,'
         DC    C'bentonite,'
         DC    C'coal,'
         DC    C carbonate,'
         DC    C ironstone '
         END
MDFIER   CSECT
         DC    F'0'
         DC    C' '
         DC    C shaley,'
         DC    C'silty,'
         DC    C sandy,'
         DC    C pebbly,'
         DC    C'boulder,'
         DC    C'calcareous,'
         DC    C'dolomitic,'
         DC    C'carbonaceous,'
         DC    C'fossiliferous,'
         DC    C siliceous,'
         END
SRTING   CSECT
         DC    F'3'
         DC    C' ,'
         DC    C' '
         DC    C'poor,'
         DC    C'moderate '
         DC    C'well,'
         END
WEATHR   CSECT
         DC    F'3'
         DC    C' ,'
         DC    C' ,'
         DC    C'recessive,'
         DC    C'moderately recessive,'
         DC    C'resistant,'
         END
GRSIZE   CSECT
         DC    F'6'
         DC    C' ,'
         DC    C' ,'
         DC    C'very fine,'
         DC    C'fine,'
         DC    C'medium,'
         DC    C'coarse,'
         DC    C'very coarse,'
         DC    C'extremely coarse,'
         END
DSPRSN   CSECT
         DC    F'5'
         DC    C' ,'
         DC    C' ,'
         DC    C'dispersed,'
         DC    C'top,'
         DC    C'middle,'
         DC    C'bottom,'
         DC    C'interbedded,'
         END
BTHKNS   CSECT
         DC    F'7'
         DC    C' ,'
         DC    C' ,'
         DC    C'thinly laminated,'
         DC    C'thickly laminated,'
         DC    C'very thinly bedded,'
         DC    C'thinly bedded,'
         DC    C'medium bedded,'
         DC    C'thickly bedded '
         DC    C'very thickly bedded,'
         END
STRUCT   CSECT
         DC    F'8'
         DC    C' ,'
         DC    C' '
         DC    C'cross bedding '
         DC    C'graded bedding
         DC    C'contorted bedding
```

```
         DC    C'flute casts.'
         DC    C'ripple marks.'
         DC    C'flame structures.'
         DC    C'mudcracks.'
         DC    C'load casts.'
         END
SAMPLE   CSECT
         DC    F'1'
         DC    C'not taken.'
         DC    C'not taken.'
         DC    C'yes.'
         END
COLORS   CSECT
         DC    F'110'
         DC    C' .'
         DC    C' .'
         DC    C'greyish pink.'
         DC    C'pale red.'
         DC    C'greyish red.'
         DC    C'blackish red.'
         DC    C'moderate pink.'
         DC    C'moderate red.'
         DC    C'dusky red.'
         DC    C'light red.'
         DC    C'moderate red.'
         DC    C'very dark red.'
         DC    C'greyish orange pink.'
         DC    C'pale red.'
         DC    C'greyish red.'
         DC    C'very dusky red.'
         DC    C'moderate orange pink.'
         DC    C'pale reddish brown.'
         DC    C'dark reddish brown.'
         DC    C'moderate reddish orange.'
         DC    C'moderate reddish brown.'
         DC    C'greyish orange pink.'
         DC    C'pale brown.'
         DC    C'greyish brown.'
         DC    C'dusky brown.'
         DC    C'moderate orange pink.'
         DC    C'light brown.'
         DC    C'moderate brown.'
         DC    C'moderate brown.'
         DC    C'light brown.'
         DC    C'very pale orange.'
         DC    C'pale yellowish brown.'
         DC    C'dark yellowish brown.'
         DC    C'dusky yellowish brown.'
         DC    C'greyish orange'
         DC    C'moderate yellowish brown.'
         DC    C'pale yellowish orange.'
         DC    C'dark yellowish orange.'
         DC    C'yellowish grey.'
         DC    C'light olive grey'
         DC    C'olive grey'
         DC    C'greyish yellow'
         DC    C'dusky yellow.'
         DC    C'moderate olive brown.'
         DC    C'moderate yellow'
         DC    C'light olive brown.'
         DC    C'pale greenish yellow.'
         DC    C'pale olive.'
         DC    C'greyish olive.'
         DC    C'moderate greenish yellow.'
         DC    C'light olive.'
         DC    C'dark greenish yellow.'
         DC    C'greyish yellow green'
         DC    C'dusky yellow green'
         DC    C'greyish olive green.'
         DC    C'moderate yellow green.'
         DC    C'pale yellowish green.'
         DC    C'greyish green.'
         DC    C'dusky yellowish green.'
         DC    C'moderate yellowish green.
         DC    C'dark yellowish green.'
         DC    C'pale green.'
         DC    C'greyish green.'
         DC    C'dusky green.'
         DC    C'light green.'
         DC    C'brilliant green.
         DC    C'moderate green.'
         DC    C'very pale green.
         DC    C'pale green.'
         DC    C'greyish green.'
         DC    C'pale blue green.'
         DC    C'greyish blue green.'
         DC    C'dusky blue green.'
         DC    C'light blue green.'
         DC    C'moderate blue green.'
         DC    C'very pale blue.'
         DC    C'pale blue.'
         DC    C'light blue.'
         DC    C'moderate blue.
         DC    C'pale blue.'
         DC    C'greyish blue.'
         DC    C'dusky blue'
         DC    C'pale purple.'
         DC    C'greyish purple.'
         DC    C'very dusky purple.'
         DC    C'pald pink.'
         DC    C'pale red purple.'
         DC    C'greyish red purple.'
         DC    C'very dusky red purple.'
         DC    C'white.'
         DC    C'very light grey.'
         DC    C'light grey.'
         DC    C'medium light grey.'
         DC    C'medium grey.'
         DC    C'medium dark grey.'
         DC    C'dark grey.'
         DC    C'greyish black.'
         DC    C'black.'
         DC    C'pinkish grey.'
         DC    C'light brownish grey.'
         DC    C'brownish grey.'
         DC    C'brownish black.'
         DC    C'yellowish grey.'
         DC    C'light olive grey.'
         DC    C'olive grey.'
         DC    C'olive black.'
         DC    C'light greenish grey.'
         DC    C'greenish grey.'
         DC    C'darkgreenish grey.'
         DC    C'greenish black.'
         DC    C'light greenish grey.'
         DC    C greenish grey.
         DC    C'dark greenish grey.'
         DC    C'greenish black.'
         DC    C'bluish white.'
         DC    C'light bluish grey.'
         DC    C'medium bluish grey.'
         END
```

Format of the file O/CDAT

This file contains re-formatted R1 (A field sheet) data as output from the program O/CFORM.

```
                    OUTCROP NUMBER    8

Horizon: A

Major lithology:  40%   sandstone

   Fresh colour:             light olive grey
   Weathered colour:         greyish orange
   Grain size:               medium
   Sorting:                  moderate
   Bed thickness:            thickly bedded
   Weathering character:     resistant
   Sedimentary structures:   none observed

Minor lithology:  30%   coal

   Dispersion:               bottom
   Fresh colour:             black
   Weathered colour:         black
   Grain size:
   Sorting:
   Bed thickness:            thickly bedded
   Weathering character:     moderately recessive
   Sedimentary structures:   none observed

Minor lithology:  30% carbonaceous mudstone

   Dispersion:               top
   Fresh colour:             moderate brown
   Weathered colour:         dark grey
   Grain size:               fine
   Sorting:                  well
   Bed thickness:
   Weathering character:     moderately recessive
   Sedimentary structures:   none observed

Outcrop data:

   Easting:  98287    Northing:  36830    Elevation: 4454

   Stratigraphic contact:    abrupt
   Stratigraphic distance:   unknown
   Outcrop type:             open pit
   Way up:                   right way up
   Airphoto number:            44
   Fossils present:          plant remains
   Rock sample:              not taken
   Photos:                   not taken
```



65000
66000
67000
68000
69000
70000
71000
72000
44000
43000
42000
41000
40000
39000
38000
37000
36000
35000
116°49'00"W
53°06'35"N
N
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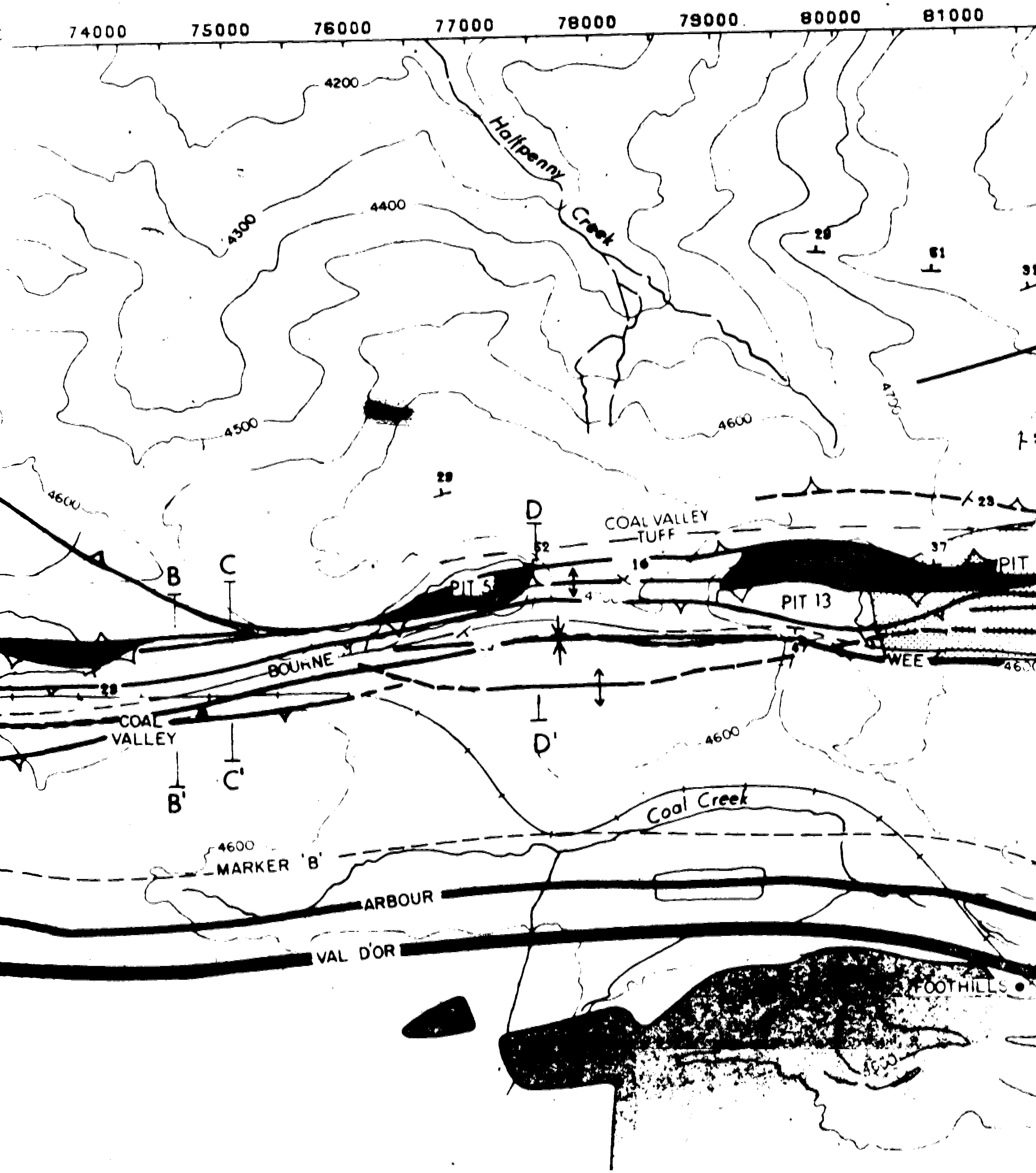
4400
4600
4700
4800
21
25
13
24
29
22
23
A
A'
STERCO

LEGEND

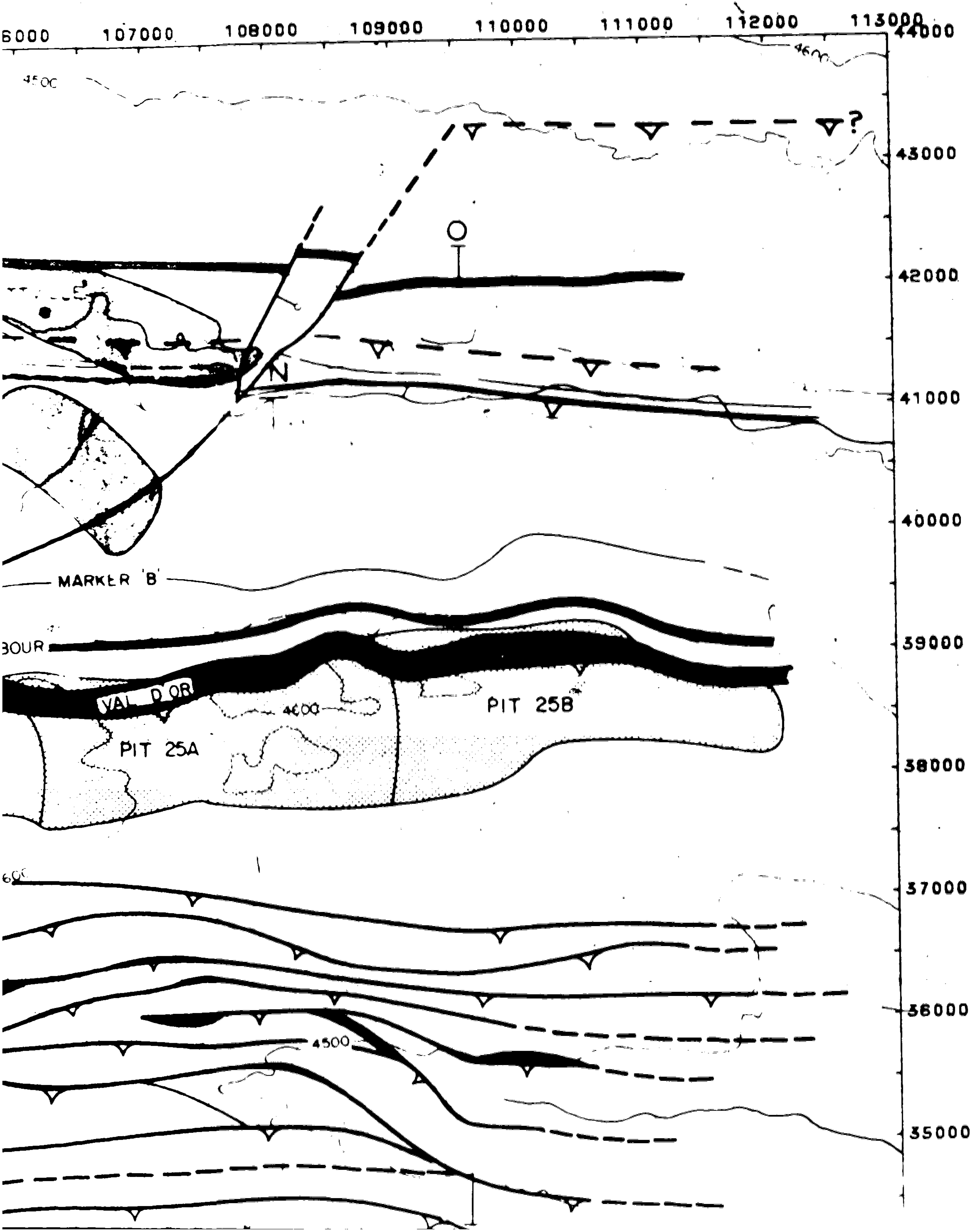


74000
75000
76000
77000
78000
79000
80000
81000
4200
4300
4400
4500
4600
Halfpenny Creek
COAL VALLEY TUFF
PIT 5
PIT 13
PIT
BOURNE
COAL VALLEY
WEE
B
B'
C
C'
D
D'
Coal Creek
MARKER 'B'
ARBOUR
VAL D'OR
FOOTHILLS

82000
83000
84000
85000
86000
87000
88000
89000
4600
4700
4900
4800
4700
4500
4500
RECO
E
F
E'
F'
PIT 14
PIT 15
PIT 16
31
17
20
20
8
16
12
31
20
10

90000
91000
92000
93000
94000
95000
96000
97000
98000
4500
J
UPPER MYNHEER
PIT
42-1
PIT 41
28
4400
32
RIVER
WEE
BOURNE
LOVETT
G
4500
MARKER 'B'
VAL D'OR
4600
4500
20
15
PIT 21

99000
100000
101000
102000
103000
104000
105000
106000
4500
M
PIT 42-2
PIT 42-3
LOVE
4400
12
MARKE
ARBOUR
ARBOUR
PIT 24
L
L'
4600
10
VAL D'OR
D'OR



6000
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111000
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43000
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39000
38000
37000
36000
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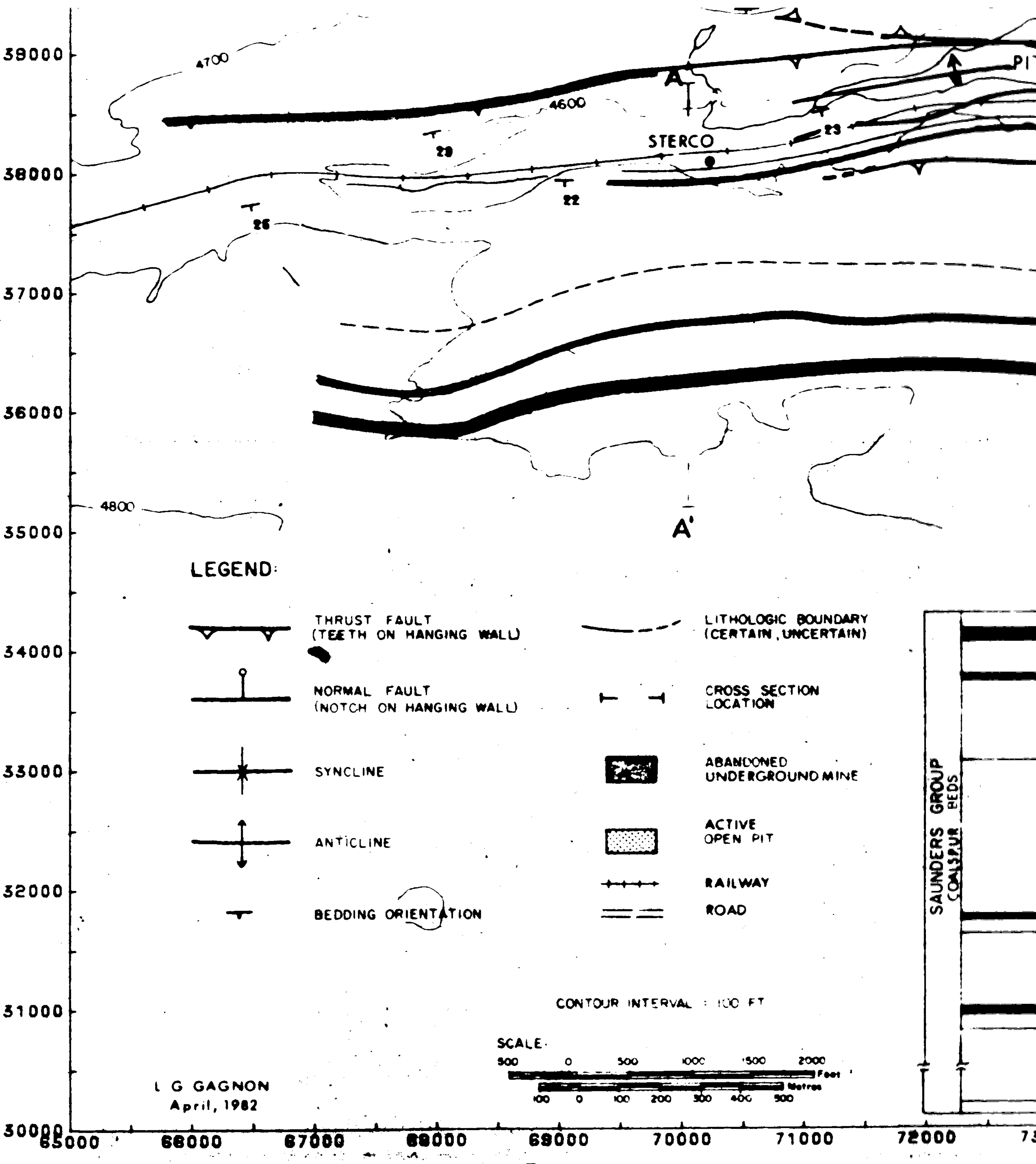
4500
4600
O
N
MARKER 'B'
BOUR
VAL D'OR
PIT 25A
PIT 25B
4600
4500



39000
38000
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36000
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32000
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30000
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70000
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72000
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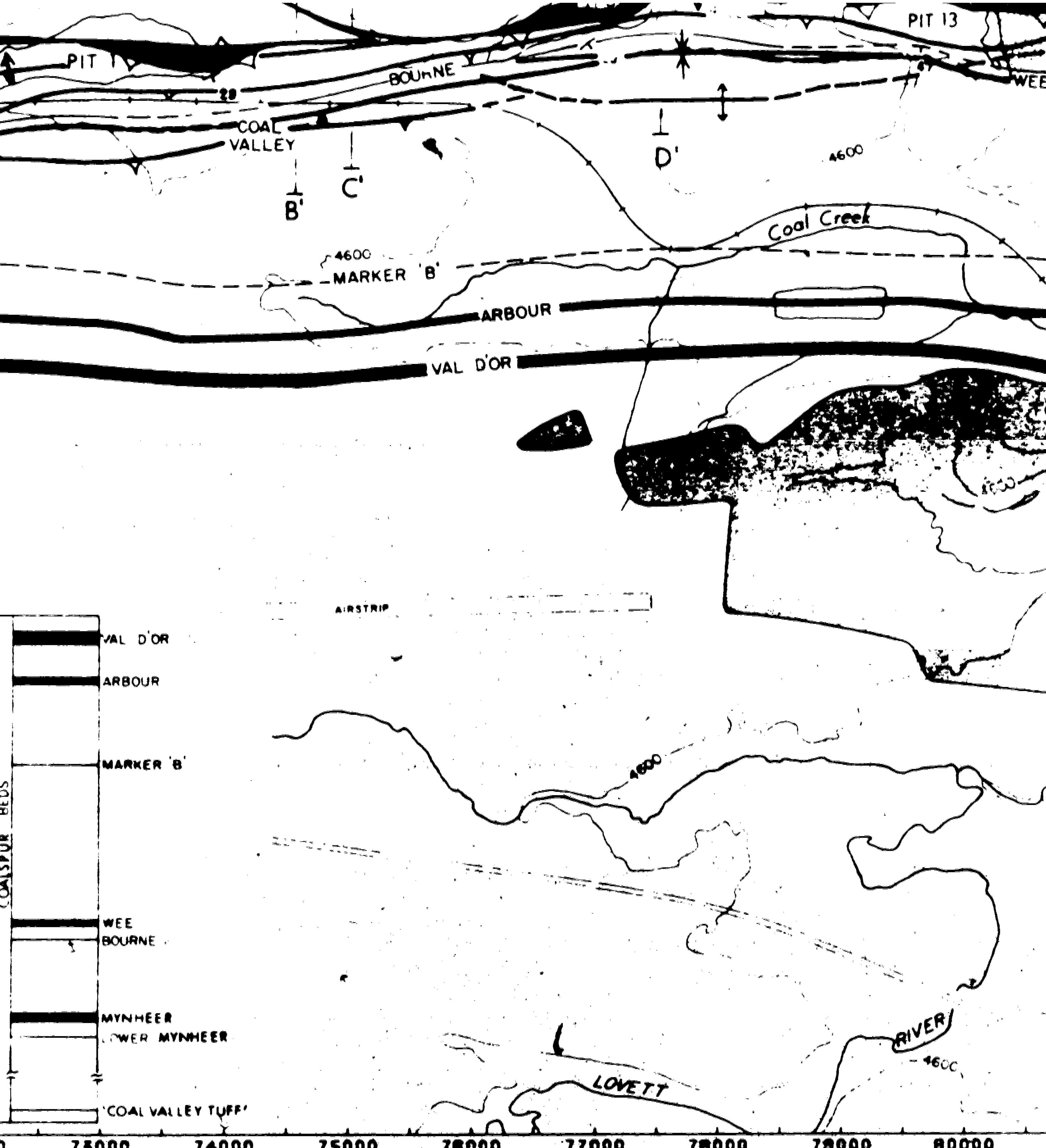
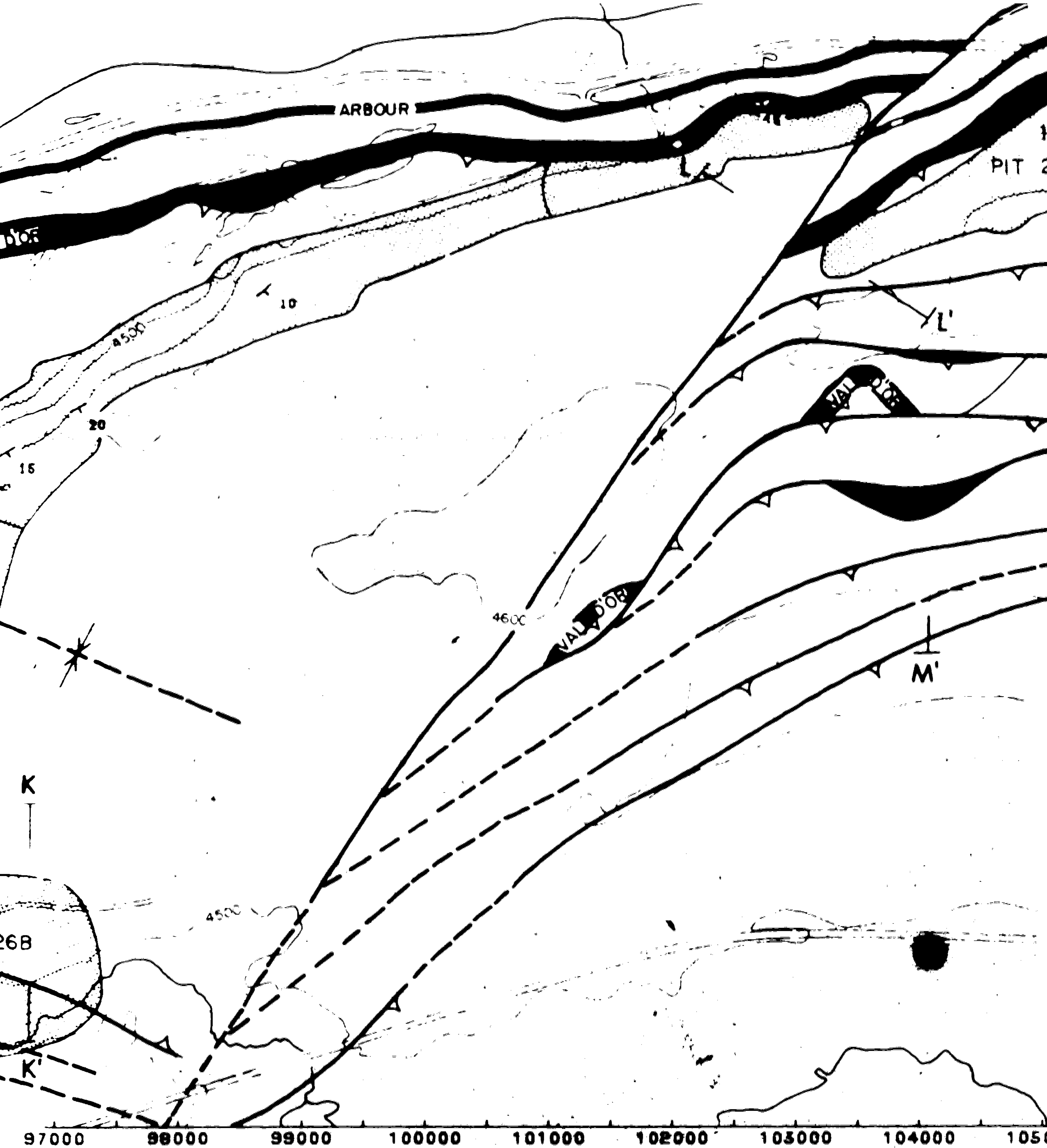
4800
A
A'
STERCO
23
29
22
26
LEGEND:
THRUST FAULT (TEETH ON HANGING WALL)
NORMAL FAULT (NOTCH ON HANGING WALL)
SYNCLINE
ANTICLINE
BEDDING ORIENTATION
LITHOLOGIC BOUNDARY (CERTAIN, UNCERTAIN)
CROSS SECTION LOCATION
ABANDONED UNDERGROUND MINE
ACTIVE OPEN PIT
RAILWAY
ROAD
CONTOUR INTERVAL = 100 FT
SCALE
Feet
Metres
SAUNDERS GROUP
COALSPUR BEDS
L G GAGNON
April, 1982



PIT 1
PIT 13
BOURNE
WEE
28
COAL VALLEY
B'
C'
D'
4600
Coal Creek
MARKER 'B'
ARBOUR
VAL D'OR
AIRSTRIP
LOVETT
RIVER
VAL D'OR
ARBOUR
MARKER 'B'
COALSPUR BEDS
WEE
BOURNE
MYNHEER
LOWER MYNHEER
'COAL VALLEY TUFF'
73000
74000
75000
76000
77000
78000
79000
80000


PIT 15
P.T 16
WEE
E'
F'
10
FOOTHILLS
4500
4500
4500
17
4600
4600
81000
82000
83000
84000
85000
86000
87000
88000

4500
MARKER 'B'
4600
VAL D'OR
PIT 21
15
12
PIT
22
10
12
I
H
G'
VAL D'OR
PIT 26A
J'
PIT 26B
K
K'
H'
Centre Creek
89000
90000
91000
92000
93000
94000
95000
96000



ARBOUR
D'OR
PIT 2
L'
10
4500
20
15
VAL D'OR
VAL D'OR
4600
M'
K
4500
26B
K'
97000
98000
99000
100000
101000
102000
103000
104000

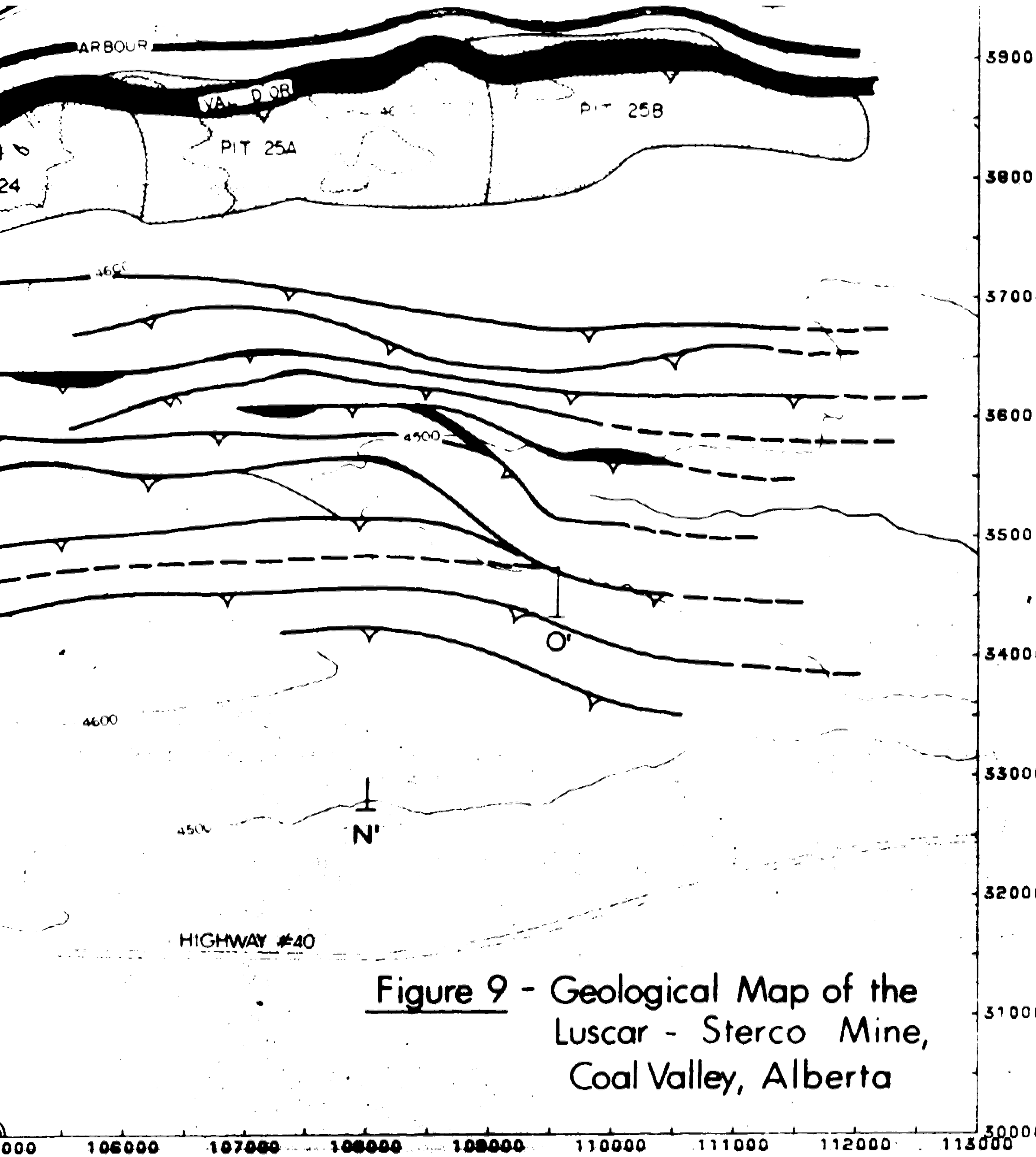


Figure 9 - Geological Map of the Luscar - Sterco Mine, Coal Valley, Alberta