THE COALBED METHANE POTENTIAL OF NORTH DAKOTA LIGNITES

by
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On the Cover: Gas (presumably methane) and water blow out of a newly installed monitoring well near the town of Lignite in northwest North Dakota. The well, drilled in 1984, was screened in a three-foot lignite at a depth of 90 feet. Gas blew out of the 2-inch well for three days before the well could be capped. Dave Lechner, former logger and geotechnician for the North Dakota Geological Survey, finishes logging a nearby hole.

TABLE OF CONTENTS

ILLUSTRATIONS

Figures

ACKNOWLEDGMENTS

Many of the maps and cross-sections were constructed using data compiled by two cooperative programs (the National Coal Resources Data System and the National Coal Assessment Program) between the North Dakota Geological Survey and the United States Geological Survey. Gerard Goven's employment was made possible by a grant provided under these cooperative programs. The National Coal Resources Data System program is administered by Ms. Debbie Carter (Reston, Virginia) and the Williston Basin portion of the National Coal Assessment Program is under the direction of Dr. Romeo Flores (Denver, Colorado). Additional U.S. Geological Survey personnel assisting with resource evaluation in the Williston Basin are Bill Keighin, Al Ochs, Gary Stricher, and Margaret Ellis.

The following people were interviewed for this report: C.G. Carlson–retired from ND Oil and Gas Commission, formerly with ND Geological Survey; Dave Lechner, Energy and Environmental Resources Research Center, formerly with ND Geological Survey; Dan Daly, Energy and Environmental Resources Research Center; Ken Kinard, Paul Wier Associates; Bill Peterson, BNI Coal Ltd, formerly with ND Engineering Experiment Station; Curtis Blohm, Knife River Coal Mining Company; Doug Davison, Knife River Coal Mining Co.; Art Kane, retired from Knife River Coal Mining Co.; Terry Rowland, Coteau Properties; Dennis James, Falkirk Mining Company; Dave Bickel, ND Public Service Commission, formerly with North American Coal Corp.; Dave Cameron, ND Department of Health, formerly with North American Coal Corp.; Jim Wald, US Geological Survey, formerly with Geotechniques Logging Services; Roger Schmid, Water Supply Inc., formerly with ND State Water Commission; Leroy Gregory, Gregory Drilling; Leo Grossman, Agri Industries; John Mohl, Mohl Drilling; Ed Englerth, retired from ND Public Service Commission; Jim Deutch, ND Public Service Commission; L. Dean Moos, ND Public Service Commission; Bruce Beechie, ND Public Service Commission; Milton Lindvig, ND State Water Commission; Joe Hartman, ND Energy and Environmental Resources Research Center; and Dave Glatt, ND Department of Health.

AUTHOR'S NOTE

The authors are preparing isopach, structural contour, and depth maps for the thick coals in Bowman, Slope, Stark, Dunn, Golden Valley, Billings, and McKenzie Counties. These maps are tentatively scheduled for release as North Dakota Geological Survey Open-File Report 98-2 in late August or September at an approximate cost of $5.00. If you would like to be put on the mailing list for this publication please contact Sheila at 701-328-8000.

INTRODUCTION

Large amounts of gas are produced during the conversion of peat to coal, possibly in the range of 150 to 200 cm^3/gram of coal (Rice et al., 1996). In addition to methane, coal gas may also consist of heavier hydrocarbons, carbon dioxide, and nitrogen (gas from a coal field near Gillette, Wyoming, is averaging 97% methane). The gas content of coals generally increases with coal rank and burial depth. In the U.S., coal gas is currently being produced from sub-bituminous and bituminous coals. In the past, it has been speculated that lignites had not undergone enough coalifaction to generate commercial quantities of methane and that anthracite had undergone too much. The permeability of coal is entirely dependent upon the fracture system, commonly referred to as the "cleat system". The gas is generally adsorbed, as a monomolecular layer along internal faces in the coal. Typically, these coals must be dewatered in order to reduce reservoir pressure and initiate gas desorption (Rice et al., 1996). The high volumes of groundwater produced during coalbed gas production can cause both an environmental and economic burden. In many areas, the water is sufficient quality that it can be discharged at the surface and not adversely impact surface water. However, depletion of fresh water aquifers is a major concern. Re-injection of water, either to protect surface water or minimize the impact to a coal aquifer, may add significantly to production costs.

The development of coal-bed gas in the United States was in large part due to a special tax credit which was given for development of unconventional gas from wells drilled and completed from 1980 through 1992 (Rice, 1996). By 1993, more than 5,300 wells were producing coal gas in the U.S. At the present time, approximately 3% of gas production in the U.S. is coalbed gas, which also accounts for approximately 6% of the country's gas reserves (Rice, 1996).

Over the years, there has been little interest expressed by industry in the potential of North Dakota lignites to contain economic quantities of methane. This has changed in recent months due to the successful capture of coalbed methane in sub-bituminous coals in Wyoming. Companies involved in the coalbed methane play in Wyoming are scrambling to identify a successful exploration model. Companies are targeting sub-bituminous coals that are 45 feet thick or thicker at depths ranging from 300 to 1200 feet. Below these depths it is more difficult, and therefore more expensive to lift the water/gas to the surface (Bob Lyman, Wyoming Geological Survey, personal communication). Dewatering and removal of coal at surface mine sites appears to stimulate gas production in coal beds down dip of the mines. Recently, the US Bureau of Land Management has declared a moratorium on new coalbed methane production in an area south of Gillette, Wyoming because the number of producing wells had exceeded the limit set by an environmental impact statement. In Wyoming, as in other states, the royalties paid for coal bed methane go to the holder of the oil and gas mineral rights and not to the coal rights, if separate. A federal judge in the 10th Circuit (Colorado) recently ruled that these royalties should be held by the coal lease, but this ruling is under appeal. Escalating lease prices and the temporary BLM moratorium are causing some companies to look at the northern part of the Powder River Basin in Montana and to contemplate venturing into the Williston Basin in eastern Montana and western North Dakota.

FORT UNION GROUP

The North Dakota portion of the Williston Basin contains up to 1500 feet of coal-bearing rocks in the Fort Union Group (Paleocene). The Fort Union Group is a clastic (sandstone, siltstone, mudstone, claystone, and lignite) wedge that thins from eastern Montana into central North Dakota. The Fort Union

Group consists of the Ludlow, Cannonball, Slope, Bullion Creek, and Sentinel Butte formations (Figure 1). These units are nonmarine, coal-bearing strata except for the Cannonball Formation. While these nonmarine units thin to the east, the Cannonball thins to the west. The Fort Union Group ranges in thickness from 1000 to 1800 feet across western North Dakota. Although little rock record remains of Miocene and Pliocene strata in western North Dakota, the deepest coals, those near the base of the Ludlow Formation, were likely never buried by much more than 2500 feet of sedimentary rock.

Lignite beds in western North Dakota are typically five feet or less in thickness, but a handful of beds maintain thicknesses in excess of 20 feet for several hundred square miles (Figure 2). The thickest coals tend to occur in either the upper Bullion Creek or lower Sentinel Butte formations (Figure 3). The Bullion Creek and Sentinel Butte formations each have maximum thicknesses of approximately 600 feet in western North Dakota and thin to 300 feet or so in central North Dakota. The Fort Union Group is overlain by the Golden Valley Formation (Paleocene/Eocene). The upper member of the Golden Valley Formation contains lignite, but the beds are typically thin, generally only a few feet thick.

Any given place in western North Dakota may be underlain by a dozen or more coal beds (Figure 4). Although the majority of these beds tend to be only a few feet thick, occasionally a very thick bed of coal will be encountered. Until recently, publically available data has made coal correlation in North Dakota tenuous at best. Most of the published coal correlations have been based on scattered outcrops and a handful of drill holes. Due to the thinning, thickening, and splitting nature of these lignites over relatively short distances, accurate correlation is often impossible without drill hole spacings of one mile or less. Since 1975, coal companies have been required to submit copies of all basic data (driller's and electric logs, etc.) generated by coal exploration permits to the ND Geological Survey. In addition, logs generated by subsurface mineral exploration, primarily uranium, have been deposited with our agency since 1968. To date, over 15,000 electric logs from these exploration programs are housed in our files and are available for public inspection (Figure 5). These logs make possible detailed coal correlation through much of western North Dakota.

Exploration holes have been drilled in all of the coal-bearing counties in North Dakota but, as should be expected, holes are concentrated in the areas of thick, shallow coals. Typically, coal exploration holes average 200 feet in depth, seldom exceeding 250 feet. Subsurface mineral holes average 400 feet, but in some cases exceed 1000 feet in depth. These shallow holes make regional correlation difficult. The deep holes drilled by the State Water Commission and the occasional oil and gas gamma logs run to the surface provide valuable information. Unfortunately, these holes are few and far between. Therefore, with few exceptions, detailed correlations have been restricted to within a few hundred feet of the surface and extend over fairly localized areas (generally several townships). The detailed cross-sections of Groenewold and others (1979) through the Knife River Basin is one of these exceptions.

DRILLING AND GROUNDWATER MONITORING PROGRAMS IN WESTERN NORTH DAKOTA

Over the past several years, enquiries related to coal bed methane have been made by our office to coal and uranium geologists, drillers, and loggers involved in many of the drilling programs that have taken place in North Dakota. A few of the well drillers contacted recalled encountering gas in lignites in western North Dakota. Leroy Gregory (Gregory Drilling) has encountered gas in lignites in northwestern

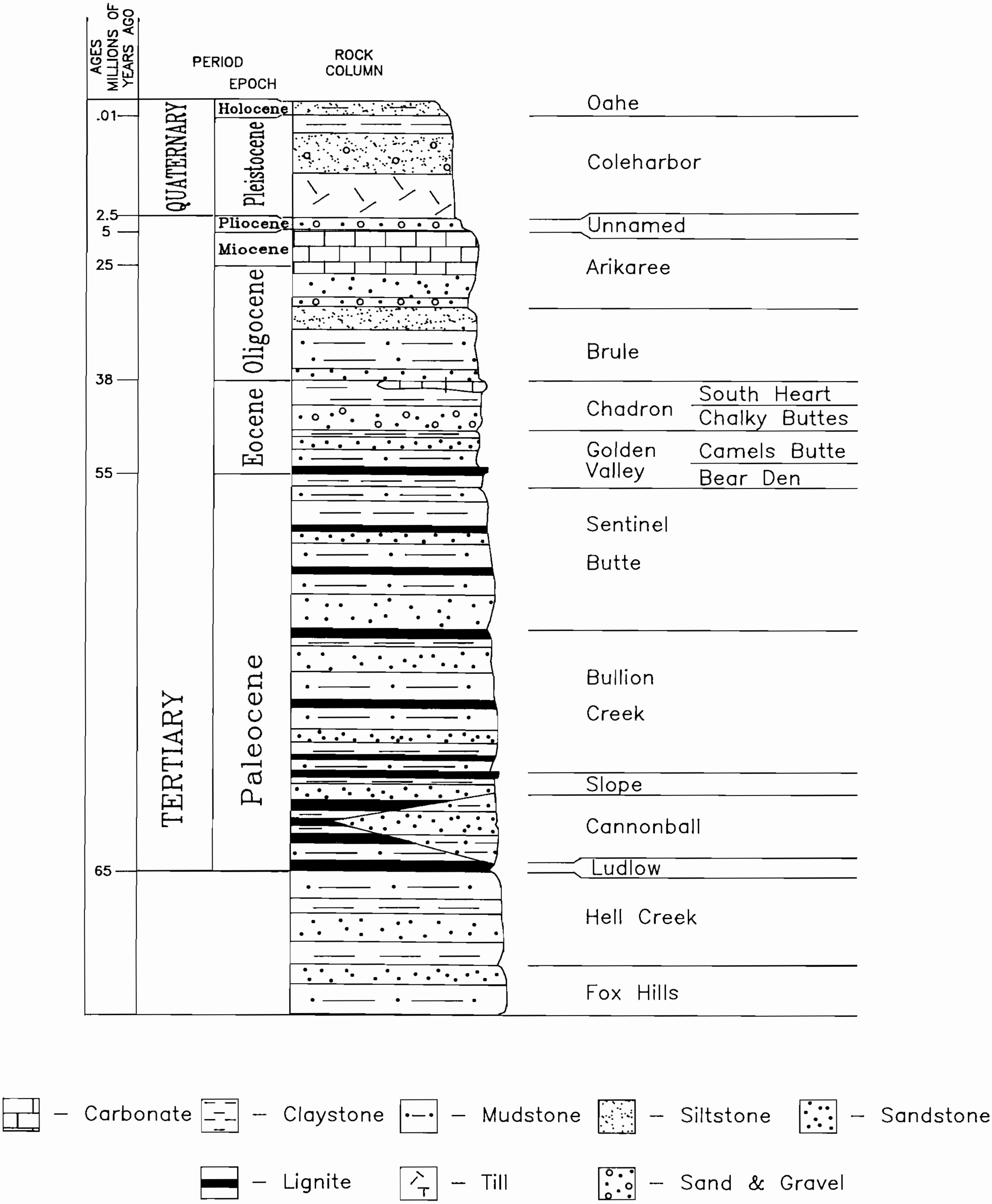

Figure 1. Generalized stratigraphic column of the coal-bearing rocks in North Dakota.

Figure 2. A portion of the Harmon bed, is exposed along East River Road south of Medora in Billings County.

and north-central North Dakota. Gas was encountered in a 400-foot well screened in lower Fort Union sandstones and lignites southeast of Fortuna in the northwest corner of North Dakota. The gas was not analyzed but did ignite. Gas and water reportedly blew 20 feet in the air only after the mud had been flushed from the well screen. The well was screened in a 15-foot sand which contained approximately three feet of coal. Gregory also encountered gas in a 400-foot hole approximately 20 miles north of Dickinson . This well was screened in either the lower Sentinel Butte or upper Bullion Creek Formation. They also encountered gas in a 900-foot hole near Lefor in Stark County. The well was screened in sandstone and coal in the lower Fort Union Group. In all three instances, gas was detected only after the well was installed and some portion of the drilling mud had been removed from the well. Leo Grossman (Agri Industries) also is familiar with gas in the Fort Union in the northwest corner of the State. In addition, he encountered ignitable gas in a well he installed near Drake in central North Dakota. It has not been determined if the well was screened in Tertiary or Cretaceous strata. John Mohl (Mohl Drilling) encountered a blow of gas in a monitoring well he screened in a lignite at a depth of approximately 300 feet near the Falkirk Mine in McLean County. Dennis James, Falkirk Mining Company, ran the gas through a methane detector but did not get a reading and assumed it was carbon dioxide.

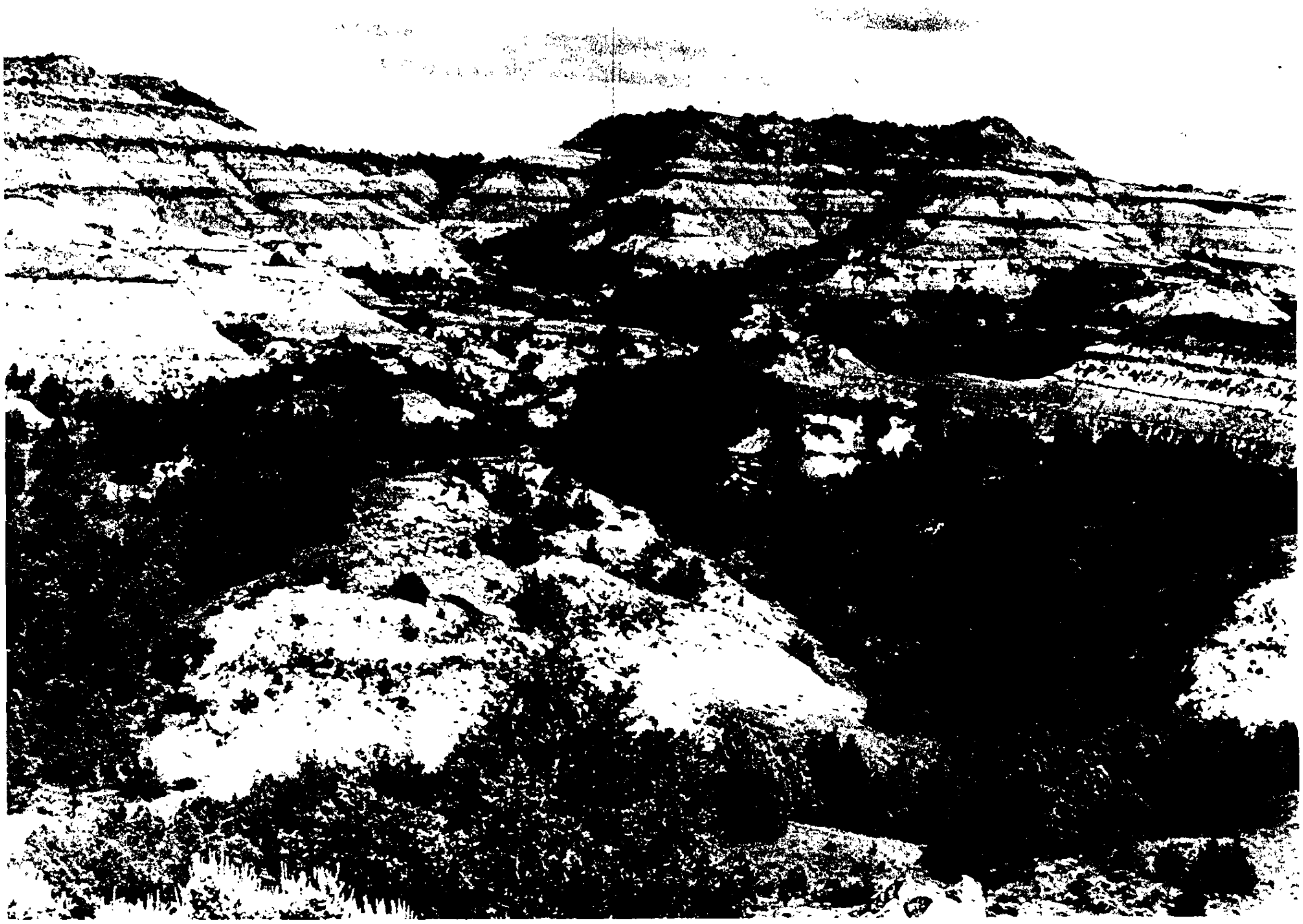

Figure 3. Bullion Creek and Sentinel Butte strata exposed in northwestern Billings County.

From 1975 to 1980, the North Dakota Geological Survey oversaw the drilling of 669 coal-exploration holes in western North Dakota. This drilling program was part of a cooperative project with the U.S. Geological Survey and the electric and geologic logs are reported in a series of USGS Open-file reports (OFR: 76-869, 77-857, 78-888, 79-1051, 80-867). No gas was observed by the geologists, drillers, or logger during this five-year project. Most of these holes were 100 to 400 feet deep, but some were drilled as deep as 700 feet.

Over the last twenty years, the State Survey has been involved in three additional drilling programs that penetrated all or parts of Fort Union strata. In 1982, we drilled thirteen holes through the Fort Union sequence in western North Dakota and eastern Montana. A total of 9500 feet was drilled during this project. Individual holes ranged from 400 to 1500 feet in depth (LeFever and Murphy, 1983). Sediment samples were collected at five-foot intervals during this project and are permanently stored in the NDGS core and sample library. Approximately 100 coal beds were penetrated during this drilling program, but no gas was detected.

Also in 1982, the State Survey participated in a project to construct seventy-nine monitoring

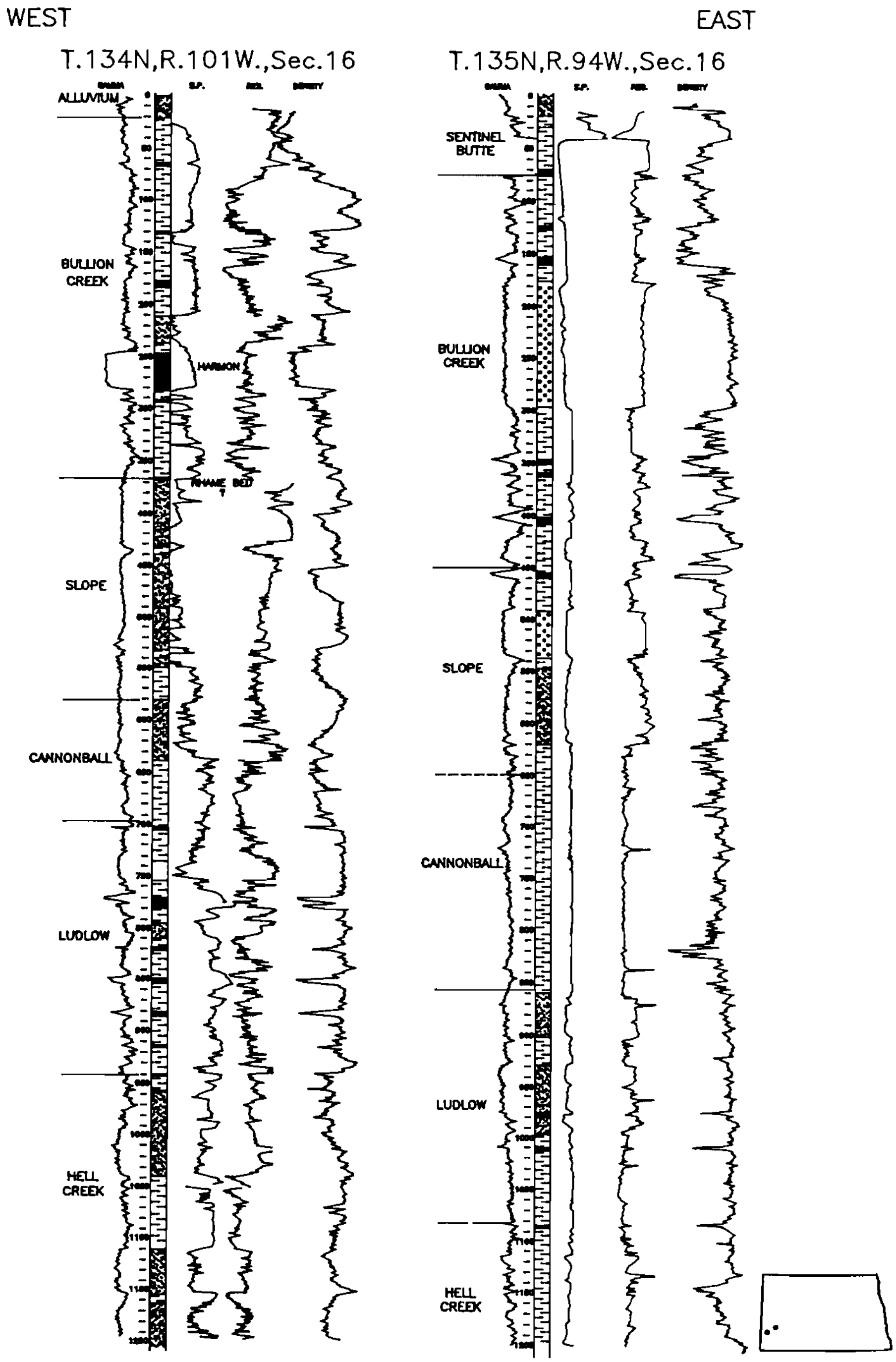

Figure 4. Lithologic and electric logs through the coal-bearing strata in southwestern North Dakota.

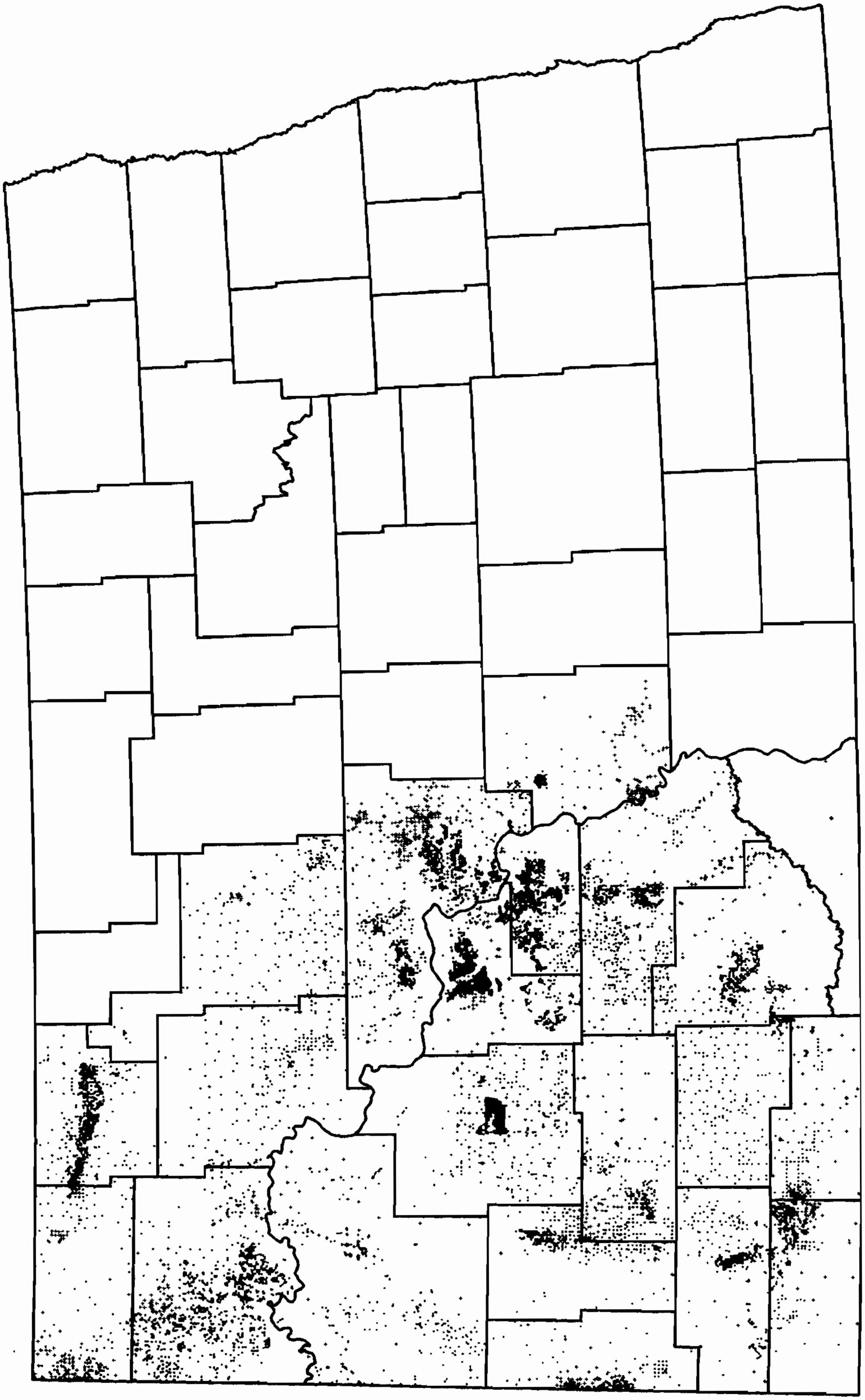

Figure 5. Locations of coal and subsurface mineral drill holes (.) and State Water Commission wells (+) in western North Dakota.

wells in and around four abandoned coal mines in North Dakota (Groenewold et.al., 1983). Twenty-seven of these two-inch wells were screened in lignite adjacent to old surface mines. Water levels were recorded monthly for at least a year and wells were bailed and sampled several times. No gas was observed in any of these wells, all but one of which were less than 100 feet deep.

In 1986, the Survey participated in a project that resulted in the installation of 40 monitoring wells near an oil and gas injection well in northwestern North Dakota. Five lignite beds were penetrated within 240 feet of the surface. Two lignites (informally designated D and E) were screened in eight monitoring well nests along a half-mile radius of the injection well. No gas was detected during the drilling of the project. However, after bailing approximately half of the drilling mud out of monitoring well #2, gas blew the remaining mud and water thirty feet into the air (Figure 6). Gas blew out of the two-inch well for several days before it dissipated to the point that we could cap the well. Water levels and samples were obtained from these wells for a year or two during which time gas was always evident in monitoring well #2. The gas was assumed to be methane, but this was never verified by analysis. The gas may also have been related to leaking casings from the twenty- to thirty-year-old oil wells in the area. The site is within a glaciofluvial system that is now occupied, in part, by Black Slough. Groundwater in the area is highly mineralized with TDS ranging from 2,500 to over 15,000 mg/l and sulfate ranging from 500 to over 5,000 mg/l in the "D" lignite. All of the wells in this area are still in existence but have not been monitored for ten years.

Monitoring at Coal Mines

Since the 1970s, the ND Public Service Commission has required coal companies to monitor groundwater adjacent to the surface mines. Hundreds of monitoring wells have been placed in and around the active surface mines in an effort to determine groundwater chemistry and direction of flow and to monitor fluctuating water levels (Figure 7). Most of these wells are within a few hundred feet of the surface. We queried coal company geologists and Public Service Commission personnel involved with these monitoring programs and none has observed gas in these wells.

Groundwater Monitoring of Fort Union Strata in Western North Dakota

The North Dakota State Water Commission has installed thousands of monitoring wells throughout western North Dakota (Figure 5). Many of these wells are listed in the Part 2 sections of the County Bulletins and are in the Water Commission on-line data base. Several hydrologists involved with this program were interviewed and none recalled encountering gas in lignites. These wells would be the best single source of deep groundwater in lignites. However, permission should be obtained from the Water Commission prior to sampling these wells. In addition, the agency has recently been plugging many of its monitoring wells so a number of those listed may no longer be available.

Underground Coal Mines

Hundreds of underground coal mines operated in North Dakota from the 1880s to 1952. In 1931, 193 underground mines were operating in the state, the highest one-year total. By 1939, the number of underground mines had fallen to 137, but the number of surface mines had risen to 169

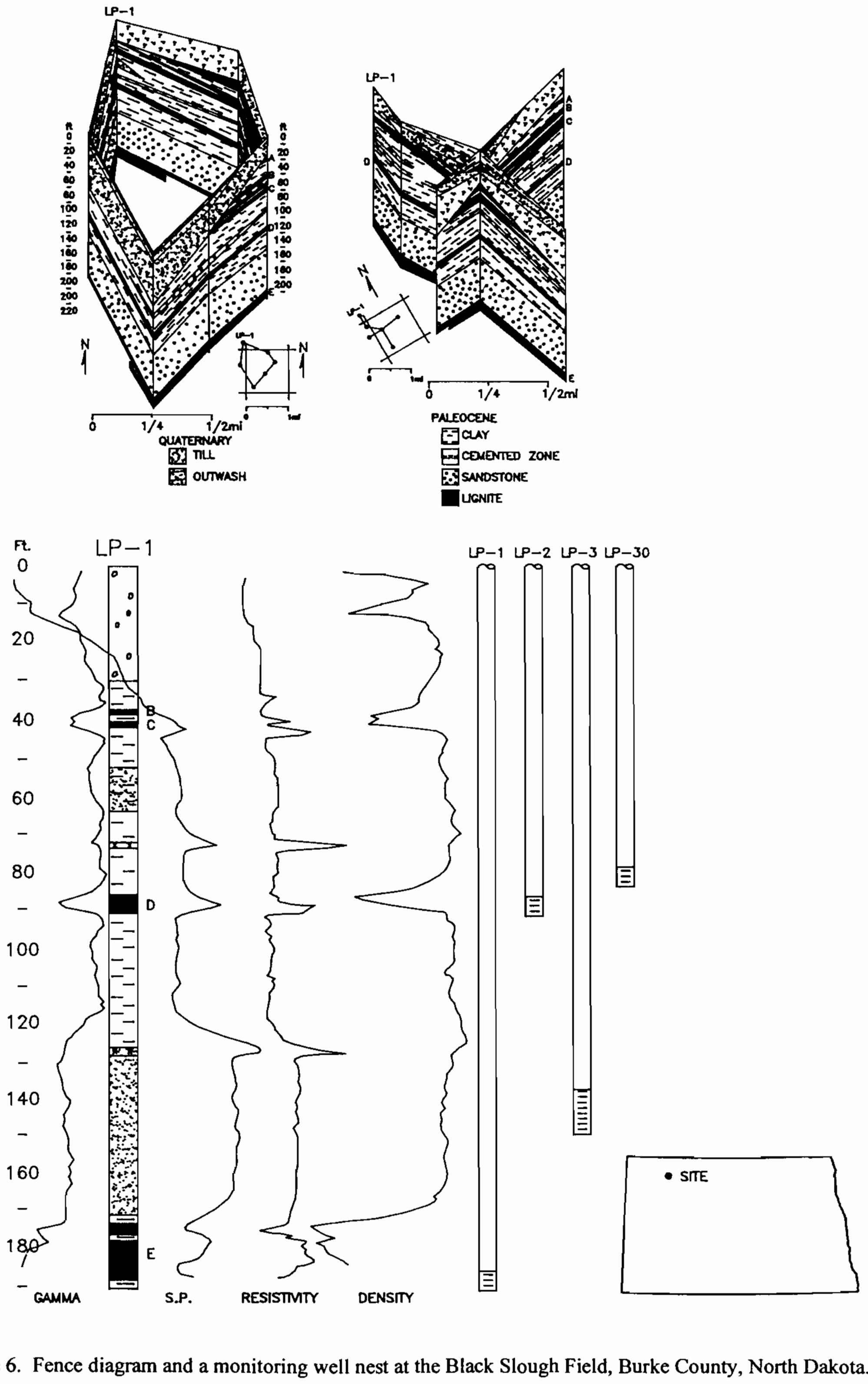

Figure 6. Fence diagram and a monitoring well nest at the Black Slough Field, Burke County, North Dakota.

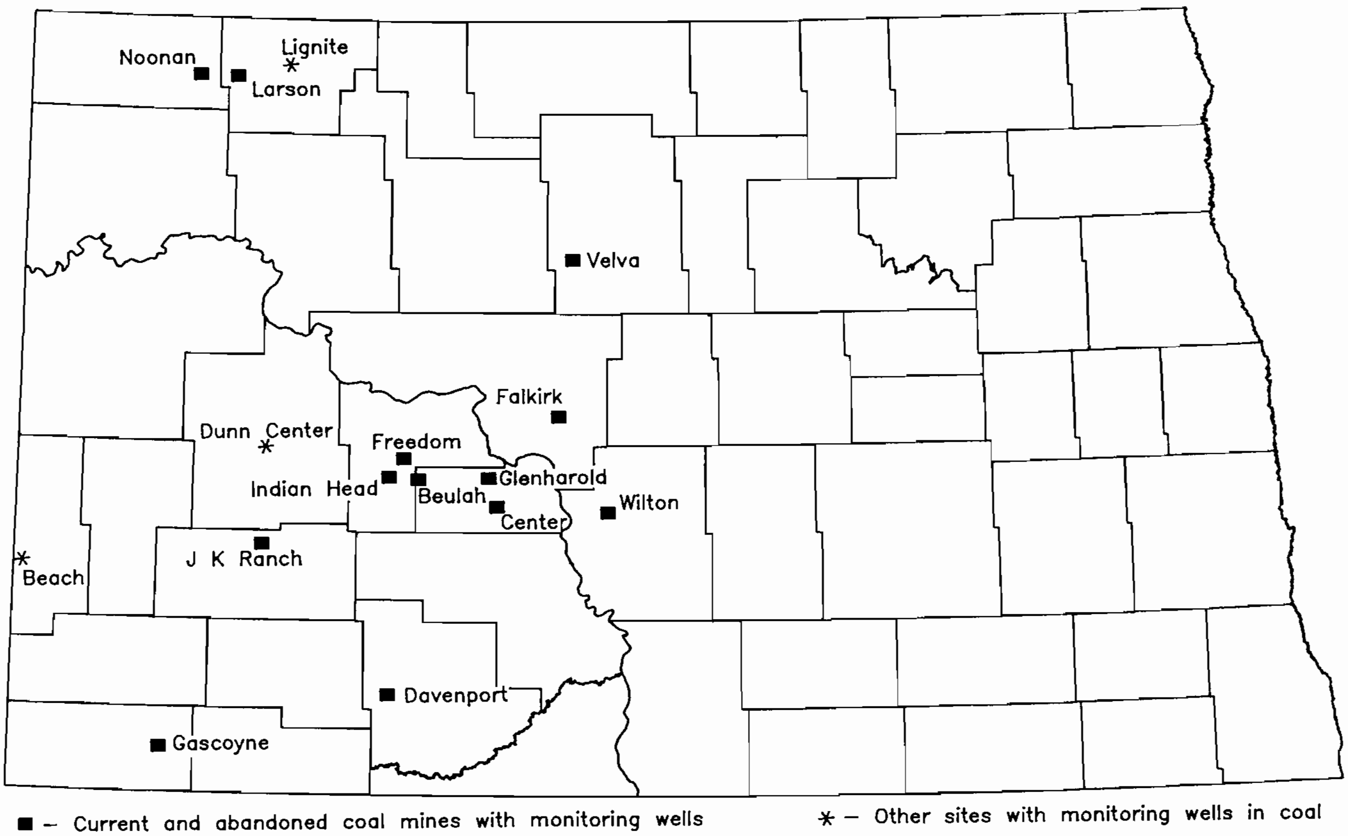

Figure 7. Sites in North Dakota which contain concentrations of monitoring wells screened in lignite.

(Oihus, 1983). Many of these mines were very small. Mine inspection reports reportedly do not contain reports of gas problems from any of these underground mines. Arthur Kane, retired Knife River Coal Mining Company employee, stated that records kept at Knife River's underground mine at Beulah from 1922 until it closed in 1952, indicated that methane was never a problem in the mine except when there was a coal fire and the heat from the fire would then generate gas. The absence of gas in this mine enabled them to use black powder explosives and to keep donkeys underground for months at a time. The Binek family also reported that no gas was encountered at the mines they operated at Lehigh in Stark County. On the other hand, it has been reported that two girls were overcome by gas in the 1920s in an underground mine at Wilton.

The Public Service Commission (PSC) has been drilling into these old underground mines for years. As part of a mine reclamation program, the PSC typically drills a series of closely spaced holes to determine the extent of the underground workings. In sensitive areas, or areas of collapse, holes are drilled into the old rooms and grout is pumped in to stabilize the area. Gas has not been detected during the drilling programs.

OTHER POTENTIAL SOURCES OF SHALLOW GAS IN NORTH DAKOTA

Pleistocene Gas

In 1907, natural gas was discovered in Pleistocene deposits nine and a half miles south of Westhope in Bottineau County (Barry, 1908). Several wells in this area had initial gas flows of two million cubic feet per day with pressures of 100 psi. The wells were 200 feet deep and screened in a 22-foot sand at the base of the Pleistocene deposits. The gas was determined to be 83% methane. Similar discoveries were made near Mohall in Renville County as well as Maxbass and Lansford in Bottineau County. By 1909, 25 wells were producing gas from the base of the Pleistocene deposits in Bottineau, Williams, and LaMoure counties. Water well driller's have occasionally encountered gas at the base of Pleistocene deposits in other areas of the State. Currently, no gas is being produced from these deposits.

Holocene Gas

Recently, gas was encountered while drilling though lacustrine deposits in playa lakes in northwestern North Dakota (Murphy, 1996). These lacustrine deposits consist of dark, organic-rich silt, mud, and clay interbedded with layers of crystalline salt (sodium sulfate). The lacustrine sediments range in thickness from a few feet to over 90 feet. Gas was present throughout the mud column, but was especially prevalent beneath layers of salt. The gas was extremely odorous and was believed to be a mixture of methane and hydrogen sulfide. Gas was also observed bubbling from vents spread throughout Miller Lake in Divide County, a phenomenon that is likely occurring at a dozen lakes in the area (Figure 8). A local farmer reported that some years back a seismic drilling rig ignited and burned when it encountered gas in deposits adjacent to this lake.

CONCLUSIONS

Exploration holes drilled and logged through Fort Union strata in North Dakota have failed to detect gas in lignites. Either the gas is not present in sufficient quantities to be detected or the mud is sufficiently weighted to prevent gas from migrating up the borehole. Typically, the drilling fluid system in these holes was "mudded up" naturally from contact with swelling and nonswelling claystones encountered in the borehole, although some bentonite gel was also typically used. Lost circulation additives such as walnut hulls, shredded paper and cellophane, flax straw, etc. were often used to plug off thick, highly fractured lignites. These mud systems would have hampered gas migration in the borehole.

The vast majority of monitoring wells and farmwells screened in lignites are relatively shallow. Only a relatively few State Water Commission holes and an occasional farm well have been screened in lignites beyond depths of 500 feet. The Water Commission has not detected gas from their wells screened in lignites. The Water Commission has detected gas in a few sandstone wells and a handful of landowners have complained of gas in their wells in southwestern North Dakota. These wells are typically screened in sandstones in either the Fox Hills or Hell Creek formations, Upper Cretaceous strata that occur below the coal-bearing units.

Only a few of the water well drillers and none of the senior or retired, geologists, miners, water-

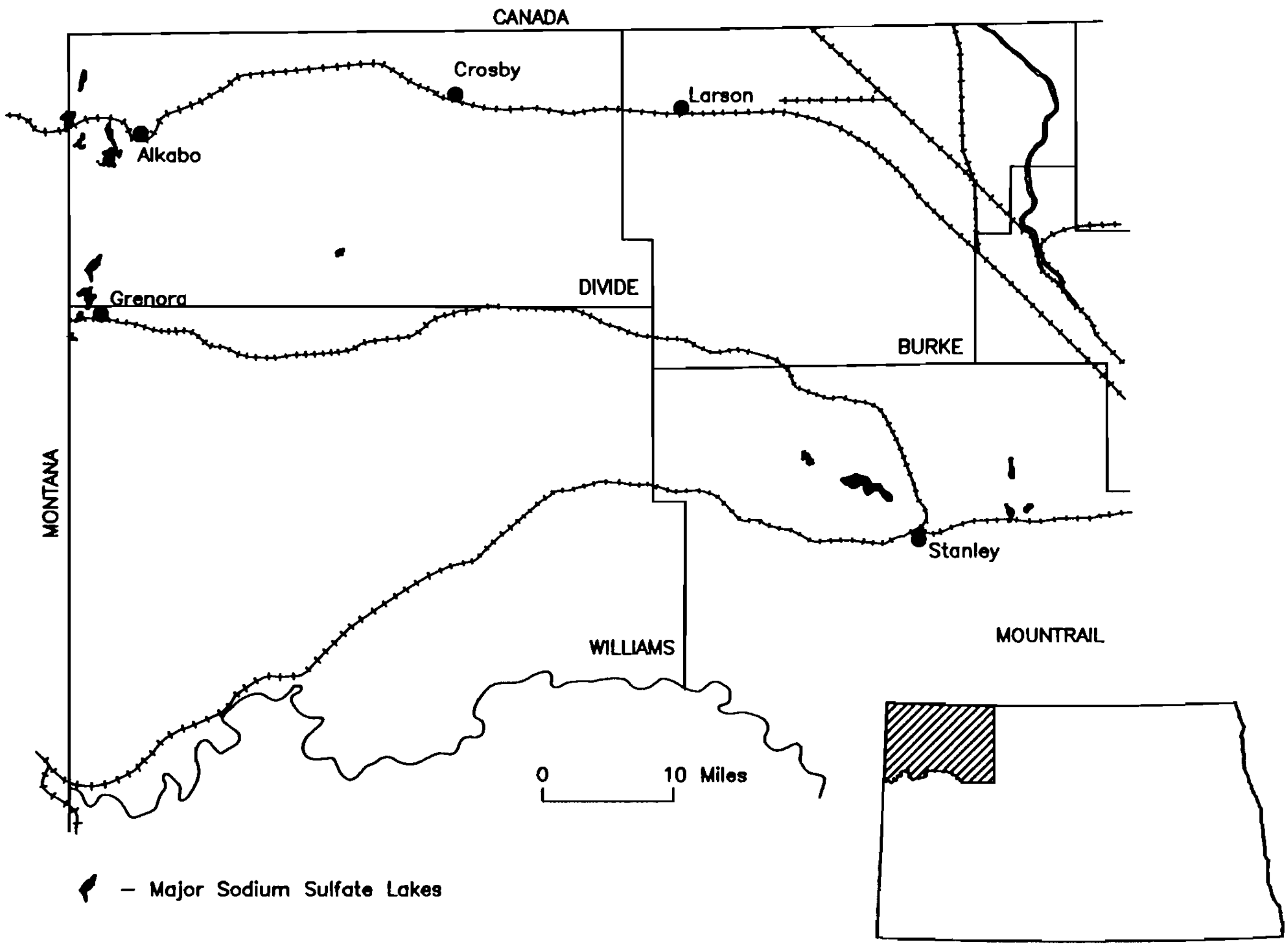

Figure 8. Location of the major playa lakes in northwestern North Dakota.

well drillers, loggers, etc. that we interviewed recalled encountering methane in coal beds in North Dakota. While this in itself is discouraging, it should be noted that most drilling programs did not exceed 400 feet in depth and specific programs aimed at detecting coal bed methane have not been run in North Dakota.

POTENTIAL COALBED GAS EXPLORATION PROGRAMS

There are at least two potential exploration programs that could generate important information on coalbed methane in North Dakota. The first project would analyze the gas content of groundwater from existing monitoring wells screened in North Dakota lignites. The State Water Commission, local coal companies, State Geological Survey, private landowners, Energy and Environmental Research Center, and US Geological Survey all maintain wells screened in lignites that could be tested.

The second, more costly, program would require drilling select holes into the thickest lignites in the

State. Drill sites should be carefully chosen based on coal depth, thickness, and structure of the beds. Based on success near Gillette, Wyoming, structural highs in the coal bed should be the prime targets of exploration. Verlin Dannar (President of Methane Services Corporation of Gillette, Wyoming) has been drilling and developing coalbed gas wells from several subbituminous coals in the Tongue River Formation in the Powder River Basin. The coals range in thickness from 18 to 70 feet and are found at depths of 50 to 400 feet in the area. Dannar has developed a successful exploration and completion method for coalbed gas. An 8 3/4 inch hole is bottomed no more than six inches below the coal. The coal interval is drilled without mud and is flushed with fresh water upon cessation of the drilling. If the hole is extended more than a few inches below the base of the coal, it increases the likelihood that nongas bearing groundwater will enter the hole. After drilling through the target coal, a pump with inflatable packers is placed in the coal interval, the packers are set, and a drill stem test is performed by pumping fluid from the hole. The permeability of the coal and the water and gas flow rates can be determined by this test. If the results of the drill stem test are favorable, seven-inch steel casing is extended from the surface to the top of the hole and the coal zone is overdrilled to a diameter of ten inches to increase the surface area of the producing horizon. To complete the hole, a submersible pump, attached to 1 ½ inch PVC production casing, is hung in the hole just beneath the base of the surface casing.

There are at least a half dozen areas in North Dakota underlain by thick, deep coals that should be good candidates for exploration (Figure 9). These areas of thick coal deposits were identified primarily on coal and subsurface mineral exploration holes and holes drilled by the North Dakota State Water Commission. Additional thick coals will likely be identified during a review of gamma logs from oil-and-gas wells in the State that we will soon be undertaking.

Coteau Bed

The Coteau bed is a thick coal in the Bullion Creek Formation that extends over an area of at least 160 square miles and possibly 300 to 400 square miles in eastern Ward, southwestern McHenry, and north-central McLean counties. It can be traced with reasonable accuracy from T.151N., R.80W. to the northwest into T.153N., R80W. and may be correlative to a 24-foot thick coal that is present at a depth of 300 feet in T.155N., R.83W (Murphy, 1998). The Coteau bed has a maximum thickness of 22 feet at a depth of almost 300 feet in southeastern Ward County (Figures 9 and 10).

Harmon Bed

The Harmon coal is a thick, aerial extensive lignite that occurs within the basal 150 feet of the Bullion Creek Formation. The Harmon coal is one of the thickest most extensive beds of lignite in the State. It can be easily traced through a 2,400 square mile area from Bowman to Beach to Belfield. The Harmon bed is over 20 feet thick in portions of west-central Golden Valley County (near Beach), southern Billings County, central Slope County, and north-central and eastern Bowman County (Figure 9). It is over 30 feet thick north of Bowman (Bowman County) and southwest of Amidon in Slope County (Figures 11 and 12). The Harmon bed in the Beach area was evaluated by Tenneco in the mid-1970s as a potential site for a coal gasification plant (Figures 13-17). Plans for the plant were abandoned in the early 1980s when gas prices failed to reach anticipated levels.

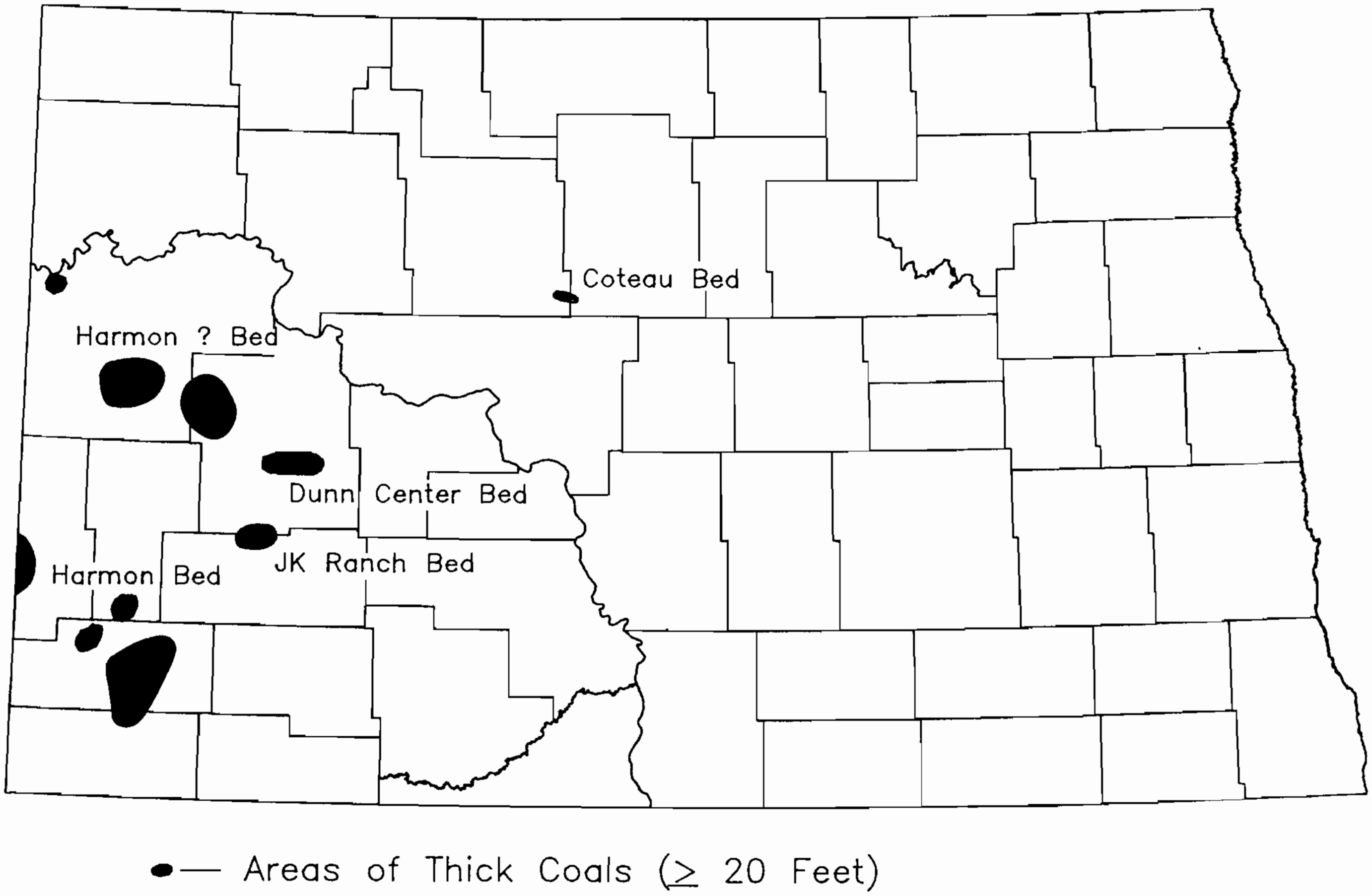

Figure 9. Approximate areal extent of selected thick lignites in North Dakota.

There are thick coals in other parts of the basin at the same approximate stratigraphic position that may be the Harmon bed, but areas of insufficient drill hole coverage make accurate correlation difficult. A thick coal in McKenzie County may be a northern extension of the Harmon bed. This coal is 20 feet or more thick over a large area of south-central and southeastern McKenzie County and northwestern Dunn County (Figures 18-21). It reaches a maximum thickness of approximately 50 feet at a depth of 600 feet in T.147N., R.92W (Figure 22).

In many areas of the State, the Harmon is underlain by the Hansen bed. Both coals are stacked together at the Hansen Ranch (Logging Camp Ranch) just south of Bullion Butte where approximately 40 feet of coal is exposed in a river cut. Typically, the Hansen bed thins and splits beneath the Harmon bed but between Sentinel Butte and Belfield the Hansen is the thicker, dominant coal.

Dunn Center Bed

The Dunn Center bed is an 18-foot thick coal located near the middle of the Sentinel Butte Formation. The Dunn Center bed extends over an area of 60 square miles in central Dunn County (Figures 23-26). It ranges in depth from less than 50 feet to more than 200 feet beneath the surface. Almost 2000 holes were drilled through this coal in the mid-1970s while the deposit was being evaluated for a coal

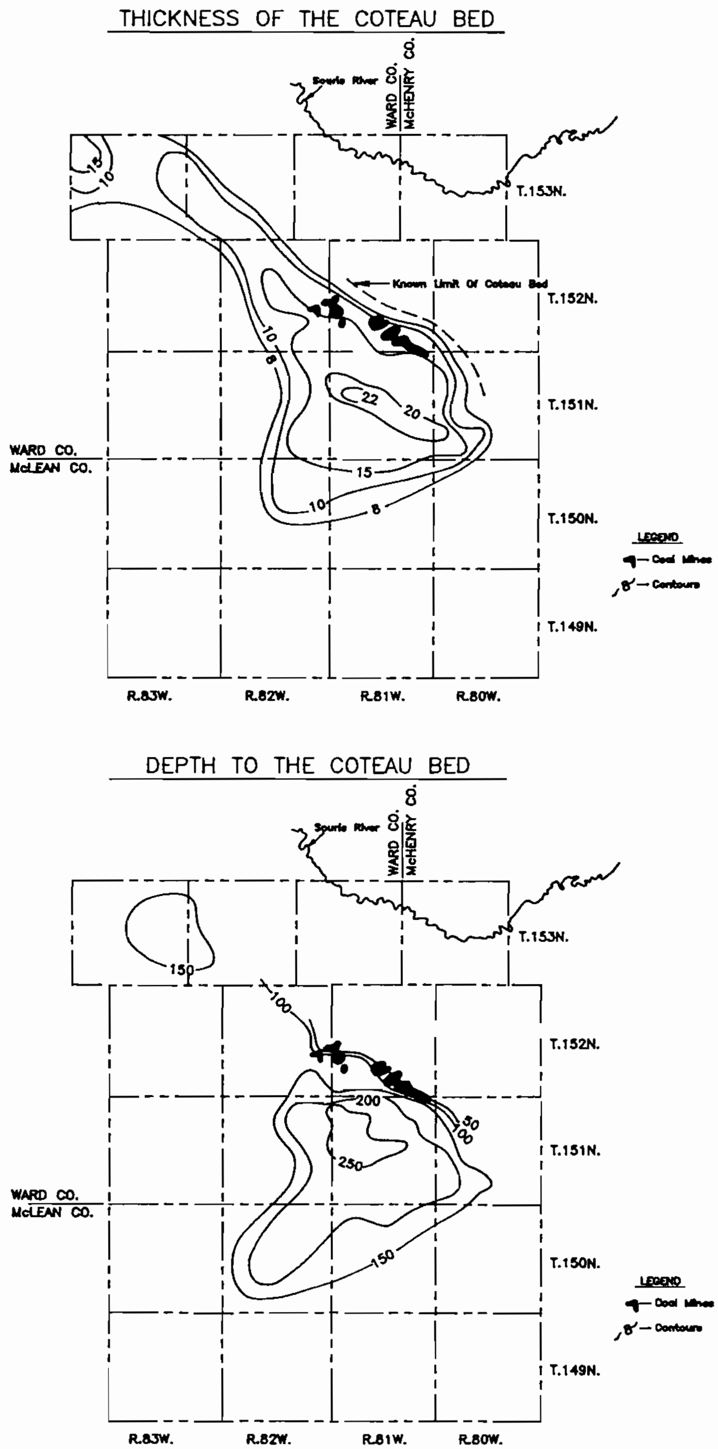

Figure 10. Isopach and overburden thickness map of the Coteau bed in Ward and McHenry counties.

gasification plant. No gas was observed while drilling or detected in the monitoring wells according to project geologist Ken Kinard, Paul Wier Associates. No gas analyses were run on the groundwater samples.

JK Ranch Bed

The JK Ranch bed is a thick coal that lies in the upper part of the Sentinel Butte Formation. In an area of at least 25 square miles along the Stark/Dunn county line, a few miles north of Dickinson, the coal is approximately 15 to 20 feet thick and present at depths of 50 to 175 feet. The coal splits, thins, and dips to the east (Figure 27). This bed appears to be correlative with a 10- to 15-foot thick coal at a depth of 300 feet near the Davis Buttes. Two thick coals are present in T.142N., R.96W., section 17 at depths of 150 and 200 feet, which may also correlate to the JK Ranch bed. No attempt was made to trace this bed to the north or west beyond the cross-section due to lack of well control.

Beulah-Zap Bed

The Beulah-Zap bed is a thick coal that occurs near the middle of the Sentinel Butte Formation. It extends over an area of at least 750 square miles in central Mercer and western Oliver counties. The Beulah-Zap bed is currently being mined at Coteau's Freedom Mine and Knife River's Beulah Mine and was mined at North American's Indian Head Mine until it closed in the mid-1980s (all three mines are in close proximity to the town of Beulah). In the vicinity of the Freedom Mine the Beulah-Zap is a single bed, with an average thickness of about 16 feet and a maximum thickness of 23 feet. North and south of the mine it splits into two beds the Beulah (upper) and the Zap (lower) which are separated by as much as 10 feet. The Dunn Center bed is in the same approximate stratigraphic position as the Beulah-Zap bed and may be correlative to this bed. Correlation is difficult from central Dunn County to central Mercer County because there are very few control points in western Mercer County.

Hagel Bed

The Hagel is a thick coal near the base of the Sentinel Butte Formation. The Hagel bed has an areal extent of at least 1500 square mile in portions of McLean, Oliver, and Mercer counties. It is currently being mined at the Center and Falkirk mines and was mined up to the late 1980s at the Glenharold mine. The Hagel is a single bed at the Center Mine and averages 12 feet thick , but is split into an A and B seam at the Falkirk Mine. At Falkirk, the Hagel A seam obtains a maximum thickness of 11 feet and the B seam a maximum of 5 feet. The seams are split by 10 to 15 feet of clay and mudstone in McLean County.

Regulatory Authority

The North Dakota Oil and Gas Division regulates oil and gas exploration, production, and development in the State pursuant to NDCC 38-08. Gas generated from coals in North Dakota falls under their regulatory authority. To obtain a copy of their rules and regulations please contact their office at 701-328-8020.

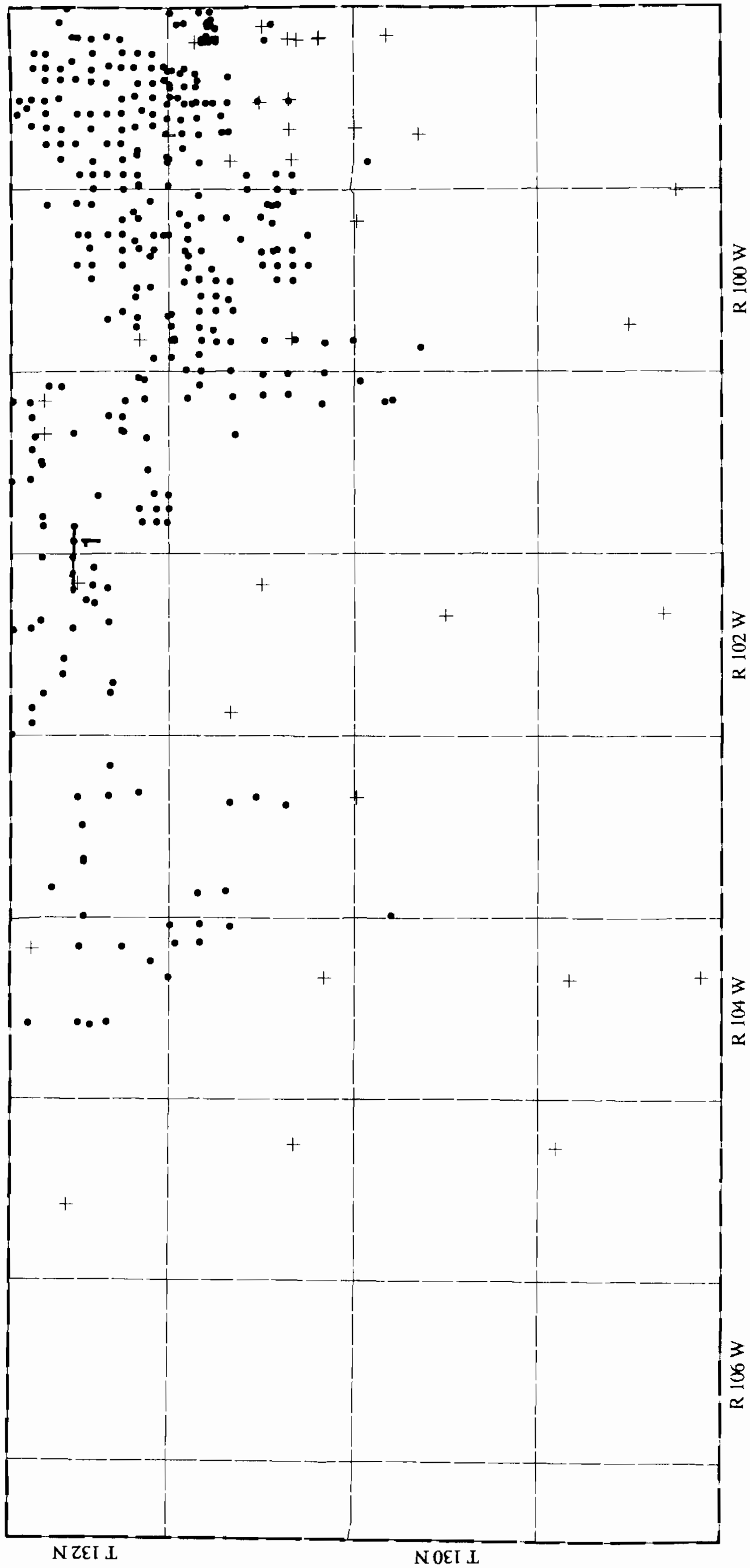

Figure 11. Coal exploration and subsurface mineral test holes (.) and Water Commission wells (+) in Bowman County.

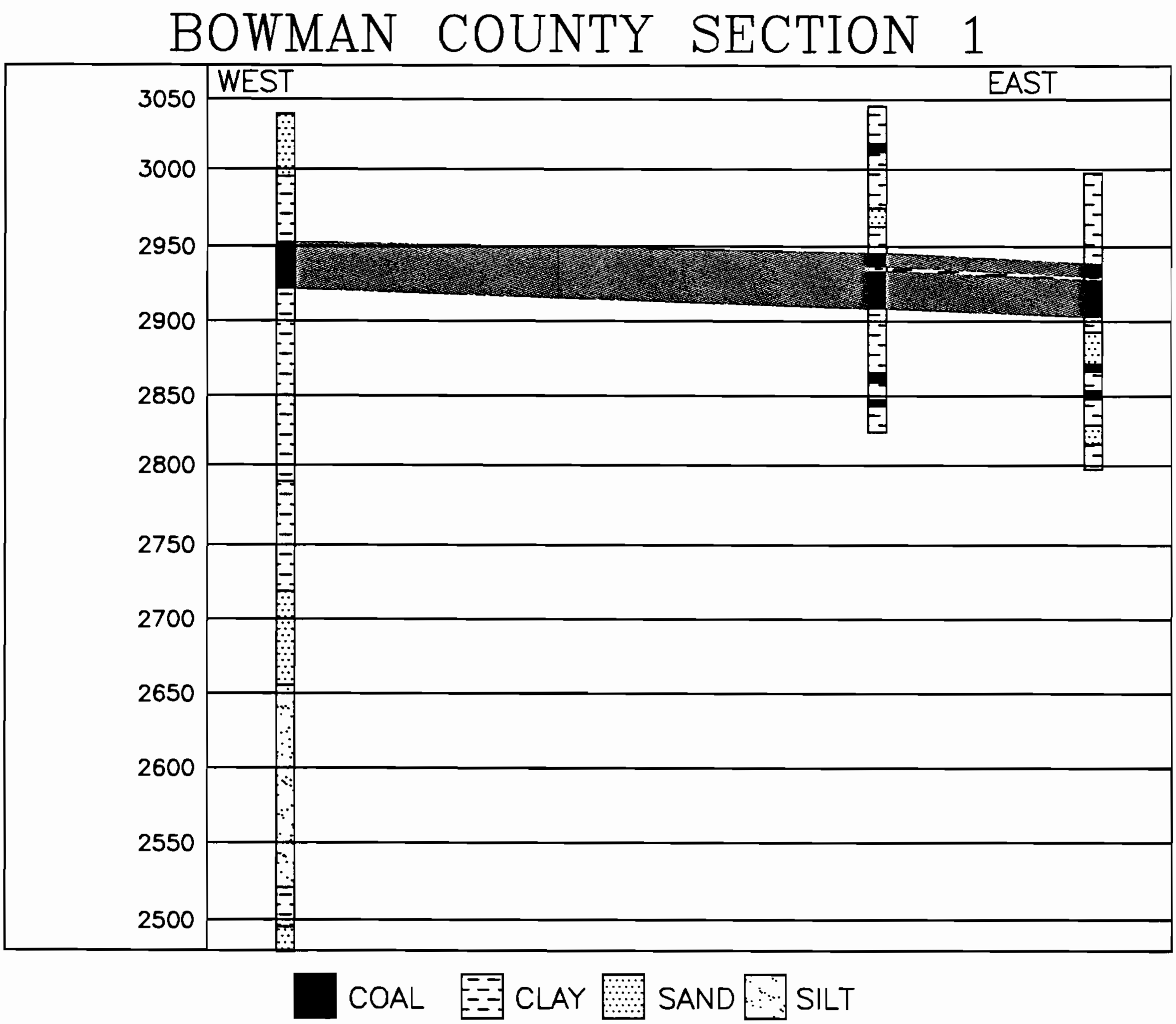

Figure 12. A geologic cross-section through the Harmon bed in north-central Bowman County. Section trace shown on Figure 11.

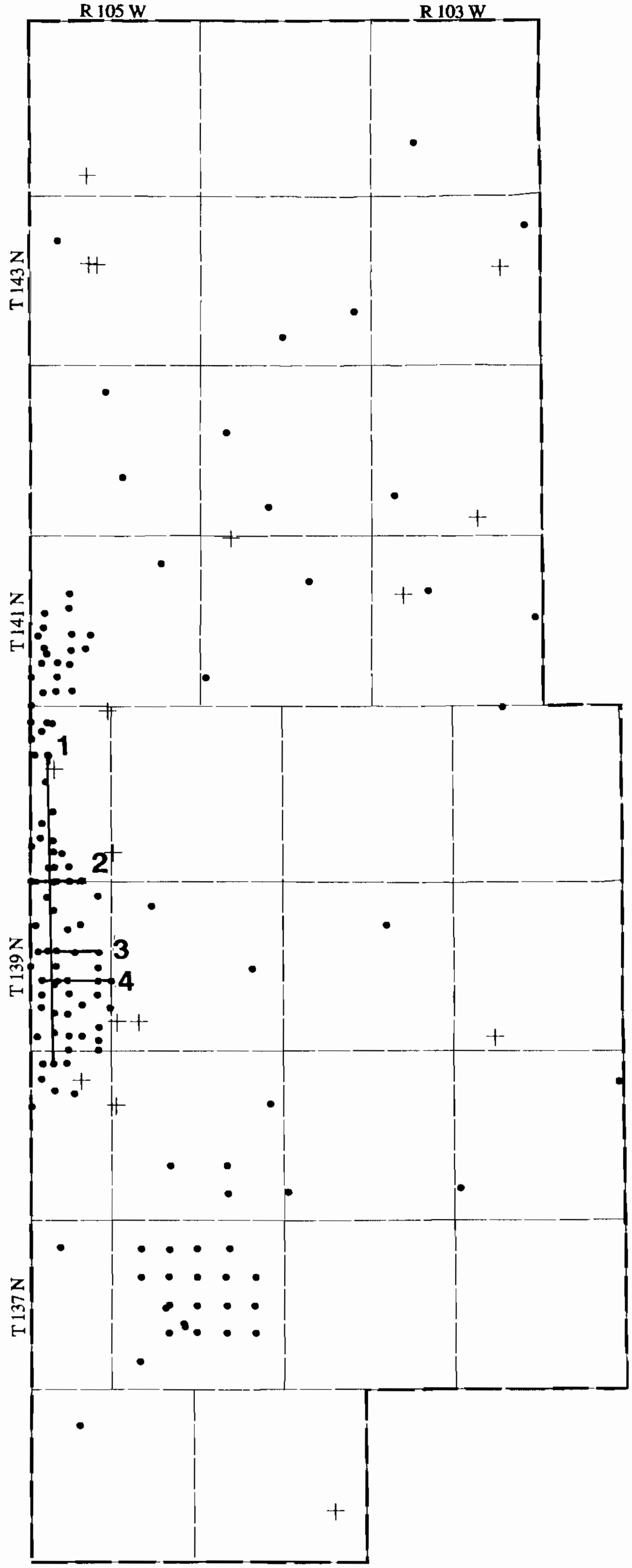

Figure 13. Coal exploration and subsurface mineral test holes (.) and Water Commission wells (+) in Golden Valley County.

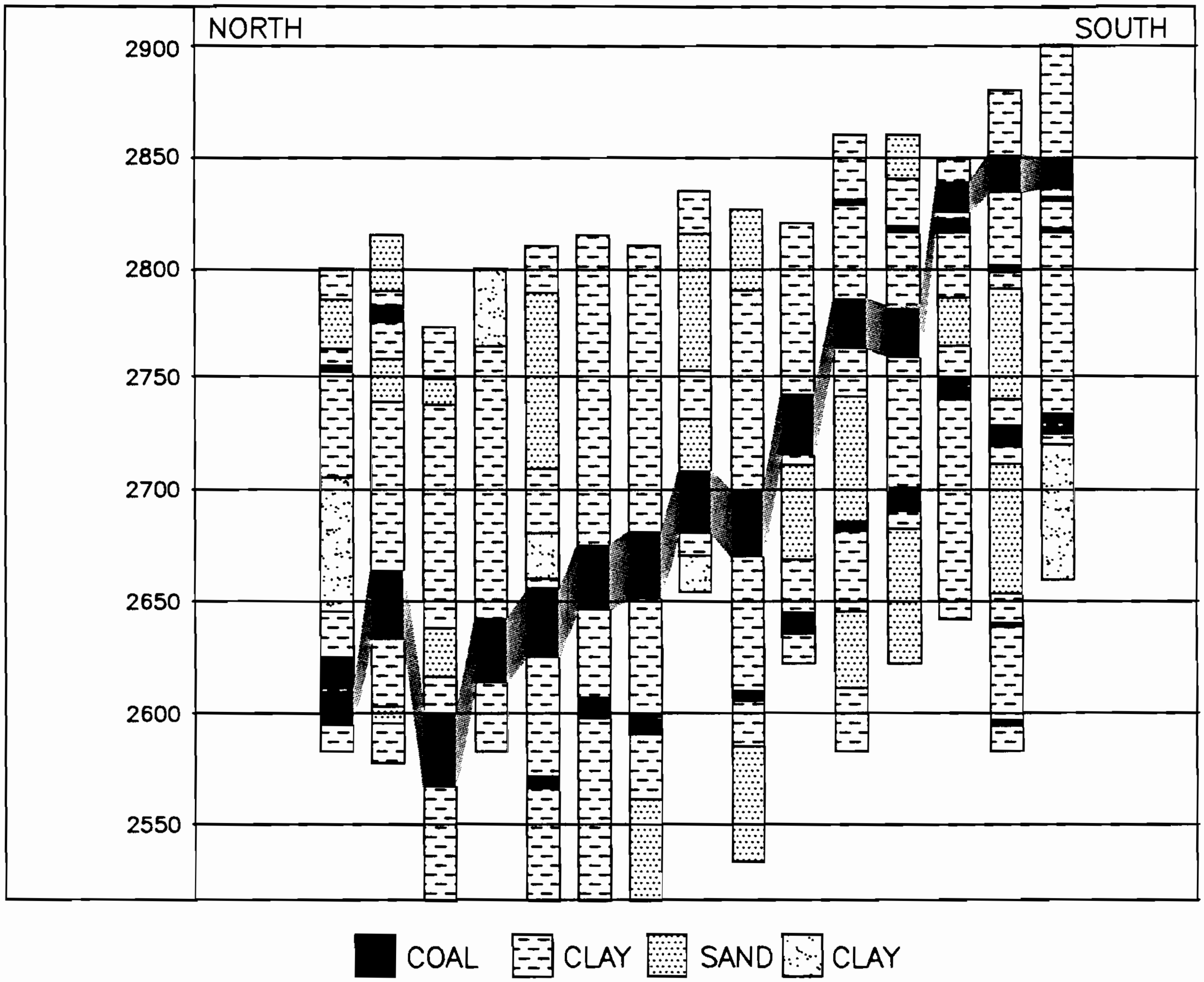

Figure 14. A north-south geologic cross-section (no. 1) highlighting the Harmon bed near Beach in Golden Valley County. Section trace shown on Figure 13.

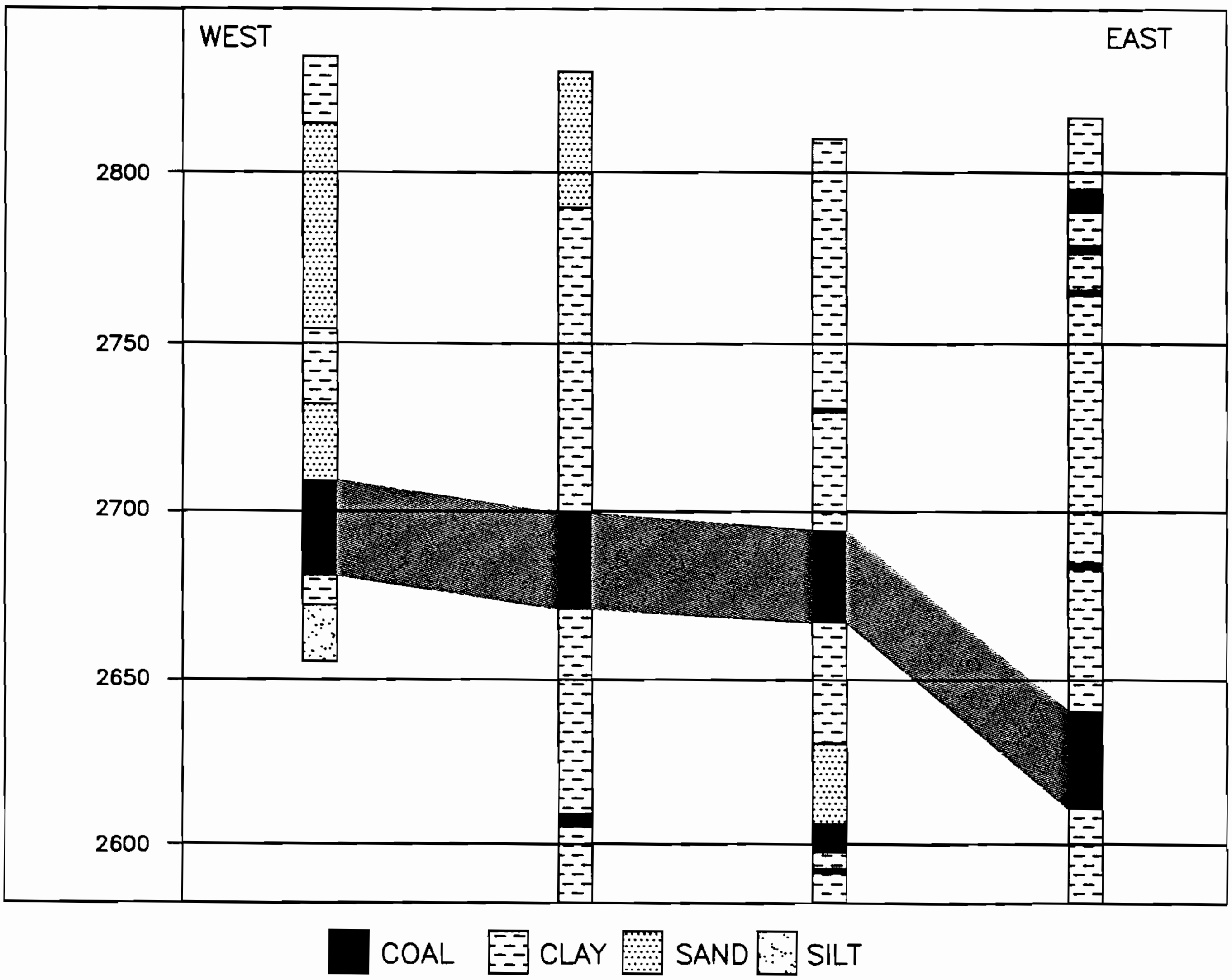

Figure 15. An east-west geologic cross-section (no. 2) highlighting the Harmon bed near Beach in Golden Valley County. Section trace shown on Figure 13.

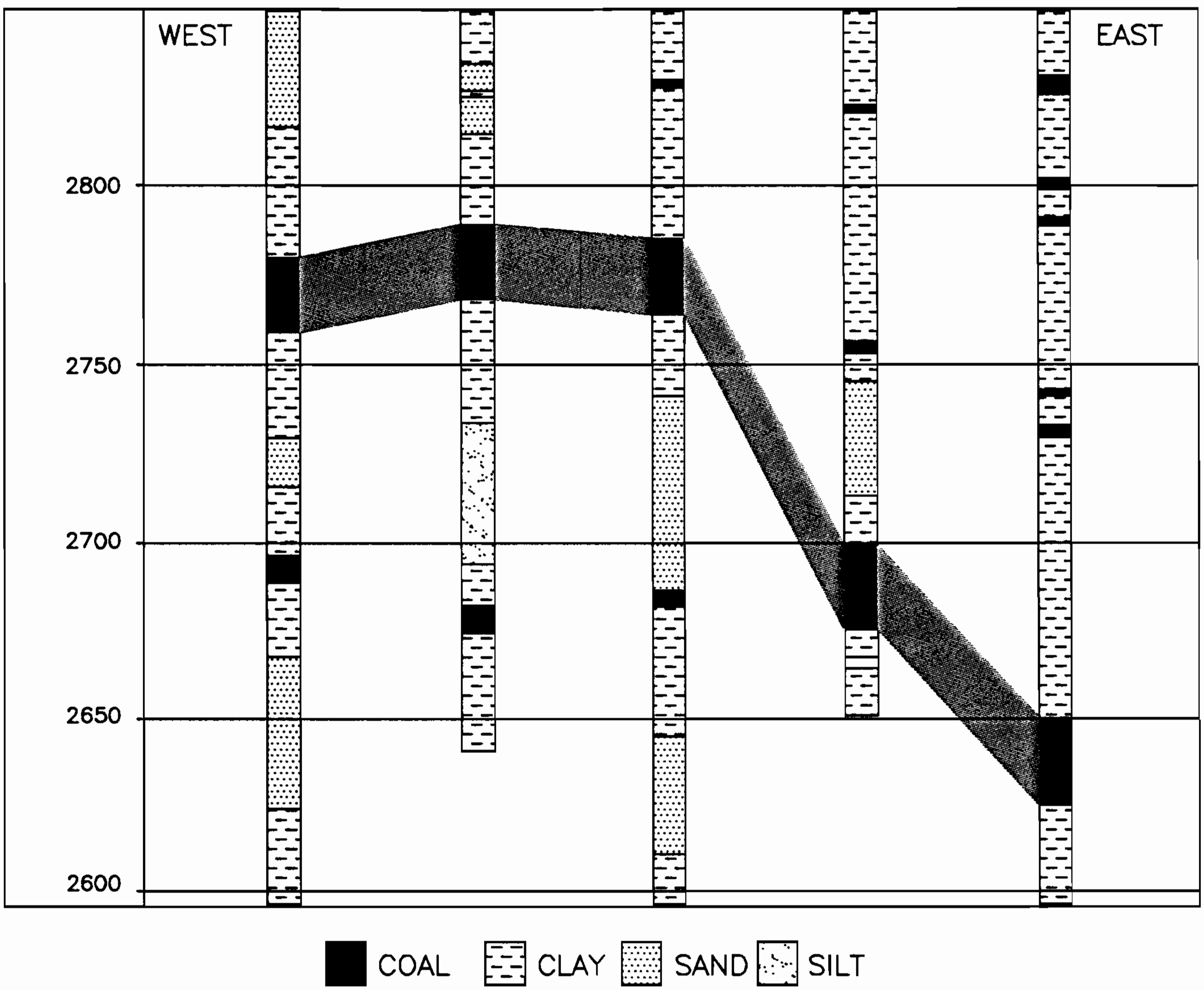

Figure 16. An east-west geologic cross-section (no. 3) highlighting the Harmon bed near Beach in Golden Valley County. Section trace shown on Figure 13.

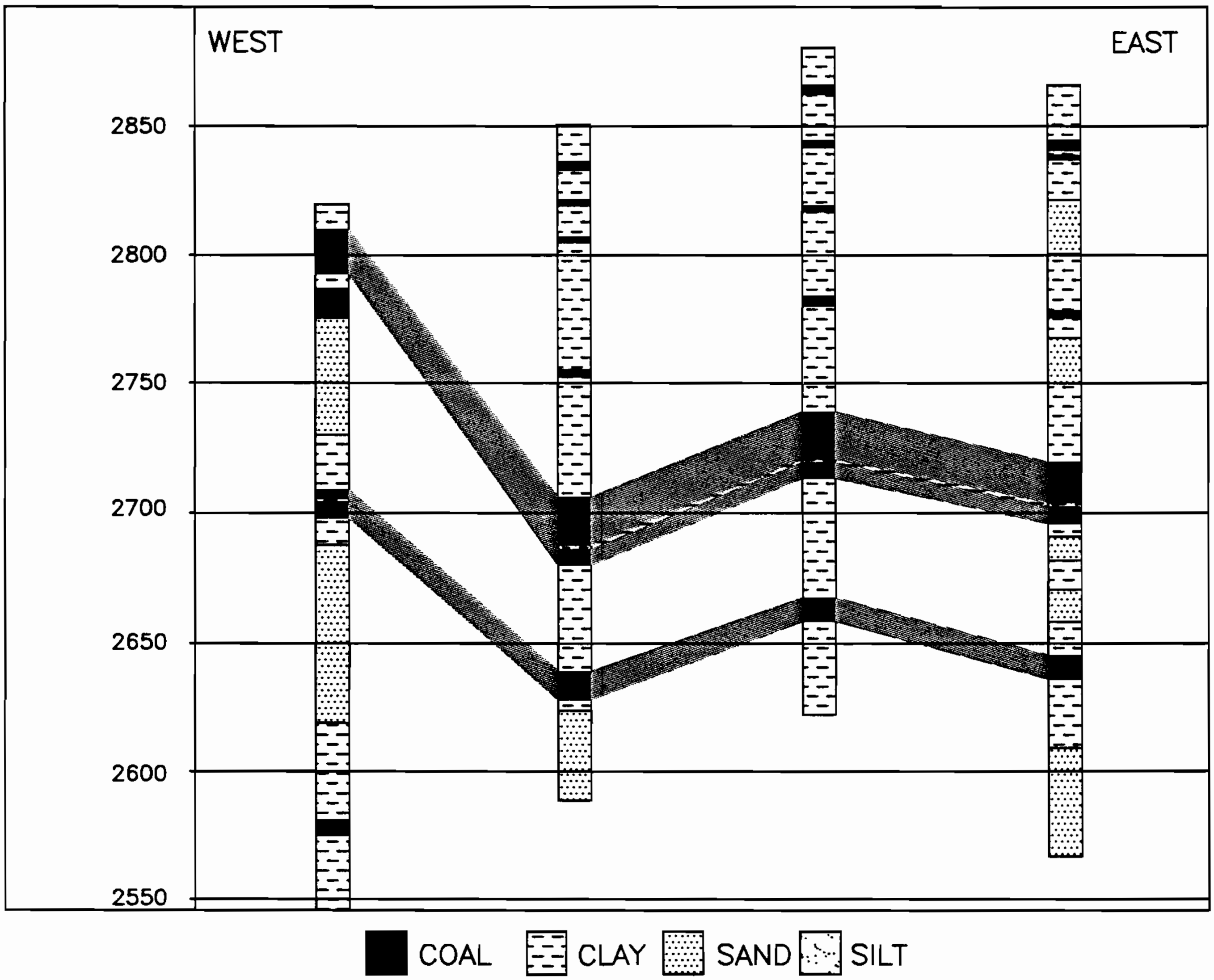

Figure 17. An east-west geologic cross-section (no. 4) highlighting the Harmon bed near Beach in Golden Valley County. Section trace shown on Figure 13.

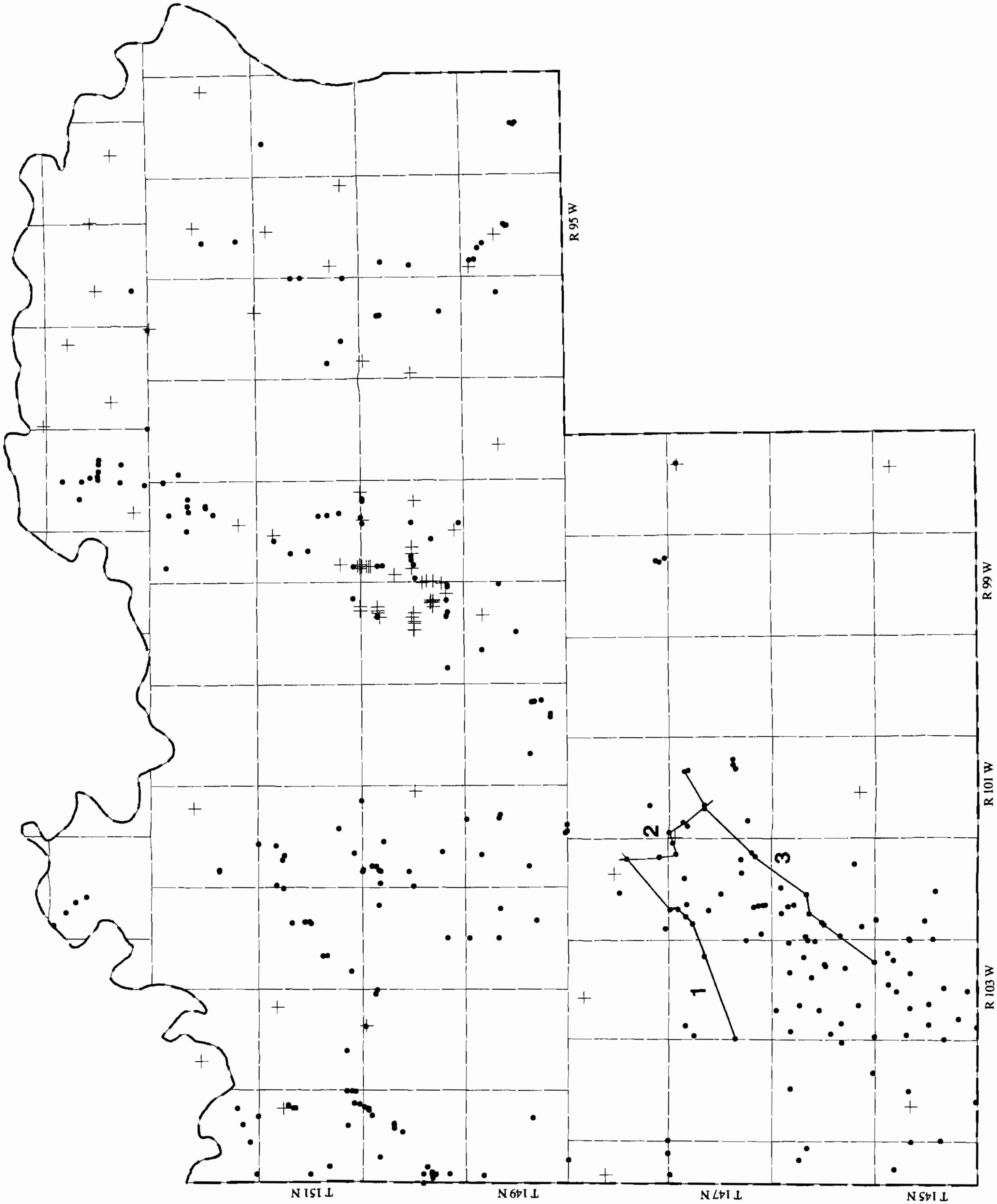

Figure 18. Coal exploration and subsurface mineral test holes (.) and Water Commission wells (+) in McKenzie County.

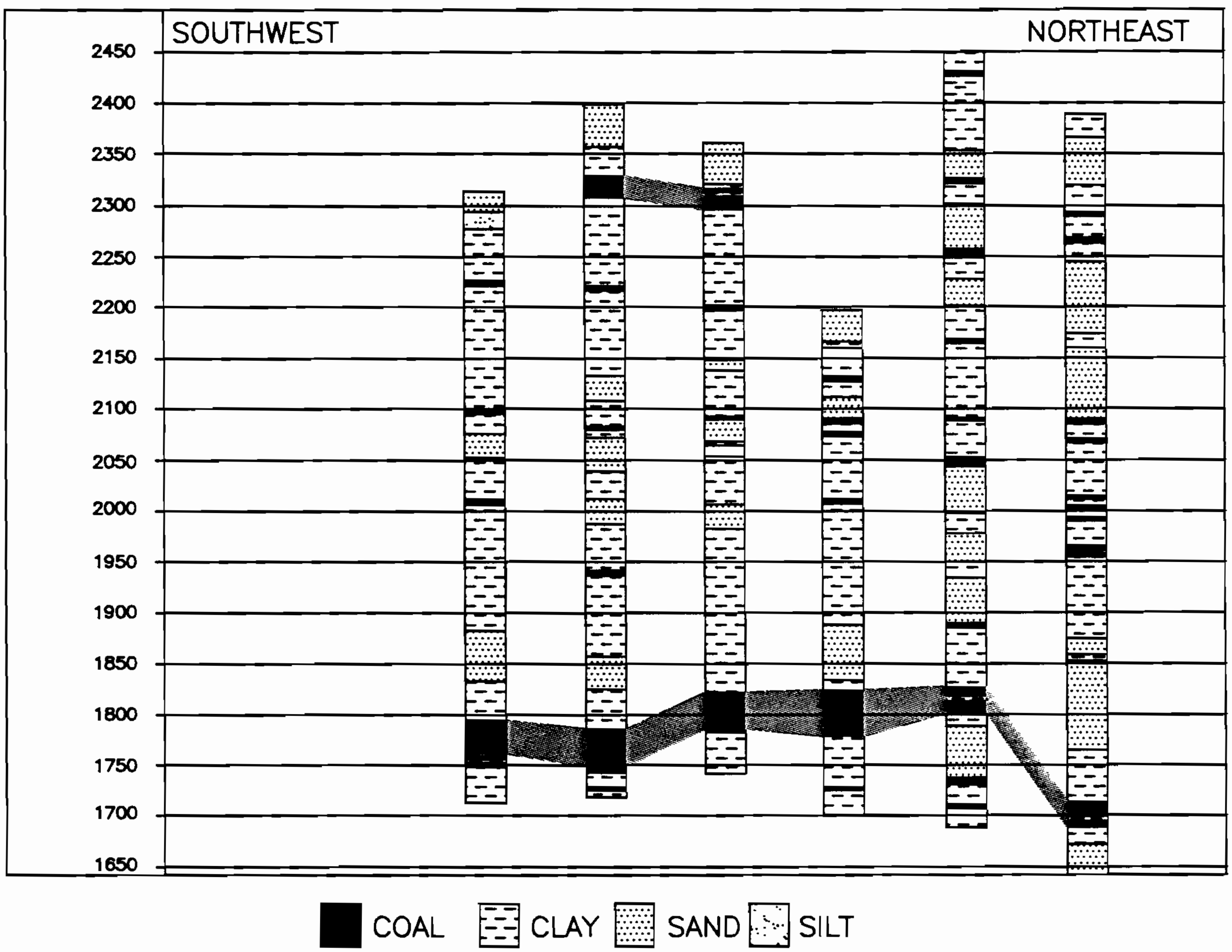

Figure 19. A southwest-northeast geologic cross-section (no. 1) highlighting the Harmon (?) bed in south-central McKenzie County. Section trace shown on Figure 18.

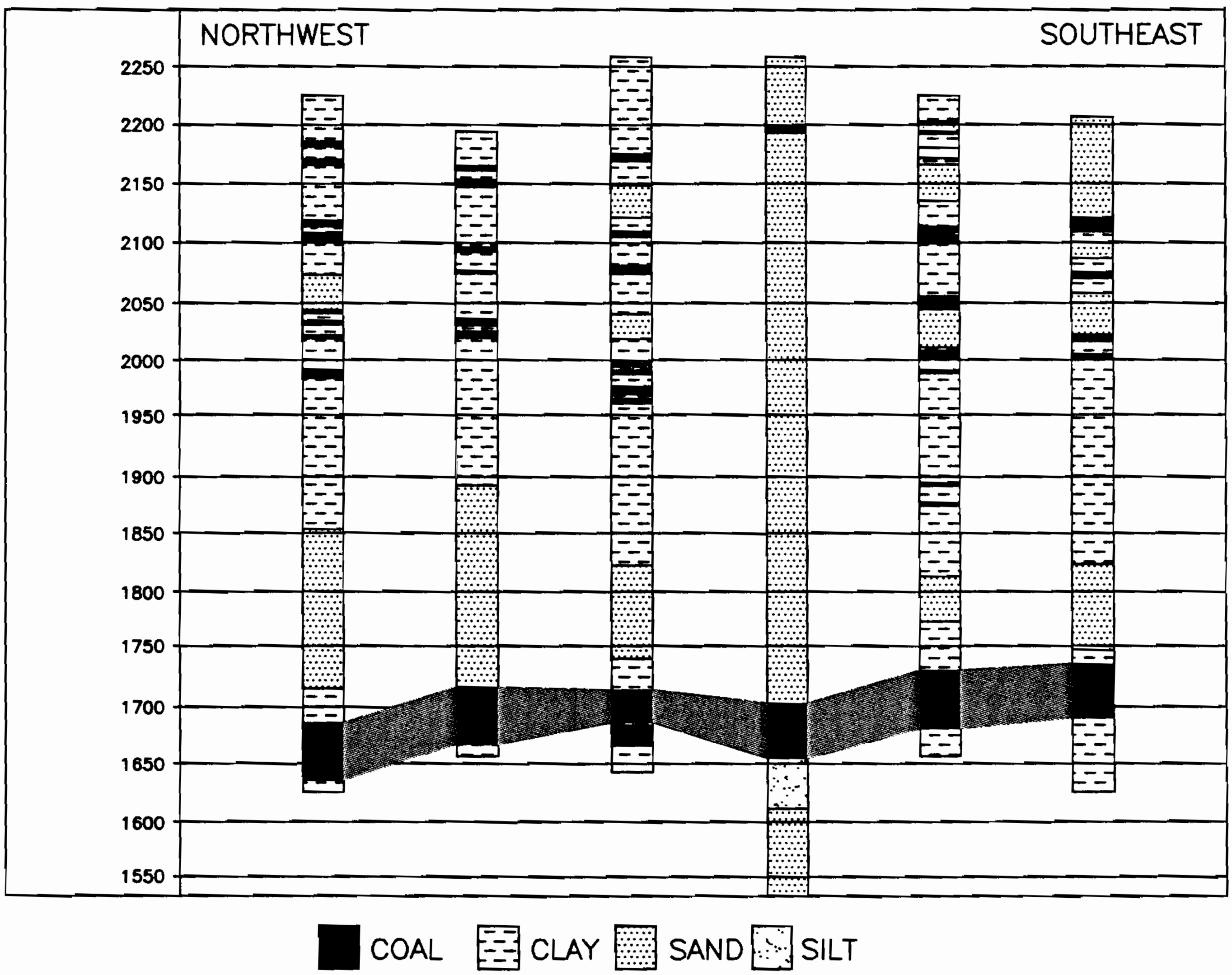

Figure 20. A northwest-southeast geologic cross-section (no. 2) highlighting the Harmon (?) bed in south-central McKenzie County. Section trace shown on Figure 18.

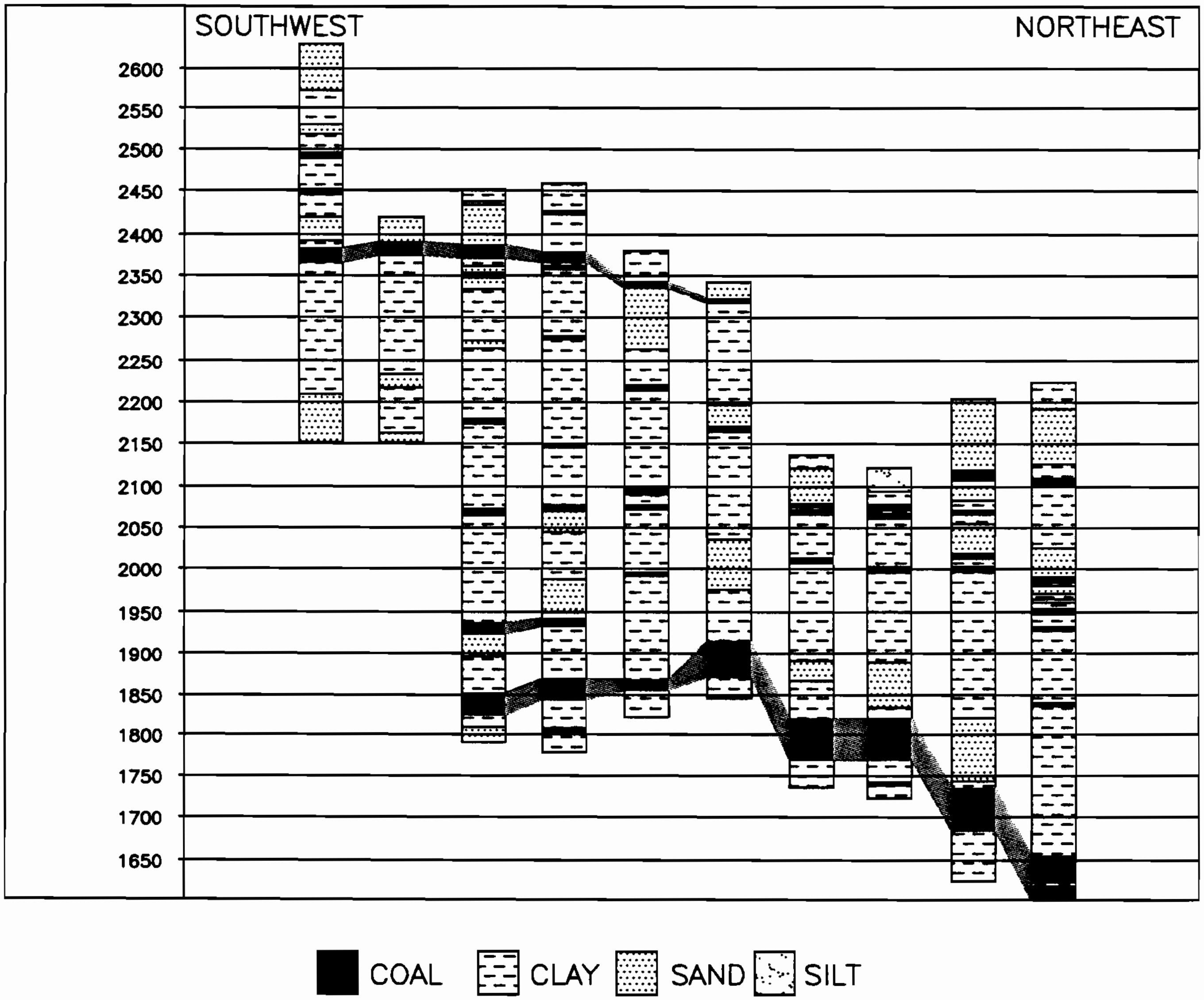

Figure 21. A southwest-northeast geologic cross-section (no. 3) highlighting the Harmon (?) bed in south-central McKenzie County. Section trace shown on Figure 18.

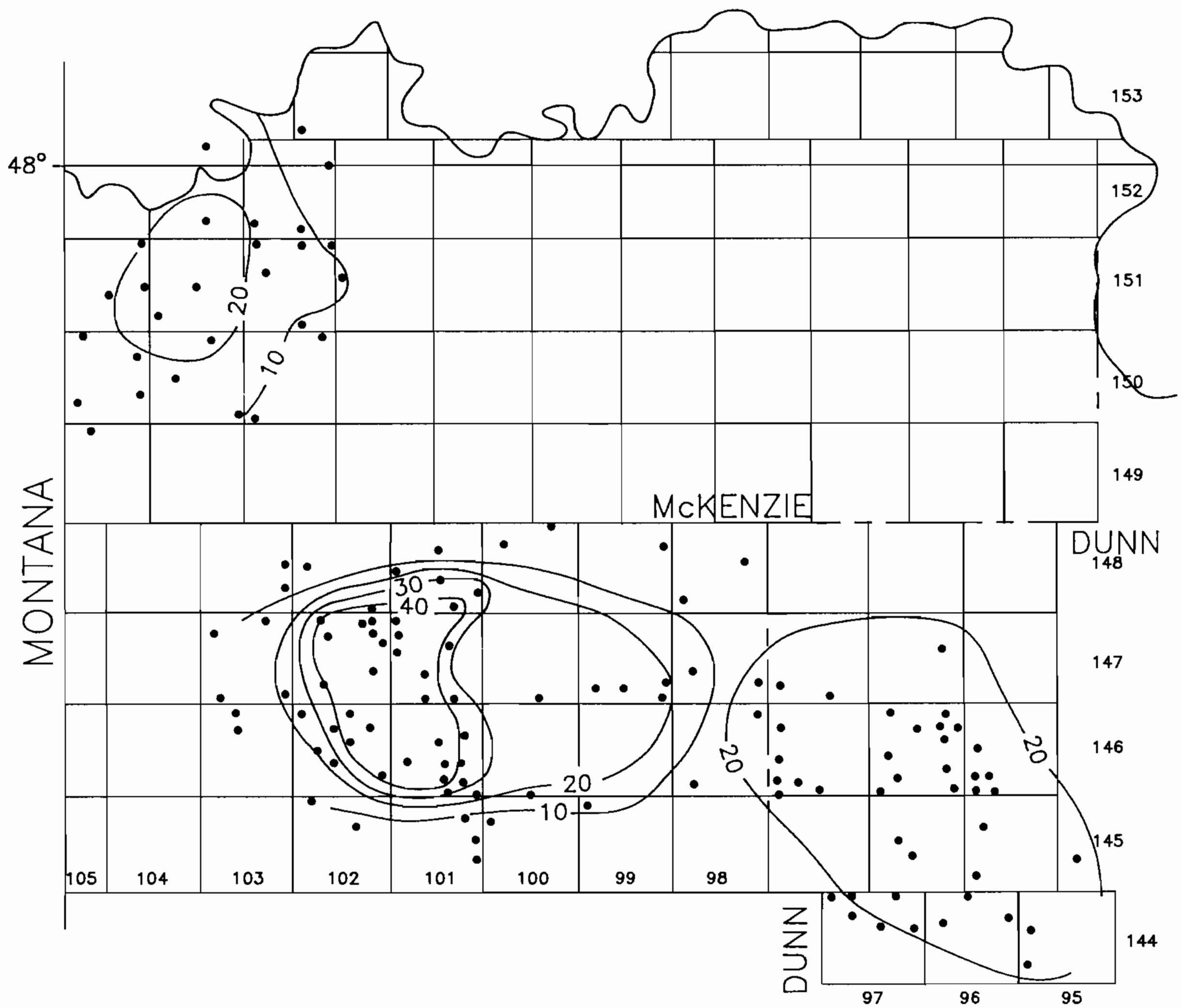

Figure 22. An isopach map of the Harmon (?) bed in McKenzie and northwestern Dunn counties (modified from Carlson, 1985).

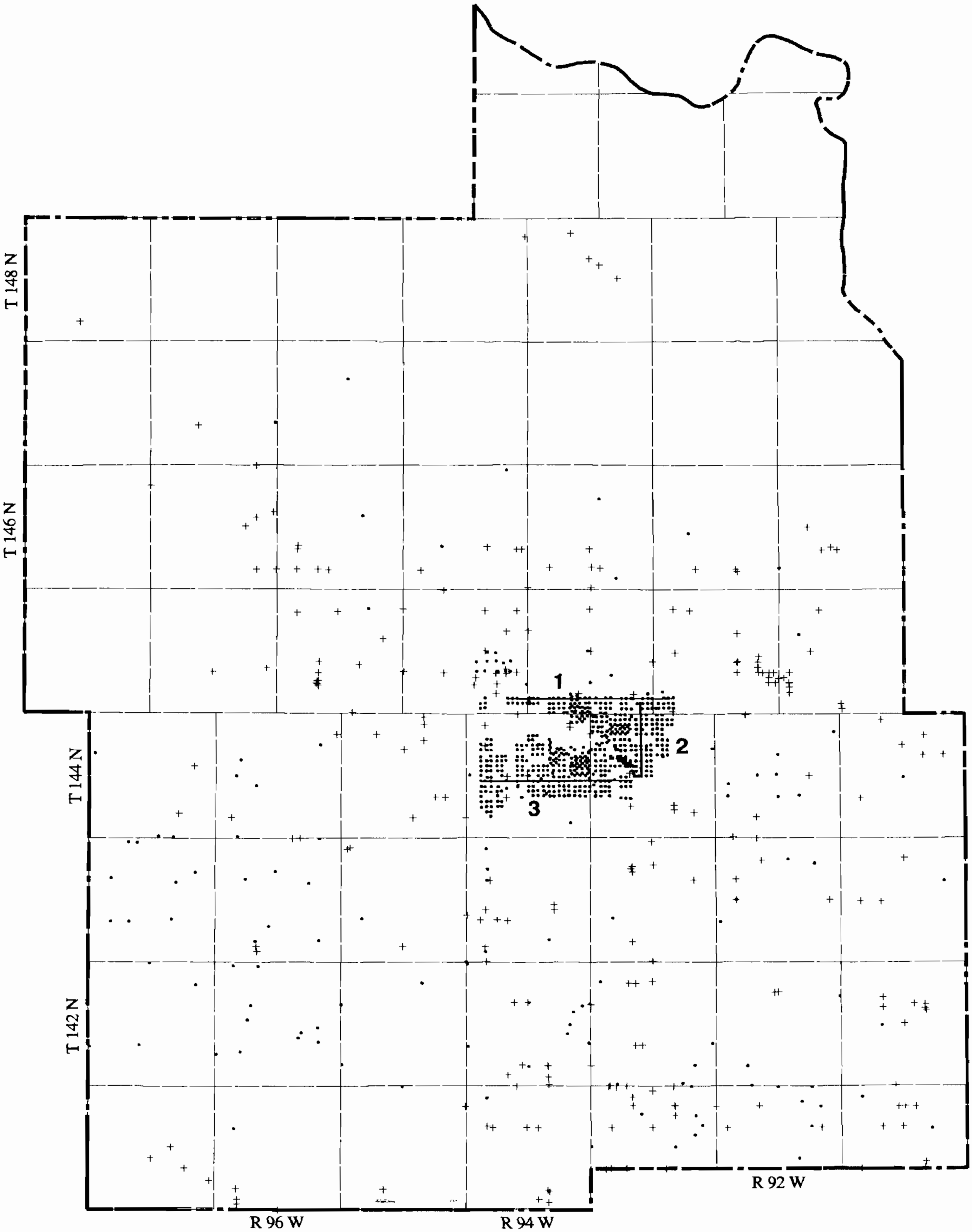

Figure 23. Coal exploration and subsurface mineral test holes (.) and Water Commission wells (+) in Dunn County.

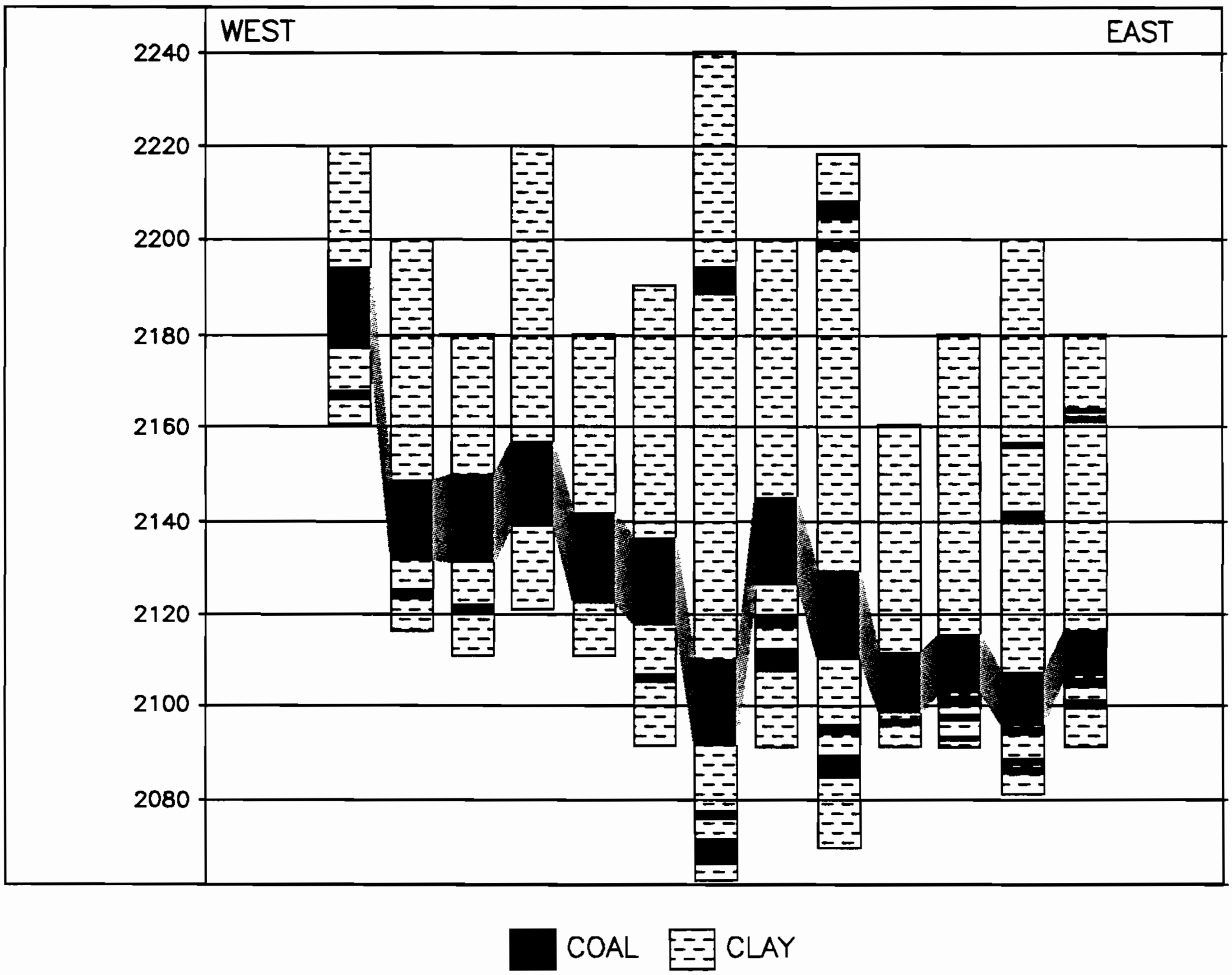

Figure 24. An east-west geologic cross-section (no. 1) highlighting the Dunn Center bed in central Dunn County. Section trace shown on Figure 22.

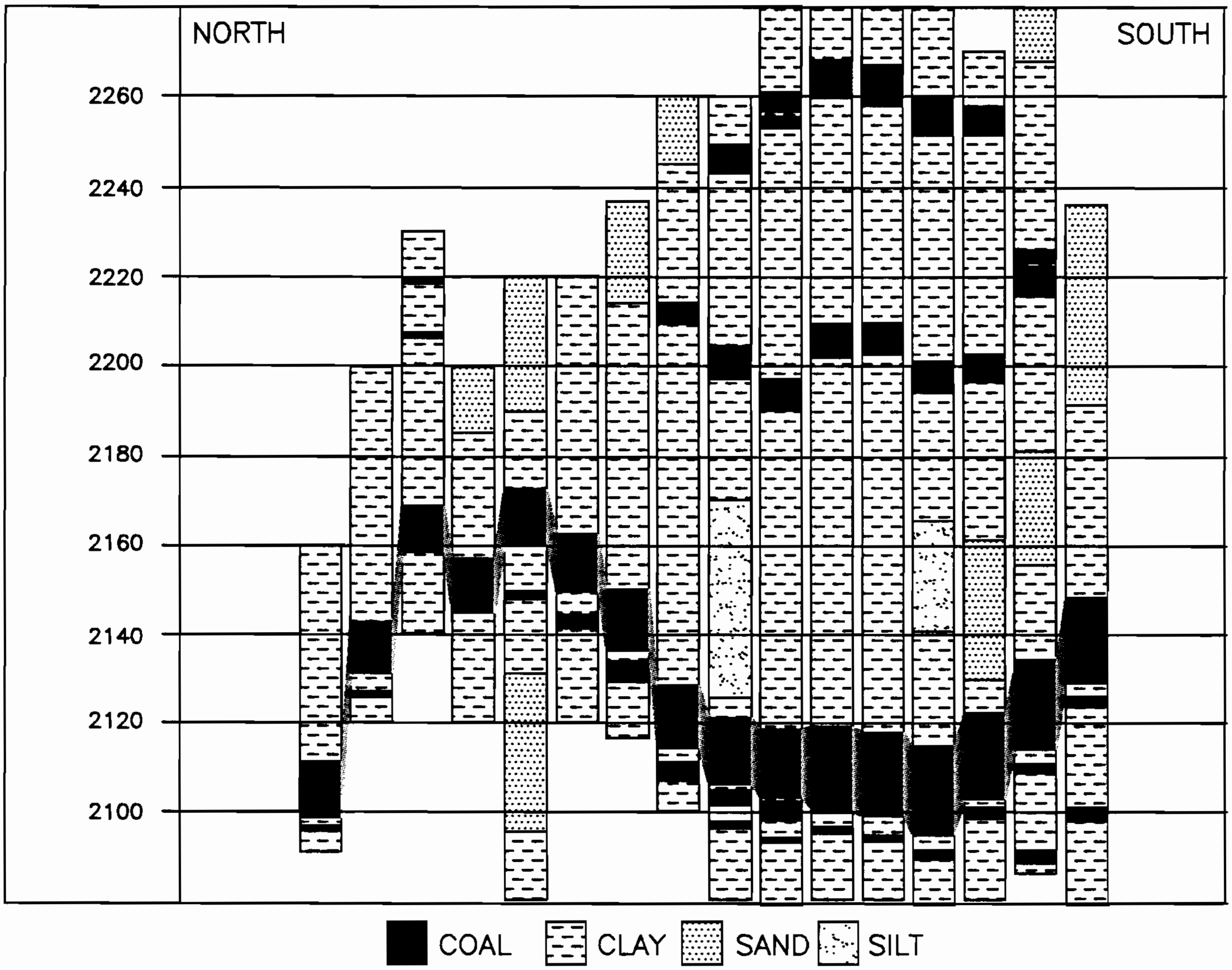

Figure 25. A north-south geologic cross-section (no. 2) highlighting the Dunn Center bed in central Dunn County. Section trace shown on Figure 22.

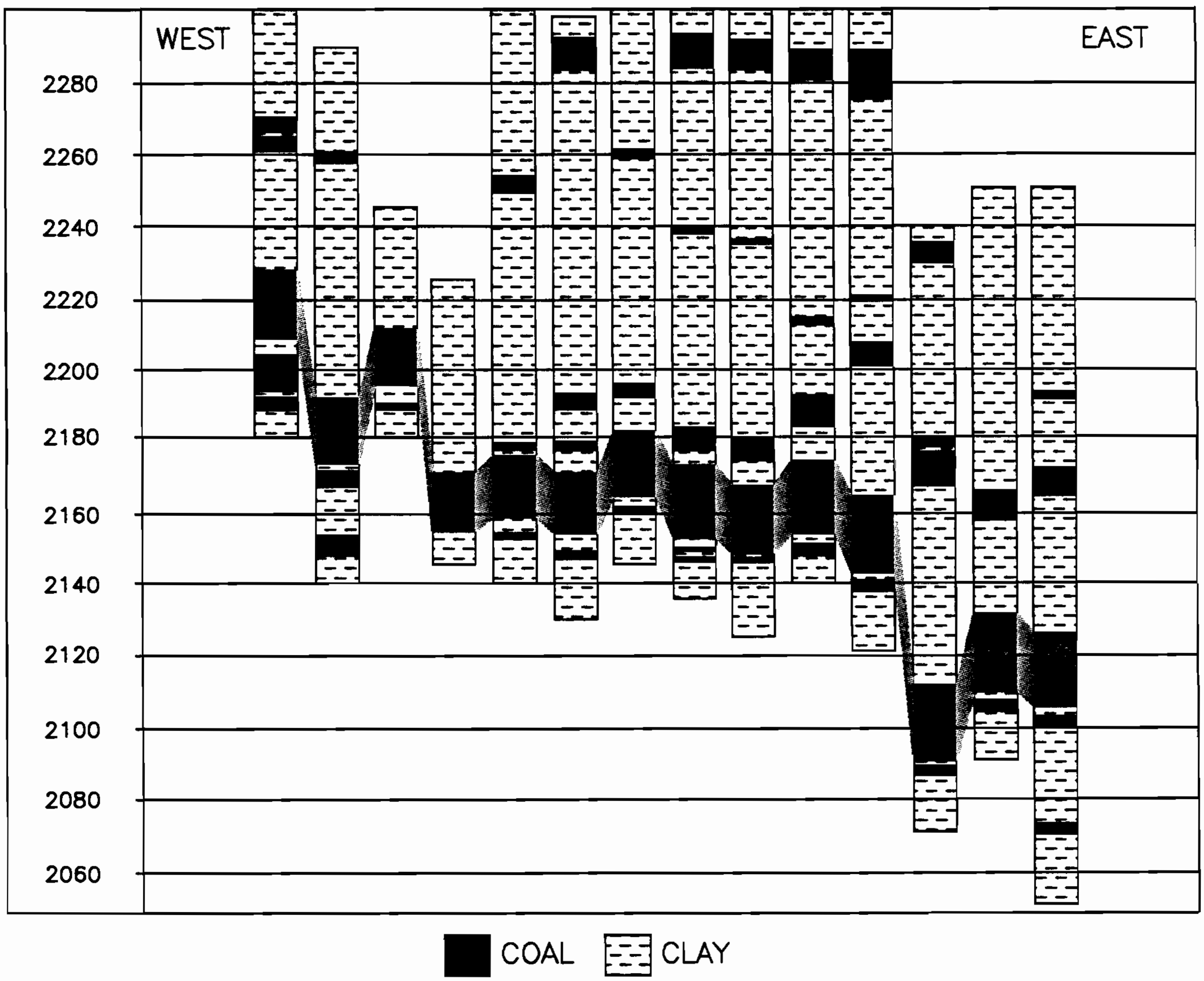

Figure 26. An east-west geologic cross-section (no. 3) highlighting the Dunn Center bed in central Dunn County. Section trace shown on Figure 22.

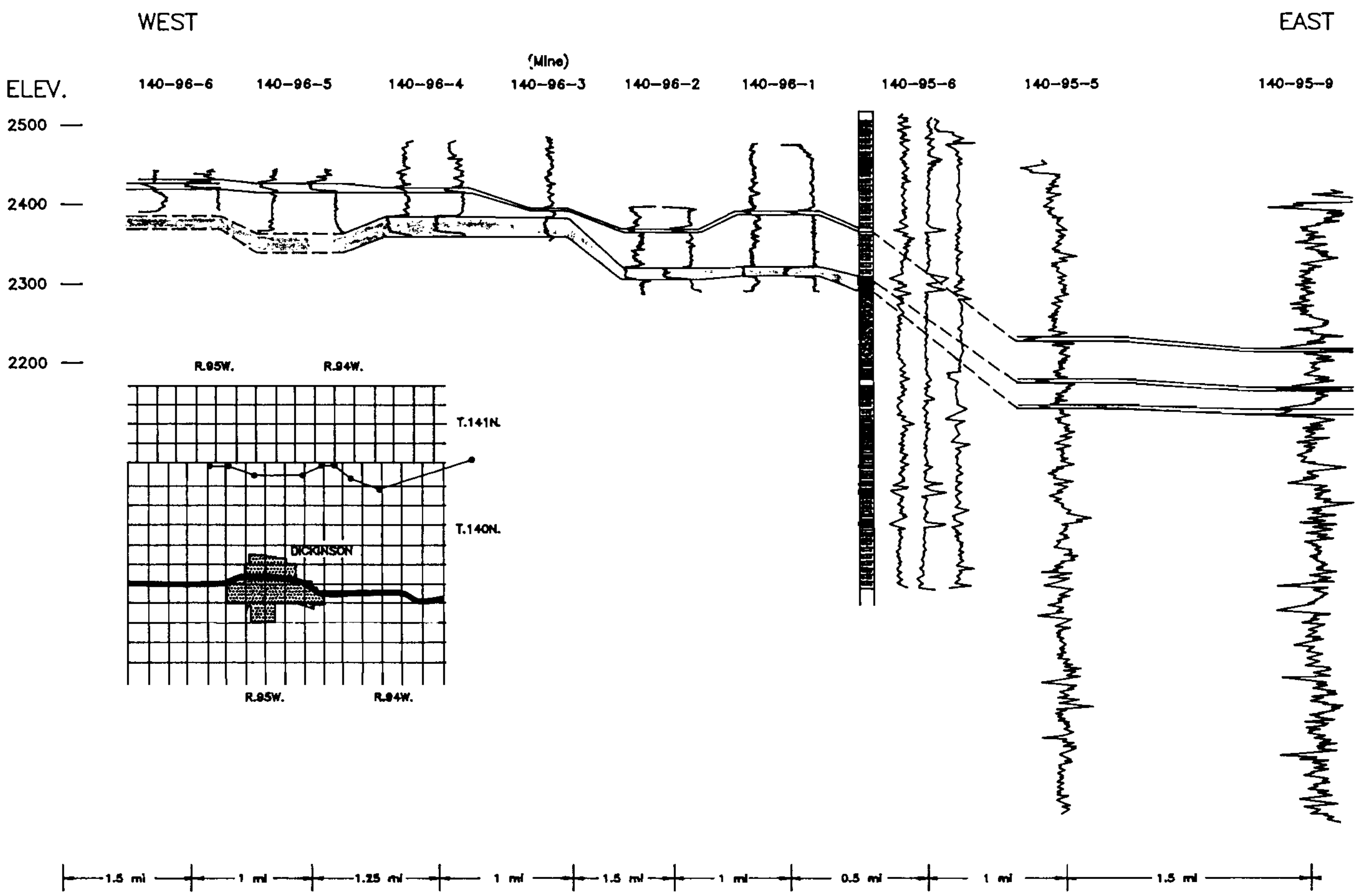

Figure 27. An east-west geologic cross-section highlighting the JK Ranch bed north of Dickinson.

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