HYDROLOGIC CHARACTERIZATION OF THE SALINE FRIO FORMATION, VICTORIA COUNTY, TEXAS GULF COAST: A CASE STUDY

Interim Report

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1 SUMMARY

Pressure data gathered from drillstem tests (DSTs) and bottomhole pressure measurements in onshore oil and gas wells along the Texas Gulf Coast were used for evaluating pressure regimes and their influence on the migration potential of formation fluids. The data were used to construct potentiometric surfaces and residual potential surfaces and to assess the effects of depressurization caused by hydrocarbon production.

This technique was utilized for preliminary geohydrologic characterization of the Frio Formation of the Texas Gulf Coast. Included in this report are the results of such an analysis for Victoria County, Texas, as a sample case study. Pressure data were evaluated for reliability, and a screening and classification system was applied to closely monitor the quality of data used for generating potentiometric surfaces. Preceding the hydrologic analysis, steps were taken to review the available geologic information in the context of Tertiary Texas Gulf Coast formations.

An evaluation of the regional pressure-depth plots reveals multiple overlapping pressure regimes. Also indicated is an area of extensive depressurization attributable to hydrocarbon production. The potentiometric surfaces also reflect depressurization that results in local variations in flow directions and a general trend of flow toward the oil and gas fields. Potentiometric surfaces for the deeper sections of the Frio reflect the high equivalent hydraulic heads in the geopressured region.

2 INTRODUCTION

2.1 Scope of Work

The proposed rule changes for the U.S. Environmental Protection Agency's Underground Injection Control Program (Federal Register, August 27, 1987) require a

Class I injection well operator to show through a permit application that either the injected hazardous wastes will degrade to non-toxic materials or these wastes will not migrate to a point of discharge in 10,000 years.

This report provides an approach in which Class I injection well operators can characterize the original injection zone hydrology that surrounds an injection well being considered for a permit. This report, an interim report for Cooperative Agreement ID No. CR812786-01-0, only addresses pressure distributions and does not integrate geologic information such as depositional facies or fault distributions with the hydrologic data.

The objective of the overall study is to evaluate regional trends in pressure regimes and the potential, direction, and velocity of fluid migration in the Texas Gulf Coast Tertiary formations. This report focuses on the Frio Formation, which has a large data-base and which is the target of most of the hazardous chemical waste disposed of by deep-well injection. It summarizes the methodology and results and includes a discussion of a hydrologic study based on the analysis of formation pressure data. As a sample case, an in-depth evaluation of hydrologic investigations in Victoria County, Texas, is presented here. Victoria County was chosen for the county study because of its large pressure data-base and because of the presence of a large injection facility for which pressure data were available in the literature. The overall regional study and the county study will be presented in a final report to the Environmental Protection Agency in 1988.

Results are presented in the form of pressure-depth profiles reflecting the pressure regimes in the Frio Formation and as potentiometric and residual surfaces defining regional trends and migration potential for formation fluids. The potentiometric surfaces will be further utilized to evaluate flow patterns, to compute flow velocities, and to compile a generic hydrodynamic model of the Gulf Coast aquifer system.

2.2 Geologic and Hydrologic Description

Tertiary saline formations of the Texas Gulf Coast have been used for over 20 years for deep-well disposal of toxic chemical wastes. The depths of waste disposal range from 2,000 to 8,250 ft below land surface in the Oakville, Catahoula, Yegua, and Frio Formations, the undifferentiated Miocene formations, and the Wilcox Group. Most injection operations are concentrated in the Miocene, Frio, Yegua, and Catahoula aquifers. To date, more than 80 billion gallons (10.7 billion cu.ft.) of industrial waste have been injected in these zones (Kreitler and Richter, 1986). In Victoria County, large volumes of chemical waste (nearly 16 billion gallons) have been injected since 1953 at the Du Pont de Nemours facility in selected intervals between 3,800 and 4,900 ft below land surface (Texas Water Commission, 1987). Figure 1 reflects the overall area of investigation covered by the regional study, identifies the location of major concentrations of deep-well injection facilities, and delineates the regions A, B, and C into which the data were separated for convenience in handling the large computer data-base.

The unconsolidated Tertiary sandstones designated for chemical waste disposal are part of a larger Gulf of Mexico sedimentary basin, deposited continuously for nearly 70 million years. The Frio Formation of Oligocene-Miocene age is one of the major progradational wedges of the Texas Gulf Coastal Plain and contains prolific hydrocarbon-producing plays. This wedge, which consists of interfingering marine and nonmarine sands and shales, extends in a band up to 50 mi wide and in places more than 12,000 ft thick along the Texas Gulf Coast (Galloway and others, 1982).

As a means of consolidating the available geologic information on the Gulf Coast saline formations, earlier published and unpublished maps, including structure, isopach, and net-sand-thickness maps done by various investigators, were acquired. The structure maps were digitized and reproduced using a computer contouring program. These computer-generated structure maps have been used for quality control and for assigning formation codes to data where such codes were missing in the original data-base. Figure 2 reflects the structure of the top of the Frio Formation along with the major fault features. Figure 3 is a generalized cross section representing the various stratigraphic units of the Gulf Coast saline formations. A steep thickening of the Frio below the 2,000-ft sub-sea depth is evident from figure 3. Stratigraphic and hydrogeologic dip section FF', through the middle section of the Texas Gulf Coast including Victoria County, is represented in figure 4. Major hydrologic units including the Frio and its updip equivalent, the Catahoula Formation, are delineated in figure 4. Exclusion of faulting from the dip section in figure 4 presents a simplistic picture of hydraulic continuity. In reality, the faults may either act as barriers to fluid flow or provide pathways for cross-formational communication.

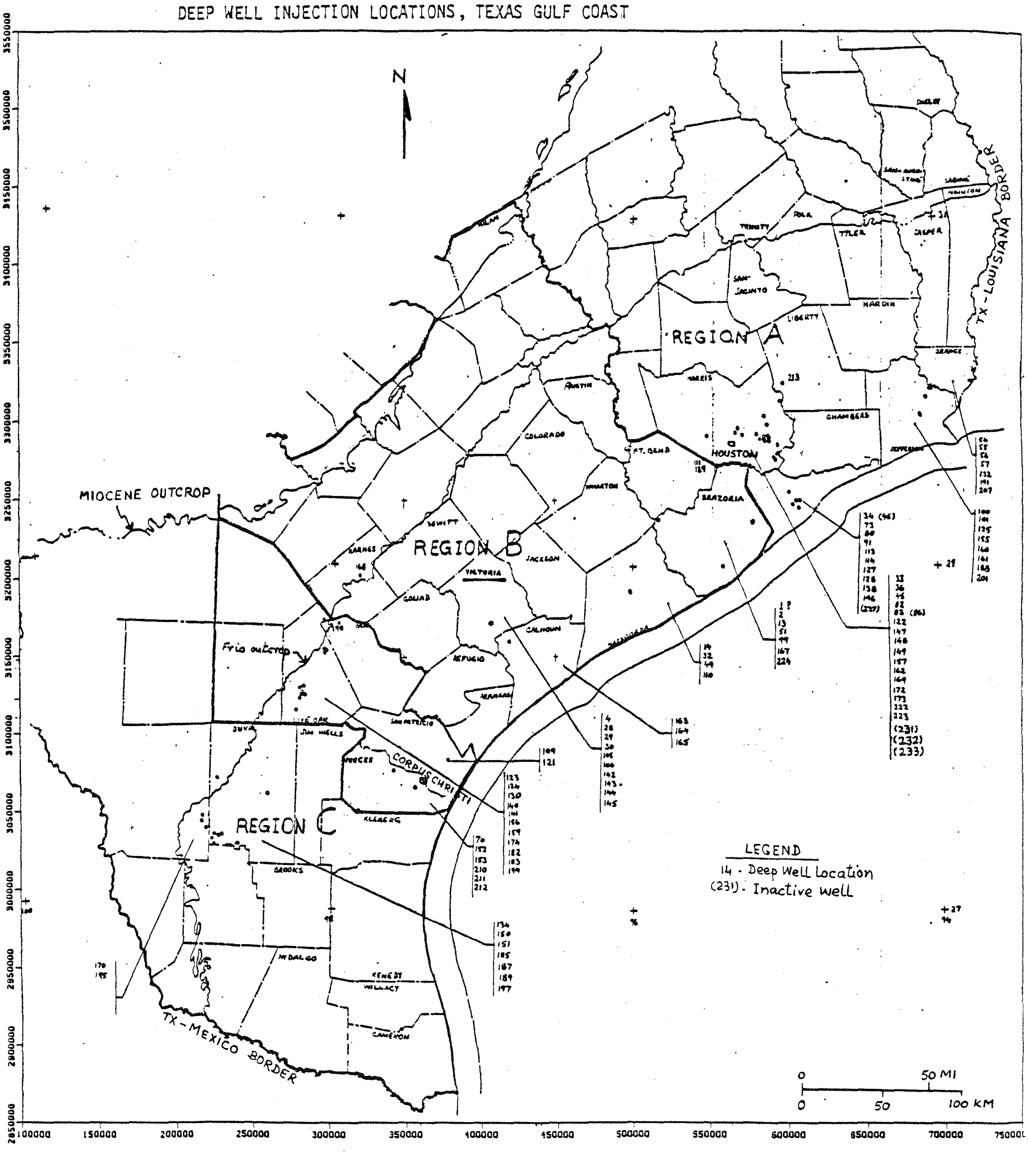

Figure 1. County map with deep-well injection locations, Texas Gulf Coast.

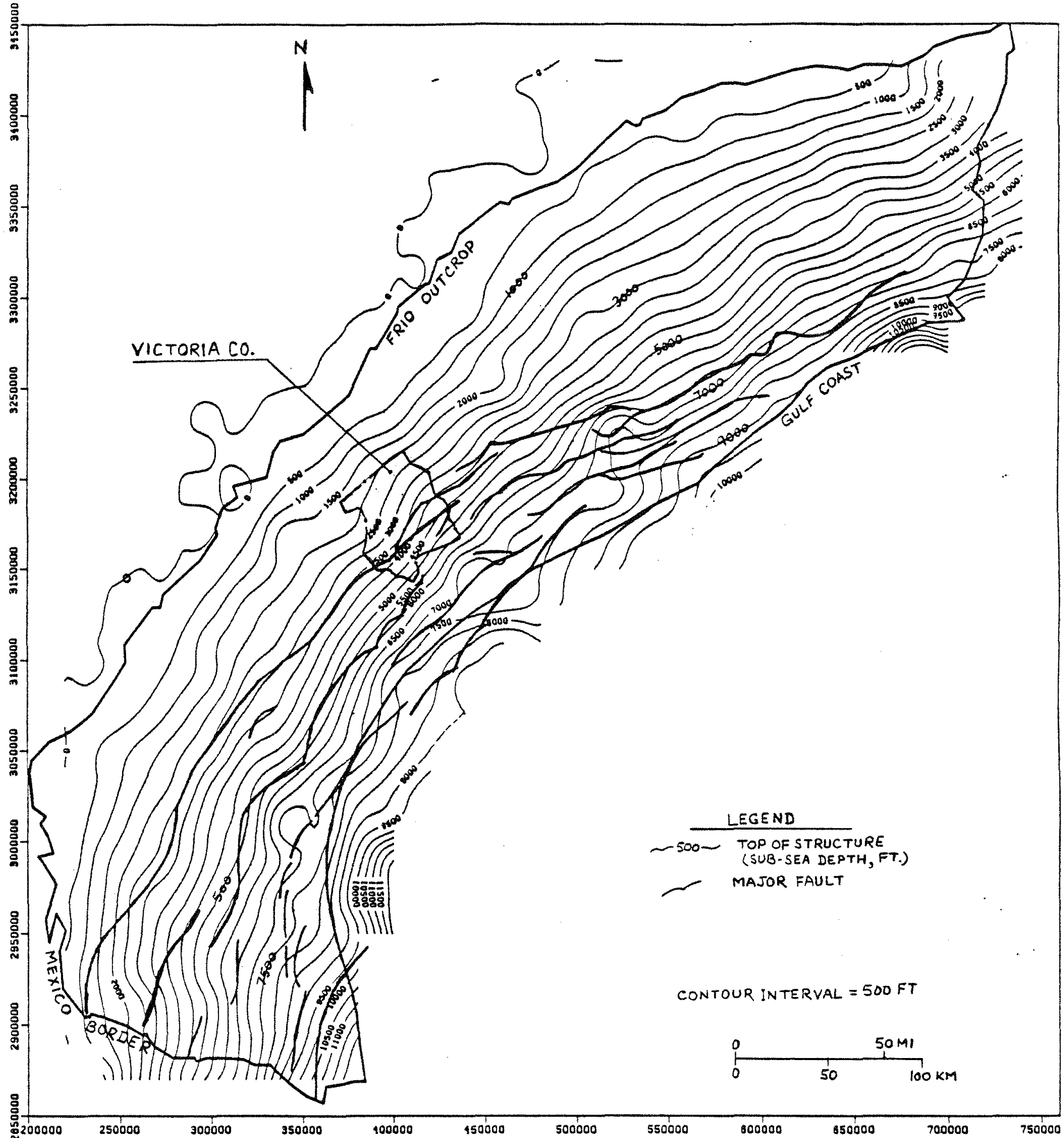

Figure 2. Structure map of the top of the Frio Formation, with major fault features (after Galloway and others, 1982).

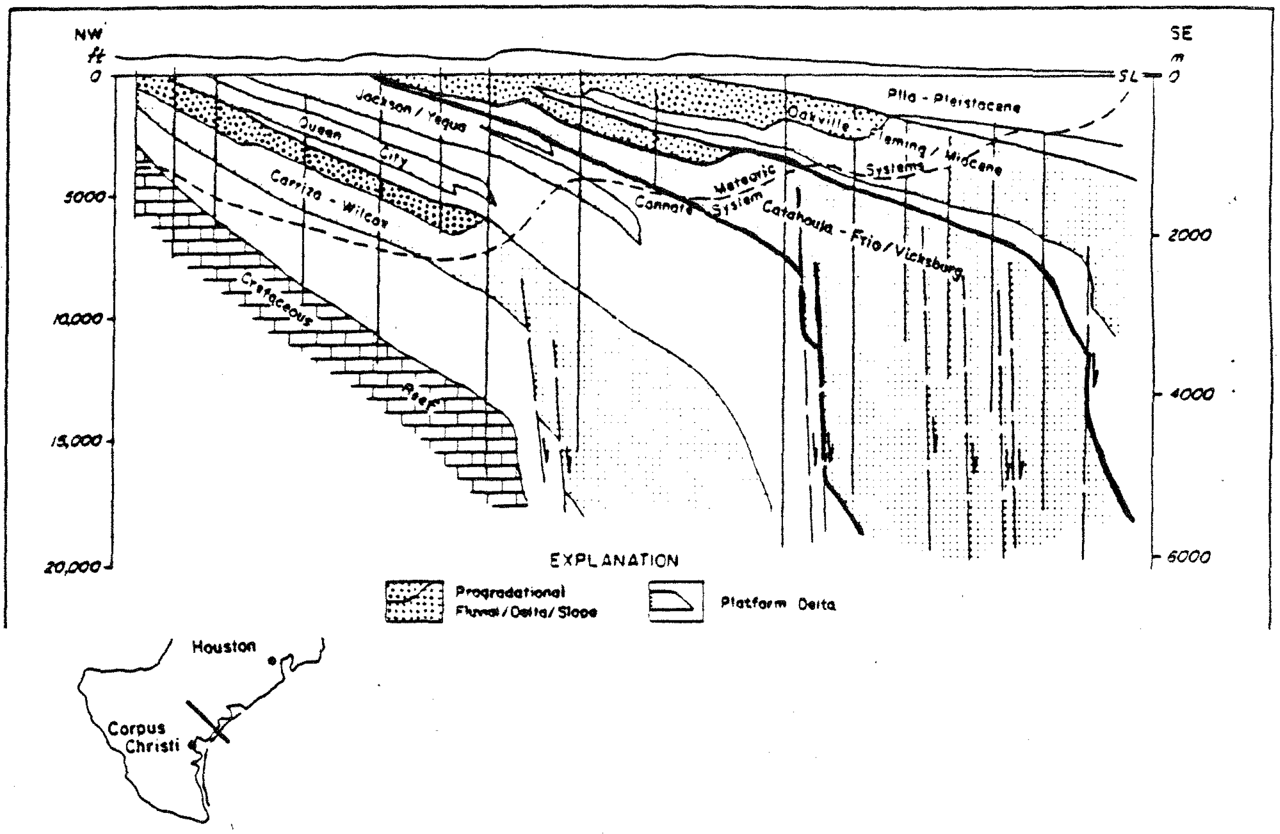

Figure 3. Generalized stratigraphic cross section, Gulf of Mexico (from Galloway and others, 1982).

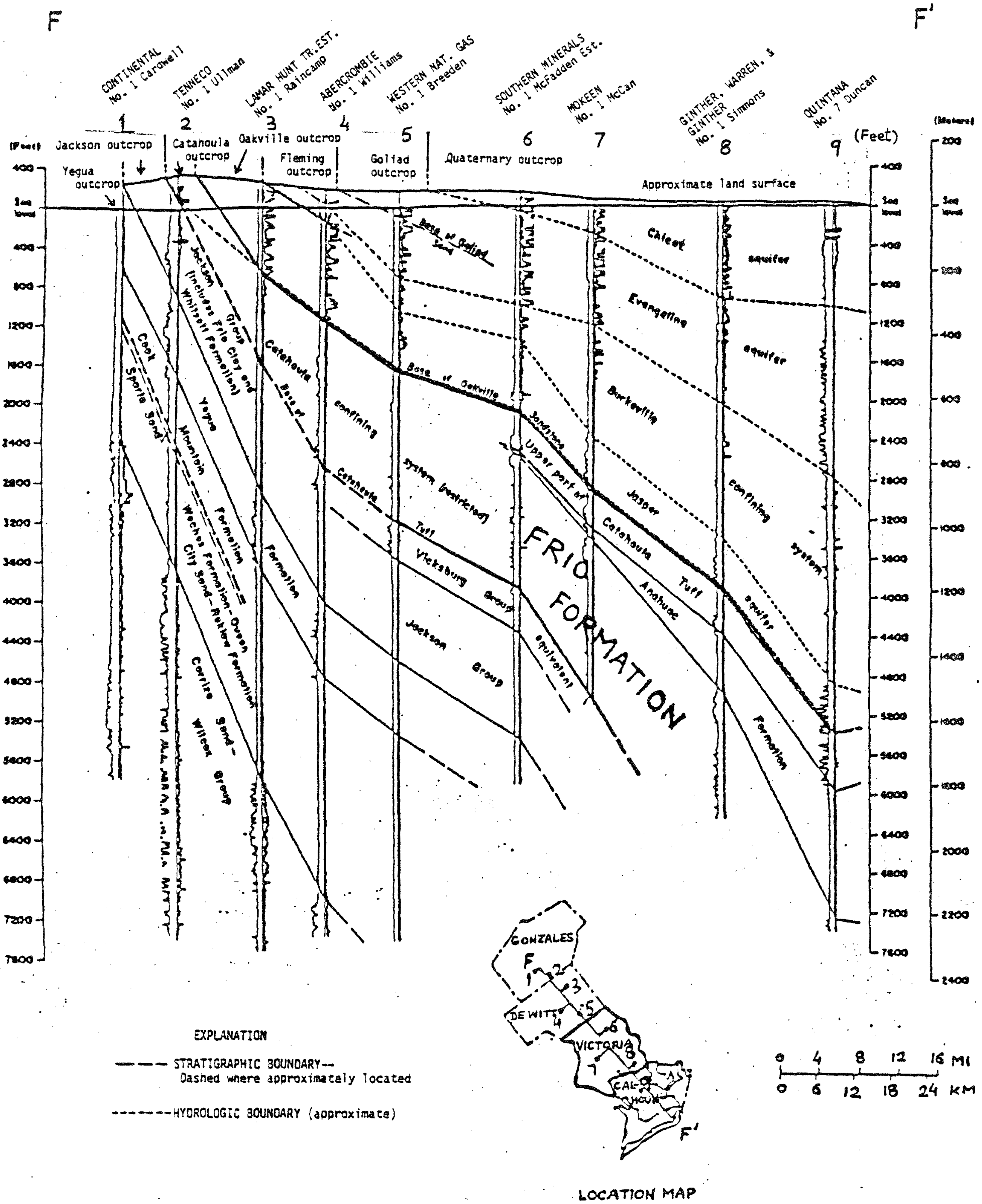

Figure 4. Stratigraphic and hydrogeologic dip section FF' through Victoria County, Texas Gulf Coast (from Baker, 1979).

Ground waters in the Coastal Plain aquifers are considered to have two origins: meteoric waters, introduced into shallow aquifers by precipitation, and formation waters from depositional environments (Kreitler, 1979). These two types of waters coexist in the basin in the following three hydrologic regimes: (1) The uppermost permeable strata are continuously recharged by meteoric waters forming a fresh-water regime, where flow is directed toward the basin center. This regime may extend to a depth of several thousand feet below land surface. (2) The underlying compacting strata are characterized by expulsion of water from sediments forming a hydrostatic system. Waters within this essentially saline section are assumed to be original formation waters or at least several million years old and hydrologically static (Kreitler and Richter, 1986). Existence of hydraulic connection between the hydrostatic and the overlying meteoric sections prevents excessive pressure buildup within the hydrostatic zone. (3) Further down, the underlying strata represent the overpressured or geopressured zone where abnormally high fluid pressures exist due to restricted drainage conditions.

Various researchers have found evidence of deep penetration of fresh meteoric waters into the saline sections of the Gulf Coast Basin (Bachman, 1979; Carothers and Kharaka, 1978; Lundegard, 1985). Deep basinal ground water from the geopressured zone is presumed to be leaking upward into shallower aquifer systems (Jones, 1968; Fisher, 1982). Downward flow of fresh meteoric water, upward movement of deep basinal brines, and the possible presence of original depositional waters suggest existence of a hydrologically dynamic system. However, flow rates within this environment need to be considered in the context of geologic time--that is, millions of years. The existence of complex fault systems and literally hundreds of thousands of oil- and gas-related holes adds a new dimension to the consideration of potential pathways for the movement of the various types of waters. Within this context, the injection and long-time confinement of toxic chemical wastes present an interesting topic of study.

3 PHYSICAL HYDROLOGY

3.1 Data Acquisition and Sources

Pressure data used for the investigation of the pressure regimes and the hydrology in this project were acquired from the Petroleum Information Corporation

(P.I. Corp.), Denver, Colorado, under a cooperative agreement with the U.S. Geological Survey and the Environmental Protection Agency. The data-base, obtained on magnetic tapes, consists of drilling, completion, and testing information on nearly 147,000 new and worked-over wells. This data-base was originally compiled by P.I. Corp. from well-data records of the Railroad Commission of Texas and private oil company records and includes bottomhole-pressure information gathered during drillstem tests, and initial flow-potential tests and by other bottomhole-pressure-measuring techniques.

3.2 Logistics of Data Processing

In-house computer programs developed at the Bureau of Economic Geology (BEG) were utilized for reading the magnetic tapes and for retrieving the relevant information from them. Figure 5 is a flow chart that was used for processing the data-base. A major part of the data manipulation was executed on the Dual-Cyber system at The University of Texas, and the subsequent graphics plotting was done on the BEG's VAX 11/780 computer. A commercially available contouring package, CPS-1 by Radian Corporation, Austin, was used for plotting the potentiometric surfaces.

3.2.1 Methodology

The formation pressures used to construct the pressure-depth profiles and the potentiometric surfaces are predominantly final shut-in pressures (FSIPs) from DST records and static bottomhole pressures taken with wireline testers during the initial completion or initial production-potential testing of oil and gas wells. A small percentage (<10%) of data are from wells recompleted during a workover. In the case of DSTs where two pressures, the initial and final shut-in pressures (ISIP and FSIP), were available, the higher of the two values was used. The pressures were converted to equivalent fresh-water heads; thus, the potentiometric surface represents the elevation from a datum (sea-level), to which an equivalent fresh-water head would rise in a well completed to the midpoint depth of the DST interval.

Thus,

$$\text{hydraulic head (ft)} = \text{sub-sea depth} + \frac{\text{measured fluid pressure (psi)}}{\text{fresh-water pressure gradient (psi/ft)}}$$

FLOWCHART FOR PROCESSING OF P.I. DATA TAPES

```
                 P.I. Data on Magnetic Tapes
                          |
                          |<==== Fortran Program
                          |
              Detailed Pressure Data by County
               - Drillstem tests (DSTs)
               - Wireline tests (WLTs)
               - Initial flow potential (IFPs)
                          |
                          |<==== Fortran Program
                          |
      Pressure & Head Data by Formation & Regions
                          |
                          |
           1. Evaluation of Data Reliability
               - Pressure-depth plots
               - FSIP/ISIP histograms
               - Gradient vs Time plots

           2. Generation of Potentiometric Surfaces
               - Pot. surface by horizontal slices
               - Residual surfaces
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Figure 5. Schematic flow diagram for data processing.

The sub-sea depth is calculated as the difference of the well elevation and the midpoint of the measured test-depth. A fresh-water pressure gradient of 0.433 psi/ft was used for computing the equivalent hydraulic heads. The use of fresh-water heads is commonly accepted for determining heads in aquifers with variable fluid density. Moreover, on a regional scale, such application provides good results for evaluation of flow directions and flow gradients in a lateral direction.

Nearly 39,000 pressure data measurements were retrieved from the P.I. Corp. data-base; of these, some 18,000 pressure measurements were from the Frio Formation of the Gulf Coast. Figure 6 is a pressure-depth plot of the Frio Formation in regions B and C (central and south Gulf Coast).

3.2.2 Quality Control

An important initial step was to evaluate the reliability of pressure measurements contained in the P.I. data-base. Pressure-depth plots were used as a diagnostic tool to assess the range and variability of pressure data, as well as an interpretive technique to delineate major trends for hydrologic regimes in the Frio.

DST pressures comprised nearly 6,000 data points and were culled to obtain about 1,000 data values, each having a minimum of two pressures: an initial shut-in pressure (ISIP) and a final shut-in pressure (FSIP). An assessment of reliability of the drillstem test pressures was performed at this stage. Histograms for the ratio FSIP/ISIP exhibited a very high degree of convergence between the two pressures. The mean value was 0.975. Nearly 82% of the ratio values ranged between 0.9 and 1.1, and an additional 10% of the values ranged within 30 percent of a 1.0 ratio. Figure 7 is a histogram showing the convergence of the two shut-in pressures for DSTs. Having thus established a reasonable degree of confidence in the DST pressures, a classification and screening scheme for the entire data-base was applied:

<u>Data Classification</u>

Class A data: Tests in which ISIP and FSIP agree within 10%

Class B data: Tests in which ISIP and FSIP diverge by more than 10%

Class C data: Tests where only one pressure (ISIP or FSIP) is available

Class D data: Pressures that convert to equivalent fresh-water heads higher than ground elevation (flowing wells)

Class Z data: Class A data within class D

The data were sorted according to aquifer (undifferentiated Miocene, Catahoula, Vicksburg, Jackson, Frio, and Wilcox).

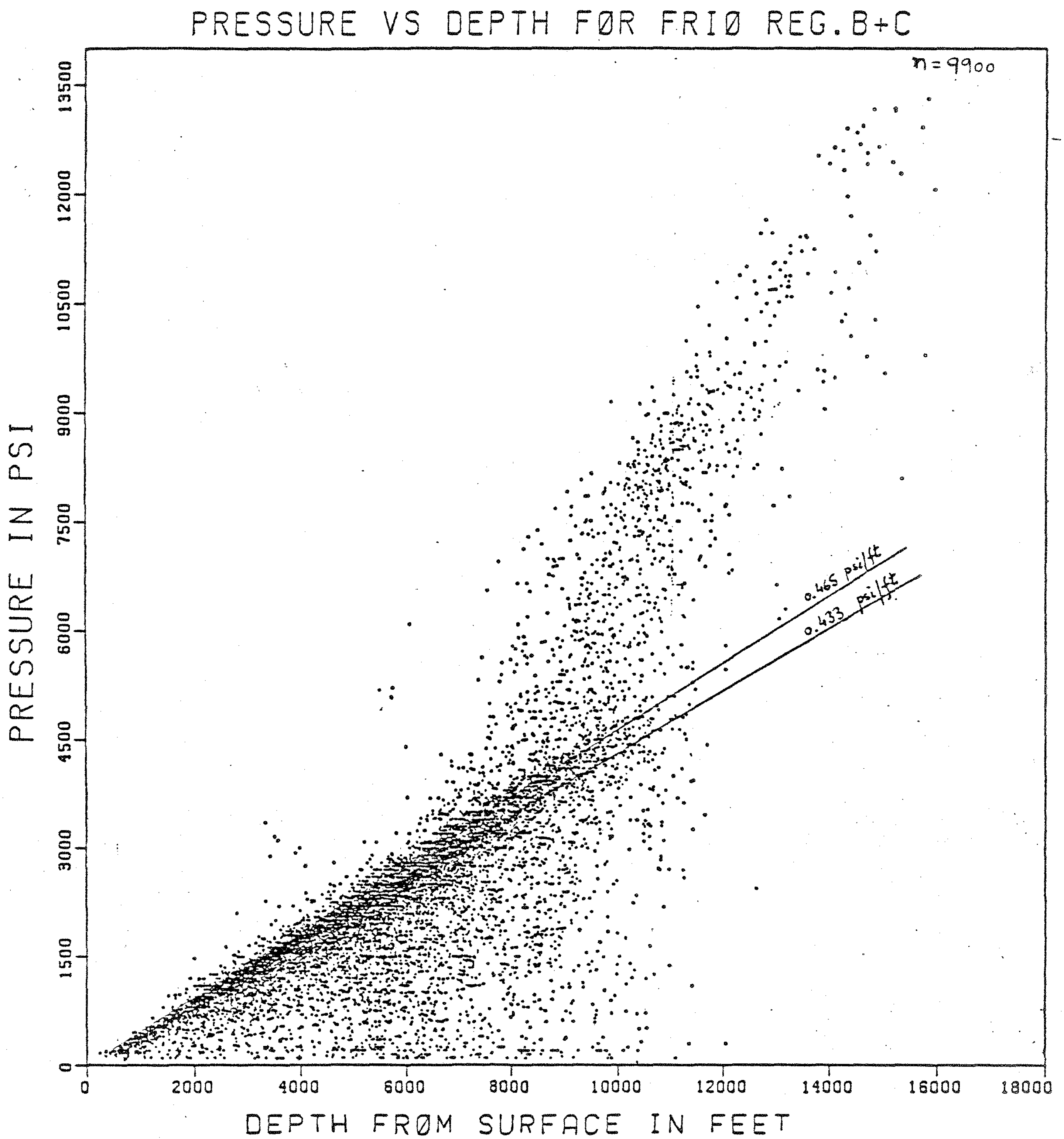

Figure 6. Pressure-depth diagram for Frio regions B and C data.

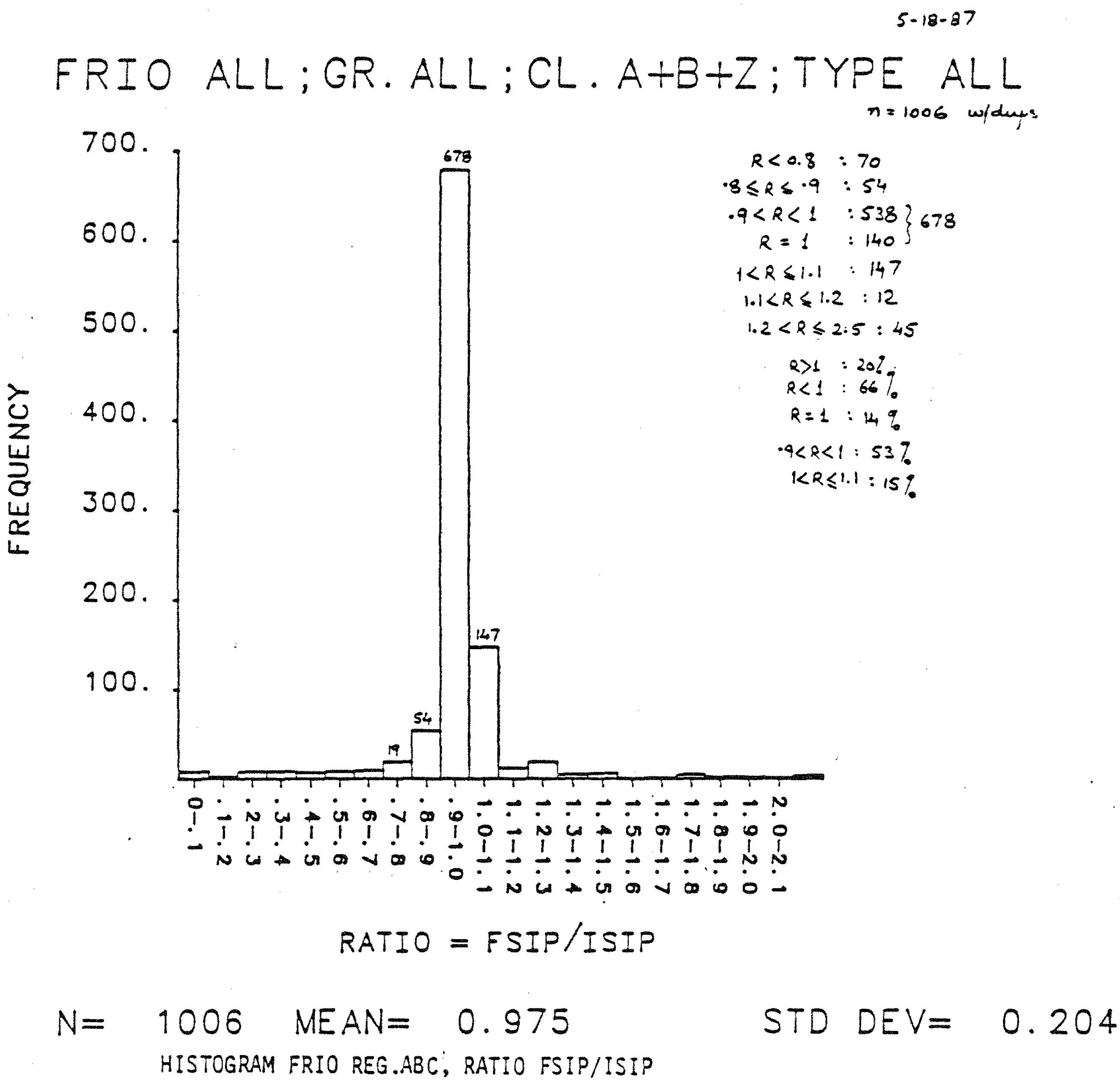

Figure 7. Histogram for FSIP/ISIP ratio. Frio regions B & C data. A, B, and Z class data included.

Data Screening

1. Non-representative pressures: data with pressure gradients greater than 2.0 or less than 0.05 were deleted
2. Multiple pressure points: in case of multiple pressure data for a single well in one formation-depth interval, only the highest class and the highest pressure from the same class was retained

Additionally, at various stages, data were also sorted by well types (i.e., wildcat, oil, and gas) and by time-span intervals for definition of trends. During the posting of head values for contouring, anomalous data that drastically differed from local surrounding values were culled.

One of the limitations of the P.I. data-base was a large number of missing formation codes for the pressure-test intervals. This problem was partly solved by assigning interpolated formation codes in such missing cases, with the help of the contouring program CPS-1. The structure tops for the Tertiary formations were digitized and transformed into a grid network. Then the tested depths were correlated to these interpolated stratigraphic picks and their values assigned reasonable formation codes. In instances where no reliable match was obtained between the tested intervals and the computerized structure contour surfaces, the data were culled from the data-base.

The contouring program CPS-1 used for mapping the potentiometric surfaces requires careful handling. The continuous contour lines are defined by the irregularly spaced head data, which are transformed to a regular X-Y grid mesh. The density of data in each grid cell is different, and the program averages all the data from each cell to determine the values at the nodes (corners) of the grid cells. Thus, the data density and grid-cell size influence the value of the averaged contour line passing through that cell. The size of the grid cells and the averaging algorithm were carefully selected in this study to produce representative surfaces. Moreover, mapping of potentiometric surfaces on a county-size scale facilitated a closer scrutiny of the data.

3.3 Regional Potentiometric Surfaces for Frio Formation

Regional potentiometric surfaces of the Frio were constructed using equivalent fresh-water heads calculated from the highest available shut-in pressures. The initial surface was generated from the screened class A, B, and Z data. This surface contained several localized highs and lows (bulls-eyes) and represented complex variations in flow trends. The enormous thickness of the Frio and the variability in hydraulic gradients as reflected on the stratigraphic cross section (figure 3) and the pressure-depth plot (figure 6) made it difficult to discern any specific flow trends in this regional surface. Consequently, it was decided to generate potentiometric surfaces for separate slices through the Frio. This allowed a rough delineation between the top fresh-water zone, the next lower hydropressured zone, and the deep overpressured formations. As part of the preliminary investigations, potentiometric surfaces were generated for 2,000-ft-thick horizontal slices of the Frio, from land surface down to a 14,000-ft depth.

Figure 8 represents the average potentiometric surface for pressures in the 4,000-6,000-ft slice. The pressure data used for this surface were selected from the years 1975-84. In this figure the depressured areas are confined by negative contours, and the normally pressured areas are represented by the mildly positive and zero-contour lines. Furthermore, residual surfaces that compare the potentiometric surfaces in the shallow and deeper intervals were created for better definition of vertical flow potential. A detailed discussion of the other horizontal Frio slices and the residual surfaces will be included in the final project report.

This regional approach provides fundamental information on the hydrology of the Frio Formation. Incorporating so much data from a large area into a single map, however, smooths trends and prevents a detailed picture of smaller areas. To understand the "regional" flow and its interaction with an injection facility, county-size maps are needed.

4 CASE ANALYSIS FOR VICTORIA COUNTY

As a representative study on a county scale, the pressure data in Victoria County were used for developing pressure-depth plot and potentiometric surfaces.

4.1 Pressure-Depth Plot

All the available pressures in Victoria County were plotted on a pressure-depth plot. The resulting profile in figure 9 is similar in character to the integrated Frio pressure-depth profile (figure 6). Two trend lines, one for 0.433 psi/ft fresh-water gradient and the other for 0.465 psi/ft brine (with 80,000 ppm salinity) are drawn on the Victoria County plot. Additionally, a scatter of overpressured data and an extended area of depressured conditions are visible on the plot.

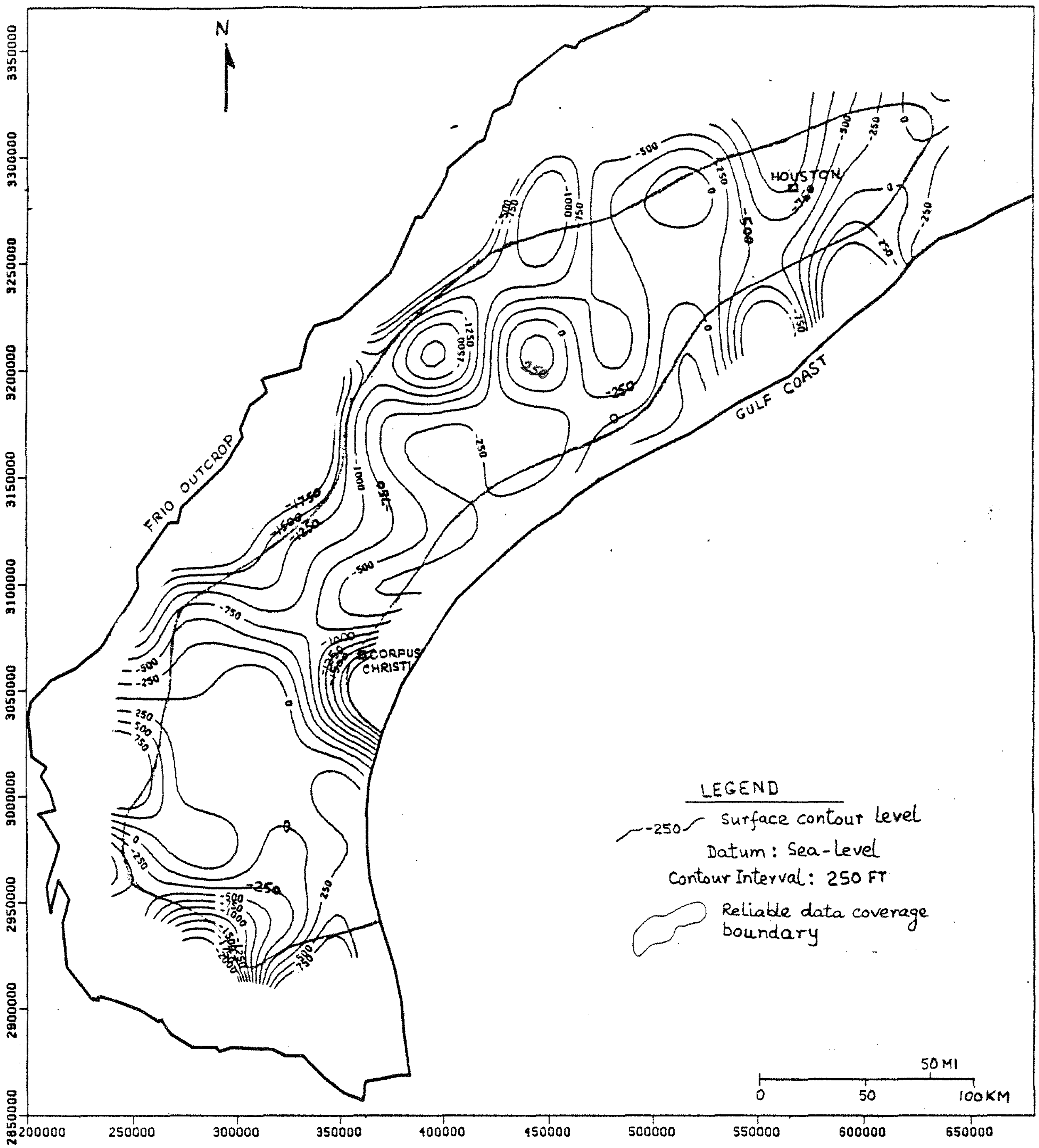

Figure 8. Regional potentiometric surface for Frio regions A-B-C, all class data, years 1975-85, 4000-6000 ft horizontal slice.

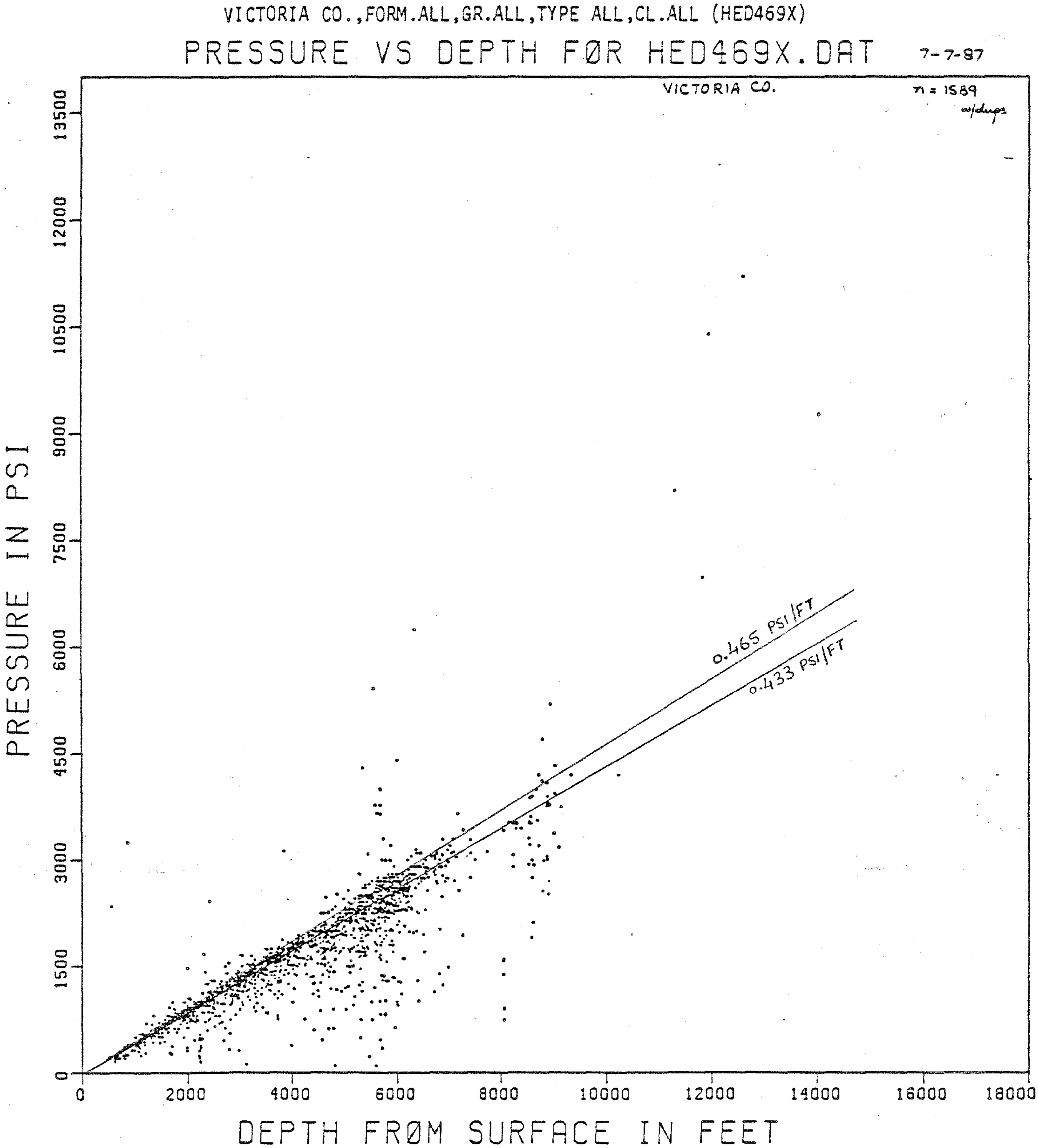

Figure 9. Pressure-depth diagram for Victoria County data.

4.2 Potentiometric Surfaces for Frio Slices

An integrated potentiometric surface of the entire Frio thickness in Victoria County would presumably be too complex due to the steep gulfward dip of the various components of the Tertiary system. Figure 10 is a simplified isometric view of the structure tops of the Frio, Vicksburg-Jackson, Claiborne, and Wilcox Formations. Analogous to the regional Frio surfaces, horizontal slices were used for constructing potentiometric surfaces in Victoria County. Figures 11 and 12 consist of the posted hydraulic-head values and the resulting potentiometric surface in the 0-2,000-ft depth interval. Pressure data from all Tertiary formations through the years 1965-85 were included in this surface. The potentiometric surface for this slice is quite flat, with near land-surface head values. The solid boundary line on figure 12 represents the confines of reliable data coverage.

Figure 13 reflects the posted head values for the horizontal slice through the 4,000-6,000-ft depth interval. The corresponding potentiometric surface for this data-set is plotted on figure 14. This data-set encompasses the time interval of 1965-84 for pressures in all formations. A general feature of this plot is the mostly negative contours reflecting the depressured conditions, except in the northwest part, where some gas wells in the Yegua Formation exhibit high positive heads. The negative depression is slightly enhanced toward the southeast. Pressure data from the injection wells operated by Du Pont De Nemours (Frank, 1986) were included in this data-set for constructing the potentiometric surface.

Figures 15 and 16 consist of the posted hydraulic-head values and the corresponding potentiometric surface in the 4,000-4,900-ft depth interval, a more restrictive depth range that encompasses the depths of injection by Du Pont. For greater areal coverage this data-set was expanded to include data for all formations in the Tertiary for the years 1945-84. A zero-contour line seems to separate the surface in figure 16 into two parts, with the northern part consisting of mostly positive or near land-surface contours and the southern part consisting mostly of negative contours. The outline of major oil and gas fields producing from the 4,000-5,000-ft depth range and the location of Du Pont's major deep well injection facility are marked on figure 16. A regional flow trend toward the southeast is again indicated on this figure. Flow from the injection facility would be south or southwest. An isometric view of this surface from the southeast direction is presented in figure 17. This data-set includes the injection formation pressure for Du Pont's facility.

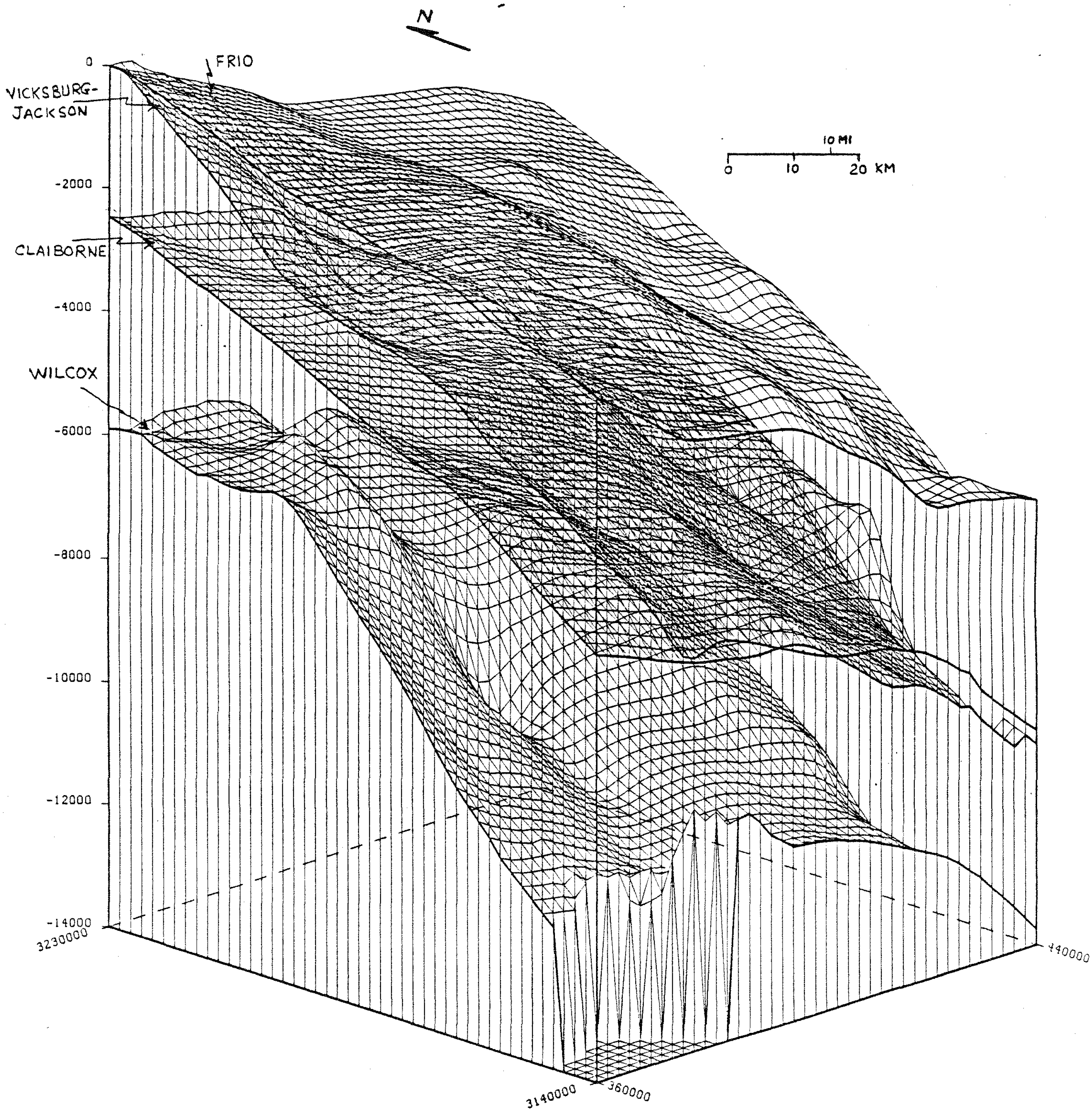

Figure 10. Isometric view of structure tops, Tertiary system, Victoria County (tops of Frio, Vicksburg-Jackson, Claiborne, and Wilcox Formations).

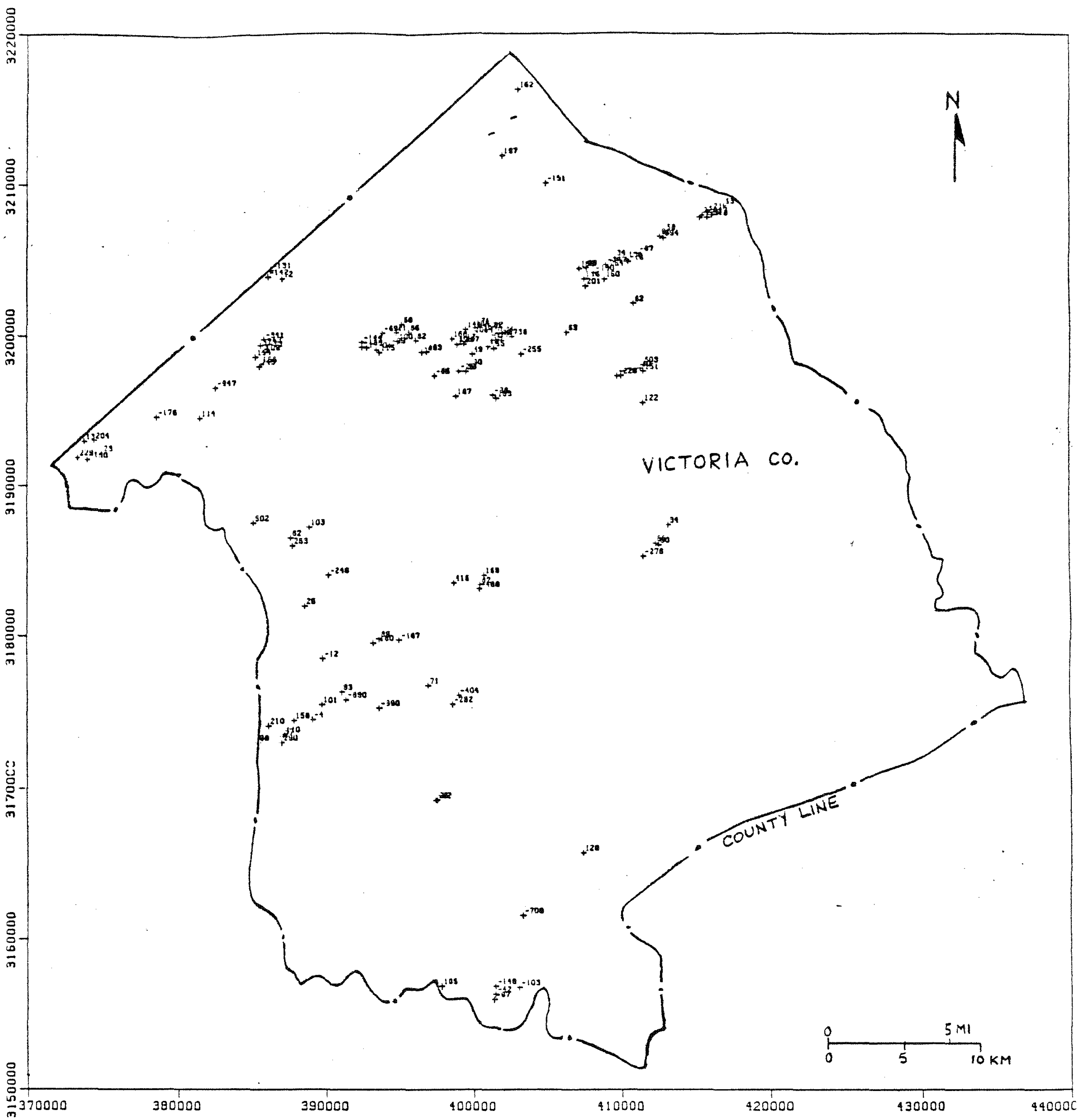

Figure 11. Hydraulic head values, 0-2000 ft horizontal slice, Victoria Co., all formations, all classes, 1965-85 data.

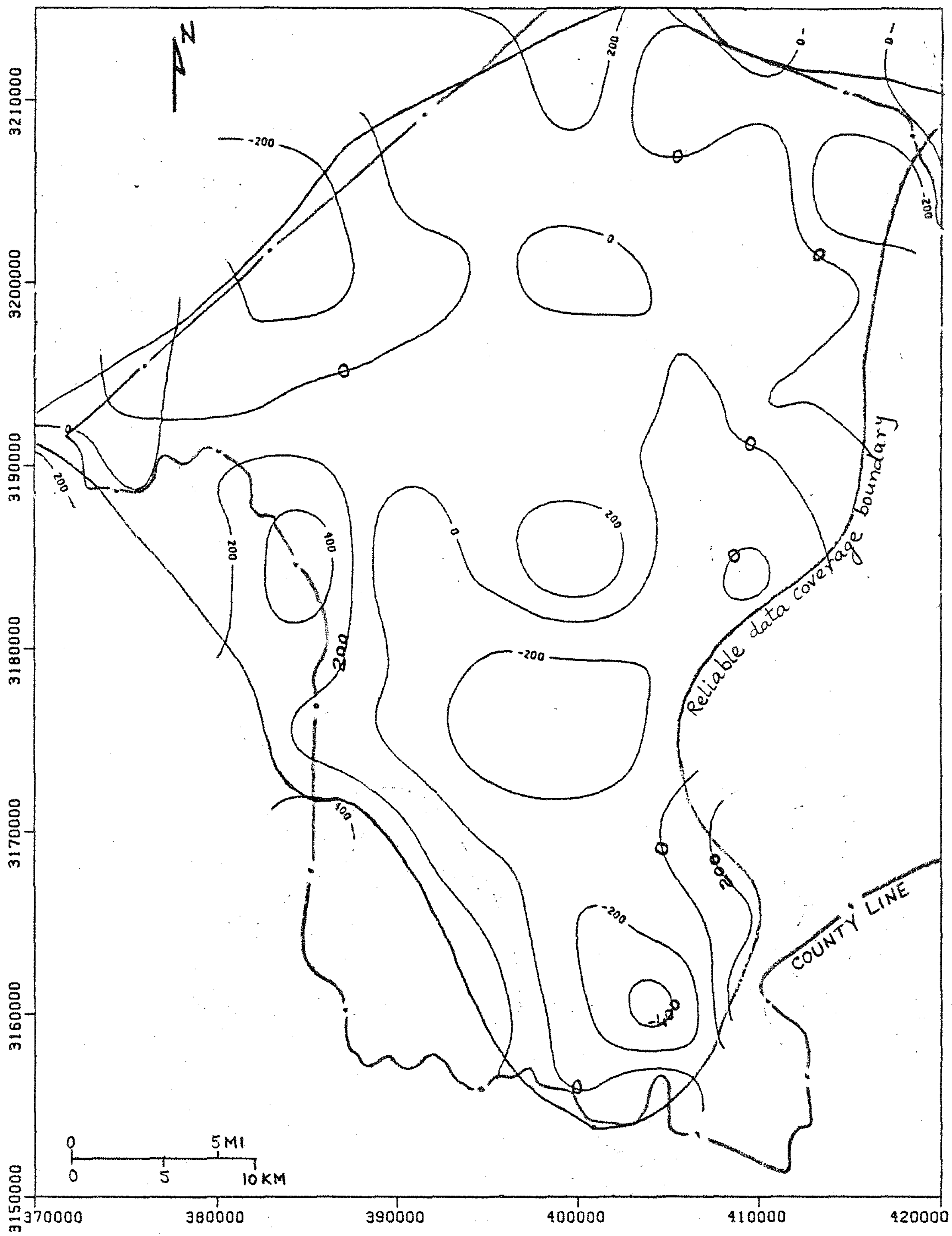

Figure 12. Potentiometric surface, 0-2000 ft slice, Victoria Co., all formations, all classes, 1965-85 data.

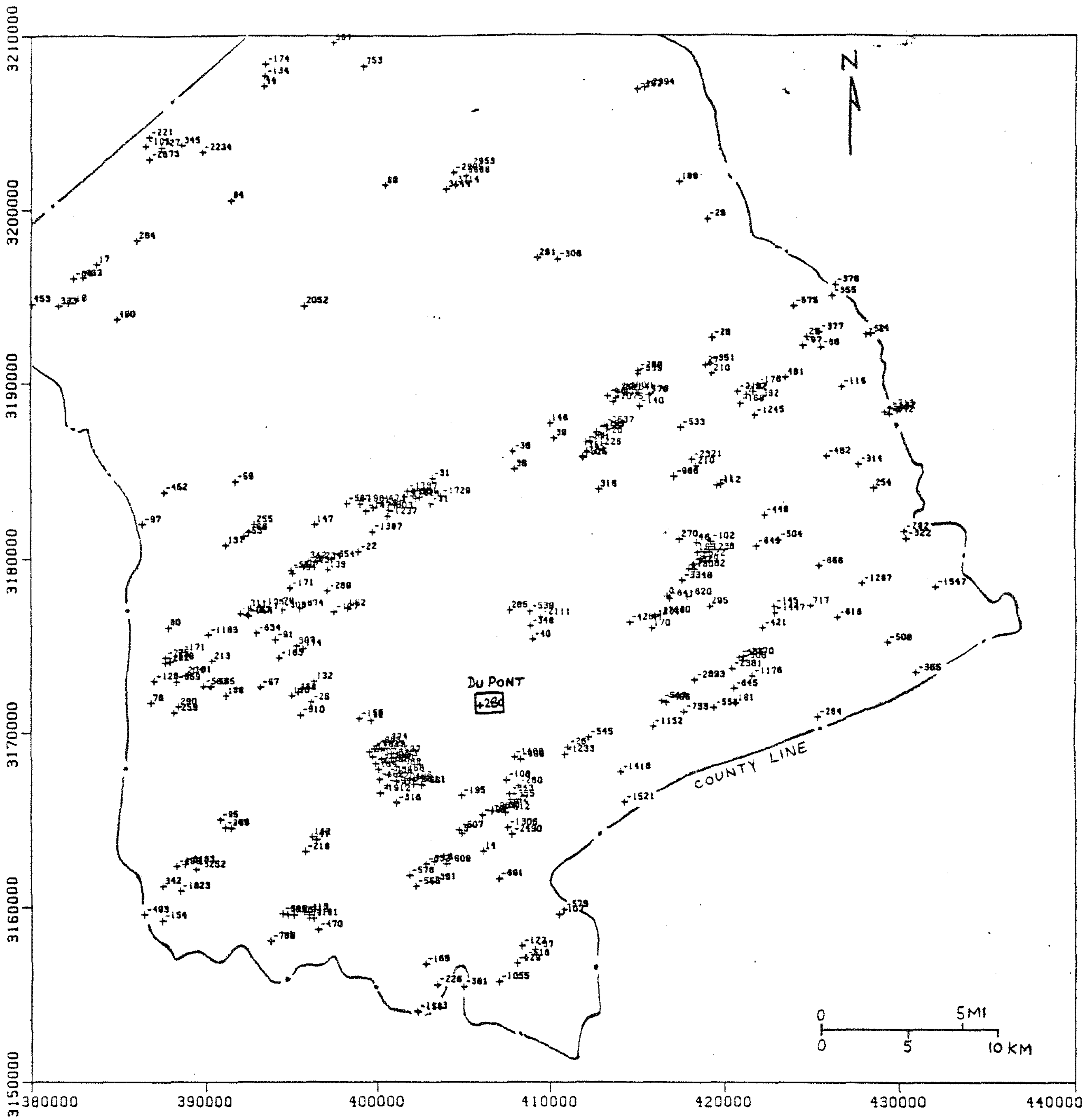

Figure 13. Hydraulic head values, 4000-6000 ft horizontal slice, Victoria Co., all formations, all classes, 1965-85 data. Includes formation pressure at Du Pont facility.

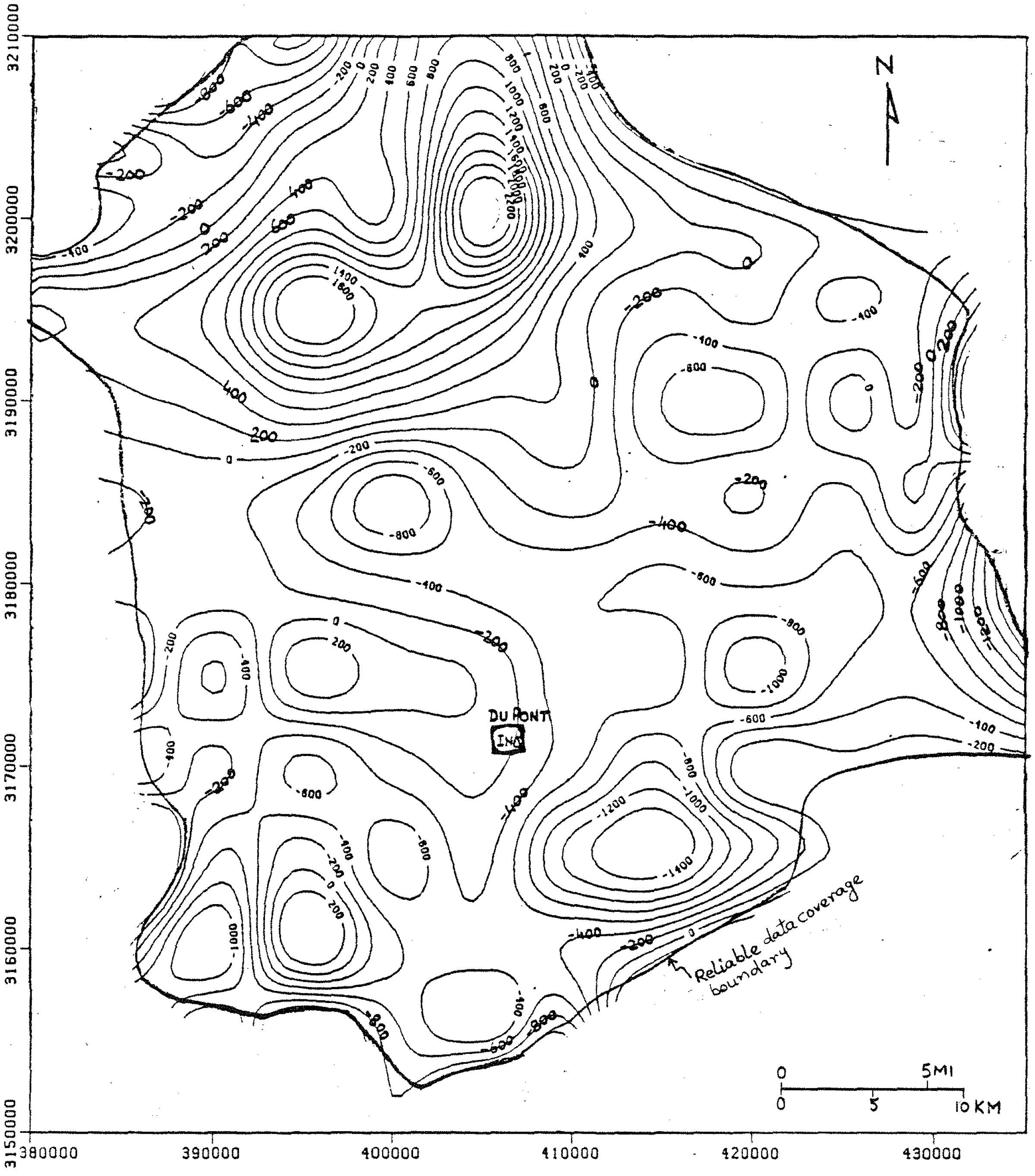

Figure 14. Potentiometric surface, 4000-6000 ft slice, Victoria Co., all formations, all classes, 1965-85 data. Includes formation pressure at Du Pont facility.

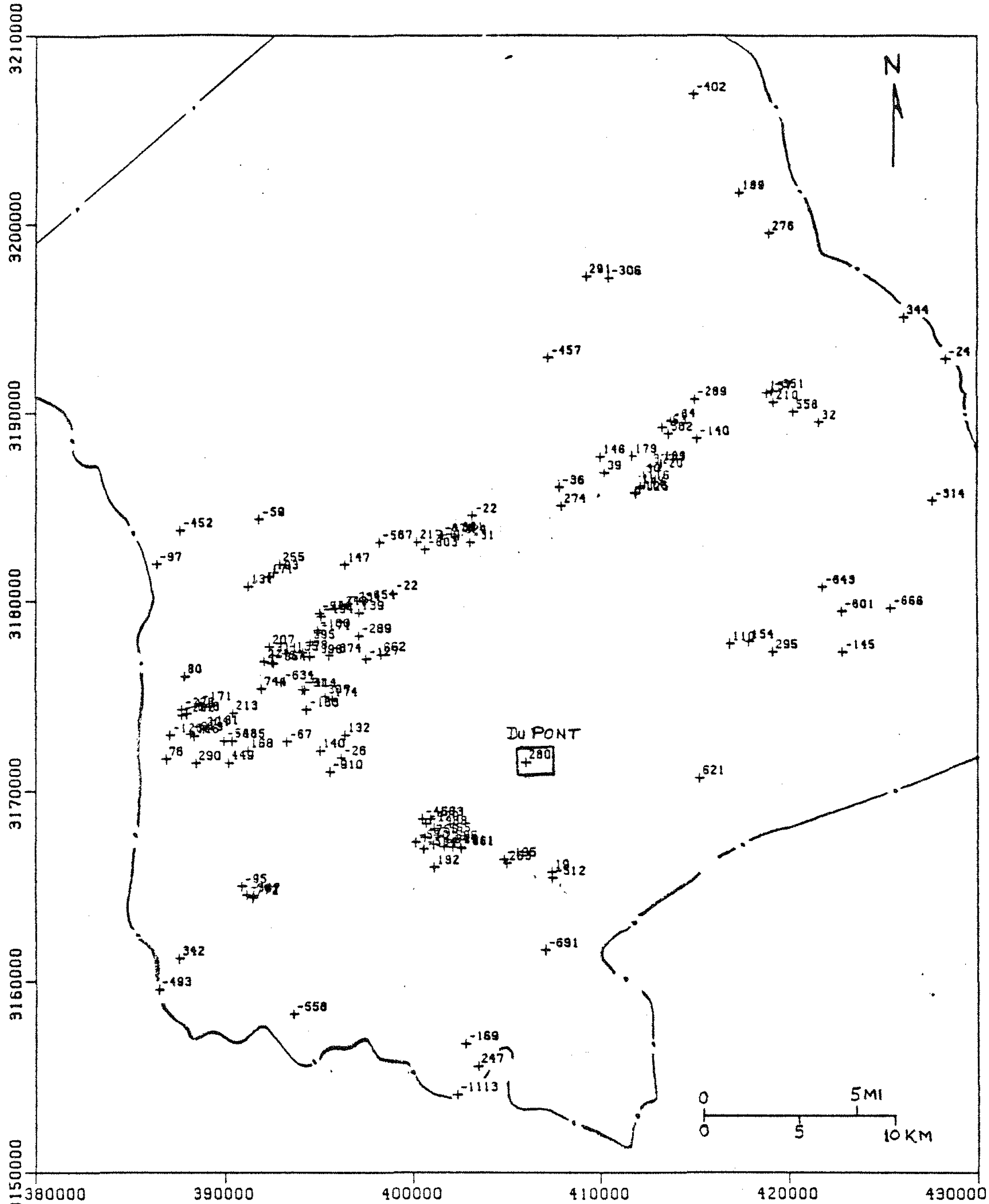

Figure 15. Hydraulic head values, 4000-4900 ft slice, Victoria Co., all formations, all classes, data for all years. Includes formation pressure at Du Pont facility.

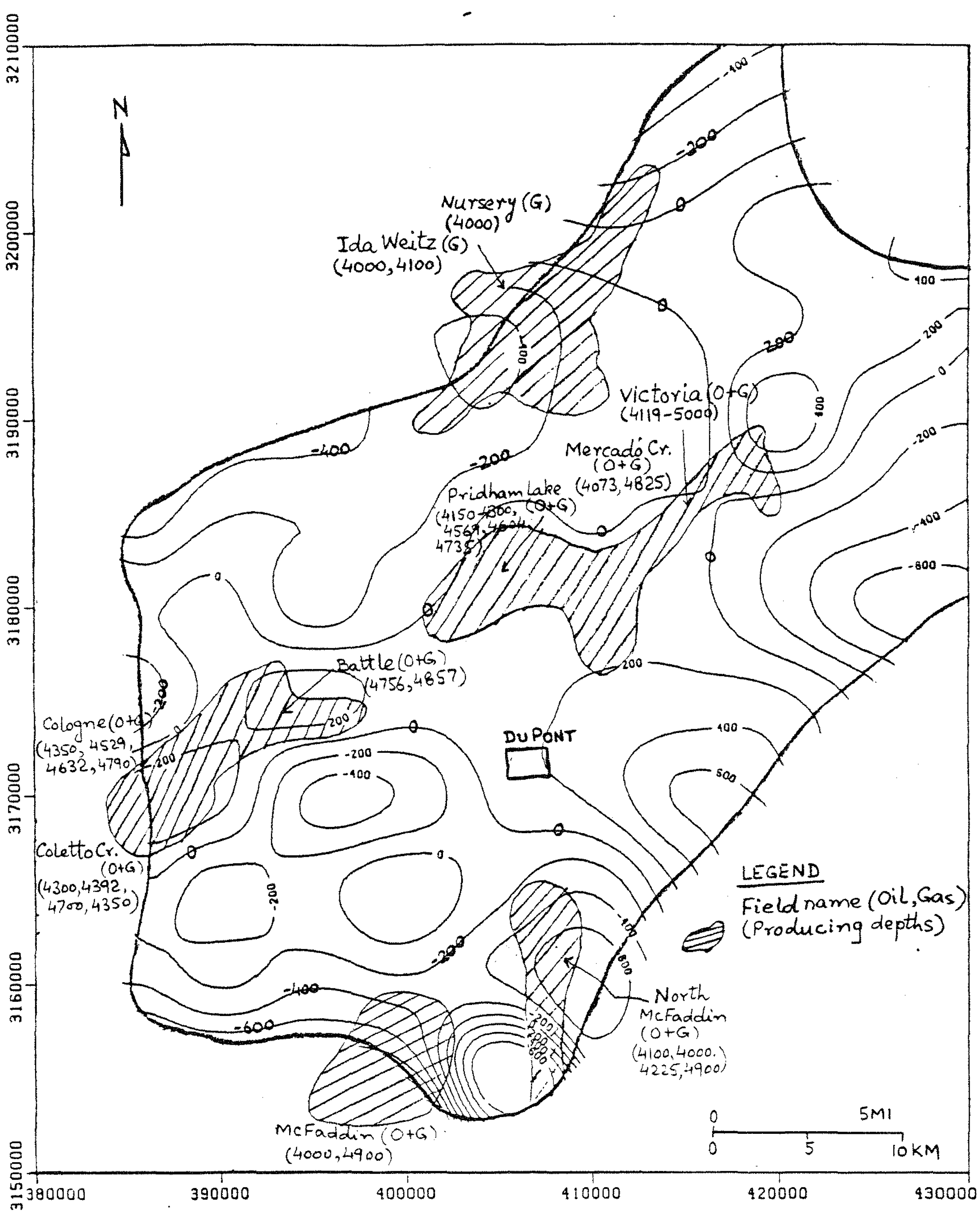

Figure 16. Potentiometric surface, 4000-4900 ft slice, Victoria Co., all formations, all classes, data for all years. Includes formation pressure at Du Pont facility.

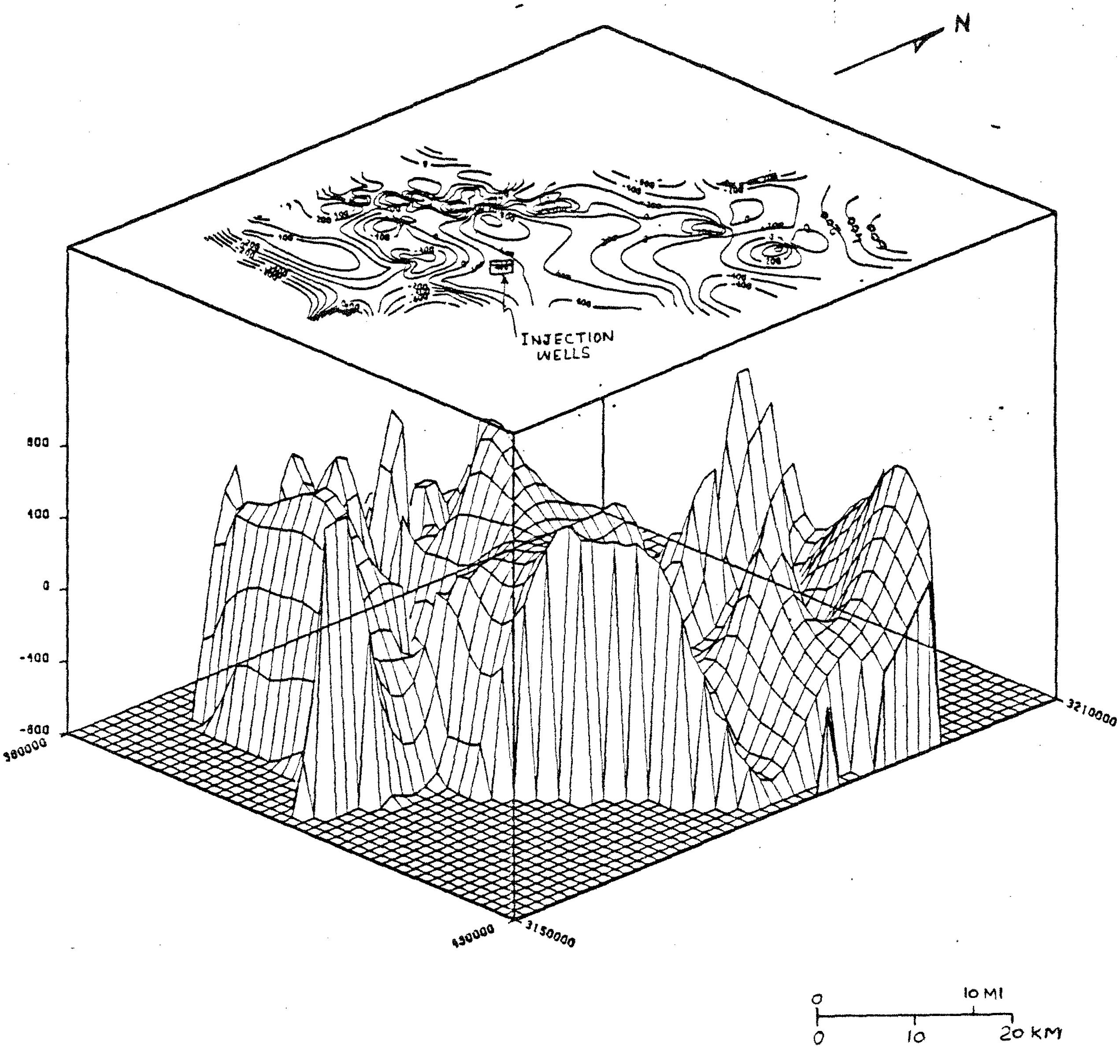

Figure 17. Isometric view of potentiometric surface, 4000-4900 ft slice, Victoria Co., all formations, all classes, data for all years. Includes formation pressure at Du Pont facility.

4.3 Residual Surface

For a qualitative definition of vertical flow potential, residual surfaces were created whereby the potentiometric surface in the uppermost interval (0-2,000 ft) was subtracted from the average potentiometric surface in the deeper (4,000-6,000-ft) interval. This residual surface is plotted on figure 18 in the plan view and on figure 19 in an isometric view. The positive contours on figure 18 reflect a fluid flow potential in the upward direction (that is, from deep toward shallow), and the negative contours imply a flow direction toward the deeper (downward) interval.

This residual surface map needs to be integrated with a structure map that locates faults and salt domes and with a deep well/abandoned borehole map. These maps show the possible permeability pathways, whereas the residual surface map shows the direction for potential flow.

5 DISCUSSION

5.1 Regional Trends

The pressure-depth profiles reflect the existence of two hydrologic systems in the Frio. Hydrostatic and subhydrostatic pressures exist in the depth interval above 10,000 ft. This is overlapped by an overpressured system observed as shallow as 6,000 ft. Extensive oil and gas development activity seems to have caused large scale depressurization and resulted in subhydrostatic pressures within the productive plays of the Frio. The overpressures at shallow depths indicate two possibilities: 1) There is continued compaction in the hydrostatic system in an environment of restricted drainage, and/or 2) Brines from deeper geopressured zones are leaking upward and have not yet completely equilibrated with the local lithostatic system. Two simultaneous processes could be occurring in the thick overpressured Frio section: compaction/overpressuring of the upper hydrostatic strata and equilibration/depressuring by upward leakage of the lower, already geopressured zones.

5.2 Implication of Depressurization and Overpressurization

The Frio Formation in the Gulf Coast has produced over 20 billion BOE (barrels oil equivalent) of hydrocarbons in the past 50 years of exploration and development. This may have led to extensive depressurization. This phenomenon is reflected in the localized depressions and negative contours on the potentiometric surfaces. Although some of these depressions may be temporal, they have serious

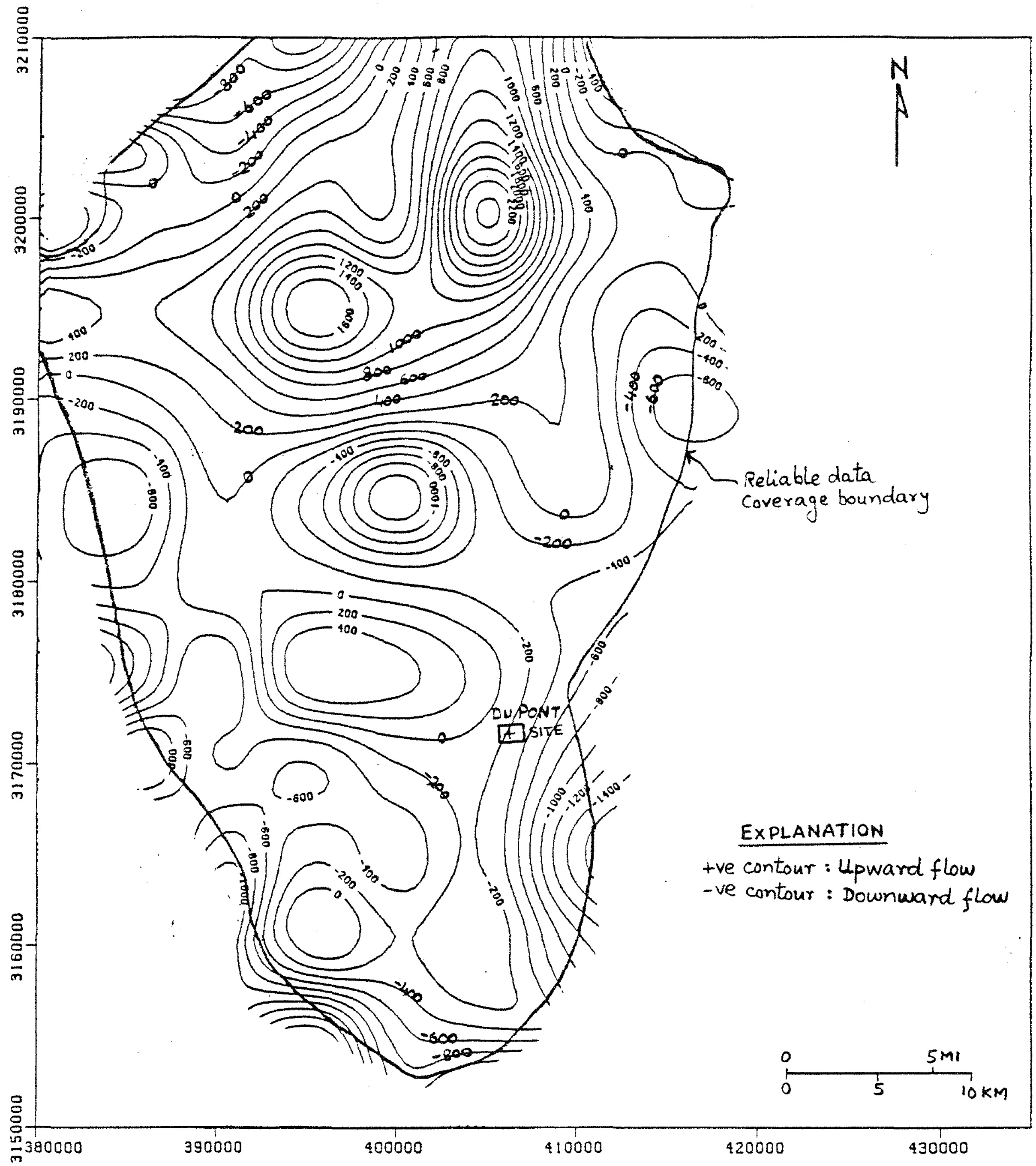

Figure 18. Residual potential surface, 4000-6000 ft minus 0-2000 ft slice, Victoria Co., all formations, all classes, 1965-85 data. Positive contours indicate upward flow, and negative contours indicate downward flow.

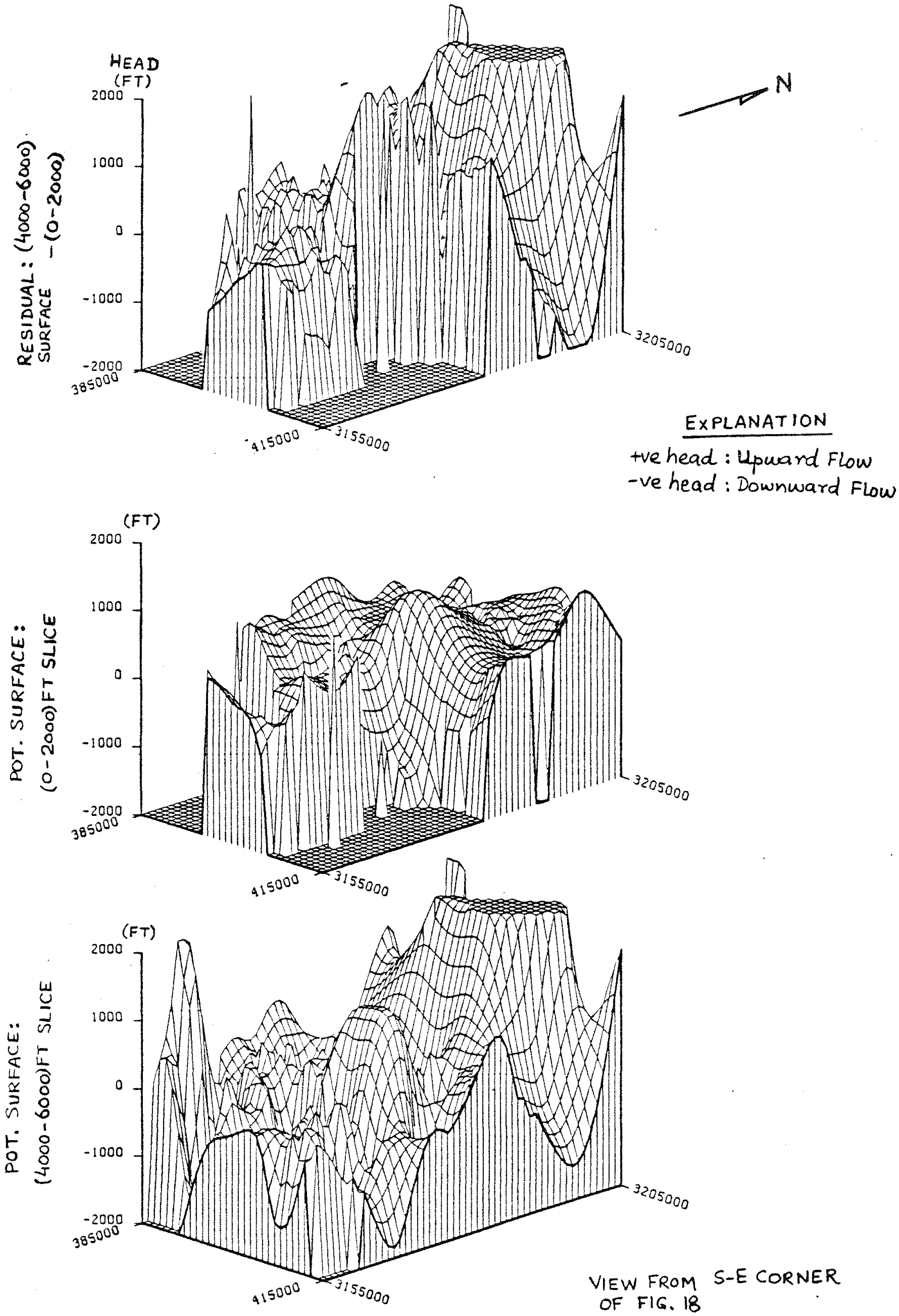

Figure 19. Isometric view of residual potential surface, 4000-6000 ft minus 0-2000 ft slice, Victoria Co., all formations, all classes, 1965-85 data. Positive contours indicate upward flow, and negative contours indicate downward flow.

implication for the regional trend in flow potential, in that the potential for fluid flow toward the oil and gas fields is enhanced. A reasonable degree of hydraulic continuity, high permeability, and a steep flow gradient could result in the flow of injected chemical wastes toward a depressured abandoned or producing field. At present we do not know how far the depressurized zone from an oil field may migrate laterally. Pressure declines may only be confined within a field, or they may migrate significantly far from the field, depending upon permeability, storativity, and presence of hydrologic barriers.

The phenomenon of overpressured conditions existing at relatively shallow depths is also complex. The presence of hydrostatic and overpressured conditions in the same depth range suggests compartmentalization that may be fault controlled. This compartmentalization may be important in locating future injection facilities.

5.3 Sensitivity of Potentiometric Surfaces to Data Selection and Fluid Density

The classification and screening system applied to the data-set allowed a more objective evaluation of the potentiometric surfaces. Surfaces were constructed with the highest confidence data (classes A, B, and Z) and were compared with surfaces for the same depth range and area resulting from all the pooled data (classes A, B, C, and D). The differences in these surfaces were analyzed and attributed to intra-class variance for a better explanation of some of the local variations in flow trends. This was helpful in culling some aberrant data from the data-set. Depressured and overpressured data introduce localized reversals in flow gradients that do not fit a smooth regional trend but that must be considered as a realistic reflection of existing conditions. The elimination of exceptionally high or low hydraulic heads relative to the surrounding values from the data-set resulted in more realistic regional surfaces. In instances of multiple head values for the same well location, retention of the highest class and highest head value eliminated some extreme heads that might represent a confined lateral or vertical hydrologic equilibrium.

The potentiometric surfaces for horizontal slices are considered representative of the regional trends since on the one hand they are not complicated by the extremes of highs and lows resulting from a mixing of depressured and overpressured data from different depths, and on the other hand they preserve the local variations in flow directions and hydraulic gradients.

A good example of the sensitivity of the potentiometric surfaces to data screening is the case of the 4,000-4,900-ft slice in Victoria County. The surface in figure 16 is constructed after eliminating some extreme high and low heads. This surface is relatively flat with near land-surface head values. These extreme values are identified within the circled areas of figure 20. The resulting potentiometric surface in figure 21, which includes all the extreme head values, exhibits greater localized highs and lows. Both these surfaces include an estimated pressure at Du Pont's injection site (Frank, 1986).

Sensitivity of the potentiometric surface to fluid density is demonstrated in figure 22 for the 4,000-6,000-ft slice in Victoria County. This surface is based on equivalent hydraulic heads computed with a fluid gradient of 0.465 psi/ft (an 80,000 ppm salinity brine with a 67.0 lb/cu.ft density). The surface in figure 22 exhibits similar characteristics to the surface in figure 14 (both are for the 4,000-6,000-ft slice), except the contours in the 0.465 gradient surface (figure 22) are lower by 150-200 ft than the corresponding contours in the 0.433 gradient surface (figure 14). The residual potential surface map (figure 18) would also change if figure 22 replaced figure 14. There would be fewer areas of upward flow. Which gradient (0.433 or 0.465) should be used to map potentiometric surfaces and residuals has not been determined. Salinities for subsurface waters are needed in Victoria County for better definition of brine densities at different depths.

This discussion of the sensitivity of the potentiometric surfaces highlights the need to examine the data-set very carefully, bearing in mind all the local variations possible within the context of the various pressure regimes.

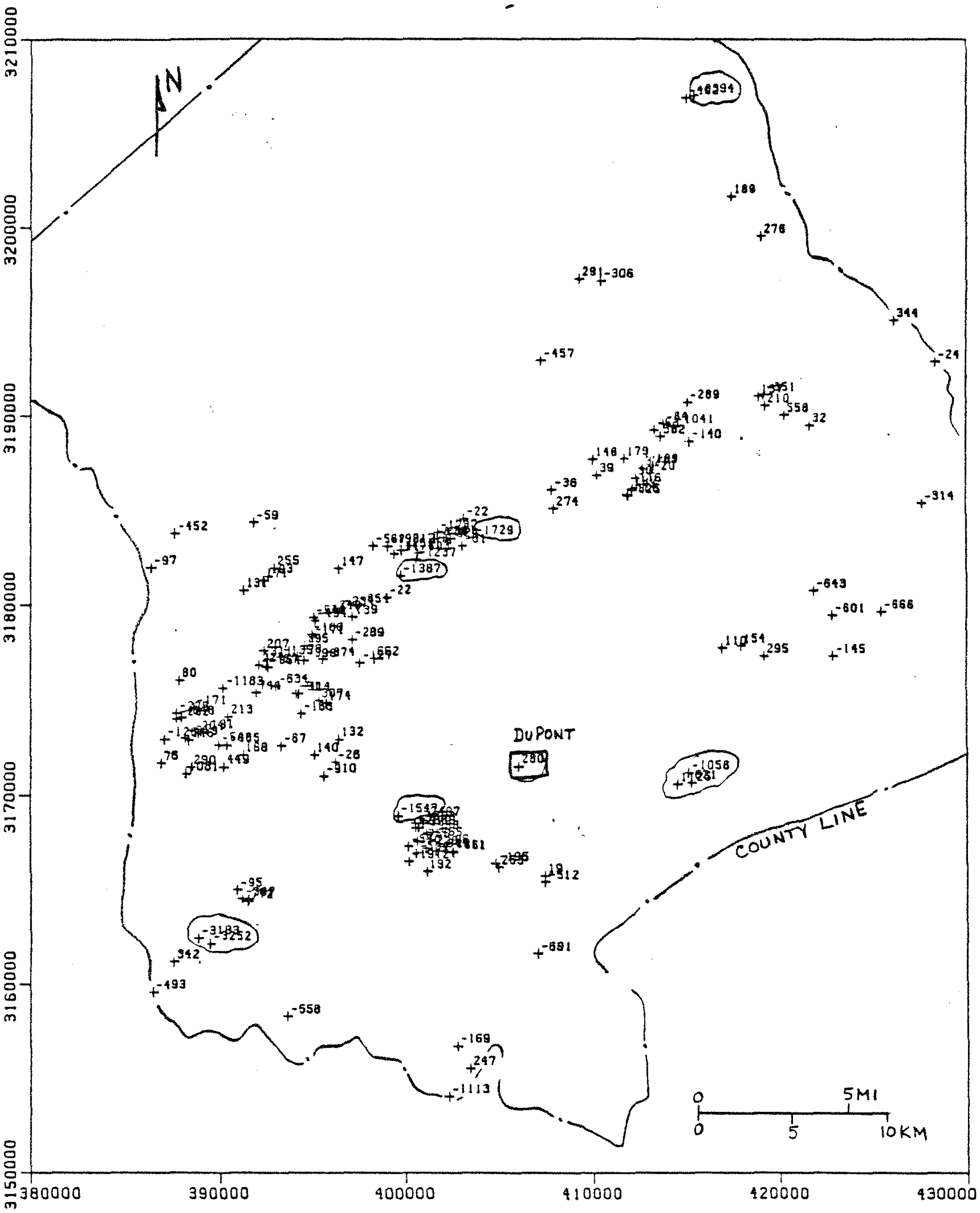

Figure 20. Hydraulic head values, 4000-4900 ft slice, Victoria Co., includes extreme head values, all classes, all formations, all years. Includes formation pressure at Du Pont facility.

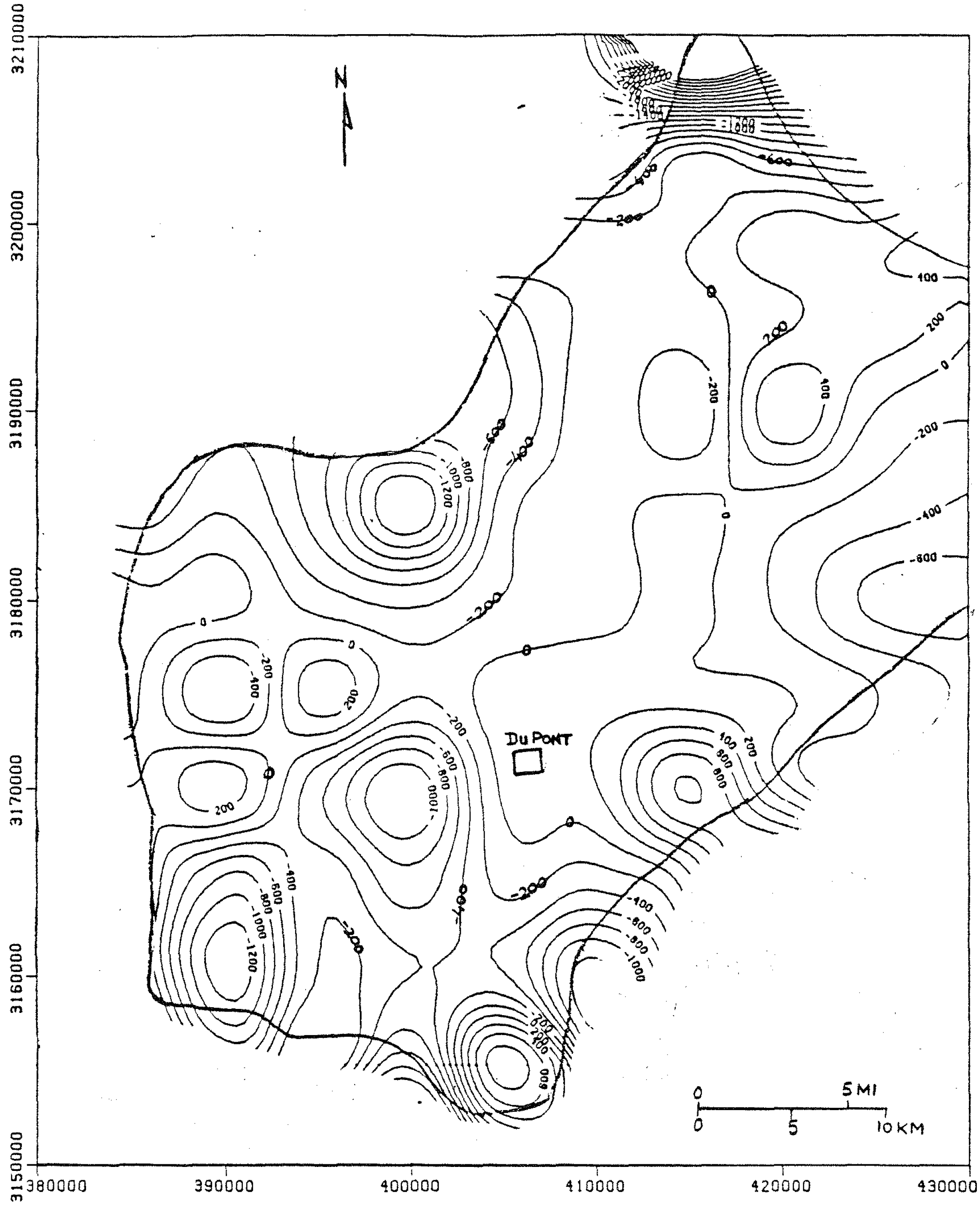

Figure 21. Potentiometric surface, 4000-4900 ft slice, Victoria Co., includes extreme heads, all classes, all formations, all years. Includes formation pressure at Du Pont facility.

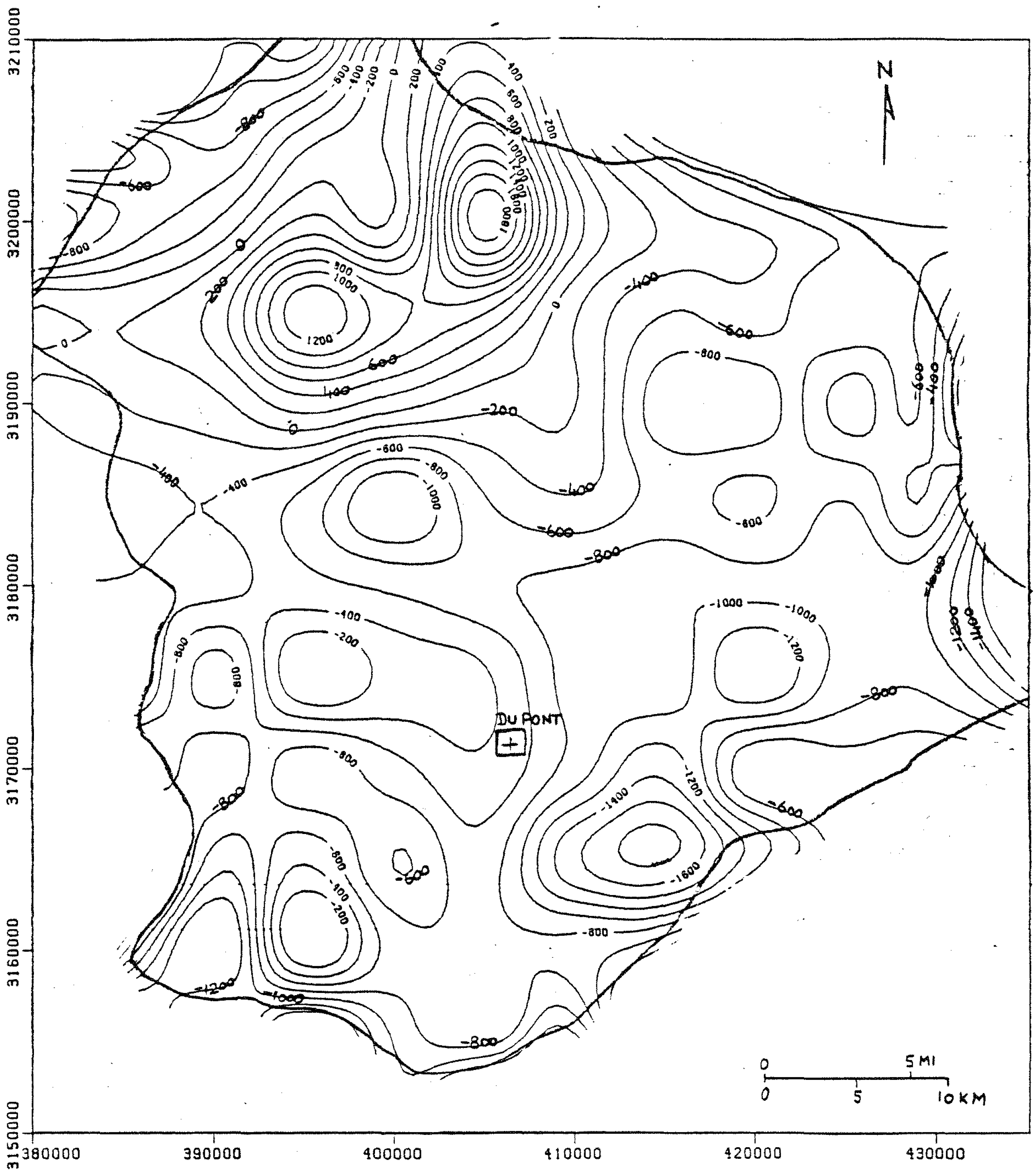

Figure 22. Potentiometric surface, 4000-6000 ft slice, Victoria Co., with 0.465 gradient, all formations, all classes, 1965-85 data. Includes formation pressure at Du Pont facility.

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