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Geologic Database Management and Computer Mapping

Topical Report

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by

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ABSTRACT

Computers play an increasingly important role in the interpretation and perception of geology. Stone & Webster Engineering Corporation has collected and interpreted a large amount of well data from the Permian Basin area in the Texas Panhandle and uses several computer programs to manage the data and to make maps that help analyze the data. Maps made by computer offer degrees of consistency and speed not readily available in manual contouring methods. Because of the speed of computer mapping programs, it is feasible to produce maps that would be prohibitively time consuming if manual techniques were used.

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1 INTRODUCTION

Computers play an increasingly important role in the interpretation and perception of geology. Computer analysis has repeatedly proven itself to be an effective tool for quickly interpreting a wide variety of geologic data. Computers and computer programs are available that offer options for efficiently presenting data in ways that cannot readily be done by hand. This report describes the data management and computer mapping programs Stone & Webster Engineering Corporation (SWEC) uses to support the stratigraphic and geologic structure studies and presents specific examples of the type of mapping that can be accomplished.

SWEC is Geologic Project Manager for the Permian Basin of Texas, as part of the Department of Energy's (DOE) Civilian Radioactive Waste Management (CRWM) Program. SWEC is contracted to Battelle Memorial Institute, which manages the Office of Nuclear Waste Isolation (ONWI) under contract to DOE. From 1977 to 1981, SWEC was Geologic Project Manager for the Salina Basin (encompassing parts of Michigan, New York, and Ohio). Responsibilities of the Geologic Project Manager include the acquisition, processing, and interpretation of large amounts of geologic data, principally from well records. For the Permian Basin, SWEC has continued to use and expand on geologic mapping and data management capabilities that were originally developed for the Salina Basin Project. SWEC has assembled an integrated system of computer programs to produce maps on an International Business Machines Corporation (IBM) mainframe computer in a batch environment. In addition, SWEC has an Intergraph interactive computer graphics system on a Digital Equipment Corporation (DEC) VAX computer that provides the project with several advantages over the batch process. Programs used on the IBM computer have been tested according to SWEC procedures, while the Intergraph programs are presently being tested.

The following programs are used by the project for data management and computer mapping on the IBM mainframe computer:

- FFIDAMS - a free format input data management system (SWEC, 1984)
- WELLMAP - data retrieval program that provides input to graphic programs (SWEC, 1983a)
- WELLPREP - a program that processes a FFIDAMS data file (SWEC, 1983b)

FOCUS - a commercially available on-line data management system (Information Builders, Inc., 1984)

SURFACE II - a commercially available graphics system/mapping program that we have modified for increased efficiency (Sampson, 1978)

The following programs are available on the DEC computer:

Intergraph - a commercially available hardware and software interactive graphics system (Intergraph 1983, 1984a, 1984b)

These programs are the basis for a system to store and retrieve data that we have collected from approximately 5,000 oil and gas wells in the Palo Duro Basin region and for preparing high-quality contour maps and cross sections. The Intergraph system provides expanded capabilities that include three-dimensional graphical representation, fault displacement of contours, interactive map editing, and use of a range of map projections. Each of these programs is discussed in Section 2.

2 SYSTEM DESCRIPTION

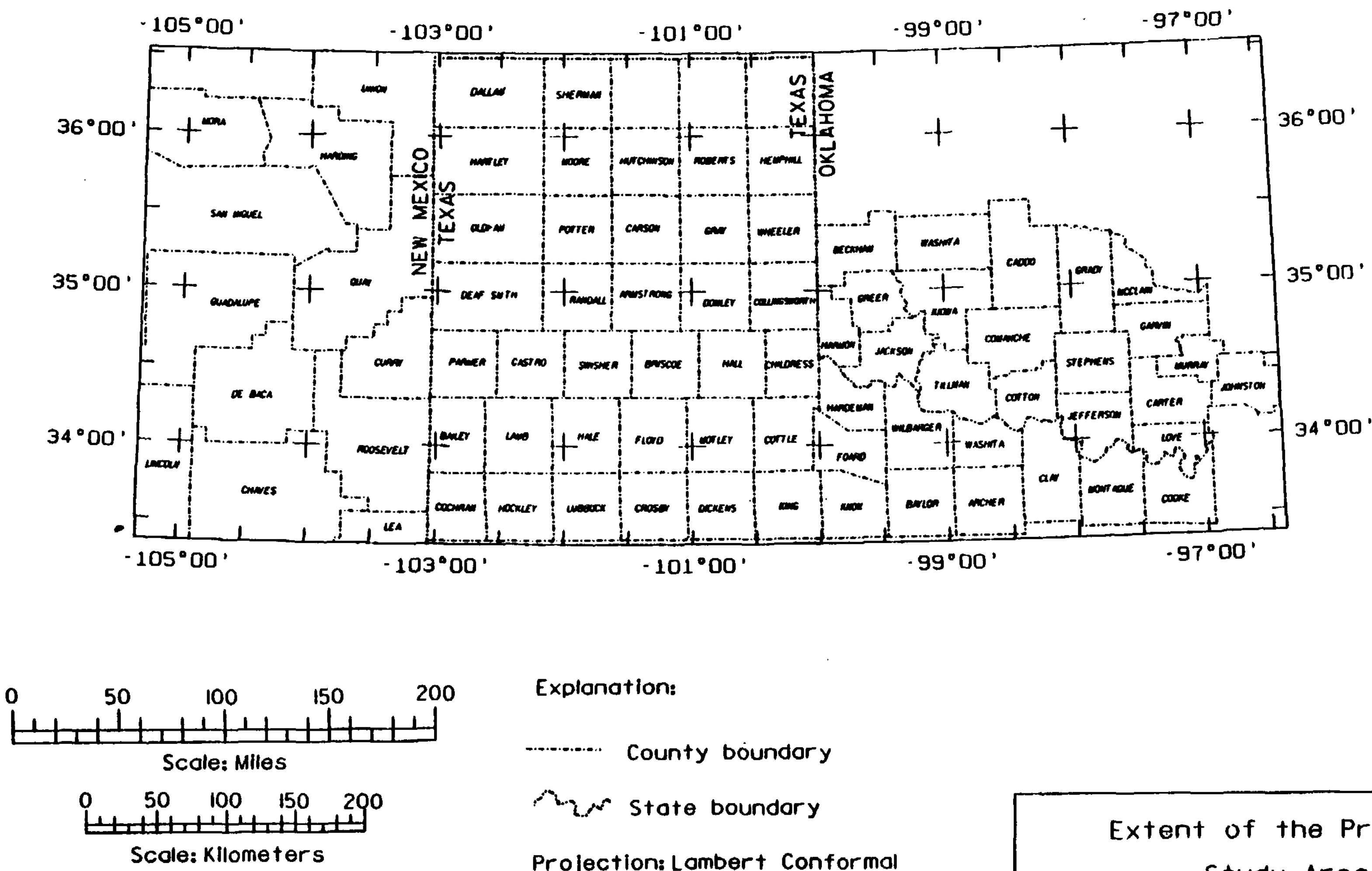
2.1 DATA MANAGEMENT

2.1.1 Database Description

We have an ongoing program to collect and interpret geophysical well logs for the oil and gas wells drilled in the Palo Duro and Dalhart basins of the Texas Panhandle, eastern New Mexico, and parts of Oklahoma. When this effort started in October 1980, the effort was confined to Texas. In 1982 the study area was expanded to include portions of eastern New Mexico and western Oklahoma.

Initially, we identified formations on geophysical logs from approximately 1,000 wells in accordance with conventions established by M. W. Presley of the Texas Bureau of Economic Geology (BEG). We have subsequently made some adjustments to those interpretations, but generally formation calls are consistent with those of the BEG. Presently, we are correlating more than 200 formations and other traceable units. Since January 1981, the database has been expanded to include a larger study area, salt layer data, and lithologic and hydrolithologic interpretations. We have begun to integrate seismic data with the petrophysical well data in the database. In addition, we are maintaining separate files of data from more than 8,000 water wells drilled in the Southern High Plains of Texas. The water well files list each well with its location, surface elevation, and, depending on the file, either the elevation of the base of the Ogallala, the elevation of the 1979 to 1981 water levels, or the elevation of the pre-1940 water level. These files are completely separate from the geologic database, and the file structures are not compatible.

To the present, data have been collected for approximately 5,000 oil and gas wells from 80 counties in Texas, New Mexico, and Oklahoma. The area is between 105.5 and 96.00 degrees west longitude and 33.50 and 36.50 degrees north latitude (Figure 2-1). In the Palo Duro Basin, data were collected for every available well within 100 km of the proposed site study areas; outside these areas, and in the Anadarko and Midland Basins, data were collected from all deep wildcat wells. However, in counties with only a few



Extent of the Project Study Area

Figure 2-1

wells, all available data were acquired. In Oklahoma, data were collected from about 20 wells in each of the counties east of the Texas Panhandle.

There are basically two sections of data within the database. The first section consists mainly of catalog information that includes:

- Operator, lease name, and permit number
- Well elevation, from which log depths were measured
- Reference for the elevation (usually Kelly Bushing)
- Latitude and longitude of well, accurate to the nearest .005 degree
- Date drilled, total depth, formation at bottom, and other information useful for identifying the well

The second section of the database consists of geologic formation and salt layer data that includes:

- Formation (or any unit to be mapped) name and identification number
- Depths to top and bottom of the unit
- Aggregate thickness of salt in the unit
- Status of unit or formation (i.e., absent, outcrop, questionable call, faulted)
- Other related data

We are presently maintaining information for almost 100,000 formation data records from the oil and gas well and water well files. There are several geologic studies in progress that are using and updating these data. These studies produce about 2,000 to 5,000 changes to the database each month. For the most part, these changes are reinterpretations of the well logs, but they also include corrections and additions to the file. Because of the volume of updates coming from several sources, detailed procedures were developed to assure the integrity of the file. The procedures require the Project Geologist to approve any changes that are to be made before they are entered and describe the methods used to assure that the approved changes are correctly made to the file. The procedures also describe methods to correct any erroneous data in the files. The procedures are independent of specific data management programs and can be used to verify any of our databases.

The data from the database are distributed to the various geologic studies in two forms. The most basic form is simple listing of the data. The listings can consist of several different formats, depending on which

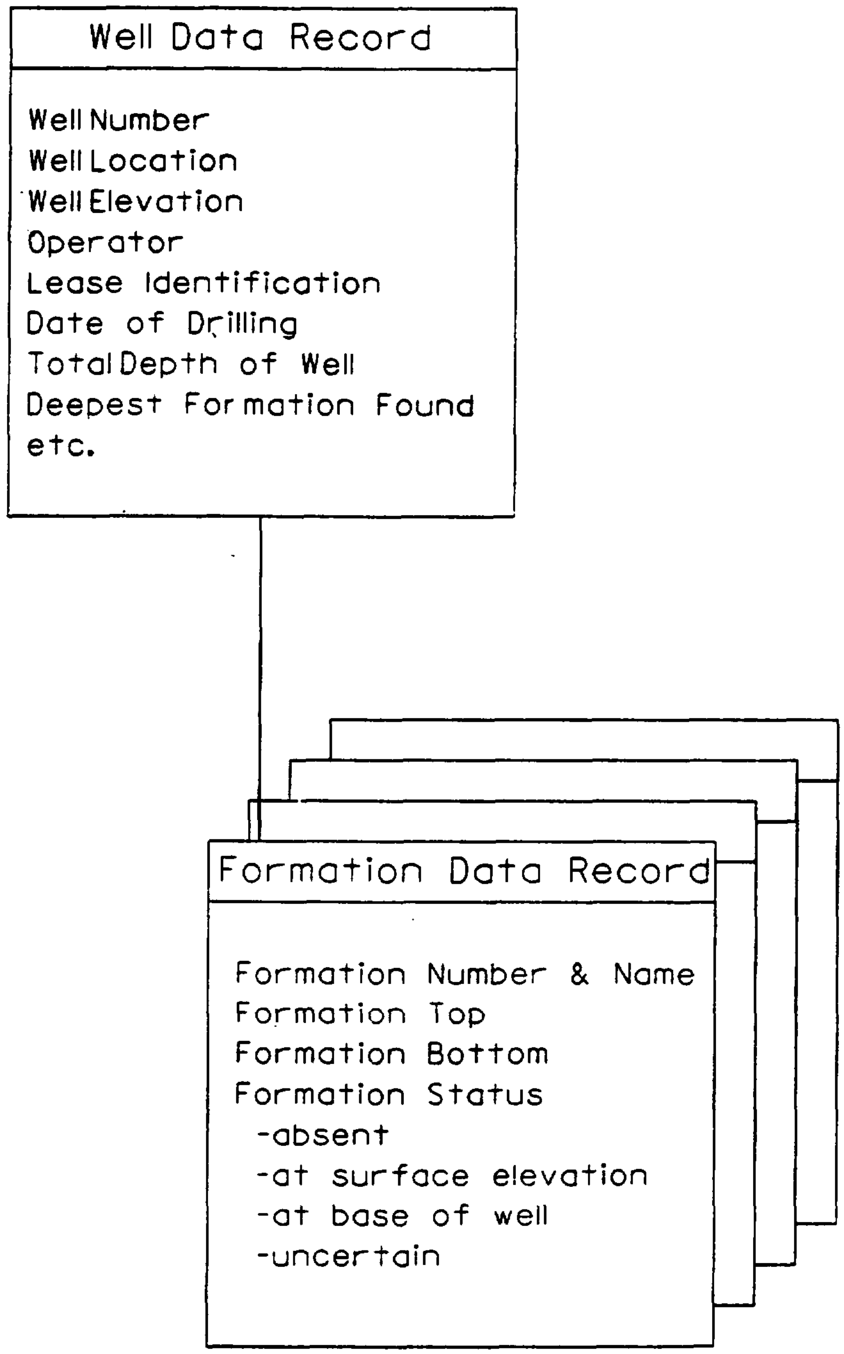
program was used to produce them (Sections 2.1.2 - 2.1.4). The second form is graphic output, such as maps. These maps (and other maps described in Section 2.2) are used to verify the database and help geologists interpret stratigraphic data.

2.1.2 FFIDAMS

The development of a computerized data storage and retrieval system began in 1978 when the Salina Basin well data became too numerous to manage by hand. After analysis of the project's needs, SWEC designed and implemented a system, written in FORTRAN, called FFIDAMS. This system is designed specifically to organize well geologic data.

FFIDAMS is a complete data management system that allows the user to design the structure of the database using a hierarchical model. We used FFIDAMS to define a database organized by state, county, and well number. The file may contain up to 999 wells for each county in each of 50 states. The data for each well consists of a single well data record and up to 999 repeating formation data records (Figure 2-2). The well data record contains well identification information such as operator, lease, date drilled, location, and elevation data. For every formation identified in a well, there is a single formation data record which contains the depth to the top and bottom of the formation and other data unique for that formation. This structure allows us to use only as much storage as is necessary for each well. A well with only one or two identified formations will require a relatively small amount of space to store the data as compared to a well with 150 or more formation records. The database can, therefore, store data for many wells while minimizing the size of the data file.

FFIDAMS also includes report writing capabilities in two basic formats (Tables 2-1 and 2-2). These formats allow flexibility in positioning data on the page and are adequate for most situations where a basic listing of the current data is required.



NOTE: The well data record occurs only once for each well. Any number of formation data records may be attached to each well data record.

Diagram of Data Structure

Figure 2-2

Table 2-1. FFIDAMS Report in Single Well Format

RUN 10/04/84 AT 18.04.53 FROM FILE CREATED 10/04/84 AT 16.25.34 PAGE 1164
IS-234 FFI/DAMS VER 01 LEV 00 PROG REPORT LKED 80.345 09.58.25

WP.70A..REPORT2.VERSION1

STATE=TX ONWI-PERMIAN BASIN

WELL CATALOG INFORMATION NO. 1

CNTY	WELL		FORMATION	DEPTH TOP		DEPTH BOTTOM	SURFACE ELEVATION		LATITUDE	LONGITUDE
DEA	36 S	0	SURFACE	0	S	1	4025	KB	035.0628	-102.4600
		60	DOCKUM	394		1096				
		100	DEWEY LAKES	1096		1188				
		110	ALIBATES	1188		1213				
		120	SALADO	1213		1280				
		130	YATES	1280		1348				
		140	U SEVEN RIVER	1348		1494				
		150	L SEVEN RIVER	1494		1686				
		160	QUEEN/GRAYBUR	1686		1885				
		170	U SAN ANDRES	1885		2368				
		200	L SAN ANDRES	2368		3018				
		214	SALS	0		0				
		215	U7RS	0		51				
		216	L7RS	0		16				
		217	USAS	0		172				
		218	LSAS	0		320				
		219	GLOS	0		89				
		220	UCFS	0		75				
		221	TUBS	0		0				
		222	LCFS	0		150				
		310	LSA5	2368		2566				
		315	LSA5T	2402		2476	74			
		330	LSA4	2566		2822				
		335	LSA4T	2570		2731	161			
		350	LSA3	2822		2945				
		355	LSA3T	2822		2894	63			
		370	LSA2	2945		3018				
		390	LSA1	3018	A	3018				
		410	GLOREITA	3018		3643				
		420	U CLEAR FORK	3643		4148				
		430	TUBE	4148		4382				
		440	L CLEAR FORK	4382		4702?				
		445	LCFT	4551		4646	95			
		450	RED CAVE	4702		5253				
		460	WICHITA	5253		5582				
		470	WOLFCAMP	5582		6798				
		500	PENNSYLVANIAN	6798		T				
		902	TSAL	1213		1213	0			
		904	TU7R	1440		1467	27			
		906	TUSA	1961		2023	62			
		908	TLS5	2402		2476	74			
		910	TLS4	2570		2731	161			
		912	TLS3	2822		2877	55			
		914	TLS2	2945		2974	29			
		916	TLS1	3018		3018	0			
		918	TGLO	3018		3045	27			

Table 2-2. FFIDAMS Report in Multiple Well Format

RUN 7/18/84 AT 16.40.42 FROM FILE CREATED 6/29/84 AT 17.13.30 PAGE 116
IS-234 FFI/DAMS VER 01 LEV 00 PROG REPORT LKED 80.345 09.58.25

HP.77A..REPORTS.VERSION0 CHECKED BY____,ON__/__/__

COUNTY=DIC OMNI-PERMIAN BASIN JOB 13697.77

WELL #	ELEV	DEPTH TO TOP OF FORMATIONS																	
		SURF	ALIB	SALA	YATE	U7R	L7R	QUEE	USA	LSA	GLOR	UCF	TUBB	LCF	REDC	WICH	WOLF	PERM	MISS	PREC
1	3000	0					635	820	1104	1625	1987	2262	2622	2850	3130	3380	4020			
2	2976	0									2840	3112	3448	3630	3902	4140	4800	6812	8172	8722
3	2766	0										2862	3264	3439	3710	3980	4612	6585	7911	8518
4	2619	0			498	638	860	1068	1360	1890	2300	2560	2910	3140	3385	3640	4238	6230	7756	8128
5	2435	0				338	499	707	964	1453	1850	2085	2450	2680	2910	3150	3812	5520		
6	2800	0	510	530	724	870	1102	1316	1635	2155	2593	2910	3298	3535	3790	4040	4690	6565		
7	2532	0			342	461	630	878	1185	1675	2060	2302	2640	2835	3080	3358	3915			
8	2404	0											2298	2520	2755	3008	3635	5692	7253	7660
9	2670	0			627	750	943	1167	1447	1950	2348	2602	2917	3067	3360	3645	4280	6230		
11	2452	0	285	305	450	601	842	1075	1400	1905	2298	2590	2908	3063	3365	3645	4230	6275		
12	2615	0			739	885	1145	1370	1600	2205	2608	2920	3265	3425	3710	4015	4682	6665		
13	2346	0					717	945	1200	1750	2136	2410	2732	2890	3175	3475	4275	6253		
14	2298	0								1868	2270	2570	2883	3030	3348	3625	4248	6303	7570	8045
15	2243	0				130	396	614	946	1390	1736	1992	2322	2490	2749	3021	3781	5538		
16	8	0																		
17	1886	0							360	750	1026	1305	1645	1856	2039	2310	3048	5050	6600	
18	1939	0							301	845	1201	1420	1749	1962	2140	2410	3133	5242		
19	2027	0								982	1302	1540	1865	2070	2263	2526	3225	5425	6770	
20	2148	0							465	952	1298	1510	1850	2071	2250	2520	3270	5132	6783	
21	1975	0								780	1115	1320	1660	1877	2063	2320	3065	5006	6590	
22	2215	0							618	1090	1428	1671	1998	2204	2415	2676	3458	5300	6900	
23	2197	0						388	717	1230	1580	1830	2158	2350	2571	2816	3577	5488	7020	7480
25	2427	0	200	212	367	508	757	970	1278	1785	2155	2428	2730	2912	3200	3500	4144	6190		

Although FFIDAMS is a useful and versatile program, it does have a few limitations that include:

- Minimal error checking and data validation
- Somewhat inefficient data input and output
- Limited report writing capabilities (i.e., it is not possible to print a list of wells based on the relationships of several data items)

In spite of these shortcomings, FFIDAMS is able to do a good job of organizing and updating the large amount of data used by the project.

2.1.3 FOCUS

A solution to the limitations of FFIDAMS was found in a program called FOCUS. FOCUS is a commercially available data management product that offers the ease of use and sophistication missing from FFIDAMS. It is beyond the scope of this report to fully describe all the features that FOCUS offers, but the following items are of immediate importance to the project:

- On-line data entry
- Ability to read FFIDAMS data files
- Powerful command language
- Temporary joining of several databases for reporting purposes
- Reports using multiple search criteria

FOCUS also allows the definition of a database structure best suited to the data. It is thus possible to define a structure that is compatible with the FFIDAMS data structure (Figure 2-2). The FOCUS data definition made it feasible to read the FFIDAMS database file into a FOCUS file and to use the same update procedures and files on both systems. The major advantages of FOCUS are that it is very easy to produce reports that are not available from FFIDAMS and to produce output files that can be used directly by SURFACE II and intergraph for contouring.

2.1.4 WELLPREP and WELLMAP

In response to the Salina Basin Project needs, FFIDAMS was written solely as a data manager without regard for its use as input to analytic or

graphic programs. However, it became apparent that computer mapping of the well data would be a valuable tool for aiding geologic interpretations of the collected data. In order to transport data from the FFIDAMS file, currently referred to as the Permian Basin Master File (PBMF), to an environment where maps could be produced, a preprocessor program called WELLPREP was written. The primary purpose of WELLPREP is to reformat the PBMF so that it can be used more efficiently by plotting programs.

WELLPREP uses the PBMF as input and produces a WELLMAP Data File (WMDF) as output. As part of the process, WELLPREP converts well locations specified in a degree-minute-second format to a decimal-degree format, calculates formation thickness and elevation, and validates the data. WELLPREP contains lists of proper state, county, and formation names for use in this validation. WELLPREP can also print a report of the formation elevation and thickness in selected counties (Table 2-3); however, it does not include options that permit the user to alter the format of this report.

WELLMAP uses the WMDF to produce two separate types of output. First, it may be used to produce sketches that aid the preparation of cross sections. WELLMAP calculates the distance between the selected wells and plots them either as a well-to-well section or by simply projecting them to a user-specified section line without adjusting strata for structure. The user specifies the vertical exaggeration and the top and bottom elevations of the interval to be plotted. WELLMAP plots the well axes, marks the top and bottom of every formation, and identifies each formation with a four-letter abbreviation (Figure 2-3). Correlation and interpretation between wells are left to the geologist.

WELLMAP's principal function is to select data to be used for map generation by SURFACE II. WELLMAP can be used to extract data from the WMDF created by WELLPREP. The user is provided options for either selecting specific wells, selecting all of the wells in a county, or selecting all of the wells within designated latitude and longitude boundaries. The user specifies a formation name and whether the elevation, depth, or thickness of the formation is to be mapped. WELLMAP can be used to set up data files that could be used later by SURFACE II; alternatively, SURFACE II commands

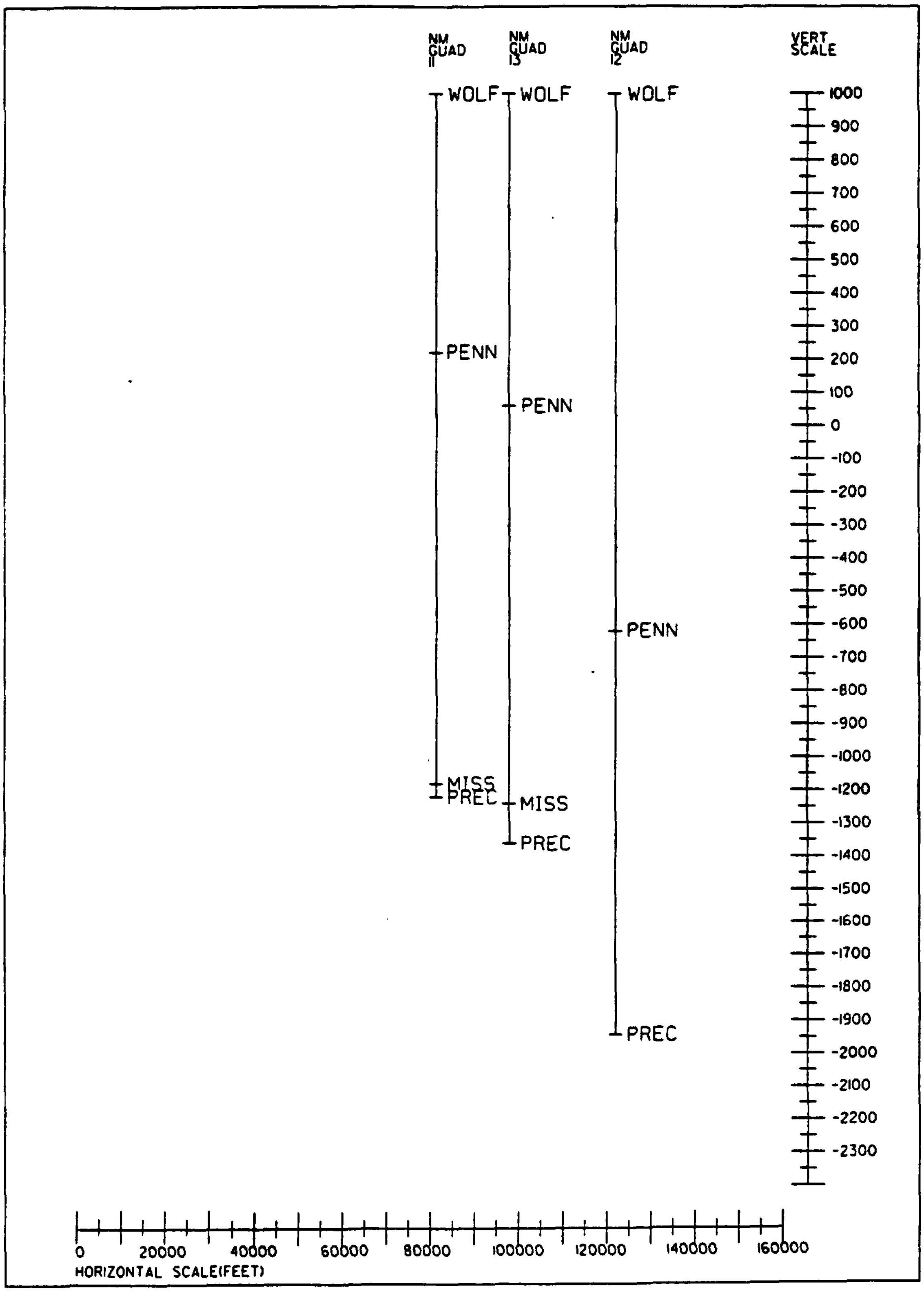
Table 2-3. WELLPREP Report

STATE: NM
COUNTY: QUAY
WELL NUMBER: 43

WELL SURFACE ELEVATION: 4318. FEET
LATITUDE : 35.11520 DEGREES
LONGITUDE: -104.09500 DEGREES

INTERNAL REFERENCE NUMBER	ABBREVIATED NAME	NUMBER	TOP ELEVATION	THICKNESS
9	SANT	75	3324	222
10	DEHE	100	3102	0
11	ALIB	110	3102	0
13	SALA	120	3102	0
15	YATE	130	3102	80
16	U7R	140	3022	30
20	L7R	150	2992	98
21	QUEE	160	2894	112
23	USA	170	2782	170
27	LSA	200	2612	458
28	LSA5	310	2612	76
31	LSA4	330	2536	184
32	LS4T	335	2534	144
34	LSA3	350	2352	150
36	LSA2	370	2202	32
38	LSA1	390	2170	16
40	GLOR	410	2154	700
42	UCF	420	1454	366
43	TUBB	430	1088	172
44	LCF	440	916	0
46	REDC	450	916	896
51	HICH	460	20	0
52	HOLF	470	20	038
53	PENN	500	-818	1548
54	HISS	600	-2366	310
63	ELLE	700	-2676	98
67	CAMB	800	-2774	0
68	PREC	900	-2774	-1
70	TSAL	902	3102	0
71	TU7R	904	3022	0
72	TUSA	906	2782	0
73	TLS5	908	2612	0
74	TLS4	910	2534	144
75	TLS3	912	2294	46
76	TLS2	914	2202	0
77	TLS1	916	2170	0
78	TGLO	918	1620	6
79	TUCF	920	1119	13
80	TLCF	922	916	0
81	TYAT	930	3102	0

INTERNAL REFERENCE NUMBER	ABBREVIATED NAME	NUMBER	TOP ELEVATION	THICKNESS
82	TQNG	932	2094	0
83	TTUB	934	1088	0
84	SALS	214	4318	0
85	U7RS	215	4318	0
86	L7RS	216	4318	0
87	USAS	217	4318	0
88	LSAS	218	4318	191
89	GLOS	219	4318	8
90	UCFS	220	4318	70
91	TUBS	221	4318	0
92	LCFS	222	4318	0
93	YATS	223	4318	0
94	QUES	224	4318	0



Example of WELLMAP Cross Section

Figure 2-3

can be included in WELLMAP so that it is not necessary to run SURFACE II separately.

2.2 GRAPHICS PROGRAMS

While database management programs are used to organize the stratigraphic information, the main purpose for collecting and analyzing the data is to gain a clear understanding of the geology of the study area. Cross sections and contour maps are among the basic tools that geologists use to help them analyze and interpret stratigraphic data. Many types of geologic data may be represented by contour maps, but the most common are formation elevation and thickness maps.

Creating a contour map is an interpretive process that can be very time consuming, but there are computer programs available that can speed up the process. Computer contouring presents the geologist the opportunity to perform complex data manipulations to an extent that is usually not feasible otherwise. Sometimes these manipulations entail changing various map projections or scales; other manipulations can alter the way the contoured surfaces are perceived. Conventional contour maps, either those drawn by computers or by hand, are two-dimensional representations of three-dimensional surfaces. Advances in computer mapping techniques make it easier to contour in three-dimensions and to combine several horizons in the same file, which adds an even greater degree of sophistication to the interpretation compared to conventional mapping techniques.

Even though computer mapping is a valuable tool, there are limitations to the systems. When a computer produces a contour map, it creates a numerical model of the surface. The computer is not able to use any of the insight or experience of the geologist. As a result, the maps made by computer require careful evaluation of the interpretation they present. The characteristics and relative merits of the specific mapping programs we use are discussed below.

2.2.1 SURFACE II

SURFACE II is a well-known computer graphics program that runs on a variety of mainframe and minicomputers. Input typically consists of

randomly-spaced X-Y-Z data points that are used to generate a regularly-spaced grid of Z'-values. This grid of Z'-values is then used to draw the contours.

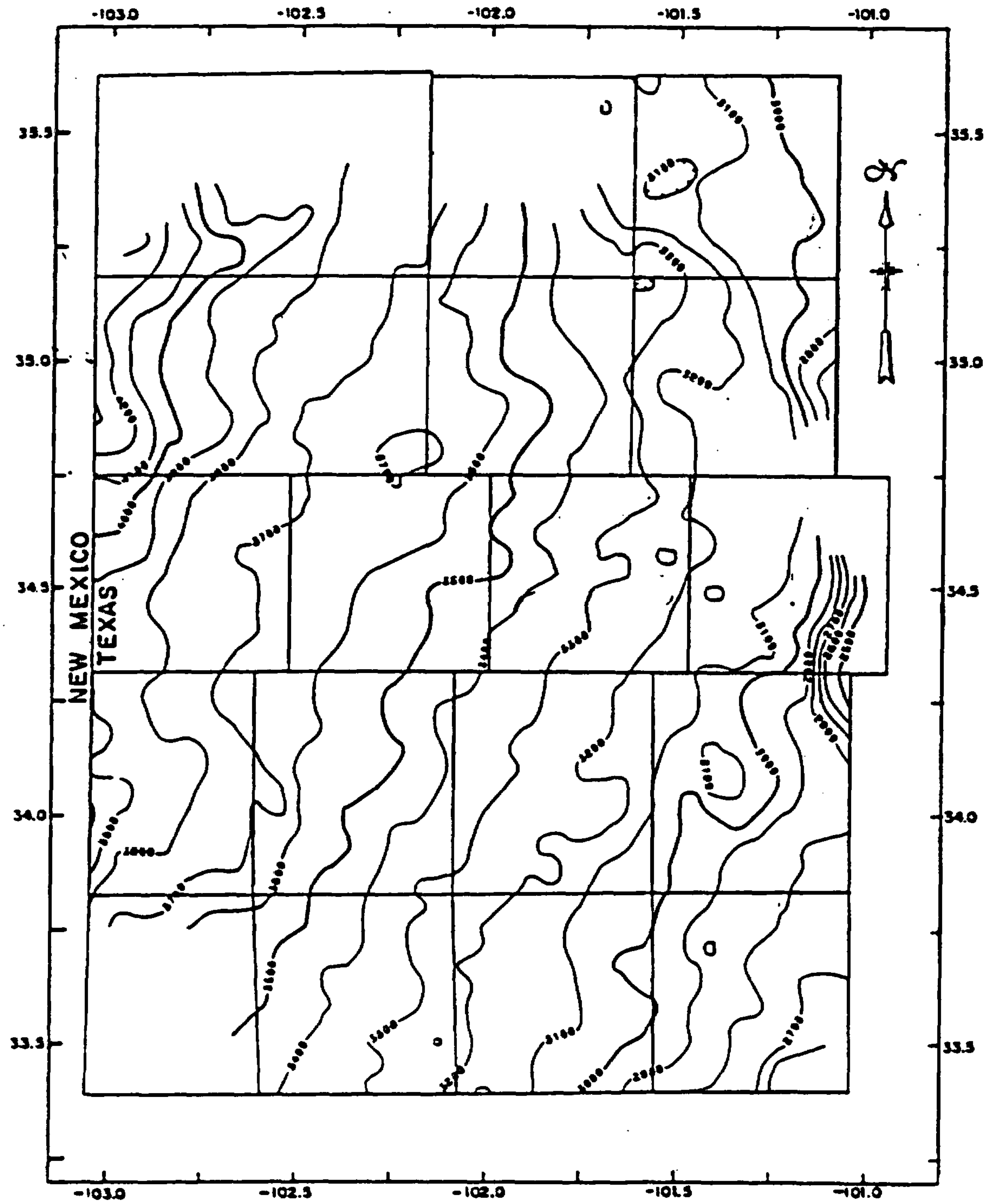
SURFACE II uses a two-part, weighted average of the nearest data points to calculate the Z'-value of each grid node. In an initial pass, the slope of the surface is estimated at every data point. A search procedure finds the nearest neighbors to the data point being considered and fits a weighted trend surface to these points. Weights inversely proportional to the distance from the data point being evaluated are assigned to the other points. The constant of the fitted regression equation is adjusted so the plane passes exactly through the data point. The coefficients of the trend are saved for each data point.

The second part of the algorithm estimates the value of the surface at the grid nodes. A search procedure finds the nearest neighboring data points around the node to be estimated. The X and Y coordinates of the grid node are substituted into each of the local trend-surface equations associated with these data points, in effect projecting these local surfaces to the location of the node. A weighted average of these estimates is then calculated, weighting each slope by the inverse of the distance between the grid node and the data point associated with the slope. If a data point lies at or very near a grid intersection, the value of the data point is used directly as the value of the grid node.

SURFACE II computer code has a modular structure, allowing the addition of functions to improve its usefulness. We have added functions that provide the following capabilities:

- Overlay one map upon another
- Add text anywhere on the map
- Select different line types (solid, dashed, etc.)
- Add title block and legend commands
- Increase file traceability
- Fix various inconsistencies and internal problems
- Modify the overlay structure of the program to increase execution speed

The version of SURFACE II resulting from these changes produces maps of near-publication quality with a minimal amount of user effort (Figure 2-4).



Explanation:

Contour Interval: 100 Feet (30 Meters)

0 50
Scale-Miles

0 80
Scale-Kilometers

Typical Surface II
Contour Map

Figure 2-4

SURFACE II produces a generalization of the data that requires close scrutiny by experienced users. SURFACE II will, under minimal user control, use the trend of the input data to project surfaces into areas where there are no data. This can be useful in predicting where a horizon may be located in areas of sparse well control, but slope projection may be disadvantageous in certain circumstances. For example, projecting slopes may create spurious highs or lows in areas of sparse control if dips are projected from areas of tightly clustered control points. In areas of no well control, SURFACE II can produce contours that are unreasonable geologically.

Typical of most contouring programs, SURFACE II has limitations which must be understood for effective use of the program. A disadvantage of the method of going from randomly spaced data to an evenly spaced grid is that the original data points are not used to make the final graphical representation. The output of SURFACE II is a graphic representation of the grid values, rather than the original data points, and the contour lines may not always strictly honor the data points. Also, the basic assumption in the SURFACE II program is that the data represents a continuous surface. Contours cannot be offset along fault zones. Finally, SURFACE II is a batch program that does not afford the user direct control over the appearance of the final map. Often it is necessary to go through a trial and error plotting sequence before producing titles, county names, scale bars, and contours that are suitable for a final map.

2.2.2 Intergraph System

The Intergraph system provides three-dimensional interactive graphics for structural and stratigraphic modeling of geologic formations. In addition to producing standard contour maps and cross sections, this system provides the ability to contour faulted surfaces, to create three-dimensional (block) diagrams, to plot maps in a variety of commonly used cartographic projections, and to calculate and map cut-and-fill volumes and slopes. The integrated hardware and software system allows the user to manage the mapping process in a single environment. Each Intergraph software package is generally self-contained and discipline-specific. At the same time, data can

be shared by all of the software packages and combined to create a network of capabilities.

Original data are input to the system in X-Y-Z format such that each line of data contains the location of a data point (X and Y) and the contourable value at that point (Z-value). These data may be the direct output of the WELLMAP or FOCUS programs described above.

The first step toward a contour map is the creation of a triangulation file. This preliminary model of the surface to be contoured is made up of triangular surface elements connecting every three nearest data points. The vertices of each triangular element have the Z-values of the constituent data points, and the surface slope of the triangle is calculated accordingly. Next, a rectangular grid of user-specified density is superimposed over the triangulation surface. The Z-value for each grid node is interpreted directly from the slope of the triangle at that location. It is this regularly-spaced grid of values that is used to draw the contours.

Both the triangulation file and the grid file can be graphically displayed in either two or three dimensions. The three-dimensional triangulation file may be used to produce a color-shaded model. The triangles may be color-coded according to the average elevation of the three vertices and can be shaded from a chosen perspective. The three-dimensional grid file is a coherent surface that can be used to depict multi-layered surface models, volumetric calculations, or cross sections.

The data in a model can be graphically modified at any stage of the contouring process. Points added, deleted, moved, or redefined at any step will in turn modify the subsequent steps. Entire areas may be deleted, modified, or set to an arbitrary value. By changing contours, the gridded representation of a surface can be redefined to reflect the geologists' interpretation of the data more closely. All surfaces can then be contoured as modified. Each step of the mapping process can be saved and the original data is unaltered by the modifications to the graphic model.

Data used on an Intergraph mapping project may come from many sources including digitized maps, previously built Intergraph models, coordinate data from a computer file, or data entered directly from the keyboard. These various data, which may occur in many possible formats using different coordinate systems, can be translated into a common coordinate system, such as latitude and longitude. The user thus has the capacity to merge a variety

of map segments differing in size and scale into a single continuous map of the desired area. Conversely, large area maps stored as a continuous base map can be segmented for maintenance or analysis in separate projects.

The user communicates interactively with the system in several ways: by typing commands from a keyboard, by specifying commands from a tablet menu, or by specifying commands on a screen menu. The user is in constant communication with the system and can evaluate and modify the results of each command as it is executed. Maps completed in this interactive, user-controlled environment can be stored in memory for future use. Portions can be copied and reused in related projects. The creation commands need not be rerun to produce a copy, as would be the case with a batch process.

The Intergraph system is thus a complete mapping environment that affords the user many advantages over batch processing on the mainframe computer, but there are limitations to the system. A system as powerful as Intergraph which offers flexibility in map creation is not a system that is immediately easy to use. There are many programs containing many commands that must be understood before they can be used efficiently. The difficulty may be compounded by the complexities of working in three dimensions as opposed to two. This problem is surmounted by a careful training program. Other problems with the system are relatively minor, such as lack of hidden-line removal in three-dimensional models, and the fact that fault displacements are not reflected in cross sections.

Intergraph contour mapping programs presently do not have some of the features found in SURFACE II. For example, SURFACE II allows the user to specify several combinations of gridding options, weighting functions, and search criteria to make up the contouring algorithm, while Intergraph offers a limited number of contouring packages which are not intended for extensive user modification. The maps from both systems are similar, but Intergraph coutours are often more angular and machine-like in appearance. Usually, the lack of these features is more than offset by the advantages of Intergraph's interactive processing of data.

3 SAMPLE APPLICATIONS

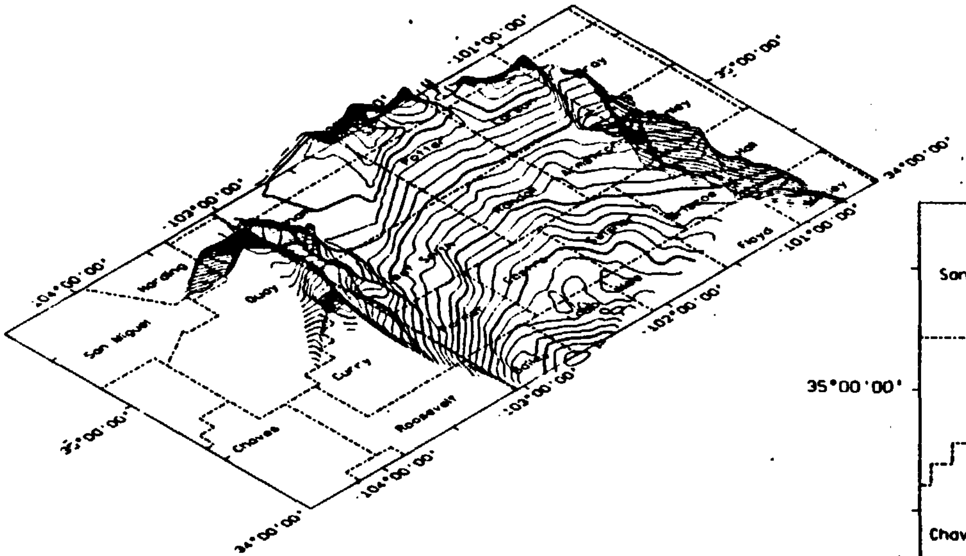
This report describes how the data management and graphic capabilities are used to help interpret subsurface geologic conditions. In order to clearly explain the methods used, the following examples were developed on the Intergraph system. Elevation data for the Ogallala, Alibates, Upper San Andres, Glorieta, Wolfcamp, Pennsylvanian, and Precambrian strata for an area surrounding Carson County, Texas, were first extracted (using FOCUS) from the database. The data were checked for accuracy, then models for each of these surfaces were produced and saved on the system. Each model may be plotted as a conventional contour map or as an oblique view of a three-dimensional contour map (Figure 3-1). It is also possible to plot an oblique view of a three-dimensional grid of the surface (Figure 3-2). The oblique views provide a perspective view of the data that can be helpful for picturing the surface, but they provide little quantitative data.

Once a surface model has been created, it is possible to produce a cross section using the model as input (Figure 3-3). Using the surface model to draw a section line adds a level of detail that would be missing from cross sections drawn by simply correlating formation tops between wells. The surface model cross sectioning process also assures that the structures present in the contour maps are consistently represented in the sections.

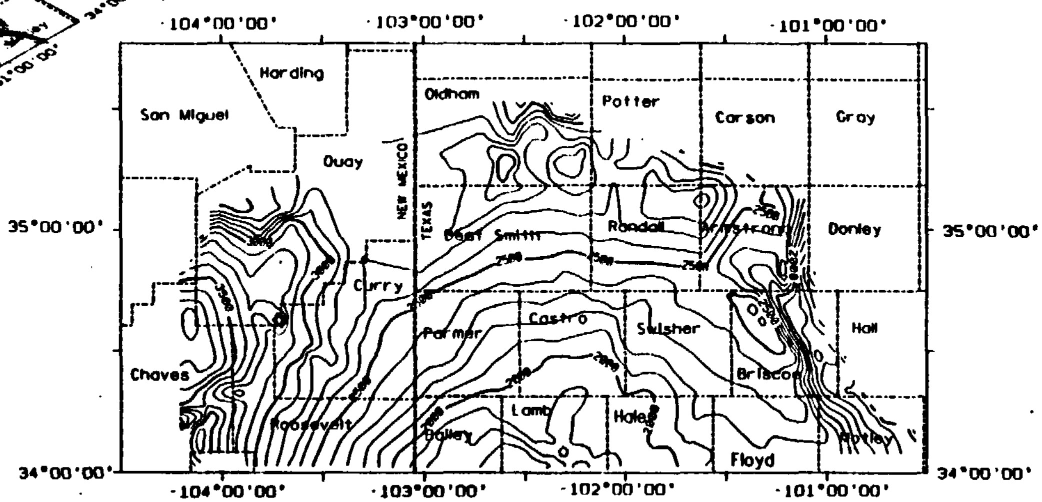
It is relatively simple to build a more complex cross section than Figure 3-3 by adding several horizons to the same figure and adding a graphic pattern between the horizons (Figure 3-4). More than one section can be placed in a drawing at one time, making it possible to produce fence diagrams (Figure 3-5) or block diagrams (Figure 3-6), depending on the location and orientation of the sections. The sections and block diagram incorporate all of the structures displayed in the contour maps.

In addition to producing the contour maps shown on Figure 3-1, it is possible to make contour maps that are automatically adjusted for any faults placed on them (Figure 3-7). Unlike the contoured surface maps, these faults are two-dimensional and cannot be used to produce three-dimensional figures easily.

Isometric View of Contours



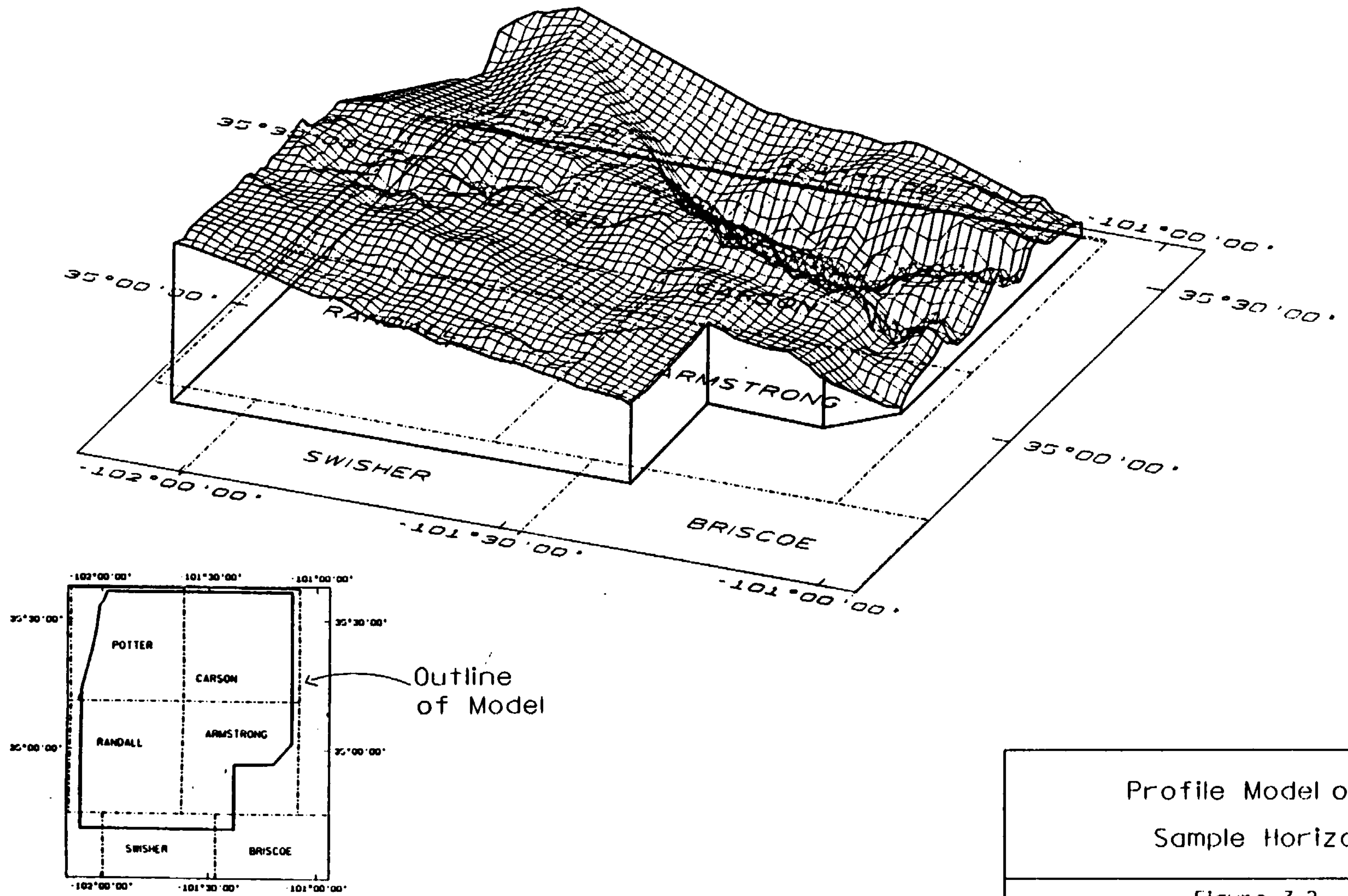
Top View of Contours



Two Views of

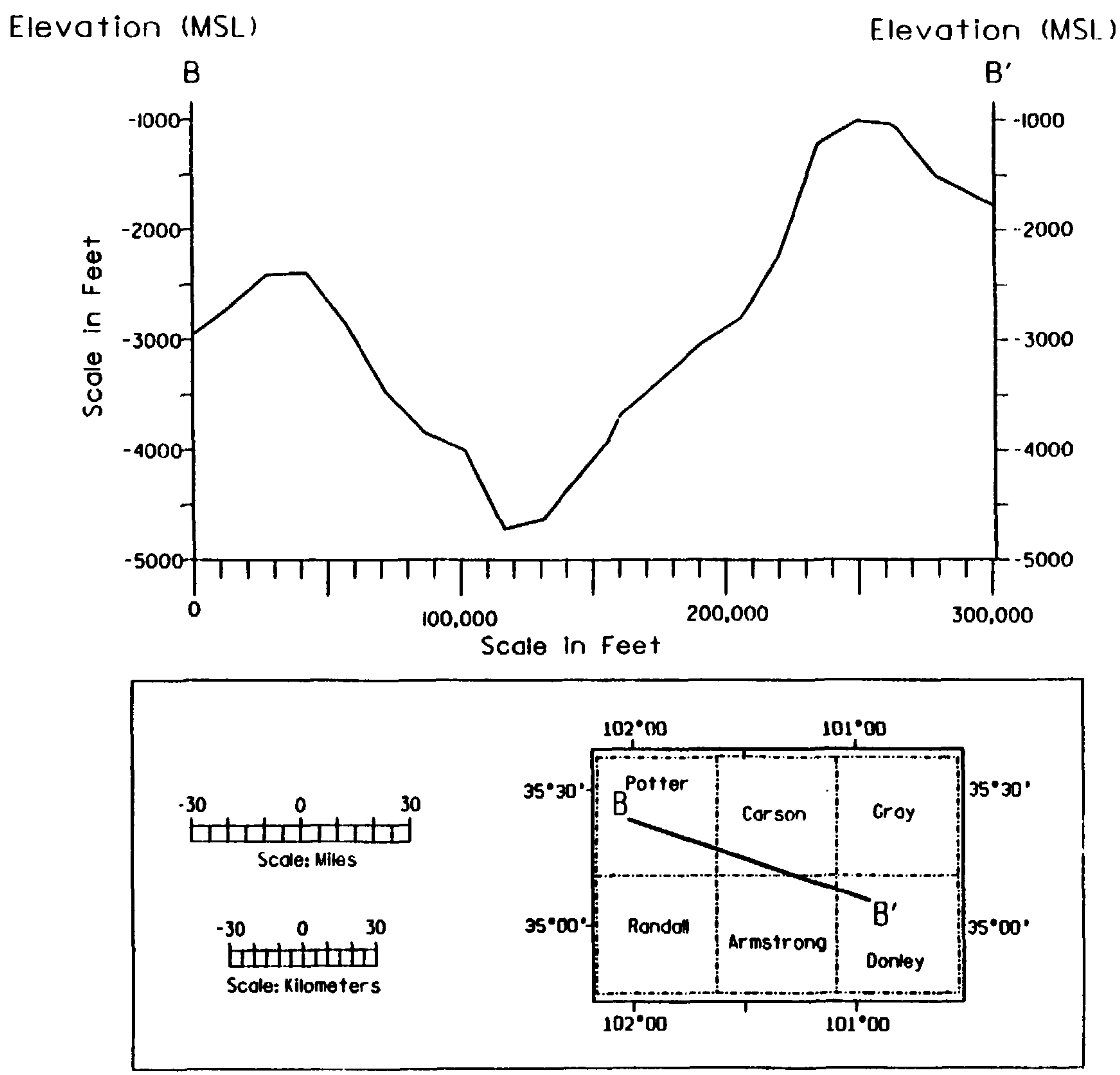
Three-Dimensional Contours

Figure 3-1



Profile Model of a Sample Horizon

Figure 3-2

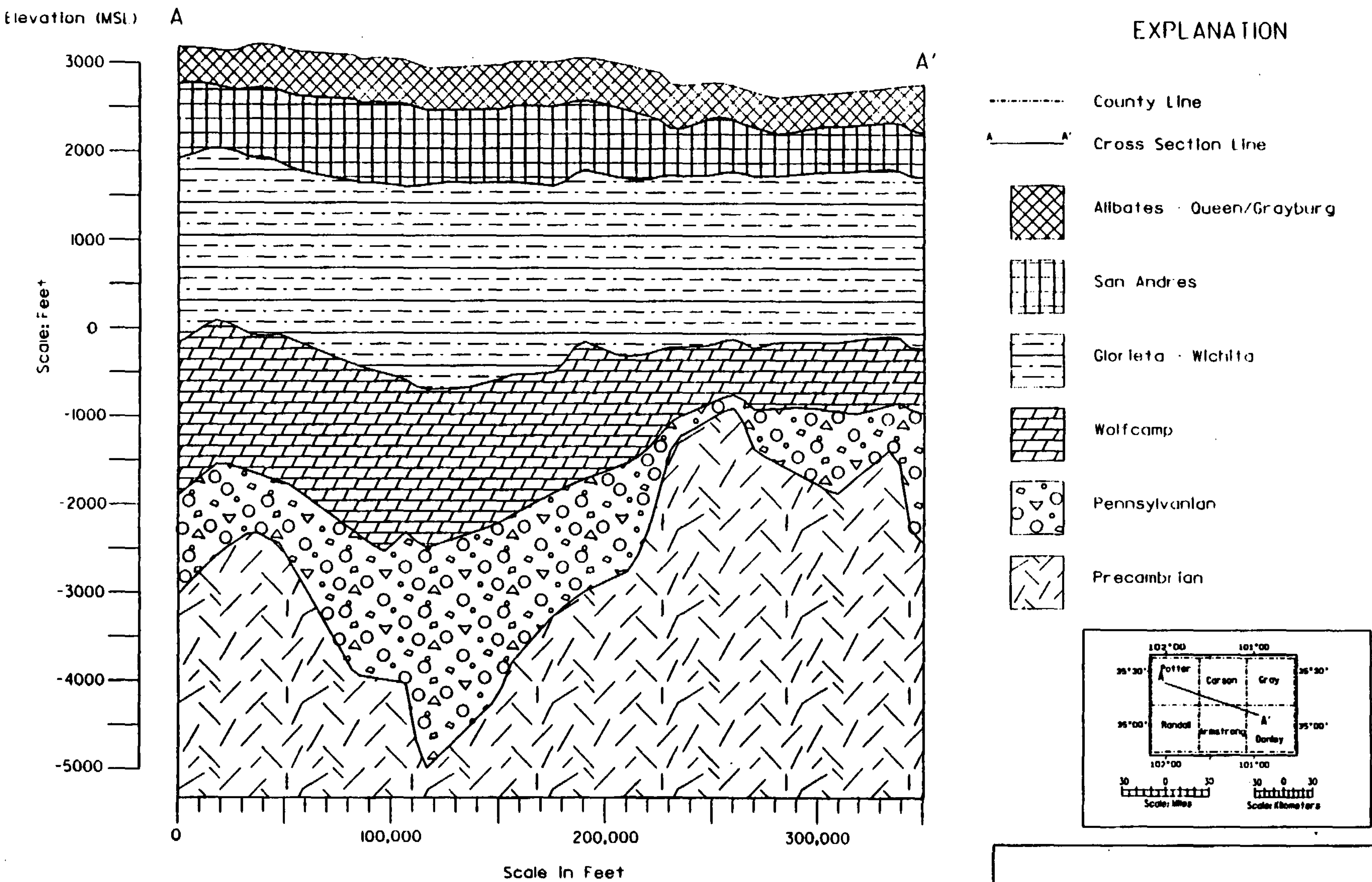


Note:

Vertical Exaggeration: 500x

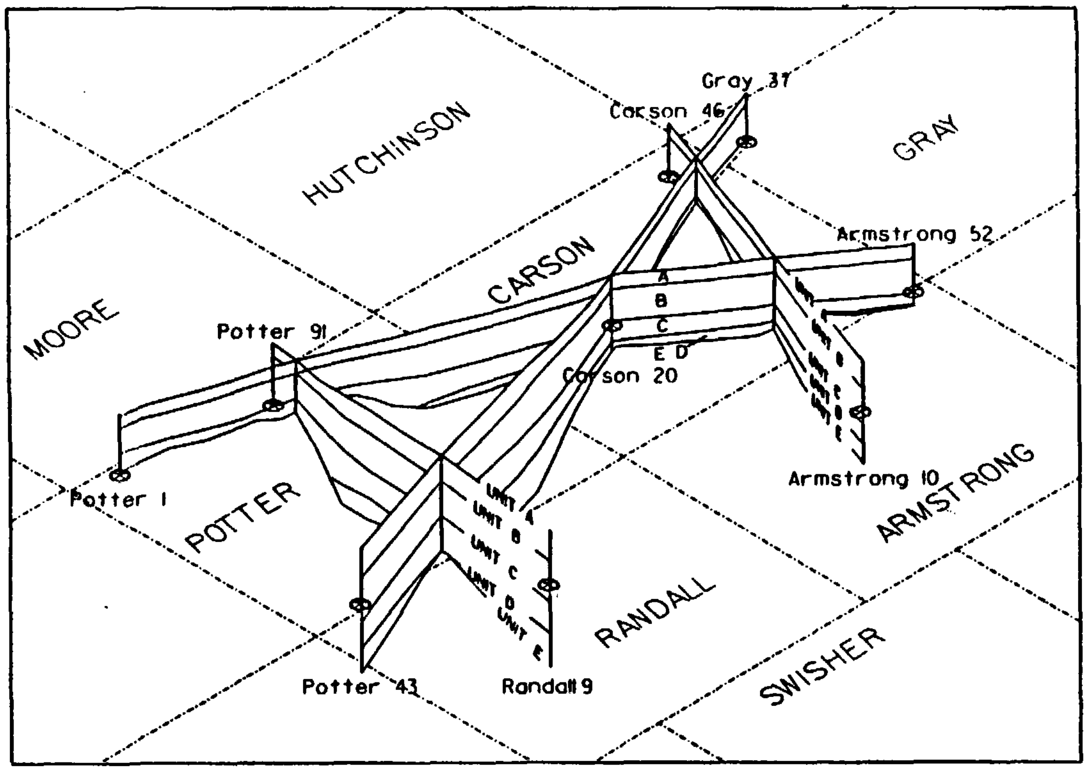
Cross Section of a Single Horizon

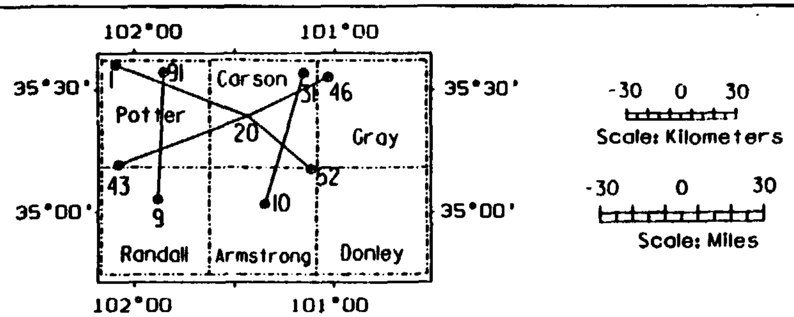
Figure 3-3



Patterned Cross Section

Figure 3-4





EXPLANATION

UNIT A: Alibates - San Andres

UNIT B: Glorieta - Wichita

UNIT C: Wolfcamp

UNIT D: Pennsylvanian

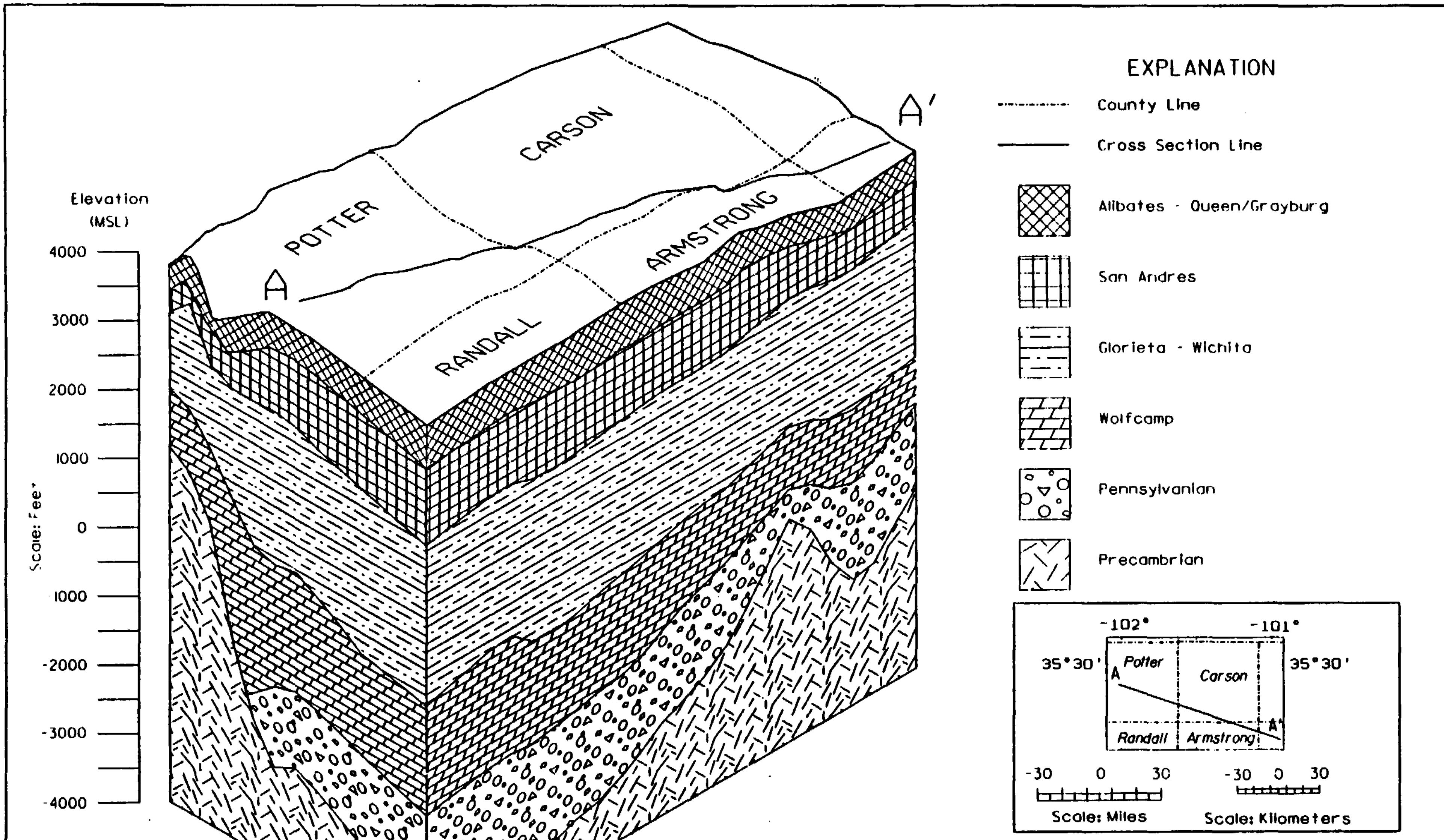
UNIT E: Precambrian

⊕ Well Symbol

Note: Well symbols are at elevation 0 (MSL).

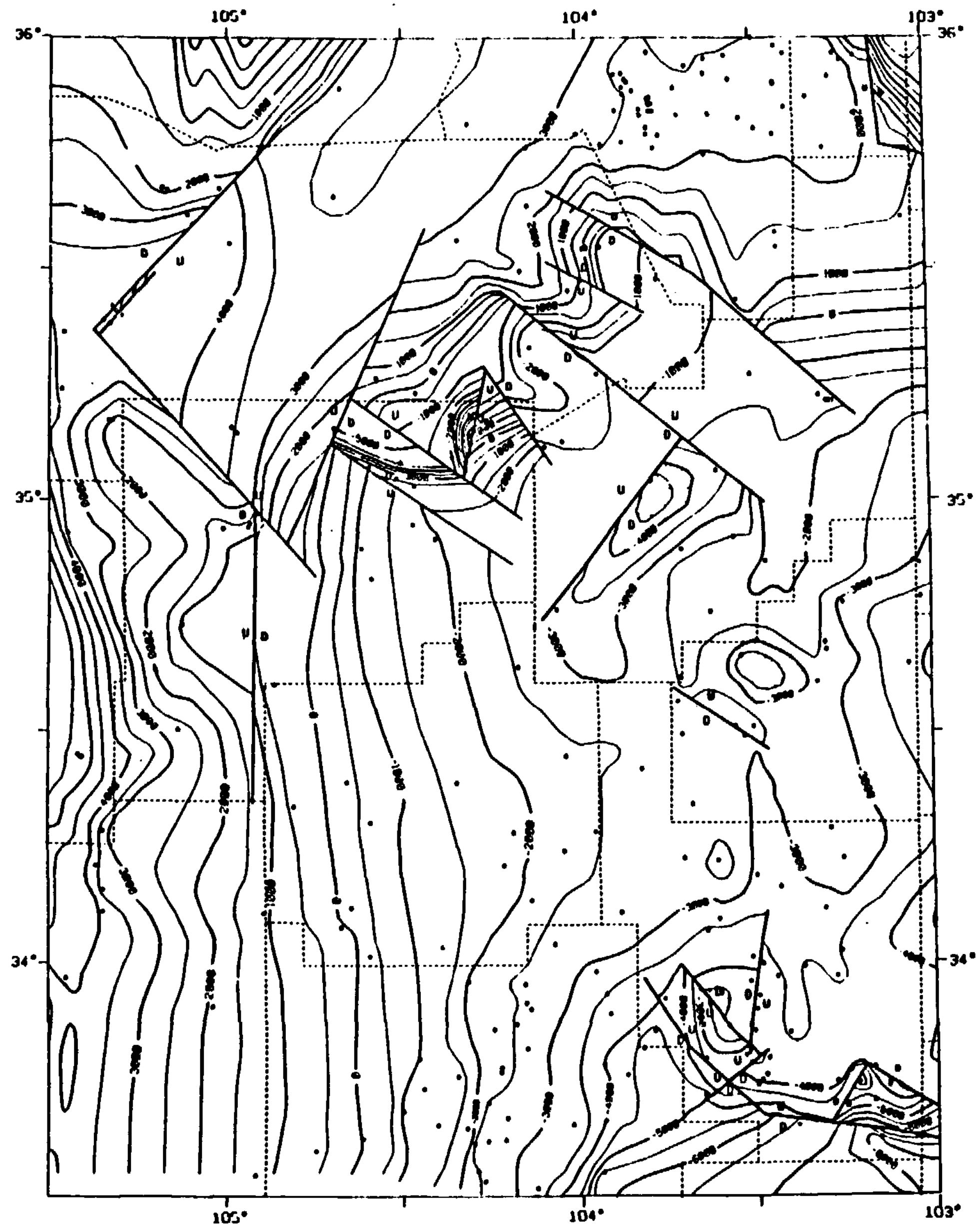
Fence Diagram

Figure 3-5



Block Diagram

Figure 3-6



EXPLANATION:

U/D Fault (U=Upthrown, D=Downthrown)

Contour Interval: 500 Ft

0 20 40 60

Scale - Miles

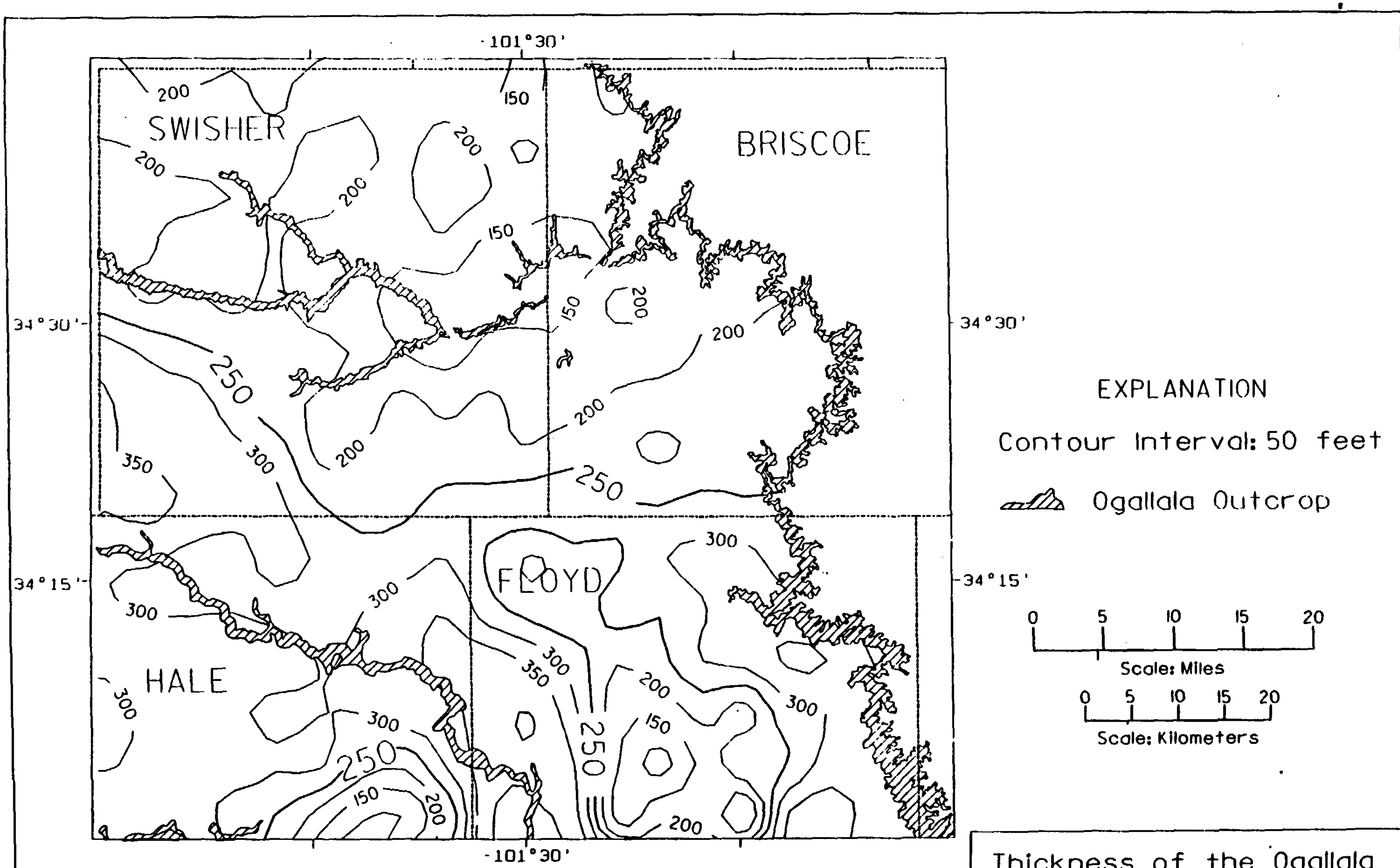
0 20 40 60

Scale - Kilometers

Faulted Structure Contours

Figure 3-7

Information from different sources may be combined to produce useful maps, such as a contour map of the Ogallala thickness based on water well data superimposed over an Ogallala outcrop map (Figure 3-8) digitized from a United States Geological Survey (USGS) geologic map.



Source for outcrop: Texas Bureau of Economic Geology Plainview sheet, 1968

Thickness of the Ogallala Formation

Figure 3-8

4 REFERENCES

Bureau of Economic Geology, 1968. Geologic Atlas of Texas, Plainview Sheet, The University of Texas, Austin, TX.

Information Builders, Inc. 1984. FOCUS Release 4.5, Information Builders, Inc., New York, NY.

Intergraph Corporation, 1983. Vax Digital Terrain Models Nucleus Package, Version 8.6, Revision 2, Huntsville, AL.

Intergraph Corporation, 1984a. Vax Interactive Graphic Design Software (IGDS), Version 8.7, Huntsville, AL.

Intergraph Corporation, 1984b. Vax World Mapping System (WMS), Version 8.6.3, Huntsville, AL.

Sampson, R.J. 1978. Surface II Graphics System, Kansas Geological Survey, Lawrence, KS.

Stone & Webster Engineering Corporation, 1983a. Well Mapping System (WELLMAP), Boston, MA.

Stone & Webster Engineering Corporation, 1983b. Well Data File Preprocessor (WELLPREP), Boston, MA.

Stone & Webster Engineering Corporation, 1984. Free Field Input Data Management System (FFIDAMS), Boston, MA.

SWEC, see Stone & Webster Engineering Corporation.