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WABEK AND PLAZA FIELDS: CARBONATE SHORELINE TRAPS IN THE WILLISTON BASIN OF NORTH DAKOTA

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ABSTRACT

Wabek and Plaza Fields in Mountrail and Ward Counties, North Dakota are expected to ultimately produce 6 to 7 million barrels of oil and 3 to 4 million barrels of oil, respectively, from the Sherwood and Bluell subintervals of the Mississippian Mission Canyon Formation. Both fields produce from intergranular, vuggy, and minor intercrystalline porosity developed in peloidal, oolitic, and pisolitic lime packstones and grainstones deposited as shoals along a low-energy shoreline. An eastward facies change to impermeable dolomudstones and anhydrites, deposited in restricted lagoon and sabkha environments, provides the updip trap.

Paleostructure, regional depositional slope, and local depositional topography controlled Mission Canyon shoreline trends and reservoir facies. In the Wabek-Plaza complex, the location and trend of Sherwood and Bluell shorelines can be related to structural trends identified in the crystalline basement from aeromagnetic data. Locally, relief on the Wabek-Plaza paleostructure was amplified by thickness variations in the Mohall interval which affected the deposition of Sherwood and Bluell shoreline reservoirs.

To explore for Sherwood and Bluell Fields, regional well control can be used to lead the explorationist to prospective areas. Then, seismic data may be used to pinpoint wildcat locations by identifying structural features and the carbonate to anhydrite facies transition.

INTRODUCTION

The discovery of Wabek Field in 1985 and Plaza Field in 1989 initiated a new phase of exploration for Sherwood and Bluell shoreline trends on the east flank of the Williston Basin (fig. 1). The wells in both fields have modern wireline logs, subsurface cores, high-quality CDP seismic data, and aeromagnetic data, which permit construction of an integrated exploration model.

REGIONAL GEOLOGY

STRUCTURAL SETTING

The Williston Basin is a cratonic basin surrounded and underlain by continental crust. The basin is dominated by flexural subsidence (Sloss, 1987) which is primarily the result of recurrent, left-lateral slip along major Precambrian crustal boundaries (Gerhard, et al, 1982). Igneous and metamorphic rocks under the North Dakota portion of the Williston Basin are part of a suture zone between two major Archean paleo-continental blocks, the Superior Province in eastern North Dakota and the Wyoming Province in Montana. This suture zone is thought to be a melange of magmatic arcs, volcanogenic metasedimentary rocks, ultramafic rocks and microcontinental remnants (Peterman and Goldich, 1982).

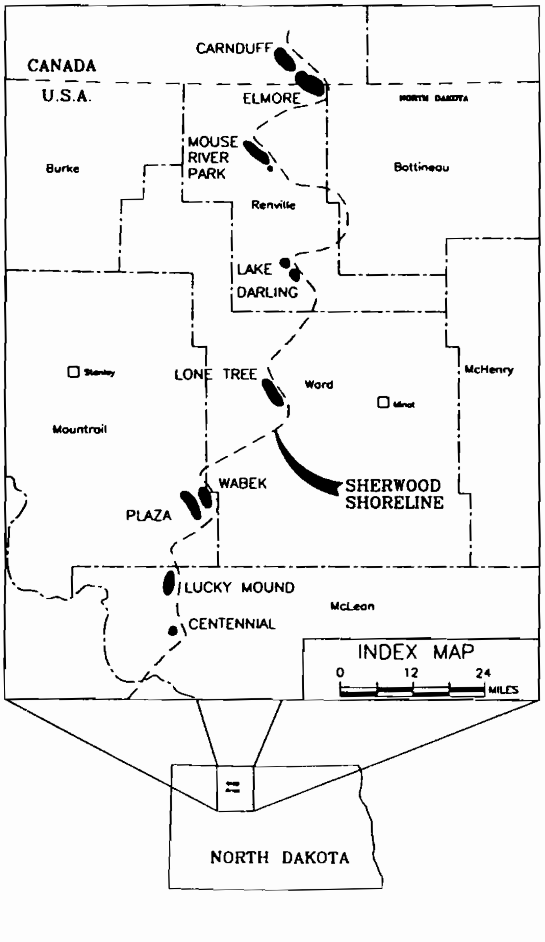


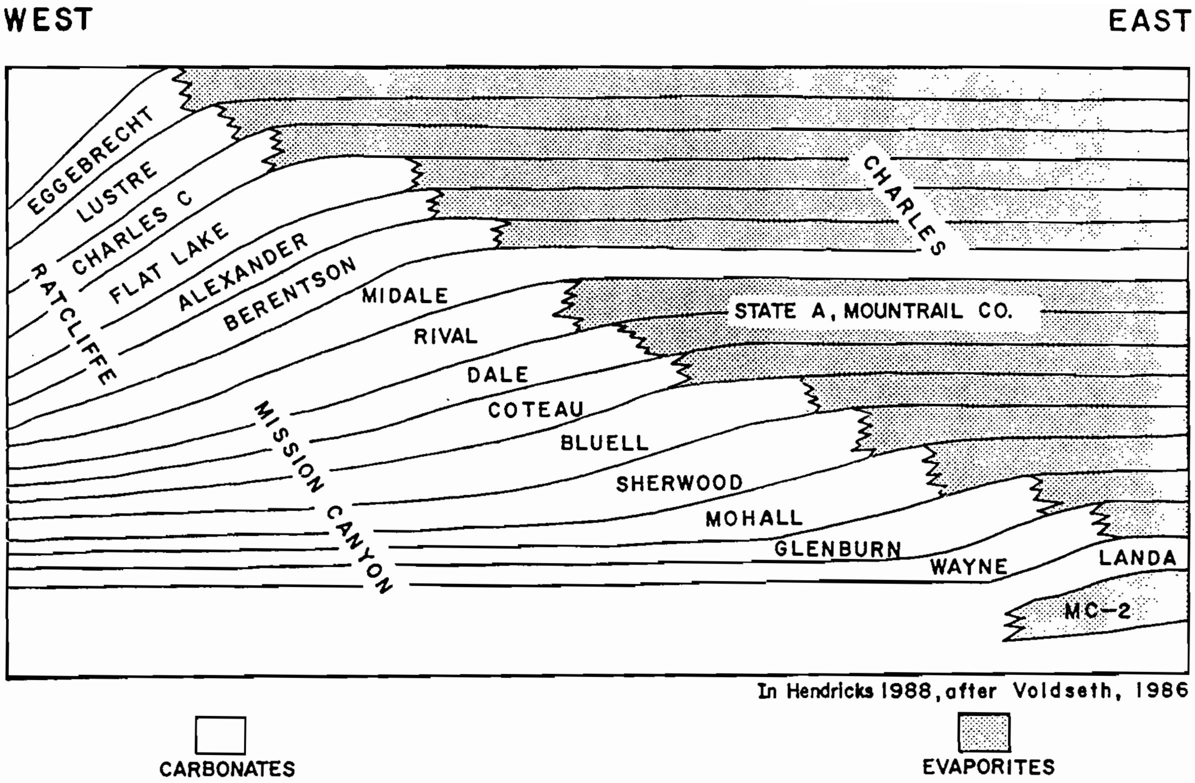
Figure 1. Sherwood shoreline trends along the east flank of the Williston Basin.

Southwest-plunging anticlines and synclines are the dominant present day structures on the east flank of the Williston Basin. These structures were also present during Mississippian deposition and are apparently related to recurrent movement and relief across tilted half grabens in the Precambrian crystalline basement (Brown and Brown, 1987).

STRATIGRAPHIC SETTING

Mission Canyon cycles are characterized by repetitious facies tracts that were controlled by bathymetry, salinity, depositional slope, and local and regional energy regimes. Preexisting depositional topography and local and regional structures also controlled the distribution of facies. Harris (1966) subdivided the Mission Canyon Formation on the eastern shelf portion of the Williston Basin in North Dakota into beds which he recognized as electric log intervals that represented the rock record of depositional cycles. Voldseth (1988) expanded the concept to include beds in the overlying Charles Formation as well (fig. 2). These "beds" represent subintervals, each of which consists, in an east to west facies track, of sabkha anhydrite and dolomite, dolomudstone deposited in restricted lagoons, shoreline and nearshore oolitic to pisolitic limestone, and shallow shelf skeletal mudstone.

The Glenburn subinterval in the Wabek area is composed of shallow shelf carbonates. These beds are overlain by restricted shelf, shoal, and intershoal beds of the Mohall subinterval. The Sherwood and Bluell subintervals are shoreline shoal, lagoon, and



In Hendricks 1988, after Voldseth, 1986

Figure 2. Mississippian stratigraphy in the U.S. portion of the Williston Basin.

sabkha carbonates and anhydrites which are, in turn, capped by anhydrites of the Coteau subinterval.

Wabek is one of a series of Sherwood shoreline fields which extend from the Canadian Carnduff Field south to Elmore, Mouse River Park, Lake Darling, Lonetree, and Wabek fields in North Dakota (fig. 1). Shoreline carbonate reservoirs are stratigraphically trapped updip by less permeable dolomite and anhydrite, often on southwest-plunging structural anticlines. Shorelines can be mapped using wireline logs, cutting samples, cores, and seismic data. Sherwood shorelines are rectilinear (see fig. 1) and change strike along inferred Precambrian crustal blocks. Oil reserves of these shoreline fields are significant for the Williston Basin: Mouse River Park and Lake Darling each have cumulative production of 3.7 MMBO, Lonetree 2.5 MMBO, and Elmore approximately 2.2 MMBO (U.S. portion). With a projected 6 to 8 MMBO ultimate recovery and average per well reserves of about 330 MBO, Wabek may be the best field along this trend.

Bluell shoreline fields are also found at carbonate to anhydrite facies changes, and generally occur downdip and on trend with Sherwood shoreline fields. Bluell fields include: Pleasant (1.5 MMBO), Bluell (259 MBO), Mackobee Coulee (1.4 MMBO), Berthold (212 MBO), and Plaza (3.5 MMBO, EUR).

Initial exploration along the Sherwood trend began in the late 1960's, and Lake Darling (1970) was the last field discovered prior to Wabek. During the 1970's and early 1980's few exploratory wells were drilled on the southeastern flank of the Williston Basin. Some exploration models of that period speculated that migration, trap, or reservoir development were missing in the area south of Lonetree Field.

Prior to the discovery of Wabek, several operators had drilled exploratory wells in the area.

Directly south of Wabek, Prairie Junction Field was discovered by Nortex Oil and Gas with the #1-13 Ryder-Kok test in 1981. That field has produced less than 40 MBO from tight, dolomitic Sherwood beds.

Since Wabek's discovery, Balcron Oil has made another significant Sherwood discovery at Lucky Mound Field. This field is 14 miles (22 km.) southwest of Wabek in T150N, R89W. Currently, the field has 23 producing wells with estimated ultimate primary recovery of 3.7 MMBO. South of Lucky Mound, yet another Balcron discovery, Centennial Field, is being evaluated. Exploration continues both northwest of Centennial and southwest along the Sherwood shoreline trend into eastern Dunn County where several wildcats are expected to be drilled in the near future.

PRODUCTION AT WABEK AND PLAZA FIELDS

WABEK FIELD

Wabek Field was discovered in June 1985, by the Home Petroleum #42-11 Rovig Ness State test (SENE Sec. 11, T152N, R88W). The well had an initial potential of only 40 BOPD, but showed no decline in production rates. It was not until August 1987, that the #31-11 Rovig Ness offset was drilled (NWNE Sec. 11, T152N, R88W). This well initially produced at 314 BOPD and was the first commercial well in the field. The field currently produces from 25 wells on 80 acre spacing (fig. 3). Ultimate production will be 6 to 7 MMBO. Through 1992, Wabek had produced 4.6 MMBO, and daily production was 980 BOPD.

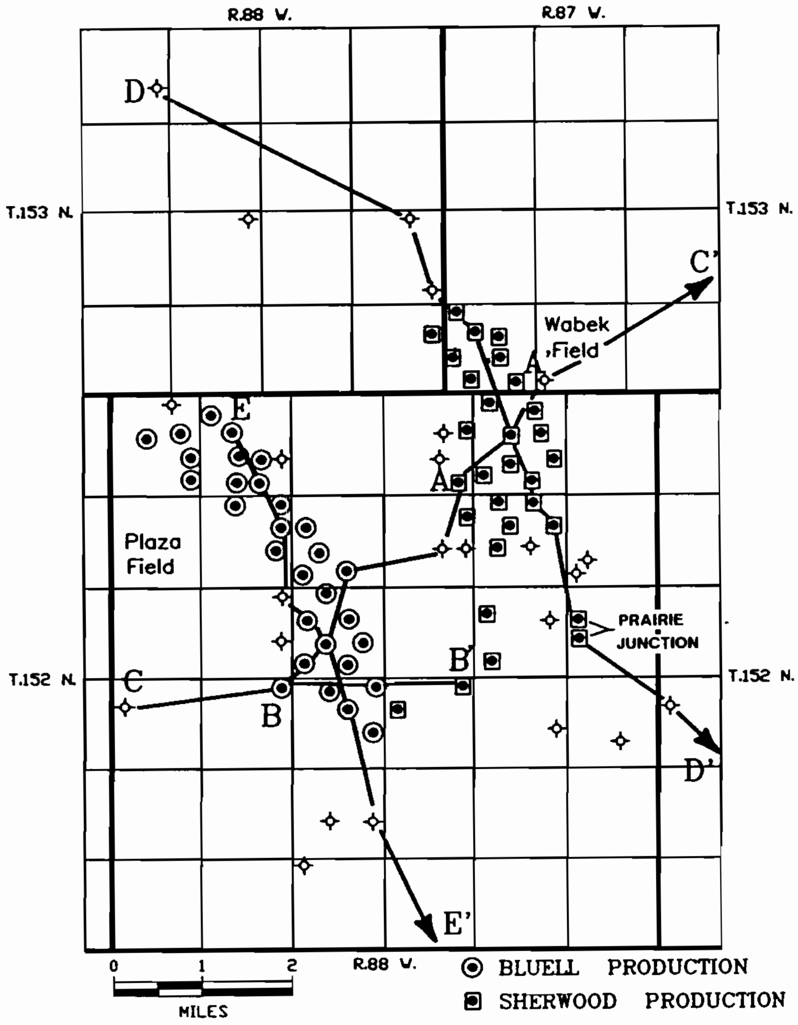


Figure 3. Wabek, Prairie Junction, and Plaza Field Production, Cross Section, and Profile Location Map.

A review of all wells in Wabek Field that have been on production for at least three years shows considerable variation in productivity and decline rates (Table 1). It is difficult to recognize a consistent field-wide decline as production was greatly increased when a change in primary operator occurred in late 1989. This increased rate causes many of the percentage declines on Table 1 to appear as negative values. A detailed look at certain clusters of wells suggests similarities in decline patterns, possible communication between wells, and local reservoir homogeneity. An example is the

TABLE 1

WABEK FIELD PRODUCTION HISTORY
All Wells With 3 Years Production

WELL NAME LOCATION	DATE COMPLETED	IP	TOTAL PRODUCTION				DECLINE PERCENTAGE		
			6 mo	12 mo	24 mo	36 mo	6-12 mo	year 2	year 3
34-2 Lynne SWSE 2-152-88	11-87	382	55251	89438	165763	243398	38	15	-7
22-2 Erickson SENW 2-152-88	12-87	308	49497	85924	151156	219310	26	24	-4
43-2 Lynne NESE 2-152-88	3-88	302	24793	43932	72129	95743	23	36	16
11-2 Erickson NWNW 2-152-88	3-88	453	46402	80231	174677	283156	27	15	-15
23-2 Fjeldahl NESW 2-152-88	4-88	196	27291	50600	85720	119794	15	31	3
32-2 Lynne SWNE 2-152-88	5-88	244	26681	40457	58680	68227	48	55	48
31-2 Bangen State NWNE 2-152-88	11-88	38	4998	9845	20872	28748	3	-12	29
14-2 Fjeldahl SWSW 2-152-88	5-88	160	37261	61135	207461	383420	36	-239	-120
							35% decline in 4th year		
42-3 Tvedt SENE 3-152-88	6-88	197	21923	40485	60620	66194	15	50	73
44-3 Bangen SESE 3-152-88	7-88	259	38213	64333	162294	190056	32	-152	72
42-10 Erickson SENE 10-152-88	5-89	417	59381	144406	259385	264708	-143	20	95
42-11 Rovig-Ness-State SENE 11-152-88	6-85	49	5633	12199	26003	38370	-16	-13	10
11-11 Wurtz NWNW 11-152-88	4-88	212	47166	78145	184250	337989	34	-36	-45
22-11 Wurtz SENW 11-152-88	6-88	328	44623	66930	135058	225836	50	-2	-33
44-31 Tvedt SESE 31-153-87	5-88	484	36207	65846	127880	164257	18	6	41
24-31 Braaflat SESW 31-153-87	7-88	231	33880	55185	115562	149986	37	-9	43
22-31 Braaflat SENW 31-153-87	1-89	120	14170	24961	40775	50764	24	37	37
13-31 Braaflat NWSW 31-153-87	7-88	222	30593	50025	78785	92566	36	43	53
1-31 Nielsen NWNW 31-153-87	11-88	136	10045	14978	19797	22617	51	2	41
1-31 Smestad SWNE 31-153-87	8-89	40	4532	8580	15207	20669	11	23	18

relationship between the 44-3 Bangen and the updip offsetting 14-2 Fjeldahl. These two wells, and their respective south offsets, the 42-10 Erickson and 11-11 Wurtz, also show the effects of water encroachment early in 1991. Water volume had increased strongly in the 14-2 Fjeldahl and 11-11 Wurtz about 18 months after similar increases in the downdip offsetting 44-3 Bangen and 42-10 Erickson. State production records show that total fluid production in the field (24 wells) had risen to 50% water by July, 1992 from only 10% in January, 1990, with the four above wells contributing 37% of that water. It is still too soon to evaluate water effects in those wells against potential water encroachment across the entire field.

The Sherwood at Wabek has over 100 ft (30 m) of oil column. Sherwood oil is 36 API gravity with an initial gas to oil ratio of 628 (SCF/STB). Initial reservoir pressure in the field was 3345 pounds per square inch, with a gas solution and partial water drive. The water drive is insufficient to support the current rate of withdrawal. Log porosity ranges from 6 to 26%, averaging about 10%, and net pay averages about 26 ft. (8 m.). Log-derived water saturations in the field average approximately 40%. Cross section A-A' (fig. 4) shows the reservoir-trap relationship in Wabek Field.

PLAZA FIELD

Plaza Field, two miles (3 km.) west of Wabek Field, produces from the Bluell subinterval of the Mission Canyon Formation, The 1989 discovery of this field was by the Home 21-16 Van Eeckhout State well which initially produced at 272 BOPD. Through 1992, thirty one wells in the field had produced 2.14 MMBO, with a daily average production at that time of 919 BO. The field operator estimates the ultimate production to be 3.5 MMBO.

The Bluell reservoir in Plaza Field produces at lower rates than the Sherwood reservoir in Wabek Field, and has been more consistent as shown by Table 2. Most wells show a substantial increase in their decline rate for the second year of production, except for the low-volume producers, which generally have little increase in their decline rate or actually decrease the rate. The production data, when added to electric log and core information, overall suggests perhaps less permeability in the low-volume wells, lower quality for the entire reservoir, probable longer payouts, and lower ultimate per-well recovery when compared to Wabek Field. Water encroachment does not seem to be a problem, though production history at Plaza is much shorter.

Plaza produces 36 API gravity oil with an initial gas to oil ratio of 410 (SCF/STB). Initial reservoir pressure was 3227 pounds per square inch, and the field has a gas solution drive with some apparent water influx. Bluell log porosity ranges from 6 to 16%, averaging about 9%, with log-derived water saturations of approximately 40%. Net pay averages about 6 ft. (2 m.). An oil/water contact is not currently known, but at least 120 ft. (40 m.) of oil column is present. Cross section B-B' (fig. 5) shows the reservoir-trap relationship in the field, with loss of effective porosity to the east in section 22.

DEPOSITIONAL FACIES

LITHOFACIES

Deposition from late Mohall through Bluell time in the Wabek-Plaza area occurred in shoreline and nearshore environments. The depositional facies in each subinterval are similar. Cores from both fields were analyzed to determine lithofacies and petrographic microfacies. Lithofacies are grouped according to similarities in lithology, sedimentary structures, fauna, and inferred depositional environments. The following are the principal lithofacies in Wabek and Plaza fields.

Gray to brown, peloidal, oolitic, pisolitic, and sparsely intraclastic packstone and grainstone. Skeletal and algal fragments are sparse and patterned beds, formed by pyrite replacement of carbonate, are locally common. This facies was probably deposited in intertidal to shallow subtidal environments and is associated with a regional deepening event near the end of Mohall time.

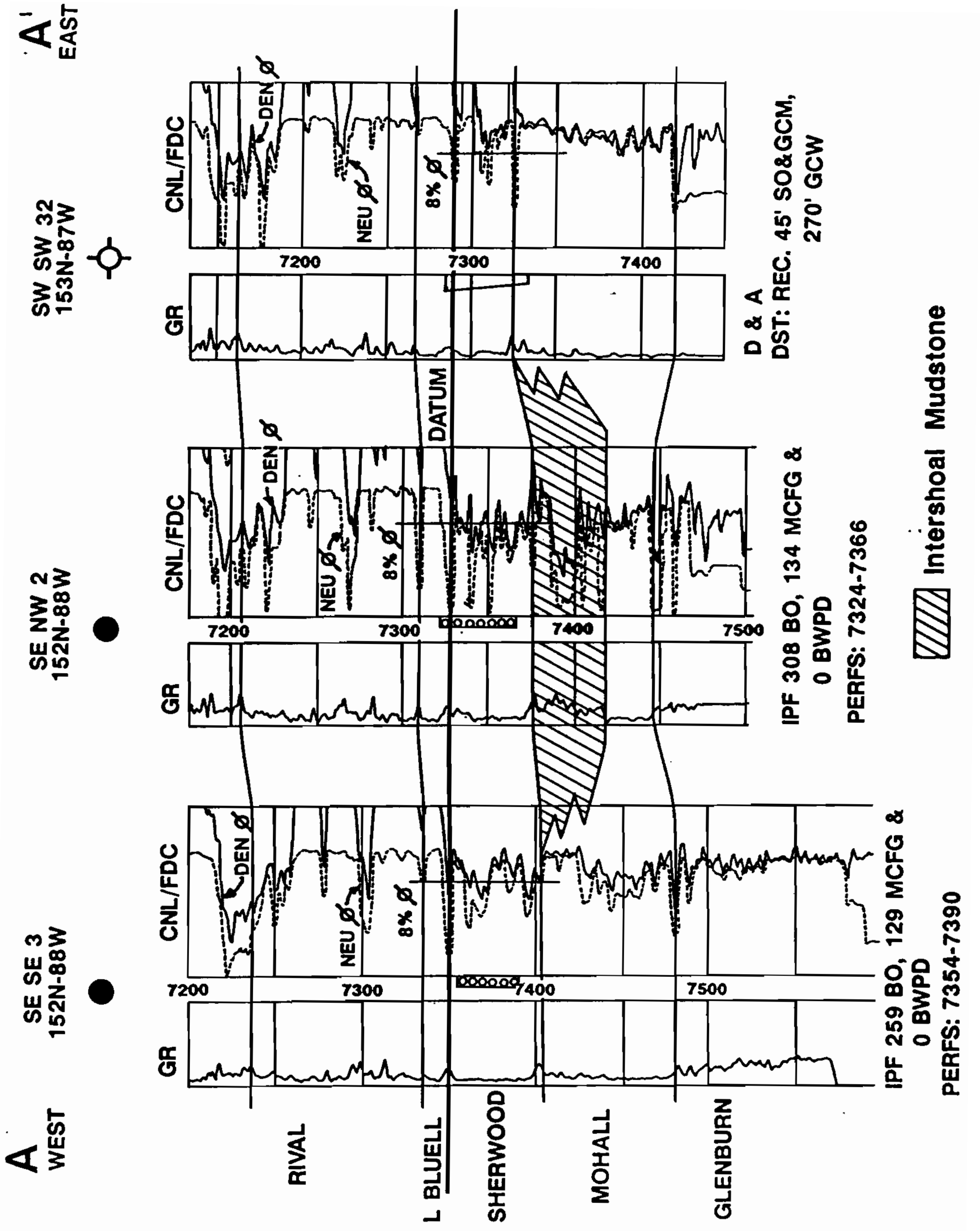


Figure 4. Cross Section A-A', Wabek Field.

TABLE 2

PLAZA FIELD PRODUCTION HISTORY
All Wells: Minimum 2 Years Production

WELL NAME LOCATION	DATE COMPLETED	IP	TOTAL PRODUCTION				DECLINE PERCENTAGE		
			6 mo	12 mo	24 mo	36 mo	6-12 mo	year 2	year 3
1 Anderson SESW 5-152-88	8-90	273	26238	43623	67294	NA	34	46	-
2 Anderson NESW 5-152-88	8-90	230	28523	47405	69653	NA	34	53	-
34-5 Van Eeckhout SWSE 5-152-88	9-90	187	16422	27754	43325	NA	31	44	-
1 Lester SENW 5-152-88	10-90	218	5386	9086	15890	NA	31	25	-
33-5 Van Eeckhout NWSE 5-152-88	11-90	34	4805	9290	16560	NA	7	22	-
1 Johnson NESE 6-152-88	10-90	113	12145	21002	37438	NA	27	22	-
1 Howe SENE 6-152-88	10-90	303	22161	31411	41069	NA	58	69	-
1-8 Lien NENE 8-152-88	7-89	195	22234	35644	51409	60161	40	56	46
2-8 Lien SENE 8-152-88	11-89	468	33254	57948	90121	112170	26	44	31
43-8 Spletstoser NESE 8-152-88	1-90	108	10437	16433	24280	NA	43	52	-
1 Skarsgard NENW 8-152-88	9-90	359	7077	10310	14978	NA	54	55	-
23-9 Van Eeckhout NESW 9-152-88	11-89	209	26165	41315	57005	63720	42	62	57
14-9 Lien SWSW 9-152-88	3-90	90	12072	22478	38701	NA	14	28	-
12-9 Howe SWNW 9-152-88	2-90	109	8241	14459	24861	NA	25	28	-
21-16 Van Eeckhout State NENW 16-152-88	5-89	272	29857	50881	70741	86564	30	61	20
32-16 State SWNE 16-152-88	6-89	321	46590	76655	112236	135381	35	54	35
43-16 State NESE 16-152-88	6-90	60	13471	25156	43192	NA	13	28	-
23-16 B & K State NESW 16-152-88	7-89	391	51809	91431	139288	176773	24	48	22
34-16 State SWSE 16-152-88	8-89	349	59204	105999	183507	217081	21	27	57
14-16 B & K State SWSW 16-152-88	2-90	152	15800	21968	25972	NA	61	82	-
12-16 Van Eeckhout State SWNW 16-152-88	3-90	281	41851	71067	113695	NA	30	40	-
32-21 Kok SWNE 21-152-88	10-89	266	40846	72480	110085	NA	23	48	-
43-21 Provident Life NESE 21-152-88	5-90	9	5556	12665	25513	NA	-28	-1	-
21-21 B & K NENW 21-152-88	5-90	155	19732	35687	57915	NA	19	38	-
41-21 Kok NENE 21-152-88	7-90	34	10743	18666	31777	NA	26	30	-

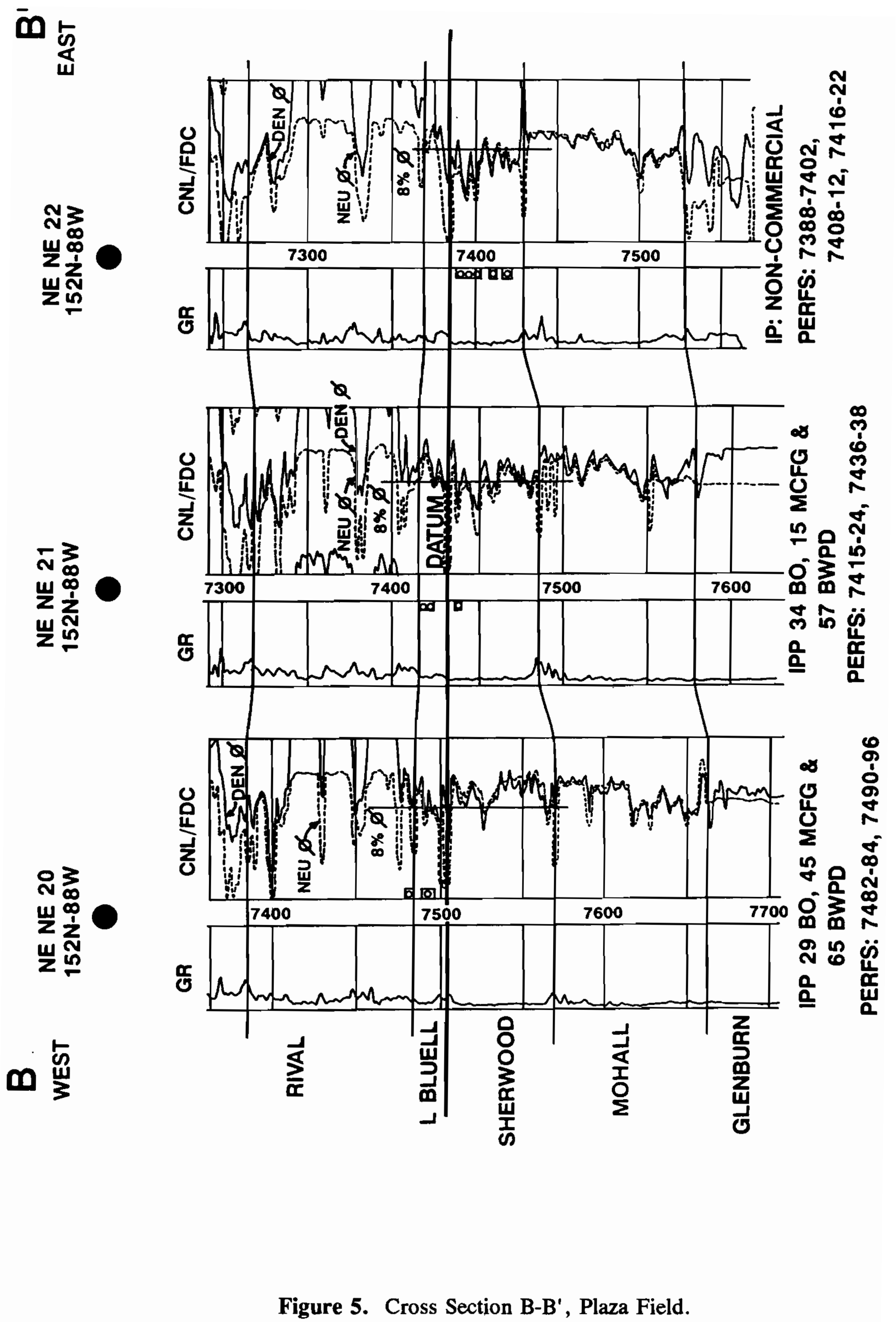


Figure 5. Cross Section B-B', Plaza Field.

Light gray, patterned and arenaceous dolomudstone. This facies is the upper part of the Mohall marker of Harris (1966). Porosity is commonly good, but permeability is poor because of small pore throats associated with this microcrystalline dolomite. Deposition was in lagoonal environments.

Light gray nodular anhydrite with thin displaced dolomudstone interbeds. This facies is the basinward extension of the Bluell and Sherwood anhydrite. The nodular and displacive nature of the anhydrite indicates deposition in a sabkha.

Light brown to light gray, locally patterned, lime mudstone to dolomudstone. This lithofacies is present throughout the Bluell and Sherwood subintervals and was deposited in shallow protected shelf and lagoon environments. Dolomitization of this lithofacies is common near the top of both of these Mission Canyon subintervals. The lack of fauna indicates highly restricted depositional environments. This lithofacies marks the top of shallowing upward sequences, and is locally oil stained. Dolomudstones are commonly impermeable because of small pore throat size and anhydrite occlusion (fig. 6).

Light brown to brown, peloidal, oolitic, pisolitic, intraclastic, and composite-grain wackestone to grainstone. This is the main Bluell and Sherwood reservoir (fig. 7). This lithofacies contains intergranular and vugular porosity. Occluding cements are fibrous calcite spar, prismatic calcite spar, anhydrite, and baroque dolomite. Cross stratification is sparse, and normally this lithofacies appears massive. Deposition was in shallow shoal (intertidal) environments along low-energy shorelines, where grains were coated by inorganic precipitation of calcite (radial fibrous coatings) and by algal-foraminiferal colonies (micritic coatings).

Gray to brown, peloidal, oolitic, pisolitic, intraclastic, and algal packstone to grainstone. This lithofacies contains fenestral fabric and algal laminations typical of intertidal deposition (fig. 8). Intercalated with these algal beds are distinct dark brown to dark gray, peloidal and intraclastic grainstones which mark local deepening or back-stepping surfaces. These beds have erosional bases and the intraclasts are mostly derived from the underlying substrate. Porosity is generally occluded and this lithofacies was observed at the downdip edge of both fields.

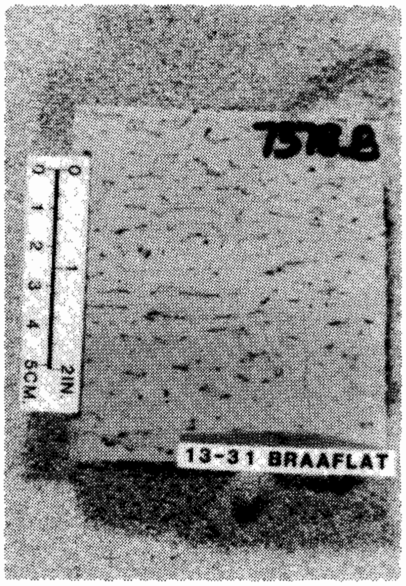


Figure 6. Dolomudstone in Wabek Field. Core slab from the Presidio Braaflat 13-31, representative of a shallow lagoonal environment.

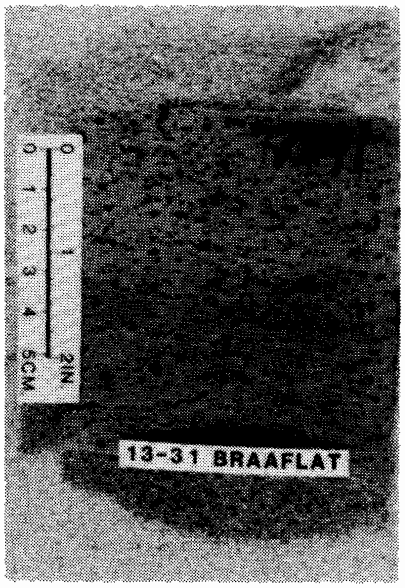


Figure 7. A typical grainstone reservoir in Wabek Field. Presidio Braaflat 13-31 core slab; compare with fig. 6.

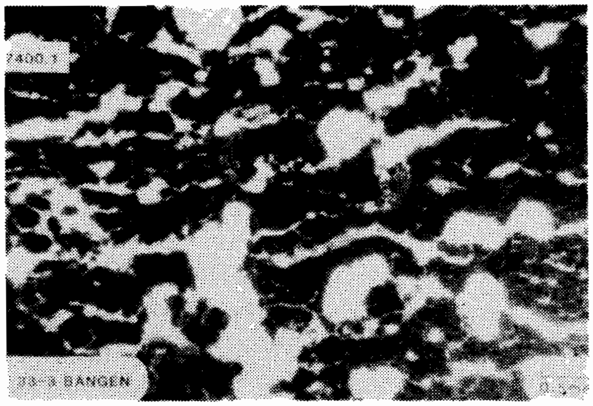


Figure 8. Photomicrograph from the Presidio Bangan 33-3 showing impermeable algal packstone typical of an intertidal depositional environment within the main Wabek reservoir.

Figure 9 summarizes the Sherwood and Bluell depositional systems with a generalized facies model for the Wabek area. Deposition resulted in predominantly peloidal, oolitic packstones and grainstones with local variations and ranged from intertidal through subtidal nearshore marine environments. Intertidal wackestones and grainstones developed on a shoal to form the Sherwood reservoir, and patterned lime mudstone and dolomudstone formed in a lagoon. The latter grades, in turn, into the nodular anhydrites of the sabkha. All of these facies were preceded by a widespread arenaceous dolomudstone that was at least partially deposited in a lagoonal environment that graded into the sabkha or patterned mudstone facies.

PETROGRAPHIC ANALYSES

The main porosity types in Wabek and Plaza fields in order of abundance are: intergranular, vugular, and intraparticle (fig. 10). Intergranular pores were preserved by the incomplete cementation of interstices within grainstones. Volumetrically, these pores are the most important and effective in the reservoir system. Intraparticle

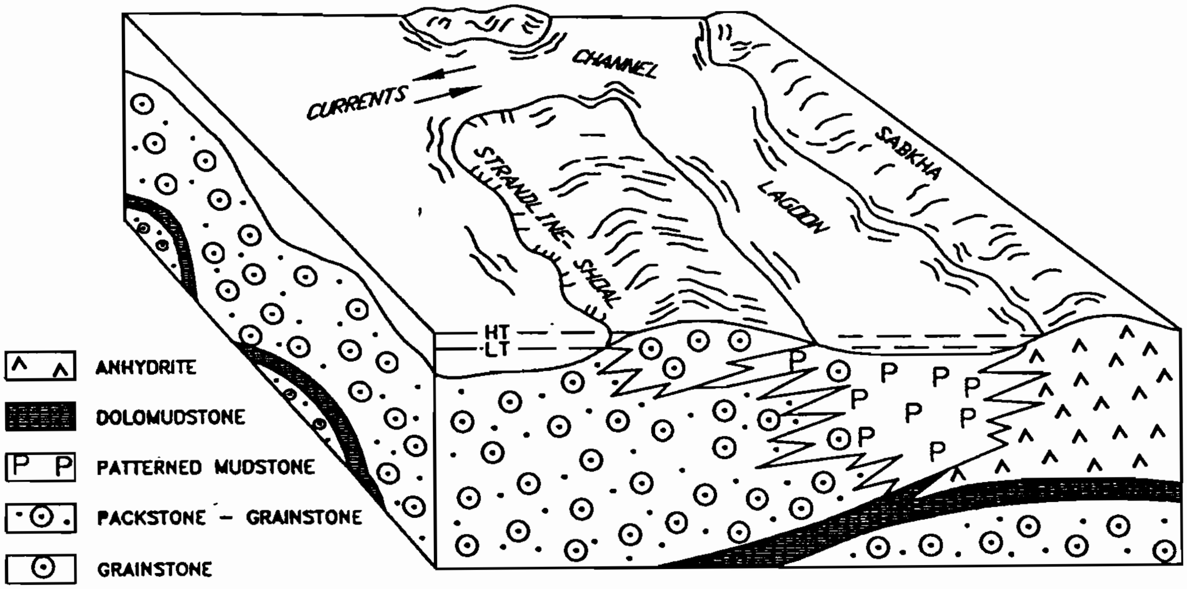


Figure 9. Depositional model for upper Mission Canyon shoreline systems in the Wabek area.

pores were formed by dolomitization of coated grain interiors, many of which are isolated and probably not effective. Where connected to intergranular or vugular pores, intraparticle porosity contributes to reservoir storage capacity. Vugular pores formed in two ways: 1) by sediment degassing or desiccation and 2) by dissolution of matrix and grains. Vugs formed by sediment displacement (degassing or desiccation) are more abundant than those that formed by dissolution. Vugs are commonly interconnected, producing good reservoir permeability.

Occluding cements in order of abundance are: fibrous calcite (which occludes intergranular pores and lines the exteriors of vugular pores), prismatic calcite spar (which partly to totally occludes vugs), anhydrite (which is pore occluding and replacive), and baroque dolomite (which partly occludes vugular pores). Fibrous calcite precipitated as an early marine cement, whereas prismatic calcite spar, anhydrite, and baroque dolomite are mesogenetic (burial) cements. Figure 11 shows cement paragenesis in the Wabek-Plaza area.

EXPLORATION METHODS

The following is a discussion of techniques that we believe are useful in delineating and evaluating similar Mission Canyon shoreline traps. These techniques proceed from a regional understanding of facies distribution to successful prospect development, utilizing a combination of geology and geophysics.

RELATION OF BASEMENT STRUCTURE TO DEPOSITION

Several authors, including Thomas (1974) and Brown and Brown (1987), have related regional structural anomalies and depositional changes in the Williston Basin to recurrent movement along major faults in the Precambrian basement and zones of weakness (linear trends). Trends in the crystalline basement strongly correspond to paleostructures, present structures, stratigraphic facies changes, and hydrocarbon accumulations in the overlying sedimentary section.

On the east flank of the Williston Basin, the crystalline basement is relatively shallow and its magnetic contrasts are high. Aeromagnetic data, therefore, give reliable indications of the relief and orientation of basement blocks and zones of weakness. For example, the facies change from anhydrite to carbonate in the Sherwood subinterval parallels basement linear trends and is strongly affected by relief across these features. Thus, delineation of basement structures and the integration of their trends with regional stratigraphic mapping is an important first step in prospecting for shoreline fields in the Sherwood or other Mission Canyon subintervals.

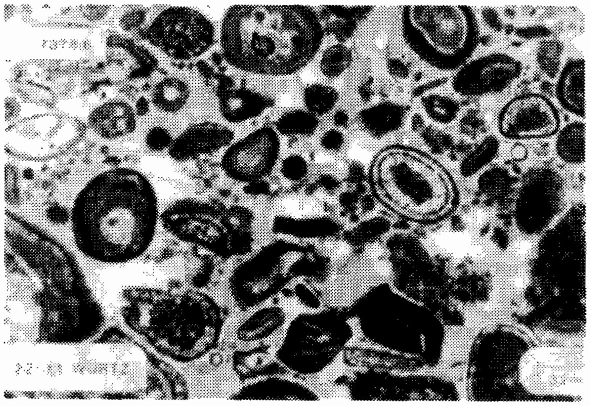


Figure 10. Presidio Wurtz 22-11, an example of intergranular, intraparticle, and vugular porosity in the Wabek reservoir.

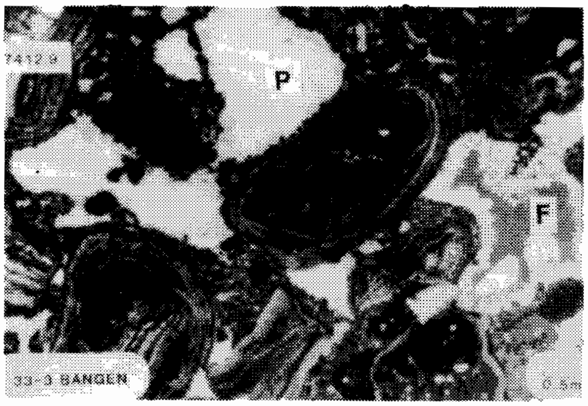


Figure 11. Photomicrograph of Sherwood shoal in the Presidio Bangan 33-3 showing occlusion of porosity by fibrous (F) and prismatic (P) calcite spar.

THE AEROMAGNETIC TOOL

A series of maps for the Wabek-Plaza area were constructed from aeromagnetic data provided by Geoterrex, Ltd. The data are part of a digitally recorded, high-resolution aeromagnetic survey flown in 1981 on a 1.25 by 4 mile (2 by 6.4 km) grid. Aqua Terra International, Inc. provided a display of magnetic intensity, calculation of the second vertical derivative (SVD), strike-pass analyses, and an interpretation of basement structure. Figures 12-16 illustrate each of these features, including both 0 to 90 degree and 90 to 180 degree strike-pass filter maps. Although variations in magnetism observed on intensity maps may be caused solely by magnetic contrasts in the crystalline basement, magnetic basement anomalies are considered reliable indicators of true basement relief in the Williston Basin.

A comparison of upper Mission Canyon maps in the Wabek-Plaza area with aeromagnetic maps shows the influence of Precambrian structures on subsequent structural and depositional patterns. A Glenburn structure map (fig. 17) in the Wabek-Plaza area shows development of a subtle, southwest-plunging nose that conforms with the SVD map trends (fig. 15). Deposition of the overlying Mohall (fig. 18) also shows a correlation to the SVD maps (figs. 15,16) in that thick shoals develop over SVD highs.

Updip and bordering Wabek Field to the east, the Sherwood facies change from anhydrite to carbonate occurs on the downthrown and basinward side (north and west) of prominent faults in the Precambrian basement (figs. 19-21).

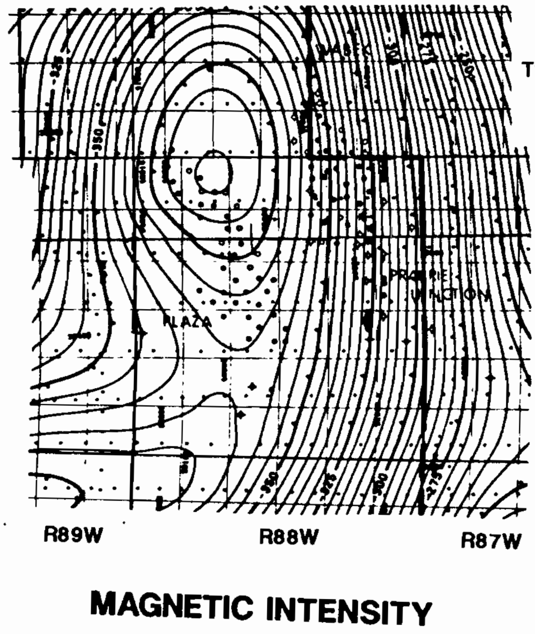


Figure 12. Magnetic Intensity Map. Contour interval is 5 nanoteslas (gammas). Normal earth's total magnetic field in the region is 59,200 nanoteslas. This map shows a steep, east to west gradient over Wabek Field culminating in a closed intensity negative centered just northeast of Plaza Field.

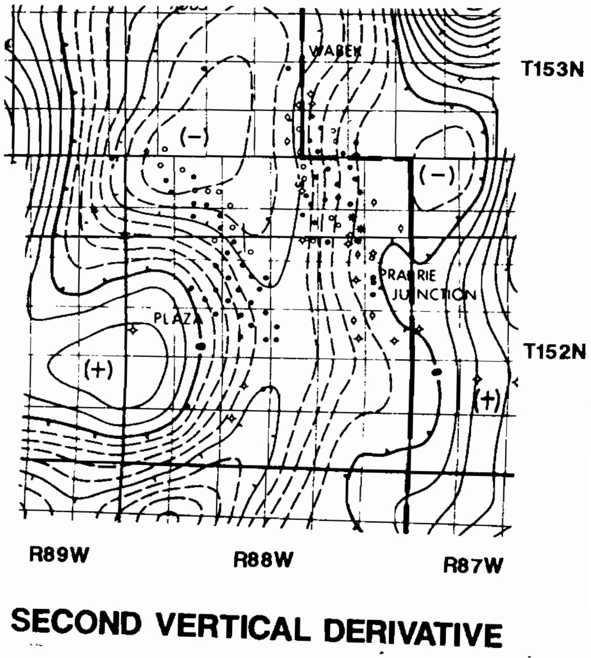
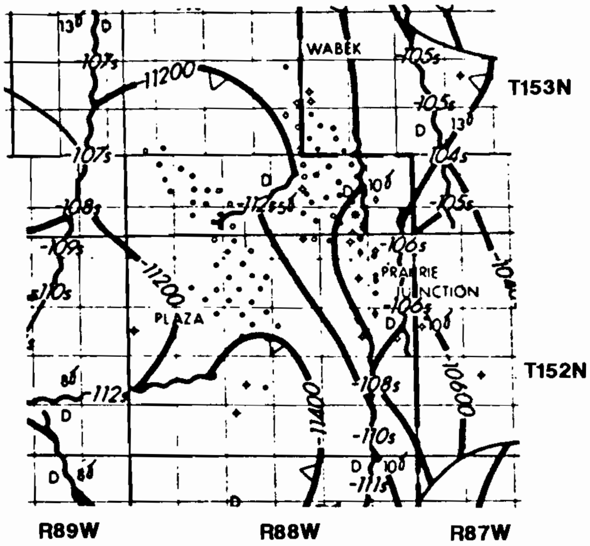
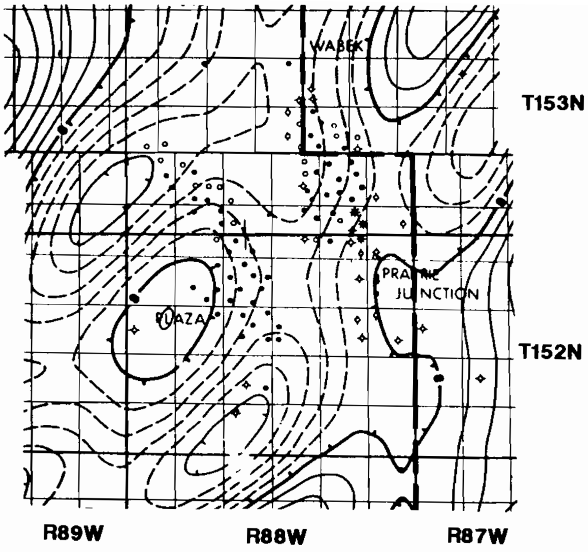


Figure 13. Second Vertical Derivative. Contour interval is 2 X 10-15 cgs units. SVD zero lines indicate the boundaries of magnetic basement blocks. Highs and lows indicate actual relief assuming homogeneous basement lithology. SVD shows a positive basement block just east and south of Wabek and southwest of Plaza with a negative area wrapping around the north, east, and south sides of Plaza Field.



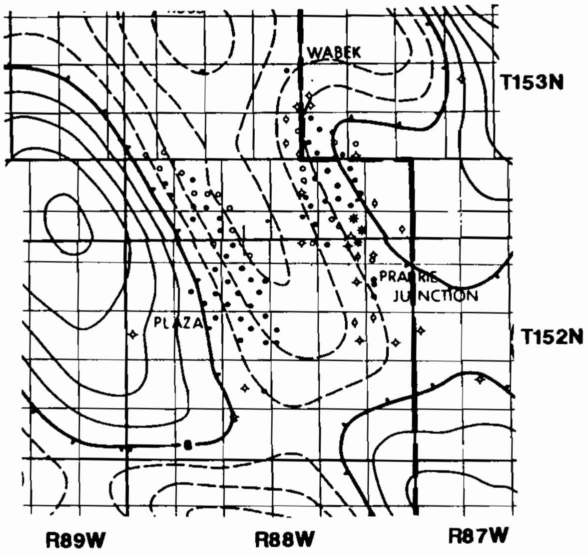
PRECAMBRIAN STRUCTURE
MAGNETIC BASEMENT

Figure 14. Interpreted Magnetic Basement/ Precambrian Structure. Contour interval is 200 feet. This map shows a basement high to the east and south of Wabek with a low area at Plaza Field. Total relief interpreted on the basement in the map area is 1000 feet.



SECOND VERTICAL DERIVATIVE
0° TO 90°
STRIKE PASS FILTER

Figure 15. Strike Pass Filter/Second Vertical Derivative. This map isolates and amplifies cross cutting northeast-southwest and northwest-southeast trends suggested on the unfiltered SVD map.



SECOND VERTICAL DERIVATIVE
90° TO 180°
STRIKE PASS FILTER

Figure 16. Strike Pass Filter/Second Vertical Derivative. This map isolates and amplifies cross cutting northeast-southwest and northwest-southeast trends suggested on the unfiltered SVD map.

The anhydrite to carbonate transition in the overlying Bluell (figs. 19-21) does not directly overlie a basement anomaly, but the abruptness of this transition and its proximity to the Sherwood facies change suggests a rather steep westward ramp (slope) into the basin. Magnetic total intensity and SVD maps show a steep gradient through Wabek and toward Plaza Field.

SEISMIC TOOL IN EXPLORATION FOR SHORELINE PLAYS

Seismic data are routinely used in evaluating Sherwood shoreline trends. Isochron maps and time-structure maps aid in the identification of subtle paleostructural anticlines, which localized shoaling environments. Seismic lines that

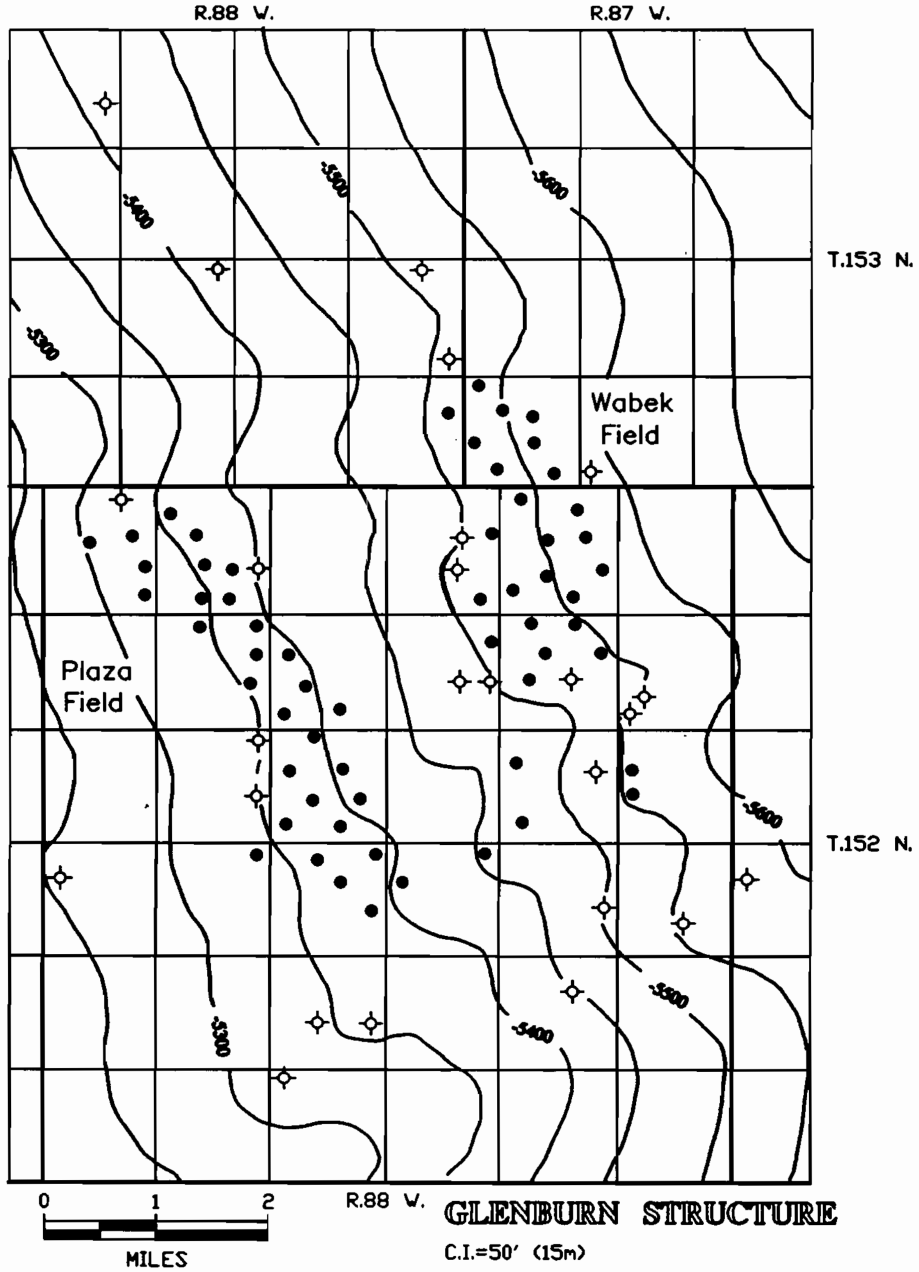


Figure 17. Glenburn Structure. Low on north end of Wabek Field is just beginning to develop at this time.

cross shorelines normal to depositional strike commonly display "steepening of dip" (close spacing of isochrons) at the change from sabkha anhydrites to tight, restricted lagoon dolomites. This localized steep dip can be observed on structure maps and may be related to basement block edges. If the seismic data have sufficiently high frequency content, an amplitude (character) change occurs in the Sherwood, or upper Mission Canyon, reflector corresponding to the facies change from anhydrite to carbonate.

Figure 22 is an example of seismic data from Wabek Field. This northeast-southwest dip section is roughly parallel to cross section A-A' (fig. 4). It was acquired in 1984 with a 96 trace

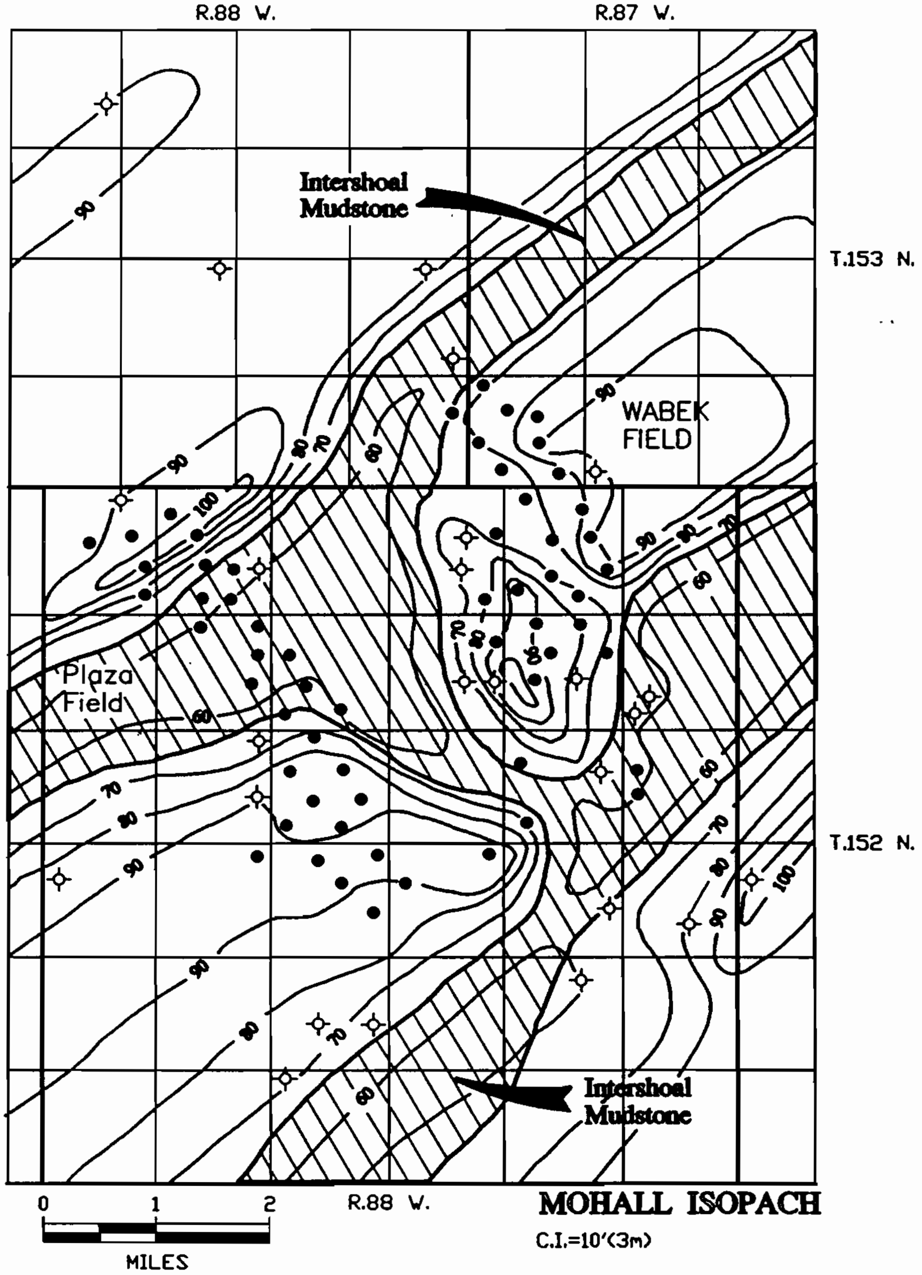


Figure 18. Mohall Isopach. Thick Mohall beds developed across the Glenburn nose. Intershoal channel facies is indicated by cross hatch pattern.

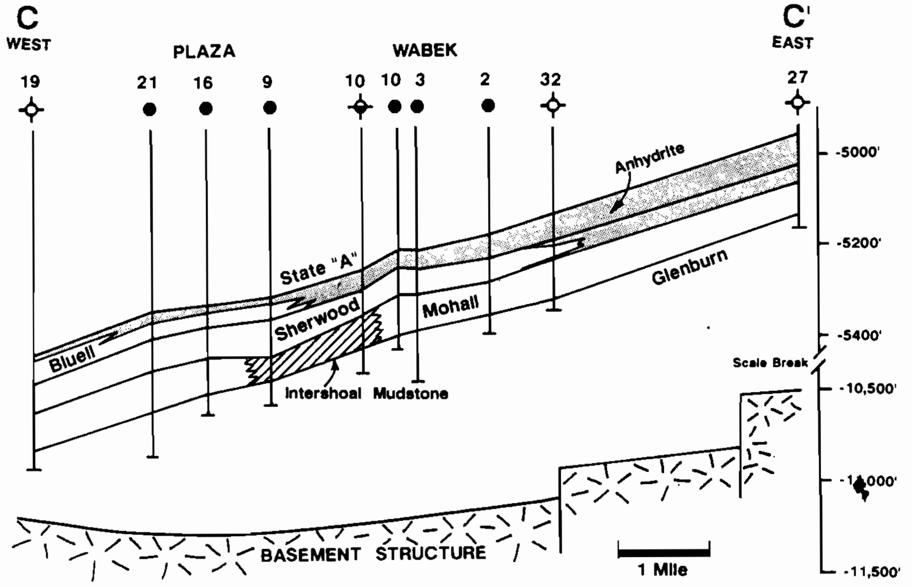


Figure 19. Profile C-C' showing relationship of the Sherwood carbonate/anhydrite facies change, and magnetic and seismic Precambrian basement structures.

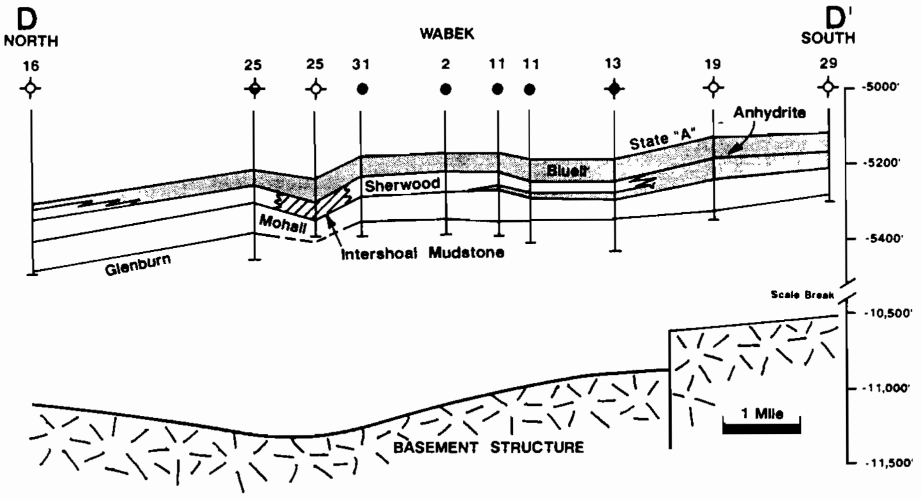


Figure 20. Profile D-D' illustrating Sherwood facies changes relative to Precambrian basement at the south end of Wabek Field.

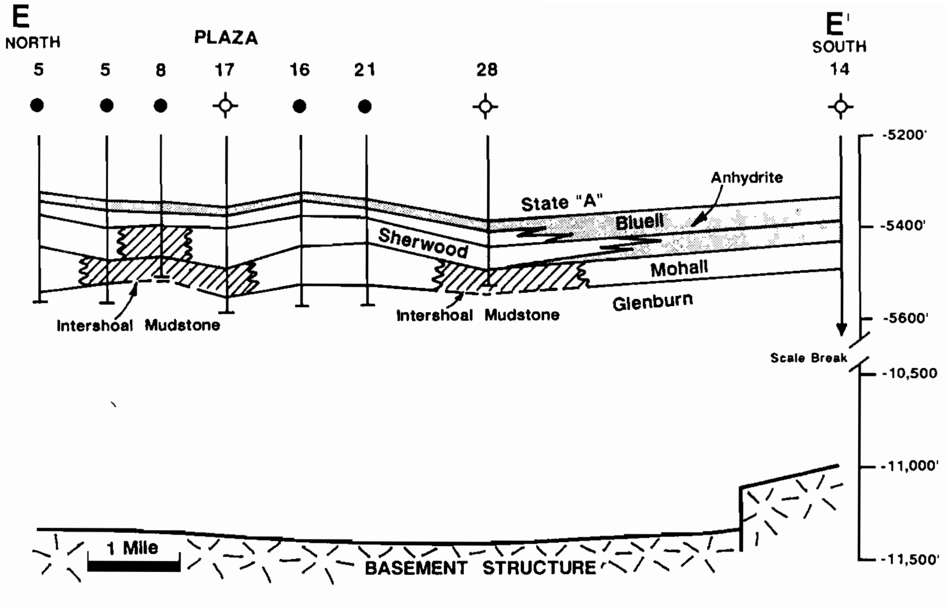


Figure 21. Profile E-E', Bluell carbonate/anhydrite facies changes are not as closely related to Precambrian basement structure.

recording system, using deep-hole dynamite (10 lbs. at 176 ft. [4.5 kg. at 53 m.]) and a closely spaced group interval (55 ft. [17 m.] groups and 440 ft. [134 m.] shots), resulting in a nominal fold of 12. The processing sequence consisted of retaining a true amplitude wavelet in order to obtain the highest frequency content possible, thought to be 80 to 90hz. The data have been phase rotated -90 degrees from zero phase to visually aid in identifying character changes. On the northeast side of the line the low-amplitude doublet in the Sherwood reflector is associated with the sabkha facies. To the southwest, this doublet changes to a well defined, higher amplitude, single peak which corresponds to carbonate facies.

INFLUENCE OF DEPOSITIONAL TOPOGRAPHY UPON SUBSEQUENT DEPOSITION

As previously discussed, Precambrian crustal structure influenced Mission Canyon deposition in the Wabek-Plaza area, and isopach mapping of the upper Mission Canyon subintervals reveals a relationship between underlying depositional topography and facies development in succeeding subintervals.

A structure map of the Glenburn subinterval (fig. 17), the lowest unit penetrated in the Wabek-Plaza area, shows a subtle structural nose trending northeast-southwest through Wabek and Plaza fields. Proceeding southwest from Wabek, the structure steepens slightly in the area of Plaza. A subtle syncline bounds the northern edge of both fields at this horizon.

An isopachous map of the Mohall subinterval (fig. 18) shows the development of a thick shoal on the southwestern edge of Wabek that may have been located here due to the underlying Glenburn nose. Along the flanks of this Mohall shoal, low-energy intershoal beds were deposited both north and south of the antecedent Glenburn high. The Mohall in these intershoal areas is composed of compactable, mud-dominated sediments, and may be only half the thickness of the shoal deposits. Even allowing for later compaction, Mohall shoals along the Glenburn nose significantly amplified the relief on the Glenburn surface.

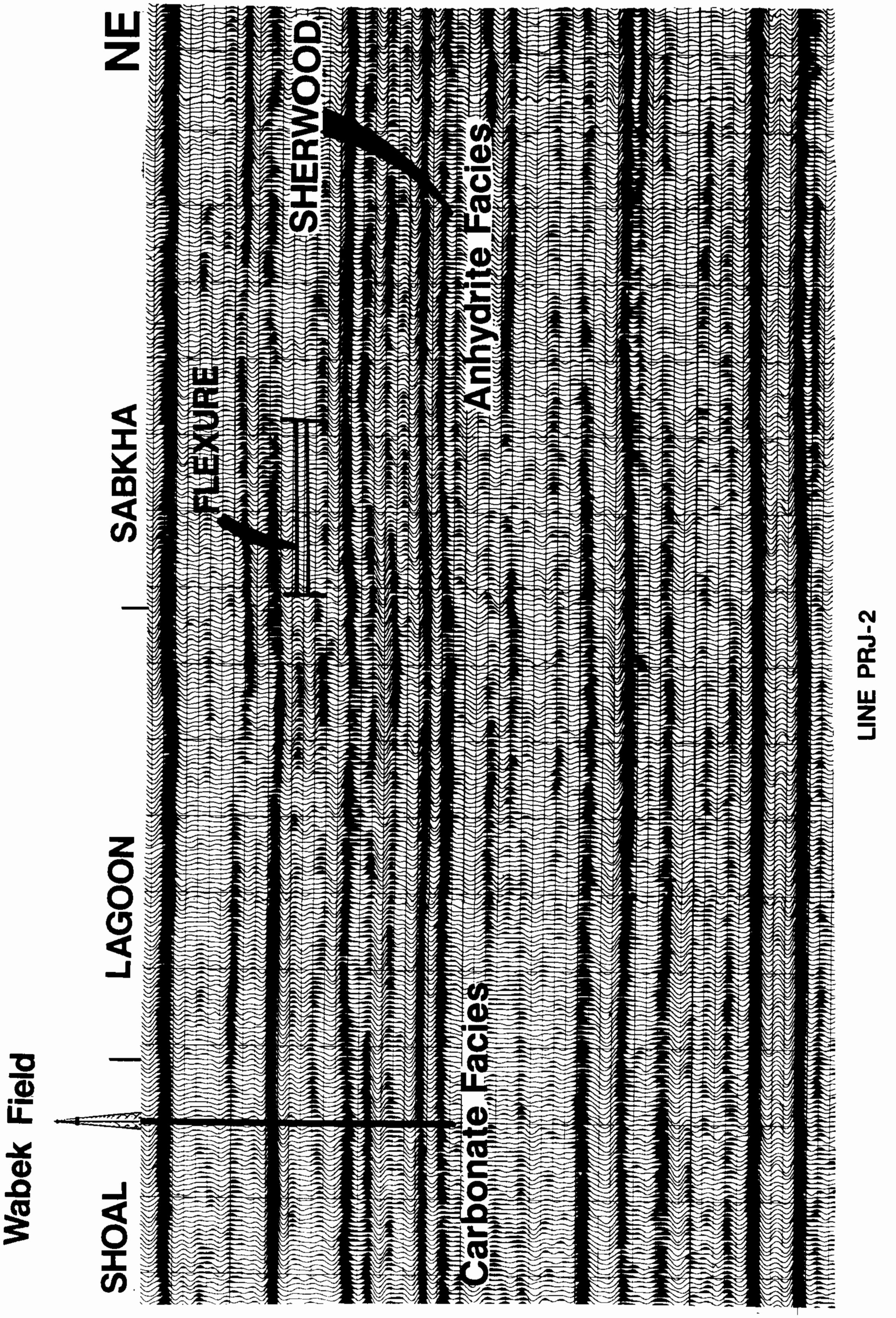


Figure 22. Seismic section across Wabek Field.

The Sherwood isopach (fig. 23) in the area of Plaza Field shows two thicks divided by an intershoal mudstone channel occupying an underlying Mohall thin. A subtle Sherwood thick also overlies the Mohall thick in Wabek Field. Its proximity to the shoreline there permitted the development of a shoal of porous grainstones and packstones adjacent to lower energy lagoonal mudstones to form a stratigraphic trap. Local tectonic influence is recognizable by comparison of the Sherwood (fig. 24) and Glenburn (fig. 17) structure maps, which show the changes in structural relief due to the deposition of the Mohall and Sherwood subintervals. Note the flattening of dip in the southern end of Wabek Field. This flattening increased the area of reservoir above the oil/water contact, thus adding significant reserves to the field.

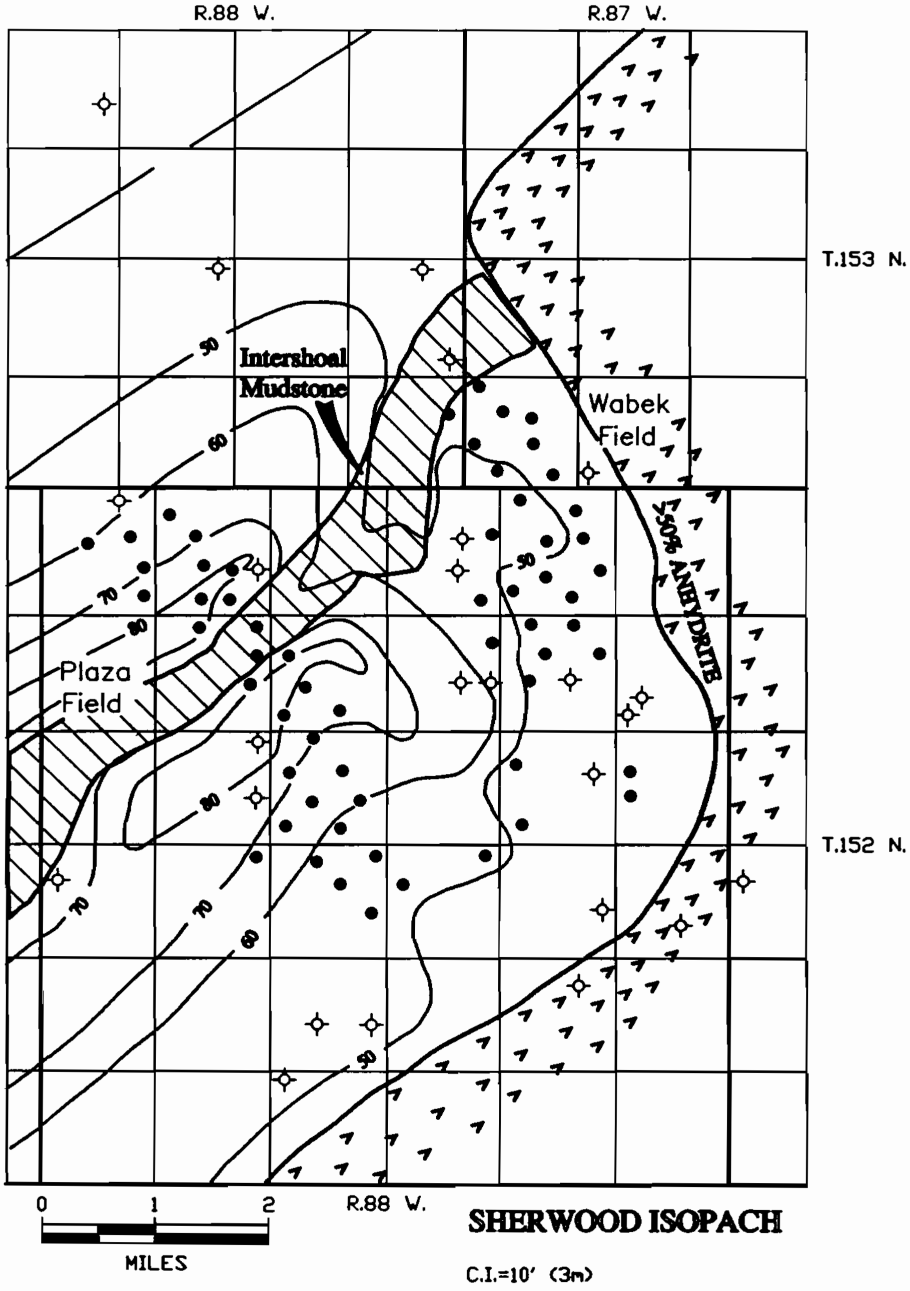


Figure 23. Sherwood Isopach. Intershoal channel facies is indicated by cross hatching, and the anhydrite trap is indicated by V pattern.

An isopachous map of the Sherwood net porosity (fig. 25) shows the thick porous zone of Wabek Field associated with the higher energy nearshore shoal facies, which in turn overlies a Mohall shoal. The thickest part of the Sherwood shoal occurs in the northwest of Section 2, T152-R88W and the southwest of Section 31, T153-R87W, where the Mohall was thicker than in adjacent areas.

The Bluell facies change from sabkha anhydrite and associated mudstones to nearshore higher energy carbonate deposits (fig. 26) may be related to bathymetry and depositional slopes. South of Plaza Field, this Bluell facies change overlies the same change in the Sherwood subin-

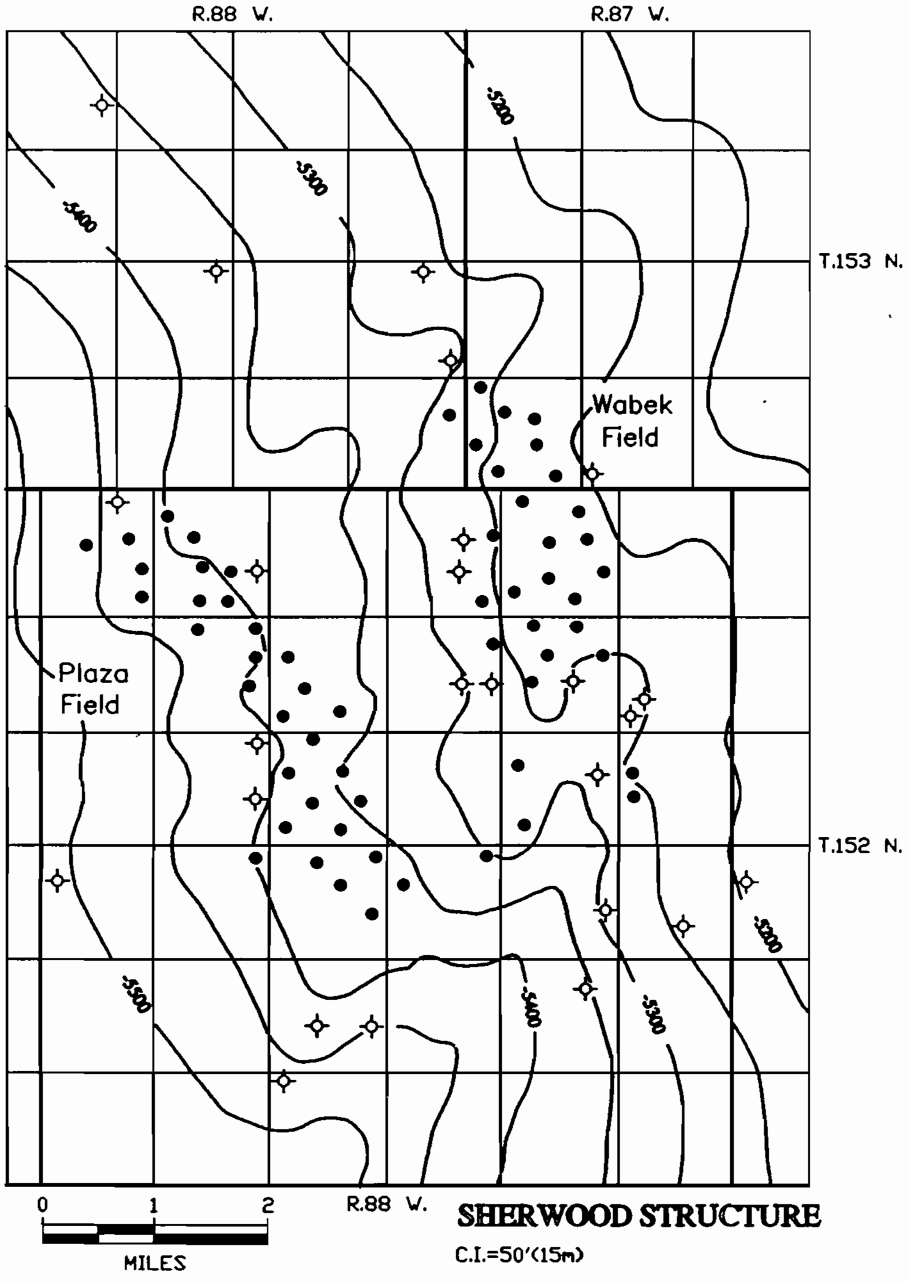


Figure 24. Sherwood Structure. Compare with the Glenburn structure in fig. 17 and note the strong low now developed at the north end of Wabek Field which enhances the trap. The present day structure exerts sparse control on Bluell production.

terval (fig. 23), implying a steep depositional slope. Oil is trapped at Plaza Field by the same Bluell carbonate to anhydrite facies change updip to the northeast (fig. 26). Control of the northeastern facies change may have been the steepening of dip in this area as shown on the Sherwood structural map (fig. 24). This steepening is probably related to the Wabek shoal and a Precambrian basement fault trend. As with the Sherwood, the facies change from impermeable beds to carbonate reservoir rocks in the Bluell is relatively abrupt, suggesting a steep depositional slope or ramp into the basin. However, the platform on which the Sherwood shoal sediments were deposited was broader (compare figs. 18,23,24,26), allowing a wider band of productive reservoir rock in Wabek Field, and hence, greater reserves.

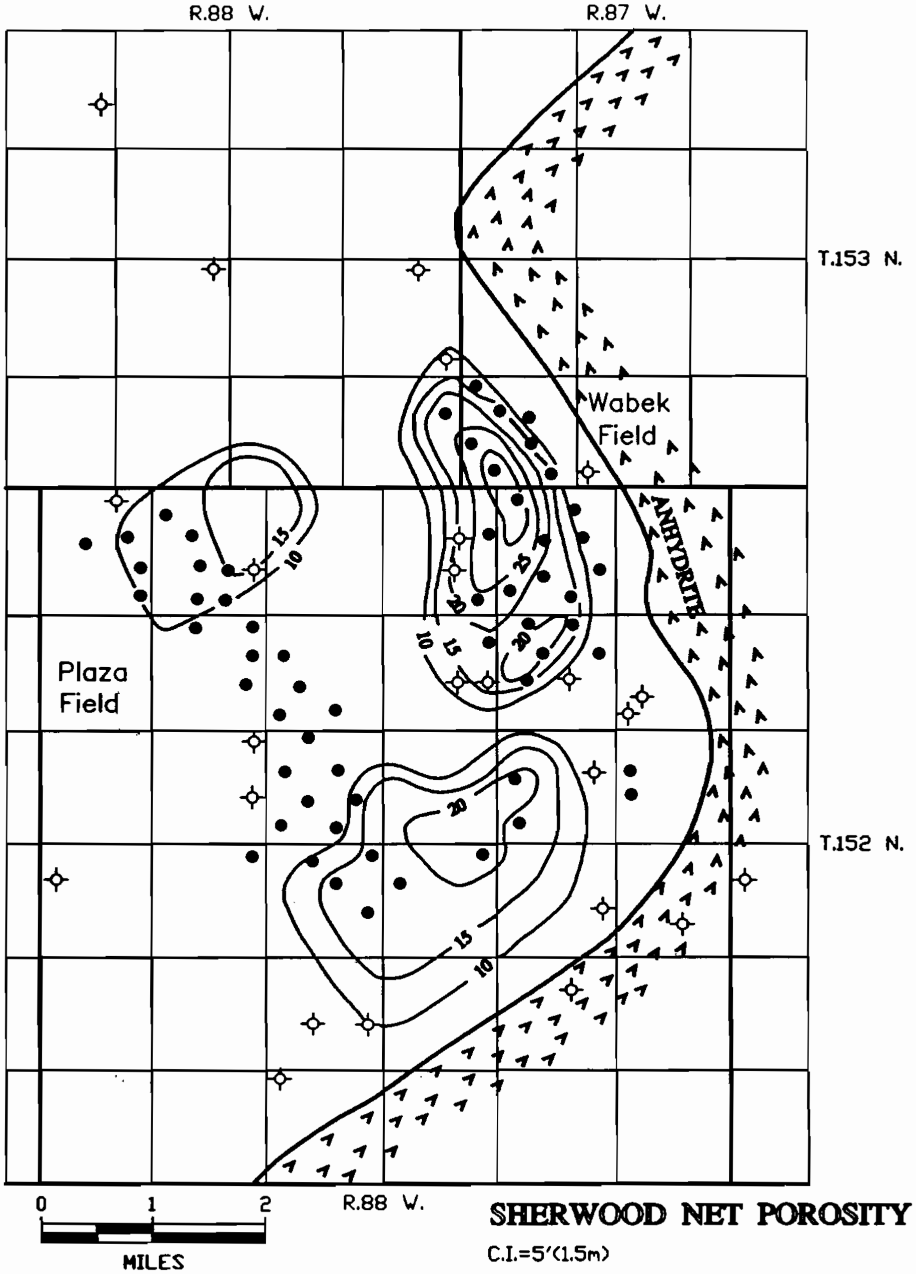


Figure 25. Net Sherwood Porosity. Density porosity greater than or equal to 8% with DXN less than 4 porosity units. Highly dolomitic porosity is not effective. This map shows the thick development of the Wabek reservoir.

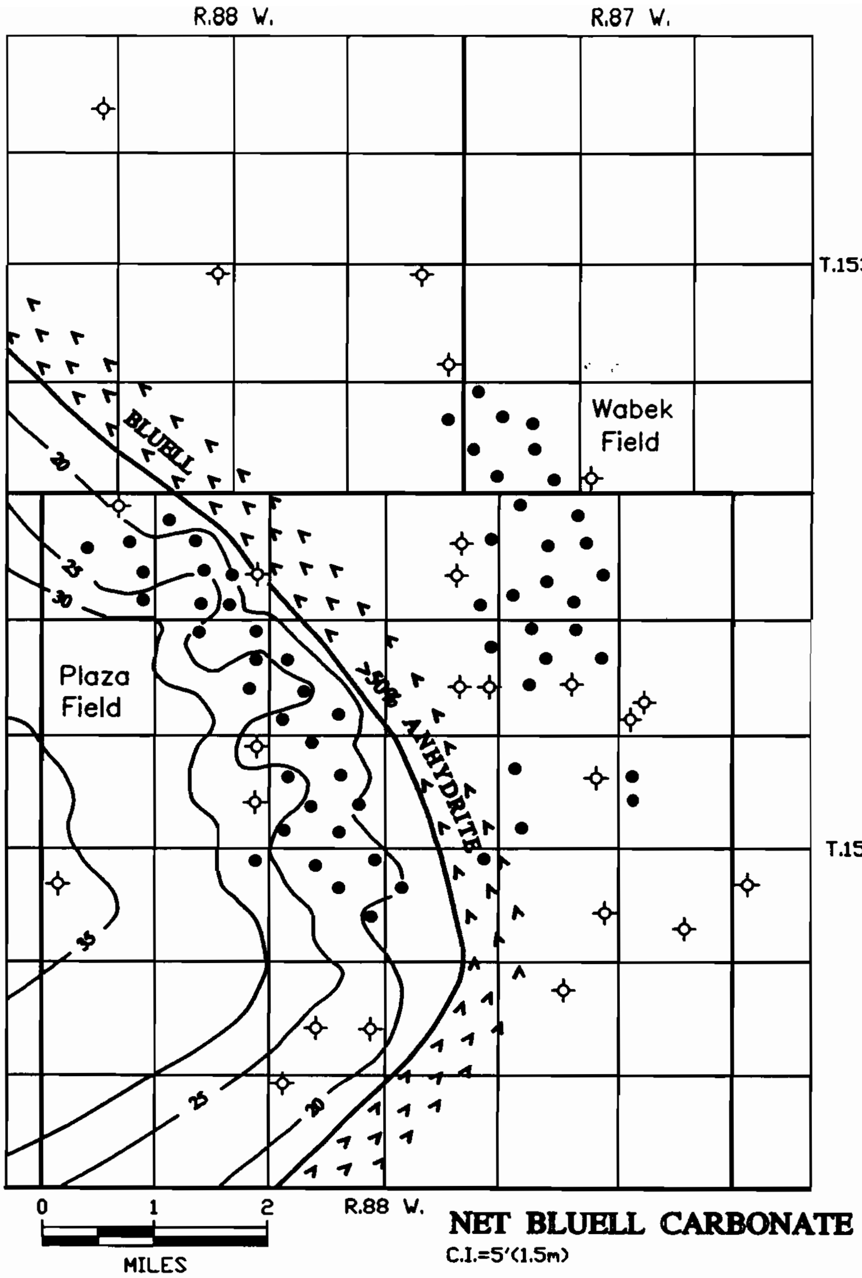


Figure 26. Net Bluell Carbonate Isopach. The lower Bluell thins as it approaches the anhydrite trap (V pattern).

SUMMARY AND CONCLUSIONS

1. Wabek and Plaza fields, the two most prolific Sherwood and Bluell shoreline fields on the northeast flank of the U.S. Williston Basin, were not discovered until the late 1980's. They have rekindled interest in the Mission Canyon shoreline play, which had been essentially dormant for 15 years.

2. The productive facies in both fields is a peloidal, oolitic, pisolitic, intraclastic and composite-grain packstone and grainstone deposited in shallow subtidal to intertidal shoal environments which persisted along a low-energy shoreline. The updip trap is impermeable lime mudstone and patterned dolomudstone deposited in restricted lagoons and nodular anhydrite precipitated in sabkhas. Porosity in the reservoir facies is predominantly intergranular and vugular.

3. Basement-related paleostructural trends controlled stratigraphic changes in upper Mission Canyon sediments in the Wabek-Plaza area. Locally, subtle structural nosing in the Glenburn subinterval was modified and enhanced by shoaling in the overlying Mohall subinterval. The location of the facies change from anhydrite to carbonate and from shoal to intershoal deposits in the Sherwood was affected by underlying Mohall topography. Bluell facies changes were similarly affected by underlying stratigraphic variations.

4. Sherwood and Bluell shoreline trends can be mapped using subsurface well control, aeromagnetic data, and seismic data. A high-quality seismic line at the updip portion of Wabek Field shows a structural flexure and a seismic "character change" which corresponds to the anhydrite to carbonate facies transition in the Sherwood.

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