DEPOSITIONAL ENVIRONMENTS IN THE ARENOSO FIELD, WINKLER COUNTY, TEXAS

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ABSTRACT

Over twenty-three million barrels of oil and thirty billion cubic feet of gas have been produced since 1963 from a stratigraphic trap in Desmoinesian age Strawn chert conglomerates in the Arenoso Field area, Winkler County, Texas. The Arenoso sub-basin on the Central Basin Platform was the site of deposition of an alluvial fan created from the erosion of weathered Devonian and older cherts off the surrounding exposed, faulted structural uplifts. This alluvial deposit filled the southeast corner of the small sub-basin while shallow marine Strawn limestones filled the remainder of the sub-basin. Numerous periods of minor sea level rise deposited shallow marine carbonates between alluvial fan debris flows; subsequent subaerial exposure created terra rossa surfaces and other evidence of soil horizon development observed in cores from the field. The alluvial deposit was drowned by Late Strawn sea level rise and buried by younger Pennsylvanian shelf carbonates. During Wolfcampian regional deformation the deposit was tilted to the west. The preservation of this coarse alluvial fan deposit created an excellent hydrocarbon trap. Updip proximal-fan facies produce in isolated small pods of porosity; medial and distal braided stream and shoreface deposits are the most prolific producing depositional facies.

LOCATION

The Arenoso Field area is located in the southeastern corner of Winkler County, Texas northeast of the town of Monahans. It takes its name from the large semi-migratory dune field in this area, the Monahans Sand Hills (Figure 1).

Geologically, the Arenoso Field is located on the hydrocarbon-rich Central Basin Platform uplift of the Permian Basin. It lies in a structurally low area on this uplift, surrounded by the oil-productive structural features of the Sand Hills-Crane uplift to the south, and moving counter-clockwise, the Yarbrough & Allen, Penwell, TXL, Keystone, Kermit, Emperor, and Monahans fields (Figure 2). The Arenoso Field is stratigraphically trapped. Over twenty-three million barrels of oil and thirty billion cubic feet of gas have been produced to date from a Strawn-age chert conglomerate reservoir. This chert conglomerate produces from five different field designations: Arenoso, Arenoso West, Hollijack, Lazy R, and Sealy Smith. The conglomerate reservoir was discovered in 1963 by Humble Oil Company in a drillstem test in an Ellenburger wildcat, the #53 Yarbrough & Allen. The DST flowed oil to the surface from a depth of 8300'; this production was the first in the Lazy R Field. In 1965 Standard of Texas #1 Vest Ranch, three miles to the north, discovered the Arenoso Field with production from the same chert conglomerate unit from a depth of 8600'. Subsequent field development showed over 800' of original oil column in the conglomerate. The field is currently under waterflood by major operators Chevron and Exxon.

STRATIGRAPHIC SECTION

The Arenoso Field is unique in that it is the largest field in the Permian Basin producing from the "Pennsylvanian Detrital". The "Pennsylvanian Detrital" is an informal term loosely and often erroneously, applied in the Central Basin Platform area. Varicolored shales, thin red and gray limestones, coarse sands, and chert conglomerates are found below the lowest Permo-Pennsylvanian shelf carbonates and in angular unconformable contact with underlying Mississippian and older strata. These deposits actually represent a series of unconformity-band units ranging in age from Atokan through Wolfcampian, many times in complex, cross-cutting relationships. This paper will deal only with the Arenoso Field area and "Pennsylvanian Detrital" relationships found there (Figure 3).

Arenoso Field
Texas and New Mexico

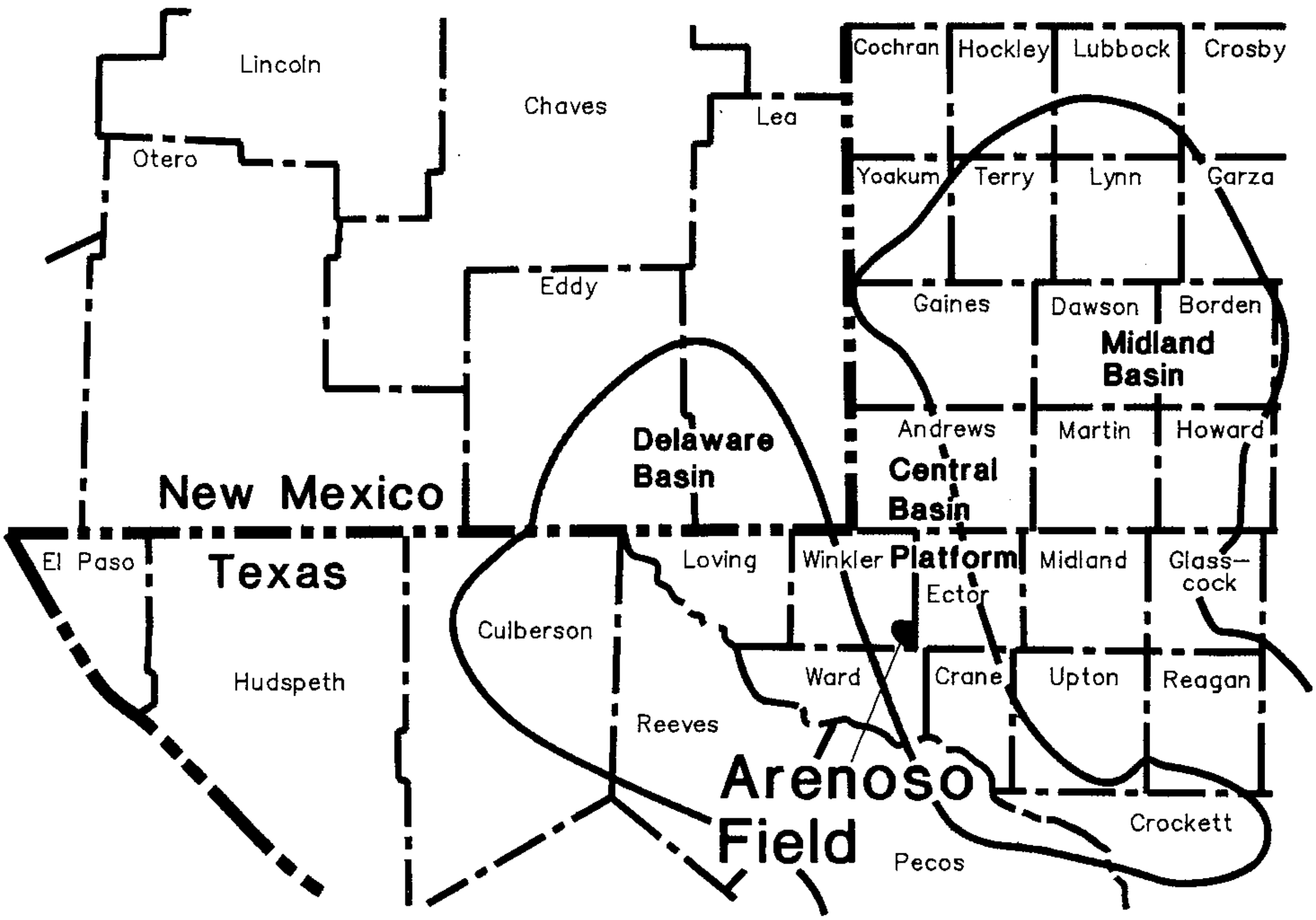

Figure 1. Location map, Arenoso Field, Winkler County, Texas.

PREVIOUS WORK

There is very little published literature on the subsurface "Pennsylvanian Detrital". However, several publications, among them Hills, 1970; Young, 1960; Walper, 1977; Font, 1985; Ewing, 1985; Ross, 1986; and Gardiner, 1990, were helpful in establishing the structural setting of the Central Basin Platform area. Pennsylvanian stratigraphy and depositional environments of the Marathon Uplift region to the south are discussed in Adams, 1958; Young, 1960; Ross, 1967; and Ross and Ross, 1985. These references proved useful in making inferences about the Arenoso study area. Gene Greenwood (pers. comm.) discussed with me the producing history and characteristics of the Arenoso Field.

METHOD OF APPROACH

A network of regional correlation cross-sections was constructed across the Arenoso Field using available electrical logs, sample logs, and paleontological reports, to accurately define and locate the "Pennsylvanian Detrital" rocks or their absence. All 250 wells in the study were tied to the nearest regional cross-section. All wells were then used to make the following maps: Structure Top Strawn Detrital, Gross Isopach Strawn Detrital, Net Isopach, Net Clean Porous Isopach [≤30 API GR units, ≥5% porosity (Net Reservoir Isopach)], and Strawn Detrital Facies Distribution.

The facies map was generated after making a core-log correlation in the Arenoso Field, and interpreting three general facies (chert reservoir rock, limestone, and shaley facies) from that correlation. The facies map records percentages of each facies present within the total interval and was calculated as shown in Table I.

TABLE I

TOTAL INTERVAL	CLEAN INTERVAL	CLEAN POROUS INTERVAL
250	120	50
(Gross Interval)	(Limestone)	(Chert Reservoir)

% Chert Reservoir	= 50/250	= 20% Chert Reservoir Facies
% Limestone	= (120-50)/250	= 28% Limestone
% Shaley Facies	= 100-% Chert Facies + % Limestone Facies	= 52% Shaley Facies (Shaley Limestone or Shaley Chert Facies)

Wells without a usable gamma ray and porosity log were not used in making the facies calculation. Commercial sample logs in general confirmed this method as did sample descriptions done by Jim Druyff (independent consulting geologist, Denver, Colorado) on eleven wells in the field.

In addition, six cores (525 feet total) from the Arenoso and Lazy R Field areas were described and photographed. Observations from these cores form the basis for the environmental interpretations presented in this study.

PALEONTOLOGY

All pertinent paleontological reports from Hollingsworth Paleontological Laboratory were used for age determinations and were tied into the regional cross-section network. The Hollingsworth fusulinid identifications date this unit as Lower and Upper Cherokee (Lower Strawn) in age. The occurrence of the genera *Fusulina* and *Fusulinella* in limestones interbedded with and immediately overlying the chert conglomerate units confirm this age for the Arenoso Field.

STRUCTURAL SETTING

Late Mississippian to Early Strawn deformation is characterized by east-west compression (Font, 1985) resulting in major basement uplifts and formation of adjacent sub-basins in the Central Basin Platform area.

The Arenoso sub-basin is an 80-square-mile inlier of Pennsylvanian strata that is surrounded by basement-cored faulted uplifts (Figure 2). These uplifts had been locally eroded down to, and locally through, the Devonian chert facies (McGlasson, 1967). The major source of the Pennsylvanian chert detrital sediments in the Arenoso sub-basin is believed to be the Sand Hills-Crane uplift, with minor contributions from other eroded uplifted structures. This asymmetric sub-basin contains up to 450' of Strawn age sediments of highly variable lithofacies character: chert conglomerates, coarse sands, shales, and limestones. While production occurs in the chert conglomerate facies and the limestone facies, this paper concerns only the chert conglomerate reservoir. The Strawn sediments are overlain by younger shelf limestones of the Canyon, Cisco and Wolfcamp. Subcropping beneath the Strawn detrital sediments in angular unconformable contact are, from west to east, Atoka, Barnett Shale, and Mississippian Limestone (Figure 4).

FIELD DESCRIPTION

Present-day dip at the top of the Strawn in the Arenoso sub-basin is to the west and south, at about 2°, into the Sand Hills-Crane bounding fault (Figure 5). Production occurs from both limestone and chert conglomerate facies (Figure 6) with the majority occuring within the chert conglomerate. Isopach of the net reservoir rock (Figure 7) delineates a group of anastomosing channels that terminate near the north end of Block B-13 and in Sections 7 and 26, Block A. This termination is supported by the facies interpretations that show the areas of >25% chert conglomerate confined to the southeastern part of this sub-basin, while the remainder of the basin is limestone and shale facies (Figure 8). The pay zones are, in general, distributed vertically throughout the Strawn detrital interval, and are not consistently found at the base or top. However, there is in general a coarsening-upward sequence with a shallow marine limestone cap at the top.

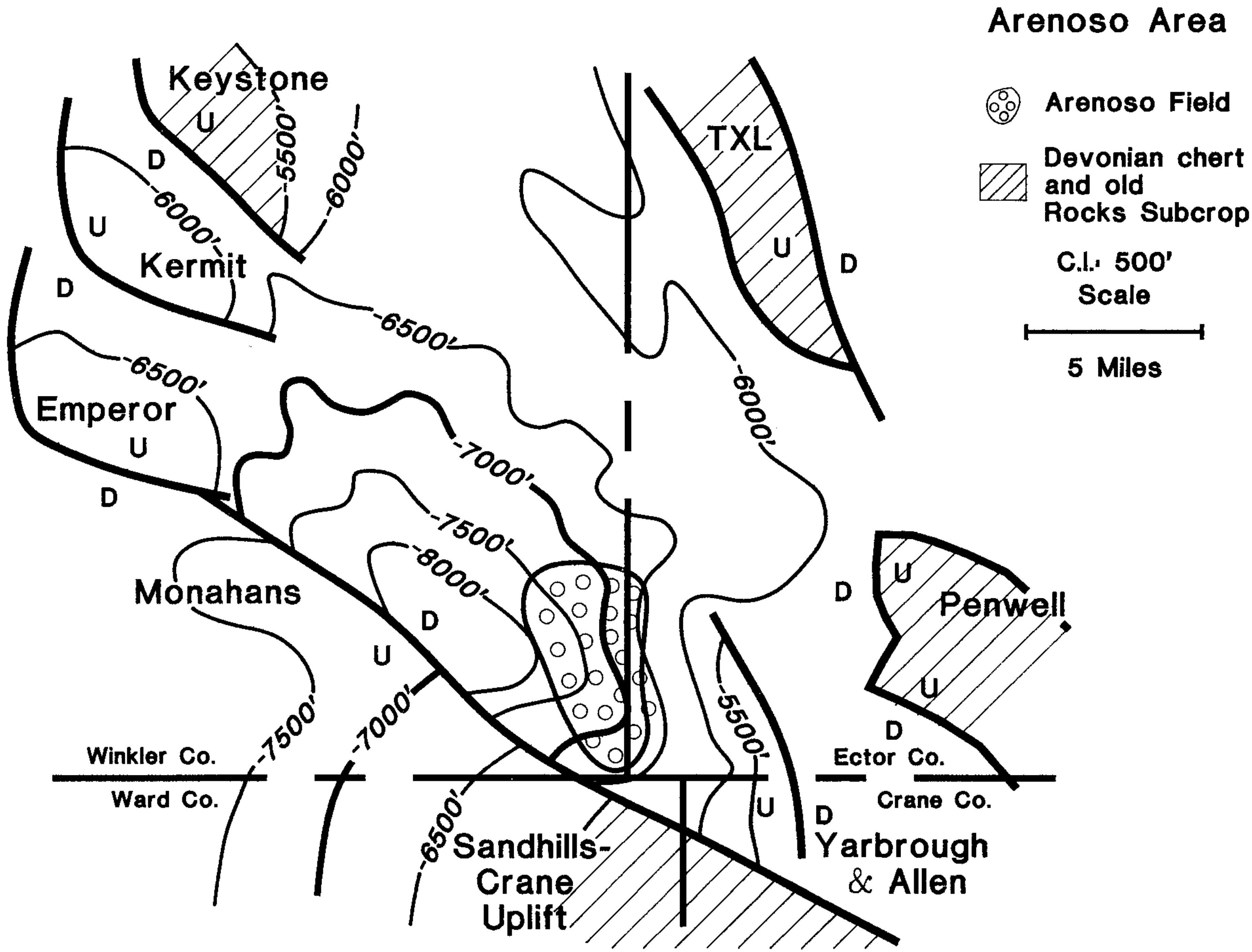

Figure 2. Generalized structure map, Arenoso Field area, Winkler County, Texas.

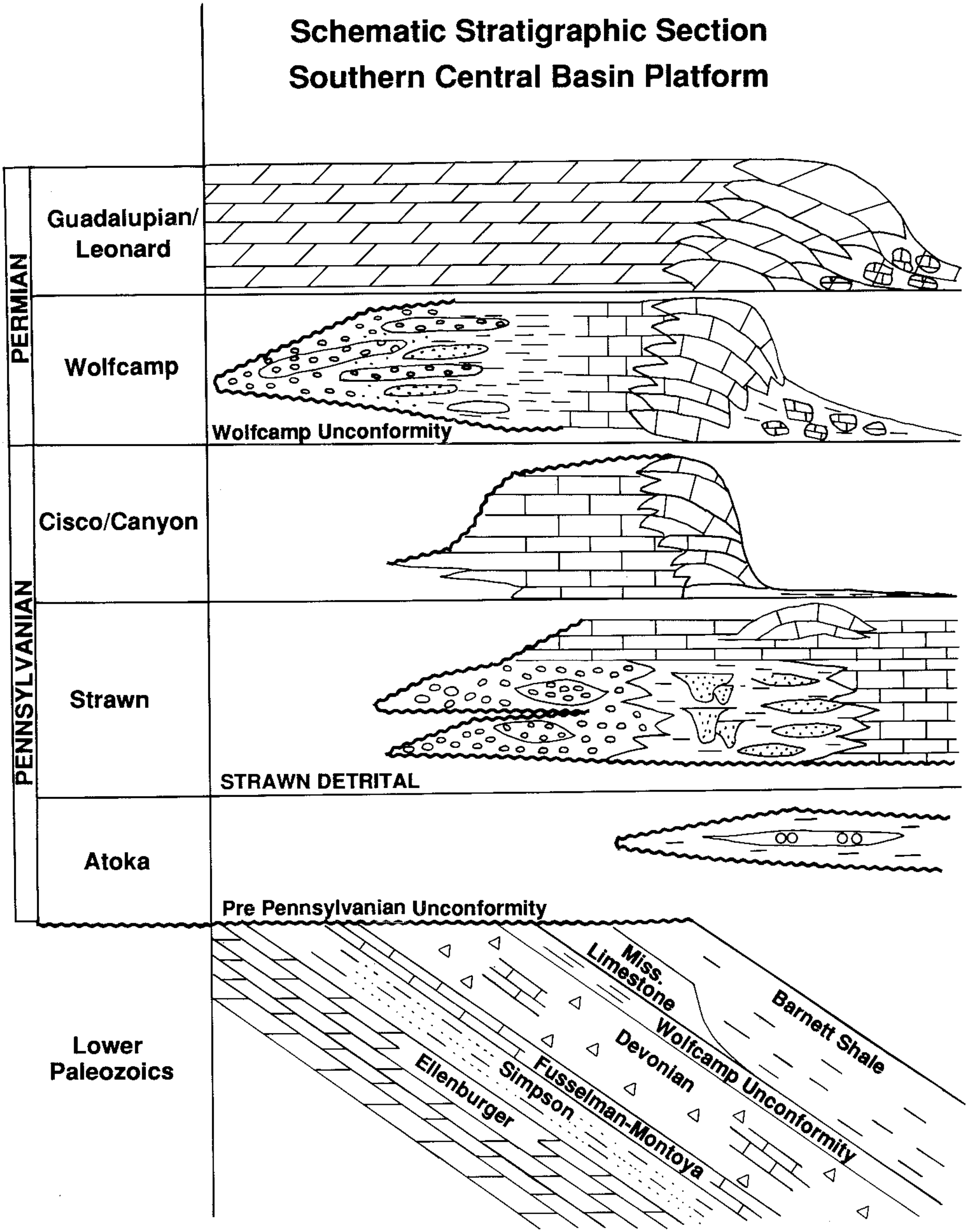

Figure 3. Schematic stratigraphic section, Central Basin Platform.

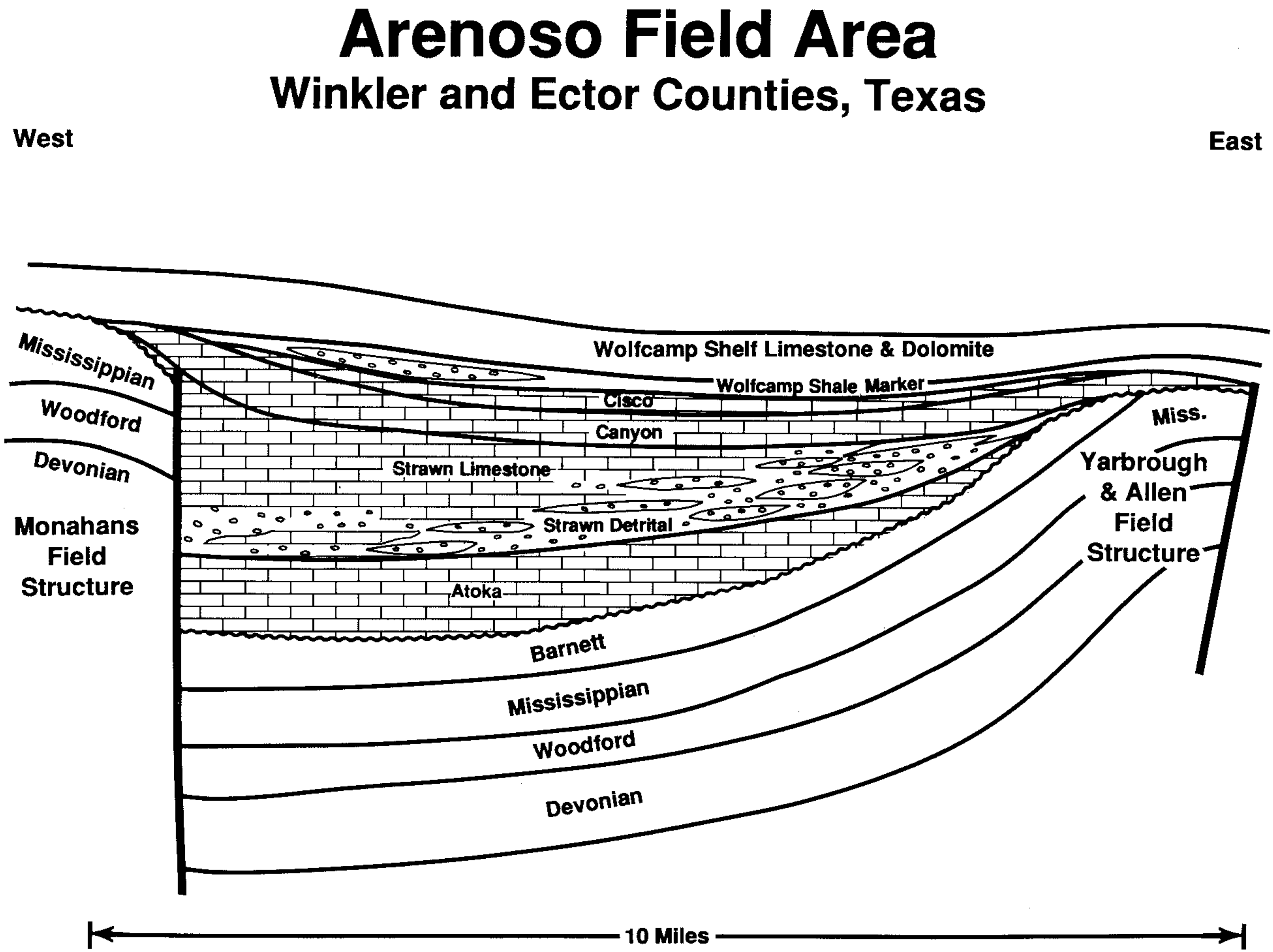

Figure 4. Cross Section, West to East, across Arenoso sub-basin.

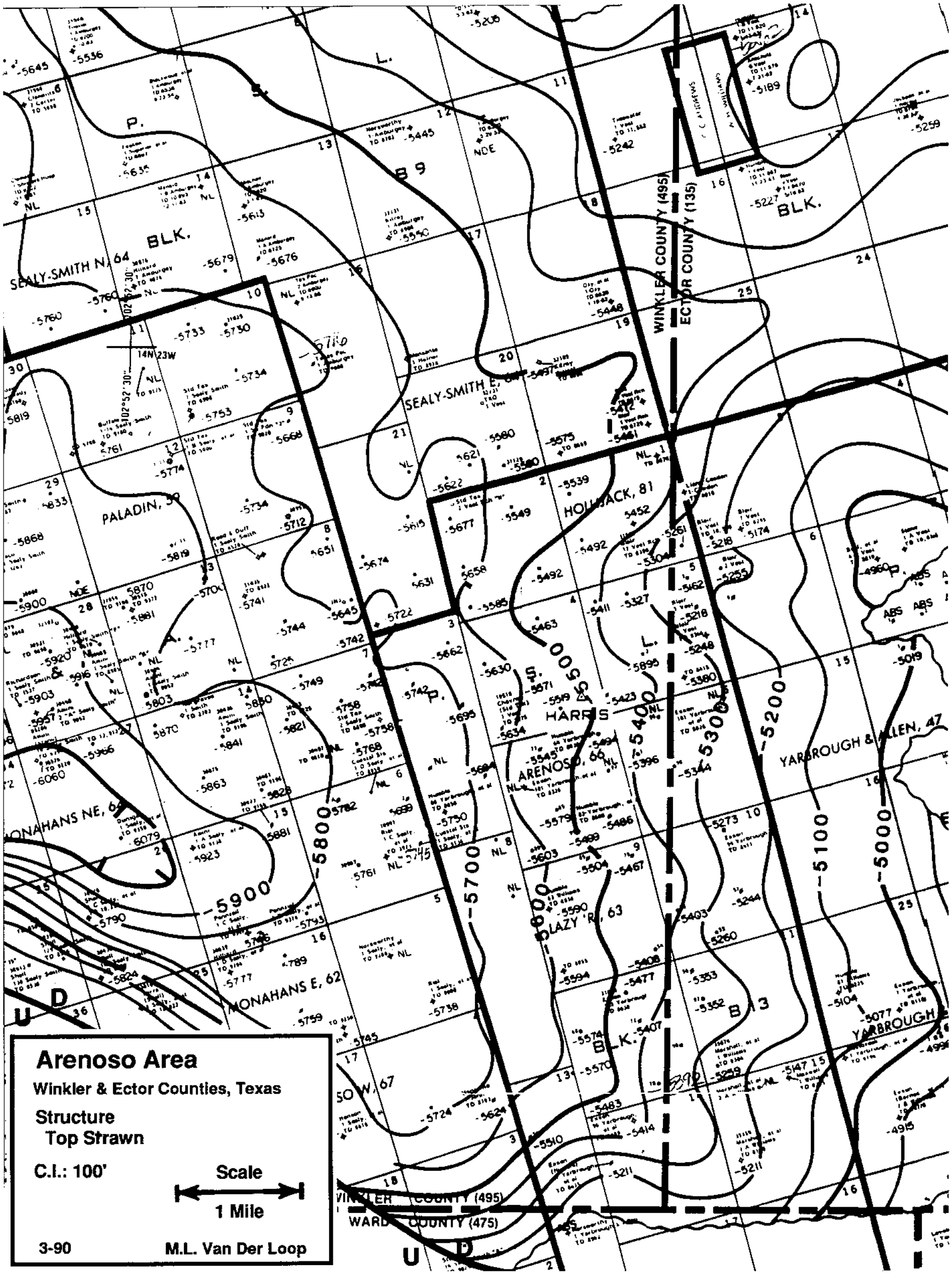

Figure 5. Structure map, top Strawn, Arenoso Field area.

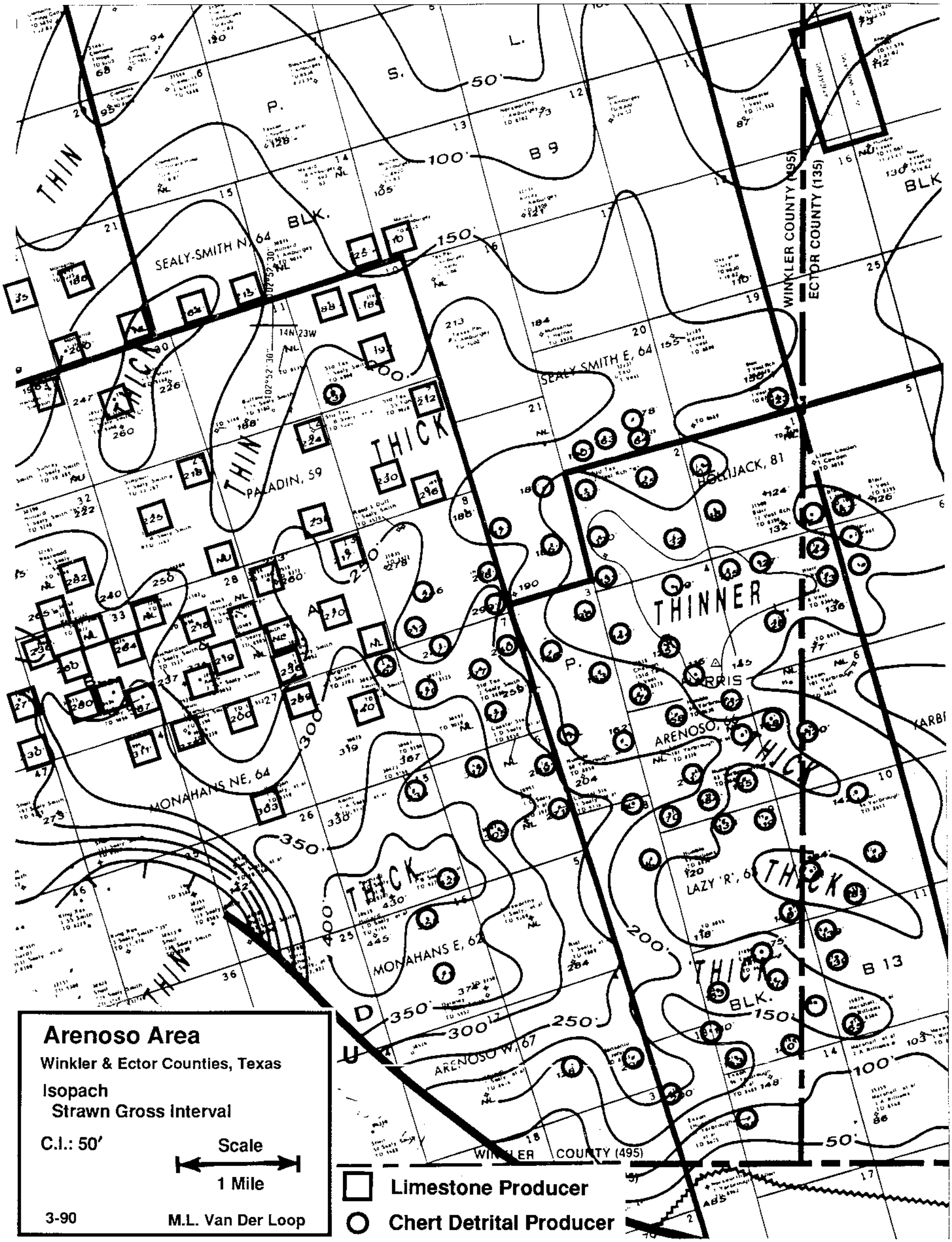

Figure 6. Isopach map, gross Strawn interval, Arenoso Field area.

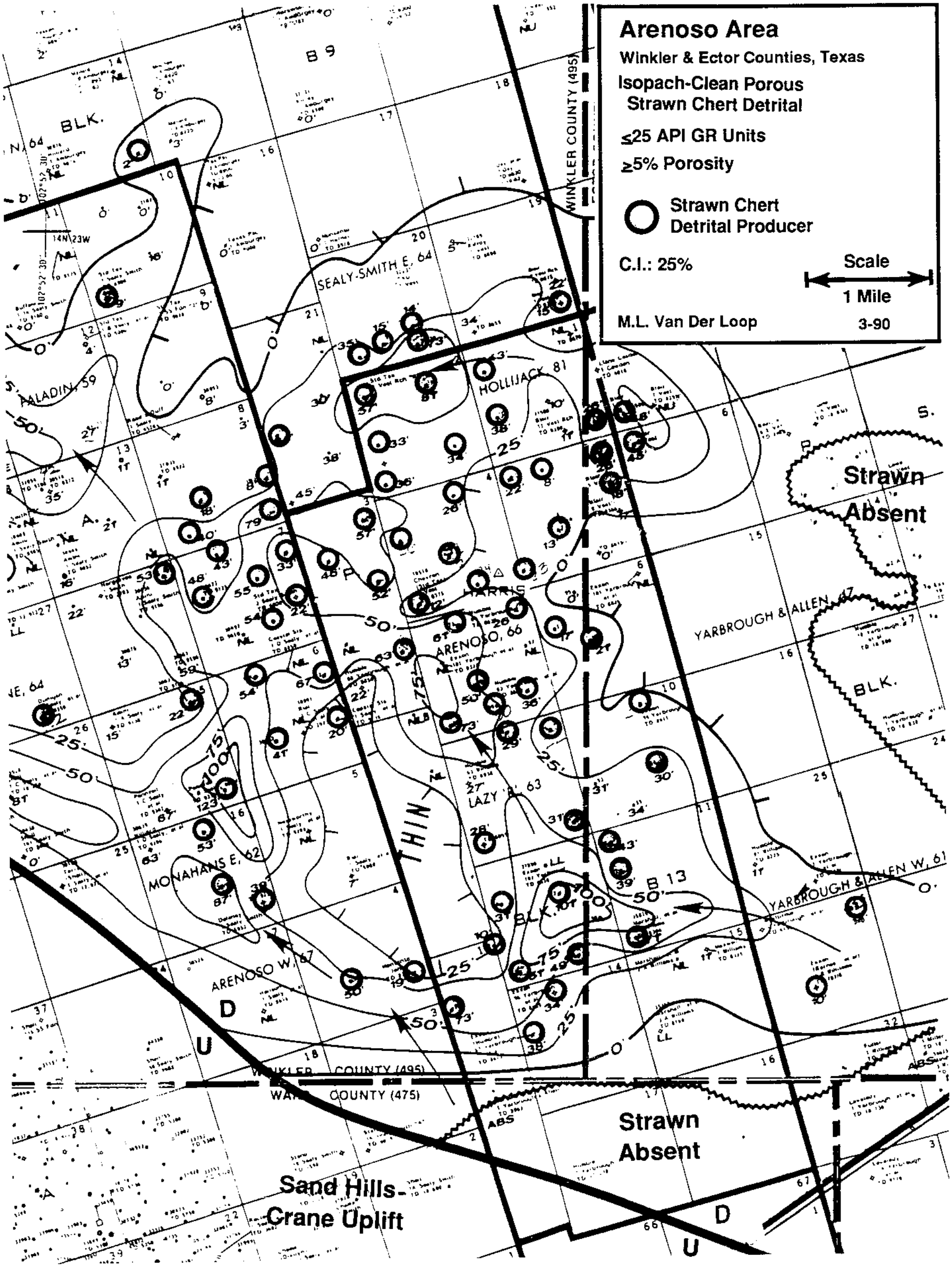

Figure 7. Isopach map, net Strawn reservoir rock (Gamma Ray ≤30 API Units, Porosity >5%).

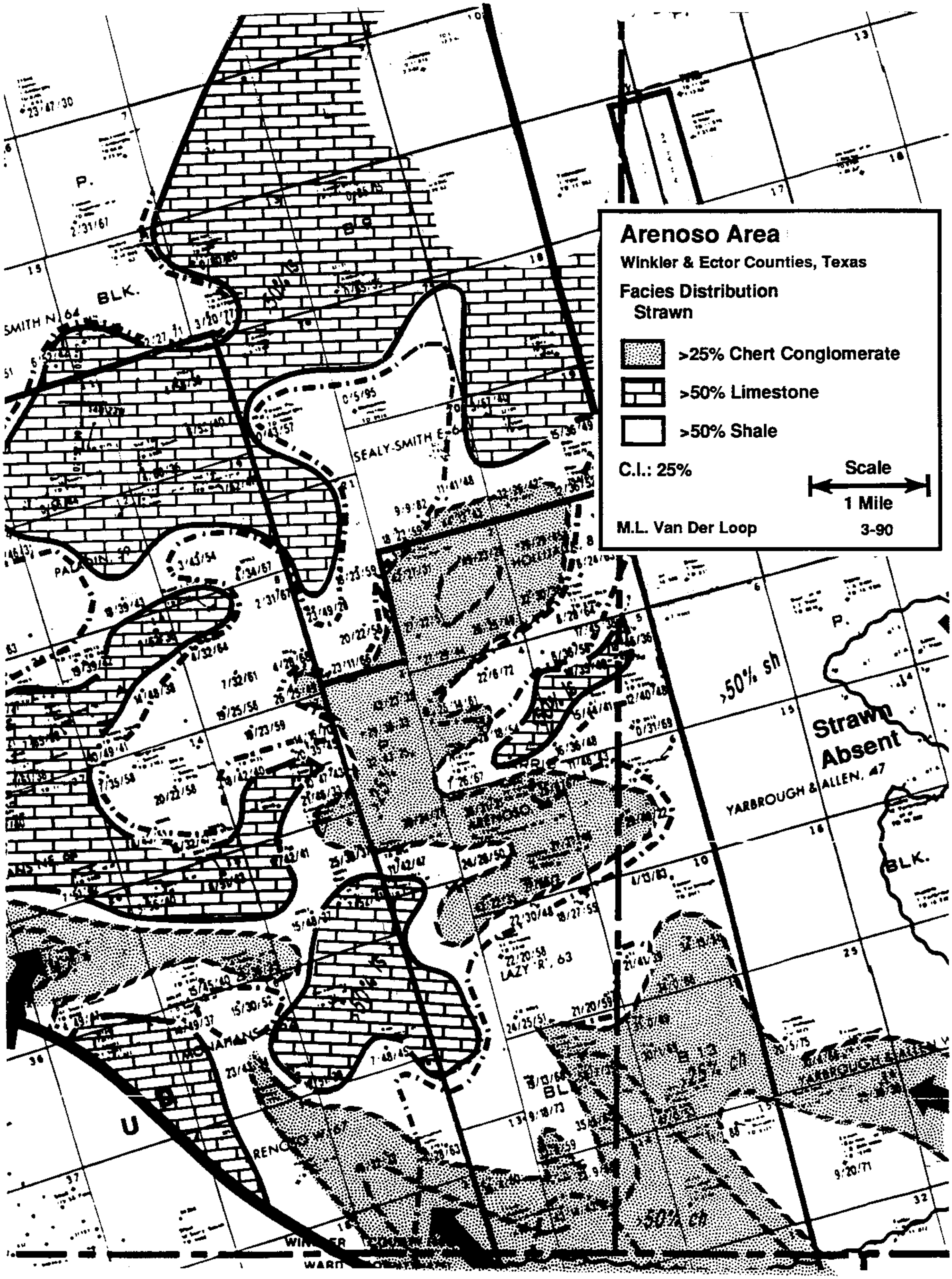

Figure 8. Strawn Facies Distribution, Arenoso Field area.

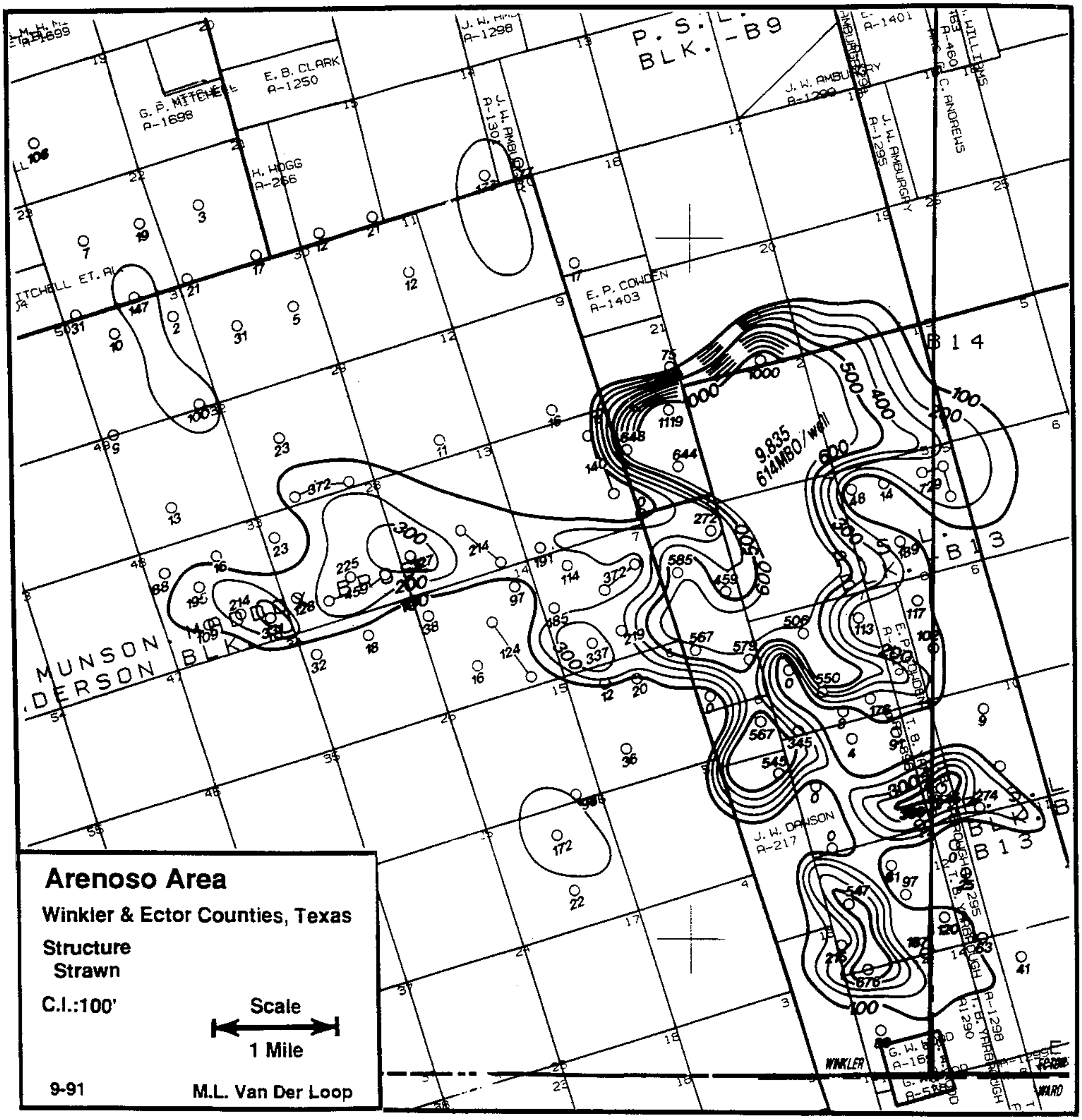

Figure 9. Cumulative Production Isopach map, Arenoso Field area.

Average net pay thickness of the Arenoso reservoir is 17.4' per well, with average porosity of 12.3%, permeability ranging up to several darcies, and average water saturation of 40%. The original oil column in the chert detrital facies of the field was approximately 832'. The field is currently under waterflood; thus, the oil-water contact has since moved erratically upward, presumably depending on bed permeability and continuity.

Field production characteristics (Figure 9) correlate moderately well to the facies map and the net reservoir rock map. The production in the far southeastern corner of the sub-basin, in the area of >50% chert conglomerate, is confined to a few 1 MMBOE pods separated by dry holes and poor recovery wells. In the northwest, downdip, area of chert detrital facies, the best production is found in a five-section area (Exxon's Yarbrough & Allen leases and Chevron's Vest Ranch leases) that has produced over 17 MMBOE to date. Some wells have produced more than 1 MMBOE each.

Examination of six cores in the Arenoso Field yielded the following observations:

1. Pay occurs in three different facies:

   a. Weathered gray-yellow, poorly sorted chert cobble conglomerate (Figure 10);

   b. Chert pebble conglomerate with red siltstone/mudstone matrix (Figure 11);

   c. Very coarse-grained gray to green pebbly crossbedded sand (Figure 12).

There are numerous coarsening-upward sequences containing rounded to subangular chert pebbles with weathered rims (Figure 13). Occasional weakly imbricate pebble conglomerates indicate paleocurrent directions (Figure 14). Several beds demonstrate inverse grading (Figure 15) typical of mud flows; some red pebbly mudstones (Figure 16) represent debris flows. Chert pebbles suspended within a red silty shale matrix (floatstone) is a common rock type. This lithofacies is interpreted to be evidence of debris flow deposition in an alluvial fan environment.

Core from only one well was available from the producing zones in the downdip richest producing area, and it was not well marked or preserved. However, very coarse-grained sandstone (Figure 12) is apparently the productive horizon in this well, and by inference, the pay zone in the most prolific part of the field may also be this coarse sandstone facies. Only one fining-upward sequence with crossbedding was observed (Figure 17). A grain-size change downdip from fan conglomerates to braided stream or shoreface environment would be expected in the alluvial fan depositional system.

Numerous thin limestones (mudstones and crinoid packstones) are interbedded with the clastic facies and show strong evidence of many subaerial exposure and weathering episodes (Figure 18). Chert cobbles and pebbles are found locally in the limestone beds (Figure 19), indicating that the clastic facies both interfingered with the shallow marine facies, and that surges of clastic deposition followed periods of subaerial exposure (Figure 20). This interfingering leads to the interpretation that there must be an adjacent shoreline facies of sorted, reworked sediments, that has not been cored. Furthermore, it is possible that this shoreline facies is not in direct contact (in terms of reservoir continuity) with the coarser proximal alluvial fan facies. Black shales with carbonaceous plant fragments indicative of a swamp or marsh environment are present but rare (Figure 21). Two thin (4") beds of massive chert represent a probable diagenetic alteration event (Figure 22). A possible origin is the formation of a silcrete horizon during long periods of exposure and soil formation (Thiry, 1987, 1991).

The most continuous core available (Humble #54 Yarbrough & Allen, Section 9, Block B-13) showed a sequence of facies (Figure 23) which support the following interpretation. A post-Atoka — pre-Strawn erosion surface is defined by a terra rossa horizon at a depth of 8408'. This surface was buried by fluvial sediments of a distant alluvial fan and then overlain by interfluvial red shales. Chert conglomerates at 8375' were then deposited in another alluvial pulse, and were capped by cobble-supported and mud-supported debris flows. The conglomerate facies is punctuated by a marine incursion (limestone bed at 8350') which is followed by a sea level fall (terra rossa surface at 8350'). The alluvial conglomerate bed at 8330' represents a final progradation of coarse clastics. It was not possible from other cores available in the area to make a

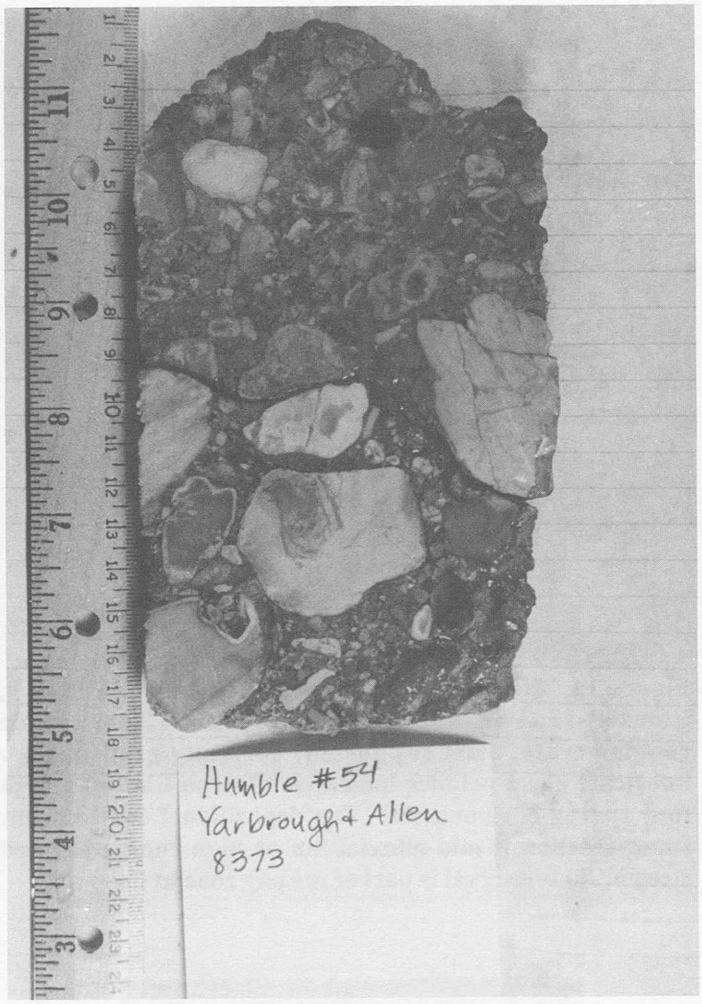

Figure 10. Humble #54 Yarbrough & Allen, Section 9, Block B-13, PSL Survey, depth 8373'. Coarse chert cobble conglomerate, varicolored, clast supported, red shale matrix, ungraded, unstratified. Chert pebbles are fractured and have weathered rims. This interval is interpreted to be proximal alluvial fan facies. This is a part of the pay interval in this well, which has made over 370 MBO to date.

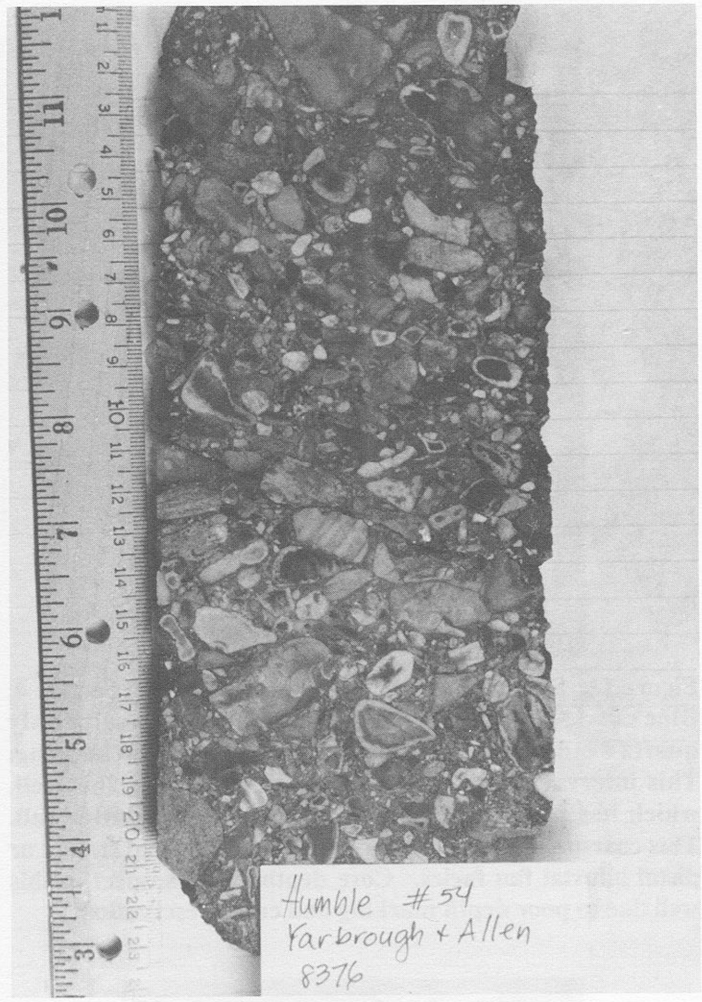

Figure 11. Humble #54 Yarbrough & Allen, Section 9, Block B-13, PSL Survey, depth 8376'. Chert cobble conglomerate, varicolored, clast supported, moderately well sorted, some imbricate pebbles, normally graded to inverse graded beds. This core, combined with Figure 10, depth 8376', defines a coarsening-upward sequence which is common in alluvial fan deposition. This interval is also part of the pay zone.

meaningful correlation of conglomerate beds from core to core.

Petrologic descriptions of key well cuttings in the Arenoso Field revealed massive, stacked chert-pebble conglomerates, mostly unconsolidated. The best wells characteristically have good drusy calcite rim cements on chert pebbles, and excellent shows of oil. Poor wells (although the samples also appeared unconsolidated) did not exhibit druse cements. The druse cement, indicative of an open pore system of a vadose environment, was the most significant discriminator between a good well and a poor well.

The top of the Strawn detrital (as seen in three different cores in other wells) is a thin (10') gray to black limestone with black shale interbeds (at about 8265' in the Humble #54 Yarbrough & Allen), and is interpreted as a sea level highstand that drowned the coarse chert alluvial fan facies.

In general, the frequent occurrences of exposure surfaces on thin limestone beds, buried by pulses of alluvial fan and braided stream deposition is consistent with the interpretation of periodic Strawn sea level rise and fall that has been documented in other basins in the southwestern United States (Algeo, in press, 1991, Goldhammer, in press).

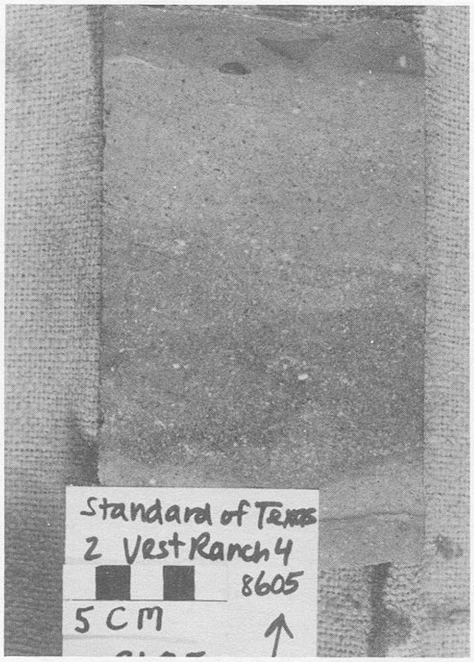

Figure 12. Standard to Texas #2 Vest Ranch "4", Section 4, Block B-13, PSL Survey, depth 8605'. Coarse pebbly quartz sand, moderately well sorted, some cross bedding. This interval comprises part of the pay zone in this well, which has produced (lease average) over 600 MBO/well. This coarse sandstone is interpreted to be braided stream or distal alluvial fan facies. Core depths were suspect in this well due to poor depth marking and core preservation.

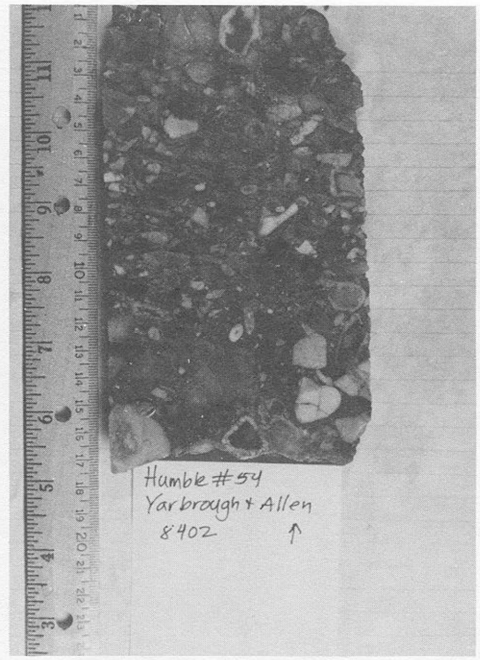

Figure 14. Humble #54 Yarbrough & Allen, Section 9, Block B-13, PSL Survey, depth 8402'. Chert cobble conglomerate, clast supported, normally graded, with imbricate chert pebbles indicative of deposition in a high flow energy environment. The depositional environment Interpretation is mid-alluvial fan or high energy braided stream. This interval is part of the pay zone in this well.

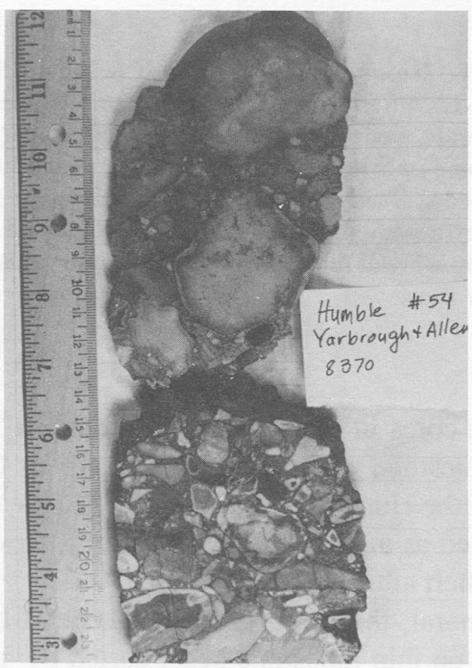

Figure 13. Humble #54 Yarbrough & Allen, Section 9, Block B-13, PSL Survey, depth 8370'. Coarse chert cobble conglomerate, clast supported, inversely graded, some imbricate pebbles, red shale matrix. Chert pebbles are fractured and weathered. Inverse grading is indicative of debris flow deposition, in an interpreted alluvial fan environment. This interval is part of the pay zone in this well.

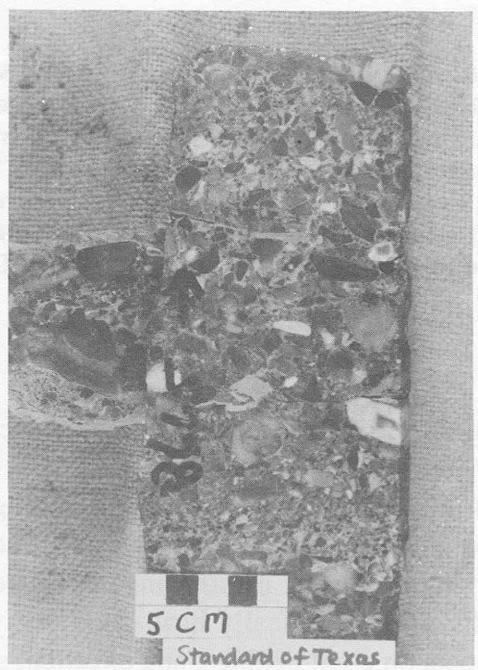

Figure 15. Standard of Texas #1 Sealy Smith "7", Section 7, Block A, G&MMB&A Survey, depth 8665'. Chert cobble conglomerate, inverse grading common, indicative of deposition in a debris flow environment.

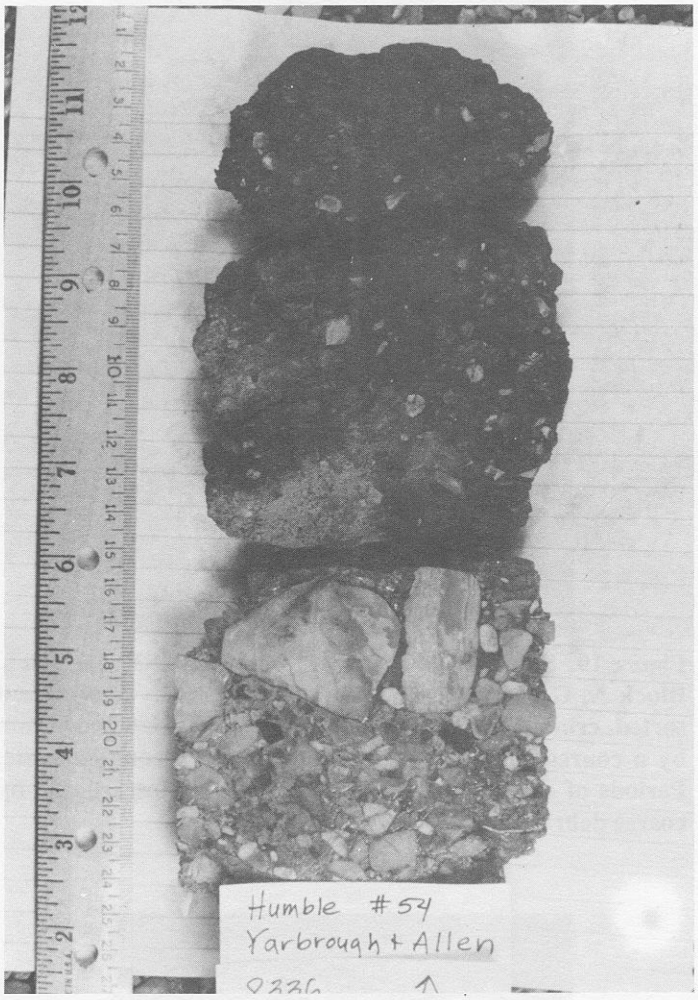

Figure 16. Humble #54 Yarbrough & Allen, Section 9, Block B-13, PSL Survey, depth 8336'. Chert cobble conglomerate, clast supported, inversely graded, capped by a red shale matrix-supported conglomerate. The shale matrix-supported conglomerate was probably a mud flow in the alluvial fan.

SUMMARY

The Arenoso Field produces from alluvial fan sediments of Devonian chert eroded from a nearby uplift and deposited in a small sub-basin. The alluvial fan grades seaward into braided stream and shoreline facies and interfingers with marine limestones. The best reservoirs are located in the braided stream/shoreline facies at the toe of the alluvial fan. The updip stratigraphic terminations of the fan to the southeast and east have been overlain by subsequent marine sedimentation and thereby protected from subsequent exposure or erosion. The proximal fan facies, where the coarsest alluvial facies is found, produces in isolated pods (1 MMBOE each). Apparently the proximal fan facies is not in communication with the best reservoir facies, the downdip braided stream and shoreface environments, that have produced over 17 MMBOE to date. During deposition, the alluvial fan complex was subjected to numerous alternating periods of subaerial exposure followed by marine incursion and renewed subaerial exposure and soil formation. The vadose environment established during subaerial exposure helped keep open an already permeable pore system in this very coarse deposit. Weathering processes in the silica-rich system created local silcrete horizons. After deposition, the alluvial fan was drowned and preserved by Late Strawn sea level rise and, during a later stage of structural deformation (probably Wolfcampian), it was tilted slightly to the west. The fortuitous preservation of this alluvial fan created conditions favorable for entrapment of the oil produced from this reservoir today.

ACKNOWLEDGEMENTS

I would like to express appreciation to ARCO Oil and Gas Company, Midland, Texas, and Energy Exploration Management Company, Houston, Texas, for their permission to publish this paper; to Jim Druyff, Denver, Colorado, for his sample descriptions; Atoll Petrophysical, Calgary, Alberta, for their petrophysical calculations; Exxon, Midland, Texas, for permission to study cores on the Humble wells; and the Bureau of Economic Geology, Austin, Texas, for their assistance in studying the Standard of Texas cores.

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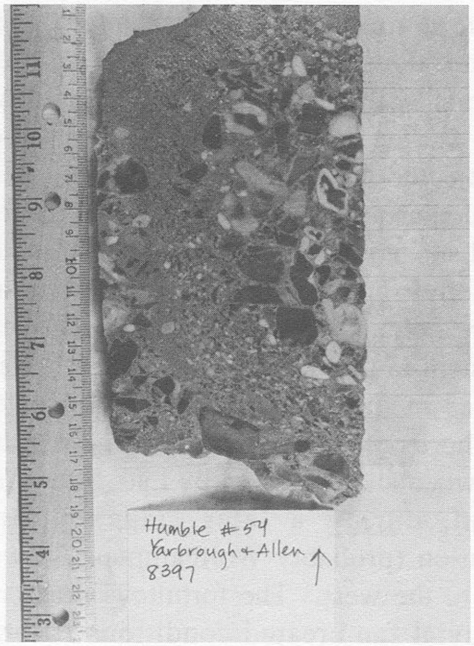

Figure 17. Humble #54 Yarbrough & Allen, Section 9, Block B-13, PSL Survey, depth 8397'. Chert cobble conglomerate, cross stratified, with very coarse-grained quartz sand. This bimodal size distribution could occur in a high-energy braided stream environment, in the mid-fan to distal alluvial fan facies. This interval is part of the pay in this well.

Figure 19. Standard of Texas #1 Sealy Smith "3", Section 8, Block A, G&MMB&A Survey, depth 8668'. Sandy, well sorted, crinoid wackestone/packstone, immediately overlain by a coarse chert pebble grain-supported conglomerate. Periods of shallow marine deposition were interrupted by coarse debris flows.

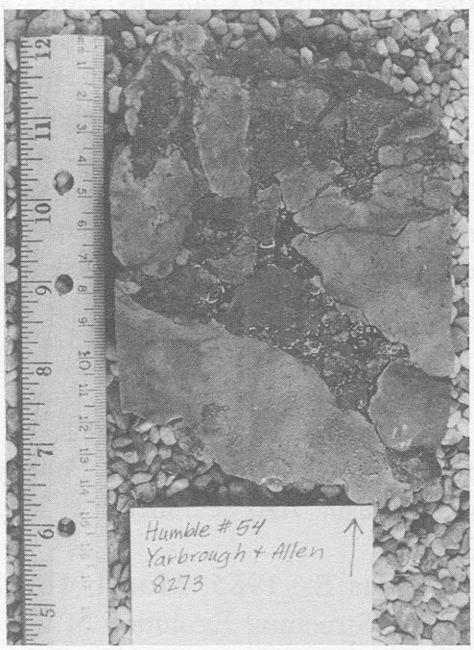

Figure 18. Humble #54 Yarbrough & Allen, Section 9, Block B-13, PSL Survey, depth 8273'. Cobbles of algal limestone, weathered red, in a red shale matrix. This was a shallow marine limestone capping the chert conglomerate facies, which was subaerially exposed and weathered; a terra rossa surface.

Figure 20. Standard of Texas #2 Vest Ranch "4", Section 4, Block B-13, PSL Survey, depth 8566-67'. Crinoidal algal limestone with chert pebbles incorporated into the top of the bed. This is a shallow marine deposit, with some evidence of exposure and formation of a terra rossa surface. The exposure surface was immature and the limestone was unconsolidated; this indicates that shallow marine deposition probably occurred very close to coarse alluvial fan deposition. Core depths were suspect in this well due to poor depth marking and core preservation.

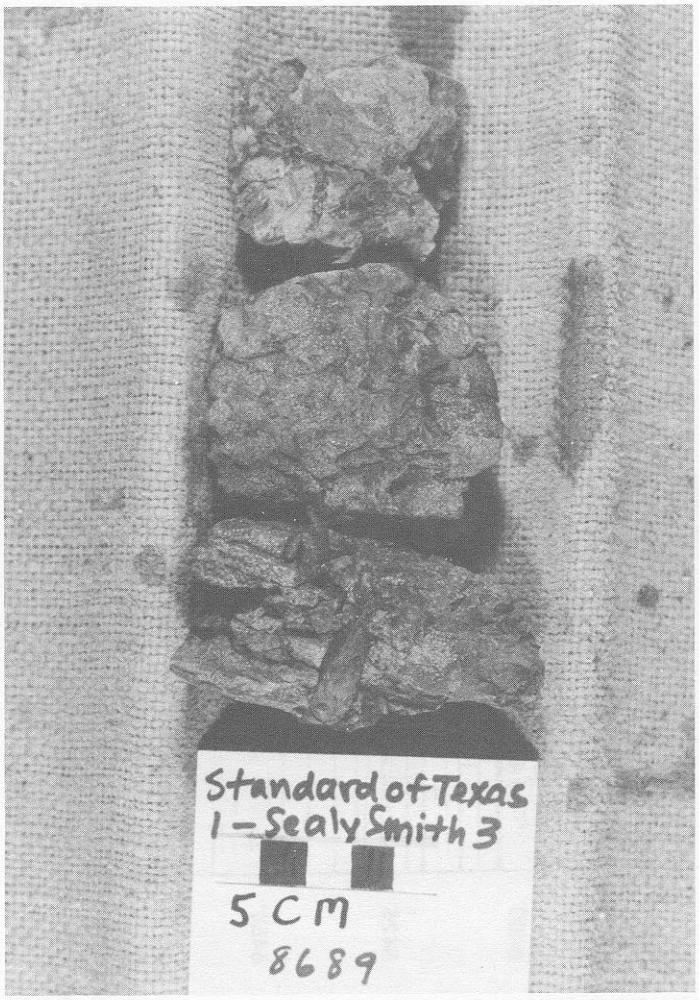

Figure 21. Standard of Texas #1 Sealy Smith "3", Section 8, Block A, G&MMB&A Survey, depth 8689'. Black shale, with some preserved plant fragments, indicating a marsh or swamp environment near the alluvial fan sedimentation. This black shale facies was rare in cores examined.

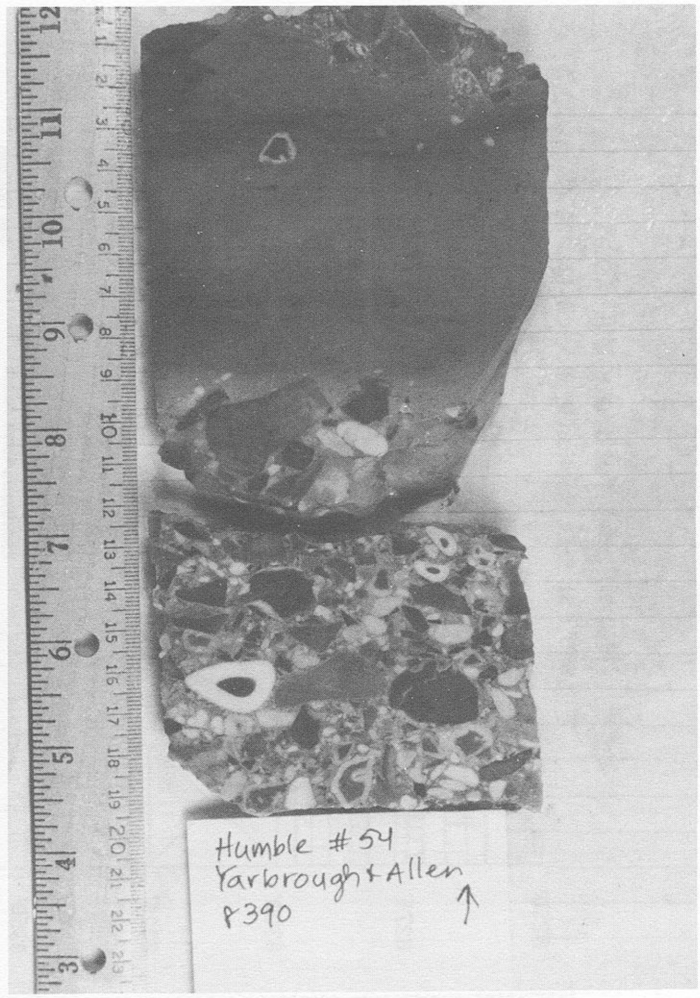

Figure 22. Humble #54 Yarbrough & Allen, Section 9, Block B-13, PSL Survey, depth 8390'. Chert cobble conglomerate, ungraded, clast supported, chert pebbles have deeply weathered rims. This conglomerate has a siliceous matrix, and is capped by a 4" (10 cm) bed of homogeneous chert. These siliceous beds were rare in the cores. They probably represent a diagenetic phenomenon such as the formation of a silcrete horizon during pedogenesis.

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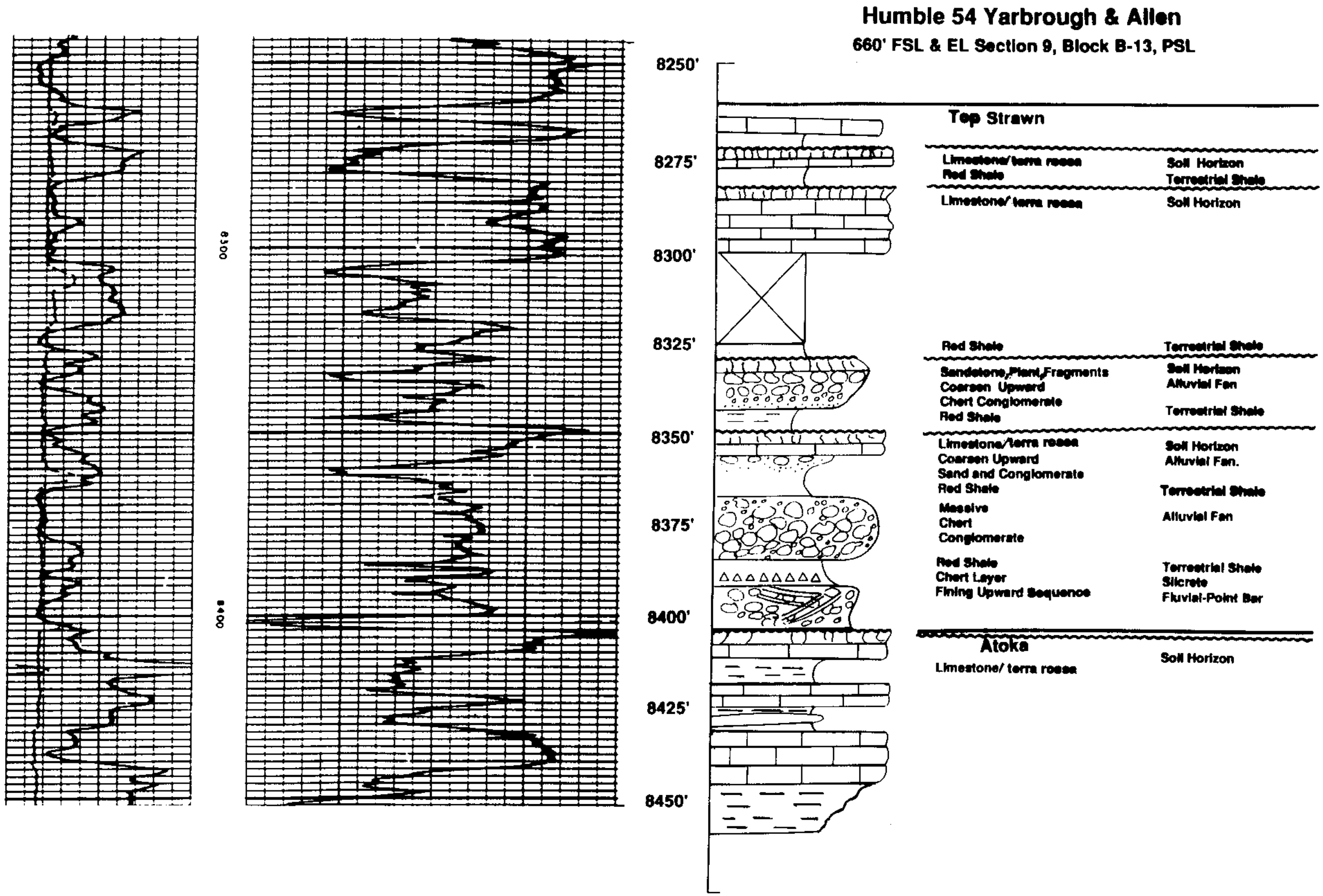

Figure 23. Graphic core description and corresponding Sonic Log on the Humble #54 Yarbrough & Allen, Section 9, Block B-13, PSL Survey. This is the most continuous core in existence throughout the pay intervals of the Arenoso Field. For a description, see text.

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