GYPSUM DETERMINATION USING ELAN IN SHALLOW WEST TEXAS CARBONATES

Harold Hedberg and Dale May
Schlumberger Well Services

ABSTRACT

The younger Permian carbonates have been prolific producers over the years. The San Andres and Grayburg dolomites, which are productive in nearly all areas of West Texas, are of particular note. Although traditional log analysis has been generally successful in these reservoirs, the presence of gypsum in many has created difficulties. Gypsum tends to result in overly optimistic porosity calculations and also tends to restrict permeability by plugging the pore throats.

This paper explains some of the difficulties encountered when using traditional log analysis techniques in gypsiferous reservoirs and shows how Schlumberger's ELAN log interpretation program has been used to give superior results.

INTRODUCTION

Accurate log analysis in the younger Permian carbonate horizons in West Texas (mainly the San Andres and Grayburg dolomites) is often frustrated by the presence of gypsum. Because of the chemical composition of gypsum, porosity estimation in gypsiferous reservoirs has been inaccurate. Poor porosity estimation coupled with the pore plugging tendencies of gypsum have resulted in overly optimistic reservoir predictions. Many of these gypsiferous reservoirs are currently candidates for secondary and tertiary recovery. In order to effectively exploit these reservoirs, it has become extremely important to be able to accurately quantify the effective porosity present and to accurately quantify the volume of gypsum as well.

Traditional methods of log analysis have not adequately addressed the gypsum problem because they have not simultaneously utilized all log information available. Interpretation with Schlumberger's ELAN, however, has given results that compare very well with low temperature core information. These comparisons indicate the efficacy of a simultaneous equation solution method in general and Schlumberger's ELAN in particular.

RESERVOIR EFFECTS OF GYPSUM

Table 1 lists the logging tool responses for some of the more common sedimentary minerals found in hydrocarbon producing reservoirs. Note the low bulk density and high neutron porosity response associated with gypsum. Although gypsum is without real porosity, both the neutron and the density indicate porosity in its presence. Chemically, gypsum is hydrated calcium sulfate — $CaSO_4(H_2O)_2$. Because of the water of hydration, gypsum is very good at slowing down neutrons (resulting in high neutron porosity) and has a density of 2.35 g/cc, while anhydrite (chemically equivalent except for the H_2O) has a density of 2.98 g/cc. This over-estimation of porosity as a result of gypsum results in poor reserve calculations and economic decisions if the effects are not properly taken into account.

The second problem related to the presence of gypsum its effect on permeability. Gypsum often occurs as pore-plugging nodules. When it does so, the fluid paths through the pore throats are restricted and poor permeability results. It has been suggested by some operators that ten to fifteen percent gypsum in the reservoir may be sufficient to reduce permeability to the extent that the gypsum plugged zones in the reservoir can not be economically completed.

Figure 1 is a Cyberlook interpretation of a San Andres well which is known to have gypsum present. This interpretation indicates that the zone would probably be productive. The interval also appears to be continuous. The Formation Micro-Scanner in Figure 2, however, shows that the zone is actually thinly bedded — thin porous beds are laminated with impermeable beds — probably gypsum plugged. Because of the gypsum, the tight impermeable beds are indicated as being porous. Note also that the resistivity in the impermeable beds is high. This is because the pore-filling gypsum (and possibly anhydrite) is non-conductive. The result of these effects is log analysis which indicates that the apparently porous high resistivity zones should be completed while the Formation Micro-Scanner images indicate that these zones are non-productive.

Perforating gypsiferous intervals results in various problems beyond the fact that these zones are likely non-productive. Because of the poor permeability and high shear strength of these evaporites, high breakdown pressures result when wells are stimulated. This may result in uncontrolled vertical fracture growth. Attempts to complete these zones also may result in excess sulfate concentration in the produced fluid. This may result in excessive sulfate scale in the perforations and in the production string requiring premature remedial action.

TRADITIONAL METHODS FOR THE CORRECTION OF GYPSUM EFFECTS

Crossplot Techniques

The extreme neutron and density responses noted in Table 1 indicate that detection of gypsum should be a rather simple matter. Gypsum has a distinct endpoint on both the sonic-density plot (Figure 3) and the sonic-neutron plot (Figure 4). It would appear to be quite simple, therefore, to calculate and correct for the effects of gypsum in a dolomite reservoir. Indeed, the identification of pure gypsum beds, and zones nearly pure, is not difficult. The problem arises when it is necessary to correct for the presence of gypsum when the quantity present is from about two percent to up to about thirty percent.

With a two-dimensional plot like the sonic-density or the sonic-neutron, it is possible to quantify at most two minerals plus porosity. If the intent is to solve for dolomite, gypsum, and porosity, then a singular system results if other minerals are present or if the porosity distribution is not compatible with a mixing law type equation (i.e. if there is secondary porosity present). This is the problem encountered with traditional crossplot methods for gypsum correction. Examination of the plots of Figures 3 and 4 indicate that other minerals plot between dolomite and gypsum so that the apparent gypsum may actually be the effect of a combination of other minerals. The opposite problem occurs when some mineral plots on the opposite side of dolomite from gypsum. In that case the effects of gypsum and the third mineral tend to cancel each other and the gypsum volume is underestimated. Anhydrite and gypsum are both frequent in the dolomite reservoirs here considered and they plot on opposite sides of dolomite on both the plots mentioned above. The result, when these plots are used, is the underestimation of gypsum and overly optimistic reservoir calculations.

No better luck is obtained with the ρ_{maa} vs U_{maa} plot (Figure 5). Although gypsum plots distinctly and nearly beneath anhydrite, there is not good resolution when trying to distinguish small amounts of anhydrite from small amounts of gypsum. This problem is exacerbated by the presence of small amounts of quartz and calcite.

Computerized Methods

Essentially, computerized methods used to quantify and correct for the effects of gypsum use one or more of the above mentioned cross-plotting techniques. Log data is evaluated and a linear interpolation between endpoints is performed resulting in an estimated gypsum volume. The logged porosity data is then corrected for the presence of gypsum. The problems with this technique include the problems mentioned in the previous section. Further error is introduced into the final answer because errors that occur in one step of the process are carried through the entire process. Typically, corrections are made in each step without sufficient regard to errors that may have been introduced previously or might be introduced subsequently.

VOLAN is an example of a processing chain which does not adequately control the propagation of errors. The first step in the processing chain consists of performing environmental corrections. Next, volumes of evaporites and feldspars may be calculated by some program other than VOLAN — typically using a computerized cross-plotting technique as mentioned above. Finally, the data enters VOLAN where the log data is corrected prior to the computation of the constituent volumes. The problem here is that computations made in VOLAN such as hydrocarbon corrections and water saturation calculations influence the log data as far as the calculation of evaporites is concerned. Environmental correction programs (particularly those for the neutron log) and evaporite calculation programs include assumptions about the reservoir that may or may not be true but which strongly affect the results. It is errors resulting from these assumptions which are not properly taken into account.

ELAN APPLIED TO THE GYPSUM PROBLEM

The ELAN Program

Consideration of the various crossplotting techniques noted in the previous section may suggest that a computer interpretation might be developed that would simultaneously use all the various relationships among logging measurements reflected in these plots. ELAN can be considered in this way. Essentially, then, ELAN is a simultaneous equation problem solver which allows all the aforementioned relationships to be considered together. All the errors that may result in the stepwise approaches outlined above are considered and the best answer is that which minimizes ELAN's incoherence function — that is, the ELAN solution is the solution to the simultaneous equation problem which minimizes the error vector in the least squares sense.

The preceding is, of course, a quite simplistic discussion of the ELAN program which is thoroughly described elsewhere. Before moving on, however, some of the characteristics which make ELAN particularly applicable to the gypsum problem should be mentioned.

Any relationship among minerals and logging tools may be easily modeled with ELAN if the relationship is linear or may be reasonably approximated as linear. This means that ELAN is very flexible and allows for the easy introduction of data from new tools. Also, other than ordinary minerals are easily introduced into the model — unlike in processing chains such as VOLAN which are hardwired to use particular tools to solve for particular minerals.

ELAN allows for the use of a nonlinear neutron model to account for the fact that the neutron formation salinity correction depends on the true porosity and water saturation. This is of particular import with respect to the gypsum problem. If neutron porosity which has not been corrected for the effects of gypsum is used in the formation salinity correction scheme, too large of a correction is performed which results in the underestimation of the gypsum volume. The effect of ELAN's method is that the formation salinity correction is performed within ELAN and the amount of the correction corresponds to the volume of water as determined by the program.

The final feature of ELAN which will be pointed out here is the ease with which the user of ELAN may switch among models. In complex reservoirs it is common to require different minerology models within the same well. ELAN allows for explicit model switching, if desired, or switching based on log responses. The switching is rational and easy to use.

ELAN Modeling

The first well on which ELAN was used to correct for the effects of gypsum was a Grayburg-San Andres well in the McElroy field in Crane County, Texas. This well is referred to as McElroy Well #1 henceforth. The logging suite included a sonic and low temperature core porosity information was provided by the customer. Low temperature porosity determination is necessary to prevent dehydration of the gypsum and the resultant erroneous porosity calculation.

From previous work in the area it was known that the measured sonic transit time does not obey a time-average type relationship to porosity in higher porosity intervals. In low porosity zones a Wiley-type equation works well, but in higher porosity the sonic tends to measure a lower transit time than would be expected. Traditionally this phenomenon has been attributed to secondary porosity — porosity which is isolated and which does not slow sound waves as does intergranular porosity.

Three ELAN models were used. The first model includes dolomite, anhydrite, gypsum, illite, isolated water (secondary porosity), flushed zone water and oil, and uninvaded zone water and oil. This is the high porosity model. The second model contains all minerals in the high porosity model except isolated porosity. This second model is the low porosity model. These two models are needed to properly account for the nonlinear nature of the sonic–porosity relationship as described above. A third model, the clastic model, was used to evaluate the minerology in sands, silts, and shales. The clastic model contains no evaporites but does include calcite and quartz. The minerals contained in each model, the tools used in each model, and the log response parameters for the flushed zone minerals are listed in Table 2.

Analysis of the logs and comparison of the log data to the core data indicated that a switch to the clastic model was reasonable whenever the sum of illite and quartz found by that model exceeded 30 percent. Switching between the low and high porosity models, however, was not nearly as simple. As expected, the low porosity model matched the core data better in low porosities and the high porosity model matched better in higher porosities. However, a coherent method for switching between the models was not apparent. None of the models' calculated minerals, or any linear combination of them, seemed to provide a reliable switch. Analysis of the sonic data in conjunction with the log–core comparison indicated that switching from the low porosity model to the high porosity model when transit time exceeded 55μsec/ft gave good results. This was the switching criteria used on the McElroy Well #1 as well as another well in the same field which also had low temperature core data — what is referred to as McElroy Well #2.

A third set of data, provided by a different client, was used to further test the ELAN models. This data was from a well which is located in the Farmer-San Andres Field in Crockett County, Texas. We call this well the Farmer Field Well in this paper. Although this reservoir is similar to that of the McElroy field in minerology, it is very different in deposition. Because the core information was not available beforehand and because it was feared the model switching system used on the McElroy wells would not be applicable to the Farmer field, it was decided to switch between the two carbonate-evaporite models when the low porosity model crossed 5 pu. That is, when the low porosity model calculated 5 pu or less it was selected as the ELAN model. When that model calculated more than 5 pu, the high porosity model was used. The clastic model was switched in the same manner as with the McElroy wells. When the core information was provided it was determined that a better switching rule than the 5 pu rule was unlikely. For Farmer Field wells that switching technique has been kept.

RESULTS

Figure 6 is the ELAN presentation that resulted from the analysis of the McElroy Well #1. The second track to the right of the depth track contains the low temperature core porosity data as well as the porosity calculated by ELAN. Generally the agreement between core data and ELAN porosity is very good. Particularly encouraging is the good fit even when the porosity is changing rapidly from low porosity (less than about 5 pu) to higher porosity. From 3070 to 2950 there are numerous model switchings and the ELAN porosity consistently follows the core porosity. Only when the core porosity is reported as less than about 2 pu is there a noticeable and systematic difference. This difference is poorly understood but it is suspected that the whole-core analysis technique used underestimates the porosity in these zones. Low temperature core analysis is relatively gentle and may not properly account for all poorly connected porosity — particularly when the porosity is low and when the analysis is whole-core.

The difference between ELAN calculated porosity and neutron-density crossplot porosity is noted in the porosity analysis track. The blank coding indicates the difference between these porosities and is the amount that porosity would be overestimated if gypsum were not taken into account.

Figure 7 is a histogram of ELAN porosity minus low temperature core porosity for the McElroy Well #1. Note the mean of the difference between ELAN porosity and core porosity is only 0.56 pu and the standard deviation is about 3.15 pu. This histogram contains all levels at which core data was available including those low porosity points noted previously.

Figures 8 and 9 contain similar information for the analysis of the McElroy Well #2. The zone from 3100 to 3000 is not presented because there was no core data from that interval. The log data on this well was processed with the exact same models and switching techniques that were developed with the McElroy Well #1. No adjustments were made based on the core data and yet the fit to the core data is actually somewhat better than on the McElroy Well #1. Of particular interest is the San Andres section below 3100 feet. Here as much as 75 percent of the apparent crossplot porosity is due to gypsum, the calculated gypsum volume is sometimes in excess of 30 percent, and the fit between core porosity and ELAN porosity is excellent. The mean of the difference between ELAN porosity and core porosity is about 0.6 pu while the standard deviation is about 2.4 pu.

The final well data presented here is from the Farmer Field Well. Figure 10 is a presentation of the ELAN computation and Figure 11 is the histogram of the difference between ELAN porosity and low temperature core porosity. On this well, switching between the low porosity model and high porosity model was based on the porosity calculated by the low porosity model rather than on the transit time. The only sections in the well in which the ELAN porosity deviates significantly from the core porosity are the shaly section above 2300 feet. This is not particularly troubling as low temperature core analysis will not accurately measure the bound water and the models were designed to evalute the dolomite sections. The histogram of Figure 11, it should be noted, includes all levels with core information, including these shaly sections. The data fit on this well is the best of the three, the mean of the difference between ELAN porosity and low temperature core porosity is -0.3 pu and the standard deviation is 2.11 pu.

To demonstrate the need for correcting for the effects of gypsum, cumulative porosity was calculated from the pay zones in the Farmer Field Well. This data is summarized in Table 3. As can be inferred from the histogram of Figure 11, using ELAN porosity to estimate porosity-feet gives a result consistent with the core data while crossplot porosity results in an estimate more than 60 percent too high.

CONCLUSIONS

The data presented here demonstrate that a conventional logging suite, which includes the BHC sonic, coupled with ELAN log analysis can give consistent and reliable answers in reservoirs plagued with gypsum plugging. The results thus obtained are clearly superior to the results obtained with any other log analysis method and give the operator the ability to make intelligent decisions based on reliable reserve calculations.

Table 1
Logging Parameters for Common Sedimentary Minerals

MINERAL	RHOB	CNL	DT	Pef	U_{ma}
Calcite	2.71	-1.0	49.0	5.08	13.77
Dolomite	2.88	1.0	44.0	3.14	9.00
Quartz	2.64	-1.0	56.0	1.81	4.79
Gypsum	2.35	60+	52.0	3.99	9.37
Anhydrite	2.98	-3.0	50.0	5.05	14.93

Table 2
Minerals, Tools, and Response Parameters Used in the ELAN models

MODEL1: DOL ANH GYP ILL ISO XWA UWA XOI UOI

MODEL2: DOL ANH GYP ILL XWA UWA XOI UOI

MODEL3: QUA CLC DOL ILL XWA UWA XOI UOI

TOOLS1: RHOB DT U PHIT CXDC CUDC GR NPHU (NPOR.LIM)

TOOLS2: RHOB DT U PHIT CXDC CUDC GR NPHU (NPOR.LIM)

TOOLS3: RHOB DT U CXDC CUDC GR NPHU (NPOR.LIM)

	RHOBA	NPHUA	DTA	UA	PHITA	GRYA
QUARTZ	2.65	-2.05	55.5	4.78	0	37.
CALCITE	2.71	0	47.8	13.8	0	37.
DOLOMITE	2.85	0.63	45.0	9.0	0	37.
ANHYDRITE	2.98	-1.	50.5	14.95	0	37.
GYPSUM	2.35	60.	52.0	9.37	36.6	37.
ILLITE	2.49	36.	90.0	7.54	20.	150.
ISO-POROSITY	1.05	100.	45.0	1.33	100.	37.
XO-POROSITY	1.1	100.	175.0	1.33	100.	37.

Table 3
Summation of Pore Volume Farmer Field Well

Porosity Source	Summed Porosity Feet	Percent Error
Low Temp Core	12.00	—
ELAN Porosity	11.98	0.13
Crossplot Porosity	19.22	60.2

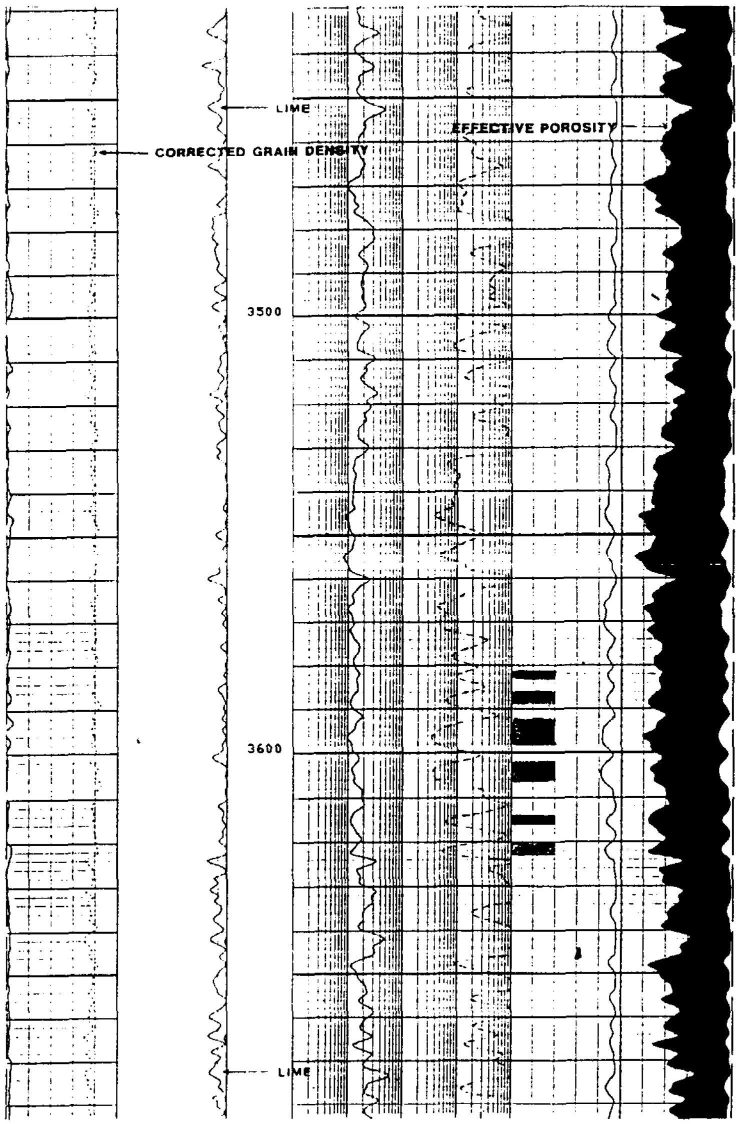

Figure 1 — San Andres formation. CNL-LDT exhibits a continuous porosity interval — FMS defines effect of porosity zones and gypsum-filled porosity zones

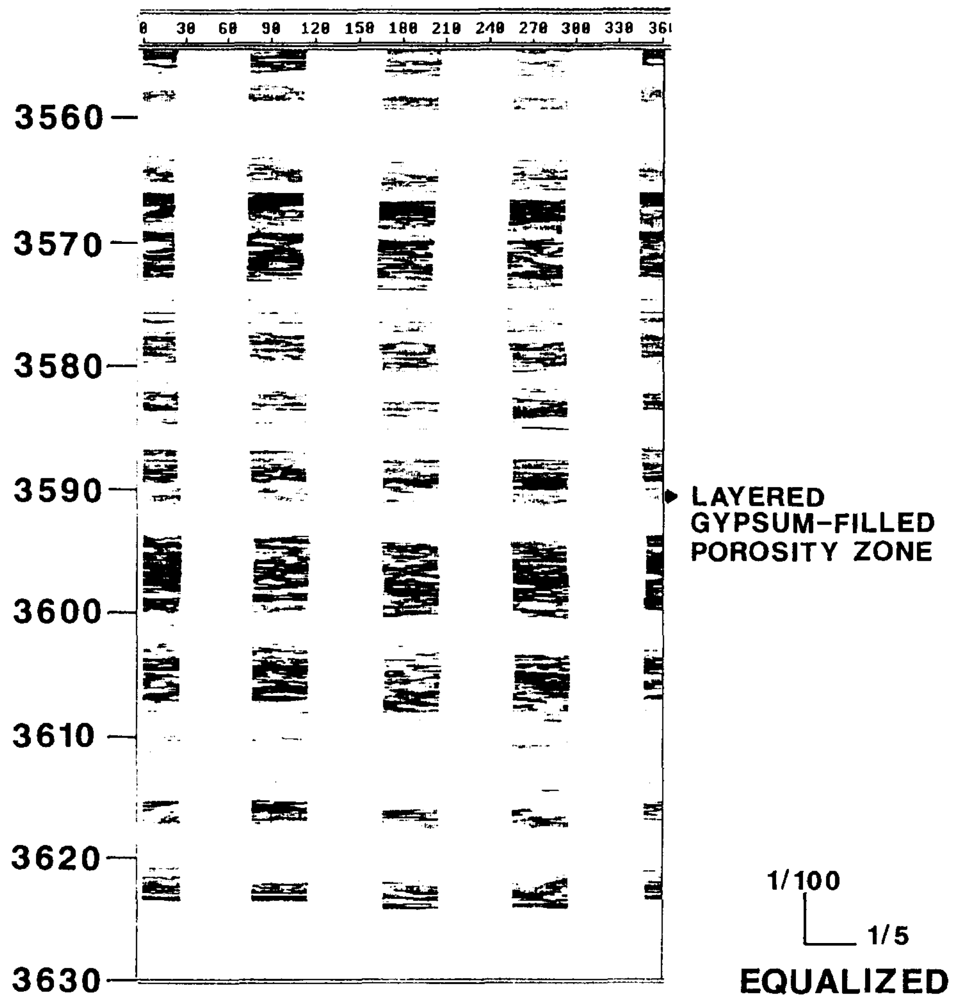

Figure 2 — FMS - gypsum-filled porosity (Permian dolomite)

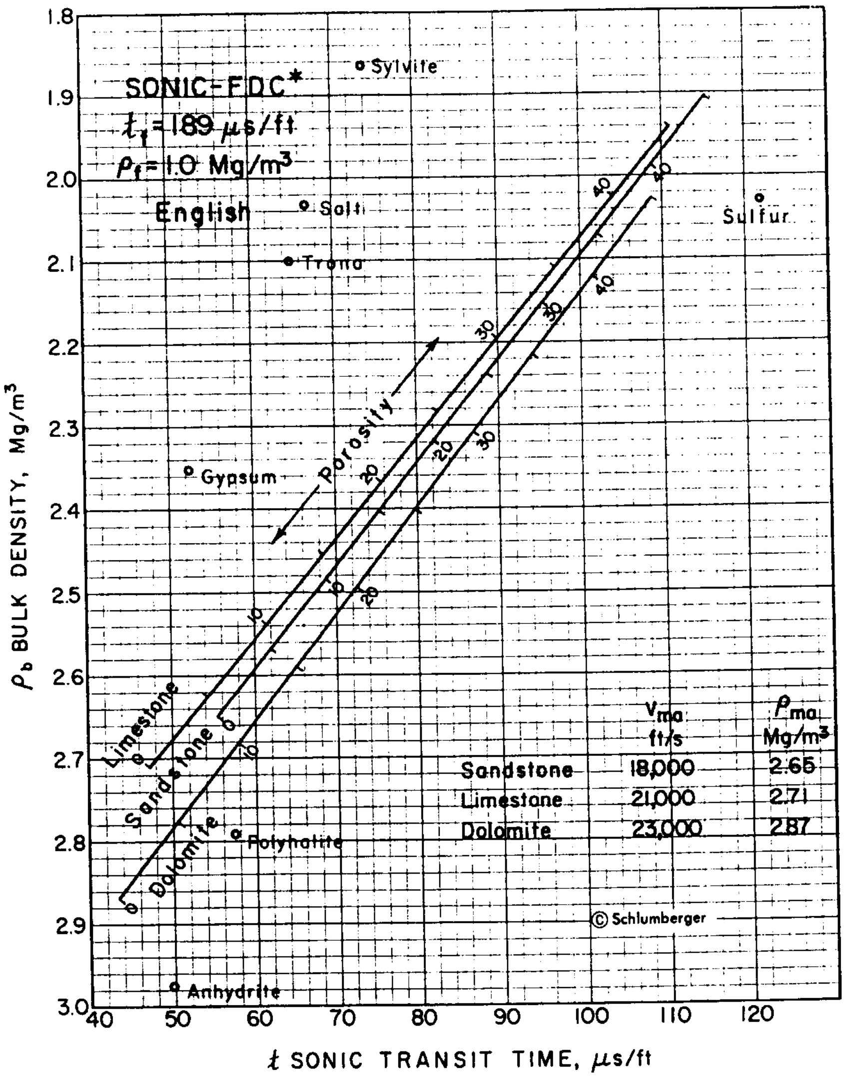

Figure 3 — Sonic-density plot for porosity and lithology determination

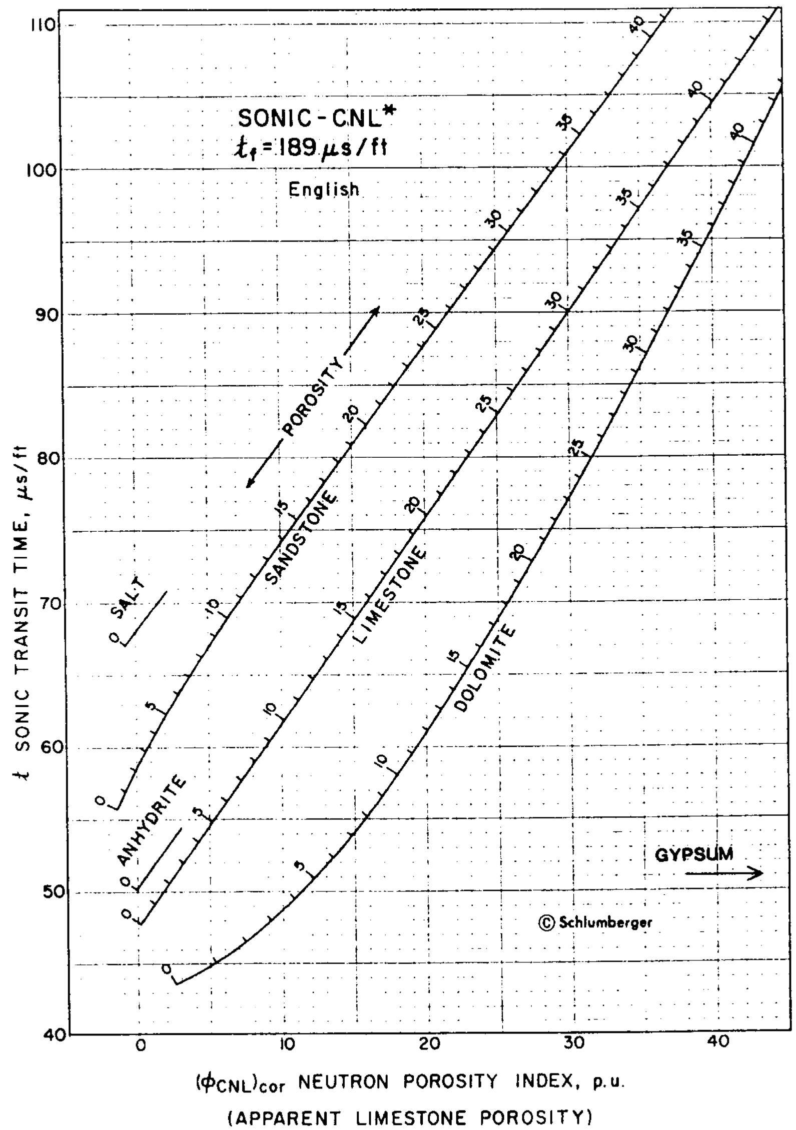

Figure 4 — Sonic-neutron plot for porosity and lithology determination

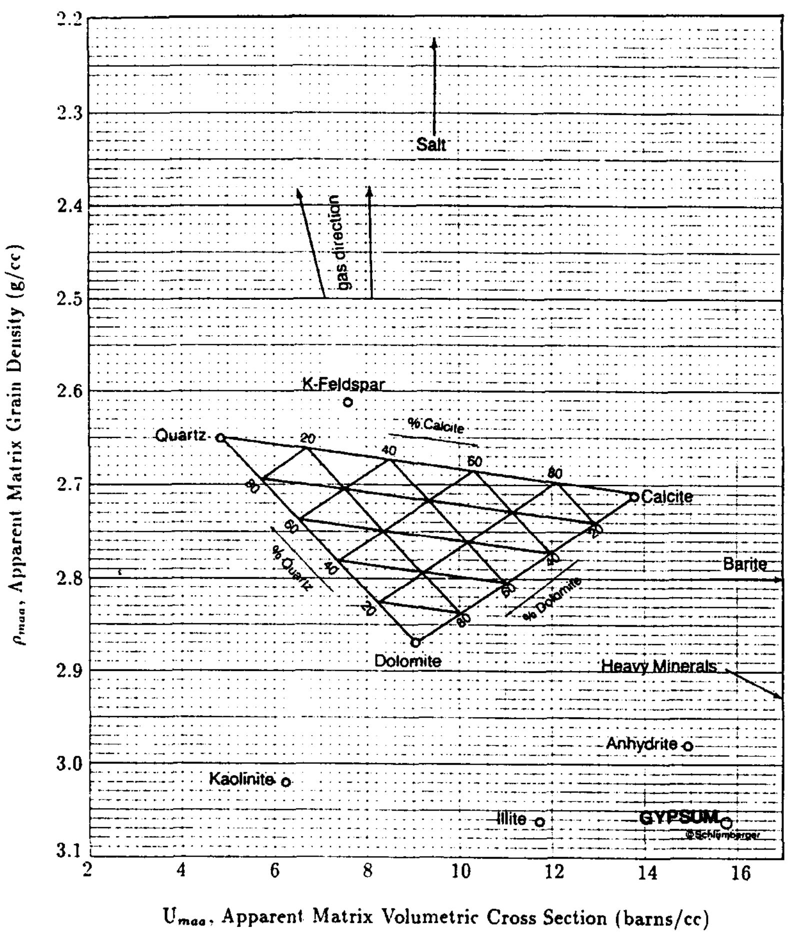

Figure 5 — ρ_{maa} versus U_{maa} for plot lithology determination

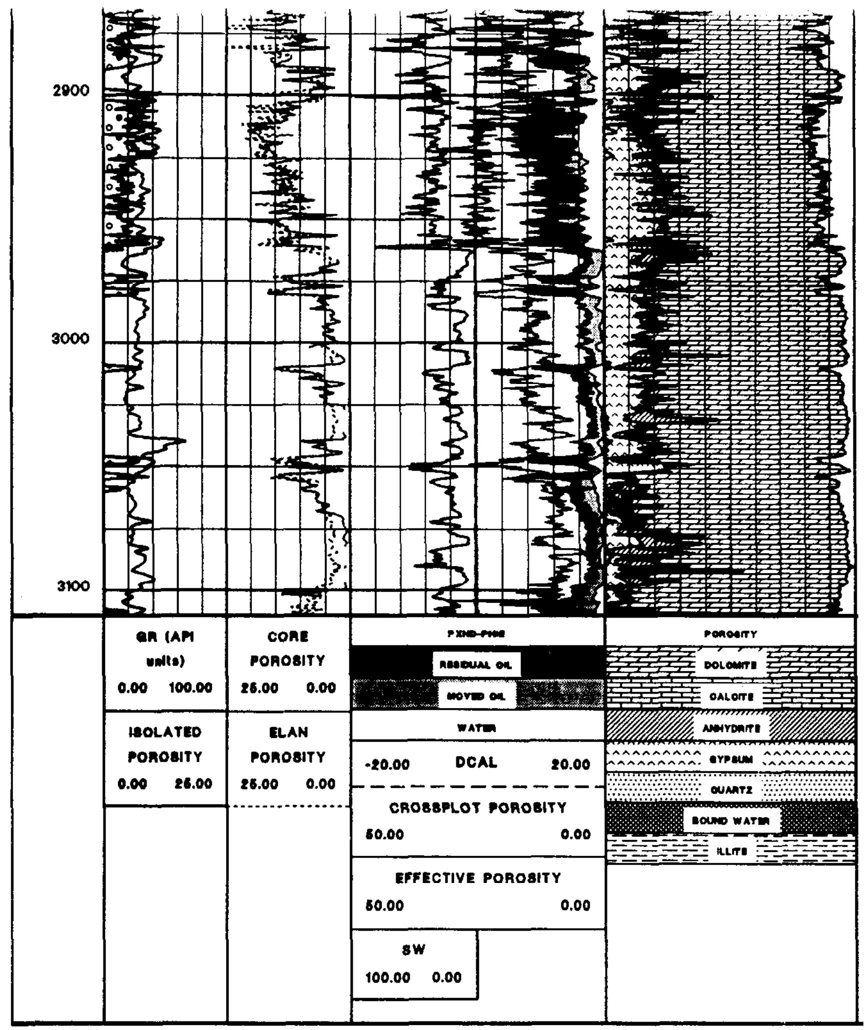

Figure 6 — ELAN and core porosity presentation (McElroy Well #1)

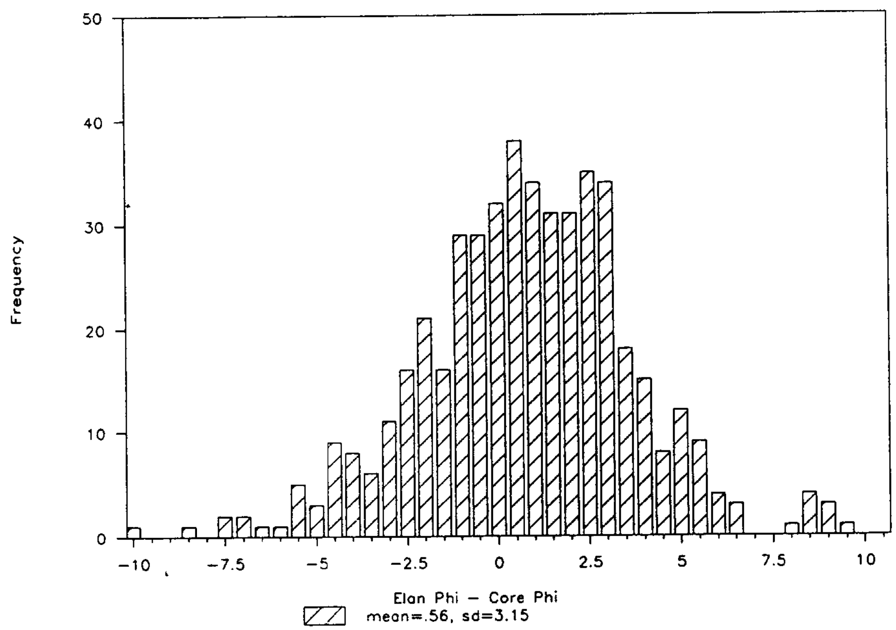

Figure 7 — ELAN porosity minus low-temperature core porosity (McElroy Well #1)

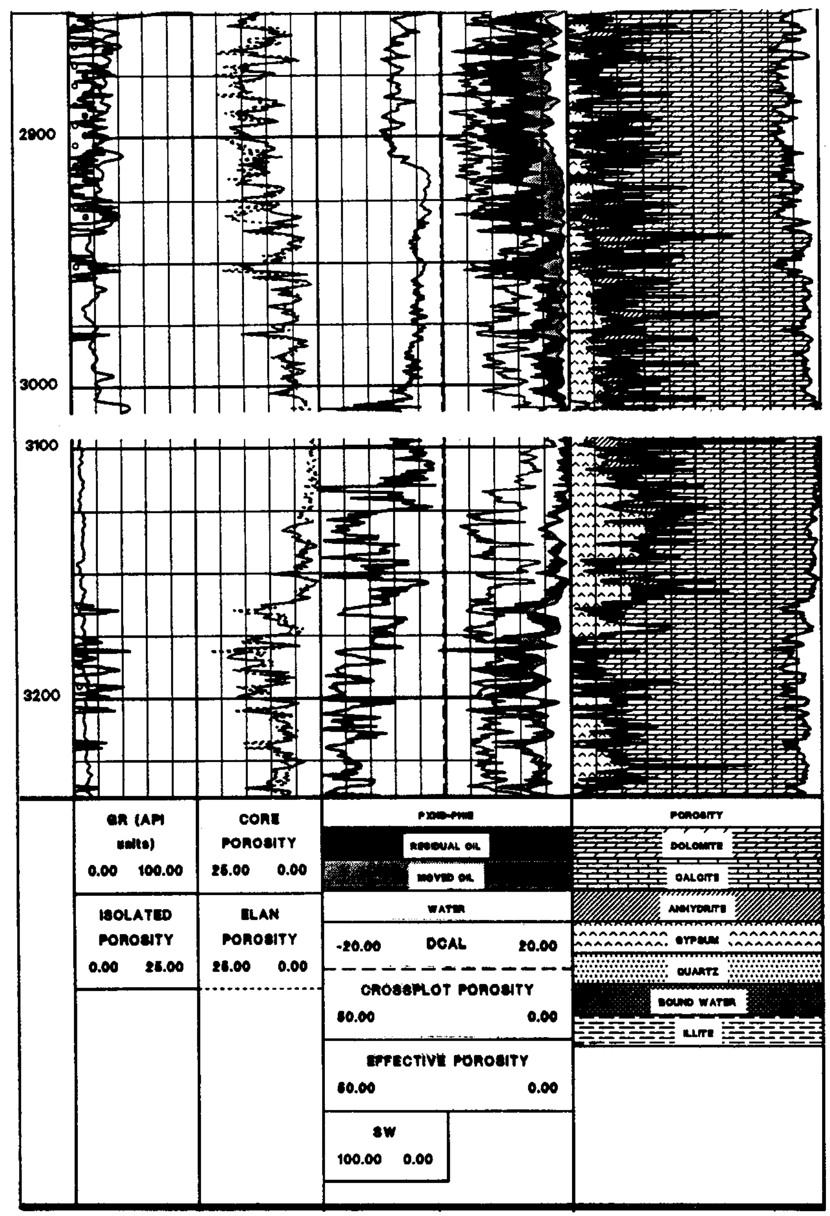

Figure 8 — ELAN and core porosity presentation (McElroy Well #2)

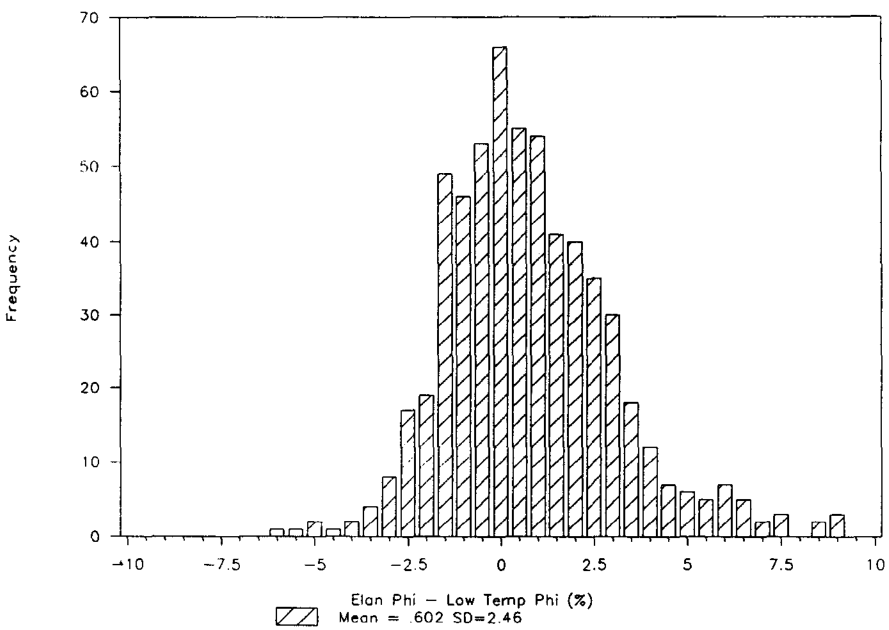

Figure 9 — ELAN porosity minus low-temperature core porosity (McElroy Well #2)

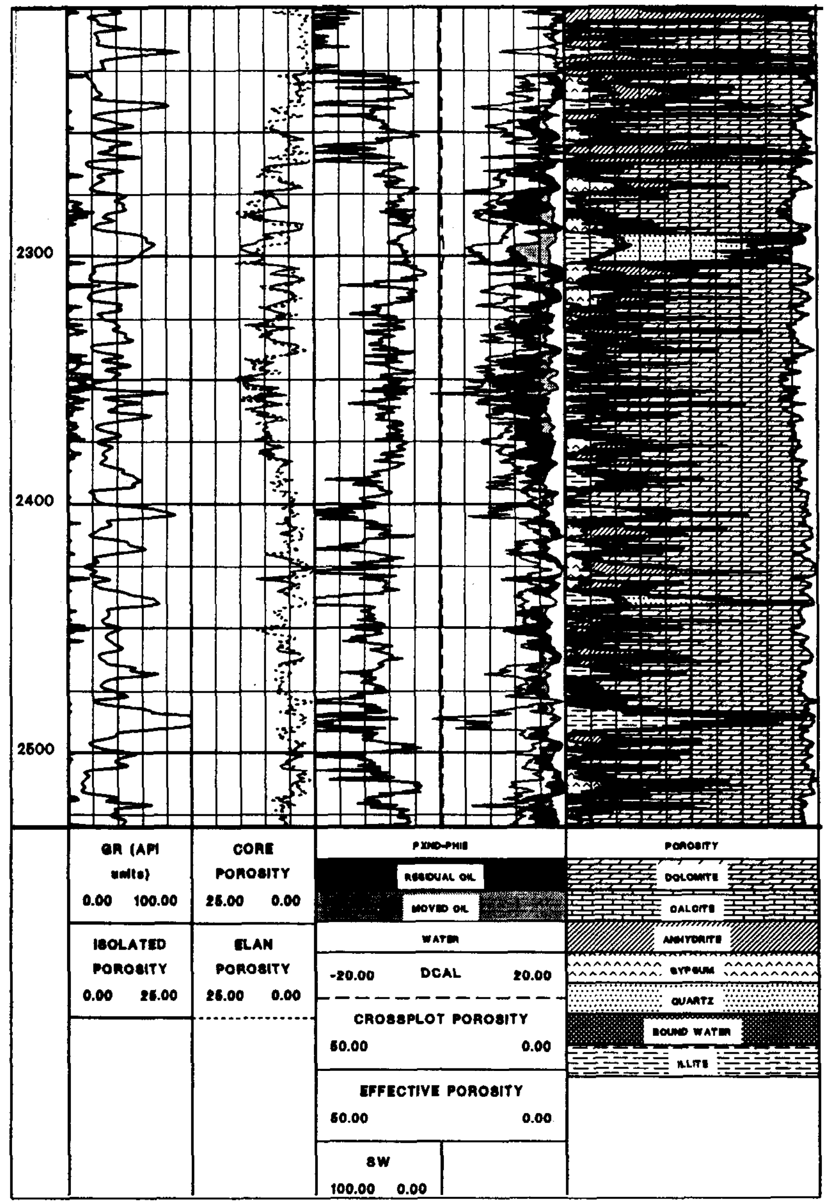

Figure 10 — ELAN and core porosity presentation (Farmer Field Well)

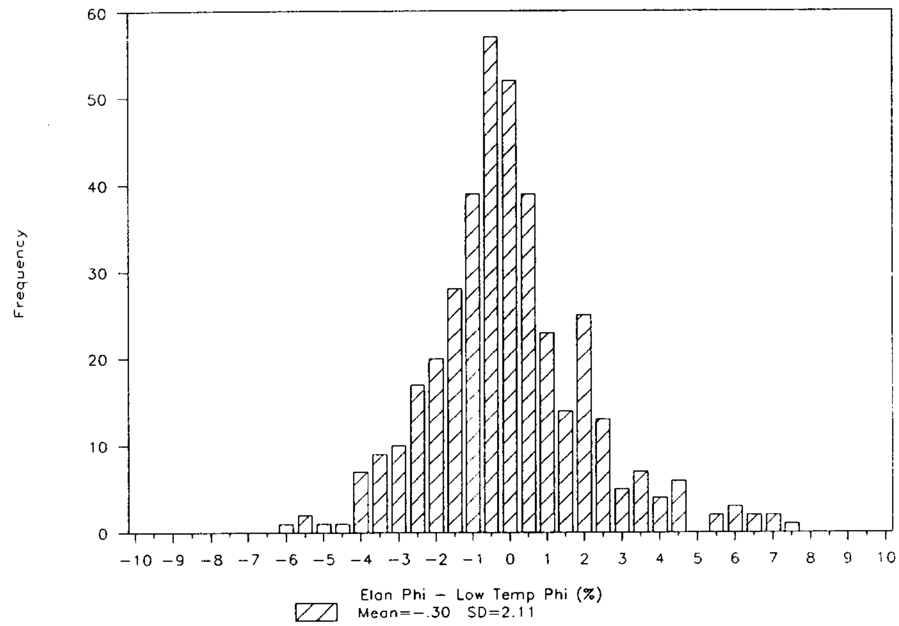

Figure 11 — ELAN porosity minus low-temperature core porosity (Farmer Field Well)