# NEW EXPANSION ADDITIVE GIVES GOOD RESULTS WITH LOW $C_3A$ CEMENTS

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## ABSTRACT

Expanding cements have been credited with improving cement bonding to casing and formation, and for providing better zonal isolation. Historically however, results have been inconsistent apparently due to misapplication and lack of meaningful job analyses.

This paper discusses different types of expansive cements, the mechanism of chemical expansion, and relates cement transition volume changes to the need for expansive cements.

Most expansive additives depend on the presence of tricalcium aluminate ($C_3A$) in the cement to complete the expansion reaction.[1] High $C_3A$ cements, due to their inherently lower quality control and erratic retarder response, generally are not preferred for most casing cementing operations.

A new expansive additive has been developed which does not depend on cement to supply $C_3A$. It can be used with any API class of cement or pozzolan-cement blend. The performance of this new additive is summarized and its limitations discussed. Case histories of selected field jobs are given, complete with cement bond logs and fracture treatment entry point evaluation surveys.

## INTRODUCTION

Expansive cement was first used in connection with oil and gas well drilling when gypsum cement was used as a setable tamp for nitroglycerine shots.[2] Expansion was likely more of coincidence than intent, but gypsum cements were eventually promoted as expansive cement and became the base for many expansive cement additives.

Application of expansive cement to primary casing cementing received little attention until the mid 1950's, which was about the time expansive cements were introduced to the concrete industry.[3,4]

Since then, interest in expansive cement has passed through several hot and cold cycles. At one time many operators looked on a new expansive cement additive as just another sales gimmick. Misapplication and inappropriate evaluation due to lack of understanding of cement expansion mechanism and downhole shrinkage phenomena were probably the principle roots of this attitude.

The plague of gas leakage or annular gas flow which was manifest in the 1960's, prompted a general research effort which is still in progress today.[5,6] One of the more important results of this research has been a better understanding of downhole cement shrinkage and cement volume reduction changes occurring during the period in which cement slurry changes from a fluid to a solid, i.e., transition period.

State of the art theory now indicates the volume reduction resulting from changes in casing pressure and temperature (microannulus) is relatively minor compared to the potential volume reduction in the cement column during the transition period. In addition, new job analysis methods and field results show a number of cement job design techniques can effectively reduce the detrimental effect of cement volume reduction.[6] Basically, any method which potentially increases the residual pressure in the cement at the end of the transition period can be helpful. These include simple devices like higher cement density and improved fluid loss control. There are two paramount characteristics of cement volume reduction:

1. Volume loss occurring during the plastic state is not likely to be evenly distributed vertically or circumferentially and
2. If fluids enter the well during the plastic state, the greatest loss of cement integrity will be adjacent the formation with the highest pressure gradients (the fluid source).

## TYPES OF EXPANSIVE CEMENT ADDITIVES

This paper is principally concerned with a new chemical-type expansive additive, its applications and limitations. However, to properly clarify application and limitations, a general discussion of the nature of cement chemical expansion and a comparison to plastic state expansion have been included.

Two types of expansive additives are currently available:

1. The older, familiar chemical-type which owes its expansion to a crystal growth-interparticle wedging mechanism.[7] Almost all the effective expansion occurs just after initial set during the early strength development period.
2. Plastic state-type which expands via in-situ gas generation after the slurry is in place. The effective expansion occurs during the transition period and stops when a measurable amount of tensile strength has developed.

Both types have been highly successful when properly applied. A general rule is chemical expansion additives are applicable to situations where no over-pressurized zones or weak formations are open to the cemented interval. Plastic state expansion additives are applicable, but not limited to more severe conditions where low density slurries must be used to help prevent lost circulation and/or over-pressured zones are involved.

In today's cement job analysis methods, annulus geometry, cement column length, initial overbalance pressure, cement transition time, and slurry fluid loss are used to calculate a flow (after cementing) potential factor[7] which is, in effect a coefficient of potential loss of cement sealing integrity. Some analysis programs not only calculate an evaluation coefficient, but also list applicable improvement alternatives. This type of analysis is especially valuable for any new situation and is strongly recommended if even a small amount of gas leakage or interzone communication is suspected, however the details of such cement job analysis techniques are too voluminous to be reviewed in this paper.

## CHEMICAL EXPANSION MECHANISM

Essentially all chemical type expansive additives used in primary casing cementing are based on an aluminate-sulfate reaction. This reaction produces crystallized calcium alumino sulfate materials which need up to 85%* water at < 176°F and up to 53%* water at higher temperatures. Expansion occurs as a result of crystal growth between solid cement particles, which in turn results in an overall dimensional increase.[2,7] This, however, only occurs after the cement has reached sufficient mechanical strength to transfer the interparticle wedging forces to an overall dimensional expansion. The forces extended by this type of expansion are relatively small compared to thermal or liquid-solid phase change expansion. Mechanical restraint greatly reduces chemical expansion. The equivalent of 1% steel by volume (290,000 psi restriction modulus) typically reduces cement expansion to only 10 to 30% of the unrestrained expansion. Restraint in one direction will not increase the expansion in other directions. [4,9]

Although the theoretical amount of reaction products is constant up to 176°F, effective expansion decreases rapidly as temperature increases. At 150°F, a 20% concentration of expansive additive will typically result in less than one-half the expansion shown by 14% concentration at 100°F.

Traditionally, chemical expansion additives have depended on cement to supply the aluminate material needed for the expansion reaction; however, cements with high aluminate (usually tricalcium aluminate, $C_3A$) are not aptly suited for general oilwell cementing operations. A high $C_3A$ content often causes retardation and early gelation problems. Except for Class A, specifications for all API cements call for moderate sulfate resistance (MSR) or high sulfate resistant (HSR). Most API Class B, G, and H cements now in use are well below the 8% $C_3A$ maximum for MSR and many meet the high sulfate resistance specification of 3% maximum $C_3A$. Such cements seldom contain enough active $C_3A$ to yield any meaningful expansion. Even a high $C_3A$ Class A cement blend with 50:50 Class F fly ash does not contain enough $C_3A$ to formulate a high performance expansion cement. API Class A specifications list no minimum $C_3A$ content. Actual $C_3A$ contents can vary from 4 to 14%, and the maximum expansion can vary from poor to good when no other source of aluminate is supplied. Further, all the calculated $C_3A$ content of a cement is seldom in an active form and disappointingly low expansion can result, even with what is reported to be a high $C_3A$ cement.

To overcome the deficiencies of depending on the chemical compositions of the cement, a composite cement expansion additive was developed. It can be used with any class of API cement or pozzolan-cement blends with predictable results and its expansion is not subject to variations of the active $C_3A$ content of the cement.

## MEASURING CEMENT EXPANSION

There is essentially no universally accepted method for measuring cement expansion as it applies to downhole casing cementing conditions. For a reliable comparison of expansion data from different sources, several factors should be consistent:

1. Value reported should be linear expansion. Volume expansion values should be divided by three.

2. Specimen curing temperatures should be the same and be near the proposed application. Data collected at 100°F should not be compared to data at 120°F; neither would be applicable to 150°F conditions.

3. Slurry preconditioning should be included. Specimens formed with freshly mixed slurries which are not preconditioned to simulate downhole placement time can show erroneously high expansion.

4. Slurries should have a thickening time suitable for the proposed applications.

5. Type of cement retarder should be similar because expansion can be strongly influenced by changes in retarder.

6. Specimens should be water cured. Data from controlled humidity conditions can be misleading.

7. High temperature high pressure expansion data based on measurements made after cool down to a lower temperature (typically $\leq$ 190°F) are at best comparative and then only when reference compositions are included. There is no standard for this type of test.

8. Tests run to measure expansion <u>after</u> a standard curing period (e.g, 24 hours) are of little value for evaluating oil well cements. In many instances most of the useful expansion has already occurred before the initial measurement is made. The test method used should be capable of measuring <u>total</u> expansion.

9. Appropriate corrections should be made for temperature effects on test specimens and test molds.

## TEST PROCEDURE

Expansion molds used for collecting the data shown in this paper were 1 × 1 × 10 in. individual specimen type molds constructed to retain an initial reference length which was measured before filling the mold. Total net expansion was obtained by measuring the cured specimen (still in the mold) and subtracting the initial length corrected to the test temperature.

High pressure high temperature condition specimens cured at 275°F were cooled to 180°F before releasing the pressure and length measurements were made at 180°F. An additional correction was used to compensate for the thermal contraction of the cement between the test temperature and the measurement temperature. Before filling the molds, all slurries were preconditioned by stirring 20 min. at the BHCT corresponding to the BHST at which the specimens were cured.

## LABORATORY TEST RESULTS

Contrary to initial expectations, a low $C_3A$ blend (50-50 pozzolan- Class C) showed greater expansion than Class A cement (Table 1).

Laboratory data for the standard "low temperature" variation of the new additive showed useful expansion, up to 150°F (Table 2). This series of tests aptly illustrated a decrease in expansion with increasing curing temperature. For a 50-50 pozzolan-Class H the final (28 day) expansion was decreased from 0.66% at 85°F to only 0.14% at 150°F.

Tests with different retarders (Table 3) showed some retarders essentially killed expansion while others apparently optimized expansion. The results strongly indicate an expansive cement failure could easily result from the use of inappropriate retarders.

At temperatures above 115°F, salt, used for whatever purpose typically increased retarder requirements and effectively decreased the expansion making higher retarder concentrations necessary. At 150°F, changing to a low chloride formulation (Table 4) resulted in greatly increased expansion, and eliminated the need of an expansion reacting modifier and extra retarder to offset the accelerating effects of the salt.

A high temperature version has also been tested and produced useful expansion at 275°F (Table 5).

## FIELD TEST RESULTS

Several jobs have been successfully completed with the standard expansive cement blend formulation:

### Case History No. 1

The first application was a relatively shallow well where expansive cement was placed from 1300 ft to total depth (TD 2274 ft). Figures 2a and 2b show the changeover from the filler cement at 1200 ft to the expansive cement at 1300 ft. In the filler cement area (above 1240 ft) three cycles of pipe signal are readily apparent on the VDL (Variable Density Log) and first arrival amplitude varies from about 4 to 40 mv. In the expansive cement area (1390 ft) pipe signals disappear from the VDL and the first signal amplitude drops to < 1.0 mv. This sort of pipe bond indication continues to TD. Strong formation signal arrivals, which indicate a good cement to formation bond, begin to appear just below 1300 ft and continue to TD. A typical log from a similar well using a more conventional expansive additive is shown in Figs. 3a and 3b. This log shows an acceptable or even good bond, but the improvement shown in Figs. 2a and 2b is readily discernable.

### Case History No. 2

The next type of application for this additive was a zone isolation problem between 6200 and 6800 ft at 150 to 155°F. "Frac Evaluation" logs (Figs. 4a, b, and c) indicate fracture treatments were not being confined to the perforated interval. The wells were being completed with pozzolan-Class H cement with 6% salt. Cement bond logs indicated very poor-to-poor casing to cement bonding and no indication of even intermittent bonding to the formation (Figs. 4b, and 4c). Both the temperature and radioactive tracer survey (Fig. 4a) indicated communication above and below the pretreated interval.

A nearby well was cemented with a low fluid loss Class H slurry with 20% of the standard version of the new expansion additive. Temperature and radioactive tracer logs (Fig. 5a) showed no indication of communication to other intervals. The cement bond log (CBL) (Figs. 5b and 5c) indicated a 100% bond to the pipe (amplitude in pipe gate was zero and VDL showed no pipe signals) and very good bond to the formation (strong formation signals on the VDL).

## CONCLUSIONS

The new expansive additive showed good performance in all types of API oilwell cement and pozzolan-cement blends regardless of $C_3A$ content. However, the experience gained during the development of this product clearly indicated:

1. Salt can not be indiscriminately added to slurries with the expectations that expansion will be enhanced.
2. Proper retardation is essential for maximum expansion, although some retarders decrease expansion.

## REFERENCES

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## Table 1
## Expansion vs Type of Cement Blend

| Cement Blends | Experimental Additive (Percent by Wt. of Cement) | Percent Linear Expansion | | |
|---|---|---|---|---|
| | | 1 Day | 3 Day | 28 Day |
| Class A | 10 | 0.20 | 0.21 | 0.29 |
| Class C | 13 | 0.07 | 0.09 | 0.27 |
| Class C | 16 | 0.10 | 0.14 | 0.30 |
| Class H | 10 | 0.15 | 0.17 | 0.21 |
| Class H | 13 | 0.36 | 0.42 | 0.56 |
| pozzolan-Class H<br>0% Gel[a] | 13 | 0.15 | 0.48 | 0.49 |
| pozzolan-Class H<br>6% Gel[b] | 10 | 0.19 | 0.27 | 0.32 |
| pozzolan-Class H<br>6% Gel[b] | 13 | 0.26 | 0.35 | 0.44 |
| pozzolan-Class H<br>2% Gel[a] | 14 | 0.17 | 0.37 | 0.39 |

[a] 50-50 pozzolan:Cement

[b] 35:65 pozzolan:Cement

## Table 2

| Cement Blends | Experimental Additive (Percent by Wt. of Cement) | Temp (°F) | Percent Linear Expansion | | |
|---|---|---|---|---|---|
| | | | 1 Day | 3 Day | 28 Day |
| pozzolan-Class H<br>2% Gel | 14 | 85 | 0.16 | 0.34 | 0.66 |
| pozzolan-Class H<br>2% Gel | 14 | 100 | 0.15 | 0.48 | 0.49 |
| pozzolan-Class H<br>No Gel | 13 | 100 | 0.15 | 0.48 | 0.50 |
| pozzolan-Class H<br>No Gel | 13 | 125 | 0.03 | 0.14 | 0.16 |
| pozzolan-Class C<br>2% Gel | 14 | 85 | 0.07 | 0.20 | 0.47 |
| pozzolan-Class C<br>2% Gel | 14 | 100 | 0.14 | 0.26 | 0.38 |
| pozzolan-Class H<br>6% Gel | 10 | 100 | 0.19 | 0.27 | 0.34 |
| pozzolan-Class H<br>6% Gel | 10 | 125 | 0.17 | 0.19 | 0.19 |
| Class H | 13 | 100 | 0.36 | 0.42 | 0.56 |
| Class H | 13 | 125 | 0.09 | 0.11 | 0.12 |
| Class H | 20 | 150 | 0.12 | 0.13 | 0.14 |
| Class H | 20 | 172 | 0.07 | 0.06 | 0.06 |

## Table 3
## Influence of Retarders on Expansion

Base Slurry: Class H cement with retarding type fluid loss control additives

Expansive Additive: 20% (by weight of cement)

| Retarders[1] (%) | Modifiers (%) | Temp (°F) | Percent Linear Expansion 1 Day | 3 Day | 28 Day |
|---|---|---|---|---|---|
| 0.3 A | 1% Hydrated Lime | 150 | nil[2] | nil | nil |
| 0.2 B | 1% Hydrated Lime | 150 | 0.20 | 0.19 | 0.20 |
| 0.3 A | None | 150 | 0.08 | 0.90 | 0.11 |
| 0.1 A | None | 150 | 0.12 | 0.13 | 0.14 |
| None | None | 170 | 0.07 | 0.06 | 0.07 |
| 0.5 A | 1% Hydrated Lime | 170 | nil | nil | nil |
| 0.45 B | 1% Hydrated Lime | 170 | 0.10 | 0.11 | 0.11 |

A = Inorganic type
B = Organic type - organic salt type blend

[2] less than 0.1%.

## Table 4
## Influence of Salt on Expansion

Base Slurry: Class A Cement with retarding type fluid loss control additive

| Salt (%) | Expansive Additive (%) | Retarder %, Type[1] | Temp (°F) | Percent Linear Expansion 1 Day | 3 Day | 28 Day |
|---|---|---|---|---|---|---|
| 0 | 20 | 0.1 A | 150 | 0.12 | 0.13 | 0.14 |
| 0 | 20 | 0.2 B + Prehydrated Lime | 150 | 0.32 | 0.35 | 0.35 |
| 5.2 | 20 | 0.3 A | 150 | 0.03 | 0.03 | 0.04 |
| 0 | 15.7[2] | 0.05 C | 150 | 0.38 | 0.38 | 0.38 |

[1] A = Inorganic type
B = Organic type
C = Organic salt type

[2] Low chloride formulation

## Table 5
## High Temperature Expansive Formulation

Slurry: Class H, 35% Silica, 0.6% Fluid Loss Additive

Expansive Additive: 14% High Temperature Formulation

| Retarder %, Type[1] | Temp (°F) | Percent Linear Expansion 3 Day |
|---|---|---|
| 0.4 A + 0.4 B | 275 | < 0.01 |
| 1.0 C | 275 | 0.10 |

[1] A = Inorganic type
B = Organic type - organic salt type
C = High temperature type

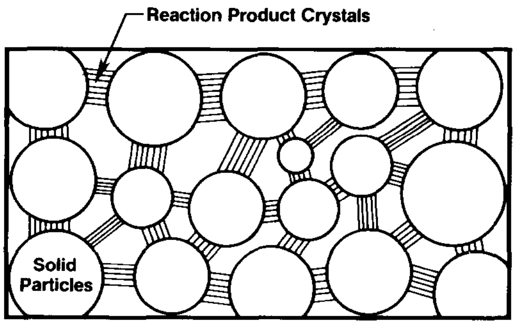

Figure 1—Chemical expansion mechanism idealized

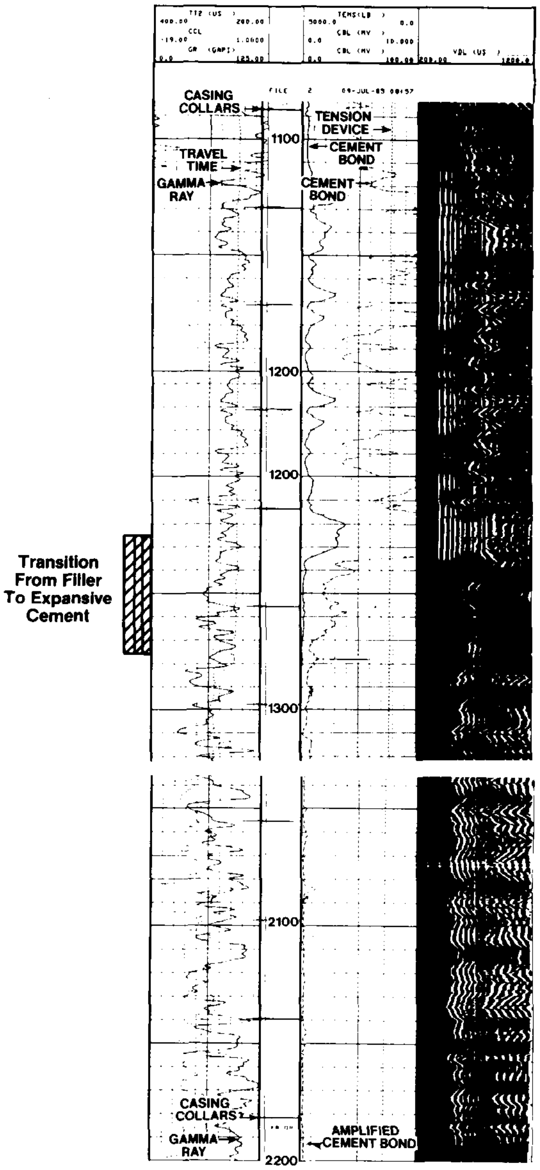

Figure 2—Expansive cement bond log with new expansion additive

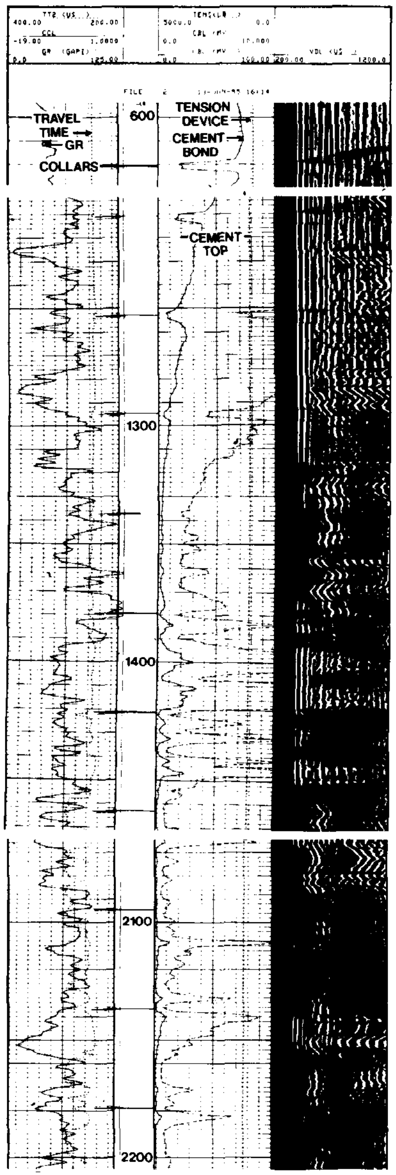

Figure 3—Log from well using traditional expansion additive

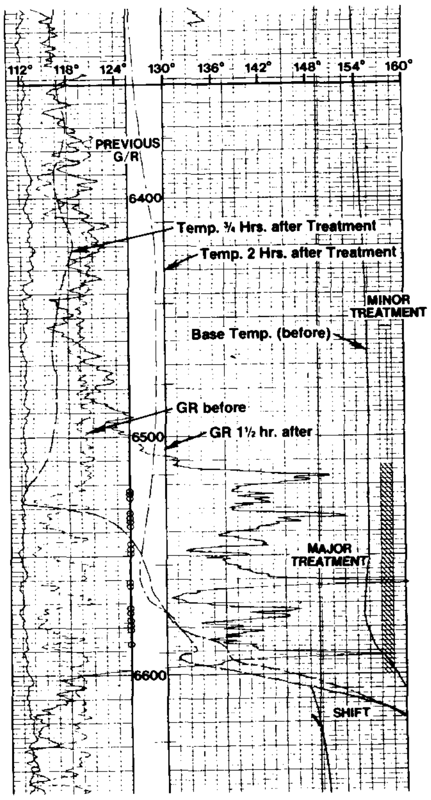

Figure 4a—Frac evaluation log with no expansion additive

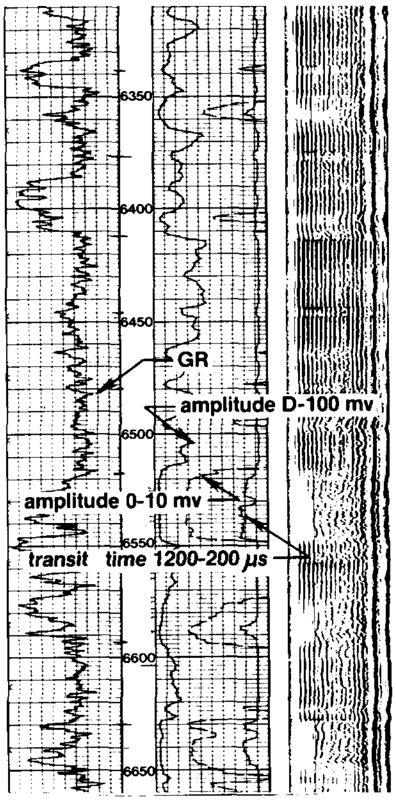

Figure 4b—Cement bond log with no expansion additive

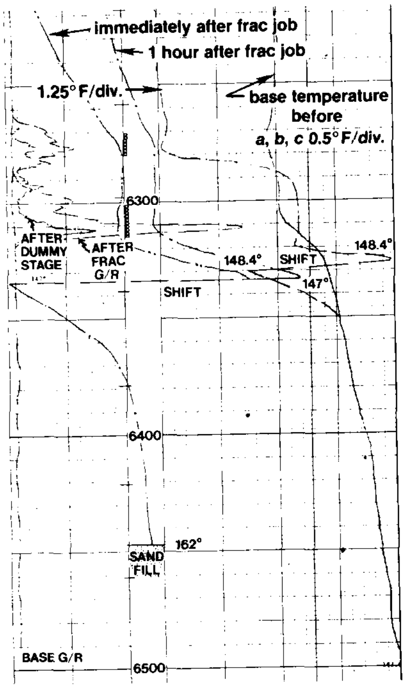

Figure 5a—Frac evaluation log with new expansion additive

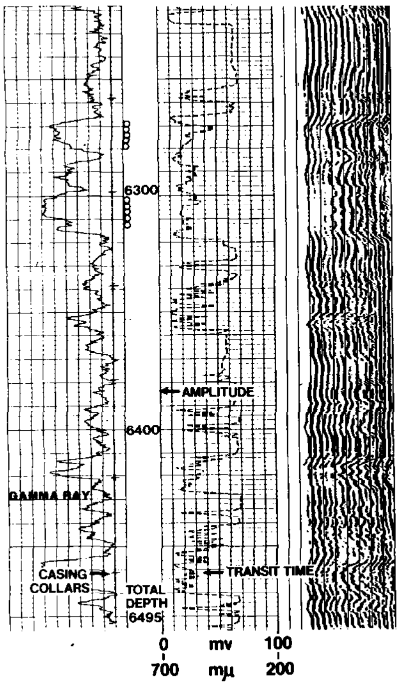

Figure 5b—Frac evaluation log with new expansion additive