NEW EXPANSIVE CEMENT SYSTEM FOR HIGH TEMPERATURE

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ABSTRACT

Expansive cements have been used in oilfield operations to produce better cement bonding which has been reported to help control annular flow, reduce water:oil ratios, and increase casing life by minimizing corrosion from well brines. Previously used chemical cement admixtures have been limited to bottomhole temperatures below 170°F, with best results seen at lower temperatures (80 to 120°F). A new cement additive has been developed which produces significant linear expansion in laboratory tests at temperatures above 170°F, with quicker expansion development seen as temperature increases.

Expansion data for this cement system and field results will be presented to introduce this expansive additive.

INTRODUCTION

Expansive cement of one type or another has been used in oilfield cementing operations for several decades.[1] Its use was actively promoted in the mid-1950's following the introduction of expansive cements in the concrete industry.[1] The principal objective of its use was and still is, simply to improve the sealing ability provided by the set cement.[2]

Until recently, most expansive cements have been limited to wells with geostatic temperatures of 170°F. Most expansive cements were based on a calcium sulfate-aluminate reaction[3] which becomes less effective as temperature increases, and changes abruptly at 176°F to a non-expanding reaction.[4,5]

A new, highly efficient expansive cement additive has been developed which provides exceptionally good expansion from 170°F to above 400°F. In contrast to calcium sulfate-aluminate systems, its final expansion is essentially constant at all temperatures. The expansion rate decreases with temperature, however, and in effect, sets the lower temperature limit for practical use at 170°F.

Laboratory data are given to illustrate the performance and temperature range of this new expansive cement additive. Job descriptions and results are shown for three applications with bottomhole static temperatures of 180 to 230°F at total depth of 8,560 to 11,329 ft.

BACKGROUND

Failure or potential failure of a set cement to provide the sealing needed for effective zone isolation is commonly judged from cement bond logs.[4] The typical detrimental end results of poor sealing are interzonal communication, annular gas flow, casing corrosion, and poor confinement of stimulation treatments. Interzonal communication can result in high gas:oil ratios or water:oil ratios. Casing corrosion can be promoted by a micro-rate interzonal water flow as well as failure to provide a protective cement sheath. Annular gas flow (expansion of the set cement is not felt to be an effective mechanism for controlling high rate or catastrophic gas flow conditions) can range from an expensive nuisance to accelerated gas zone depletion. Poor confinement during fracturing or acidizing can lead to excessive water or gas production.

Poor sealing or cement bonding is mostly attributed to incomplete mud displacement and volume decreases during the slurry's transition period or plastic state.[6] Pressure and temperature changes between the cement setting period and operational conditions can both contribute to microannular occurrence,[2] but the end results are felt to be comparatively minor. Even the best mud displacement techniques often leave a low strength filter cake which can reduce cement sheath confinement. The volume losses come from both plastic state shrinkage and fluid loss during the plastic state (or transition time).[6] The results of volume loss are, first, a decrease in cement column pressure (often referred to as cement pore pressure), which is followed by flow of fluid or gas into the cement column as the cement pressure drops below the adjacent formation pressure. Fluid entry reduces cement confinement, forms flow channels, and results in loss of sealing integrity.

Volume losses can be minimized by reducing the downhole fluid loss rate, and the influence of volume loss can be alleviated by reducing the transition time period. But, within the realm of cost effectiveness, these methods often do not yield the preferred cement bond quality. Expansive cement provides a useful tool for supplementing, or as a partial alternative to, other proven techniques for improving cement bonding.

EXPANSION THEORY

The two general types of cement expansions are (1) plastic state expansion, which occurs before the cement completes its initial set, and (2) chemical expansion, which occurs after initial set.[7] The new high temperature expansive cement additive is the chemical expansion type. Traditionally, chemical expansion is explained as crystal growth between solid cement particles which form wedges between the particles and push them apart.[7,8]

Most expansive cement additives and expansive cements are based on a calcium sulfate-aluminate reaction which yields ettringite and requires 85% water (by weight of initial solids) for complete hydration.[3] The final amount of ettringite formed is relatively constant between 32° and 170°F, but above 176°F, ettringite does not form. In addition, changes in crystalline forms and expansion reaction rates relative to strength producing reaction rates result in a general decrease in expansion from a maximum at about 110°F, to as little as 10 to 20% of the maximum at 170°F.[7] Above 170°F useful expansion from calcium sulfate-aluminate systems should not be expected.

The mechanism for the new high temperature expansive cement additive has not yet been completely resolved but it is, in part, felt to be similar to the mechanism for the calcium sulfate-aluminate system. The reaction, however, is based on completely different chemicals and physical state of the chemicals. The amount of the new high temperature additives needed to produce useful expansion is much smaller than for the low temperature additives.

LABORATORY EXPANSION TEST RESULTS

Good expansion has been seen with as little as 3% of the new expansion additive (Table 1). Temperature accelerates the expansion rate but does little to change the final amount of expansion as illustrated in Table 2.

This new expansive cement additive is compatible with most cement additives including retarders, fluid loss additives, dispersants, foam stabilizers, and gas generating additives. It can be used in densified cement slurries as well as in normal density slurries. There is a moderate decrease of thickening time at BHCT ≥ 190°F, but normal times are restored with only slight addition of retarders (Table 3). Compressive strength development for slurries using this new additive appears to be normal, and apparently it neither adds to nor prevents strength retrogression (Table 4). As with all highly expansive cements, specimens unrestrained during curing can show low strength values. Its water requirement is similar to that of cement and causes no slurry viscosity design problems.

Expansion tests reported in this paper were conducted by first pre-conditioning the slurries in an atmospheric consistometer at the given temperatures. Slurries were then poured into 10 in. × 1 in. × 1 in. unrestrained linear expansion molds. These molds are used to measure expansion after initial set of the slurry. Cement was then cured at test temperature under pressure inside an autoclave. The samples were cooled below 180°F and placed in a water bath at 170°F for 1 hour before they were measured.

FIELD APPLICATION

Case No. 1. An operator drilling in a field characterized by a high frequency of remedial cement work (squeeze) and poor bond logs, decided to use the new high temperature cement expansion additive. Pre-cementing conditions of the well included the following: production casing of 4-1/2 in. to be cemented in 7-7/8 in. hole, drilling mud weight of 9.8 lb/gal with a plastic viscosity of 15 cp and a yield point of 12 lb/100 ft^2, and a bottomhole static temperature of 238°F. A 16.0 lb/gal cement slurry was designed for these conditions consisting of Class H cement, 35% silica flour, 3% KCl, 1.0% fluid loss additive, and 4.0% high temperature expansion additive. A 16.2 lb/gal slurry with a similar composition in laboratory test conditions developed over 3% expansion within 7 days when cured at 220°F (Table 5).

The job was conducted after the hole was circulated for 2 hours. Forty barrels of fresh water were pumped ahead of a 14 bbl fly ash spacer, followed by 81 bbl cement, a cement wiper plug, and 140 bbl fresh water displacement fluid. Results from a bond log taken after the cement job show excellent bonding across the bottom 200 to 300 ft, with good bonding over the rest of the interval.

Case No. 2. The same operator ran the same size casing to 8560 ft where the bottomhole static temperature was 200°F, with a 9.8 lb/gal lignosulfonate mud in the hole. The cement composition consisted of Class H cement, 3% KCl, 0.4% fluid loss additive, and 4.0% high temperature expansive additive, mixed at 16.4 lb/gal.

The job was conducted after the hole was circulated for 70 minutes. Thirty barrels of fresh water was pumped followed by 18.5 bbl of 14 lb/gal fly ash spacer. Fifty-nine barrels of cement slurry was pumped and displaced by fresh water at 6 bbl/min. Pipe was reciprocated during the job and for 20 minutes after cement placement. The bond log (Fig. 1), conducted 19 days afterward, showed very good bonding of the cement.

Case No. 3. A remedial job was conducted in Midland County to repair a well with a corroded 5-1/2 in. casing set at 11,300 ft. A 4-in. liner was set inside of the old casing from 7,856 ft to 11,329 ft after the hole was deepened.

The well was cemented with a slurry consisting of 50:50 Class H cement:fly ash, 2% bentonite, 5 lb salt/sk, 0.5% fluid loss additive, and 6 lb/sk high temperature expansive additive mixed at 14.4 lb/gal. Pumping sequence was 12 bbl of gelled water spacer followed by 43 bbl of cement slurry.

The cement bond log (Fig. 2) showed good bonding to both the old and new casings. The well was reperforated and fractured with 60,000 gal of fluid and 52,500 lb of sand. Production test indicated good zonal isolation was achieved with the expansive cement.

CONCLUSIONS

1. An expansive cement additive has been developed which provides significant, consistent expansion performance at well temperatures above 170°F.

2. The new expansion material does not require special mixing or handling procedures, and does not interfere with the properties of other cement additives.

3. Initial field application of cement slurries containing the new expansion material has produced excellent bond logs and zonal isolation.

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Table 1
Concentration vs Expansion

275°F and 3000 psi

High Temperature Expansion Additive (%)	Retarder (%)	Water (%)	Consistency[1] Bc @ 180°F Initial	20 Min	3 Day Expansion (%)
Class H cement, 40% silica sand, 10% silica flour, 0.6% fluid loss additive					
2.00	0.4	37.0	9	10	0.14
3.00	0.4	37.5	8	9	1.73
2.66	0.4	42.1	10	10	0.82
3.55	0.4	41.4	8	12	1.18
4.44	0.4	41.8	13	11	2.96
5.33	0.4	41.0	12	13	4.49
Class H cement, 40% silica sand, 0.6% Fluid Loss Additive					
2.0	0.5	37	8	8	0.14
3.0	0.5	37.5	11	8	1.73
3.5	0.5	38	8	9	1.34
4.44	0.4	38	10	12	2.14

[1] Atmospheric consistometer (preconditioning period)

Table 2
Expansion Rate vs Temperature

3000 psi

Class H cement, 40% silica sand, 0.6% fluid loss additive, retarder as shown, 38% water and 4.44% high temperature expansion additive in all slurries

Retarder % and Type	Consistency[1] (Bc) Init	20 Min	°F	% Linear Expansion @ Curing Time 3 Day	7 Day	14 Day	28 Day	°F
0.1% Low Temp	10	13	129	nil	nil	1.43	2.15	170
0.4% Low Temp	11	12	139	0.05	0.35	2.88	dis	190
0.4% Low Temp	10	13	158	0.16	2.47	dis[2]	--	210
0.3% Low Temp	10	13	163	2.69	dis	--	--	240
0.4% Low Temp	10	12	180	2.14	dis	--	--	275
1.0% High Temp	10	14	190	2.53	dis	--	--	300
1.0% High Temp, 0.4% Enhancer	10	13	190	2.35	dis	--	--	350

[1] Atmospheric consistometer (preconditioning period)
[2] dis - discontinued

Table 3
Influence of High Temperature Expansion Additive on Thickening Time

Base Slurry

Item	Parts by Weight[1]
Class H cement	100
silica sand	25
silica flour	10
fluid loss additive	0.6
high temperature expansion additive	as listed
retarders	as listed
water	as listed

High Temp Expansion Additive (%)	Retarders % and Type	Water (%)	BHCT (°F)	Thickening Time to 70 Bc[2] (Hr:Min)
None	0.25% LT[3]	40	1290	4:00
None	0.30% LT	40	190	6:00
4.0	0.25% LT	41.6	190	3:40
4.0	0.30% LT	41.6	190	4:55
None	1.0% HT[4] 0.5% RE[5]	40	308	8:00+
None	0.75% HT 0.4% RE	40	308	5:25
None	0.50% HT 0.4% RE	40	308	1:09
4.0	0.7% HT 0.7% RE	41.6	308	4:00
4.0	1.0% HT 0.5% RE	41.6	308	1:49

[1] Also percent by weight of cement
[2] HP-HT Consistometer
[3] LT = Low Temperature Retarder
[4] HT = High Temperature Retarder
[5] RE = Retarder Enhancer

Table 4
Compressive Strengths

Ultrasonic Cement Analyzer (UCA) Test Results

Base Slurry

Item	Parts by Weight
Class H cement	100
silica sand	25
silica flour	10
fluid loss additive	0.6
high temperature expansion additive	4.0
water	41.6
Retarders	as shown

Static Curing Temperature (°F)	Retarders % bwc, Type	Initial Set (Hr:Min)	Time to Reach 1000 psi (Hr:Min)	Strength at 72 Hours (psi)
170 (129)	0.1% LT[1]	5:20	7:00	3600
190 (139)	0.2% LT	7:57	9:20	3400
210 (163)	0.3 LT	3:23	4:30	3200
275 (190)	0.4% LT	1:10	2:00	1600
300 (190)	0.7% HT[2] 0.4% RE[3]	2:00	4:15	4300
350 (190)	1.2% HT 0.8% RE	9:30	13:50	5100

[1] LT = Low temperature retarder

[2] HT = High temperature retarder

[3] RE = Retarder enhancer

Table 5
Laboratory Tests for Field Applications

Case No. 1

Slurry:

Class H cement, 35% silica flour, 3% KCl, 1% fluid loss additive, 4% high temperature expansive additive, 6.1 gal water/sk
Density - 15.9 lb/gal, Yield - 1.5 ft^3/sk

Test Results:

HP-HT Thickening Time - 5:40
BHCT - 171°F

Case No. 2

Slurry:

Class H cement, 3% KCl, 0.4% fluid loss additive, 4% high temperature expansive additive, 4.5 gal water/sk
Density - 16.4 lb/gal, Yield - 1.10 ft^3/sk

Test Results:

HP-HT Thickening Time - 2:14
BHCT - 125°F
Compressive Strength at 200°F
12 hours - 1650 psi
24 hours - 2100 psi

Case No. 3

Slurry:

50:50 Fly Ash:Class H cement, 2% bentonite, 0.5% fluid loss additive, 5 lb salt/sk, 6 lb high temperature expansive additive/sk, 6.28 gal water/sk
Density - 14.4 lb/gal, Yield - 1.38 ft^3/sk

Test Results:

HP-HT Thickening Time - 3:40
BHCT - 134°F

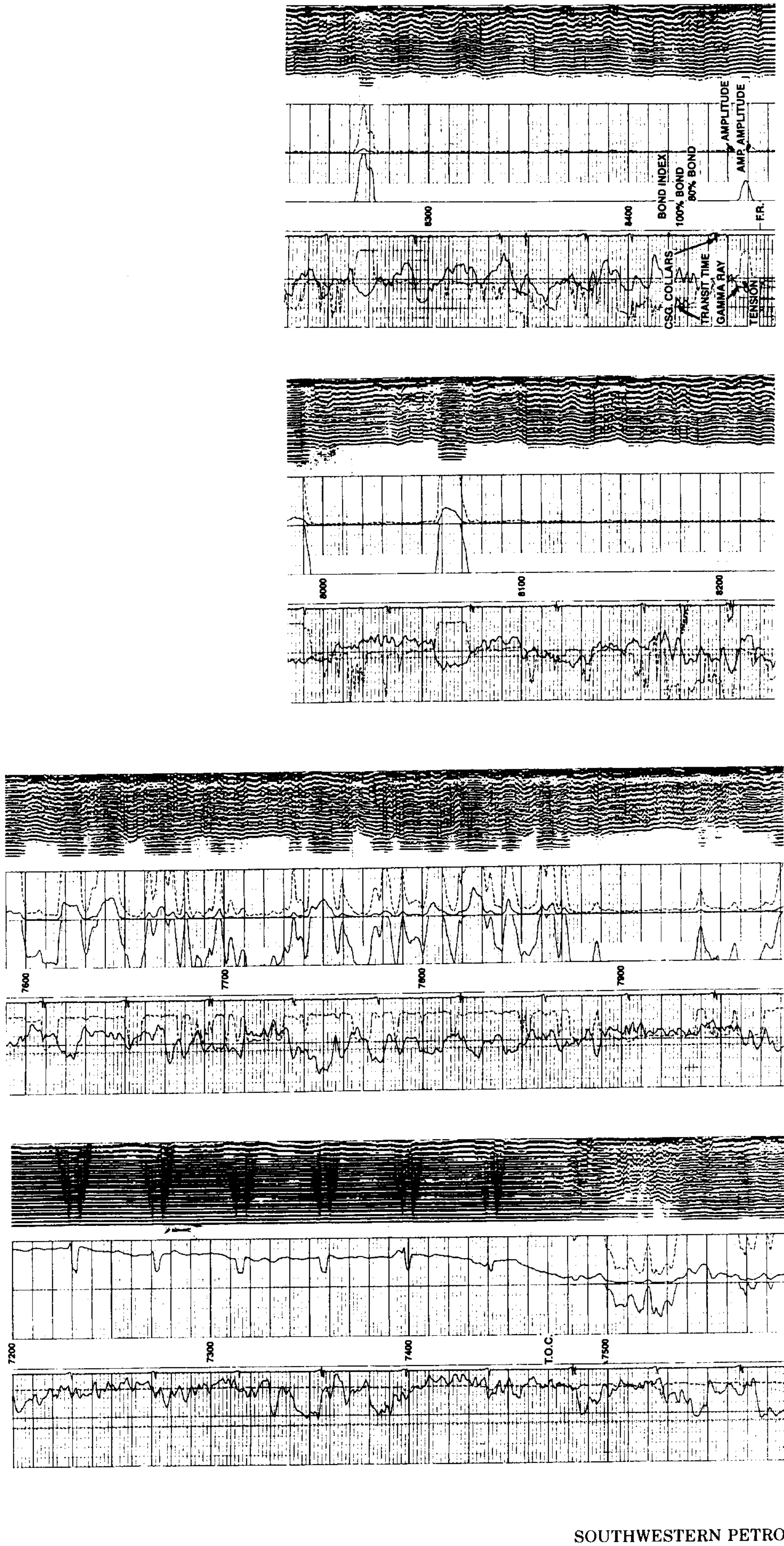

Figure 1 - Case History No. 2

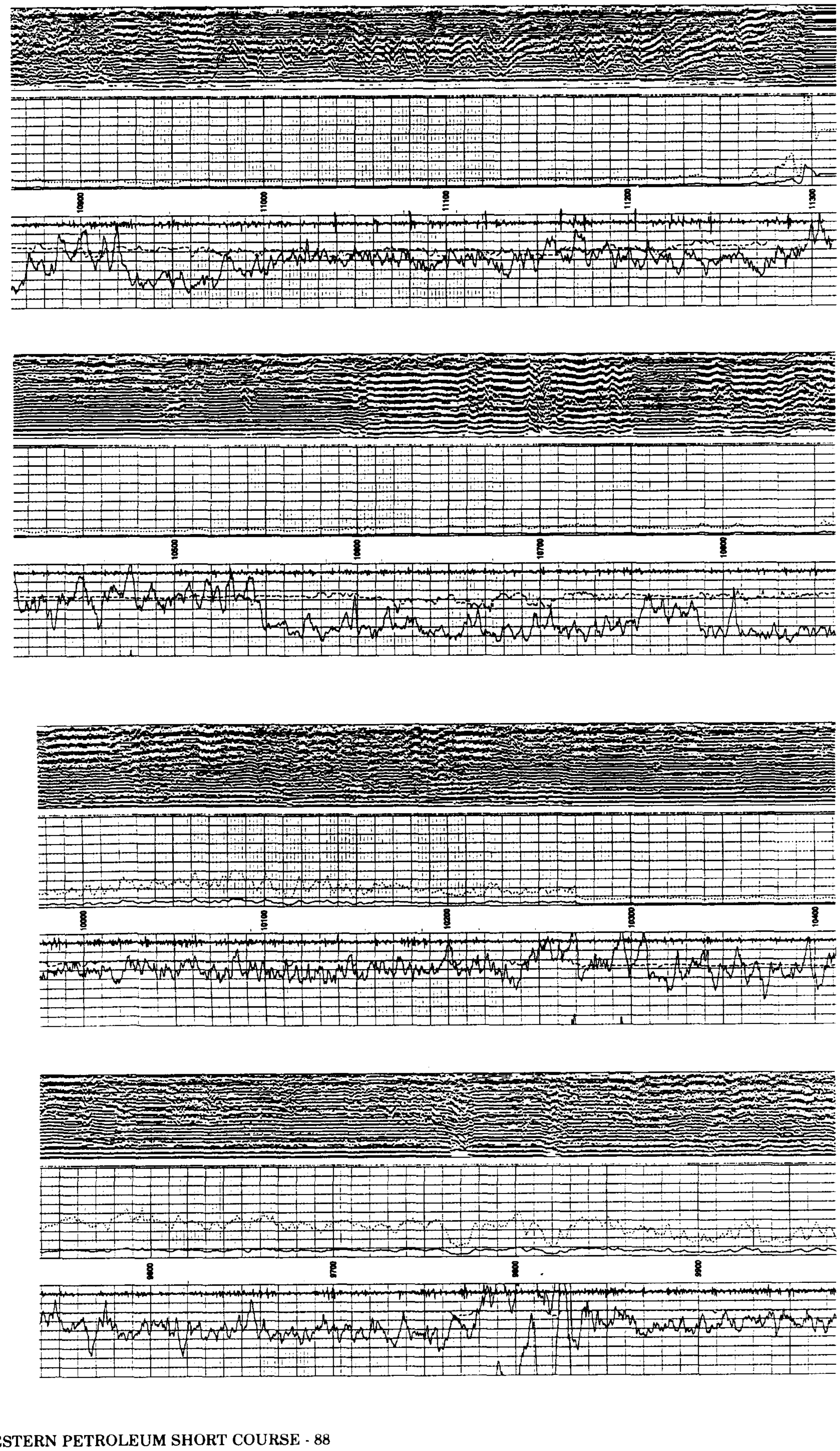

Figure 2 - Case History No. 3