USING TIME LAPSE IMAGING TO DETECT PROPPANT REDISTRIBUTION AND/OR FLOWBACK AFTER FRACTURING

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INTRODUCTION:

Using spectral gamma ray imaging to identify issues of fracture stimulation placement has been well documented and enhanced by providing methods to interpret inside or near wellbore phenomena as well as fracturing phenomena occurring within 25 inches of the wellbore. Recent studies by Robinson and Voneiff have confirmed that in most vertical or near vertical wells, fracture heights determined by tracers are equivalent to or within ten percent of fracture heights predicted by 3D models or post-fracture treatment performance testing. [1] Furthermore, it has been determined that when tracers are proportioned properly throughout proppant slurries and carried as an integral part of non-washing, non-crushing, non-abrasion loss carriers, the counts as determined by spectral gamma ray imaging are directly related to fracture width.[2] This has successfully been corroborated by correlations made using long-spaced or dipole sonic logging and refined by an algorithm developed to quantify fracture width at the wellbore. Most recently a case study has shown that tracers may be used to confirm that fracture closure may not occur as quickly as is often calculated or assumed. [3]

PROPPANT PLACEMENT:

The goal of a hydraulic fracturing operation is to enlarge the effective wellbore drainage area by creating a highly conductive propped fracture system within a pay interval which contacts stored reserves located some distance away from the wellbore. Since in-situ stress is acting to close the created fracture, proppant is placed in the fracture to prop or hold open the induced fracture.

Once fracture closure is achieved, fracture conductivity is a function of localized proppant concentrations which remain in a specific interval. Most fractures do not close instantly nor completely, which may allow some proppant to settle to the bottom of a created fracture or even flow back into the wellbore or near wellbore region as the well is cleaned up and brought on line.

Proppant flowback is most easily identified by proppant production at the surface or in the wellbore below or within the perforated interval. Proppant settling, flowback or some form of redistribution can be readily identified using a technique known as 'time-lapse-imaging" using a gamma ray logging tool.

With time-lapse-imaging, a spectral gamma ray image is recorded within a short time period after a fracturing procedure is performed (usually a few days to allow wellbore clean-up) and then the image is re-recorded thirty to ninety days later.The change in proppant concentrations at the wellbore, calculated fracture width and overall proppant distribution can then be compared and evaluated over time. Both images are corrected for isotope half-life and decay. This process can currently be done for Iridium 192, Scandium 46 and Antimony 124 as long as they are pumped in precise proportion to the proppant slurry concentration without any loss or redistribution due to the wash-off by injected or produced fluids, and crushing or loss due to abrasion between particles or other solid substrate (i.e formation, tubulars).

BLACK WARRIOR BASIN CASE STUDY:

Work done by Barba, Dein and Woodroof verified that excessive downward proppant movement or growth can occur when in-situ stress barriers are stronger above the perforations than below a perforated interval.[4] Multiple radioactive tracers confirmed that initial downward growth was verified with time-lapse-imaging after sixty days following the initial survey. In addition, Barba, et. al., demonstrated that mechanical properties have a significantly greater effect on proppant than the placement of perforations in the tubulars.

In addition, several zones were completed in the Black Warrior coals, and proppant redistribution investigated using time-lapse-imaging. Proppant movement with time, usually settling downward or returning to the wellbore after being displaced beyond the spectral tool's depth of investigation, occurred in the majority of zones. Thirty pound linear gels, nitrified linear gels, foamed linear gels (70 quality) and crosslinked fracture fluids were all evaluated and comparisons made between tracer and 3D model predictions.

There was excellent agreement with these predictions on all but one 70 foot interval, A gap in tracer presence was difficult to explain but could have been due to over-displacement of proppant or minor proppant flowback. Other possibilities for the discrepancy could be interzonal tortuosity causing localized entrapment of proppant while the primary fracture's slow closure allowed some settling to occur. It was noted that if stress barriers are close to the perforated interval above the zone, undesirable proppant movement can occur in spite of an adequate proppant pack-off.

Of the fluids run in the Black Warrior Basin coals, linear gel based nitrogen assisted systems were effective in minimizing fracture height growth and maximizing fracture length. It was determined that if a minimum height growth above the perforations could not be obtained, post fracture proppant settling could be severe.

Brady, Blauer, Robinson and Holcomb determined that non-damaging fluid systems could be designed to carry sufficient proppant concentrations to obtain tip screenouts in multi-intervals without generating "conductivity-wasting" excessive fracture height in the Niobrara formation of northeastern Colorado.[5] Holcomb and Blauer's work in the Mesa Verde stimulations indicated in SPE #37404 confirmed this phenomenon as well.

SLOWLY CLOSING FRACTURES:

The concept of slowly closing fractures was tested in several Rocky Mountain and Black Warrior Basin examples. The Rocky Mountain tests included the layered/lenticular Mesa Verde sandstone formation in the Piceance Basin and the Black Warrior Basin example was the Gwen Coal Seam. Production test methods used allowed the determination of producing reservoir transmissivity, effective fracture length and skin damage.[6] This portion of the study demonstrated that effective reservoir transmissivity and fracture lengths often decrease during the first one to two years, especially in low permeability reservoirs. A slowly closing, unpropped fracture which gradually reduces the reservoir interval and infinite conductivity fracture length connected to the wellbore provides a reasonable explanation for this behavior.

The evidence for slowly closing fractures was further tested by measuring movement of radioactively traced proppants during the first ninety days after hydraulic fracturing. Logging was done once during the first week after the fracture stimulation. Generally it would be assumed that the fracture would have sufficiently closed within the first time period to fully trap the proppant. A second image was logged approximately sixty days after the first log and it was shown that significant proppant movement during this time occurred indicating the fractures were insufficiently closed and thus permitted proppant movement. The majority of proppant movement was either downward (due to gravity) or less frequently upward toward a perforation (set) due to reservoir fluid movement. Most unusual was the case where proppant appeared on the second time-lapsed-image after there had been no indication of proppant or fluid tracer on the first log.

Reservoir production performance and radioactive imaging both offered support to the presence of slowly closing fractures. Slowly closing fractures permit proppant settling or other redistribution and create unpredictable production performance. Finite element analysis was used by Blauer, et.al. to perform a conceptual study utilizing production monitoring and radioactive tracer imaging to study the existence and subsequent effects of slowly closing fracture apertures.

EXPLANATIONS FOR INCOMPLETE FRACTURE CLOSURE:

These explanations are currently offered to explain why incomplete fracture closure may occur: 1. Plastic failure at the face of the fracture; 2. Slip discontinuity during the fracturing process; and 3. Proppant bridging. Figure 1 shows three diagrams that conceptualize each of these non-closure modes. These modes could actually be exhibited simutaneously in different areas of a fracture. Blauer et.al discussed each of these modes in SPE #37404 in addition to the mechanisms for brittle failure and plastic deformation as supported by the work of Bathe and Brace.[7] Figure 2 illustrates their findings using three separate strain diagrams including total volumetric strain and strains in the maximum and minimum principle directions.

In addition the Mesa Verde sandstone in the Piceance Basin was studied using equivalent field pressures rather than being stressed to failure. After running a three dimensional solid finite-element simulation, an estimate was made of the depth of plastic deformation created during hydraulic fracturing, and the possibility of a slowly closing fracture after the stimulation was indicated (Figure 3).

EXAMPLES OF PROPPANT MOVEMENT:

Figures 5 through 9 present several examples of proppant movement observed during the first 90 days of well production. Significant proppant movement is observed in each interval indicating the possibility of a slowly closing fracture near the wellbore in each interval. Presented along with the information are the density logs and perforation locations. The original proppant bed location for each of the three intervals is below the probable pay interval. The proppant bed location after the time lapse imaging across each interval is lower than the original location, indicating gravity segregation is probably responsible for moving the proppant away from the potential pay interval which is consistent with a slowly closing fracture aperture. Further work is continuing and it appears that this phenomenon occurs on the majority of fracture images investigated with the time lapse imaging and furthermore, production data variation is consistent with these investigations.

CONCLUSIONS:

1. Hydraulic fractures may not close during the first few hours after a stimulation and may require days, weeks, or months to totally close so that proppant redistribution may occur, and be signifcant due to gravity or fluid movement.

2. Since fractures in many reservoir rocks may not close completely, thereby permitting proppant settling, fractures growing downwards may leave significantly productive pay intervals unpropped.

3. The effects of slowly closing fracture apertures may not be fully realized for a period up to two years due to early time infinite dimensionless fracture conductivity and reasonable fracture length which slowly disappears as the unpropped fracture closes.

4. Multiple radioactive tracer imaging can be useful in the time-lapsed detection of various types of proppant movement and subsequent redistribution consistent with the phenomenon of slowly closing fractures. Proppant movement downward, upward, or while early fluid/proppant stages are returning to the wellbore region are some of the indications that fracture closure may not be complete after 30, 60, or 90 days. Due to half lives of 60-84 days for the commonly used isotopes Iridium, Scandium, and Antimony, time-lapsed images should be obtained within 90 days, although newer, more sensitive spectral gamma ray imaging and processing may allow detection after as long as one year after an initial post-fracture survey.

5. Early estimates (within 90 days) of production performance for reservoirs exhibiting slowly closing fractures may be overly optimistic. Reservoir simulations, fracture design models and optimization studies based on early post-fracturing analyses can lead to incorrect analysis and can cause inconsistent results and false conclusions about stimulation success. Current methods using more efficient well history evaluation over longer periods of time are more desirable if true long term completion/production optimization is to be achieved

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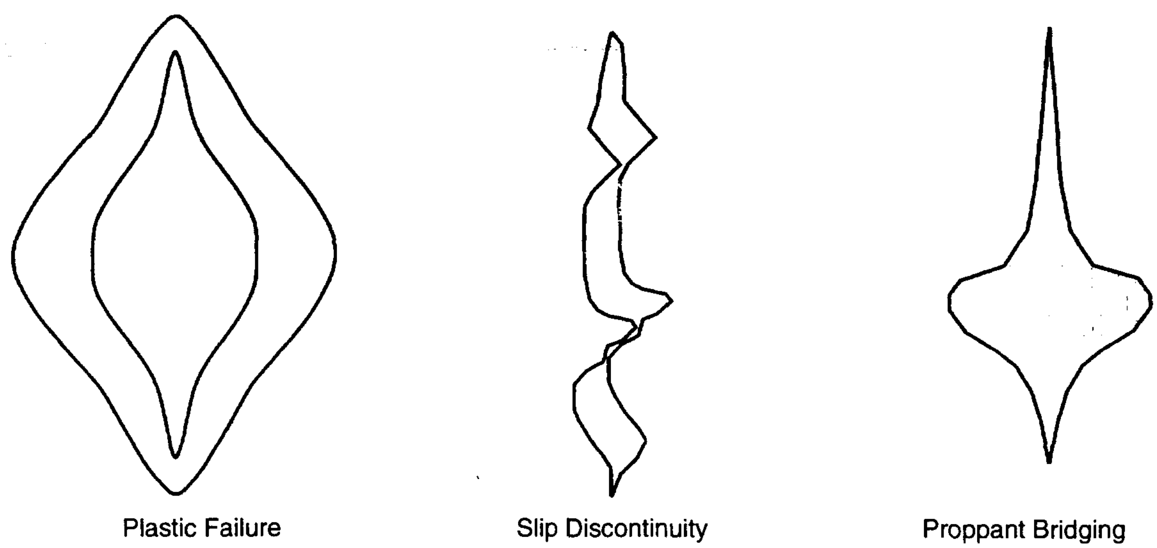

Figure 1 - Three Modes for Non-Closure of Fractures

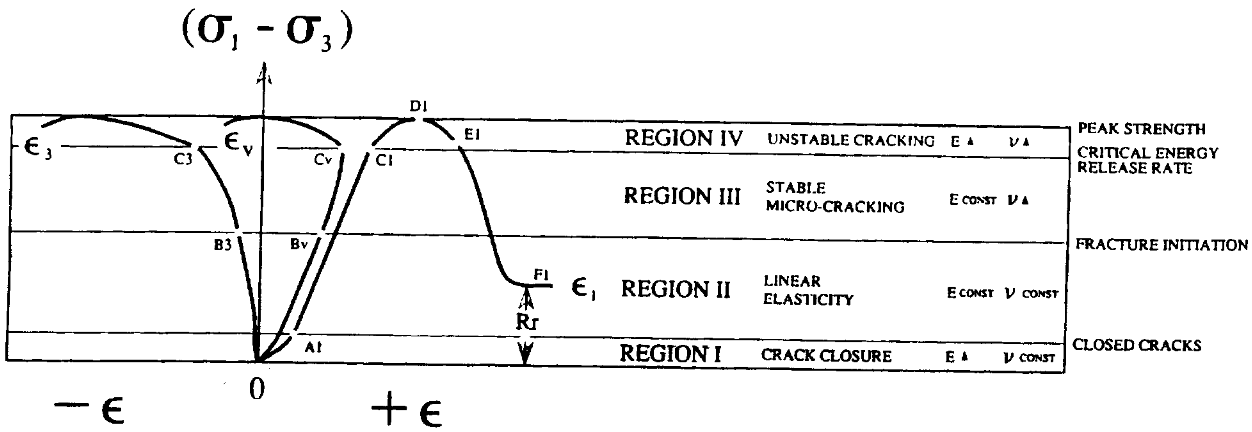

Figure 2 - Stress-Strain for Rock Failure Regions
Failure Mode: Compression

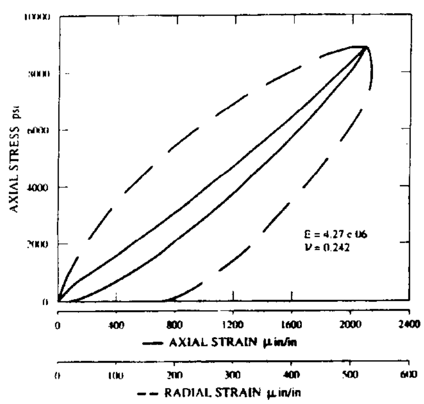

Figure 3 - Stress-Strain Relationship
Mesa Verde Sandstone

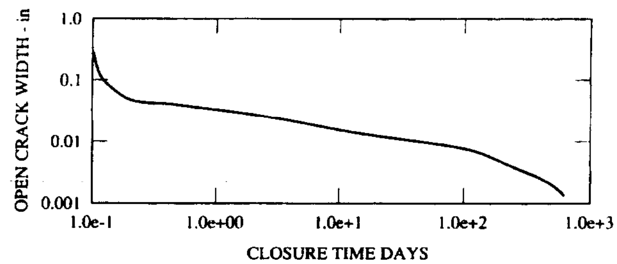

Figure 4 - Finite Elements Simulation Results
Includes Creep

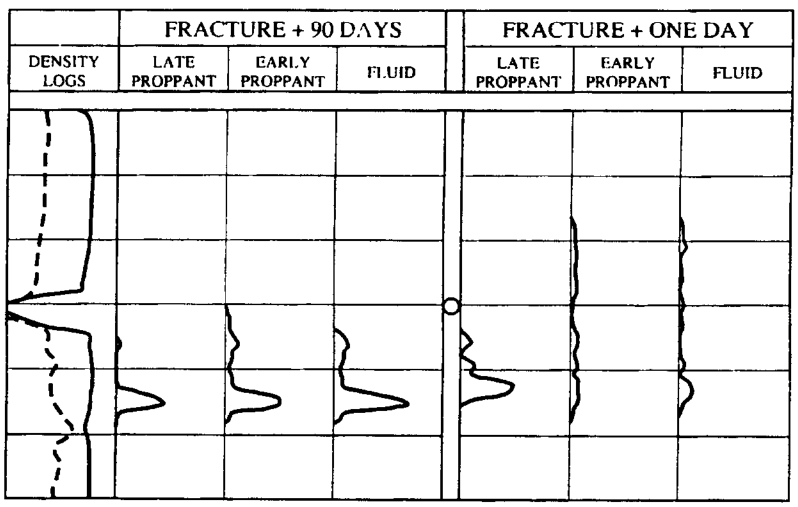

Figure 5 - Radioactive Tracer Log
Black Warrior Coal
2000' to 2600'

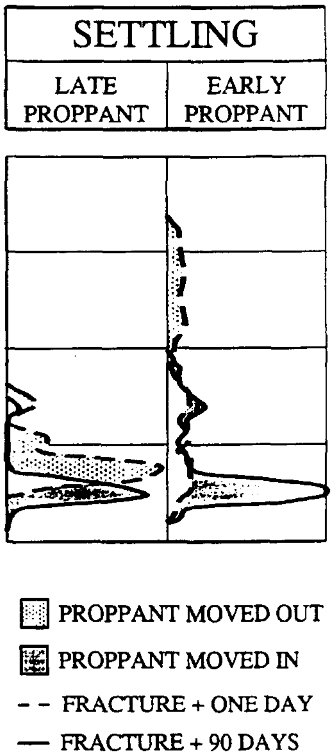

Figure 6 - Settling Detail
Black Warrior Coal
2000' to 2600'

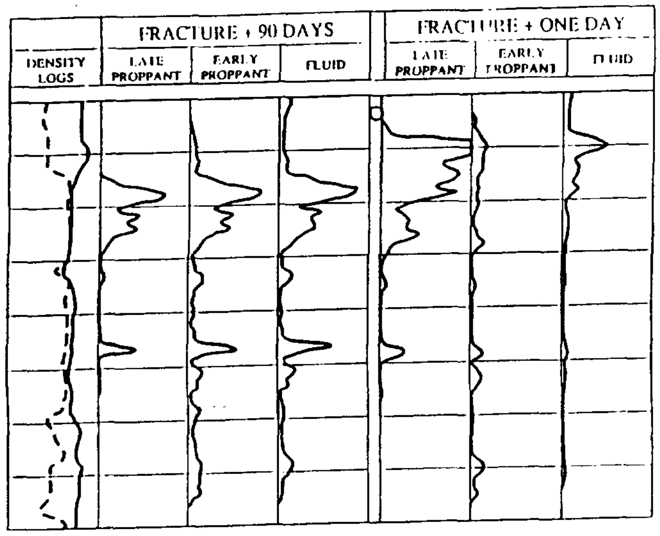

Figure 7 - Radioactive Tracer Log
Black Warrior Coal
1720' to 1800'

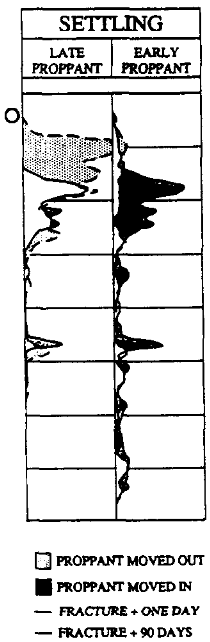

Figure 8 - Settling Detail
Black Warrior Coal
1720' to 1800'

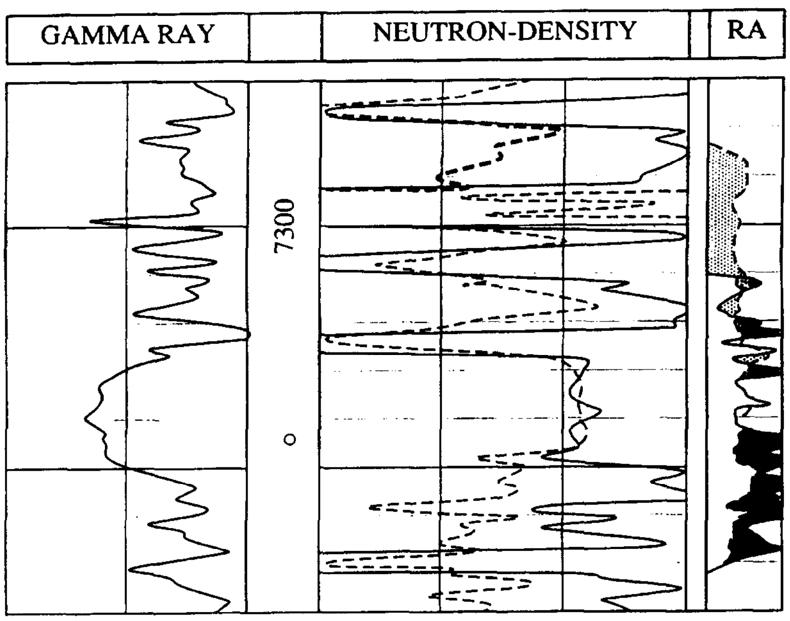

Figure 9 - Well Log & Settling Detail Mesa Verde
Sandstone