ENHANCED OIL RECOVERY AND INCREASED OIL PRODUCTION BY SEISMIC STIMULATION

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INTRODUCTION

Over the past decade ASR has progressed and applied its in-situ seismic stimulation technology to carbonate, sandstone, and diatomite fields. These fields have wide variations in API gravity, depth, porosity, permeability, drive mechanisms, and heterogeneity. Through its experience ASR has found that the underlying key to success depends on: (1) heterogeneity which relates to the amount of by-passed oil stocks; (2) gas content which relates to how far the seismic shockwaves travel; (3) API gravity which relates to the viscosity/mobility of the oil, hence, the power required to mobilize it, specifically the density of tools in a field; and (4) permeability which governs how quickly the formation responds. Conversely, it does *not* depend on: (1) depth; (2) wettability; (3) distance from the seismic source, provided target zones/areas are within ¾ mile or less from the source; (4) fault blocks in the horizontal case or lithology changes in the vertical case as shockwaves cross either to stimulate multiple production blocks and horizons; (5) presence or absence of a waterflood; (6) new or old fields; (7) rock type, or (8) porosity.

Regrettably, seismic stimulation has often been confused with acoustic methods used for near well zone cleaning based on piezoelectric, magnostrictor, and Coanda-effect generators and to a lesser extent on pulsing methods. These are single-well technologies. Seismic stimulation, on the other hand is a *multi-well* stimulation and in most cases a single Hydro-Impact™ tool will easily cover a section of production.

HOW IT WORKS

As seen in **Figure 1** the ASR Hydro-Impact™ tool installed into an injection or production well with perforations open to the formation. The tool installs similar to a standard tubing pump. In injection wells a perforated sub is placed immediately below the packer to allow injected water to bypass the tool and enter into the formation. In production wells the tool does not produce and it is placed below the perforations provided sufficient distance is available from the end of the tool to the bottom of the well to avoid drawing debris into the tool compression chamber. Another well type is an abandoned well wherein cement is placed across the perforations and the well is filled with water. In the later case there are few considerations such as injection pressure, water quality, debris in the wellbore and so on. The only loss is around 5 percent of the shockwave power as it crosses the cement plug.

Figure 2 shows the operation cycle of the tool. In a nutshell the tool is comprised of two plungers, a lower plunger with a traveling valve and an upper plunger that is blocked and remains in the upper barrel acting as an upper seal. The lower plunger is larger than the upper and as shown in the figure as the assembly is pulled upward the lower plunger brings in more water than the upper plunger can displace causing pressure to build up between them. At the top of stroke the compressed fluids are released within microseconds and a huge hydro-dynamic shockwave is released. The magnitude of the shockwave is on the order of 2 million watts of power. Running the pumping unit at 6 strokes/minute the formation receives one of these shockwaves each 10 seconds. The typical lifespan of a tool is around 8 to 10 months over which time at least 1 million shockwaves have been applied to their targets. The shockwaves travel at 1.5 miles per second and the amount of released water is less than 2 gallons, so there is no way the wave have sufficient time or mass to damage casing/cement bond integrity, move fines, fracture rock, or otherwise cause harm to the wellbore/formation system. So, how do the shockwaves move oil?

The mechanisms by which the shockwaves released by the tool result in enhancing oil recovery and increasing oil production are depicted in a series of steps in **Figure 3**. Step 1 is the mobilization of the immobile oil contained in the bypassed areas of the reservoir. The mobilization occurs by coalescence of thin oil films into larger mobile droplets and dislodging oil. The process does not reduce irreducible oil saturation. Los Alamos studies in cores found that a pressure disturbance of as little as 0.01 psi will dislodge oil droplets, considering our high energy elastic waves passing through the formation at 3,500 psi it is no wonder why seismic stimulation dislodges oil droplets. Another result of passing high energy elastic waves through porous media is increase in fluid flow, ie, increase in permeability which is depicted by Step 2. As a result water can now flow through these newly opened channels carrying mobilized oil droplets. In Step 3 these channels are shown as semi-permanent, which we have found to be the case in many fields and benefits will continue for as long as mobilized oil is available to production. However, eventually the field will return to its pre-stimulation decline profile so it is advised to continue application of seismic stimulation for as long as the economics warrant rental of the tools.

AGE OF FIELD

Often the question arises as to the application of seismic stimulation to new fields rather than to fields in the twilight of their productive lifespan. For instance, an increase of 20 % in fields with oilcuts of 90 % or greater would only result in a 2 % increase in oilcut; however, increases to overall fluid (oil) production of 20 % could be expected and in this case, beneficial. In **Figure 4** a low oilcut well, averaging 9 % oilcut undergoing seismic stimulation increases oilcut to 92 %, and oil production rises from 5 to and 40 Bbls/D. **Figure 5** shows a high oilcut well, one averaging 70 % that increases to 91 % during seismic stimulation, oil production rises from 65 to 102 Bbls/D.

PERMIAN BASIN STIMULATIONS

Since the late 1990's ASR has performed several stimulations of carbonate fields in Texas. What we have found is these low permeability formations take several months to respond and the response can be characterized of a true change in slope of the oilcut and oil production curves, contrasted to the drastic "jump" in oilcut and oil production that we observe in high permeability sandstone formations. In **Figure 6** the oilcut curve and in **Figure 7** the oil production curve both have noted changes in slopes due to seismic stimulation. One attribute of carbonate stimulation is the distances over which the seismic shockwaves travel; ASR has measured responses from its stimulation in wells as far away from the source as 1 mile, so coverage in these types of fields is excellent.

MULTI-WELL STIMULATION

As noted in the introduction, seismic stimulation is a not a single well stimulation but a field-wide, multi-well enhanced oil recovery stimulation. In one field, a diatomite, we took a close look at 23 wells with test data which allowed historical declines to be constructed. For the most part the response of each well was good and **Figure 8** shows the spatial distribution of the studied wells.

EFFECTIVE STIMULATION RADIUS

Typically, we tell clients that the seismic stimulation covers at least ½ mile in all directions, including vertical. In most fields this extends horizontally to ¾ mile radius or greater. Factors governing the distance covered are of course faults, lithological changes, and gas contacts/content. Lawrence Berkeley did measurements in sandstone and diatomite fields using hydrophones and vertical/horizontal geophones. In a sandstone field containing numerous fault blocks between the source and the measurement instruments, the signals created by our tool were easily measurable at ¾ mile, as shown in **Figure 9**.

LONG-TERM BENEFITS

In nearly all fields we have stimulated the benefits from seismic stimulation tend to last long after the stimulation has ceased. In the next three graphs the benefits to sandstone, **Figure 10**, diatomite, **Figure 11**, and carbonate, **Figure 12** are illustrated. As noted previously no stimulation is permanent and at some point, once the newly dislodged oil is fully swept the reservoir will return to its original decline, hence, it is always better to continue seismic stimulation as long as rental of the tool(s) is justifiable.

DAMAGE TO THE PUMPING UNIT

The final figure, **Figure 13**, shows a typical dynocard for a well that is being used as the seismic source. The dynocard might seem quite unusual but close inspection of the downstroke showing the hanging rod weight and upstroke showing the gradual load increase due to compression of fluids in the chamber, begin to make sense of the shape. ASR uses monthly dynocard measurements to determine when surface adjustments to the polish rod setting need to be made and to monitor tool performance downhole. The tool does not cause damage to the pumping unit as the unit never goes through a zero load as shown in the figure.

SUMMARY

The main points of the ASR seismic stimulation can be summed up as:

- Simple installation: installs and runs like a tubing pump
- Broad application: installs on production, abandoned or injection wells
- Long lifespan: over eight months delivering in excess of 1 million shockwaves
- EOR: shockwaves dislodge oil that will otherwise sit there forever
- Wide coverage: a single tool covers at least a section and multiple horizons
- Effective: typical increases in oil production and oil cut range from 15 to 30 percent
- Low Cost: low initial and rental costs - the operator only provides rods, tubing, pumping unit, preparation of the wellbore, and wellhead items.
- Tax credits: in Texas the process qualifies for EOR credits for TOTAL field production undergoing seismic
- Field screening available: our computer model can ascertain whether or not seismic stimulation will benefit your field and if so, by how much – we do this at no charge.

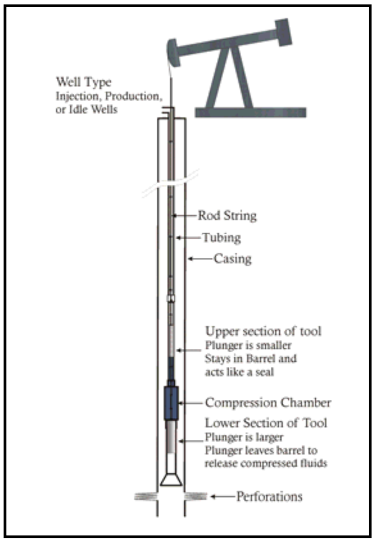


FIGURE 1 - TOOL INSTALLED INTO WELL

FIGURE 2 - OPERATION CYCLE

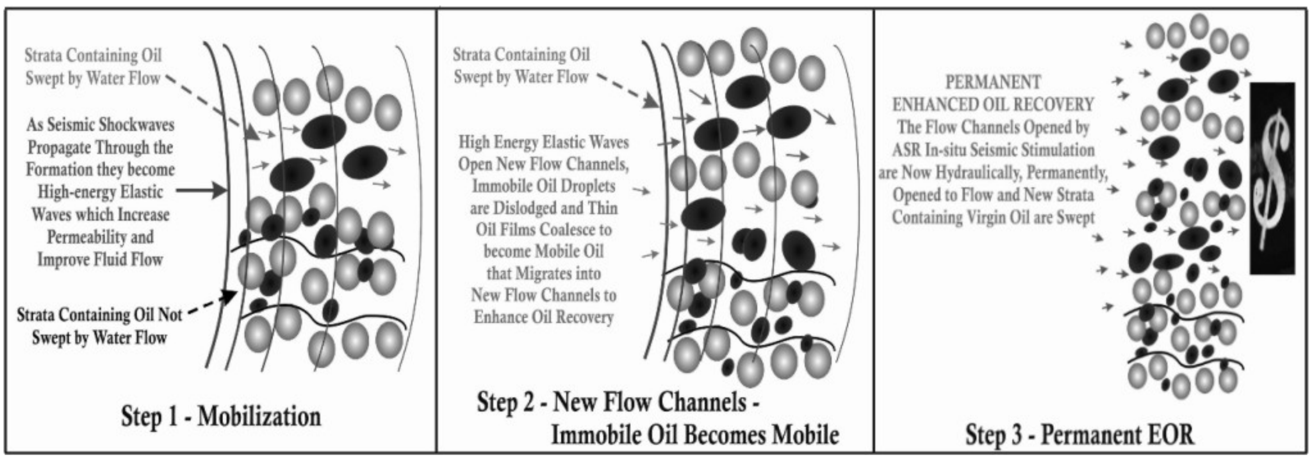


FIGURE 3 - MECHANISMS FOR ENHANCED OIL RECOVERY AND INCREASED OIL PRODUCTION

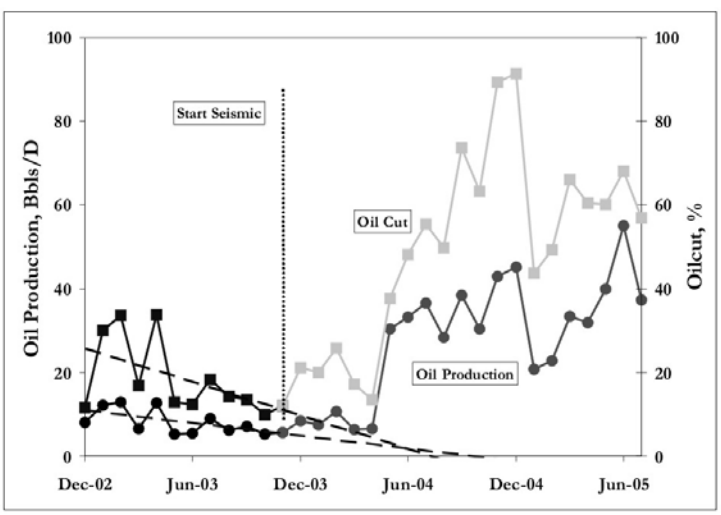


FIGURE 4 - LOW OILCUT WELL (9%) SANDSTONE SANDSTONE

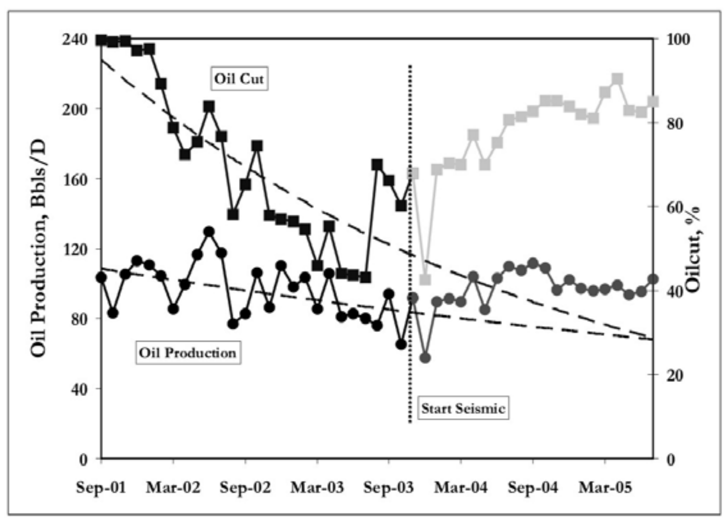


FIGURE 5 - HIGH OILCUT WELL (68%)

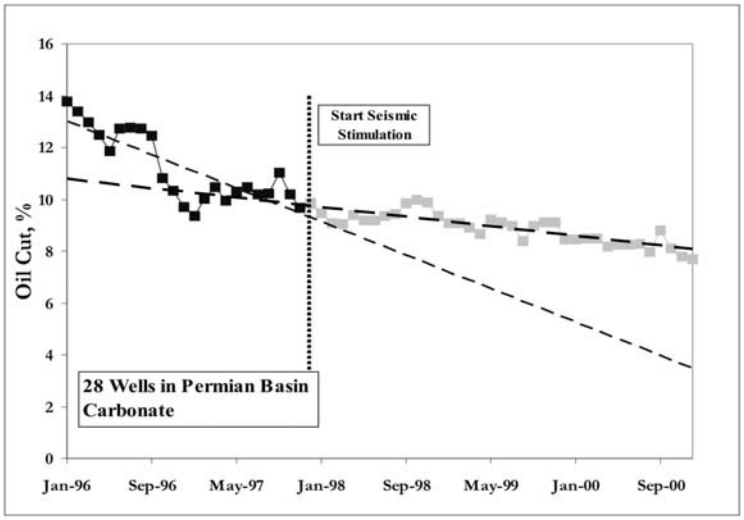


FIGURE 6 - PERMANENT EOR CARBONATE CARBONATE

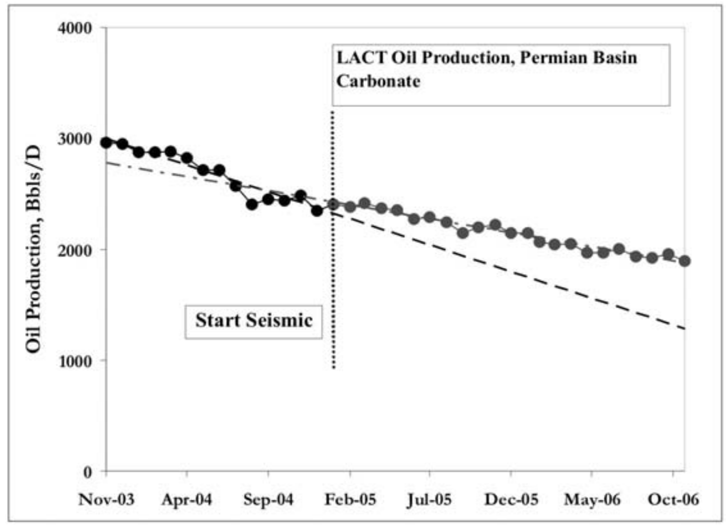


FIGURE 7 - INCREASED PRODUCTION

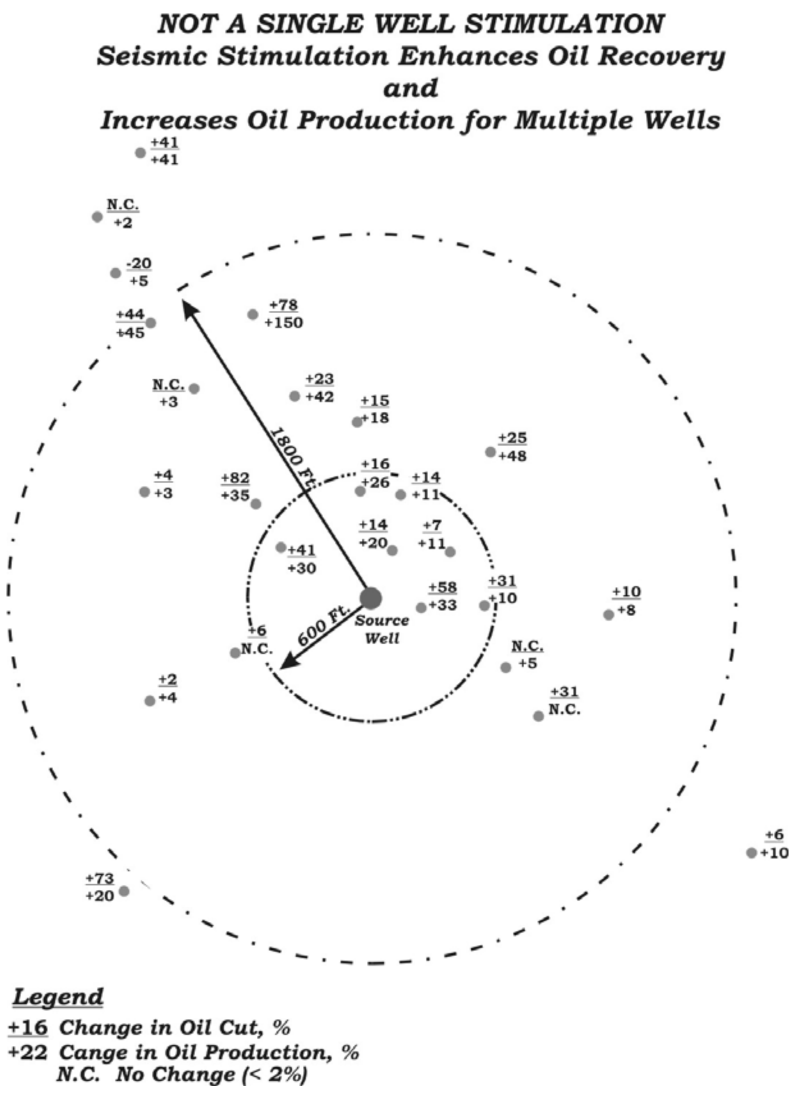


FIGURE 8 - MULTI-WELL STIMULATION

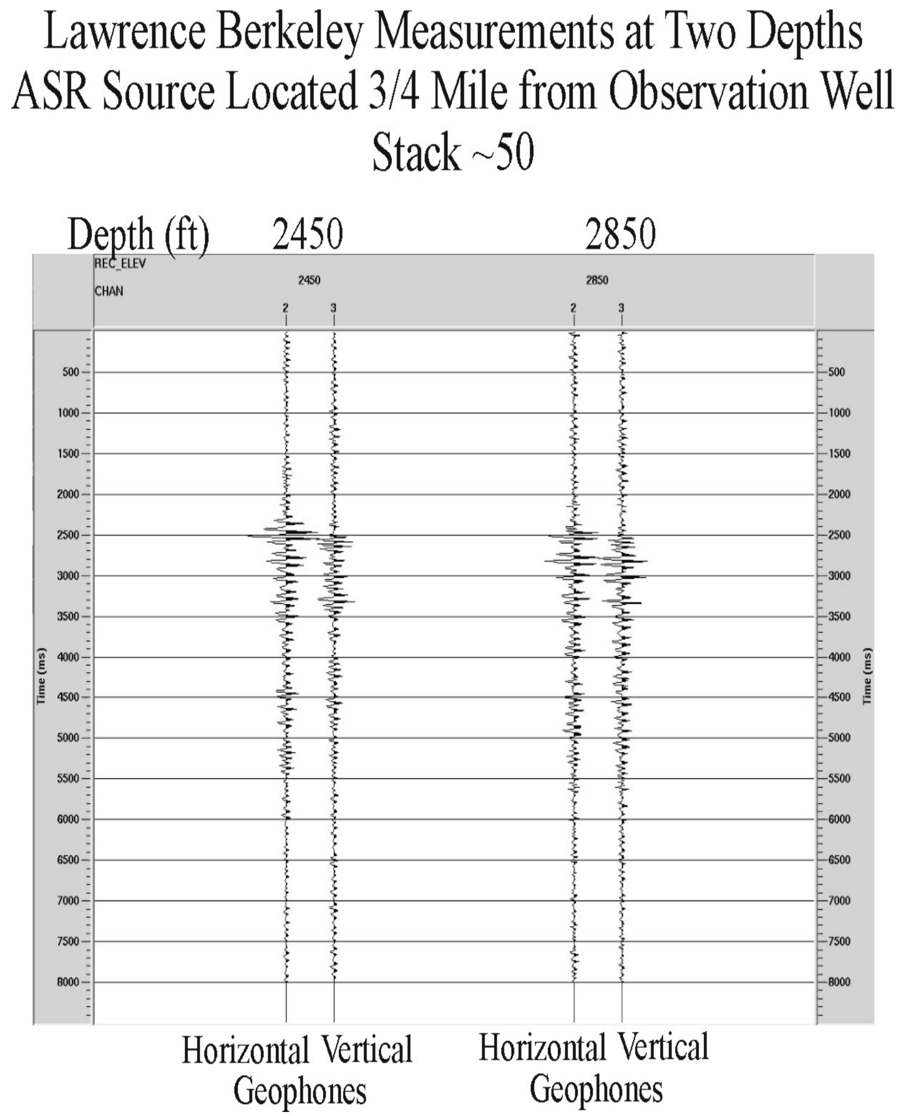
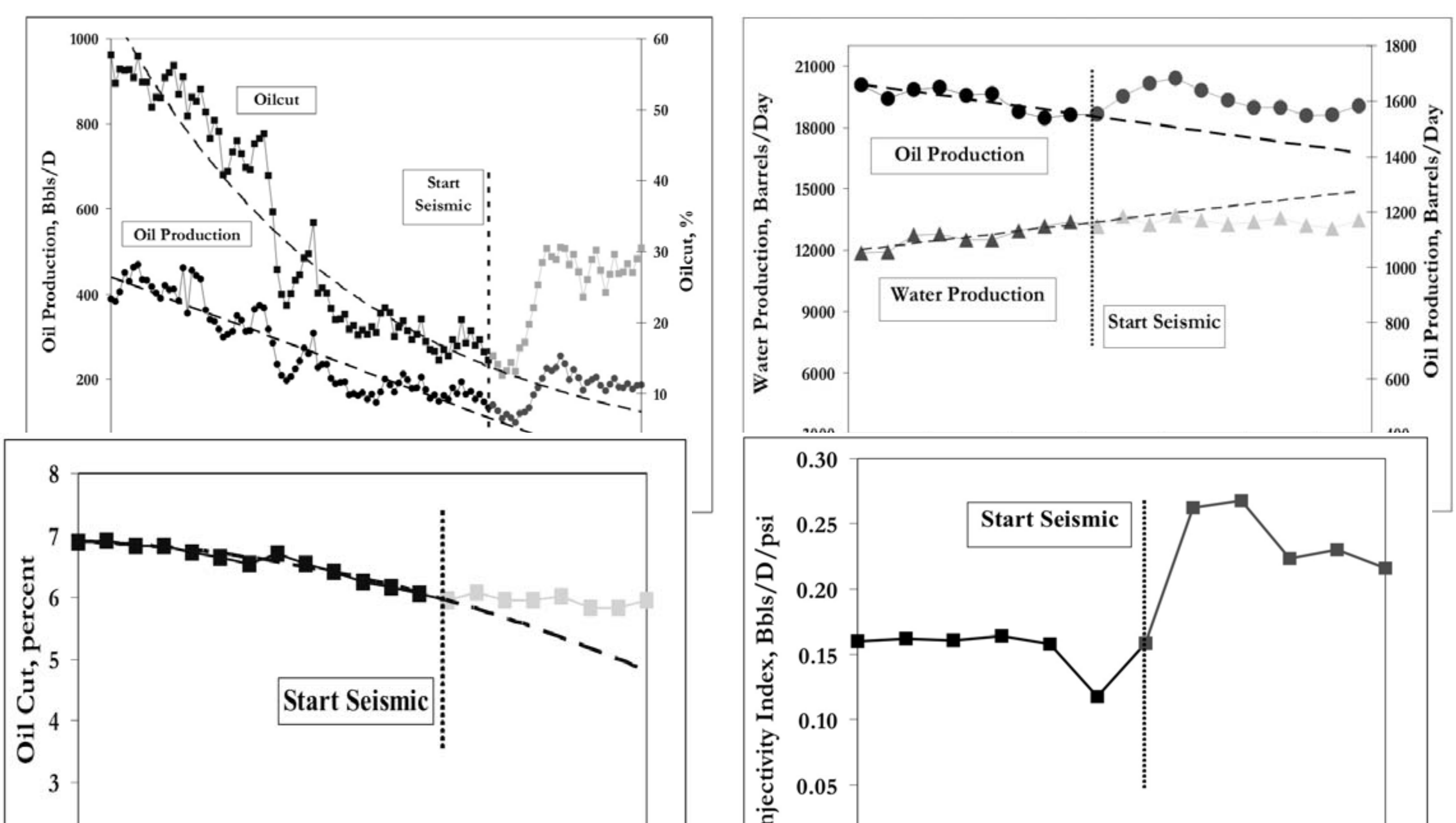


FIGURE 9 - SEISMIC CROSSES MULTIPLE FAULTS OVER LONG DISTANCES



(AND STABILIZED WATER PRODUCTION)

FIGURE 12 - LONG-TERM BENEFITS TO SANDSTONE

FIGURE 13 - LONG-TERM BENEFITS TO DIATOMITE

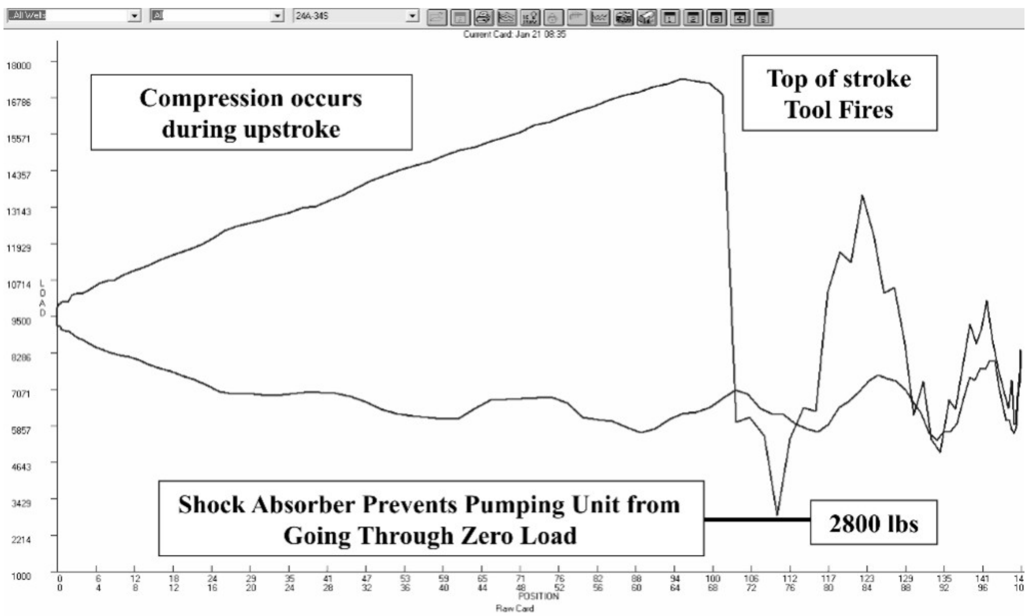


FIGURE 14 - PUMPING UNIT DYNOCARD