



## AADE 01-NC-HO-24

### Title: Subsidence Remediation – Extending Well Life Through the Use of Solid Expandable Casing Systems

Company: Enventure Global Technology, LLC

Presenting Author: Gerry Cales/ Chevron USA, Inc.

Co-authors: David Shepherd , Brad Wiest/ Chevron USA, Inc.,

Pat York, Chan Daigle, Larry Rose / Enventure Global Technology, LLC;  
and Mike Patterson / Jet Research Center

## Subsidence Remediation – Extending Well Life through the Use of Solid Expandable Casing Systems

### Abstract

Loss of wells and / or production due to significant casing damage caused by formation subsidence can be a costly problem, particularly in shallow high porosity reservoirs. Solid Expandable Tubular (SET) Cased-hole Liners (CHL) is one method being utilized to overcome damage to casing due to formation subsidence. The techniques developed for this remediation solution could also be used to repair casing in a number of other environments.

Subsidence has been reported in many fields throughout the world including the Ekofisk field in the Norwegian sector of the North Sea, the northern Adriatic, the Groningen gas field in the Netherlands, Lake Maracaibo in Venezuela and in several fields in both Long Beach and Bakersfield, California.<sup>1</sup> Subsidence can have dramatic consequences on production operations and eventually can completely shut down a producing well.

Subsidence is expected within and above a producing formation where the reservoir rock is weak and porous (Fig. 1). As the fluids are extracted from the reservoir the rock is compacted, and in a shallow reservoir, this compaction can alter the over-

burden and may even be observed on the surface (Fig. 2).

This paper discusses:

- Techniques developed to remediate wellbores that have been damaged due to subsidence
- Wellbore preparation
- Installation procedure of a Solid Expandable Tubular Cased-hole Liner System
- Challenges solved while attempting to expand the SET Cased-hole Liners downhole once the wellbore was prepared
- Final solutions customized to remediate these subsidence challenges.

### Introduction

The Lost Hills field consists of a massive (up to 1,000 ft thick), fairly soft, high porosity (up to 50%) diatomite in the shape of a plunging anticline (Fig. 1). This anticline is overlaid with a series of sands, silts and shales. There is no surface indication of the anticline in the Lost Hills field.

Production of oil and gas from this formation has caused surface subsidence of the field

of up to 20 feet in its center (Fig. 3). This process manifests itself as a bowl-shaped indentation dipping to the center of the field. Primary production is proportional to reservoir thickness; and as expected, waterflooding has greatly slowed, and in some areas arrested subsidence in Lost Hills.<sup>2</sup>

The mechanism that produced this "bowl" has caused two non-exclusive modes for casing failure. At the edges of the bowl, the overburden can slide on the soft clays toward the bowl center (Fig. 4a). This side-loading causes the casing to bend with the flow, thus creating a dogleg. Bending of the casing can happen at various depths in the same wellbore.

Near the center of the bowl (field), a different problem exists. The extensive compaction of the diatomite, over time, causes a shortening of the distance from the surface to the bottom of the well (Fig. 4b). As expected, the casing buckles, just as it would if the same length of casing was run into a shorter length hole.

The subsidence solution discussed here to remediate Lost Hills wells damaged by subsidence, is an expandable cased-hole liner (CHL) system.

Although this remediation technique will not prevent further damage to the casing, it will lengthen the useful life and profitability of the well. The refurbished wellbore is expected to produce at least as long as the initial wellbore did and with sufficient waterflood support, longer still.

### **Well Candidate Selection**

There were three wells selected for an initial pilot program at Lost Hills. Each was capable of producing 35-40 bbls/day. However, the degree of wellbore damage caused by subsidence had dictated that all three wells be classified as "plug and abandon" candidates.

The wells selected for the pilot program will be referred to as Well A, Well B and Well C. (Figure 5 depicts Wells A and C. Well B was not remediated.) The casing in Well A was 7-inch 29 ppf, that in Well B was 7-inch 23 ppf and the casing in Well C was 5-1/2 inch 15.5 ppf. The dogleg had become so severe

in each of the wells that the effective inside diameter (ID) of the casing no longer allowed tubing and rods to operate in the boreholes. The three abandonment candidates would require replacement to recover the remaining reserves attributable to that portion of the field.

### **Wellbore Preparation**

The approach taken to remediate these Lost Hills candidates was to divide each operation into two phases. The first phase entailed preparing the well for the CHL system — that is, opening the wellbore enough to run the system. The second phase of the operation was to run and set the expandable cased-hole liner.

Wellbore preparation is critical to the success of using expandable CHL systems to remediate subsidence-damaged wells. The casing immediately above and below the damaged wellbore section(s) must be round and within dimensional tolerance of the setting range for the CHL. Any debris in the wellbore either must be removed and / or "ballooned out" through plastic deformation. Therefore, damaged casing also must be removed or "altered", and the wellbore properly cleaned using high-rate wellbore "sweeps", while circulating debris and running wireline junk baskets.

For Phase One, *wellbore preparation*, two methodologies were evaluated to remove the damaged wellbore casing and halt the encroaching formation so that CHL(s) could be installed.

### **Removal of Damaged Casing**

The first wellbore preparation method utilized a tri-blade mill developed specifically for the removal of subsidence damaged casing. Once the casing was removed, a "lace" collar was run to ensure a straight, full-gauge hole. The second method of removing damaged casing employed the Engineered System for Casing Preparation with Explosives (ESCaPE). This system plastically deformed and explosively expanded, or removed, the damaged casing and "pushed back" the subsided formation that had encroached on the cased borehole.

Because this method was perceived to be untried technology, the first two wells (A and B), were prepared utilizing the tri-blade

milling procedure. Well A was prepped, then the "best practices" learned during the tri-blade milling process on Well A were applied to preparing Well B. However, during milling operations on Well B, the milling assembly exited the milled section and the wellbore was lost.

The ESCaPE system had been reserved for the third well, Well C, whose wellbore had been deemed beyond repair.

### **Subsidence Milling Solution**

Severe doglegs created by the lateral shearing of layers in the formation and overburden are extremely difficult to mill. This is due to the bending moment caused by lateral displacement of the mill as it attempts to follow the offset casing, creating a cyclic loading that fatigues the metal very quickly. Milling had to be conducted at a slow rate to avoid failures, resulting in a job time that was far too excessive to be economic.

Two different milling procedures were attempted in Lost Hills - one using an articulated reamer (Fig. 6) and the other with a tri-blade mill (Fig. 7a). The articulated reamer comprised a tapered mill with articulated collars hung below it to provide weight to pull the mill through the dogleg while rotating, keeping the mill inside the casing. The articulated reamer had been used with moderate success on two wells with mild doglegs (< 6 degrees) – however, milling time and resulting costs were too high to be economic.

**Tri-blade theory and use.** The tri-blade milling process proved to be the most promising (Fig. 7a). This mill is similar to a section mill with three blades that cut on both the side and the bottom. Its overall length is less than 6 feet, so lateral bending is minimized. A 30-ft long stinger is run below the mill to ensure it remains inside the casing as it cuts. Two "laced" collars (30 ft in length) [Fig. 7b] are then used to bring the milled section back to its original casing diameter and to "smooth" the cuts made with the tri-blade.

The tri-blade milling method also had been used successfully in two wells but costs were high. The Tri-blade milled through the dogleg quickly while the "laced" collars were much slower - the primary cause for this was

thought to be the high wear on the Tri-blade blades creating more work for the "laced" collars than their design could tolerate. The tri-blade mill was successfully tested in 7-inch casing. The mill shifted the casing's full diameter within five feet, which is more severe than the majority of well failures in Lost Hills.

### **Engineered Explosive Solution**

**Explosives theory and use.** The ESCaPE system utilizes specific engineered explosive material housed within a pliable flexible housing (Fig. 8). The system is customized by the type and length of explosive material used to create the specific energy needed to either re-form or remove the casing damaged by formation subsidence.

It was decided to use the ESCaPE system to remove the damaged casing and to "push back" the encroaching formation in the third Lost Hills well, Well C.

There are several key criteria to consider in determining the appropriate explosive system and charge design necessary to provide the optimum impulse loading of the casing steel:

- cost
- low debris
- maximum assembly flexibility:
  - a) delivery system must be flexible enough to pass through tight restrictions and conform to deviations of the casing doglegs
  - b) wide variety of delivery housing ODs to adjust as necessary since true ID and deviation of dogleg is unknown
- maximum dogleg expansion – an explosive that provides maximum plastic deformation of steel and ensures sufficient re-sizing of casing in the dogleg
- minimize wireline assembly lengths.

Components of the explosive system include:

1. a range of flexible nylon/rubber hoses to provide containment and durability to deliver explosive to target area
2. special blend of liquid explosive for maximum burn rate and detonation pressures to achieve maximum impulse-loading for given OD

3. high output booster/initiation assembly to maximize full yield of explosive
4. aluminum bull plug with special seal to contain non-viscous explosive material
5. aluminum fill-neck to facilitate pouring liquid explosive at wellsite.

**Casing removal process.** In Well C, the charge was run in on electric wireline, using the wireline depth meter and weight indicator to position the charge. Once in position, an electrical impulse was used to detonate the charge.

The first wireline run with the charge was not successful. Several key lessons were learned:

- Initially the well was filled with water, as the charge was designed to be suspended in well fluid. Although the water tanker was pulled back to a safe distance, the well was taking fluid more rapidly than expected, causing the charge to be unsupported in the well while being filled. The additional weight on the bull plug seal may also have caused a leakage of explosive liquid through the seals.
- With no "feel" for the weight of the assembly being run, the wireline speed was too fast, which was thought to have caused fluid loss through the top of the filler tube. Being flexible, the assembly would collapse when "set down" and fluid would flow from the top of the filler neck.
- Fluid loss caused an unsuccessful initial detonation.

**Lessons learned.** The following modifications were made in the running procedures during the second wireline run, and proved successful.

- A continuous water flow ensured the well was kept full of fluid
- Lowering of the charge was kept under 50 ft/min, "yo-yoing" was eliminated
- A special vented plug was used in the filler-tube assembly to ensure no explosive fluid was lost. Bull plug was modified to improve the bottom seal.

## Remediation - Bridging Damaged Casing

Once the casing has been removed or "ballooned" and the subsided formations either

removed or "impinged" (pushed back), the expandable casing was positioned in the prepared wellbore and expanded across the damaged casing, sealing it against the ID of the undamaged cased wellbore (Fig. 9).

### **Installing the CHL**

Figure 10 illustrates the steps required to install an expandable cased-hole liner system. First the CHL launcher is run and the system hung off in the slips. (The CHL launcher contains the expansion cone and mandrel, as well as the casing that is to be expanded.) The workstring is then run inside the expandable CHL system and latched onto the top of the expansion cone. Next, the entire assembly is run into the wellbore, supported by the workstring.

The CHL system is then positioned across the prepared area of the wellbore damaged by subsidence. The surface pumping unit increases hydraulic pressure down the workstring, through the expansion cone and into the pressure chamber area. When the pressure inside the pressure chamber (across the expansion-cone / expandable-casing interface) reaches the required mechanical force, the casing begins to extrude over the expansion cone.

**Note:** The mechanism that extrudes the expandable casing downhole can be compared to that of tearing off the end of a paper-wrapping around a soda straw and then blowing the paper off the straw...the paper is being "extruded" off the straw as the pipe is extruded over the expansion cone downhole.

The expandable casing moves over the expansion cone and down the well until it expands the first elastomer sealing element (about 1 foot). Once the sealing element is compressed between the expandable casing and wellbore casing, a seal is made and the CHL is hydraulically and mechanically sealed to the wellbore casing wall.<sup>3</sup>

When the expansion process nears the top of the CHL, another set of elastomer seals are encountered and an additional hydraulic and mechanical seal is formed, cladding the two tubulars together. The elastomer serves a dual purpose. First, it fills the voids caused by ovality problems or workstring

wear. Secondly, the elastomer improves the mechanical and hydraulic integrity of the damaged casing. Typically, this seal forms a mechanical connection with a pullout strength of 500,000 ppf of clad pipe.

The CHL forms a "sealed bridge" across the damaged area with expandable casing that has physical properties similar to those of L80 grade conventional casing. Because the ID of the remediated casing is only reduced by about two times the thickness of the expanded casing and the compressed elastomer (typically 0.125 in.), there is minimal inside diameter restriction through the remediated area. Also, since the repair has been made using casing with mechanical properties similar to those of conventional casing, the area of expanded casing enhancement and below can be "worked through" without fear of damaging the expanded casing.<sup>4</sup>

### **Lessons Learned During Engineered Explosive Solutions**

- Each subsidence well presents unique characteristics, and therefore requires special adaptations based on the specific well conditions observed.
- The explosive assemblies must be capable of being adjusted "on the spot", be provided in a variety of lengths, outside diameters and explosive "loadings" for various casing sizes.
- Ideally, using a minimum explosive impulse loading to achieve plastic deformation that yields no separation in the casing, more reliably ensures the workstring remains inside the wellbore.
- Some well deformations may require more than one charge or type of charge to remedy the dogleg severity.

### **Challenges Solved During Expansion Operations**

When casing was removed or extensively plastically-deformed, such as is done during the well preparation for subsidence remediation, certain operational precautions must become part of the operational processes.

One of these precautions necessitated protection of the expandable CHL in a well with potential protrusions or sharp edges, or

possibly in a well that requires significant milling. If the casing is damaged while being run in-the-hole or during expansion, the potential of splitting the casing during expansion exists. Protection could either be provided in the form of "standoff" of the expandable casing while running it in the well, or of a protective coating placed on the OD of the expandable CHL.

In Well A, for instance, once the damaged casing was milled out, a casing centralizer arm was partially exposed, protruding into the wellbore. When the CHL was run in, the sharp end of the tempered steel centralizer arm severely damaged the expandable casing connection. This reduced the expansion pressure, halting the expansion process.

The casing was then cut just below the transition face, above the damaged base casing. The unexpanded casing and the expansion face were removed from the well. After retrieving the upper portion of the casing, the expansion cone was retrieved, allowing repair of the well to proceed. The second CHL system was then run in and placed on the top of the first CHL (Fig. 11).

Another enhancement to the CHL system is the use of a standard float shoe (Fig. 12) on the bottom of the launcher. The float shoe allows circulation and / or annular control through the CHL while running in the hole and before removal of the debris and "flowing formation" from the backside of the liner, prior to expansion. When running the second cased-hole liner in Well B, this aforementioned system enhancement would have allowed the removal of a bridge created by the diatomite formation flowing into the wellbore from the opening where the casing had been removed. This formation bridge, formed between the CHL and wellbore casing, presented problems during expansion of the second system (Fig. 13a).

The unexpanded casing and the expansion face were removed from the well (Fig. 13b). Then both the upper section of the casing and the expansion assembly were retrieved, freeing the wellbore so the repair could be finished.

The repair was completed with a third, specially-designed CHL that incorporated a 6-in. diameter "mule shoe" extension below the CHL (Fig. 14). Once this "special" CHL was installed, the mule shoe was inserted into the second CHL installation, and the "special" CHL was expanded, bridging across the subsided area of the wellbore that had been removed. Figure 15 depicts the CHL installation originally planned for Well A.

### Results of the Operations

Well A was remediated using the expandable cased-hole liner and put back on line. It is currently producing at the same level that it did before subsidence caused the well to fail.

Well B was lost due to the mill exiting through the window that had been cut to remediate the well.

During the CHL installation in Well C, the liner was initially anchored below the casing "pushed back" with the ESCaPE explosive. However, the base casing was damaged / altered sufficiently so that the expandable liner did not hold and the liner was pulled up the hole and set off-depth. The top elastomer seals on the CHL in Well C were milled off and the system was "pushed" approximately 8 feet down the wellbore. However, about a 12-foot "gap" still remains between the bottom of the expanded CHL and the top of the 5-1/2" base casing. There may be further attempts to push the CHL down the wellbore in order to reconnect the CHL to the base casing below the removed casing.

### Conclusions

Successful implementation of SET Cased-hole Liner Systems can extend the life of Lost Hills wells. Economic production from the Lost Hills field depends upon very large hydraulic fractures (1.3 MM pounds), which also contribute to over half the cost of the wells. Repair of the wellbore allows continued access to this thin fracture

system. Many of the wells that fail in Lost Hills due to subsidence leave significant reserves undepleted. The current practice is to replace the failed wells.

The Engineered Explosive Assembly appears to be a viable, more economic method of clearing a path through the dogleg for installation of a SET system. The use of mills, while successful, is slow and therefore costly, calling into question the economics of well repair.

### References

1. "SINTEF project sheds light on mechanics of reservoir subsidence", *Offshore*, April 2000, pp. 187-188.
2. Morris, C.W. and Mitzel, D.P., Schlumberger Wireline & Testing; Gwinn, R.L., Aera Energy; Rambow, F.H.K., Shell E&P Technology, "Ultrasonic measurements monitor casing offset damage", *World Oil*, July 1999.
3. Daigle, C., et al, "Expandable Tubulars: Field Examples of Application in Well Construction and Remediation", SPE 62958 at 2000 SPE Annual Technical Conference, Dallas, 2-4 October.
4. Mack, R., Shell E&P Technology; McCoy, T., Halliburton Energy Services; Ring, L., Enventure Global Technology; "How in-situ expansion affects casing and tubing properties", *World Oil*, July 1999, pp.69-71.
5. Addis, M.A., Choi, X and Gunning, J. (1998) "The influence of the reservoir stress-depletion response on the lifetime considerations of well completion design", *Eurock '98*, Vol. 1, Proceedings SPE/ISRM, Rock Mechanics in Petroleum Engineering, pp. 443-441.
6. Germanovich, L. N., Chanpura, R.A. and Ring, L.M., (1999) "Fault Slip and Seismicity Induced by Subsurface Fluid Withdrawal", Proceedings of the 37<sup>th</sup> U.S. Rock Mechanics Symposium, B. Amadei, et al (eds), Balkema, Rotterdam, pp.1145-1154.

**Figures:**

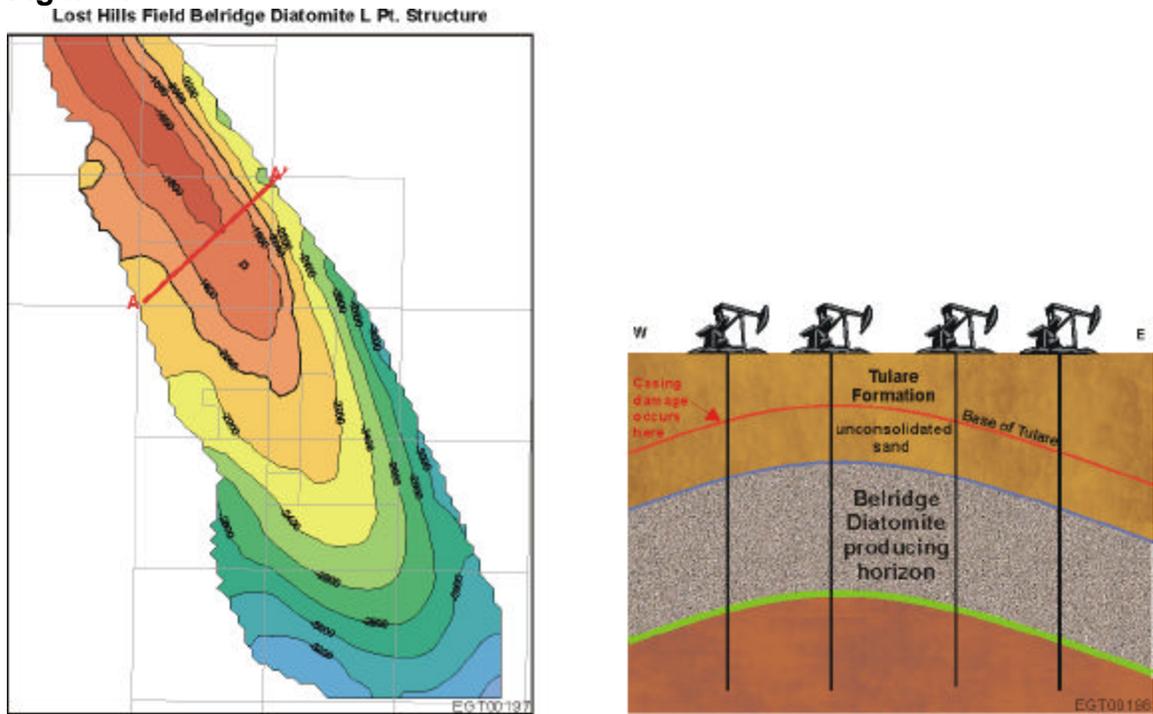


Figure 1 - Lost Hills field Belridge diatomite structure



Figure 2 - Photo showing the results on the surface of compaction as fluids are extracted.

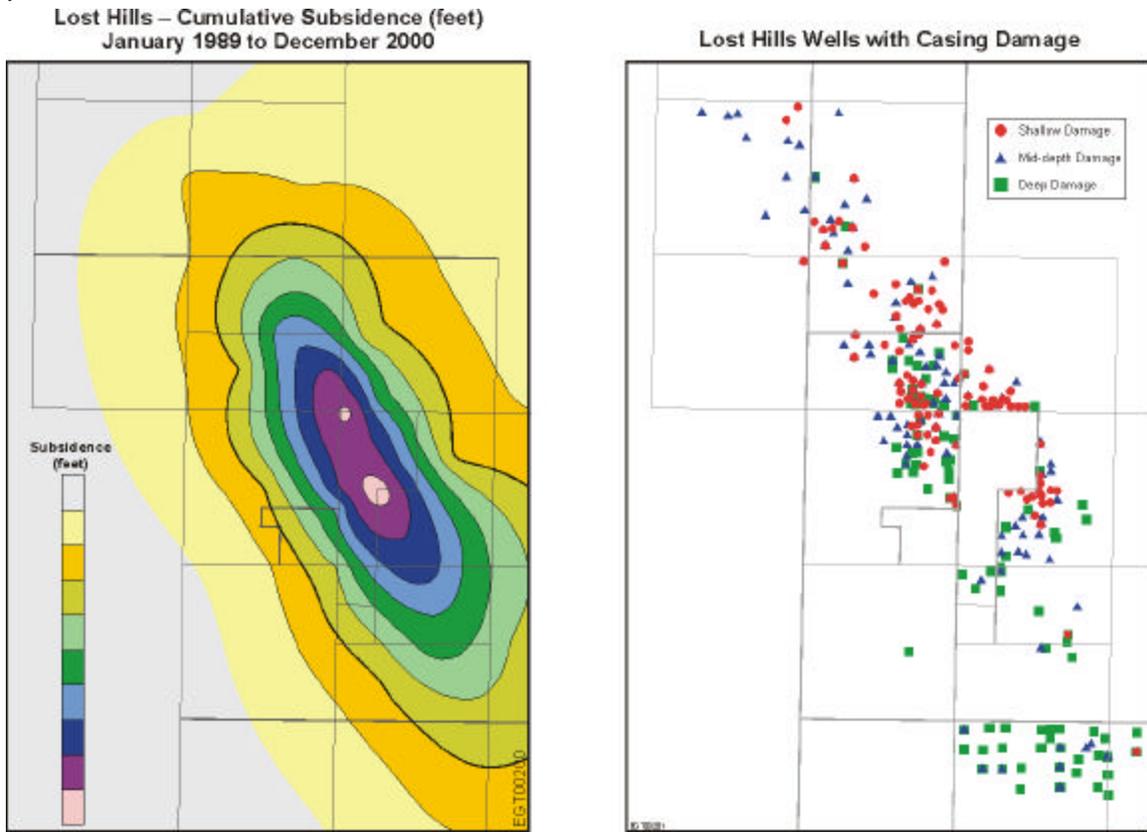


Figure 3 - Diagrams of Lost Hills field illustrate: (left) production from the formation has caused surface subsidence in the center up to 20 ft and (right) the variety of casing damage caused by subsidence throughout the field

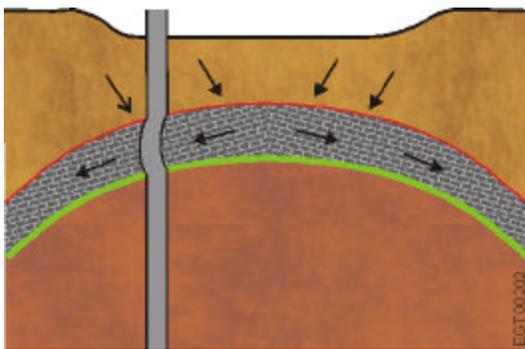


Figure 4a - Subsidence evidenced in well damage due to side-loading of casing

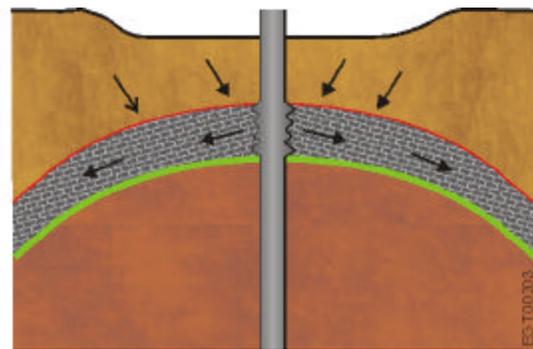


Figure 4b - Extensive compaction near "bowl" center causes shortening of the distance from surface to bottom of the well, buckling the pipe

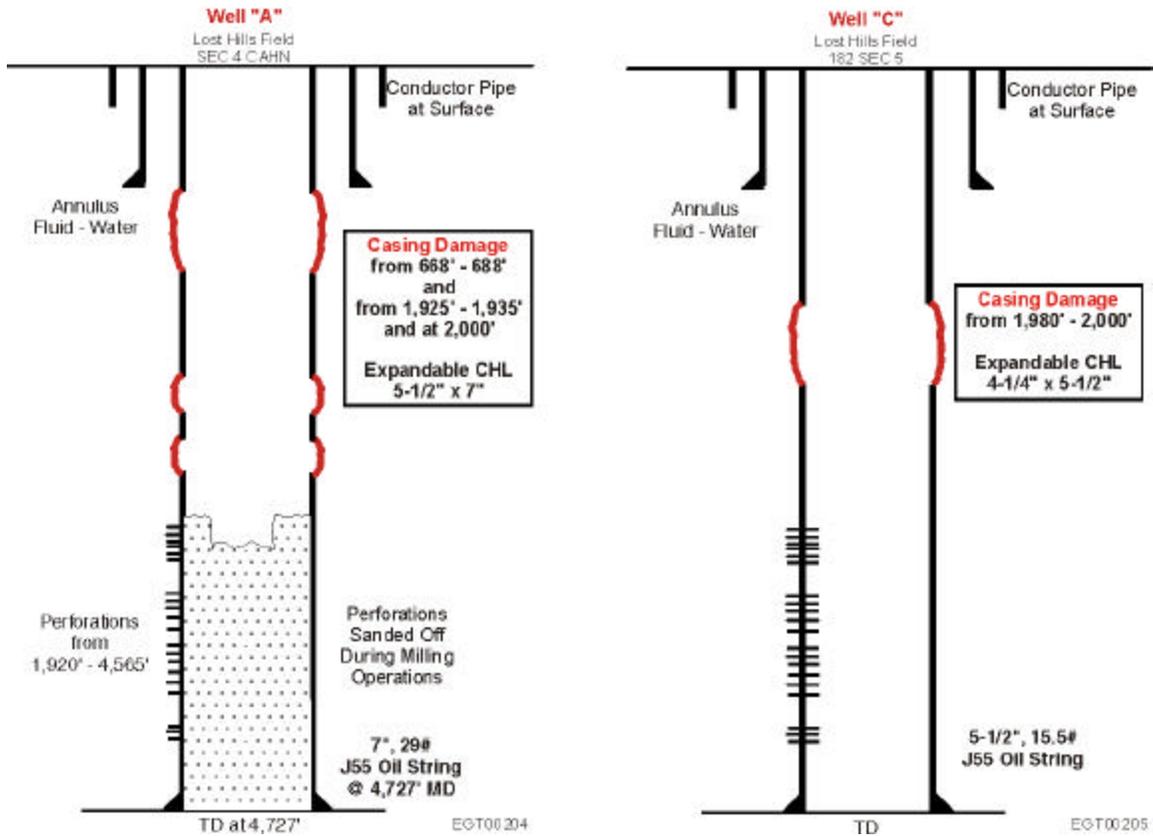


Figure 5 - Wellbore schematics of Well A and Well C



Figure 6 - Articulated reamer



Figure 7a - Tri-blade mill



Figure 7b - "Lace" collars



Figure 8 - The ESCaPE system is pictured at far right. One of the key components is the pliable flexible housing, shown onsite.

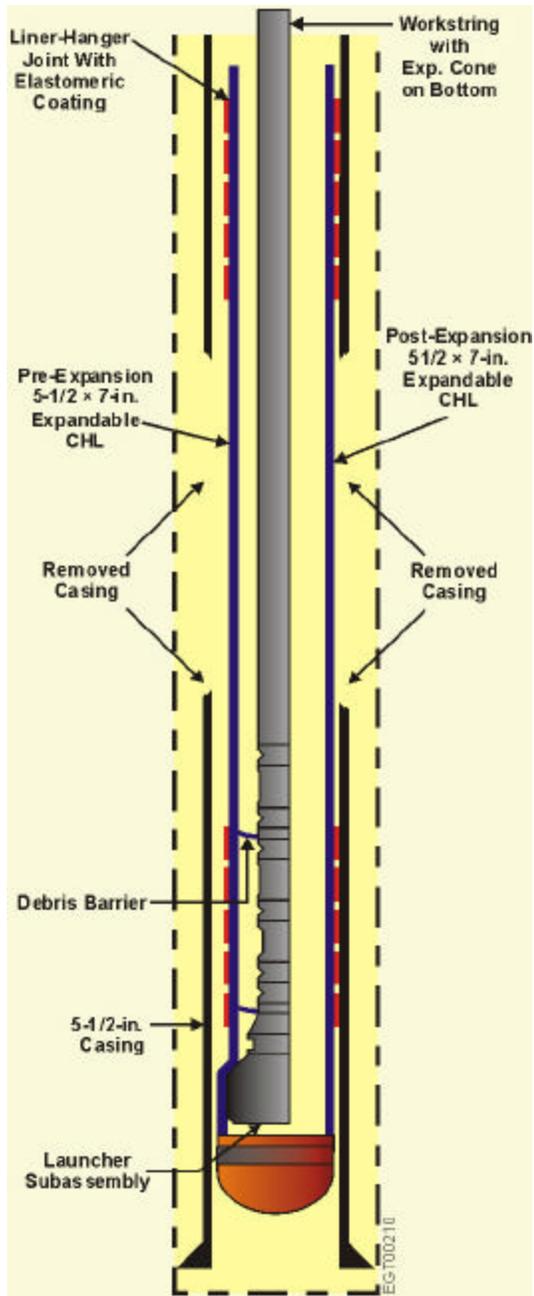


Figure 9 - Schematic of 5-1/2" X 7"  
Expandable Cased-Hole Liner System

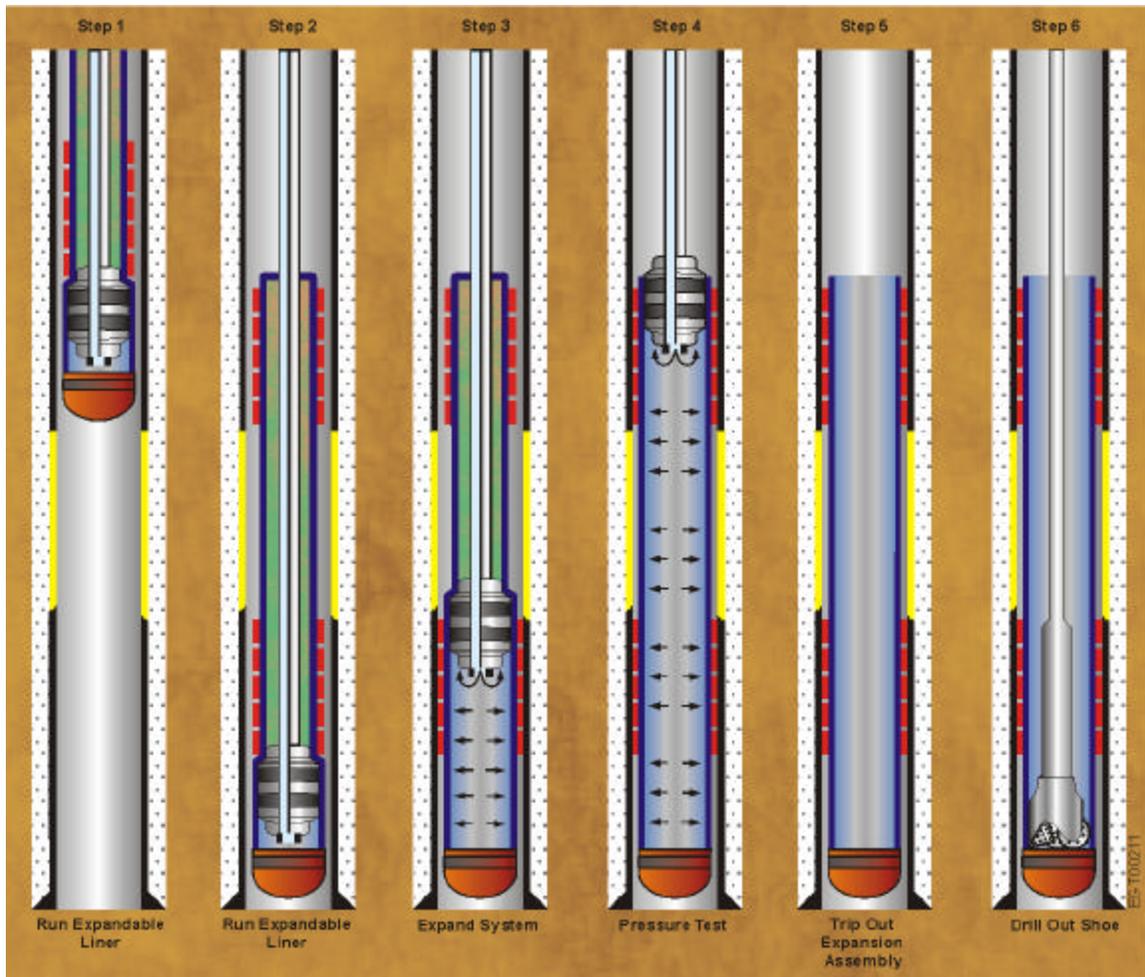


Figure 10 - Installation sequence for Expandable Cased-hole Liner System

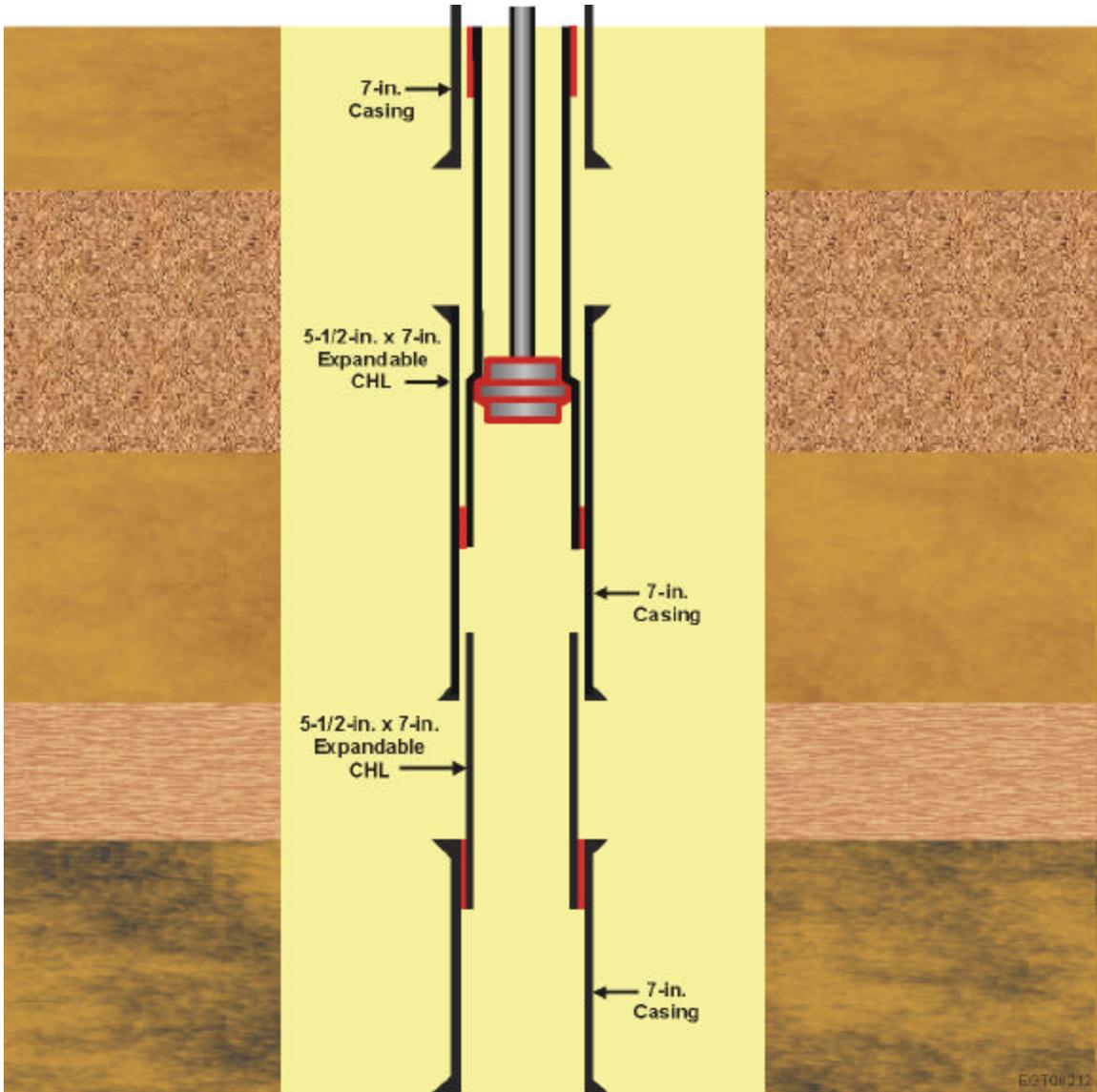


Figure 11 - Second CHL installation in Well A

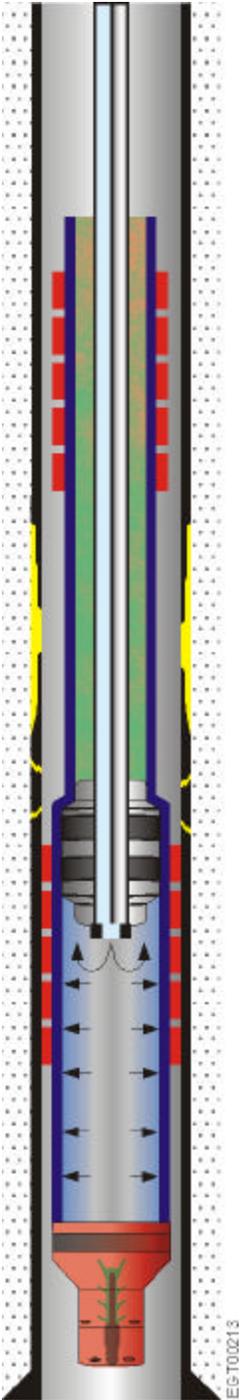


Figure 12 - Expandable CHL  
system using standard float shoe

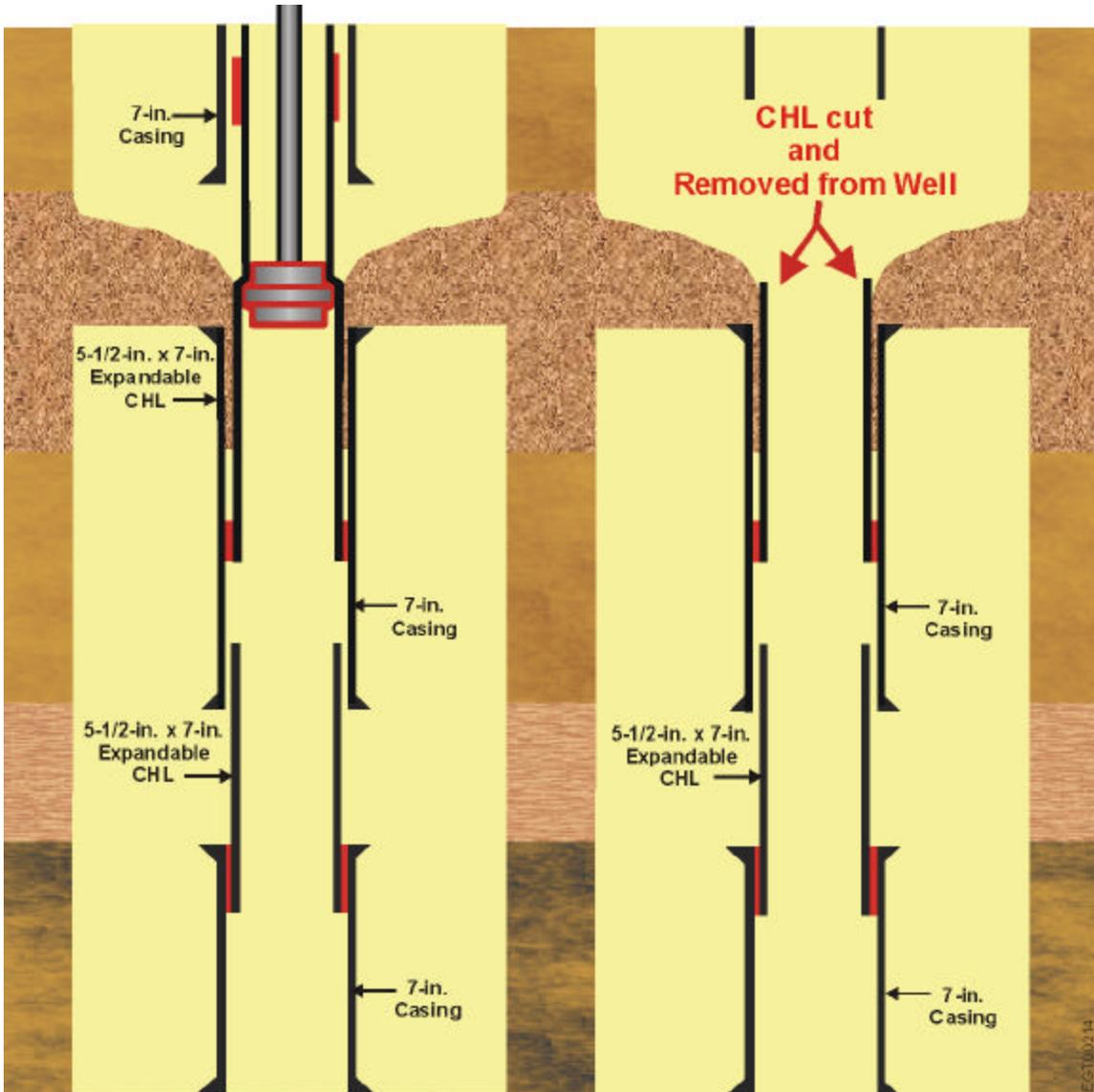


Figure 13a – Diatomite formation flow shown in Well A schematic

Figure 13b - Unexpanded casing and expansion face removed from Well A

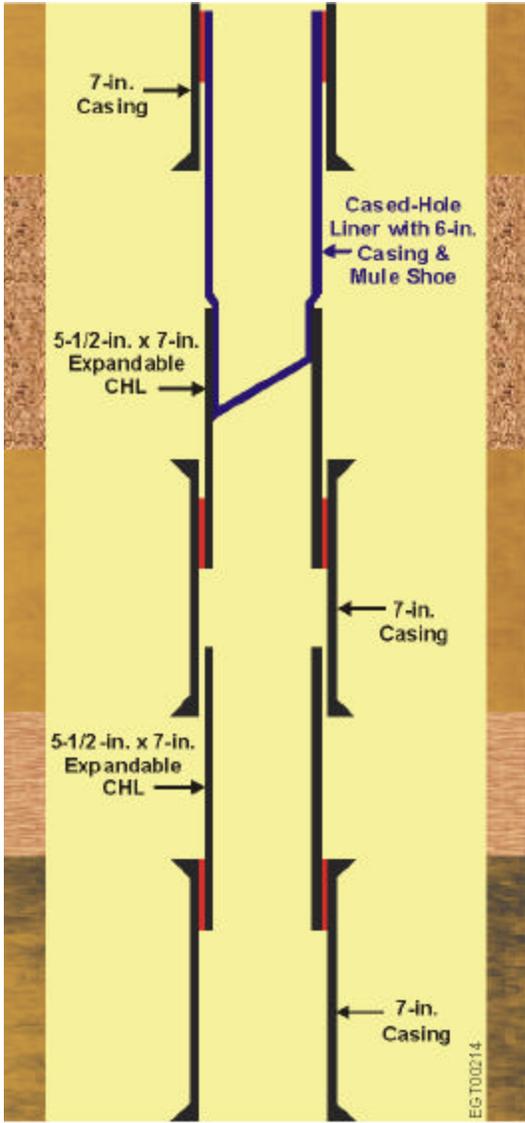


Figure 14 - Customized CHL with mule shoe installed in Well A

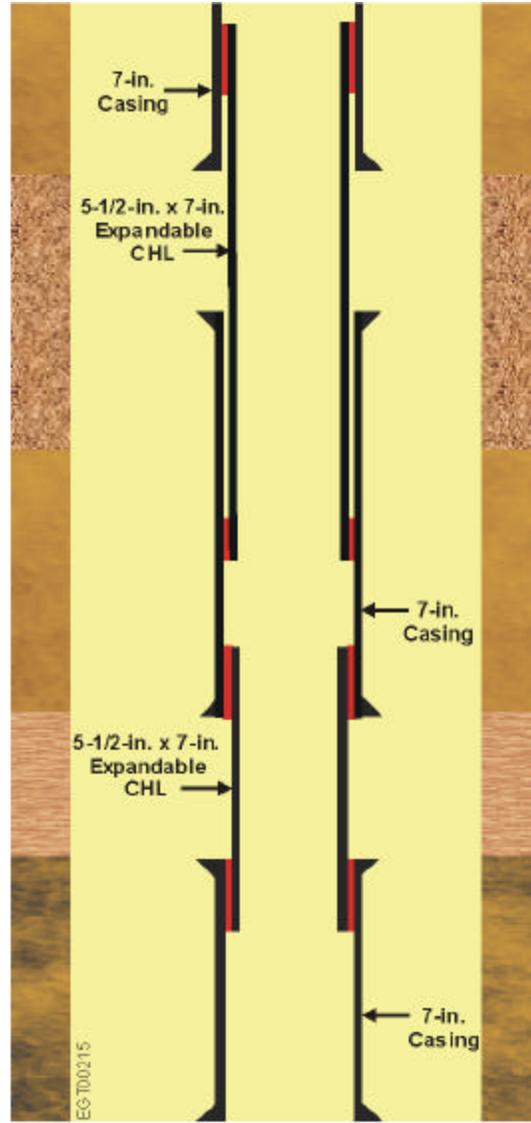


Figure 15 - Originally planned CHL installation for Well A

This paper was prepared for presentation at the 2001 National AADE Technical Conference held at the Omni Hotel, Katy Freeway, Houston, Texas, March 27-29, 2001. The information presented in this paper does not reflect any position, claim, or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individuals listed as author/s of this work.