

EFFECTIVE RESERVOIR DEVELOPMENT USING ULTRA SHORT RADIUS DRILLING AND COMPLETION

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April 2008

INTRODUCTION

During the past two decades, the oil and gas industry has witnessed a steady increase in the use of horizontal drilling to enhance well productivity. This trend will no doubt continue well into the 21st century as operators become increasingly aware of the benefits associated with drilling horizontally. As the database of horizontal projects has grown, operators have developed a better understanding of how and where horizontal wells should be utilized and which technology is best for a given application.

Economics will, in most cases, dictate the technology to be used. The implementation of laterals in mature fields requires substantial cost reductions over the methods most often used for drilling horizontal wells. Initiating a lateral from an existing wellbore is often much more cost effective than drilling a new well to kickoff point. Because of this, the use of Ultra-Short Radius (USR) Drilling and Completion technology to re-activate and rejuvenate existing fields is being widely regarded as a viable technology for Brownfield development.

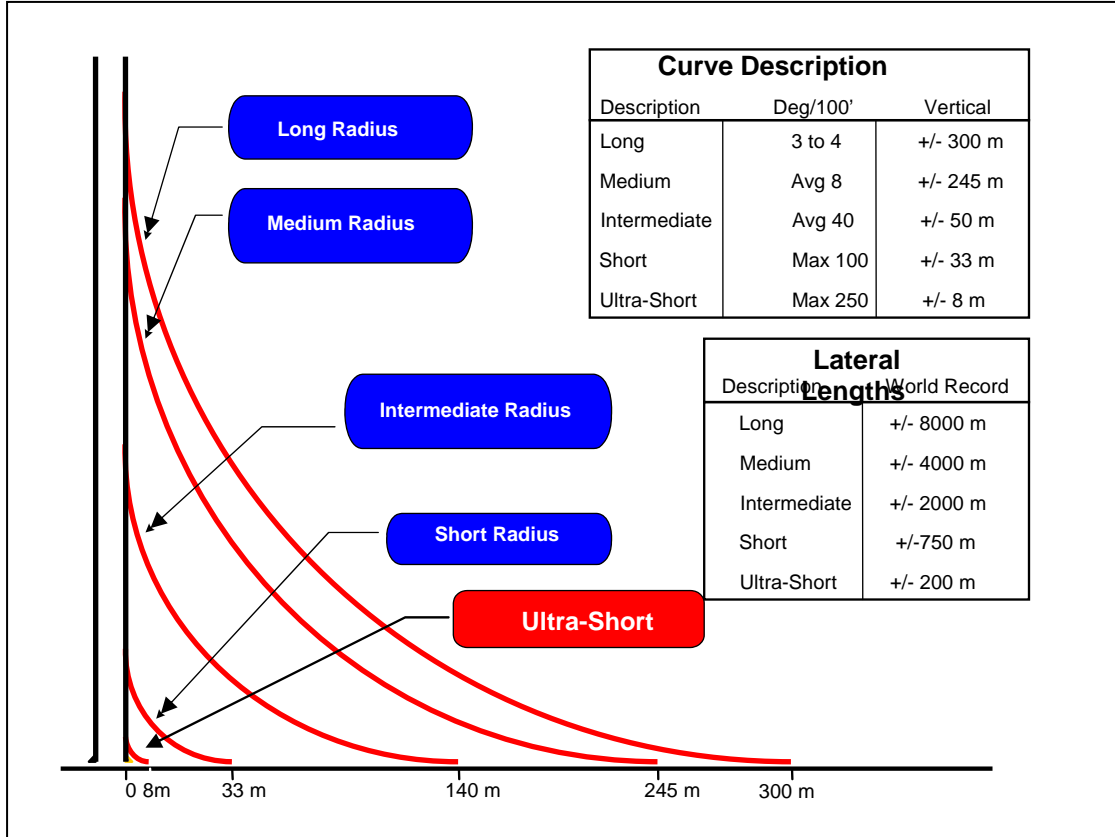
USR drainholes can also be used as an alternative to conventional completions of new wells. In many cases the cost is similar, but the advantage of putting a drainhole in the desired direction and at the desired depth can offer much greater benefit than perforating, acidizing and fracing a well.

In either case, whether it is a re-entry or a new well completion, horizontal drilling costs must be kept low to achieve acceptable economics. This paper describes USR, its applications, advantages and attributes, the USR drilling and completion technologies that are in use today and provides case histories of some of the wells where USR has been applied.

Most horizontal wells are currently drilled with conventional mud motor drilling systems or expensive rotary steerable systems. These systems are well-suited for drilling medium and long radius curves, but short radius and USR wells (particularly those with less than a 60' radius of curvature) are more difficult and risky.

WHAT IS USR?

By definition USR is Build Up Rates (BUR) of 100 to 250 degrees per 30m which equates to Radius of Curvatures of 7 to 17m.



USR Can Be Used for a Variety of Applications, Including:

- Sidetracks from Vertical Wells in Tightly Spaced Fields;
- Sidetracks from Vertical Wells with Water Coning;
- Sidetracks from Vertical Wells with Near Wellbore Damage;
- Sidetracks into Channel Sands with Surrounding Shale;
- Exploitation of Attic Oil from a Vertical or Horizontal Wells;
- Exploitation of Low Producing Vertical or Horizontal Wells;
- Exploitation of Slim Hole Vertical or Horizontal Wells;
- Sidetracks from Water Injectors to Increase Injection Rates; and Improve Sweep Efficiency;
- To Increase Injectivity and Deliverability in Gas Storage Reservoirs;

USR Offers the Following Advantages Over Conventional Horizontal Drilling Systems:

- USR drilling enables kick-off point to be at a depth very near, or in numerous cases, inside the objective hydrocarbon zone itself. This is due to its ultra short ROC of 7-14m as compared to over 300m in the above chart.
- Downhole Pumps or Gas Lift Valves, for instance, can be placed at or near the top of the payzone to maximize production efficiency and extend the productive life of the well due to lower abandonment pressures.
- USR drilling enables the landing of the well bore at a distance very near to original well bore in case of re-entry drilling from existing well i.e. Sidetrack, at 8-9m from original well bore as compared to a much greater distance of over 300m.
- Due to such low ROC, landing in thin targets near the existing well bore can be more easily achieved.
- It can eliminate the need of expensive electric wireline logging due to its ultra short vertical section and landing point from the original well bore from which geology, production and reservoir data are readily available.
- Tighter curves allow horizontal sections to be initiated nearer to the existing well bore with known data. Often times the objective pay zone is missed due to the presence of lenses or minor faults which are not identified by seismic or other field data.
- A more precise placement of the horizontal well bore allows for a more efficient development of closely spaced fields.
- Enables precision placement of a horizontal section across the objective hydrocarbon zone, at a very close distance to the kick-off point.
- The drilled distance from kickoff depth to end of curve depth is much shorter than conventionally drilled wells. USR curves require less than 20m of drilled hole as opposed to more than 500m.
- Shorter curves can in many cases save hundreds of thousands if not millions of dollars in drilling costs.
- In most cases kickoff points can be set below problem zones with water, gas caps or shales that can be difficult to drill due to hole stability. The entire curve and lateral can be drilled in the producing formation and below cap rock.

- Wellbores are slimhole which allows for less expensive Workover Type Rigs or Hydraulic Workover Hoists, smaller pumps and circulating systems to be used.

Capabilities of Current USR Technologies Include:

- Ability to Re-enter Existing Wells Completed with 4-1/2” OD Casing (or larger);
- Drills a Consistent Radius of Curvature as Small as 25 Feet;
- Multiple laterals can be drilled in opposing directions or in the same direction, landing at the same true vertical depth (“TVD”) or at varying TVD’s.
- Laterals Ranging from 100’ to 1,000’ can be Drilled;
- Multiple Laterals can be Drilled From a Single Well-bore;
- Compatible with Any Drilling Medium Including Air, Mist and Foam;
- Can be Implemented with a Drilling Rig or Service Rig.

CURRENT USR DRILLING SYSTEMS

There are currently two systems used to drill short radius and USR wells.

USR Rotary Steerable System (USR RSS)

The only RSS developed for USR is a rotary steerable “push the bit” system that was developed by Amoco Production Company. Due to the low oil prices of the 1990’s there was a need for a reliable cost effective USR drilling system that used the equipment and cost structures associated with workover and repair services. The need for a low cost system provided the impetus for the development of the initial USR technology.

Amoco’s development criteria consisted of four main objectives:

- (1) develop a system low in cost to manufacture, repair and operate;
- (2) develop a system that will drill a predictable and consistent radius of curvature in a desired direction;
- (3) develop a system capable of operating from a service rig using a power swivel; and
- (4) develop a system capable of working inside 4.5” casing.

Following development of the prototype tools, more than 200 test wells were drilled at Amoco’s Catoosa Test Facility near Tulsa, Oklahoma. Following testing, the technology was taken to the field where it was used to drill several wells at Amoco’s Levelland Unit. These initial test wells proved the basic capability to install USR lateral drain holes at a reasonable cost with a top drive power swivel and workover rig.

Amoco's USR RSS has been tested, developed and improved to the point where it is a successful and commercially viable technology. Since the first quarter of 1995, more than 200 USR wells have been drilled with the system.

USR Mud Motors (USRM)

In 2007 Mud Motors were specifically designed and developed to drill 8-14m radii and achieve high build up rates (BUR) of 250° per 30m.

A key component required to drill USR wells with motors is that wellbore surveys must be taken near bit. Micro electronic tri-axial magnetic survey instrumentation can be placed only 2 to 2.5m from the bit and provide inclination and azimuth readings. This reduced projection to the bit distance allows for a planar curve and smoother lateral section. Thin pay zones can be more accurately drilled with less wellpath tortuosity.

Both Curve Drilling and Lateral Drilling Motors have been developed with specially designed and manufactured Articulated Sections. These newly developed USRM have successfully drilled curves as short as 9m. An entire range of BUR can be achieved resulting in the desired ROC using varying sizes of kick pads for each type motor. The size and position of the kick pad will affect the BUR.

USRM combined with the miniaturized near bit surveying tools offers a USR system that delivers the accuracy necessary to land and steer within thin targets. Lateral lengths are similar in range to that of USR RSS.

As is the case with USR RSS the horizontal drainhole length of a USRM well is dependent on lithology, hole stability, compressive strength and radius of curvature.

USRM vs. USR RSS

The USRM system has distinct advantages over USR RSS. USRM totally eliminates drill pipe rotation while drilling the curve and reduces the total pipe rotation when drilling the horizontal section by up to 90%. USRM simply extends the useable life of various types of drill pipe used for USR and short radius drilling. USRM allows for a wide range of drill pipe for USR drilling.

CONSIDERATIONS IN WELL PLANNING

One key advantage associated with working within a producing field and existing wellbores is access to geological maps, core data, reservoir characteristics, well logs, wellbore schematics and well completion reports. The more complete the information, the better the chance of an operator achieving an economic success.

When selecting a target interval and screening a wellbore for suitability as a re-entry candidate, consideration should be given to overlying formation properties. Many times,

problem formations such as reactive shales, washouts and gas or water zones exist above the zone of interest. While the application of USR drilling can often allow the operator to avoid drilling through these potential problems, consideration should be given early in the planning process to determine how they can be avoided. In addition, high concentrations of pyrite, anhydrite or chert can drastically affect penetration rates and should be avoided when possible.

The radius of curvature, which may range from 7 to 17m, is determined by up hole conditions, the desired lateral displacement, thickness of the target interval and completion requirements. The kickoff point is determined by the radius of curvature, desired landing depth of the curve and location of casing collars and perforations.

Once all data is reviewed, a proposed wellpath is chosen, the kickoff point is selected and a wellbore preparation schematic is prepared.

The planning process is not complete without careful review of the drilling medium to be used. Factors to be considered should include formation pressures, hole stability, drill cuttings transport, fluid flow regime, lithology, the presence of corrosive gases and fluids and fluid compatibility with formation water.

Borehole problems can be considerably more severe in a horizontal well than in a vertical well. Therefore, drilling fluids should be tailored to the target formation to insure maximum production.

The curve is initiated at a predetermined kickoff depth from either a cement plug, whipstock or from formation below the casing shoe.

The major steps in a re-entry operation when the target is behind pipe include well preparation, drilling the curve, drilling the lateral and completing the well.

COMPLETION OF A USR WELL

Articulated and Rotatable Pre-packed Sand Screens “SnakeScreen™” have been developed for use in USR wells where screened completions are required. These screens are run prior to displacing the drilling fluid and independently of a completion packer. After the screens are landed to TD a completion packer is then run separately. The key advantages to these screens are:

- Articulated, Rotatable and Pre-Packed
- 80% Screenage per 30' Joint
- Articulation Every Meter Serves as Standoff and Protects Screen while Being Rotated to TD.
- Rotation Reduces the Risk of Friction Lockup and Landing Completion Short of Objective
- Full 2” ID Allows for Clean Out with CTU

- Designed to Sand Particle Size

EQUIPMENT REQUIREMENTS

Minimal surface equipment requirements give USR drilling an advantage over conventional mud motor technology. The rig is usually a standard service/workover rig capable of pulling double stands with an adequate hook load capacity of 60,000 lbs. over string weight and equipped with pipe racks and catwalk. Handling tools should include open faced tubing tongs with torque gauge, 2-7/8" bottleneck type elevators, an accurate weight indicator, a mud pump gauge on the rig floor and an adequate supply of spare parts.

Other equipment should include a 500 bbl frac tank for water storage, a 100 bbl mud mixing pit, a 200-400 bbl working pit, a lined sump pit, a high frequency linear shale shaker, a tri-plex pump, a standard workover BOP stack and accumulator, a power swivel, a workstring (2-7/8" PH-6, AOH or DSS), 3-4 light plants and a 60 KW generator. In the event hydrogen sulfide is present, a safety trailer containing air packs and fire extinguishers should be on location.

The power swivel is a key piece of the surface equipment. A remote control panel with electric controls over air or hydraulics and a back brake system is required. The remote controls should have an accurate torque gauge. Torsional control (both left and right) is critical. The swivel must respond immediately to the remote controls.

The exact equipment package may vary depending on formation pressure, depth, casing size, the drilling medium used, location restrictions and operator and/or state requirements.

CONCLUSION

USR Drilling offers operator a viable alternative technology that is especially well suited for use as a re-entry tool in mature highly developed "Brownfields" or as a completion technology for new wells.

CASE HISTORIES

Case Histories 1 through 11 offer a sampling of the wells drilled with the RSS and USRM Systems and indicate the capability and versatility of the system. Exact production increased can not be given due to confidentiality. Production increases have been noted where confidentiality allows.

Figure 1 illustrates a well drilled for Texaco in Hutchinson County, Texas. Two 4.5" laterals were drilled with a polymer based mud to complete a newly drilled vertical hole.

Completion entailed sweeping the lateral with coiled tubing to spot acid. Total job time was approximately 3 weeks for the horizontal operation including well preparation and completion. Production resulted in a five fold increase over what is achieved from a vertical well.

Figure 2 illustrates a well drilled for Oxy USA in Seward County, Kansas. One 4.5” lateral was drilled with foam as an extension for a new vertical hole. Completion included a coiled tubing/acid treatment. Total job time for the horizontal operation was 7 days of daylights only.

Figure 3 illustrates a well drilled for Trueblood Resources in Beaver County, Oklahoma. One 3.875” lateral was drilled inside 4.5” casing as a new well completion. The lateral was drilled with an oil-based mud. No completion data is available. Total job time for the horizontal operation was 6 days.

Figure 4 illustrates a well drilled for Oklahoma Natural Gas in Creek County, Oklahoma. This was a re-entry inside 7” casing and two laterals were drilled in opposing directions. Radius of curvature was 27 feet and 28 feet respectively. The laterals were drilled with a water based balanced mud system. Total job time for the horizontal work was 3-1/2 days. Gas deliverability increased 5 fold.

Figure 5 illustrates a well drilled for Chevron USA in Kern County, California. This was a re-entry inside 7” casing. Up hole perforations were preserved by sectioning below the perforations and drilling with a calcium carbonate system that temporarily sealed the perforations. Completion included running two frac subs in a solid liner string and applying a 200,000 lb. sand frac stimulation. Four days were required to drill the horizontal segment.

Figure 6 illustrates a well drilled for Phillips Petroleum in Ector County, Texas. This was a re-entry inside 5.5” casing. The horizontal segment was drilled with a weighted water based mud system due to working in a carbon dioxide flood. Completion entailed jetting acid through coiled tubing. Total job time including wellbore preparation, drilling and completion was 3 weeks. Increase in production was from 0 to 84 BOPD.

Figure 7 illustrates a well drilled for Petroleum Development Oman. Two horizontal injectors were drilled with a polymer based mud to increase injectivity rates and improve sweep efficiency. Completion entailed the use of an articulated hydraulically actuated kicksub to re-enter each leg and displace drilling fluids until well flowed for natural cleanup. Total job time including wellbore preparation, drilling and completion was 17 days. Injectivity increase three fold.

Figure 8 illustrates a well drilled for Petroleum Development Oman. Existing well was watered out and completed with gravel pack. The objectives was to target by passed oil. An 8 ½” pilot hole was drilled to land approximately 80m of displacement away from vertical well. Logs were run and indicated 95% oil saturation in top 6m of formation. A 7” liner was topset one meter into the reservoir and a USR drilled with a horizontal

section of approximately 100m. Total job time including pilot hole, logging, running liner, and USR section and completion was 21 days. Production increase was significant from 0 to more than 400BOPD.

Figure 9 illustrates a well drilled for Petroleum Exploration Mediterranean in SE Turkey. Existing well had 7" topset two meters in reservoir and open hole completion. The open hole was plugged back and a USR well was drilled exposing approximately 450' of reservoir. The well was completed open hole after acid stimulation with drill pipe. Total job time including wellbore preparation, drilling and completion was two weeks.

Figure 10 illustrates a well drilled in Assam State in the North Eastern part of India. The horizontal section was drilled with non damaging water based drilling fluid. The well was completed with 2 3/8" slotted liner in the horizontal section. On activation the production increment from the well was about 16 times the production before USR operations.

Figure 11 illustrates a well drilled in Gujarat State on the West coast of India. The USR horizontal section was drilled with non damaging water based drilling fluid. The well was completed with a 3 1/8" pre-packed articulated and rotatable sand screen specially developed for USR completions. On activation the production increment from the well was 6 times the production before USR operations.

Texaco E&P
Hutchinson County, TX
Dual Lateral - Separate Zones

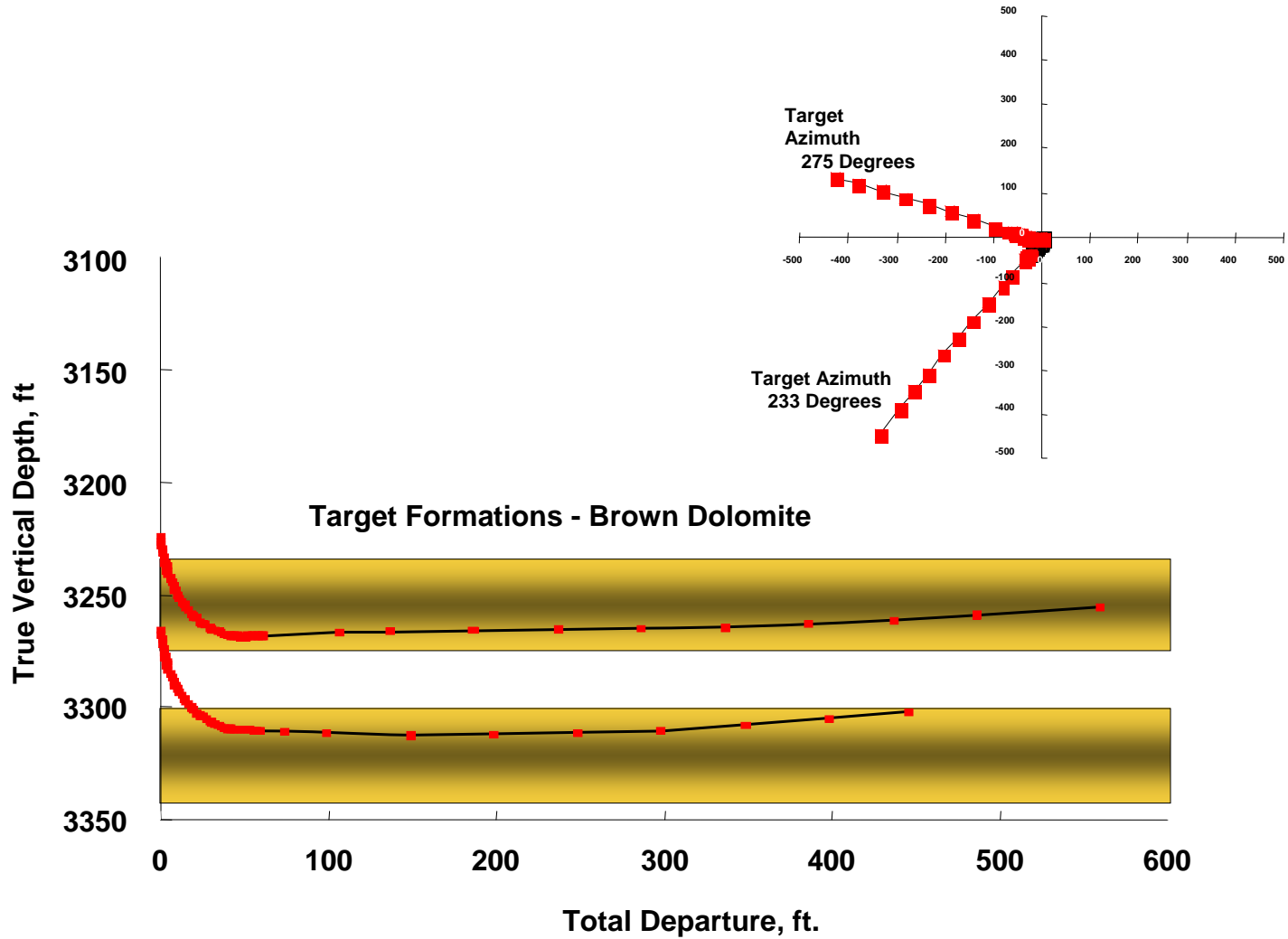


Figure 1

Oxy USA
Seward County, KS
Drilled with Foam

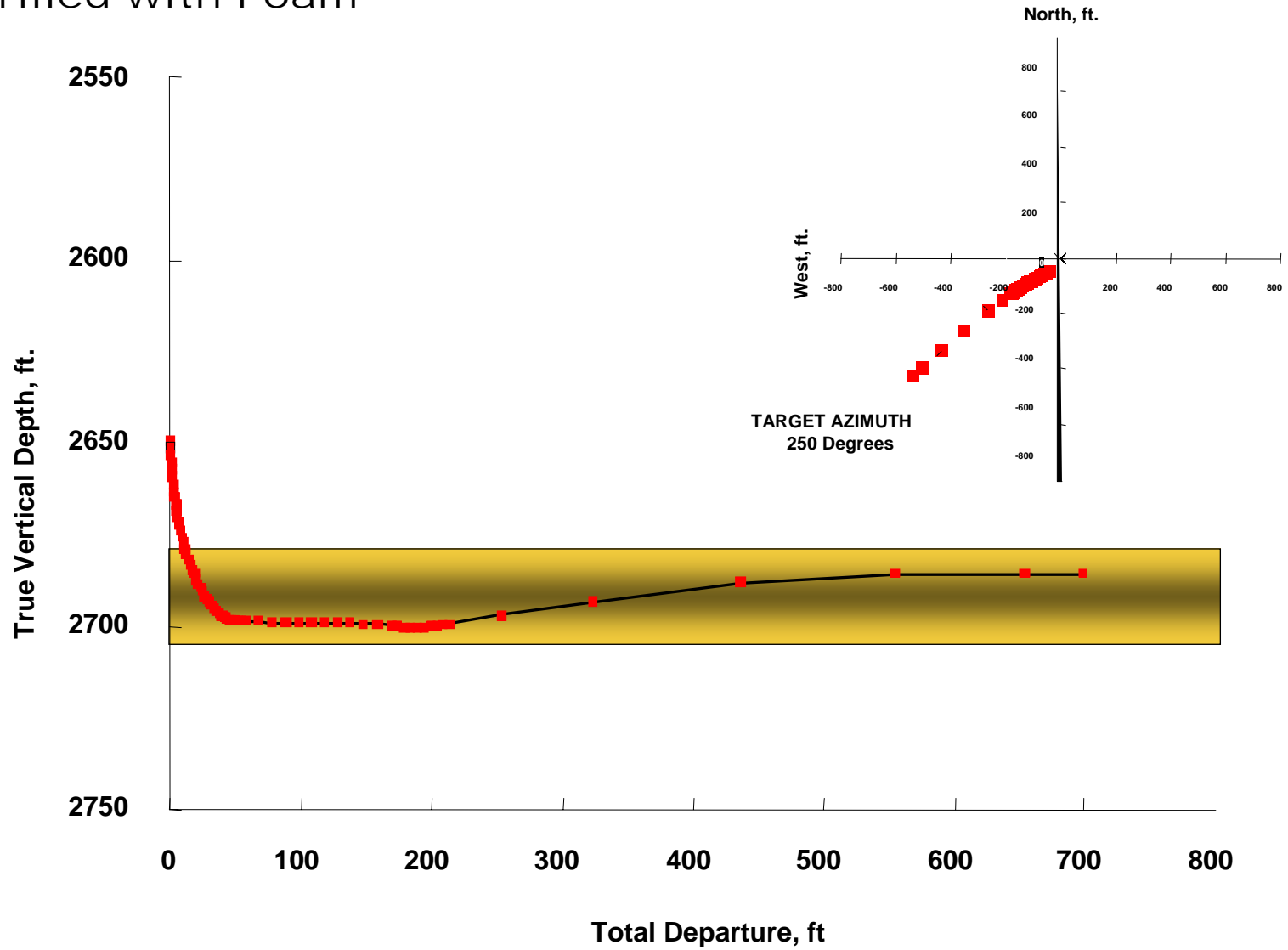


Figure 2

Trueblood Resources
Beaver County, OK
Drilled with Oil Base Mud

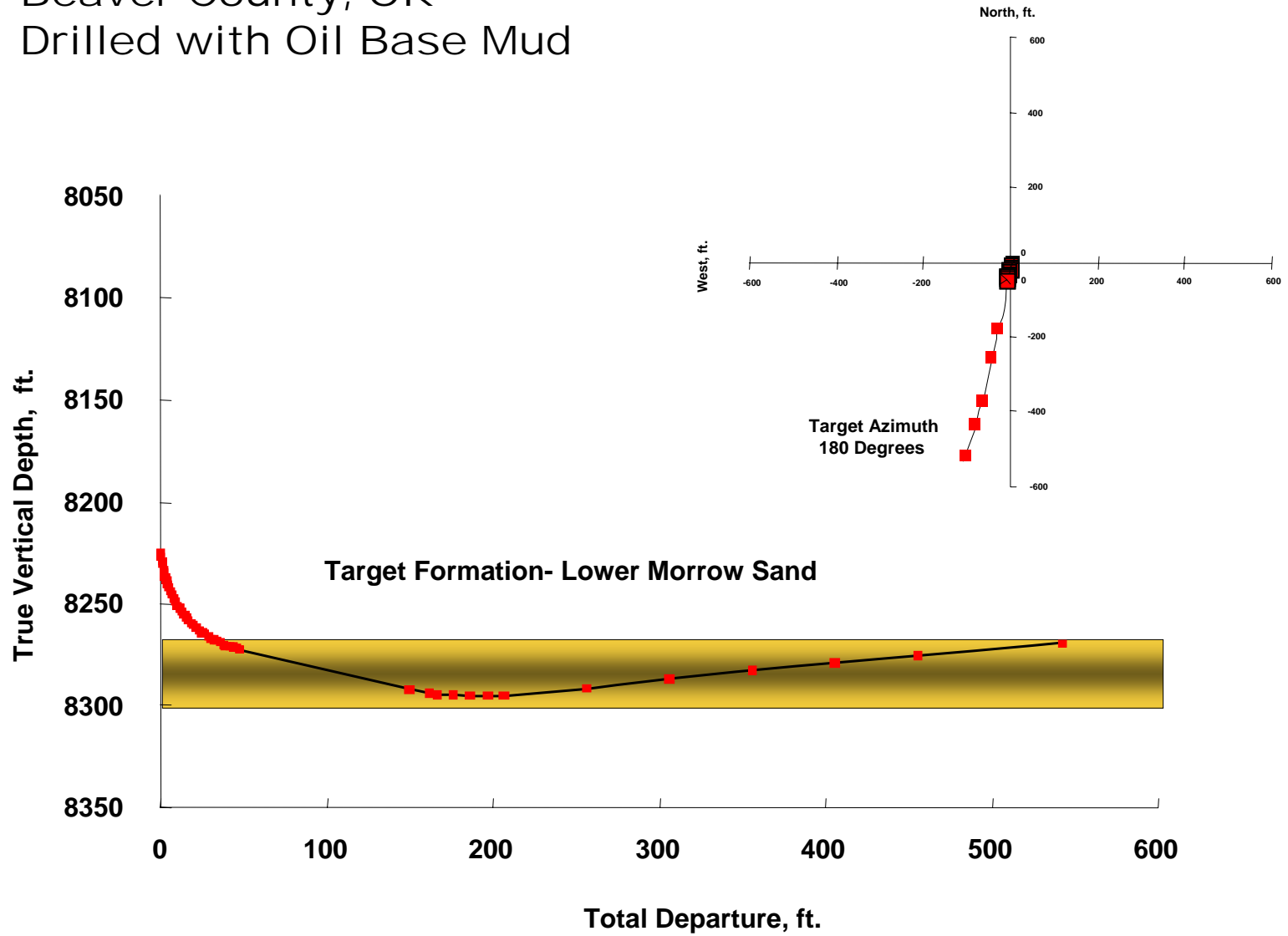


Figure 3

Oklahoma Natural Gas
Creek County, OK
Depew Gas Storage Field

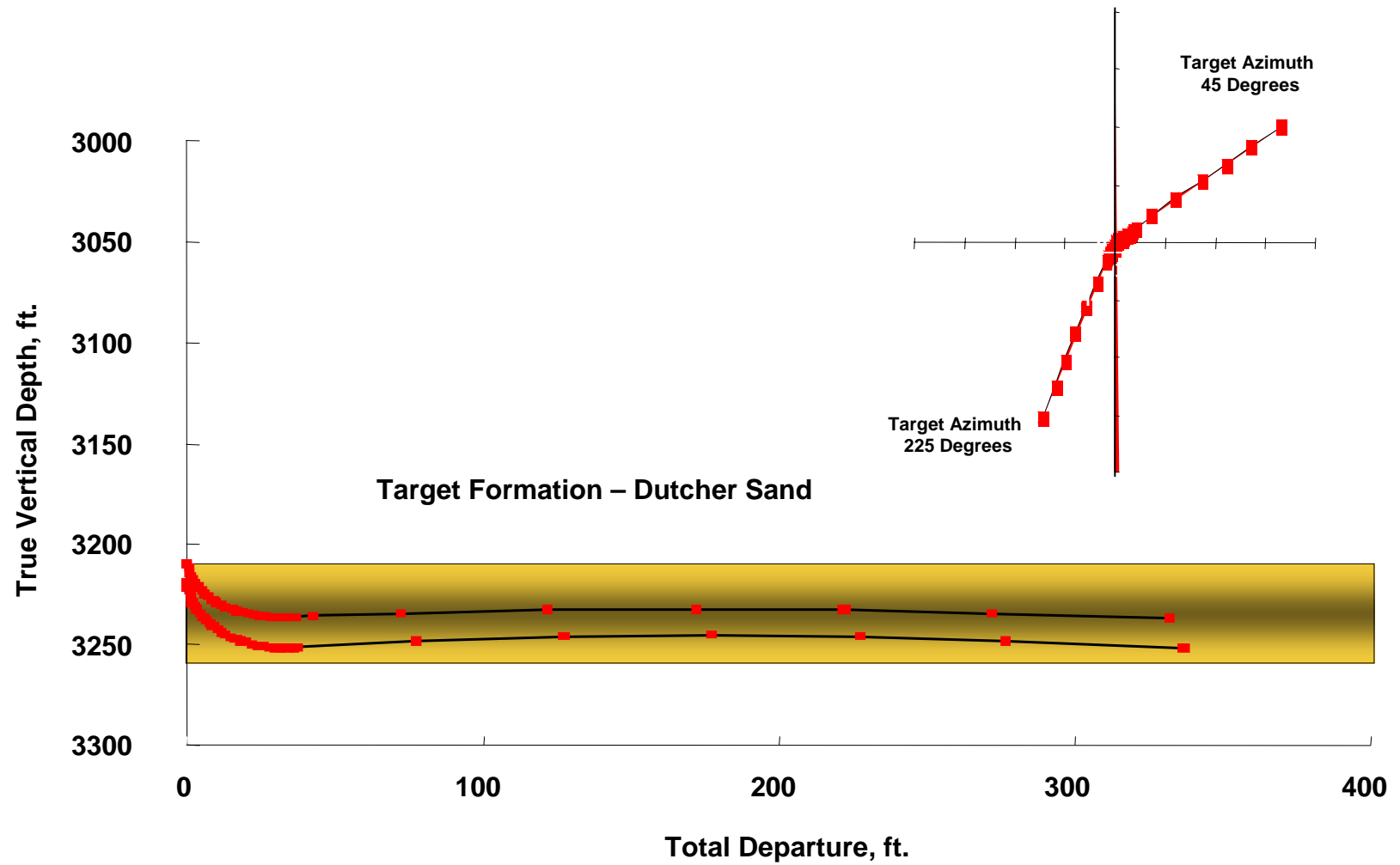


Figure 4

CHEVRON U.S.A.

Kern County, California

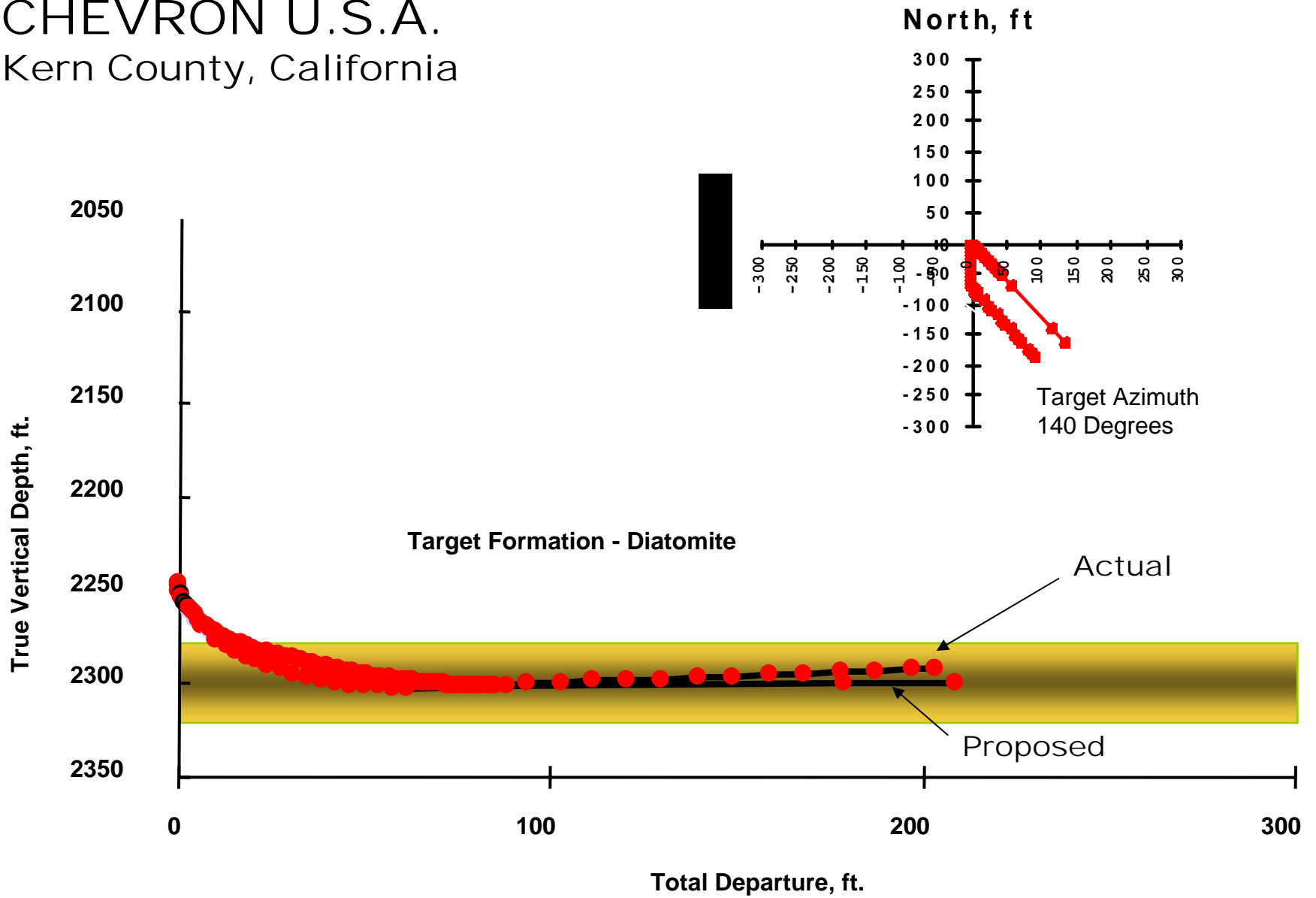


Figure 5

PHILLIPS PETROLEUM
COMPANY
Ector County, Texas

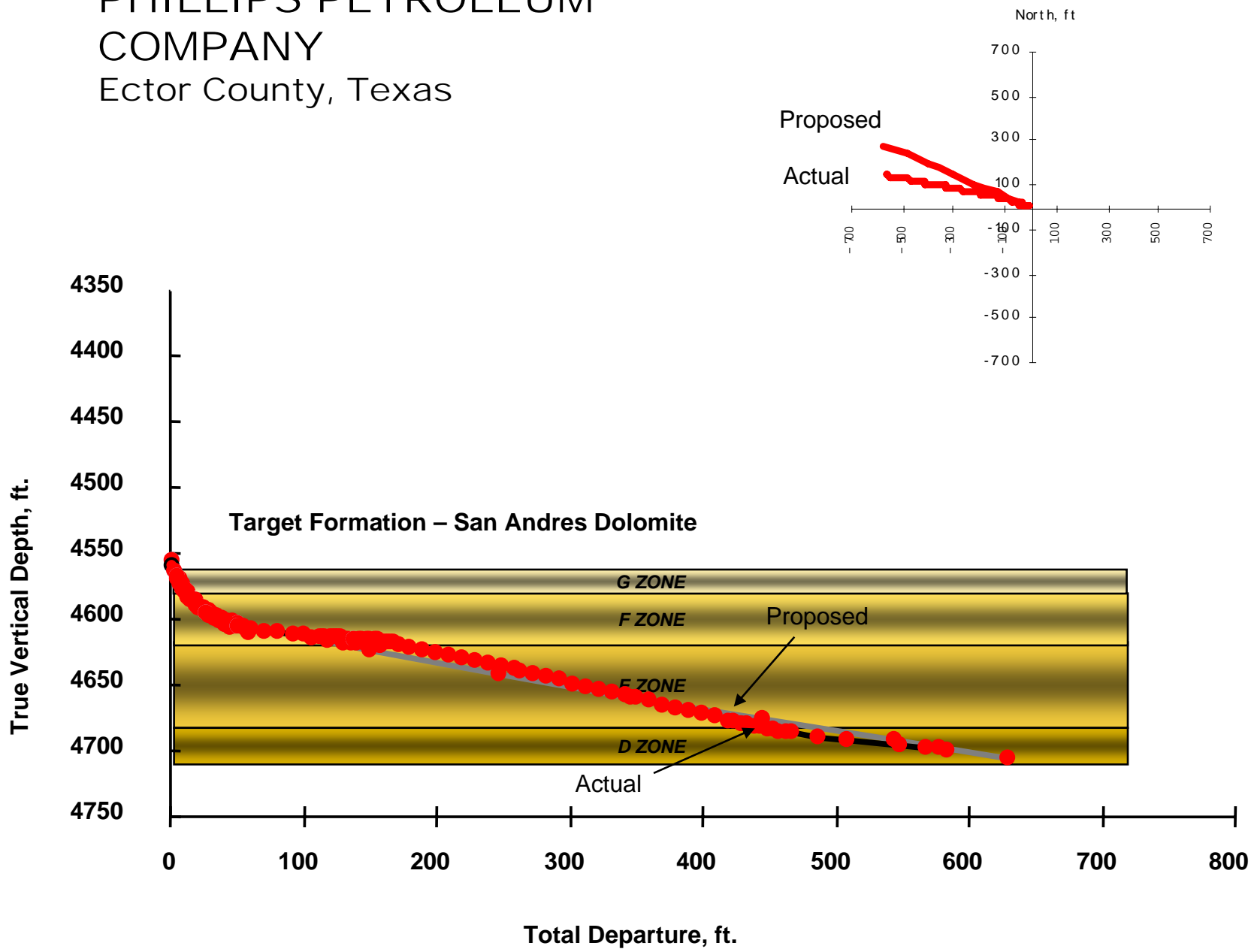


Figure 6

PETROLEUM DEVELOPMENT OMAN - Lekhwair Field

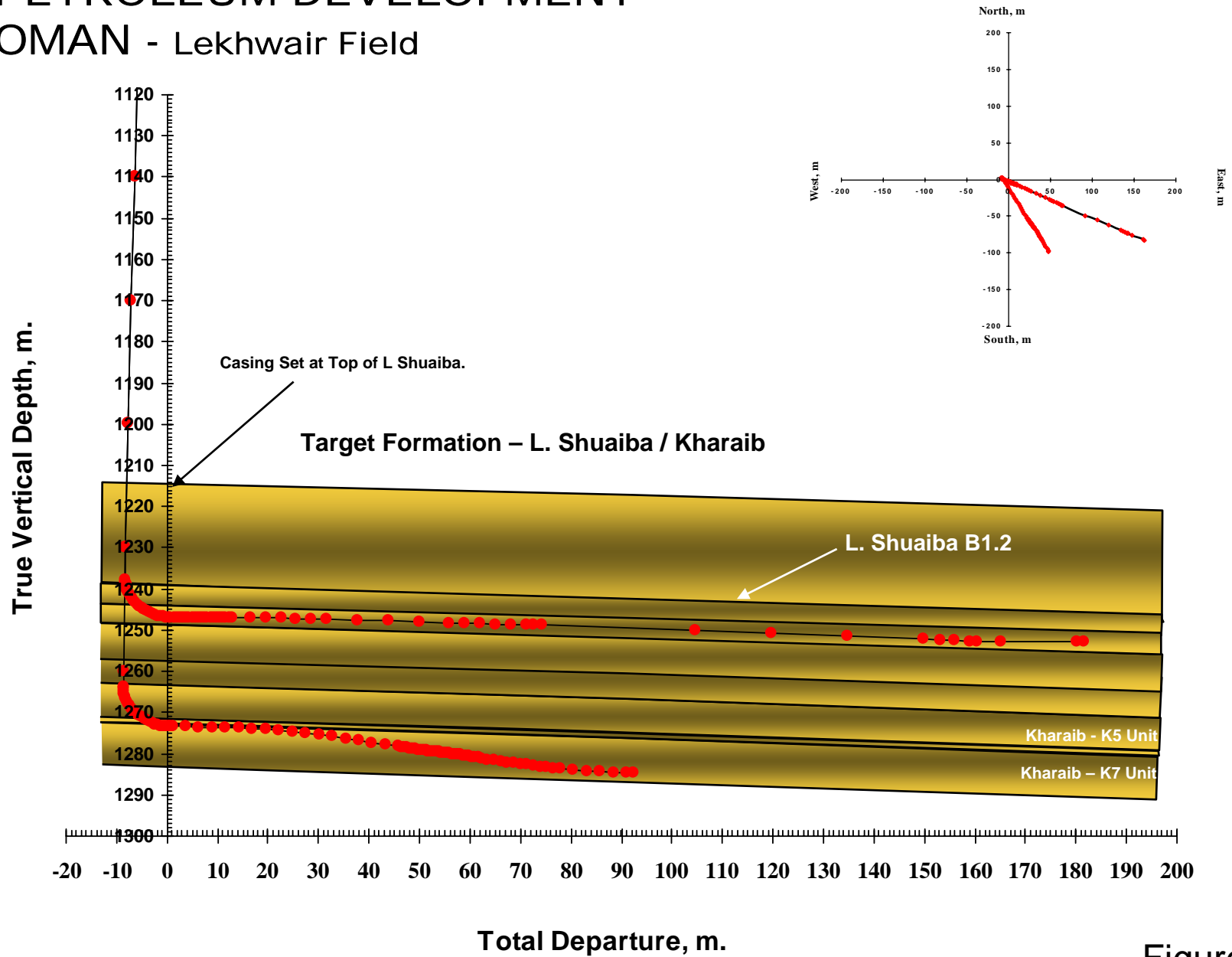


Figure 7

PETROLEUM DEVELOPMENT OMAN - Rima Field

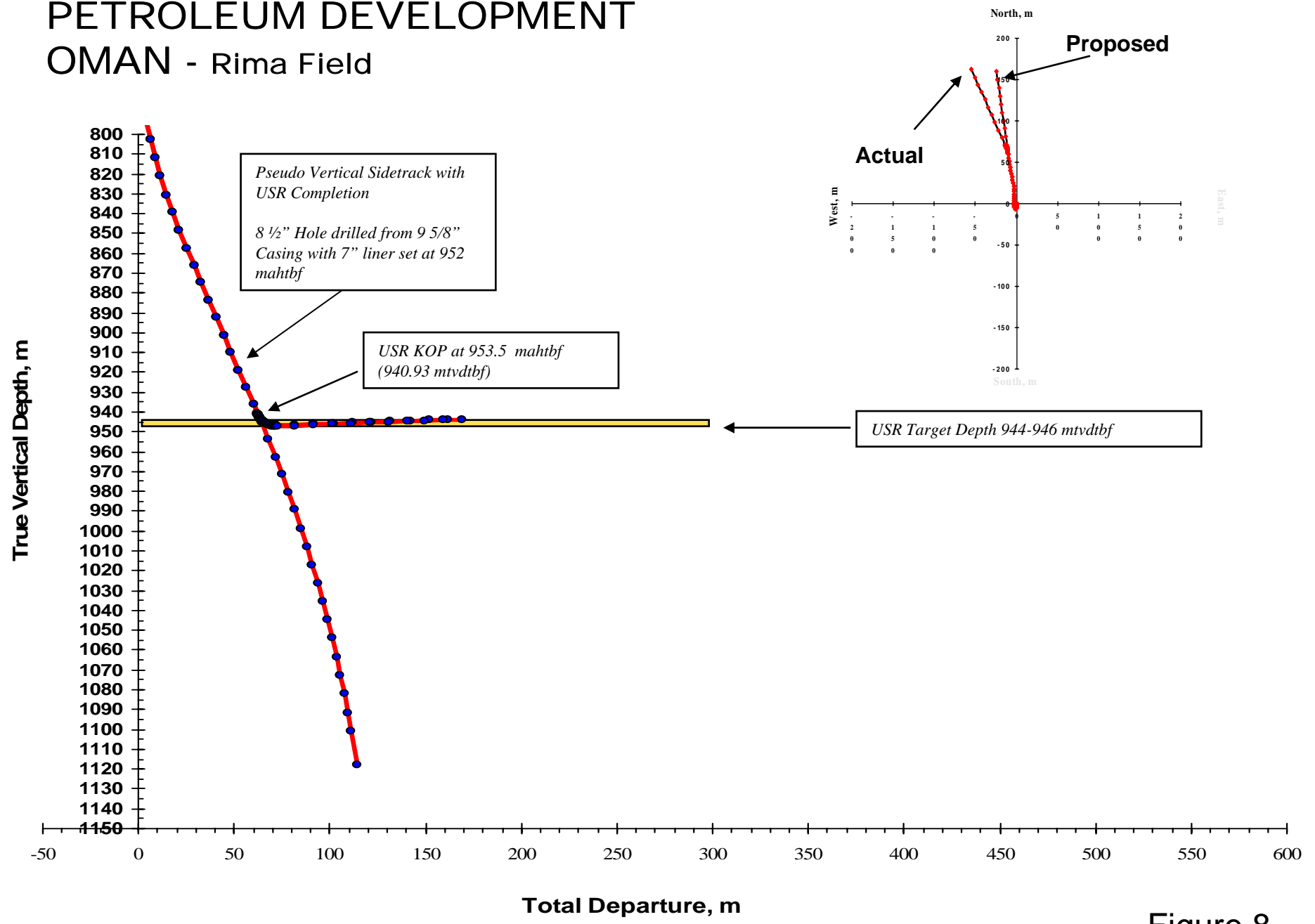
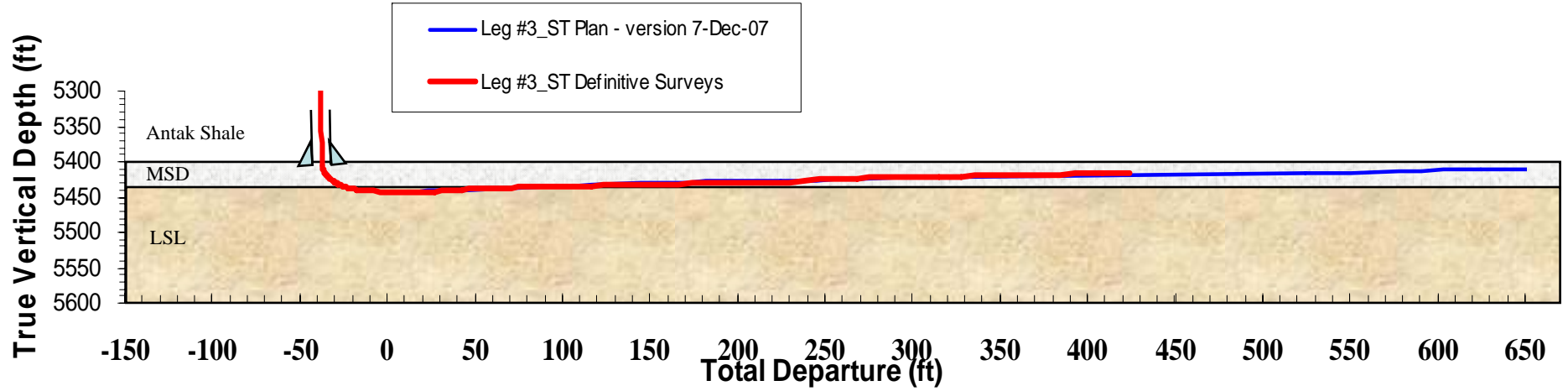
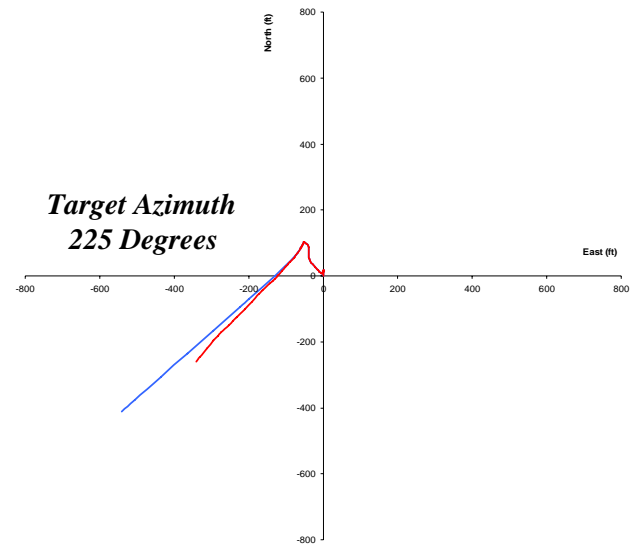


Figure 8

PEMI – 2007 USR CAMPAIGN
SELMO-36 USR3
DEFINITIVE SURVEYS
 Projected to 5898' Well TD, 5882' Last Survey Depth
 TD called when Top MSD unexpectedly encountered
Target Formation – High Porosity MSD

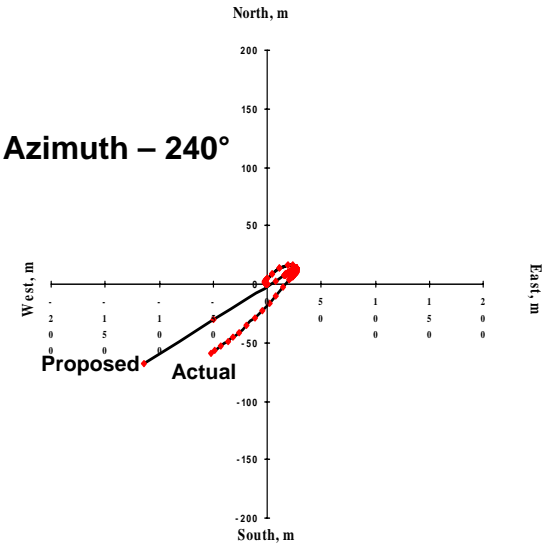


Assumes no formation dip.

Figure 9

Assam State, India
PROPOSED vs. ACTUAL USR SIDETRACK
KOP @ 2425 m ahrkb
Target Depth 2435-2537m tvdrkb
Target Formation – TS 3A

Target Azimuth – 240°



Section Interval
2423-2438m

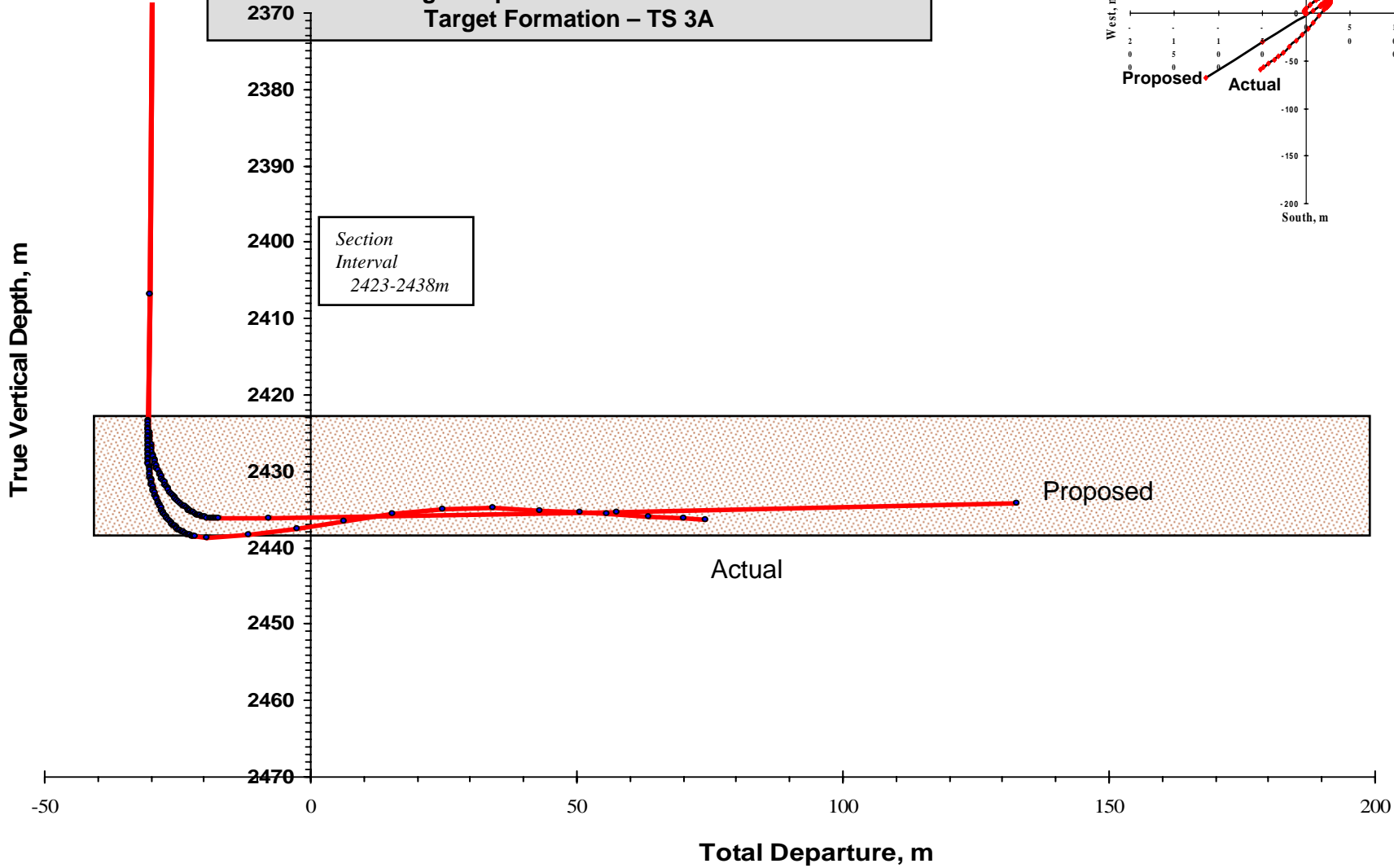


Figure 10

Gujarat State, India

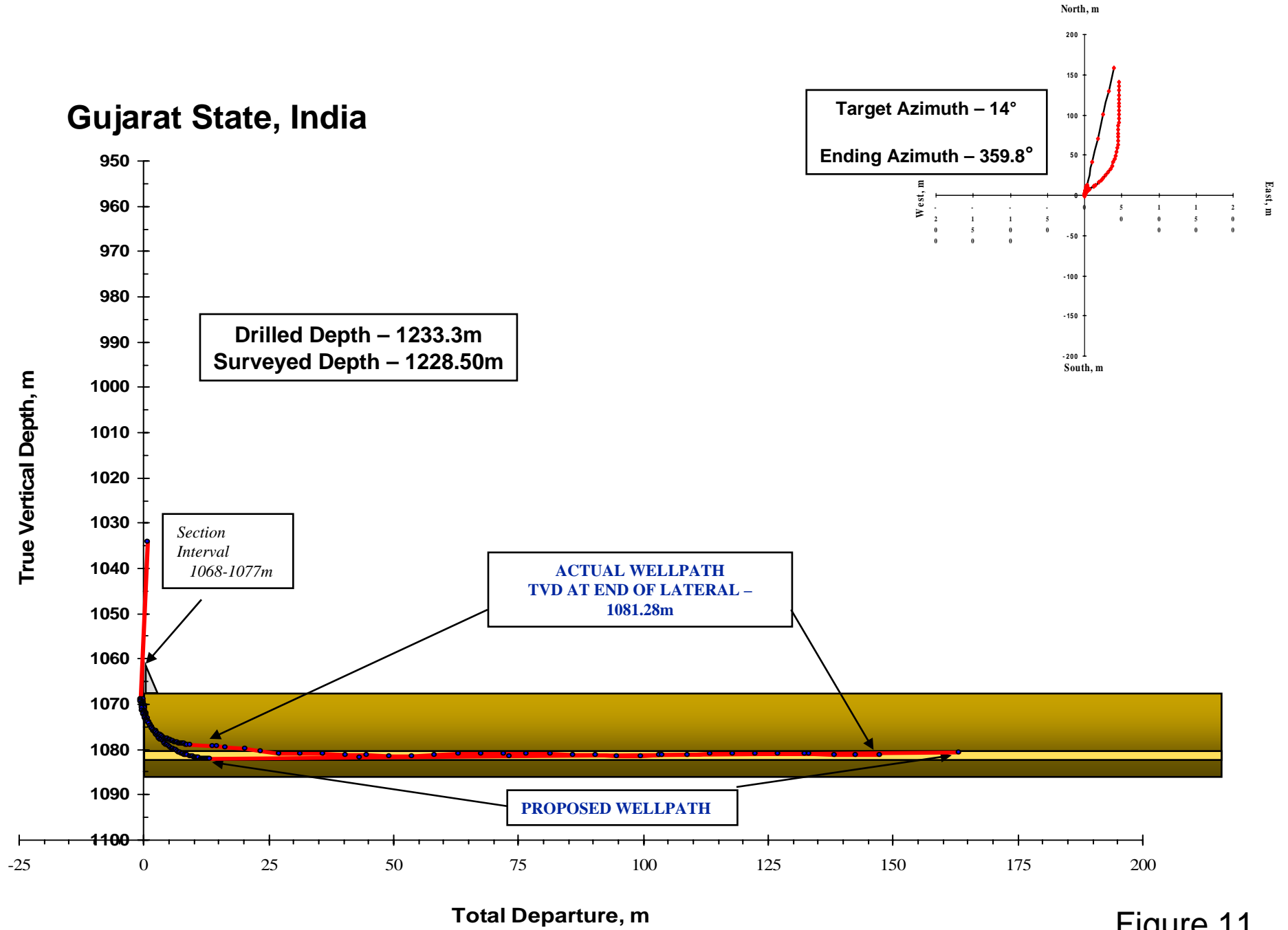


Figure 11