

# Downhole .50-Caliber Rifle: An Advance in High-Resolution Seismic Sources

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## SUMMARY

In a direct comparison, the downhole .50-caliber seismic source produced more seismic energy, a broader body-wave frequency spectrum, an amplitude drop in the air-coupled wave, and a higher dominant frequency of the recorded body-wave energy than the silenced surface .50-caliber source. The recorded seismic energy of the downhole rifle showed an increased amplitude of 6 to 12 dB over that recorded by the silenced surface rifle. The dominant frequency of the recorded reflection energy was consistently 20 to 40 Hz higher than the surface rifle. The air-coupled wave amplitude was decreased over 12 dB by subsurface firing of the rifle. The frequency spectrum of the body-wave pulse was broadened by almost a half octave on the high end. The safety of operation of the source is not compromised. Reflectors with a dominant frequency in excess of 180 Hz can be easily identified on field files at depths of less than 30 m using the downhole .50-caliber rifle. Identification of 100-Hz reflectors from 1,100 m is possible on field files of multiple vertically stacked downhole .50-caliber shots. The source will operate in an efficient manner collecting CDP data, common-offset data, or spot-correlation data.

## INTRODUCTION

Increasing environmental and engineering applications of reflection seismology have spurred research and development of shallow high-resolution reflection techniques and equipment. Resolution on the order of a meter is necessary to detect ultra-shallow targets which are generally the goal of most environmental and engineering studies. This increased resolution can be obtained by boosting the frequency of the source pulse which, in turn, increases the dominant frequency of the recorded seismic-reflection energy. Generating the high-frequency seismic source pulse necessary for shallow applications has been accomplished in a multitude of different ways in the past (Miller et al., 1986).

Recent seismic source advances at the Kansas Geological Survey (KGS) have mainly revolved around surface projectile-type sources (Steeples and Knapp, 1982; Miller and Steeples, 1986; Seeber and Steeples, 1986). A .50-caliber rifle, which was designed and built to safely fire a 750-grain bullet vertically into the ground, has more recently been adapted to operate partially underground with only the firing apparatus above ground. This allows safe operations, a higher-frequency source pulse, and an increased signal-to-noise ratio.

## DESIGN AND TECHNIQUE

The general design centers around optimizing the conversion of energy produced by a .50-caliber rifle bullet into seismic (acoustic) waves. The

majority of the energy produced by a .50-caliber round goes into accelerating the projectile and into exhaust gases. Previously, with above-ground sources, we have silenced and dispersed the exhaust gases in hopes of eliminating or at least greatly reducing the effects of the air-coupled wave on seismic data. The downhole .50-caliber rifle nearly simultaneously excites the earth with a projectile and with exhaust gases while containing most of the air-coupled wave, resulting in increased frequency and signal-to-noise ratio on seismic record sections.

The downhole .50-caliber seismic source consists of a .50-caliber rifle bolted to a 0.6-cm-thick steel plate. The rifle itself is a standard .50-caliber breech and bolt, built by Texas Gun and Machine Company, attached to a standard .50-caliber machine-gun barrel. Machined grooves in the barrel are used in conjunction with a pressure clamp to attach the rifle to a 30-cm by 90-cm steel plate. The rifle barrel is lowered into a 60- to 80-cm-deep borehole 4 cm in diameter until the plate is flush with the ground surface. This steel plate acts as a ground seal and a platform to stand on while firing the gun. The weight of the shooter on the plate and the snug fit of the barrel to the borehole walls help seal the gun to the ground. The rifle can be equipped with a source sensor or closure switch to generate a time break. Firing can be done either electrically by solenoid or manually by pulling the trigger. The downhole .50-caliber weighs about 30 kg and is easily two-person portable.

## FREQUENCY AND AMPLITUDE

The downhole .50 caliber produces from 6 to 12 dB greater recordable seismic energy at equivalent offsets than the silenced surface .50 caliber (fig. 1). The increased recorded energy boosts the signal-to-noise enough to substantially clean up the record section. The source-to-closest geophone offset in fig. 1 is 43 m. Besides this noticeable increase in recorded seismic energy, a consistent 20-40 Hz boost in the dominant frequency of the source wavelet is characteristic.

In previous shallow-source comparisons (Miller et al., 1986), the surface .50-caliber performed comparably to Mini-Primacord and a 10-gauge Buffalo gun in total energy and frequency spectrum. The noted increase in frequency and energy would make the downhole .50-caliber rifle comparable to the 8-gauge Buffalo gun which was among the best sources tested for reflection energy versus ground roll, total energy, and frequency content.

## SAFETY

Safety should be of the utmost concern in any operation involving seismic sources. The rifle is

mounted on a 0.6-cm-thick steel plate to protect the operator from fragments and to help hold the gun securely in place. Since the projectile is fired from a bolt and breech, originally designed as a standard firearm, the utmost in safety has already been designed into the actual firing mechanism. The bolt and breech manufacturer designed the apparatus not to fragment even if the barrel was completely obstructed. The barrel is in standard use by the U. S. military on .50-caliber machine guns. The extra thickness of a machine-gun barrel serves to dissipate heat and, especially in our case, protects from blow-out if foreign material gets into the barrel. This makes continuous operations safe and consistent.

#### CASE STUDY

##### Silenced surface .50-caliber vs Downhole .50-caliber.

The direct comparison of the surface and the downhole .50-caliber rifles was performed near Winter Park, Colorado, in an attempt to detect the Moffat railroad tunnel, 85 m below the surface. The receivers were single 100-Hz geophones with a 1.2-m station interval. The sources were 43 m from the closest receiver station. The resulting recorded field files plotted, using true amplitude, clearly show the increased amplitude and the increased signal-to-noise ratio of the downhole rifle as compared to the surface source (fig. 1). A glaring difference is the absence of air-coupled wave on the field file using the downhole rifle. The frequency difference is obvious on the amplitude spectra (fig. 1).

##### Downhole .50-caliber Field Files and Spectrum

The downhole .50-caliber rifle can produce a source pulse with a dominant reflection frequency in excess of 180 Hz (fig. 2) when used with analog low-cut filters that have a -3 dB point of 220 Hz and a 24 dB/octave rolloff. Clean minimum-phase reflection wavelets, easily in excess of 150 Hz, can be identified down to 270 msec directly off the field file (fig. 3). The spectrum of the reflector at 85 msec is almost 3 octaves across with corner frequencies of 40 and 290 Hz (fig. 3).

The downhole .50-caliber rifle has not only been proven to be a useful shallow high-resolution reflection-seismic source, it also possesses the capability to penetrate as much as 1,100 m of sedimentary veneer overlain by 15 to 30 m of weathered alluvium (fig. 4). The reflection at 720 msec on the field file is Arbuckle dolomite at a depth of 1,100 m in central Kansas. This eight-shot stack was recorded with 30-Hz low-cut filters and ten 40-Hz geophones. The dominant frequency of the reflection energy is about 100 Hz.

#### ACKNOWLEDGMENTS

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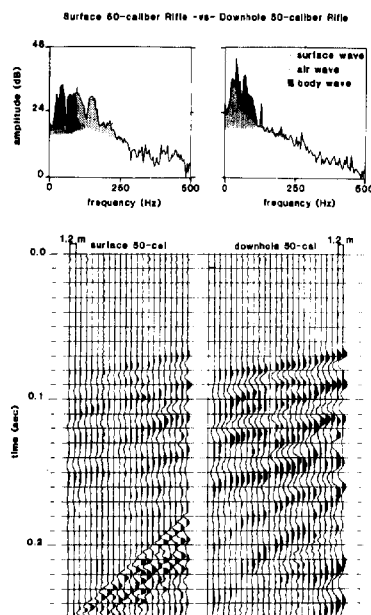


FIG. 1. Single shot comparison plotted true amplitude with identical recording parameters clearly shows increased S/N and improved frequency content of downhole .50-cal.

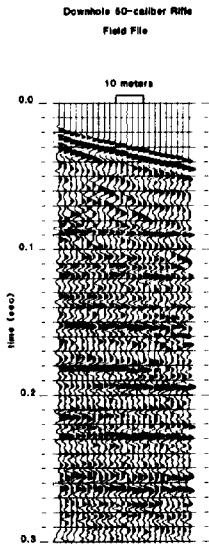


FIG. 2. Single-shot field file with AGC applied illustrates high frequencies, and therefore resolution easily obtainable with downhole .50-cal.

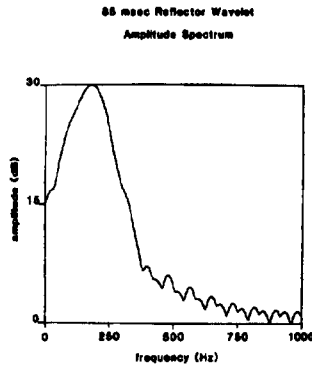


FIG. 3. Amplitude spectrum of reflection pulse at 85 ms in almost 3 octaves wide.

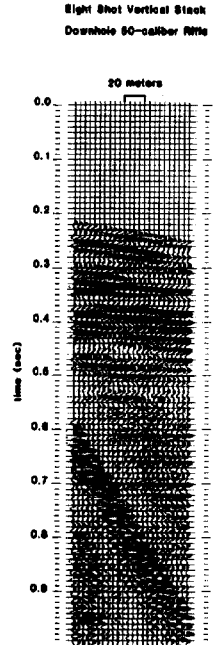


FIG. 4. Stacked field file has 100 Hz reflection energy as deep as 1100 m.