

Redisplay of the 1970 Flathead Lake Seismic Data

By
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Abstract

The seismic data that were collected on Flathead Lake in 1970 employed system components common in that era for analog bathymetry and sub-bottom profiling with recording on paper charts. A typical recording system, however, was embellished to provide analog magnetic tape recording. Data from about 60 km of the 200 km of the original survey have survived on tape. The analog data on tape were digitized and were redisplayed in seismic section form using color-coding of the signal amplitudes. In 1970, the seismic sections were displayed in a monochrome, facsimile format with dots to indicate signal levels above some threshold. The color displays brought out waveform subtleties not previously recognized in the facsimile images.

The success of the initial redisplay of the data digitized from the surviving analog tape invited application of modern digital processes to reduce multiple reflections and noise phases introduced by the air gun source. While attenuation of the multiples has not been particularly successful to date, bubble oscillations and the first phase of the bubble wave train have been successfully attenuated through homomorphic deconvolution.

Introduction

In the summer of 1970, Richard Wold, at that time on the faculty at the University of Wisconsin-Milwaukee (UW-M), and Gary Crosby, then a faculty member at the University of Montana (UM), joined forces to conduct a seismic survey on Flathead Lake in northwest Montana. Some funding for the survey probably came from the Office of Naval Research (ONR), which supported Wold's experiments with marine seismic systems. A snippet of data from Line E of the Flathead Lake survey appears in Figures 4, 6, and 7 of an obscure Wold report to the ONR (Wold, 1976).

In the mid to late 1960's, Wold and his technician, Ronald Friedel, assembled a seismic system for surveying lakes using components readily available in those days. According to Friedel (2011), the basic system was used to survey part of Lake Michigan in 1968, Great Salt Lake and Green Bay in 1969, Flathead Lake in 1970, Bear Lake in 1971 and 1972, and Yellowstone Lake in 1972 and 1973.¹ The heart of the system was commonly employed gear for bathymetric

¹ Otis et al. (1977) indicate that the Wold-Friedel seismic system was used in Yellowstone Lake in 1973 and 1974.

work and sub-bottom profiling (Simpkin, 2007). What made possible our new look at the 1970 data is the fact that the data were also [recorded on magnetic tape](#).

By 1970, analog recording on magnetic media had been common in the petroleum industry for almost 20 years, and digital recording was rapidly replacing the analog technology. However, the Wold-Friedel system did not use petroleum industry technology for magnetic recording. Instead, the system used a reel-to-reel stereo unit of the day that would have been more at home in the audio-visual or music department of a university than on a seismic survey boat (Hess, 2006). Unfortunately, the technical details of the seismic recording system, such as dynamic range and availability of filters and automatic gain control (agc) have been lost.

The energy source was a 1 in³ air gun made by Bolt Technology Corporation. This size of source is still in regular use for surveys in shallow water.

The Flathead Lake survey was conducted over a period of about a week in August 1970, and about 200 km (120 mi) of line were traversed. According to [Wold](#) (1982), some post-acquisition processing was applied to the data that had been recorded on magnetic tape. However, Wold (1982) does not detail the processing, and Wold was unable to provide any details during a conversation with me in 2006. Assuming that the processing was all analog, the processing was probably limited to band pass filtering and agc. Wold's (1976) report to the ONR includes concerns with designing time varying analog circuitry, such as agc and filters.

Paper seismic sections from the 1970 Flathead Lake survey that survive at UM include the original field recordings and images from some sort of redisplay of the recorded data, possibly products from the processing that Wold mentioned in his 1982 paper. Those paper seismic sections are available for view in the K. Ross Toole Archive of the Maureen and Mike Mansfield Library at the University of Montana. The paper sections have been scanned and became available on-line in 2013 through the UM library's ScholarWorks [website](#).

The Toole archive also holds a paper copy of an apparently unpublished bathymetric map that was prepared by Silverman et al. (1971). The map shows Silverman's bathymetry survey lines and the 1970 Wold-Crosby seismic survey lines. An [image](#) of the map is also on the ScholarWorks site. Moreover, in 2015-16, staff of the Montana Bureau of Mines and Geology enhanced the image of the original Silverman et al. (1971) map. [This version](#) is much easier to read than the scan of the surviving paper copy of the map.

An analog tape, which is clearly a derivative of the field recordings, was discovered at the United States Geological Survey (USGS) library at Woods Hole, MA, in 2006. The tale of that discovery and the conversion of the data from its analog form to digital .wav files is reported in Lankston (2007). Some details of field operations and the recovery of the data are presented in [Book A](#): Overview of the Flathead Lake Seismic Survey.

[Figure 1](#) shows the locations of the six lines of data that are on the tape. This paper describes my efforts to generate new images of the subsurface from data recorded along those six lines. The results, in general, provide geologic details that were not seen in the facsimile displays of the early 1970's.

The Digital Data

Based on a photograph provided to me by Richard Wold (2006), the data were recorded on a common studio stereo tape recorder. That machine used 0.25 in (6.35 mm) tape. The tape that was discovered in the USGS library, however, is 0.5 in (12.7 mm) wide indicating that it contains some derivative of the field tape(s). I do not know whether the archive tape includes simple copies of the field data or whether it represents the output of some stage of processing, e.g., bandpass filtering. Whatever the case, after transcription from analog to digital form, the data can be displayed with modern seismic imaging tools to show details that could not be seen in the [original paper recordings](#) and the initial [redisplayed sections](#).

I had to write some [custom software](#) to convert the data from their trace-streaming format on the .wav file digital image of the analog tape to a digital format recognized by modern seismic processing and display software. Once reformatted, I plotted the traces with color-coded amplitudes using a blue-white-red color scheme. The plot of the (presumably) raw traces showed distinct red and blue bands across the sections ([Figure 2a](#)). I interpreted this banding to be the result of air gun bubble oscillations.

A monochrome analog to these subtle color bands was not seen in the [original facsimile displays](#) for two reasons. First, the blue bands, the ones relating to negative signal amplitudes, were not displayed at all. Second, the red bands, from the positive signals, would have been manifested only as a single dot on any given trace. All dots were the same, i.e., they carried no amplitude information other than the indication that a signal exceeded a threshold value.

Chelminski (2011) attenuated air gun bubble noise like this with analog high pass filtering, probably during data acquisition. I tried applying a high pass filter to the digital data, and it worked reasonably well in attenuating the red and blue striping. However, I chose a different process for attenuating this phenomenon because I did not believe that the striping was truly limited to a band below 40 Hz.

In my alternative process, I summed all of the traces in a line. In this stacking process, the components of the striping added constructively while the more randomly-arriving geologic signals added to zero, at least, in principle. The normalized, stacked trace was then subtracted from each of the traces in the line. [Figure 2b](#) shows the result of the stack and subtract process. Some alternatives to this process might yield better results, but I did not investigate them. For example, instead of summing all of the traces in a line, the stacked trace to remove from any given input trace might be the sum of some set of n traces adjacent to the input trace.

In Line F (Figures 2a and 2b) as with all of the other lines, the striping pattern at the start of the line, the west (left) end in the case of Line F, is not synchronous with the pattern along the rest of the line. I do not know what caused this. It might be related to the air pressure that was available to the source at the start of recording on the line, or it might be related to the depth of the source changing as the boat came up to speed at the start of the line. Band pass filtering was somewhat more effective than the stack and subtract process in removing the striping in

these line startup segments. Summing fewer traces might have been effective in these line start segments.

The next issue to address was removal of the bubble pulse, particularly the strong first oscillation. The first cycle of the bubble pulse occurs at 26 ms after primary reflections, such as the water bottom and the Precambrian Belt floor of the basin. This time delay is consistent with [data on air gun sources](#) provided by Chelminski (2011). For sources discharged at depths of one meter or less, the first pulse of the bubble wavetrain occurs 25-30 ms after the primary pulse. A photograph provided to me by Richard Wold (2006) shows the pontoon from which the air gun was suspended. The photo suggests that the gun was suspended approximately 1 m below the surface.

The bubble pulse phase is clear in [Figure 2b](#). It can be easily traced as a relatively bright red event from shotpoint 240 to 520 following the water bottom reflection by approximately 25 ms. This phase is also visible, though perhaps less continuously, on the shotpoints higher than 520. As obvious as this phase is in the case of the strong water bottom reflection, one knows that it must be present after all of the primary reflections and, consequently, that it is causing interference throughout the seismic section. Experiments to remove this phase with classical gapped deconvolution were not successful.

As noted above, the Wold-Friedel seismic system was employed in a study at Yellowstone Lake. Otis et al. (1977) gave some details of the Yellowstone Lake survey, e.g., 4 s shot intervals and a 9 km/h (5.6 mi/h) boat speed, which agreed with the shot interval on the Flathead Lake archive tape and the apparent boat speed given the shot interval time, the number of traces in a line, and the line length scaled from the [Silverman](#) et al. (1971) map. The 4 s shot interval and the nominal 9 km/h boat speed yield reflection points spaced at 10 m intervals.

Otis et al. (1977) also mentioned the bubble pulse issue and stated that they attenuated that phase using homomorphic deconvolution, which was described in detail in Otis and Smith (1977).

I tried the homomorphic process on the Flathead Lake data, and it appeared to work fairly well. It seems to be dependent on the number of traces used in the summation in the frequency domain. Lines C, D, E, and F, which each have about 1000 traces, showed better results than Line A, which has fewer than 400 traces. [Figure 3](#) is an image of Line F after removal of the bubble pulse and application of agc. The bubble phase following the water bottom reflection is much attenuated.

Summary

Richard Wold's insightful integration of magnetic tape recording into an otherwise standard sub-bottom profiling system provided us with some data from the 1970 Flathead Lake seismic survey that we can redisplay and process with modern tools. By being able to display color-coded amplitudes, we can see geologic details that were not rendered in the displays generated

in the 1970's. With the data in digital form, we have an opportunity to enhance features through filtering, gain functions, and various forms of deconvolution. With modern software, we can also time key events such as the water bottom reflection. We can trivially double the arrival time of the water bottom reflection to make a new horizon that shows the expected arrival time of the water bottom multiple. A signal arriving at that time would, therefore, be suspected of being noise, not a primary reflection. It could be a primary reflection, but it might be a multiple.

Detecting bubble pulse phases is similar. Instead of doubling the arrival time of a primary reflection, the primary arrival time is increased by the time lag expected between primary reflections and their respective bubble phases. This technique was particularly useful in verifying the bubble pulse phase during this study.

Finally, with these few seismic images of the structure and stratigraphy below Flathead Lake, we are left to imagine what details could be extracted from data recorded with today's instruments and processed and displayed on today's computers. Positioning with GPS would be virtually absolute compared to the theodolite and sextant methods used in 1970. Multichannel recording would provide data from which multiple reflections could be more easily removed through CMP stacking or other multichannel process, and the velocity analysis for CMP stacking would provide more accurate estimates of the depths to reflectors below the lake bottom.

Perhaps the most significant value for a modern survey might be in refining previously estimated earthquake risk.

For whatever objective, as geoscientists, we are always anxious to see a better picture of the subsurface.

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Figure Captions

1. Locations of lines with digital data (after [Wold](#), 1982). This is the northern half of Wold's Figure 1 map showing the locations of the lines he used in his interpretation (dashed lines). His report shows the seismic data for Line F displayed in the facsimile style. The locations for Lines A and B (dot dash lines) were transcribed from the Silverman et al. (1971) map. Bathymetric contours are in feet. Wold credits the bathymetry to [Kogan](#) (1980), however, Kogan's source was the [Silverman](#) et al. (1971) map.
2. Line F. Both images are plotted west (left) to east (right). The color bars indicate that red is positive amplitude and that blue is negative amplitude. Labels at the top along the horizontal axis are shotpoints. Shotpoint interval is approximately 10 m. Vertical axis is time in seconds.
 - a. Raw traces with horizontal bands of red and blue caused by bubble oscillations.
 - b. Data after removal of oscillations with the stack and subtract process described in the text. With the horizontal banding attenuated, the bubble pulse that follows the water bottom reflection by 25-26 ms is clearly visible across most of the line. The bubble pulse can also be seen, though less distinctly, following the bedrock reflections between shotpoints 250 and 400.
3. Line F after removal of the bubble pulse. The water bottom bubble pulse event that was obvious in Figure 2b is significantly attenuated. Scaling is the same as in Figure 2.