

**High Resolution Seismic Reflection Survey
at Mud Mountain Dam
near Enumclaw, Washington**

Final report submitted to
U.S. Army Corps of Engineers
Seattle Engineers District
Seattle, Washington

Kansas Geological Survey
University of Kansas
Lawrence, Kansas

Open-file Report No. 95-8

March 1, 1995

**High Resolution Seismic Reflection Survey
at Mud Mountain Dam
near Enumclaw, Washington**

by

**Richard D. Miller
Joe M. Anderson
David R. Laflen
Brett C. Bennett
Choon B. Park**

of the
**Kansas Geological Survey
University of Kansas
Lawrence, Kansas**

**final report submitted to
U.S. Army Corps of Engineers
Seattle Engineers District
Seattle, Washington**

Open-file Report No. 95-8

March 1, 1995

Summary

The high resolution seismic survey consisted of two approximately 1200 ft intersecting lines, designed primarily to image the bedrock surface at between 300 and 600 ft beneath the ground surface and any acoustically significant features on or within a sequence of lake bed deposit approximately 100 ft beneath the ground surface. Consistent with the goal of the survey, the two 24-fold stacked sections possess interpretable reflections tentatively identified as an interface within the Vashon Outwash, the top of Vashon Lake Bed sequences, a cut and fill feature near the top of the Vashon Lake Bed sequence, an apparent inter-Lake Bed surface, the contact between the Lake Beds and the Mud Mountain Complex, possible contact between Hadden Creek Till, the Lake Bed, and the bedrock surface. Interpreted erosional features near the top of the lake bed sequence represent potential short path channels. The reflections have an average dominant frequency of approximately 80 Hz and an apparent NMO velocity ranging from 1600 to 3800 ft/sec. The field recording parameters and quality control were based on the reflection interpreted during walkaway tests to be from reflectors between 50 and 400 ft deep.

The primary long path bedrock channel (Big Springs Channel) may be expressed on stacked sections as a gentle westward bedrock dip near the end of line 2 and subtle undulations in the bedrock surface across most of the lines. Time-to-depth conversion suggests subtle undulation on the order of 10 to 20 ft across most of the sections with an apparent ridge possessing about 40 ft of elevation change between about CDP 260 and CDP 300 on line 2. At least three cut and fill channel looking features are present in the top of the lake bed sequence. The infill material at all three locations is relatively uniform with a lower apparent velocity than the surrounding sediments, producing an apparent pull-down in the reflection interpreted to be from near the top of the lake bed. Gravel and boulders mapped in surface exposures north and west of the lines are consistent in depth and horizontal expanse with the two larger erosional channels interpreted on the northwest end of line 1 and the east end of line 2. **Extrapolating beyond what can be justified with this data set**, it is possible to suggest that the feature on line 1 could be horizontally consistent with an exposure of gravel and boulders on the opposite side of Mud Mountain in the White River Valley walls.

Introduction

Mud Mountain Dam was originally designed in the 1930s for flood control on the White River which heads at Carbon Glacier on the flanks of Mt. Rainier. Springs, seeps, and increased material saturations were observed during periods of elevated pool levels. Considered changes to pool storage and use would require elevated pool levels more frequently and sustained for longer periods of time. The potential of a seepage-induced failure of the reservoir rim similar to the 1918 landslide at Masonry Pool on the Cedar River prompted concern for the integrity of the Mud Mountain Dam.

The two 1250 ft seismic lines were located along one active and one inactive haul road intersecting at an oblique angle north and east of the dam and approximately parallel to the current river channel (Figure 1). The primary targets of the seismic reflection survey were the bedrock surface topography and any cut/fill features within the 300 to 600 ft of unconsolidated materials that lay between bedrock and the ground surface. Imaging intra-till features in areas with near total saturation has been successfully done using basic reflection techniques in various settings in Canada (Hunter et al., 1984). The lack of saturated fine-grained surface materials drastically complicates the effectiveness and resolution potential of shallow reflection (Miller et al., 1994).

The lines were deployed (Steeple and Miller, 1990) in hopes of imaging a long path channel (Big Springs) suspected to possess at least 150 ft relative elevation difference in the top of bedrock and represents an interglacial course of the ancestral White River (U.S. Army Corps of Engineers, 1986). Of equal interest is any sub-surface expression of a localized outcrop of boulders in the side hill approximately 20 ft below and 150 ft northwest of the road where the data was acquired. A chimney sink exposed on the top of a ridge approximately 60 ft higher and 250 ft southwest of line 1 could be suggestive of deeper sediment erosion. The oblique angle of intersection between the lines should allow for a direct tie of interpreted reflection events.

The unconsolidated material that overlies bedrock as well as the topography of the bedrock surface has been influenced by multiple episodes of Pleistocene glaciation combined with periodic deposition of pyroclastic mudflows originating from the present and ancestral Mount Rainier volcanic center (Galster, 1989). The maximum depth to bedrock within the channel is 550 ft as defined by U.S. Corps of Engineers drill information. The proposed seismic line intersects the Big Springs

channel at an oblique angle. The primary short path channel is suggested to be within the Vashon outwash overlying the drill confirmed 200 ft deep and 100 ft thick Vashon lake bed and deltaic deposits. The shallow seismic reflection data possess the necessary resolution and penetration at this site to image the bedrock surface at 350 to 550 ft and resolve cut and fill features on the order of 20 ft wide and 10 ft deep.

The seismic reflection survey was conducted between August 29 and 31, 1994. The project consisted of several walkaway noise tests and two nominal 170 shot-point, 24-fold P-wave CDP lines. Line 1 was acquired in the road ditch of a frequently used logging road that possessed very unsorted till ranging from clay size particles to large boulders. Line 2 was along an unused logging road with a very hard, gravelly surface. The surface conditions were consistent for each line. No shots were recorded while background noise levels were greater than 0.2 mV peak-to-peak. A gradual surface slope resulted in about 30 ft of relative elevation change across the survey area. The field recording parameters and quality control were based on the reflection interpreted during walkaway tests on the north end of line 1 to be from reflectors about 100 and 400 ft deep. Future borehole logging, both geologic and geophysical, as well as VSPs based on the surface seismic data, should greatly enhance the quality and quantity of the seismic interpretation.

Data Acquisition

Data for this study were acquired on a 48-channel EG&G Geometrics 2401x seismograph. The seismograph amplifies, filters (analog), digitizes the analog signal into a 15-bit word, and stores the digital information in a demultiplexed format. Analog filters have an 18 dB/octave rolloff from the selected -3 dB points. The 1/2 ms sampling interval resulted in a record length of 500 msec and a 1000 Hz Nyquist frequency. A 500 Hz high-cut filter with a 24 dB/octave rolloff acted as an anti-alias filter and to reduce wind noise. This floating point seismograph possesses a dynamic range that was more than adequate to record high-quality reflection information in the presence of source-generated and cultural noise at this site.

The walkaway noise tests were conducted on the northeast end of line 1. The source (8-gauge auger gun) (Healey et al., 1991) and receivers (three Mark Products L28E 40 Hz) were selected based on field conditions and previous experience. On-site testing concentrated on source/receiver geometries and recording parameters. Test data were recorded with analog low-cut filters out, 50 Hz, 100 Hz, and 200 Hz

and source-to-receiver offsets ranging from 8 to 376 ft with adjacent stations separated by 8 ft. The analog filters effectively attenuate ground roll while increasing the dominant frequency of the reflection wavelets. The data quality was sufficient to allow selection of optimum parameters and geometries for acquisition of data at this site targeting reflectors between 50 and 400 ft deep.

Based on the walkaway data and the dynamic range of the recording instrument, the source-receiver geometry was split-spread with a source-to-nearest-receiver spacing of 20 ft and a furthest offset of 204 ft. The recording parameters included an analog low-cut filter of 50 Hz and a sampling interval of 0.5 msec. Identification of various unique arrivals on the walkaway data allowed for confident selection of parameters and geometries used for the CDP portion of the survey.

The production portion of the survey took just under 2 days and included approximately 330 shotpoints along the two lines. The 8-gauge auger gun allowed detonation of a 400 grain black powder load 2 to 3 ft below the ground surface in a water saturated, tightly stemmed 2" hole. The terrain, near-surface boulders and cobbles, as well as the trail conditions made the auger gun an acceptable source for the conditions and the required data quality. The three geophones were placed in a 3 ft in-line array to help attenuate source-generated air-coupled waves. The source was detonated in and the receivers were planted into competent material. The seismograph was configured to focus on reflections within the upper 250 msec with average velocities from 1200 to 6000 ft/sec. The pre-digital conversion spectrum was shaped with 50 Hz analog low-cut filters in an attempt to enhance the higher frequency components of the recorded energy. This emphasis on pushing the high side of the spectra was necessary if any chance was to be given to separating reflections from within the lake bed sequence and any layers that might produce a coherent reflection between the base of the lake beds and the bedrock surface.

Data Processing

Data processing was done on an Intel 80486-based microcomputer using *Eavesdropper*, a set of commercially available algorithms. The processing flow was similar to those used in petroleum exploration (Table 1). The main distinctions relate to the conservative use and application of correlation statics, precision required during velocity and spectral analysis, and extra care during muting operations. A very low percentage allowable NMO stretch (< 20%) was extremely critical in avoiding wide-angle reflections, maximizing resolution potential, and avoiding

distortion in the stacked wavelets (Miller, 1992). Many processing techniques that have not routinely been effective on shallow data sets (including f-k migration, deconvolution, and f-k filtering) were tested to evaluate their potential on this data set.

For most basic shallow high-resolution seismic reflection data the processing steps/operations are a simple scaling down of established petroleum-based processing techniques and methods. However, processes such as deconvolution have basic assumptions (Yilmaz, 1987) that are violated by most shallow data sets, this data set being no exception. Migration is another operation that, due to non-conventional scaling (vertical and/or horizontal), many times may appear to be necessary when in actuality geometric distortion may be simple scale exaggeration (Black et al., 1994). Processing/processes used on data for this report has/have been carefully executed with no *a priori* assumptions and with care not to create anything through processing, but to simply enhance and correct what can be interpreted on unstacked data.

Results

Unequivocal identification of reflection energy on field files is essential for accurate interpretation of CDP stacked sections. Raw field files acquired during the production portion of the survey from each line have identifiable reflection events between 50 and 250 msec (Figure 2). The reflections have an average dominant frequency of approximately 80 Hz and an apparent NMO velocity ranging from 1350 to 3300 ft/sec. These would result in an approximate depth to the reflector of between 40 and 400 ft. The signal-to-noise ratio on the raw field files is very good and allows confident identification of reflections on most of the raw field files.

Analysis of processed field files improves confidence in interpretation of CDP stacked sections. Digital filtering, first-arrival muting, appropriate trace balancing, bad-trace editing, and conservative application of correlation statics were key processes in improving the pre-stack appearance of coherent events interpretable on raw field files (Figure 2). The coherent events identifiable on filtered and scaled files possesses an arrival pattern consistent with the classic hyperbolic moveout of a reflection. These interpreted reflection arrivals allow significant confidence in interpreting the CDP stacked section. It is still prudent to practice care and a conservative approach to interpretations of coherent energy on stacked data.

The CDP stacked time section of line 1 possesses several interpretable reflection events (Figure 3). The dominant frequency of the stacked reflections are around 80 Hz, which represents a practical bed resolution potential of around 15 ft (Miller et al., 1995) and a horizontal resolution of just more than 100 ft. Line 1 possesses the high quality and therefore allows high confidence interpretations (Figure 4). Two cut and fill features can be interpreted on line 1, the largest beneath station 40 (CDP 280). This channel feature is around 400 ft wide at the top with a maximum depth at station 45 of around 75-80 ft. The top of the channel cannot be confidently determined, but speculation based on the hint of a reflecting event near 30 msec would place the top about 25 to 30 ft beneath the ground surface. The second cut and fill feature is beneath CDP 405 (station 102). This channel is much smaller and was the result of erosion prior to the deposition of the 60 to 70 ft deep reflector.

The stratigraphy interpreted on line 1 is generally consistent with drill information available along the rim. The red area is interpreted to be a cobble and gravel fill possibly related to the boulder deposit mapped on the side slope directly north of line 1. The purple is probably related to an inter-Vashon outwash reflector at a depth of around 30 ft. The blue and aqua reflections are probably from somewhere near the top of the Vashon Lake Bed sequences. The brown reflection is interpreted as top of the Mud Mountain Complex (MMC). The yellow reflection interpreted on the southwest end of the section may be the top of the Hadden Creek Till. The bedrock surface interpreted in orange, has no major structural features. The overall interpretation is consistent with drill information and clearly indicates that shallow seismic reflection can be effectively used to image channels in the Vashon Lake Bed sediments.

The CDP stacked time section of line 2 possess several interpretable reflection events (Figure 5). The dominant frequency of the stacked reflections is around 70 Hz, which represents a practical bed resolution potential of around 15 to 20 ft (Miller et al., 1995) and a horizontal resolution of just more than 110 ft. Line 2 does not possess the high data quality of line 1 and therefore some of the interpretations are judgments that need to be improved with drill information (Figure 6). A large cut and fill feature can be interpreted near the east end of line 2 beneath station 55 (CDP 310). This channel feature is around 300 ft wide at the top with a maximum depth at station 55 of around 80 to 90 ft. A second small feature not interpreted as cut and fill but is presumed at this point to be a data bust is located beneath CDP 415

(station 107). The diffraction looking characteristics and lack of similarities with the other three channels is the basis for this interpretation.

The stratigraphy interpreted on line 2 is generally consistent with line 1 with the exception of the proposed mound of Hadden Creek Till. The interpreted yellow is at a time depth that dictates what reflecting horizons are possible sources. The Hadden Creek is the most likely. The red area is interpreted to be a cobble and gravel fill possibly related to either the boulder and cobble drift or boulder and cobble outcrop both mapped on the side slope directly north of line 1. The purple is probably related to an inter-Vashon outwash reflector at a depth of around 30 ft. The blue and aqua reflections are probably from somewhere near the top of the Vashon Lake Bed sequences. The brown reflection is interpreted as top of the Mud Mountain Complex (MMC). The yellow reflection may be the top of the Hadden Creek Till. The bedrock surface interpreted in orange has no major structural features, only a subtle slope change beneath CDP 280. The overall interpretation is consistent with drill information and clearly indicates that shallow seismic reflection can be effectively used to image channels in the Vashon Lake Bed sediments.

Joining the two processed section at the tie point enhances the interpretation of line 2 and allows for larger trends to be observed (Figure 7). The tie point between line 1 (CDP 490) and line 2 (CDP 225) have different fold and therefore the correlation of reflections between the lines is difficult east of about CDP 270 on line 2. The low fold on line 2 is attributed to the haul road and the hard rocky fill material on the eastern end of the line. Correlating of reflection events was facilitated by character and time match between the two processed sections. The interpretation of the combined section allows for a very vivid picture of the general geometry of the material above bedrock (Figure 8). The cut and fill features seem to be consistent in terms of age and general size. The interpreted mound of Hadden Creek Till is overlain by at least part of the lake bed sequence. The decrease in bedrock elevation at approximately CDP 260 is consistent with the local well data. There is no strong evidence to support a major bedrock channel beneath the surveyed area.

An alternate interpretation of the combined stacked sections is possible (Figure 9). The tie point between line 1 (CDP 490) and line 2 (CDP 225) represent the most speculative portion of the combined interpretations (Figures 8 and 9). If the alternate interpretation is accurate, a mound of Hadden Creek Till is still present but its size is greatly reduced in comparison to the previous interpretation. The

alternate interpretation suggests a third acoustic contrast within the lake bed sequence. The nonunique appearance of the middle lake bed layer is probably a result of thinning and insufficient data resolution, therefore the apparent tuning with shallower thin sequences. The alternate interpretation suggests a slightly thinner lake bed sequence (maybe 20 ft) on the west than observed on the northeast. Other than the third distinct lake bed layer and the reduced size of the Hadden Creek Till mound, the two interpretations are identical and consistent with interpretations of surface exposures and drill holes.

Suggestions

Time-to-depth information is a very critical piece of the geophysical picture that is missing here. Attempts to acquire uphole information from borehole 23 was not successful. It would be very helpful to have a walkaway VSP to confirm interpretations presented here that are based on stacking velocities only. To determine if any commonality exists between the boulder outcrop on the north slope to the one on the south slope of Mud Mountain, another seismic line or two would be necessary to map the subsurface meander of the channel feature. If subtle bedrock features are important, a slightly higher-energy non-invasive source would probably produce slightly better penetration possibly at the expense of the higher frequencies.

References

- Black, R.A., D.W. Steeples, and R.D. Miller, 1994, Migration of shallow seismic reflection data: *Geophysics*, v. 59, p. 402-410.
- Galster, Richard W., Mud Mountain Dam: in R.W. Galster, ed., Engineering Geology in Washington, Volume I: Washington Division of Geology and Earth Resources, Bulletin 78, Olympia, WA, p. 241-248.
- Healey, J., J. Anderson, R.D. Miller, D. Keiswetter, D.W. Steeples, and B. Bennett, 1991, Improved shallow seismic-reflection source: Building a better Buffalo [Exp. Abs.]: Soc. Explor. Geophys. v. 1, p. 588-591.
- Hunter, J.A., S.E. Pullan, R.A. Burns, R.M. Gagne, and R.S. Good, 1984, Shallow seismic-reflection mapping of the overburden-bedrock interface with the engineering seismograph—Some simple techniques: *Geophysics*, v. 49, p. 1381-1385.
- Miller, R.D., N.L. Anderson, H.R. Feldman, and E.K. Franseen, 1995, Vertical resolution of a seismic survey in stratigraphic sequences less than 100 m deep in Southeastern Kansas: *Geophysics*, v. 60, in press.
- Miller, R.D. S.E. Pullan, D.W. Steeples, and, J.A. Hunter, 1994, Field comparison of shallow P-Wave seismic sources near Houston, Texas: *Geophysics*, v. 59, p. 1713-1728.
- Miller, R.D., 1992, Normal moveout stretch mute on shallow-reflection data: *Geophysics*, v. 57, p. 1502-1507.
- Steeple, D.W., and R.D. Miller, 1990, Seismic-reflection methods applied to engineering, environmental, and ground-water problems: Soc. Explor. Geophys. Investigations in Geophysics, Investigations in Geophysics no. 5, Stan Ward, ed., *Volume 1: Review and Tutorial*, p. 1-30.
- U.S. Army Corps of Engineers, 1986, *Mud Mountain Dam, Dam Safety Assurance Program, General Design Memorandum No. 26, Supplement No. 1, Core of Dam, Seepage Control Measures*: U.S. Army Corps of Engineers, Seattle District, Seattle, CA, 269 p., 16 plates.
- Yilmaz, O., 1987, Seismic data processing; S.M. Doherty, Ed.; in Series: Investigations in Geophysics, no. 2, Edwin B. Neitzel, Series Ed.: Soc. of Explor. Geophys., Tulsa, Oklahoma.

TABLE 1

Processing flow

Primary Processing

format from SEG2 to KGSEGY

preliminary editing (automatic bad trace edit with 10 msec noise window)

trace balancing (150 msec window)

first arrival muting (direct wave and refraction)

surgical muting (removal of groundroll based on trace-by-trace arrival)

assign geometries (input source and receiver locations)

elevation correction to multiple, floating datums

sort into CDPs (re-order traces in common midpoints)

velocity analysis (whole data set analysis on 100 ft/sec increments)

spectral analysis (frequency vs amplitude plots)

NMO correction (station dependent ranging from 1350 to 2,500 ft/sec)

correlation statics (2 msec max shift, 7 pilot traces, 100 msec window)

digital filtering (bandpass 25-50 250-375)

secondary editing (manual review and removal of bad or noisy traces)

CDP stack

amplitude normalization (whole trace with 40 msec delay)

correct to flat datum (48 ft above sea level)

display

Secondary Processing

f-k filtering

f-k migration

deconvolution (spiking and second zero crossing)

Table 1. Processing flow for CDP stacked data. Parameters were determined by analysis for each prior step as well as through iterative analysis of particular operations.

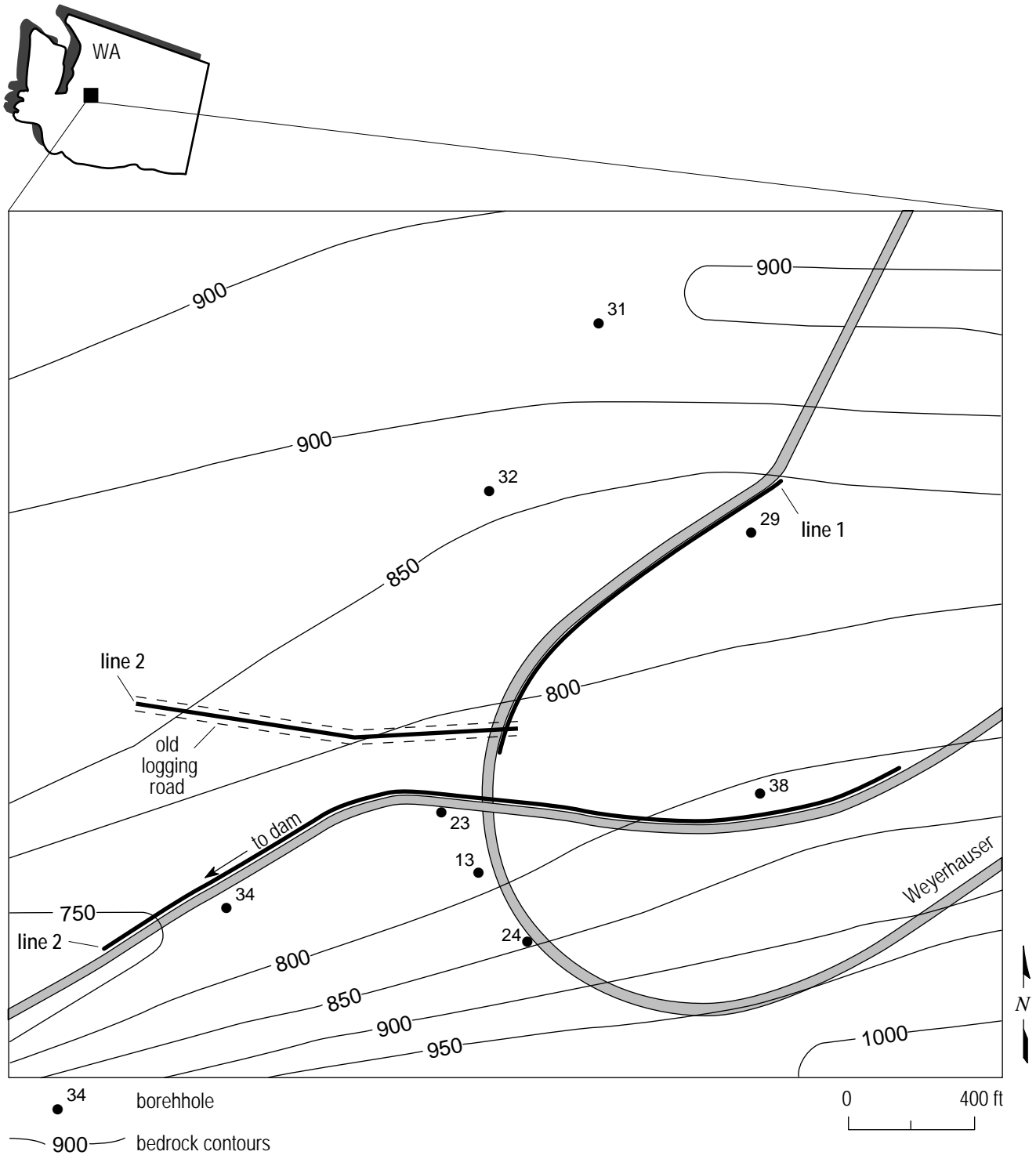


Figure 1. Site map indicating the relative location and orientation of the survey lines and bedrock elevations.

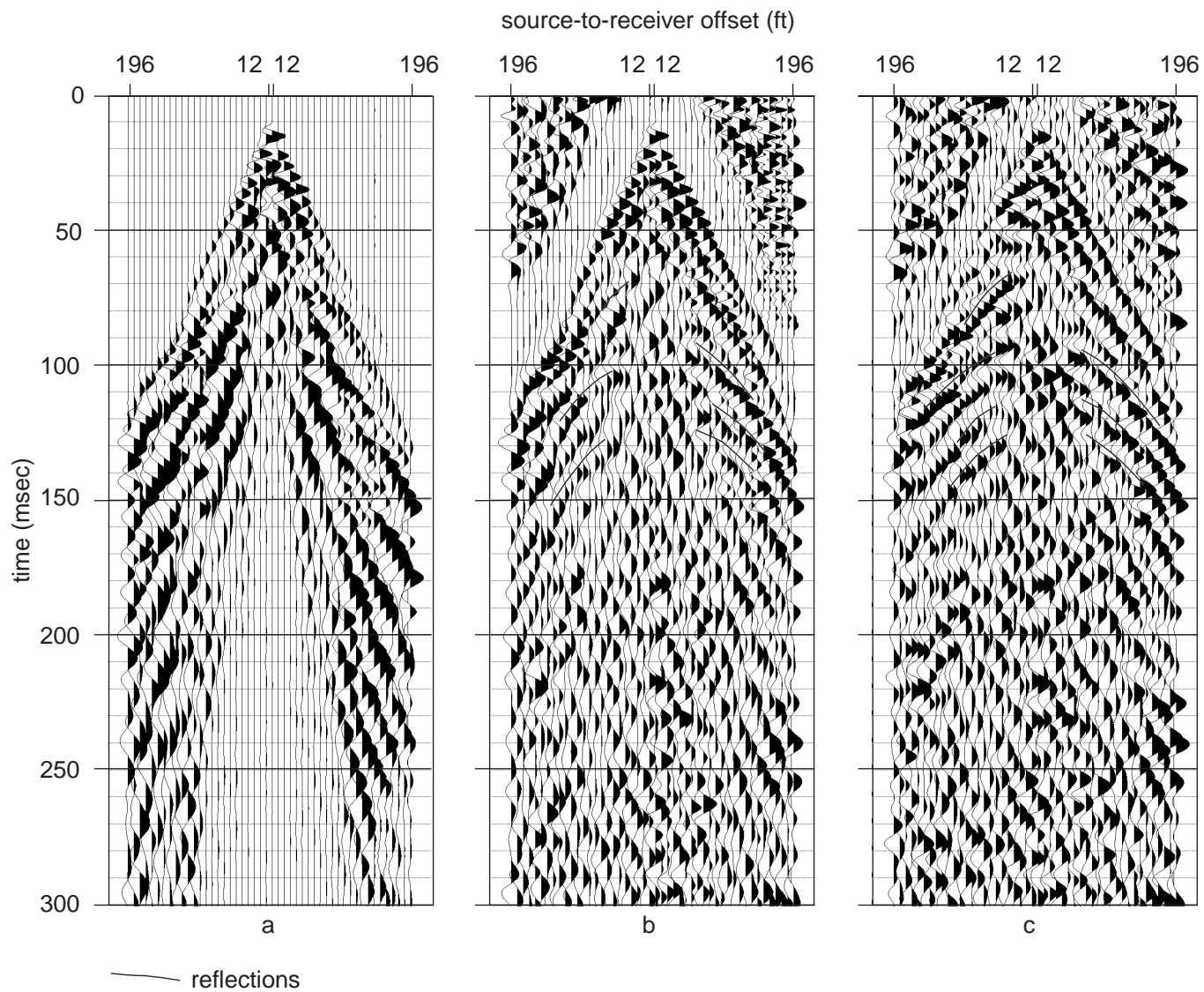


Figure 2. 48-channel field file: a) raw shot gather, b) filtered and scaled, and c) filtered, scaled, and F-k filtered.

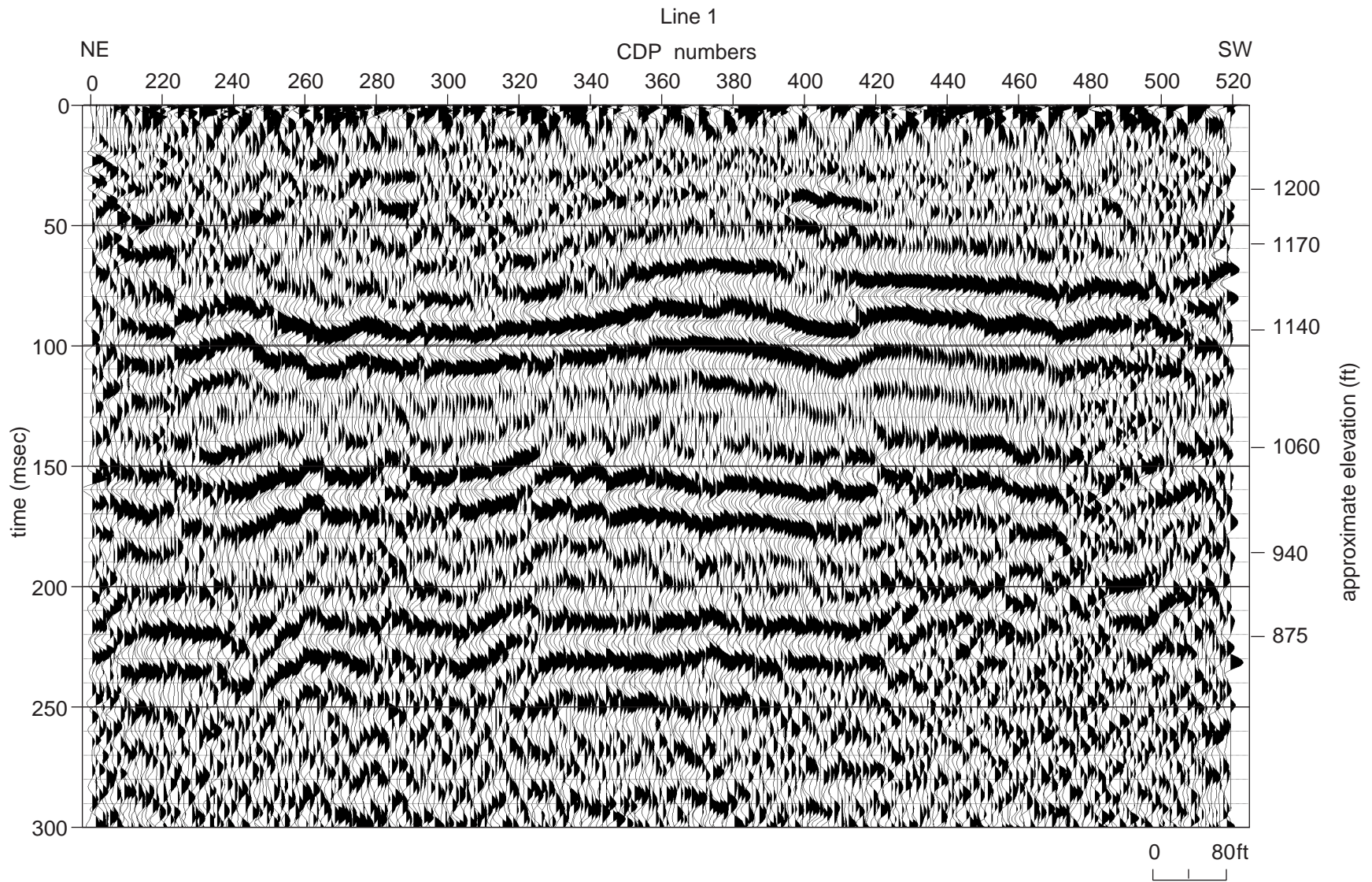


Figure 3. 24-fold CDP stack of line 1.

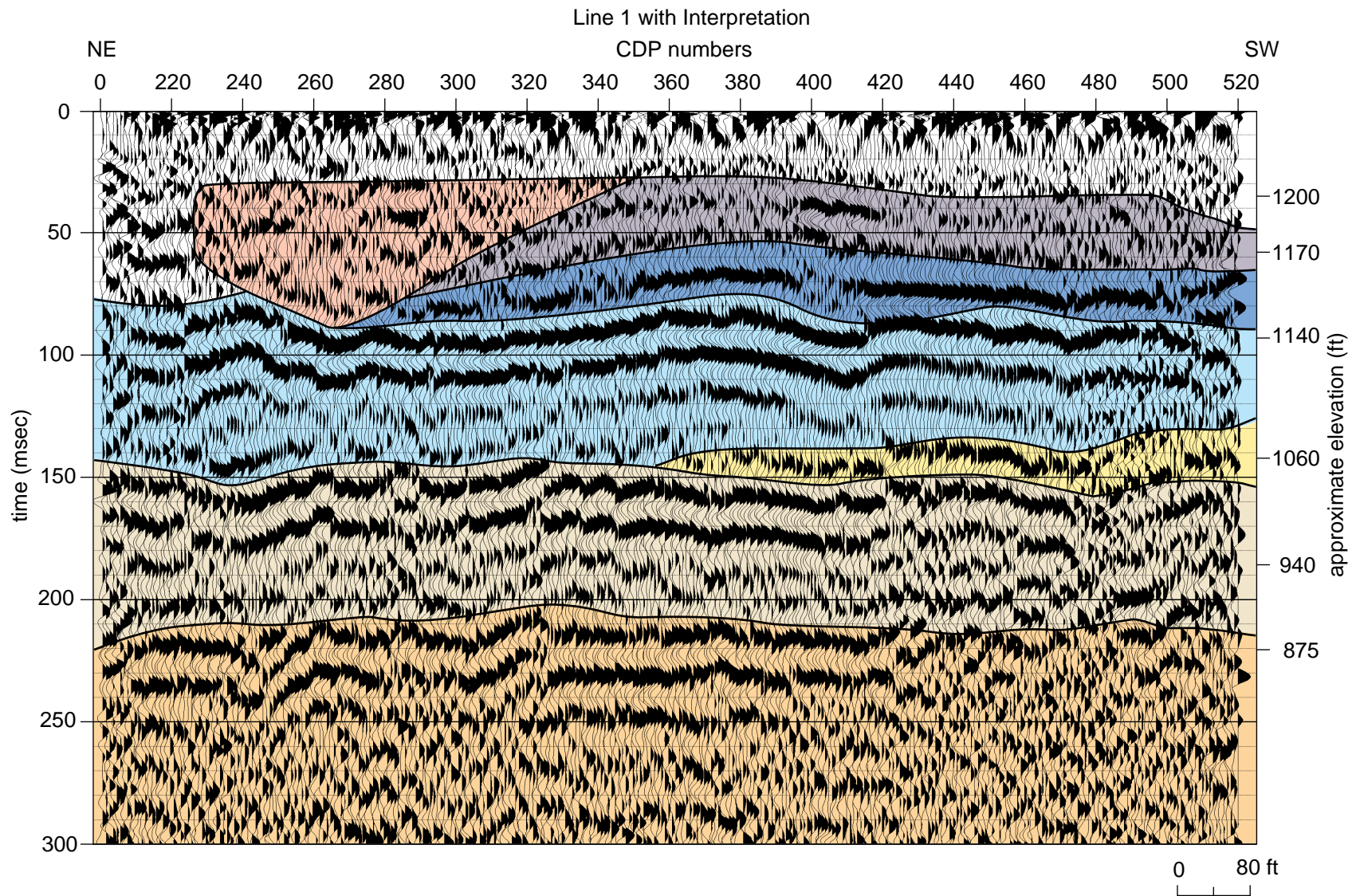
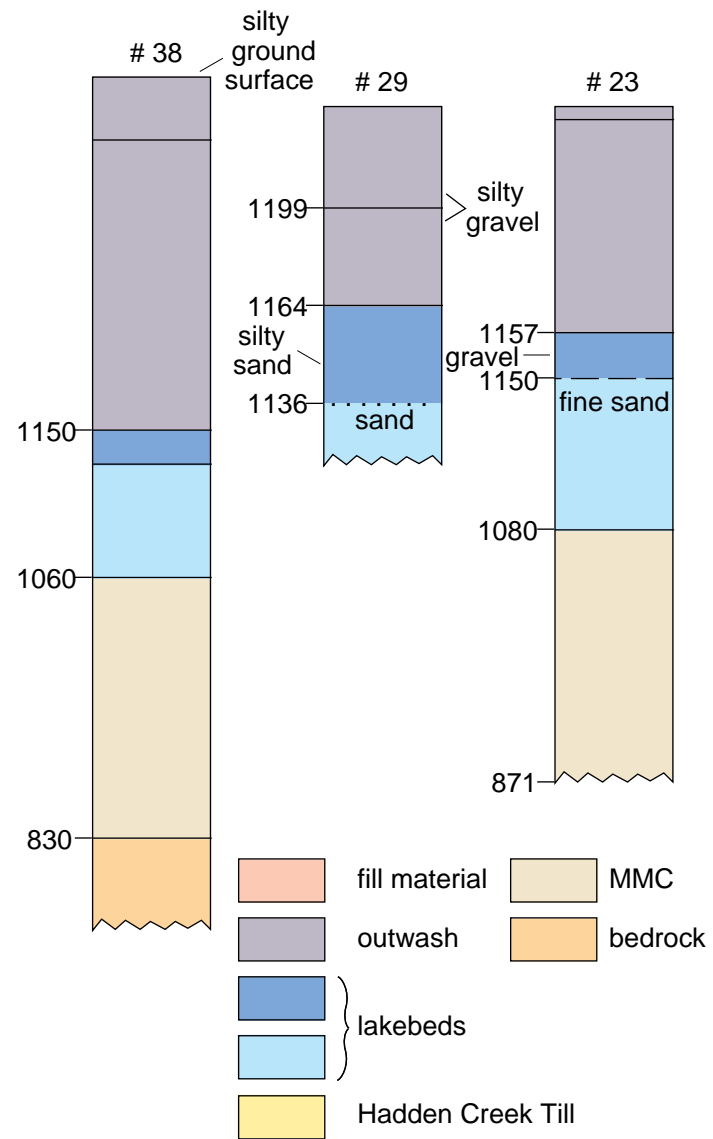


Figure 4. Line 1 with interpretation.



Based on wells # 38, # 29, and # 23.

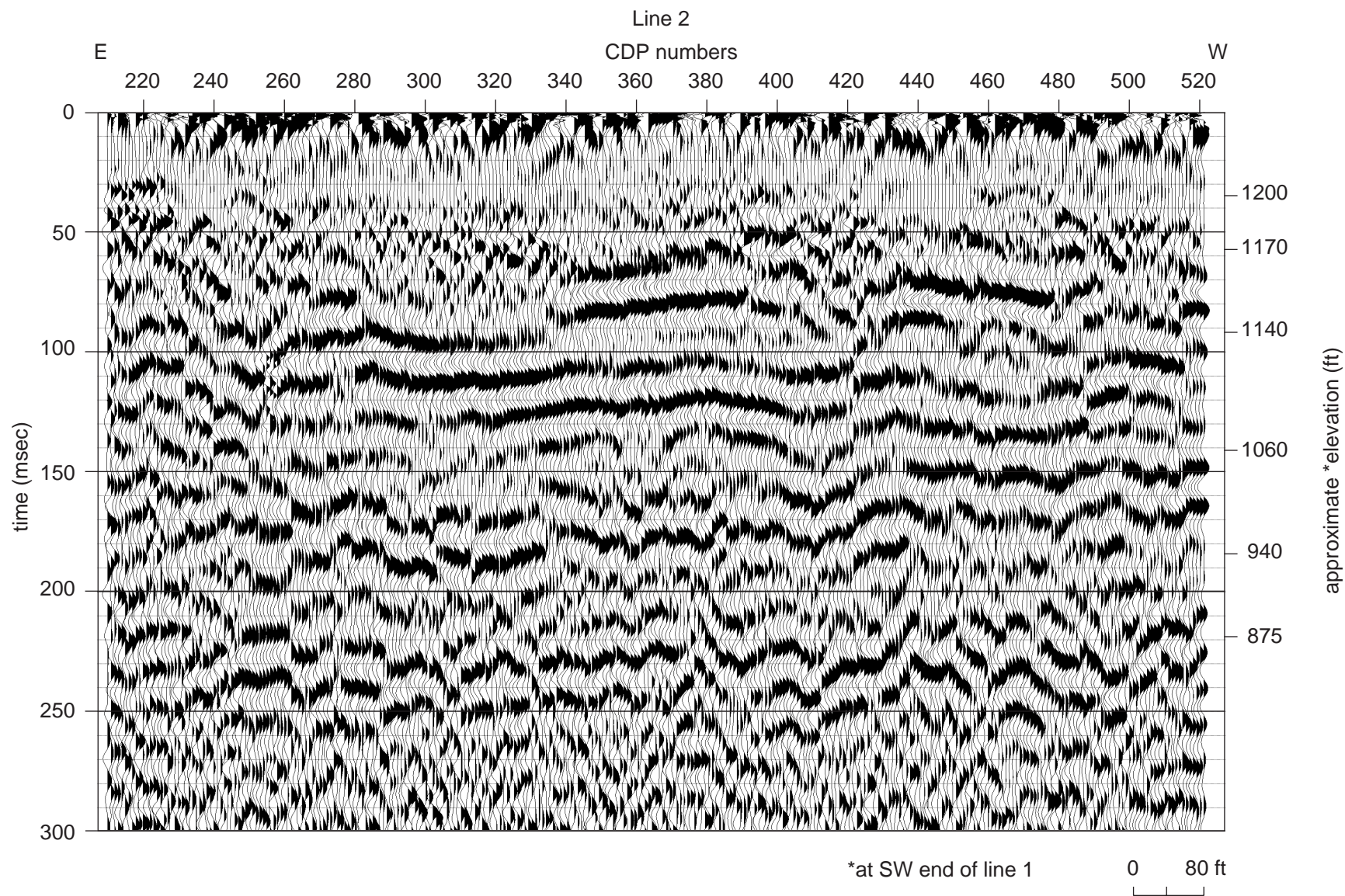


Figure 5. 24-fold CDP stack of line 2.

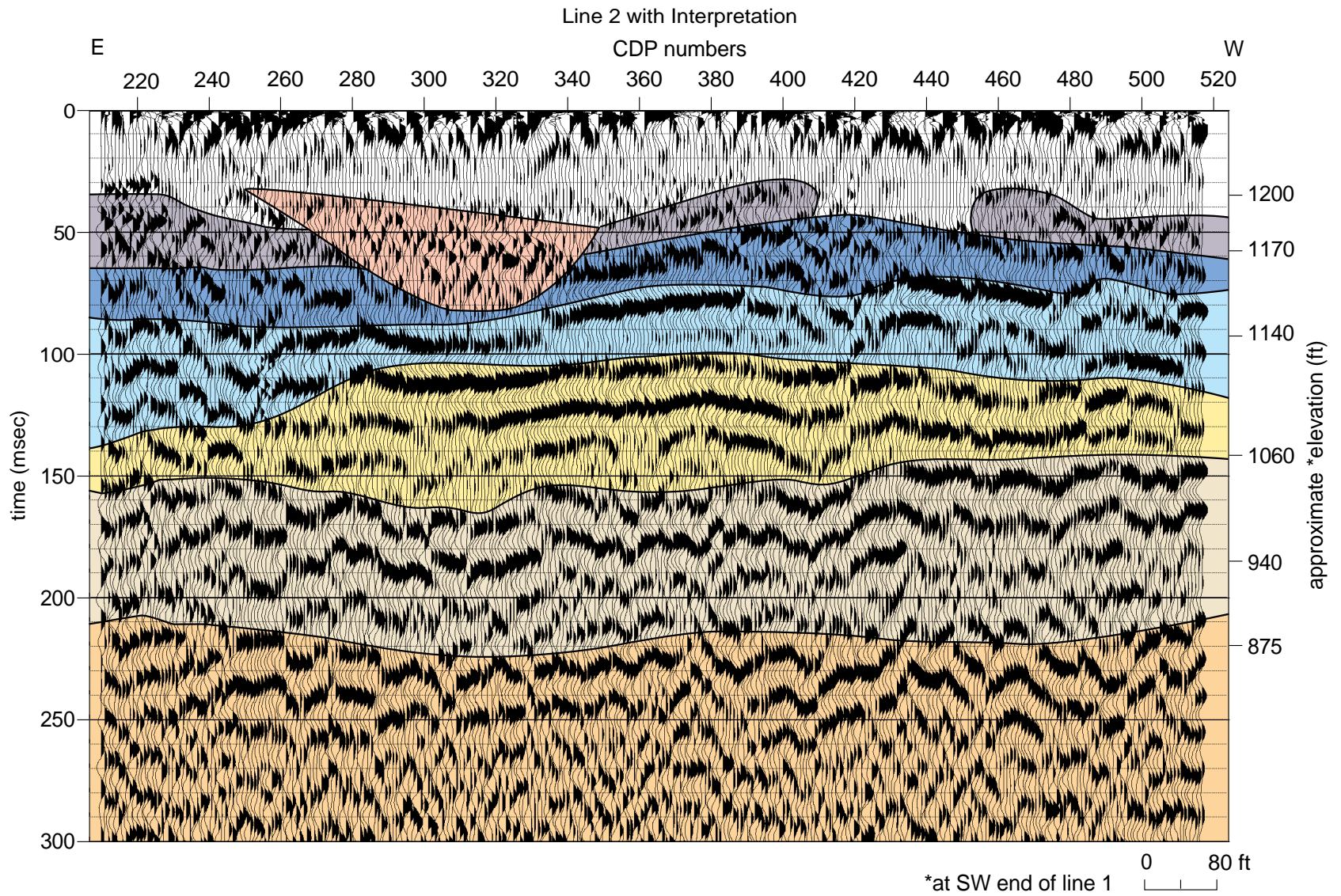
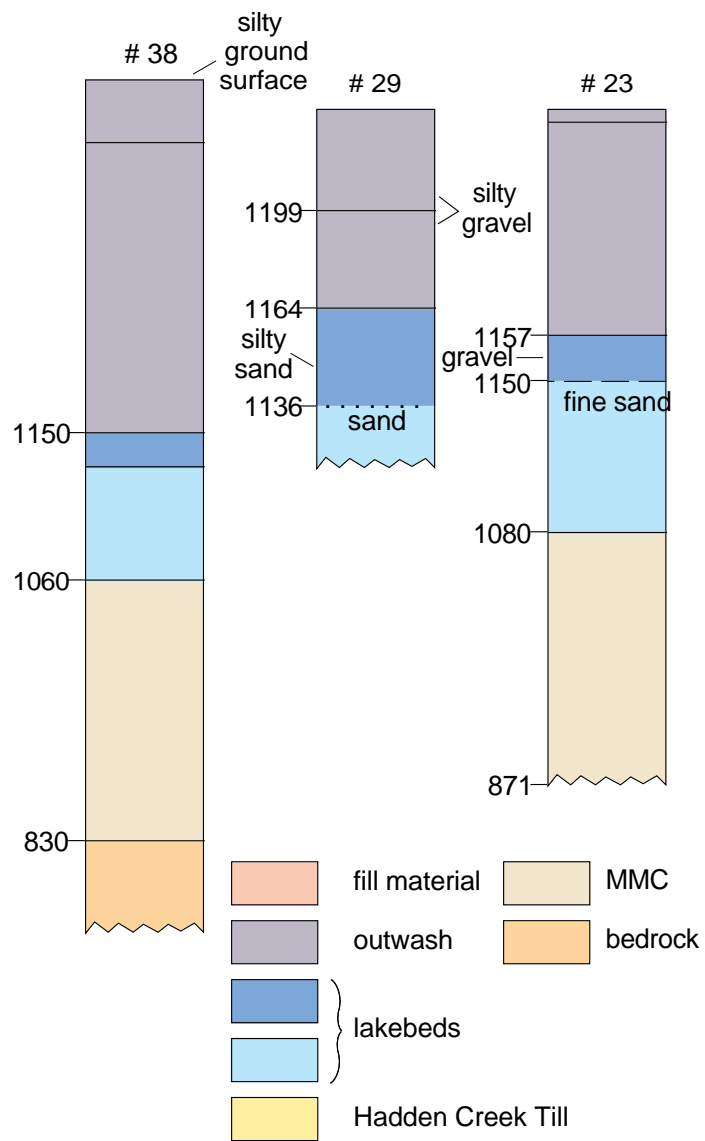
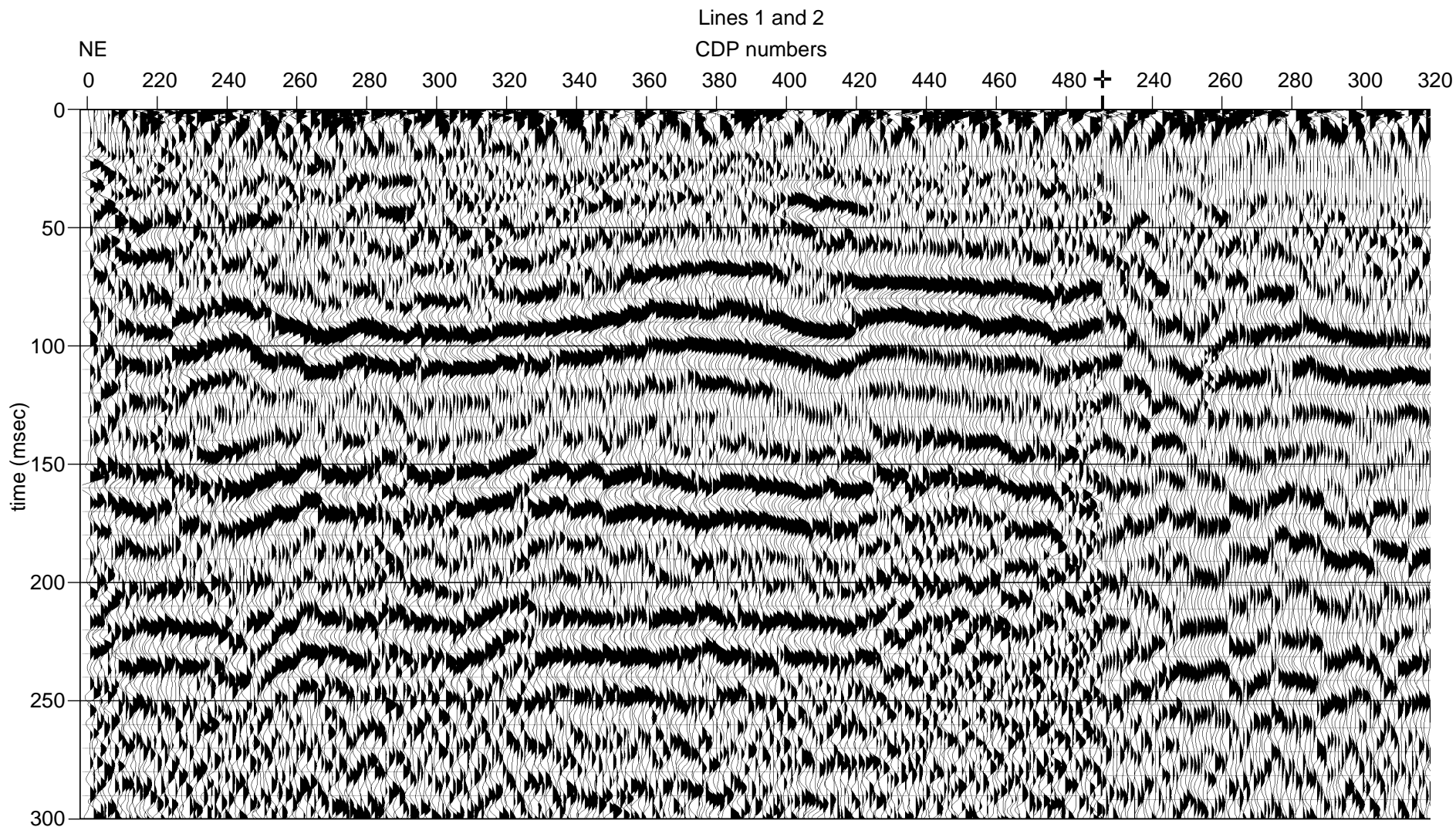


Figure 6. Line 2 with interpretation.

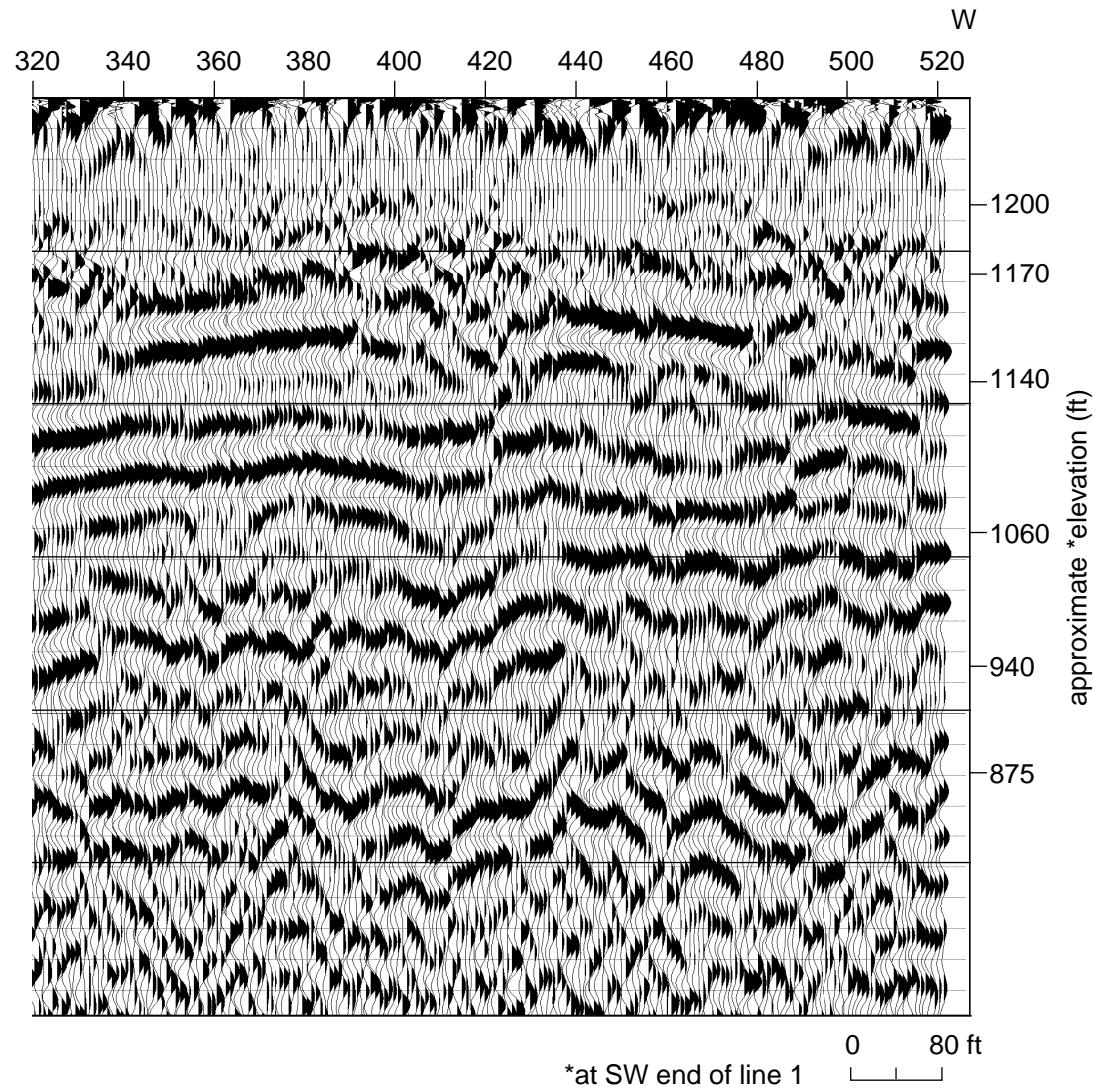


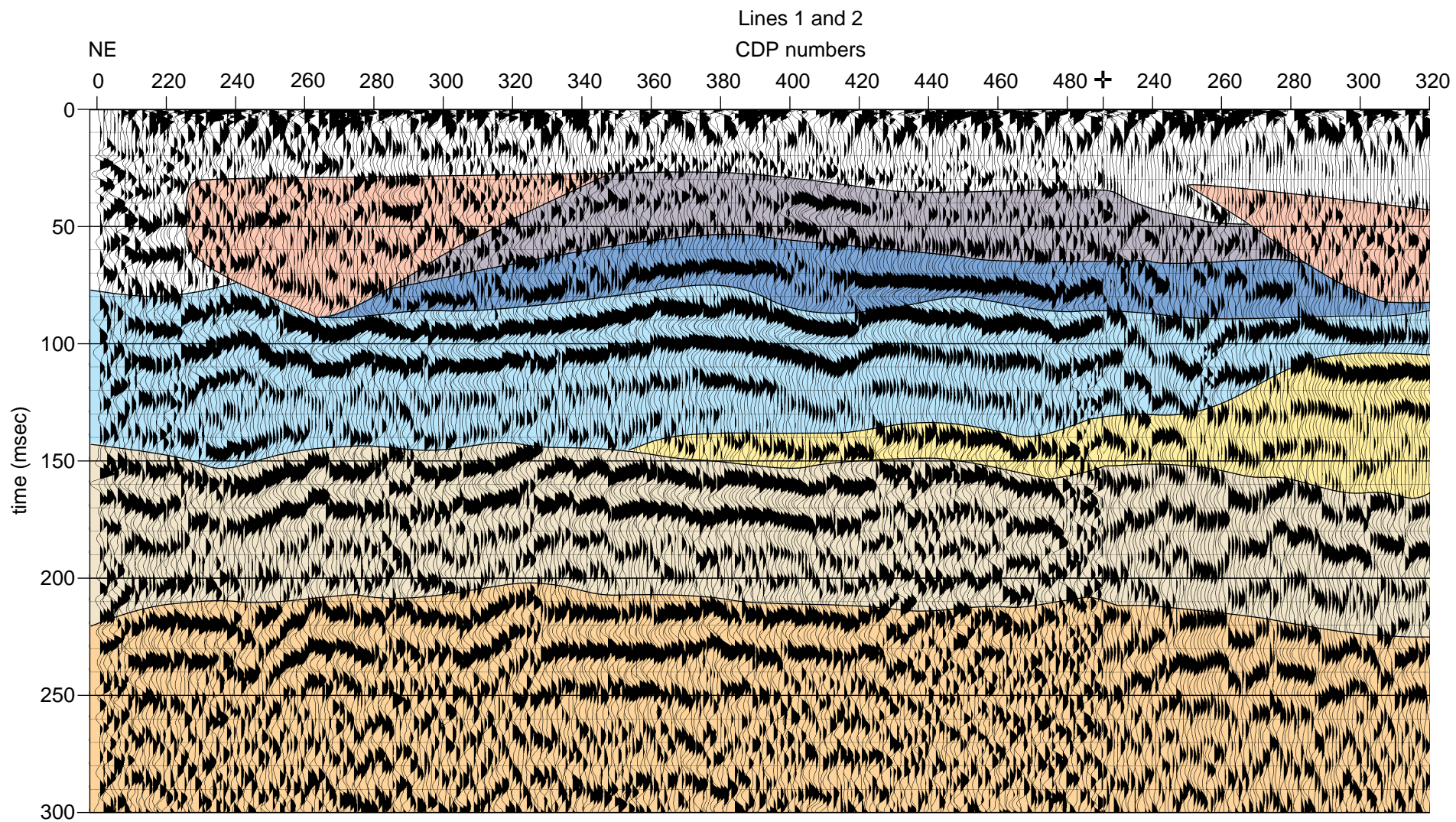
Based on wells # 38, # 29, and # 23.



+ tie point line 1 and 2
| graphically sutured

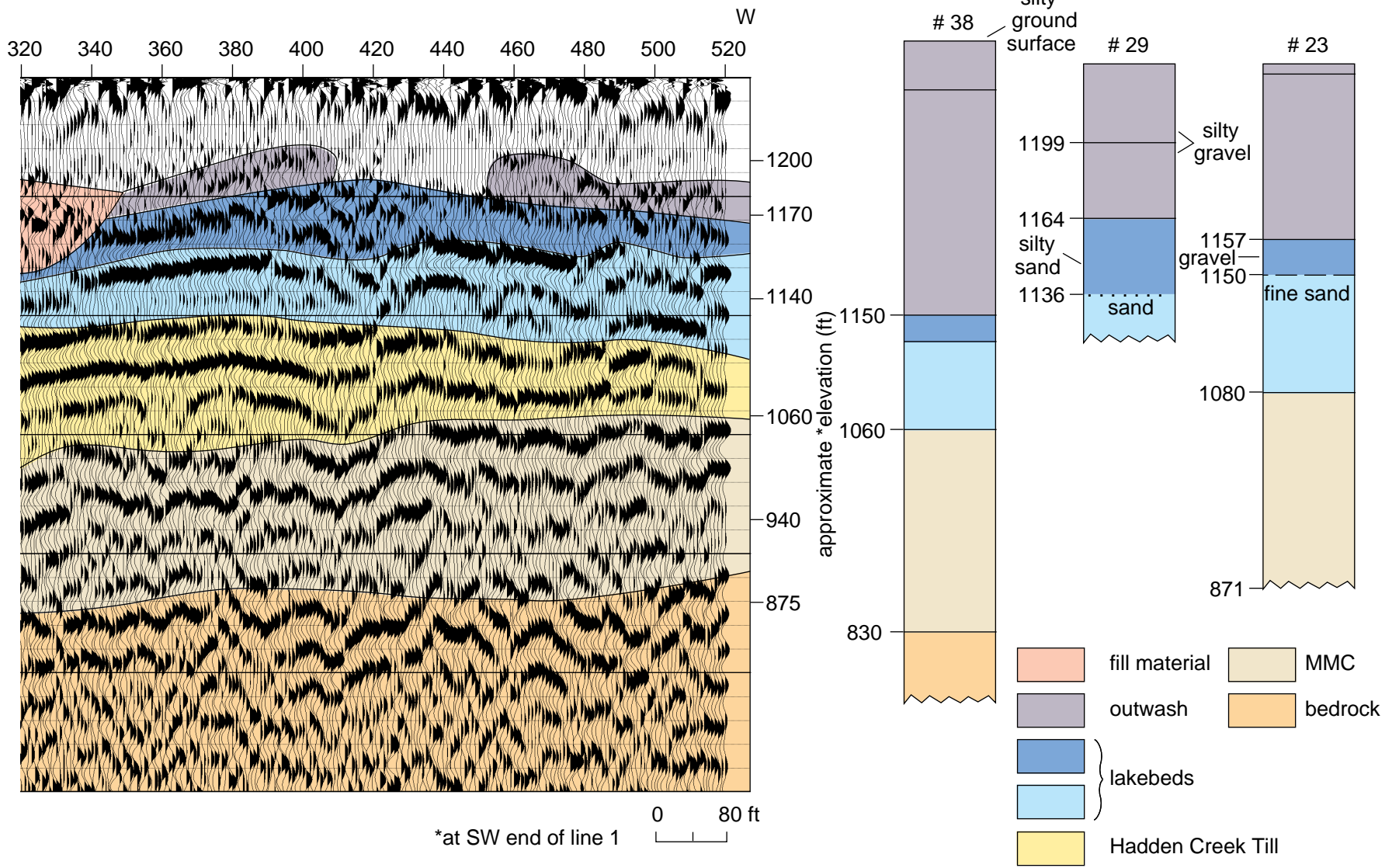
Figure 7. Lines 1 and 2 joined at the tie point between line 1 (CDP 490) and line 2 (CDP 225).





+ tie point line 1 and 2
 | graphically sutured

Figure 8. Lines 1 and 2 with interpretation joined at the tie point between line 1 (CDP 490) and line 2 (CDP 225).



*at SW end of line 1

0 80 ft

Based on wells # 38, # 29, and # 23.

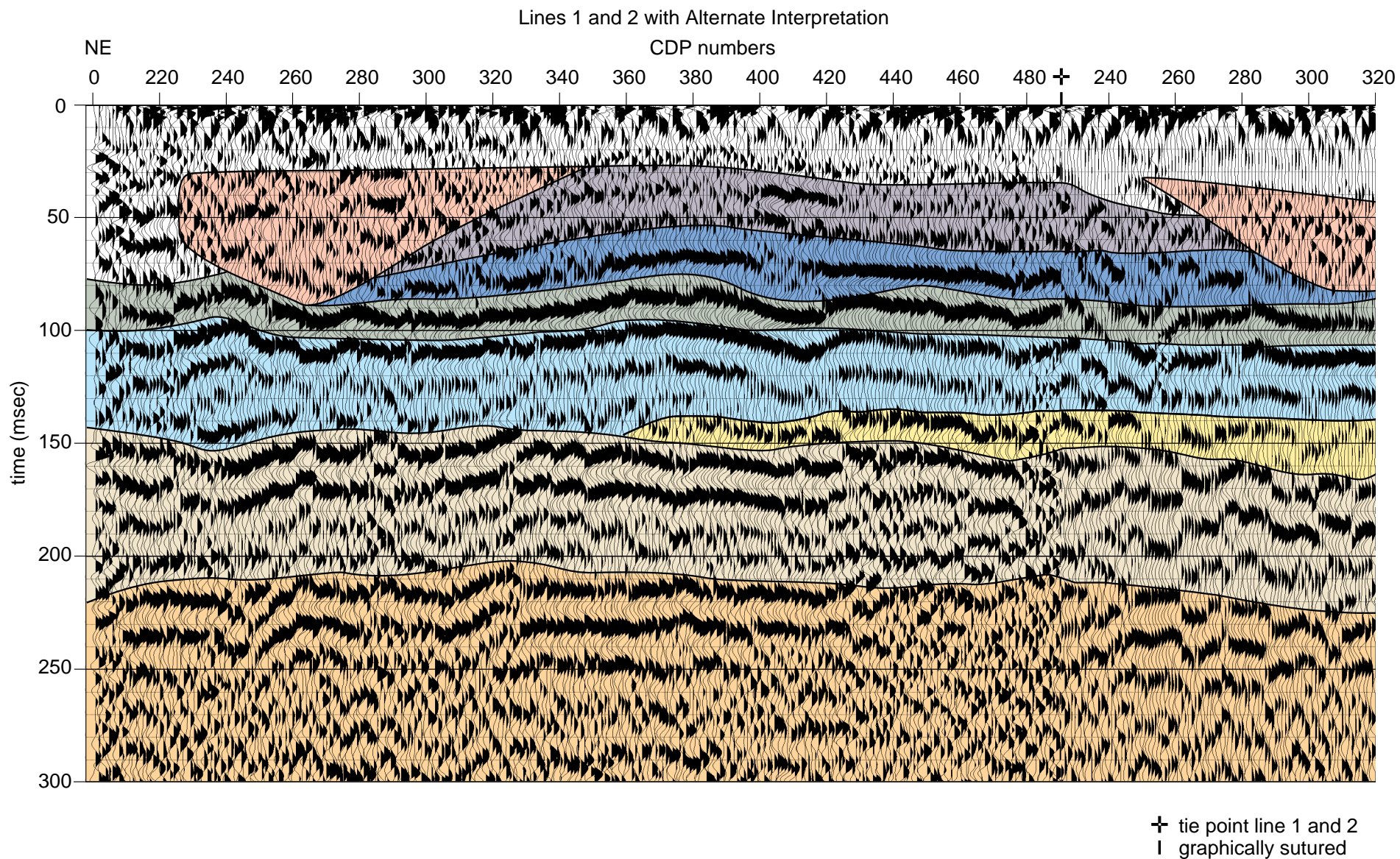
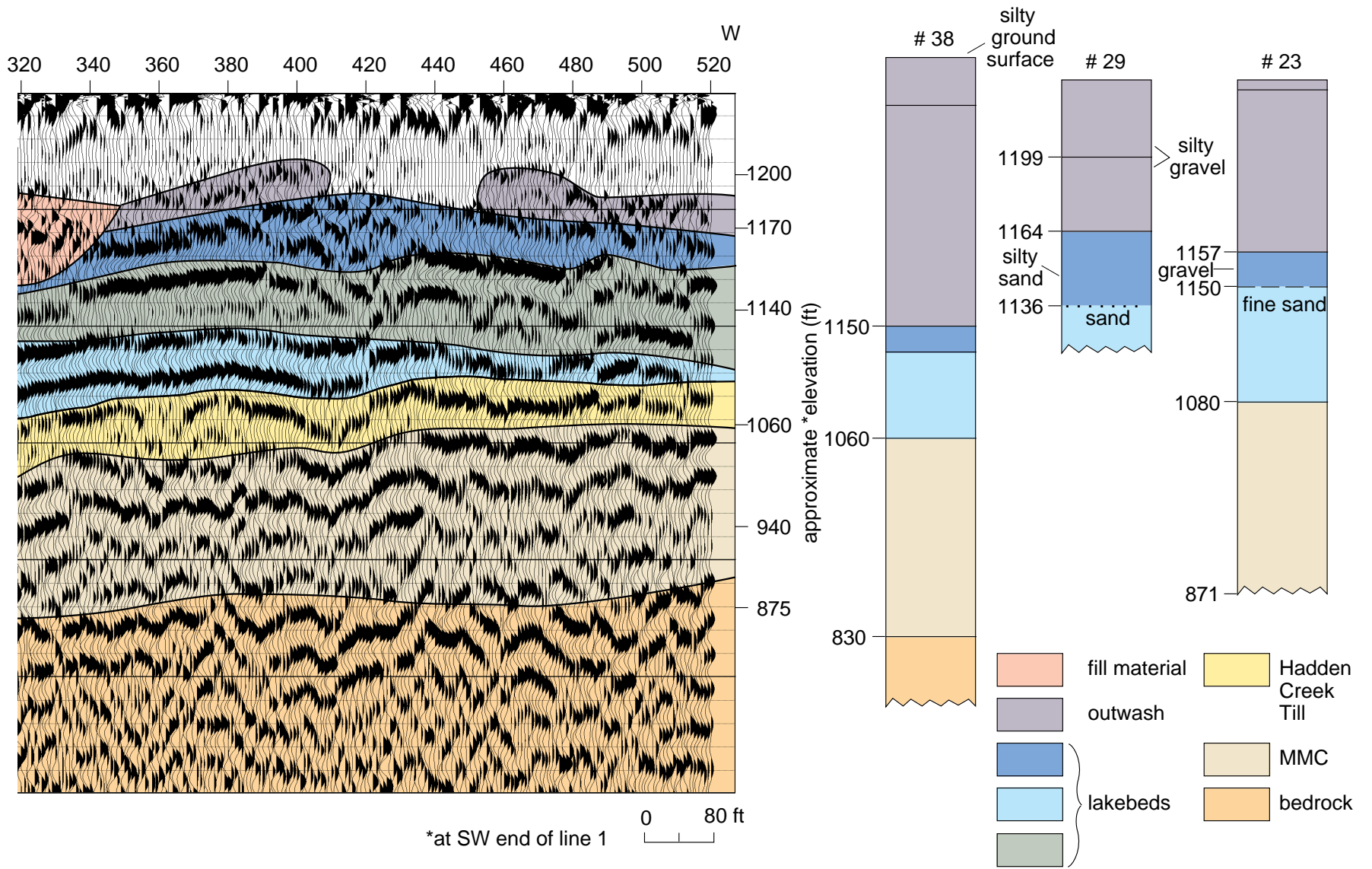


Figure 9. Lines 1 and 2 with alternate interpretation joined at the tie point between line 1 (CDP 490) and line 2 (CDP 225).



*at SW end of line 1

0 80 ft

Based on wells # 38, # 29, and # 23.