APPENDIX A

Final Report Shallow Seismic Survey
Piñon Ridge Project, Montrose County, Colorado

FINAL REPORT
SHALLOW SEISMIC SURVEY
PINON RIDGE PROJECT
Montrose County, Colorado

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FINAL REPORT
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SUMMARY

A shallow seismic survey, using both refraction and reflection methods, was carried out in the Pinon Ridge project area during the autumn of 2007. The purposes were (1) to determine the location of a major fault zone (indicated by drilling) between evaporite-bearing Paleozoic rocks and Mesozoic rocks which do not have significant evaporite content, (2) to determine if faults of Recent (less than 11,000 years ago) displacement are indicated and (3) see if any evidence could be obtained regarding ground water in the area.

The survey has apparently shown the location of the major fault zone between Paleozoic and Mesozoic rocks, has suggested that few if any Recent faults are present in the project area and has suggested possible limits for the area of groundwater found by Monitor Well MW-6.

INTRODUCTION - During the autumn of 2007 an extensive shallow seismic survey was carried out in the area of the Pinon Ridge Project, Sections 5, 8 and 17, Township 46 North, Range 17 West, Montrose County, Colorado. The survey consists of three seismic lines, each slightly over a mile in length, arranged in something of a fan shape (see Figure 1). The lines are designated, from west to east, S-1, S-2 and S-3.

The purposes of the survey were to trace the top of bedrock (Paleozoic and Mesozoic rocks), determine what faults might be detected and whether any of the faults might have Recent (during the last 11,000 years) movement. Of particular interest was the boundary between Paleozoic gray shales and evaporites to the north and red and brown sandstone, siltstone and shales of Mesozoic age to the south. Also of interest was any information regarding ground water in the area.

METHOD - The technique used was Geological Associates' combined refraction and reflection system, which utilizes an accelerated weight-drop source ("thumper") and a "landstreamer" receiver array to produce 12-fold shallow reflection seismic and multi-fold refraction coverage.

A recording sequence begins with the instrument operator and the thumper operator chaining out a set of drop points, using a surveyor's tape. Twenty successive drop or source points are measured 16.4 feet (5 meters) apart along the assigned seismic line and marked with pin flags.

The instrument operator then drives the seismic truck forward until the thumper operator signals that the thumper is even with the first pin flag. A thick aluminum plate is placed under the thumper weight

position. The thumper, a Gisco ESS-100 elastic wave generator, is then operated, introducing about 1,000 foot pounds of energy into the earth. Typically, four "thumps" are recorded and summed at each drop point, for a total energy input of about 4,000 foot pounds per drop point. If indicated by the seismograph monitor, more thumps may be used.

The returned seismic energy is then recorded digitally, field notes are written, and the truck driven to the next drop point, where the process is repeated. Fixed gain and out-out filters are used, with one millisecond sample interval and one second record length. Notch filters may be used if there is evidence of AC current interference. After completion of the recording of the twenty records, the pin flags are recovered and the process repeated, beginning again with the measuring out of twenty positions. A wooden stake marked with the line and station identification is driven into the ground beside the trail each 20 stations to allow later surveying or position recovery.

The receiver array consists of a series of 12 receivers or geophones attached to a "landstreamer" or cable towed behind the seismic truck. The geophones are spaced 32.8 feet (10 meters) apart along the landstreamer, with the first geophone being 32.8 feet (10 meters) behind the thumper position. The receiver array is thus 393.6 feet (120 meters) long.

After the recording of a seismic line is completed, the data are brought to Geological Associates' Albuquerque office for processing, analysis and interpretation.

The refraction results are converted into reversed refraction profiles by the Dix-Reynolds method and analyzed using Rimrock Geophysics' SIP computer system. Usually about each tenth refraction profile is analyzed; this means a new refraction profile is analyzed each 164 feet (50 meters). More closely spaced refraction profiles may be analyzed for special cases, such as studying a fault zone or a buried stream channel.

The reflection data are processed using software written by ourselves specifically for results of this seismic system. The normal series of steps, and that used for this project, include removal of headers, reformatting to one-half second records (still at one millisecond sampling rate), muting to remove refractions and groundroll (in this case from zero on the near trace to 159 ms on the far trace), normal moveout removal (in this instance at a fixed velocity of 3,000 ft/sec), 12-fold CDP stacking, filtering 50-240 Hz and plotting record sections 0.250 seconds long, with variable area plotting.

RESULTS - The refraction data quality is uniformly good, except for the first few days' recording on line S-1, when wind noise reduced the data quality. Even these records, however, have useable refraction breaks. The plotted results of the analysis of the refraction data are shown by Figure 2, which shows plots of the calculated refractors, indicating depth, form, and velocity in feet per second. Note that the horizontal and vertical scales used produce a vertical exaggeration of 4:1, which causes dips and forms to appear much exaggerated. This was necessary because, at a scale of 1:1, the data would be very crowded near the surface, making details difficult to see.

The reflection data quality varies from one line to another, as can be seen by examination of Figure 3. Line S-1 is the best; both Lines S-2 and S-3 are of lesser quality, but are definitely useable. There is vertical exaggeration here also, about 2.5:1. The gap in Line S-2 at

about Stake 13 was caused by the loss of survey stakes from this area when the line was extended south; the existence of the gap was not discovered until after completion of the survey.

INTERPRETATION - Two features of the refraction data (see Figure 2) are particularly useful in this study of the Pinon Ridge Project. The first is that there are stretches of apparently unbroken shallow refractors. For example, on Line S-1 from about Station 235 to about Station 285, there appears to be an unbroken refractor at a depth of about 10-15 feet (see Figure 2). This tends to preclude the possibility of a Recent fault cutting this line in this interval.

The second factor which is especially useful about the refraction data is that in the northern part of all three seismic lines there are refractors which exceed 10,000 ft/sec. This is significant because the drilling done in the area did not encounter large bodies of either carbonate rocks or quartzite, which could have velocities greater than 10,000 ft/sec, but did encounter large bodies of evaporites (anhydrite and gypsum) which could easily exceed 10,000 ft/sec in velocity. As a consequence, refractors calculated to have velocities greater than 10,000 ft/sec are interpreted as probably being evaporites (see red-marked refractors on Figure 2). The southern limit of these high-velocity refractors is interpreted as probably marking the southern limit of the evaporites, and thus probably showing the southern limit of the Paleozoic strata in the project area.

Figure 4 shows the reflection data as interpreted. The yellow horizon is believed to be the reflection from the top of bedrock. It is characterized by a lower frequency and higher amplitude than the events above it (see Figure 3). There appears to be a large number of possible faults cutting this reflection (steep red and black lines). The most outstanding possible fault zone is the one, shown as three faults, at about Reference Stake 7 on Lines S-3 and S-2 and at about Stake 6 on Line S-1. This major fault zone apparently has large down to the south displacement at the top of bedrock on Lines S-3 and S-2, and less displacement on Line S-1. The most southerly of the three faults shown as making up the fault zone appears to be the southern limit of the high velocity refractors (compare with Figure 2), and hence may mark the contact between evaporite-bearing Paleozoic rocks to the north and the Mesozoic sandstones, siltstones and shales to the south.

Many of the lesser interpreted faults shown on Figure 4 can be eliminated as having no Recent displacement by examination of the shallow refractions above the top of bedrock (compare with Figure 2). Interpreted seismic faults which might have had Recent movement are marked by heavy red lines on Figure 4.

Figure 5 shows in generalized form the vertical seismic velocity through the alluvium necessary to make the interpreted top of bedrock reflection (yellow horizon on Figure 4) tie satisfactorily to the nearby drill holes which penetrated the top of bedrock. The smoothed velocity contours of Figure 5 decrease from over 3,000 ft/sec at the southern edge of the project area to less than 1,600 ft/sec at the north. This northward velocity decrease may reflect increasing sediment fineness with increasing distance from the high terrain to the south (and perhaps northward decreasing moisture content) of the alluvium above bedrock.

Figure 6 is a structure map with contours on the top of bedrock, based on drill hole and seismic data. The area of deepest bedrock (thickest alluvium) appears to be in the southern part of the area, probably mainly reflecting proximity to sediment source. The highest area of bedrock (thinnest alluvium) appears to be in the west-central part of

the project area, where Drill Holes PR1-9 and PR1-12 encountered bedrock at 30 feet of depth; Seismic Line S-2 shows depth of less than 30 feet in the vicinity of Reference Stake 6.

Drill Hole PR1-11, in which bedrock was reported at 85 feet, is clearly located within the major fault zone, and may even have encountered fault gouge above bedrock. It is also possible that a stream bed might have followed the fault zone, as possibly suggested by a concave-upward refraction at about 50 feet of depth between Stakes 7 and 8 on Line S-2 (see Figure 2).

Figure 6 shows the interpreted faults which appear to cut the top of bedrock where there are no unbroken refractors or reflectors above bedrock and hence might possibly have had Recent displacement (red lines). There also appear to be a number of small faults north of the major fault zone on Line S-2, a few on Line S-1 and none on Line S-3 (see Figure 4). These small faults may be the result of collapse due to dissolution of evaporites. This would probably have occurred during times wetter than at present, which is likely to have been during the last ice advance more than 12,000 years ago. The refraction data on Line S-2 between Stakes 3 and 4 show a funnel shape, narrowing downward, which sometimes characterizes sink holes. As there is no topographic expression of a sink hole here, if this is a sink it must have been inactive for a considerable amount of time.

Of the wells drilled in the project area, only MW-6, in the southeast part of the area, encountered water. The water may be confined to the fault block in which MW-6 was drilled (see Figure 6), or it might extend north to the major fault zone, where the Mesozoic aquifer is presumably terminated. Drill Hole MW-5, in the southwest part of the project area, was evidently drilled in the next fault block south, and did not encounter water. No drill holes south of the major fault zone, however, were drilled as deep as the aquifer of MW-6 except MW-5, so it is possible that the water may be limited to the south by the fault between MW-6 and MW-5 and to the north by the major fault zone. This would seem perhaps to be in keeping with the high sulfate content of the MW-6 water; the water could have come over or passed through the gypsum and anhydrite-bearing rocks north of the major fault zone. Accordingly, the drilling of a deep well to the aquifer zone in the area between the MW-6 fault block and the major fault zone might be advisable, to determine the limits of the water-bearing area.

CONCLUSIONS - The following conclusions appear to be merited on the bases of the geological and seismic evidence:

1. The evaporite-bearing Paleozoic rocks appear to be limited on the south by the major fault zone (see Figure 6),

2. The top of bedrock, at a depth of 25-90 feet, appears to be cut by many small faults, though few appear likely to reach shallow enough depth to indicate Recent displacement (see Figures 4 and 6),

3. The vertical seismic velocity through the alluvium above bedrock seems to decrease northward, away from the high terrain to the south (see Figure 5), and

4. The water encountered in Drill Hole MW-6 appears to be limited on the south by a fault between MW-6 and MW-5, and might extend as far north as the major fault zone, where the aquifer is apparently terminated.

3. The vertical seismic velocity through the alluvium above bedrock seems to decrease northward, away from the high terrain to the south (see Figure 5), and

4. The water encountered in Drill Hole MW-6 appears to be limited on the south by a fault between MW-6 and MW-5, and might extend as far north as the major fault zone, where the aquifer is apparently terminated.

RECOMMENDATIONS - The following suggestions are offered for consideration:

1. The faults which might have had Recent movement (see Figure 6), including at least some of the numerous small faults suggested on Line S-2 north of the major fault zone, should be considered for further investigation by trenching, and

2. A deep drill hole north of the MW-6 fault block and south of the major fault zone (for instance, near Stake 9 on Line S-2) should be considered for drilling to determine whether the water area extends as far north as the major fault zone.

Respectfully submitted,

Charles B. Reynolds

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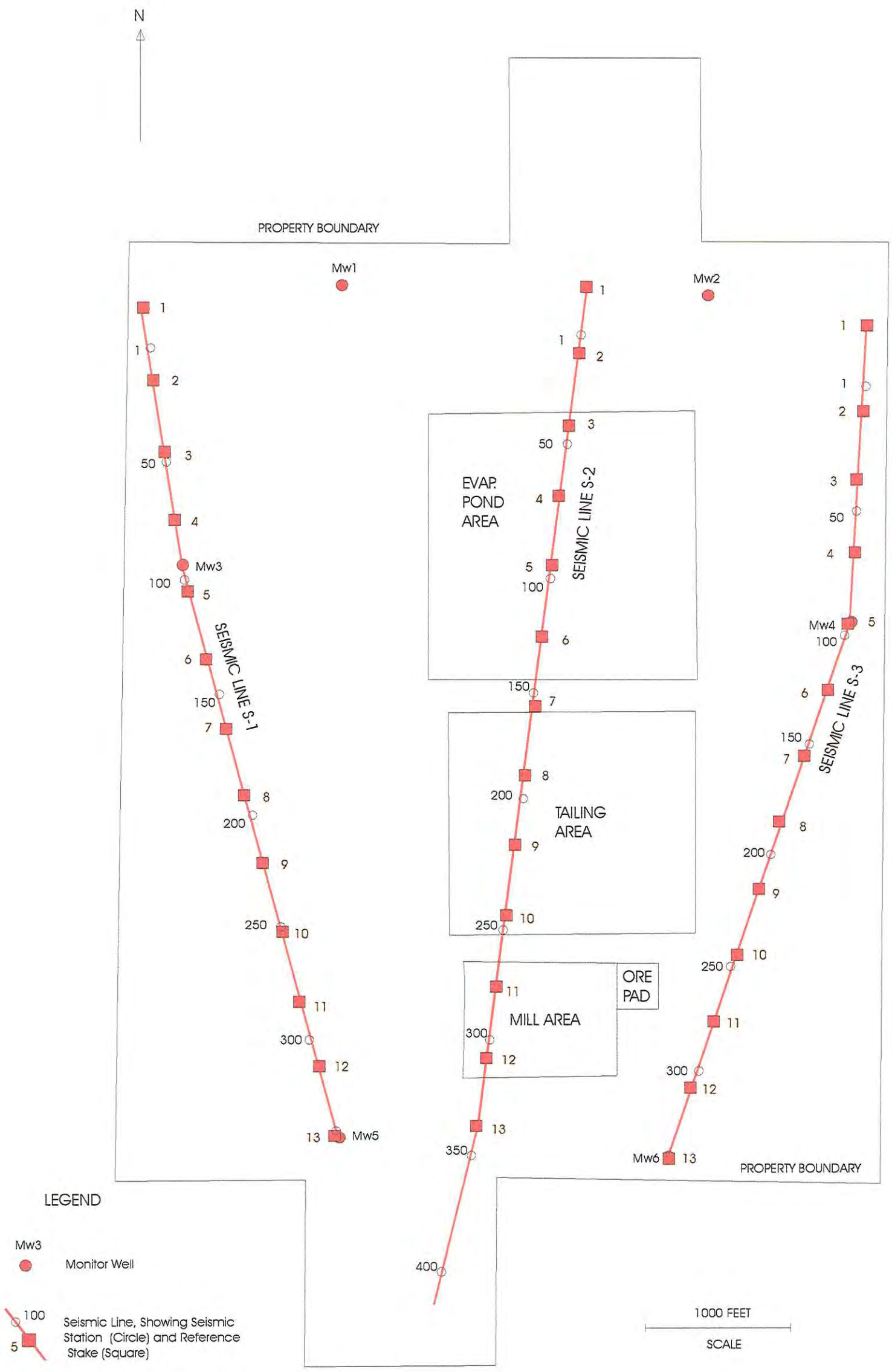
December, 2007

6 Figures

prcorpt.w21



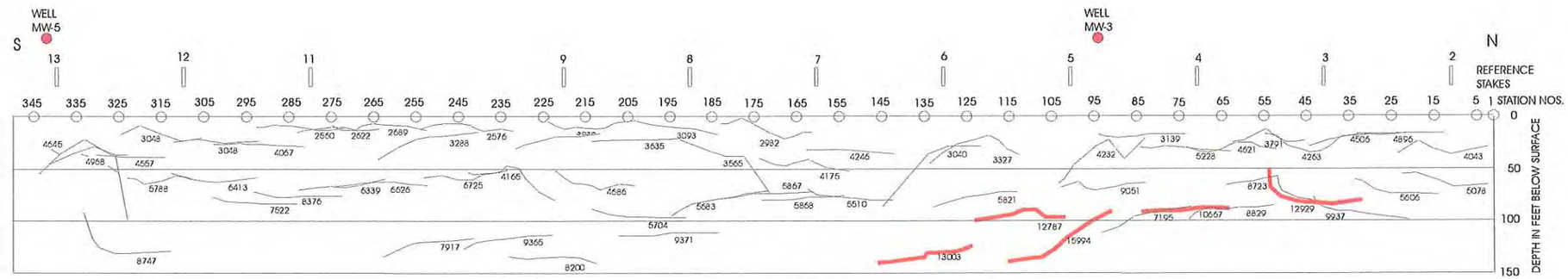
Township & Range
CO T46N, R17W

KLEINFELDER

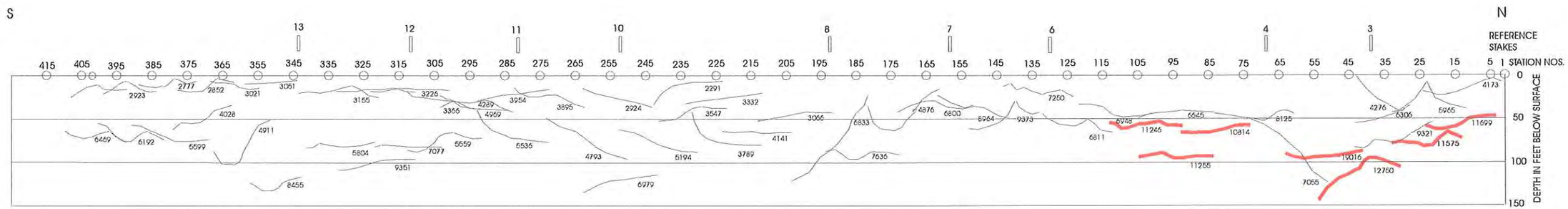
SEISMIC LINE LOCATION MAP
Pinon Ridge Project, Montrose County, Colorado

FIGURE 1

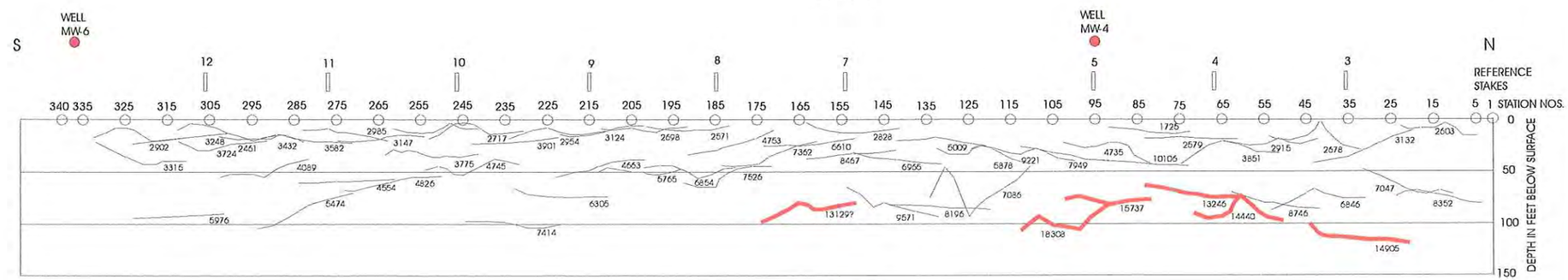
Originator: C. Reynolds	Drawn By: C. Reynolds	Date: December 2007
	Project No.: 83088	
	Scale: 1" = 800'	



LINE S-1



LINE S-2



LINE S-3

LEGEND

MW-3 — Drill Hole on or very near Line

3418 — Refractor Showing Form, Depth and Calculated Velocity in ft/sec
Velocity <10,000 ft/sec

12196 — Refractor Showing Form, Depth and Calculated Velocity in ft/sec
Velocity >10,000 ft/sec

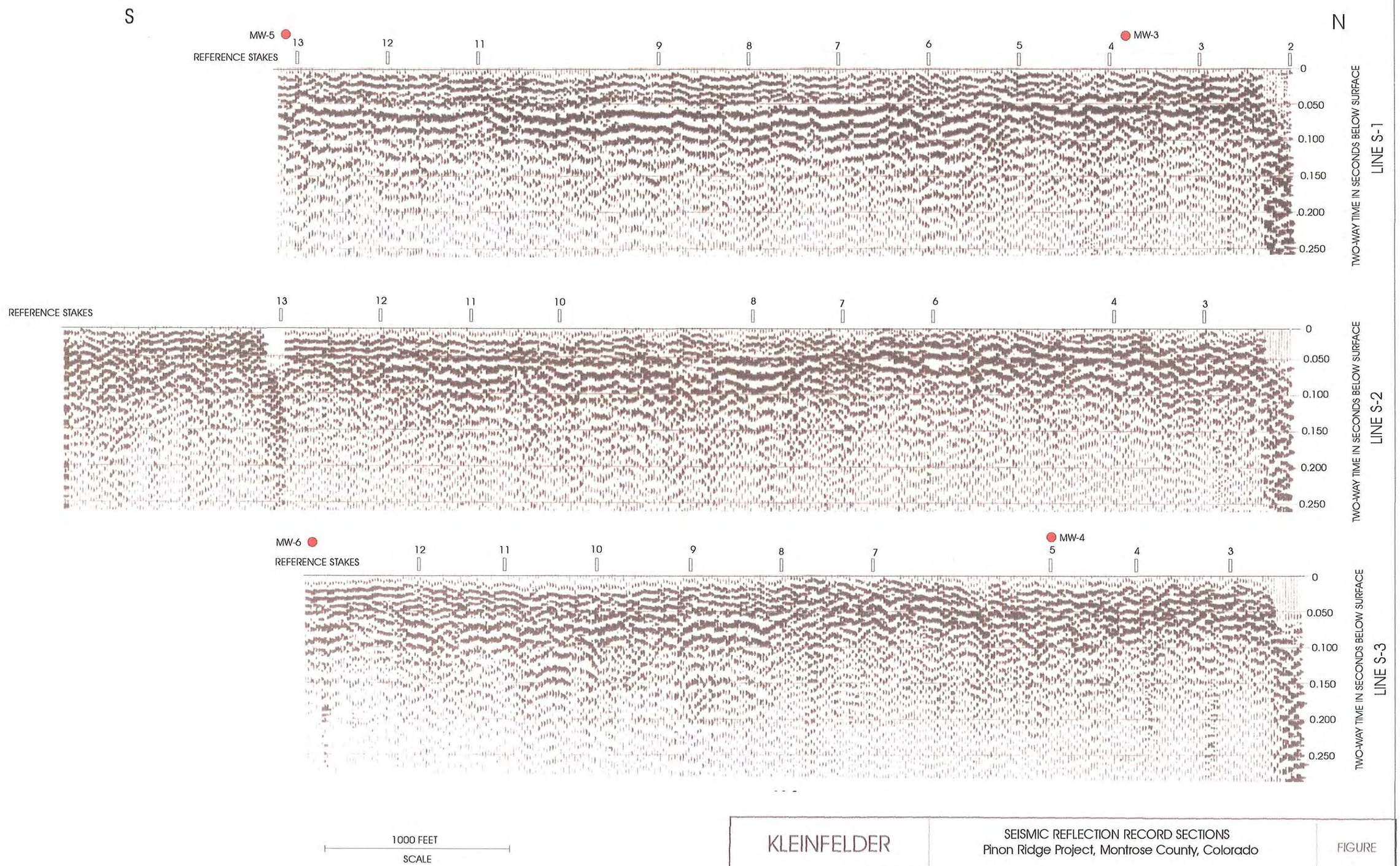
Vertical Exaggeration 4:1

Refractors Calculated from Reversed Refraction Profiles

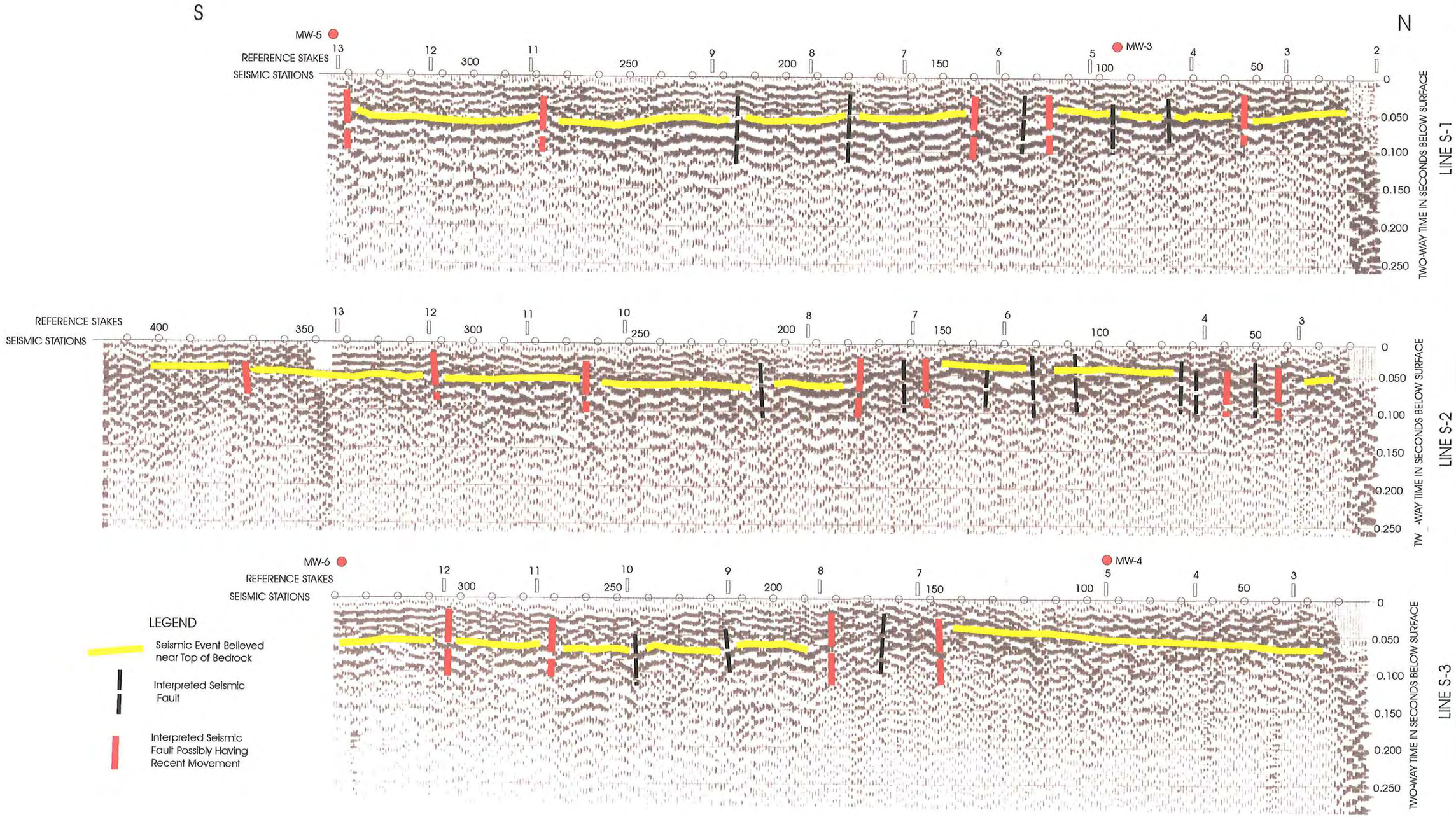
1000 FEET

SCALE

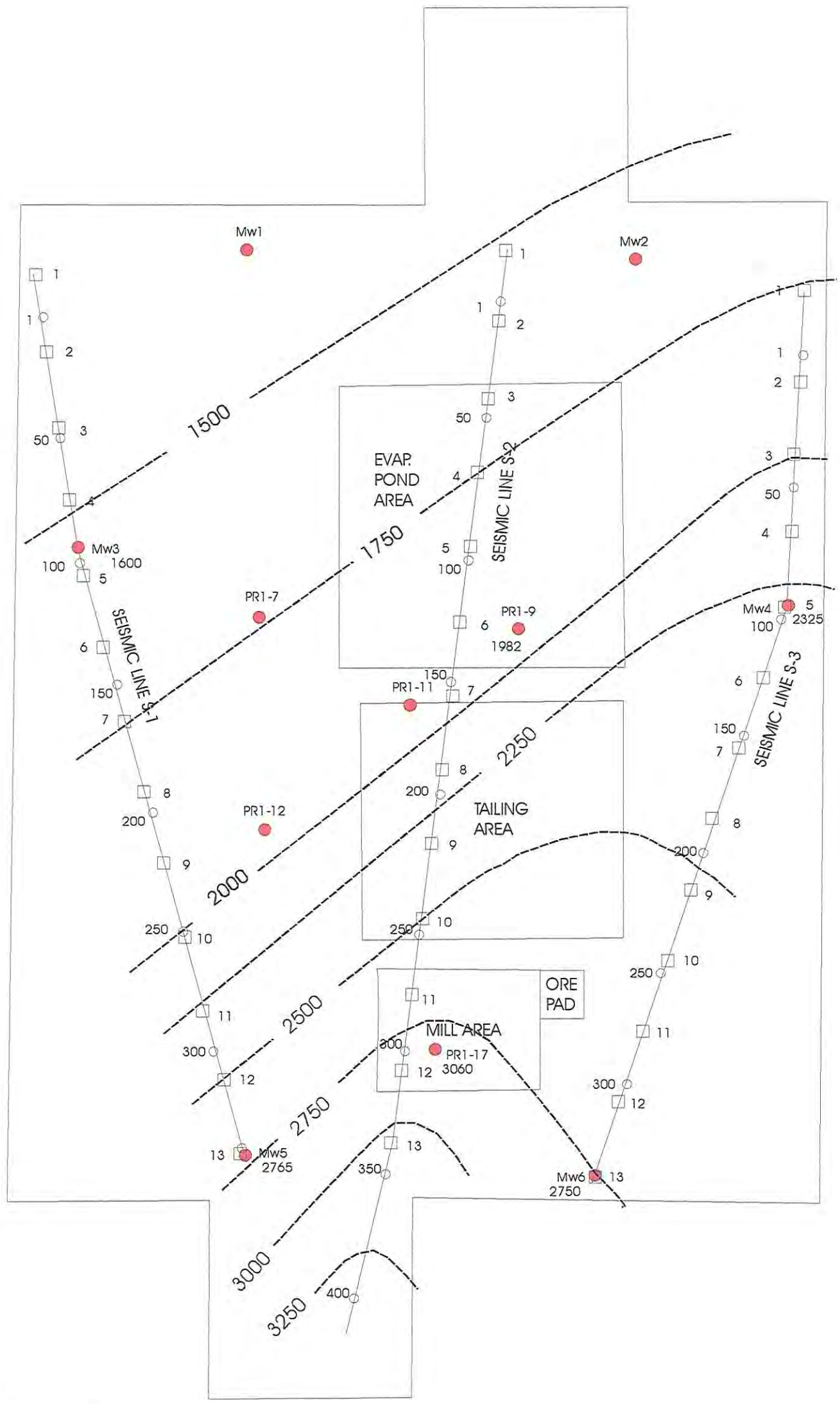
KLEINFELDER	SEISMIC REFRACTION DEPTH SECTIONS Pinon Ridge Project, Montrose County, Colorado	FIGURE
Originator: C. Reynolds	Drawn By: C. Reynolds Project No.: 83088 Scale Horizontal 1" = 500 feet Date: December 2007	2



KLEINFELDER	SEISMIC REFLECTION RECORD SECTIONS Pinon Ridge Project, Montrose County, Colorado		FIGURE
Originator: C. Reynolds	Drawn By: C. Reynolds Project No.: 83088 Scale: Horizontal 1" = 500"	Date: December 2007	3



KLEINFELDER	INTERPRETED SEISMIC REFLECTION RECORD SECTIONS Pinon Ridge Project, Montrose County, Colorado	FIGURE
Originator: C. Reynolds	Drawn By: C. Reynolds Project No.: 83088 Scale: Horizontal 1" = 500'	Date: December 2007	4



LEGEND

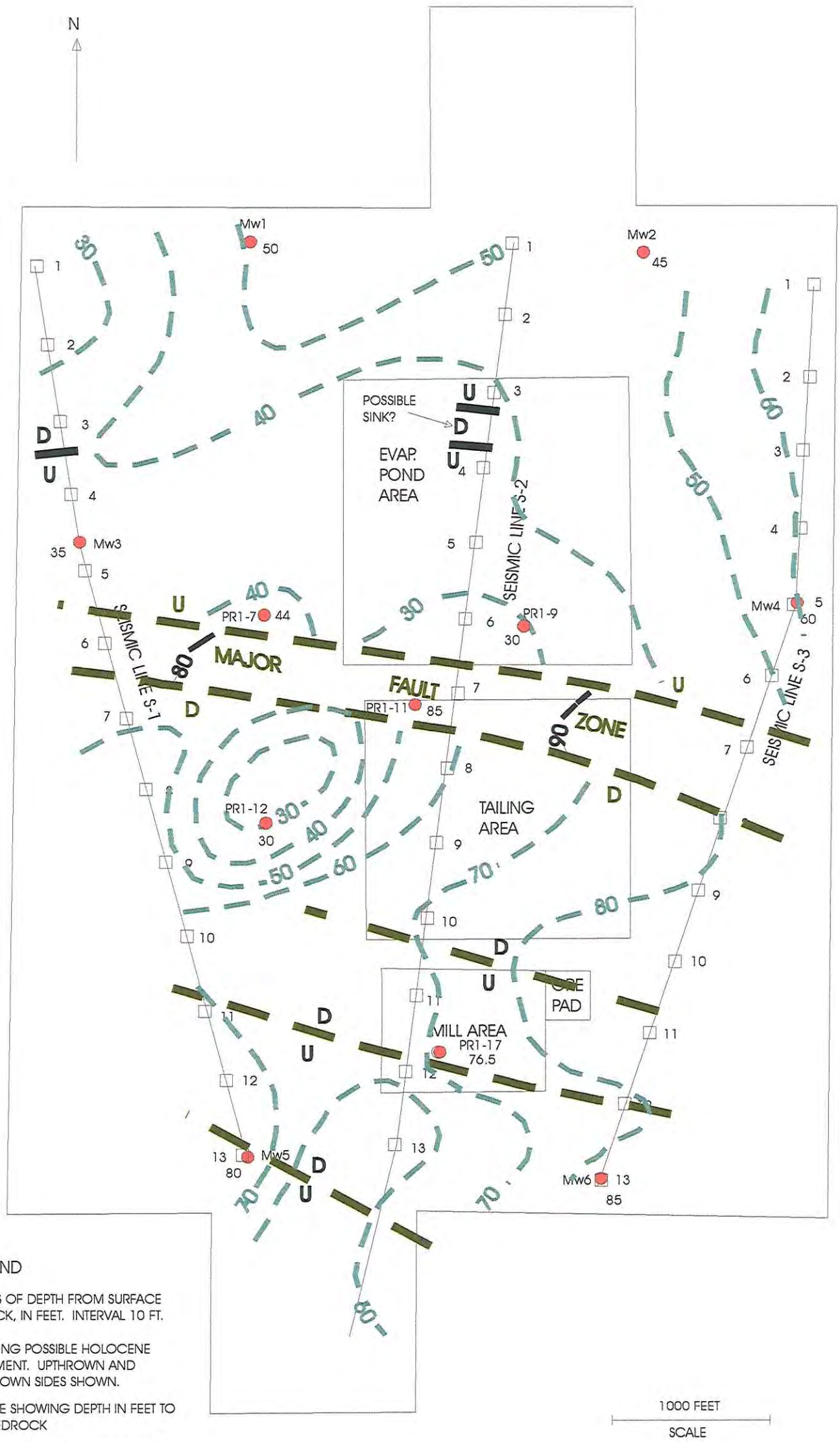
PR1-9 1982 — Drill Hole with Verical Velocity through Alluvium in Feet per Second

2500 — Contour of Vertical Velocity through Alluvium in Feet per Second

12 300 — Seismic Line Shoiwing Seismic Station((Circle) and Reference Stake (Square)

1000 FEET
SCALE

KLEINFELDER	GENERALIZED VERTICAL ALLUVIAL VELOCITY CONTOURS Pinon Ridge Project, Montrose County, Colorado		FIGURE
Originator: C. Reynolds	Drawn By: C. Reynolds	Date: December 2007	5
	Project No,: 83088		
	Scale: 1" = 800'		



LEGEND

CONTOURS OF DEPTH FROM SURFACE TO BEDROCK, IN FEET. INTERVAL 10 FT.

FAULT HAVING POSSIBLE HOLOCENE DISPLACEMENT. UPTHROWN AND DOWNTHROWN SIDES SHOWN.

PR1-7 44 DRILL HOLE SHOWING DEPTH IN FEET TO TOP OF BEDROCK

10 SEISMIC LINE WITH REFERENCE STAKE SHOWN

1000 FEET
SCALE

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KLEINFELDER	TOP OF BEDROCK MAP Pinon Ridge Project, Montrose County, Colorado		FIGURE
Originator: C. Reynolds	Drawn By: C. Reynolds	Date: December 2007	6
	Project No.: 83088		
	Scale: 1" = 800'		