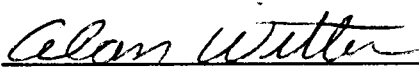
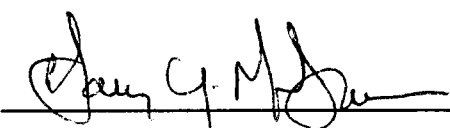
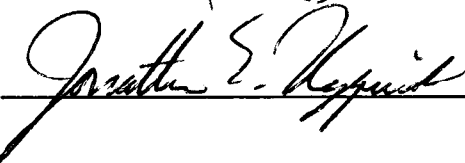


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SEISMIC REFLECTION STUDIES OF AN ARTIFICIAL MAGMA

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Mark R. Goldman

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ABSTRACT

Seismic reflection images of a solidified artificial magma body ~5 cubic meters in volume were compared to cross-sections produced independently from temperature measurements and core drilling the cooled, solidified rock. The data were obtained during *in situ* vitrification (ISV) of a simulated waste disposal trench at Oak Ridge National Laboratory. Four migration schemes were compared, prestack Kirchhoff time migration and three post-stack migrations: Kirchhoff, Stolt FK, and finite-difference. The images produced using prestack Kirchhoff migration were superior to images from the post-stack migrations, and detail both the top and bottom of the ISV rock. Images produced using post-stack Kirchhoff migration were contaminated by high-amplitude noise, while images from Stolt FK and finite-difference migration contained less noise but showed only the upper portion of the ISV rock.

Different field experiment designs were compared by processing subsets of the data. Almost all information concerning the geometry of the ISV rock was found in the backscattered (geophones on the same side of the ISV rock as the source) subset. Wide-angle reflection data (geophones on the opposite side of the ISV rock from the source) provided only limited information about the upper surface. Data from horizontal (radial) component geophones contained significantly stronger reflections from the ISV rock than vertical component data, although both geophone components recorded sufficient information to image the body. Combining partial

images from radial and vertical data produced the most complete pictures. This work demonstrated that it is possible to produce satisfactory seismic reflection images of complexly shaped objects at relatively shallow depths when near-vertical incidence data cannot be obtained. The results from this study apply to imaging magma chambers and plutons at crustal scales, and to applied waste management problems at shallow depths.

A new procedure called *seismic masking* was applied to seismic reflection data recorded during the ISV experiment. The procedure masks selected volumes in the earth containing the known objects prior to stacking, and is based on the seismic response of hypothetical scattering points (*masking points*) located within the volumes. Portions of the data traces in each shot gather that coincide with arrival times from the masking points are muted. The procedure involves forward modeling the traveltimes for each masking point, and thus requires an accurate velocity model. The masking algorithm was tested by successfully attenuating reflections from the limestone in data acquired prior to melting. Images of the melt showed unwanted reflections from a subsidence zone above the melt, which interfered with reflections from the melt itself. Masking the subsidence zone significantly improved the seismic image for the upper portion of the melt.

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PART 1
INTRODUCTION

The principal objective of the work described in this thesis is to study the effectiveness of reflection seismology for imaging the results of an *in situ* vitrification (ISV) conducted at Oak Ridge National Laboratory. The body of this thesis consists of two parts. The first part details the processing and imaging results for the reflection data. The second part describes a new data processing technique called *seismic masking*, which partially removes unwanted reflections from the data set.

A seismic reflection survey over an artificial magma body, produced during a test of *in situ* vitrification (ISV) to stabilize old waste disposal trenches at Oak Ridge National Laboratory, offered an unusual opportunity to compare different data acquisition and processing methods for possible use in imaging magma chambers at crustal scales. The melt was well-characterized by temperature data from an array of thermocouples, and core drilling and petrologic study of the cooled, solidified rock at the end of the test. Cross-sections of the ISV site produced from these data served as objective standards for evaluating seismic images of the melt. Seismic reflection data for the ISV experiment were acquired using closely-spaced shotpoints and three-component geophones along a profile passing over the ISV test site. The first part of this thesis examines (1) the optimum field experiment, in terms of locations for shotpoints and geophone stations, and whether more information is obtained if horizontal rather than vertical geophones are used, and (2) the performance of four different migration algorithms for processing the data to produce images of the artificial magma.

A new procedure called *seismic masking* was developed to reduce the effects

of unwanted reflections from objects whose locations are known or suspected. The procedure involves forward modeling to calculate the reflection traveltimes for hypothetical *masking points* (point scatterers) situated within regions where the known objects are located, and requires an accurate velocity model. Data acquired prior to melting contained prominent reflections from limestone aggregate placed 0.8 meters deep in the disposal trench. The masking algorithm was tested by successfully suppressing these reflections. The remainder of the image was not affected by the masking except for a slight increase in background noise, which was judged to be insignificant. Images of the melt showed unwanted reflections from a subsidence zone above the melt, which interfered with reflections from the melt itself. Masking the subsidence zone significantly improved the seismic image for the upper portion of the melt, again with a slight increase in background noise.

PART 2

COMPARISON OF SEISMIC REFLECTION EXPERIMENT DESIGNS

AND MIGRATION METHODS USING A FIELD-SCALE,

SOLIDIFIED, ARTIFICIAL MAGMA CHAMBER

ABSTRACT

Seismic reflection images of a solidified artificial magma body ~5 cubic meters in volume were compared to cross-sections produced independently from temperature measurements and core drilling the cooled, solidified rock. The data were obtained during *in situ* vitrification (ISV) of a simulated waste disposal trench at Oak Ridge National Laboratory. Four migration schemes were compared, prestack Kirchhoff time migration and three post-stack migrations: Kirchhoff, Stolt FK, and finite-difference. The images produced using prestack Kirchhoff migration were superior to images from the post-stack migrations, and detail both the top and bottom of the ISV rock. Images produced using post-stack Kirchhoff migration were contaminated by high-amplitude noise, while images from Stolt FK and finite-difference migration contained less noise but showed only the upper portion of the ISV rock.

Different field experiment designs were compared by processing subsets of the data. Almost all information concerning the geometry of the ISV rock was found in the backscattered (geophones on the same side of the ISV rock as the source) subset. Wide-angle reflection data (geophones on the opposite side of the ISV rock from the source) provided only limited information about the upper surface. Data from horizontal (radial) component geophones contained significantly stronger reflections from the ISV rock than vertical component data, although both geophone components recorded sufficient information to image the body. Combining partial

images from radial and vertical data produced the most complete pictures. This work demonstrated that it is possible to produce satisfactory seismic reflection images of complexly shaped objects at relatively shallow depths when near-vertical incidence data cannot be obtained. The results from this study apply to imaging magma chambers and plutons at crustal scales, and to applied waste management problems at shallow depths.

INTRODUCTION

A seismic reflection survey over a solidified artificial magma body produced during a test of *in situ* vitrification (ISV) to stabilize old waste disposal trenches at Oak Ridge National Laboratory (Jacobs et al., 1992) offered an unusual opportunity to compare different data acquisition and processing methods for possible use in imaging magma chambers at crustal scales. Magma bodies and plutons are central features in many tectonically active regions, and seismic methods are important tools for investigating them. No standard technique has emerged for seismically imaging magmatic structures, however. Examples from past surveys include seismic reflection methods (Detrick et al., 1987, Morton et al., 1987, Collier and Sinha, 1990, Black et al., 1991), tomographic methods (Hill et al., 1985, McMechan et al., 1985, Stauber et al., 1988, Lees and Crosson, 1989), and traveltime inversion using reflections from the Moho (Nercessian et al., 1984, Achauer et al., 1988, Evans and Zucca, 1988). Seismic reflection methods have proven most successful for imaging the upper

portion of magma bodies. Tomographic and inversion methods are sometimes limited by the nonuniqueness of the interpretation, due in part to a lack of corroborating information from other geophysical studies or drilling.

Conventional seismic reflection methods are severely tested by geological conditions within magmatic terranes. Magma bodies can form a variety of complex shapes involving steeply dipping and possibly overhanging reflectors along the sides and bottom of the magma-rock interface (Black et al., 1991). Velocity gradients along these reflectors can lead to significant errors in the output from standard seismic migration algorithms. These errors are often compounded by uncertainties in the velocity model used for the migration.

Imaging the ISV body combined elements of a field-scale seismic reflection project with aspects of a controlled laboratory experiment. The melt was well-characterized by temperature data from an array of thermocouples, and core drilling and petrologic study of the cooled, solidified rock at the end of the test (Dunbar et al., 1993a, Dunbar et al., 1993b). Cross-sections of the ISV site produced from these data served as objective standards for evaluating seismic images of the solidified melt. Seismic reflection data for the ISV experiment were acquired using closely-spaced shotpoints and three-component geophones along a profile passing over the ISV test site (Fig. 1)*. In this paper, we examine (1) the field experiment, in terms of the optimum locations for shotpoints and geophones, and whether more information is obtained if horizontal rather than vertical geophones are used, and (2)

* all figures may be found in the Appendix for Part 2

the performance of four different migration algorithms for processing the data to produce images of the artificial magma chamber.

The conclusions arrived at in this paper address the problem of imaging the complex shapes associated with magma chambers and plutons, particularly when it is not possible to locate shotpoints and geophones directly over the target. They also bear on the general issue of using geophone offsets that are several times the target depth to image complexly-shaped objects.

THE ISV EXPERIMENT

The ISV artificial magma chamber provided an analog to natural magmatic systems for petrologic and geophysical studies on a scale not usually available to researchers. A simulated waste disposal trench (Fig. 1), which contained approximately one cubic meter of limestone aggregate at a depth of 0.8 m below the surface, was constructed and melted via electrical resistance heating, by applying power to graphite electrodes inserted into the soil above the melt (Spalding et al., 1992). A roughly hemispheric magma body, approximately 2.9 m deep at the center, was produced after 127 hours of heating, with maximum temperatures reaching almost 1500°C. The upper surface of the melt subsided to a depth of 1.5 m due to volume reduction of the soil during melting. The melt ultimately solidified to form a rock similar to a high-Ca, low-Na basalt. The body was chemically homogenous and almost completely crystalline with a porphyritic texture. The degree of

crystallinity increased systematically from vitreous near the edge of the melt to several millimeter-long crystals near the center (Dunbar et al., 1993b).

The physical, petrologic, and geochemical properties of the melt and ISV rock were well-characterized by a wide range of geological and geophysical studies. A hood placed over the melt site collected gases and particulates released by the vitrification process (Dunbar et al., 1993a). Continuous temperature information was obtained from a three-dimensional array of 87 thermocouples installed within and around the volume to be melted (Jacobs et al., 1992, Dunbar et al., 1993b). Seismic velocity measurements were made on core samples from the ISV rock (Douglas Green, written communication). Three-dimensional DC resistivity measurements were made using six vertical electrode arrays in boreholes surrounding the melt (Spies and Ellis, 1993). These data provided a comprehensive picture of both the melt and the ISV rock, allowing for an independent evaluation of images produced from seismic reflection profiles.

Seismic reflection data were obtained using 3-component, 100 hz geophones at 1.0 m intervals along the profile. The seismic source was a 21 mm (8 gauge) shotgun fired into the ground at 0.5 m intervals. An 8 m gap in the seismic profile directly above the melt was necessary due to the presence of the gas-collecting hood and heating electrodes. A total of 8 profiles were recorded: 1 before heating, 3 during melting, and 4 during cooling and solidification. A typical data set consisted of 46 shots recorded at 24 geophones, 12 on each side of the melt. Data for the portion of the profile containing the melt ranged from 16 fold to 24 fold for each

geophone component.

The seismic reflection data were processed using algorithms from the SierraSeis seismic data processing system (Sierra Geophysics, 1991). The usable frequency range was from 120 to 600 hz. The images were displayed in color (Fig. 2) using the reflection strength attribute computed for each time section through a Hilbert transform (Tanner et al., 1979). The radial and vertical component data were processed separately, and the reflection strength attributes combined via the square root of the sum of their squares to produce the final images. The color scale for the reflection strength images ranged from red for the strong reflections (0 db) to blue for weak or no reflections (-38 db).

The upper boundary of the ISV rock occurs within a 0.5 to 1 m thick band of high amplitude (red) reflections (Fig. 2). Polarity studies suggested that the reflection polarities shown below the boundary were positive, while negative polarities predominated above the boundary. The negative polarity reflections originated within the subsidence zone above the melt, which contained poorly consolidated rubble from cold caps that formed and collapsed above the melt (Spalding et al., 1992). The bottom of the ISV rock corresponds approximately to the change from no reflections (blue) to moderately strong (-20 db green) reflections in the migrated image. The position of the boundary from core drilling, indicated by a thin line superimposed on the color seismic images, was interpolated in three dimensions using 17 coreholes, and is smoother than the boundary indicated by seismic reflections. The apparent roughness of the boundary in the seismic image

may be real, and may also be partly due to focusing and defocusing of the wavefield by undulations in the boundary, causing amplitude variations. The zone where soil temperatures exceeded 100°C was only vaguely indicated by a few weakly reflecting points (pale blue to green) on the 100°C isotherm, which is also superimposed on the seismic images. This zone was not extensively sampled by coring, but probably involved gradational changes in seismic velocity due to changes in soil moisture content. It was not expected to cause strong reflections.

COMPARISON BETWEEN BACKSCATTERED AND WIDE-ANGLE DATA

A question of fundamental importance when designing the ISV seismic reflection profile was where to locate shotpoints and geophones to obtain the maximum amount of information about the magma chamber. This question was addressed after the fact by subdividing the data, and migrating each subset to produce partial images that simulated the results from different choices of shooting geometry. One subset simulated a wide-angle reflection experiment (geophones on opposite sides of the melt from the shot), while the other recorded backscattered energy (geophones on the same side of the melt as the shot). Comparison of the images produced from each subset showed that the backscattered data contained nearly all the information concerning the shape and location of the ISV rock. Images produced from the backscattered subset (Fig. 3A) were almost indistinguishable from

images based on the full data set (Fig. 2A). Images from wide-angle reflection data alone (Fig. 3B) contained little additional information concerning the sides or bottom.

The reason that backscattered energy provided more information concerning the ISV body than wide-angle reflections is related to the time separation between reflections from the ISV body and source-generated noise, including the direct arrival through the soil (Fig. 4). The time separation between the earliest backscattered arrival and the direct arrivals ranged from 16 ms to 76 ms, as shown in Figure 5 for a shot at one end of the profile. In contrast, the traveltimes for wide-angle reflections were only slightly greater (1-2 ms) than the traveltimes for the direct arrivals. It was not possible to separate completely the wide-angle reflections (signal) from the direct arrivals (noise) during data processing. Thus, muting the direct arrivals unavoidably muted a significant amount of the wide-angle reflections also. Alternately, not muting the direct arrivals produced an unacceptable amount of noise in the images. Another issue was the range of traveltimes for backscattered arrivals versus wide-angle reflections within each trace. For geophones on the backscattered side, the time separation between arrivals from different portions of the ISV body was as much as 18 ms, while wide-angle reflections were separated by not more than 5 ms (Fig. 5). Consequently, spatial resolution of the ISV body was better using backscattered energy instead of wide-angle reflections.

These results from the ISV experiment may also apply to seismic reflection surveys of geologic-scale magma chambers. The optimal shooting strategy for the

ISV survey, in hindsight, would have been to increase reliance on backscattered raypaths by concentrating the available geophones and shotpoints on the same side of the artificial magma chamber. This geometry is somewhat counter-intuitive, as seismic studies of natural magma chambers are often designed with shotpoints and geophones on opposite sides of the target region to record raypaths passing through the suspected location of the magma chamber. It is essential, however, that the seismic profile be approximately symmetrical with respect to the location of the magma chamber. Otherwise, if shotpoints and geophones are placed on one side of the magma chamber only, backscattered reflections present on the recorded traces will not be migrated to the actual position of the magma chamber. No clear image of the artificial magma was formed when data traces from only one side of the ISV profile were migrated. Rather, the result was a weak image broadly smeared beneath that side of the profile.

COMPARISON OF MIGRATION ALGORITHMS

Images from four different migration schemes were compared to each other and to cross-sections of the ISV body. These migration algorithms were a prestack Kirchhoff migration (Sullivan and Cohen, 1987) and three post-stack migrations: Kirchhoff (Schneider, 1978), Stolt FK (Stolt, 1978), and finite-difference (Yilmaz, 1987). Stolt FK migration in particular does not properly treat rapid or large changes in velocity, while finite-difference migration is expensive and has difficulty

migrating data containing dips greater than 45° (Dobrin and Savit, 1988, p. 275). Kirchhoff migration, which involves a statistical rather than a deterministic approach to migration, may be more sensitive to noise than either Stolt FK or finite-difference migration (Chun and Jacewitz, 1981).

The velocity model used to process the data was developed from the first arrivals in the field records. A constant velocity of 350 m/s was observed for the soil surrounding the trench, and no increase in velocity with depth (in the 0 - 5 m range) was apparent. The initial images, produced using only the 350 m/s soil velocity, showed the solidified magma chamber but were fuzzy and indistinct. A high velocity region corresponding approximately to the position of the melt was added to the model to improve the images. The actual velocity in this portion of the model was not well-determined: it was only important that the velocity in the region of the magma chamber be much faster than the soil velocity. Using realistic velocities for the ISV rock, approximately 10 times faster than the soil, did not improve the image but triggered SierraSeis warning messages about excessive velocity gradients. As a compromise, a standard velocity 2 times faster than the soil, i.e., 700 m/s, was adopted for the ISV rock for processing the data, although using a velocity 3 or 4 times faster than the soil would have made little difference in the results presented here.

The theoretical limitations of each migration algorithm were corroborated by their respective output images of the ISV body. Prestack Kirchhoff migration (Fig. 2A) provided results superior to any of the three post-stack migrations. The images

produced using post-stack Kirchhoff migration (Fig. 2B) showed the entire ISV body, including the sides and bottom, but were ruined by numerous, high-amplitude artifacts and noise. The images produced by Stolt FK migration (Fig. 6A) clearly revealed the flat upper surface of the ISV body, and the artifacts due to truncation of the Fourier transform were relatively small (approximately -30 db). FK migration did not reveal the curved lower surface and sides of the ISV body, consistent with the expected limitations of the algorithm.

Finite-difference migration produced images of the solidified magma chamber (Fig. 6B) similar to those from Stolt FK migration (Fig. 6A), showing only the flat upper surface. However, the finite-difference image also contained a strong, subhorizontal artifact at approximately 22 ms travelttime, which was not present in the images from other migrations nor in the earth. This artifact had a realistic appearance for a reflector at a depth of approximately 3.7 m, and exhibited pull-up beneath the higher velocity zone of the magma chamber. Its source was the lower boundary of the data processing grid, and it was possible to move the artifact downward, out of the field of view, by padding the traces to extend the grid in the time direction.

Resampling the data to a higher digitizing rate was essential to obtain satisfactory performance from both Stolt FK migration and finite difference migration. Most of the data processing was performed at a sampling rate of 0.5 ms. However, Stolt FK migration at this sampling rate (Jacobs et al., 1992) resulted in migration artifacts with amplitudes larger than reflections from the solidified magma

chamber itself. Resampling 10 times to 0.05 ms reduced the artifacts to acceptable levels (Fig. 6A). Finite-difference migration failed to form an image at the 0.5 ms sampling rate. The result shown in Figure 6B was obtained after resampling to 0.05 ms.

A possible explanation for the superior quality of the prestack images, particularly for portions showing the sides and bottom of the ISV body, may be that diffractions rather than reflections dominated in the energy returned from these portions of the target object. Prestack migration is more accurate in collapsing diffractions (Jain and Wren, 1980), since normal moveout (NMO) corrections and common midpoint (CMP) stacking, prerequisites for post-stack migration, emphasize signal from planar, reflecting surfaces, at the expense of diffraction and other information. A comparison between the Fresnel zone size for the ISV experiment and the dimensions of the melt provides evidence that the sides and bottom of the body produced primarily diffractions, with reflections from planar surfaces limited to the top of the body. The minimum radial width (F_w) for a smooth surface to produce reflections (the first Fresnel zone) is given as:

$$F_w = \frac{v}{4} \sqrt{\frac{t}{f}} \quad (1)$$

where v is the velocity, t the two-way travel time, and f the frequency (Dobrin and Savit, 1988, p. 290). The smallest value of F_w for the ISV survey was 0.5 m, based on the traveltimes (20 ms) for the shotpoint and geophone combination closest to the

melt, and at the highest usable frequency of 600 hz. At the lowest usable frequency of 120 hz, F_w was increased to 1.1 m. The sides and bottom of the ISV body were curved or undulating, and thus did not have planar reflecting surfaces of this size. In contrast, the top of the ISV body, a flat, subcircular surface approximately 3 m in diameter, was considerably larger than the first Fresnel zone.

The poor performance of post-stack Kirchhoff migration compared to prestack Kirchhoff migration (Fig. 2) is puzzling, as the underlying migration strategy is the same in both cases. The principal difference is that a NMO correction is explicitly performed in the post-stack case, but not in the prestack case, where constant-offset gathers are migrated instead. Thus, suspicion falls on the accuracy of the NMO correction. NMO corrections, when applied to CMP gathers, may time-shift reflected (or diffracted) signals incorrectly. For the ISV survey, the error (e) in the NMO correction can be estimated from (refer to Figure 7):

$$e = \frac{1}{V} \left\{ \left[(m-x)^2 + h^2 \right]^{\frac{1}{2}} + \left[(m+x)^2 + h^2 \right]^{\frac{1}{2}} - \left[4(m^2 + h^2) + x^2 \right]^{\frac{1}{2}} \right\} \quad (2)$$

where h is the depth, x is the horizontal distance from a particular shot or geophone to the common midpoint, m is the horizontal offset from a diffracting point on the ISV body to the common midpoint, and V is the stacking velocity, which for the ISV survey was equal to the 350 m/sec velocity in the soil surrounding the melt. The maximum error amounted to approximately 2 ms, which occurred for a hypothetical reflecting point located on the upper surface of the melt ($h = 1.5$ m), and a shotpoint

10 m from a geophone ($x = 5$ m) and 13 m from the magma chamber ($m = 8$ m). Given the relatively high frequency of the data, a 2 ms error in the NMO correction is substantial. For example, at a frequency of 250 hz, the period is 4 ms and the phase error is 180° . Thus, the higher frequencies may be stacked out of phase, increasing the noise in the subsequent image from post-stack migration.

COMPARISON OF RADIAL AND VERTICAL COMPONENT DATA

Images from radial and vertical component data produced using prestack Kirchhoff migration were compared to each other and to the combined image produced from both kinds of data. The purpose of these comparisons was to determine the value of radial-component information for producing images of the ISV body, relative to a more common seismic reflection survey where only vertical-component information is recorded. The results are shown in Figure 8. The image produced from radial component data showed higher reflection strength and was more complete than the image from vertical component data. The greater reflection strength for radial component data may be a consequence of the length of the seismic profile compared to the target depth, resulting in raypaths with low angles of emergence. Particle motions for these raypaths would tend to be more nearly horizontal. Although both components recorded sufficient signal to image the ISV body, the maximum amount of information was obtained by combining the images produced from both the radial and vertical component data.

CONCLUSIONS

1. It was possible to obtain satisfactory seismic reflection images of the solidified artificial magma chamber, despite the inability to record near-vertical reflections due to the absence of shotpoints and geophones directly above the target. Prestack Kirchhoff migration was essential to form an acceptable image under these circumstances. The images produced by post-stack Kirchhoff migration contained excessive noise, possibly due to the predominance of improperly migrated diffractions rather than reflections from the curved lower surface of the ISV rock. Post-stack Stolt FK and finite-difference migration both successfully imaged the flat upper portion of the ISV body but not the curved lower portion.

2. Backscattered data provided almost all of the seismic information concerning the shape of the solidified artificial magma chamber. The importance of backscattered signal for imaging the ISV body suggests that reflection surveys in natural magmatic terrains, or surveys applied to waste management problems at shallow depths, should also attempt to include backscattered raypaths, in addition to wide-angle reflections and refractions.

3. Radial and vertical geophone components both recorded sufficient information to locate the solidified, artificial magma chamber. Reflections were significantly stronger in the radial component data, probably due to the large aperture (31 m) of the recording profile in comparison to the depth of the target (1.5 - 2.9 m).

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APPENDIX - PART 2

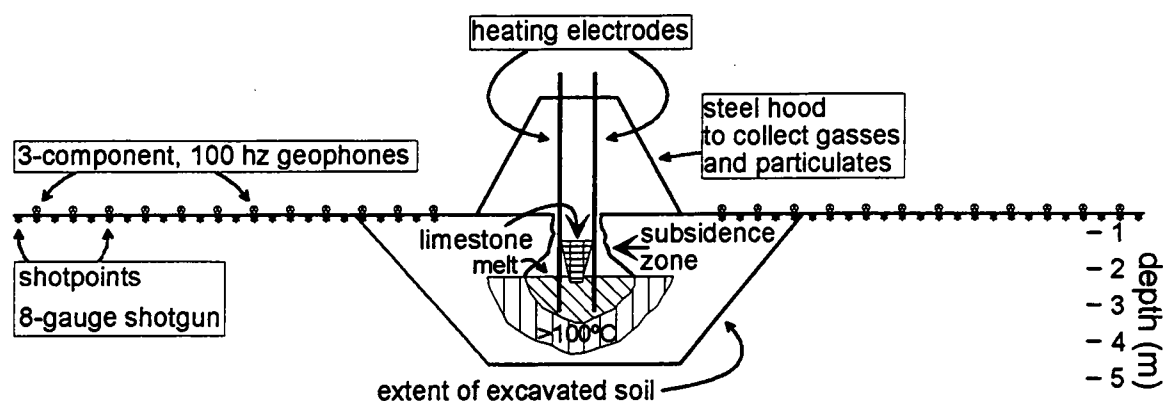


Figure 1. ISV seismic profile geometry. The trench contained limestone aggregate before heating. Heating produced the ISV magma body and a subsidence zone. The seismic reflection profile passed over the melt and extended 15.5 m on either side. Hachures show the limestone before melting, the melt at its maximum extent, and the zone where soil temperatures exceeded 100°C .

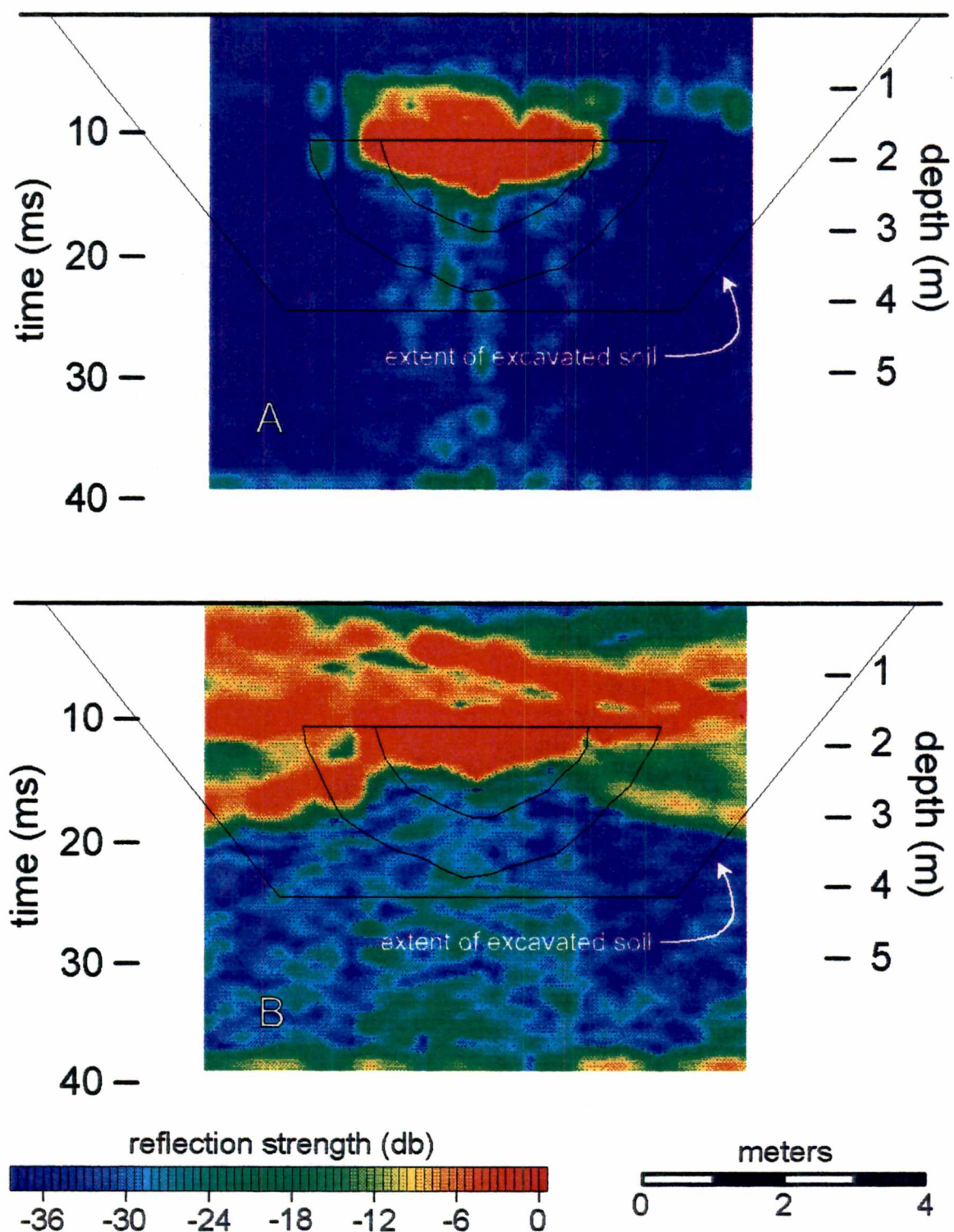


Figure 2. Comparison of reflection strength images from prestack and post-stack Kirchhoff migration. (A) Prestack. (B) Post-stack. Data recorded after solidification of the ISV melt. Combined radial and vertical components. Outlines of ISV body and excavated soil (Fig. 1) are shown for reference.

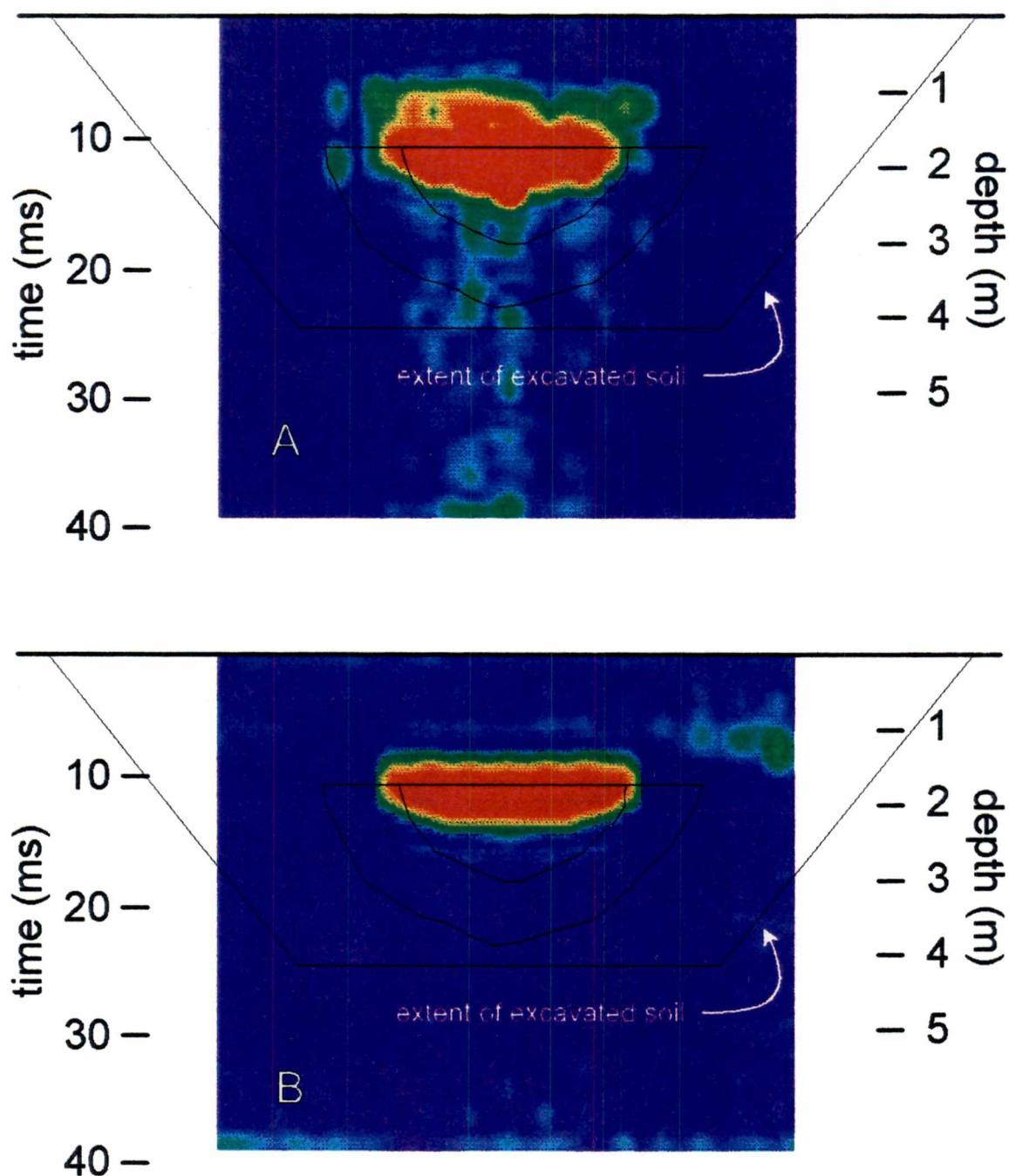


Figure 3. Comparison of reflection strength images from backscattered and wide-angle data subsets. (A) Backscattered. (B) Wide-angle. Data recorded after solidification of the ISV melt. Prestack Kirchhoff migration. Combined radial and vertical components. Outlines of ISV body and excavated soil (Fig. 1) are shown for reference.

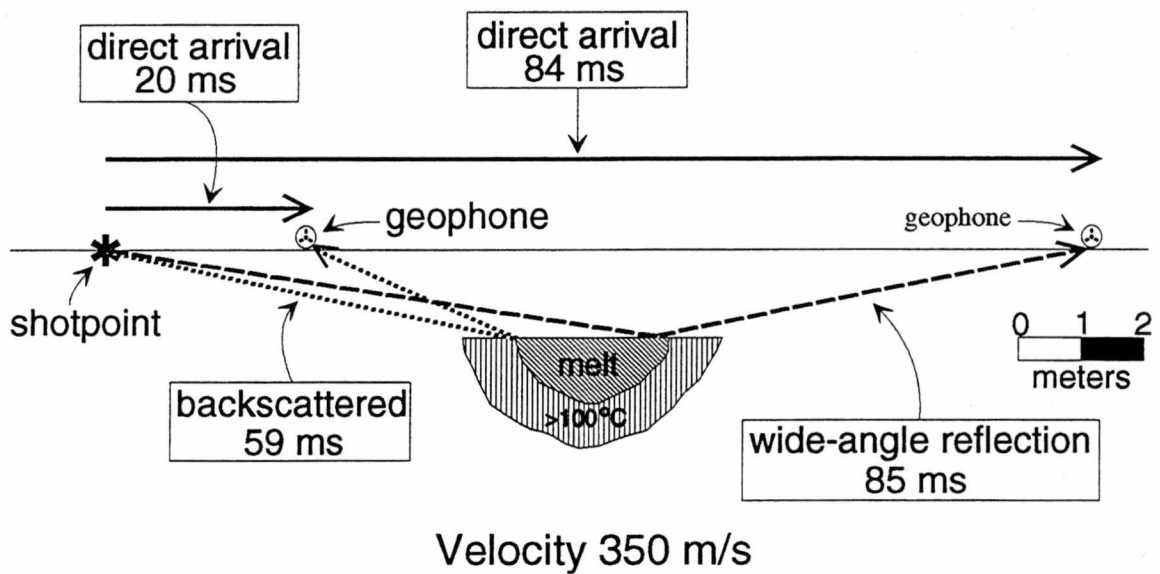


Figure 4. Comparison of traveltimes for backscattered and wide-angle reflection data. The traveltime difference between the direct arrival and a typical backscattered arrival is 39 ms. For wide-angle reflection the time difference is approximately 1 ms.

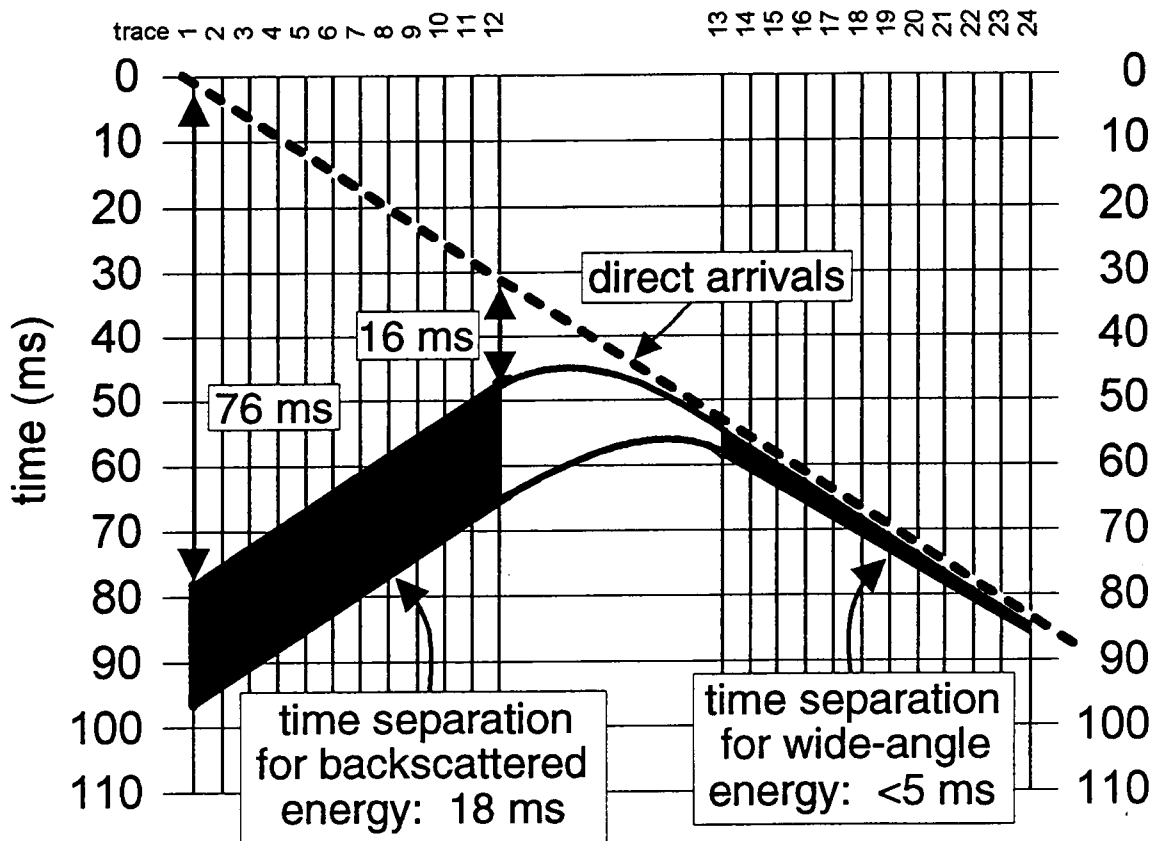


Figure 5. Ranges of traveltimes for backscattered and wide-angle reflection energy, for a shot at one end of the ISV profile. The time separation between the direct wave and the backscattered energy (16 to 76 ms) is much greater than the time separation between the direct wave and the wide-angle reflections (<2 ms). The range of traveltimes from different parts of the ISV body is much greater for backscattered energy (18 ms) than for wide-angle reflections (<5 ms), allowing for better spatial resolution of the ISV body.

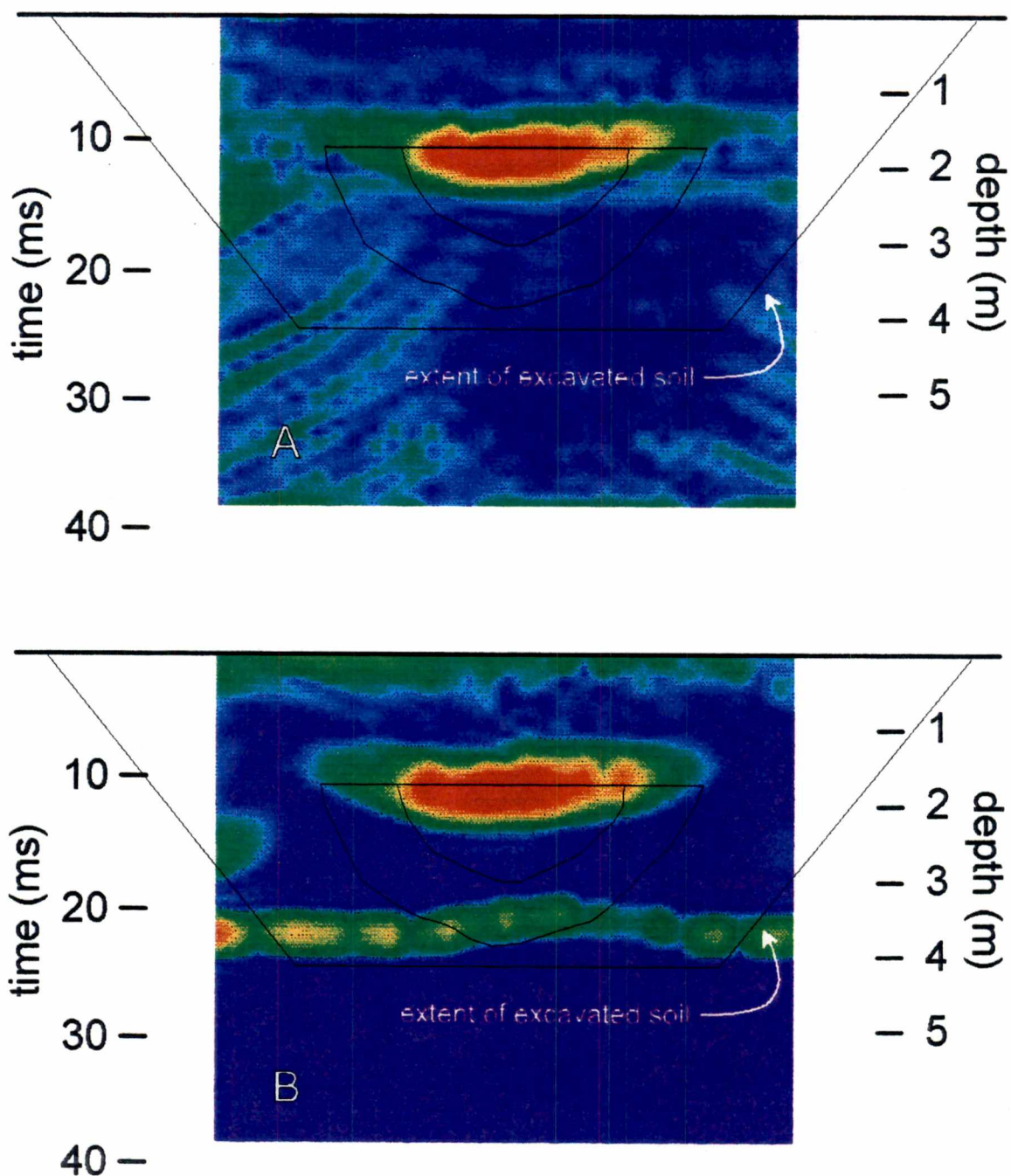


Figure 6. Comparison of reflection strength images from post-stack Stolt FK and finite-difference migrations. (A) Stolt FK. (B) Finite-difference. The finite-difference image contains a subhorizontal artifact at ~22 ms, which can be moved downward by padding the traces (see text). Data recorded after solidification of the ISV melt. Combined radial and vertical components. Outlines of ISV body and excavated soil (Fig. 1) are shown for reference.

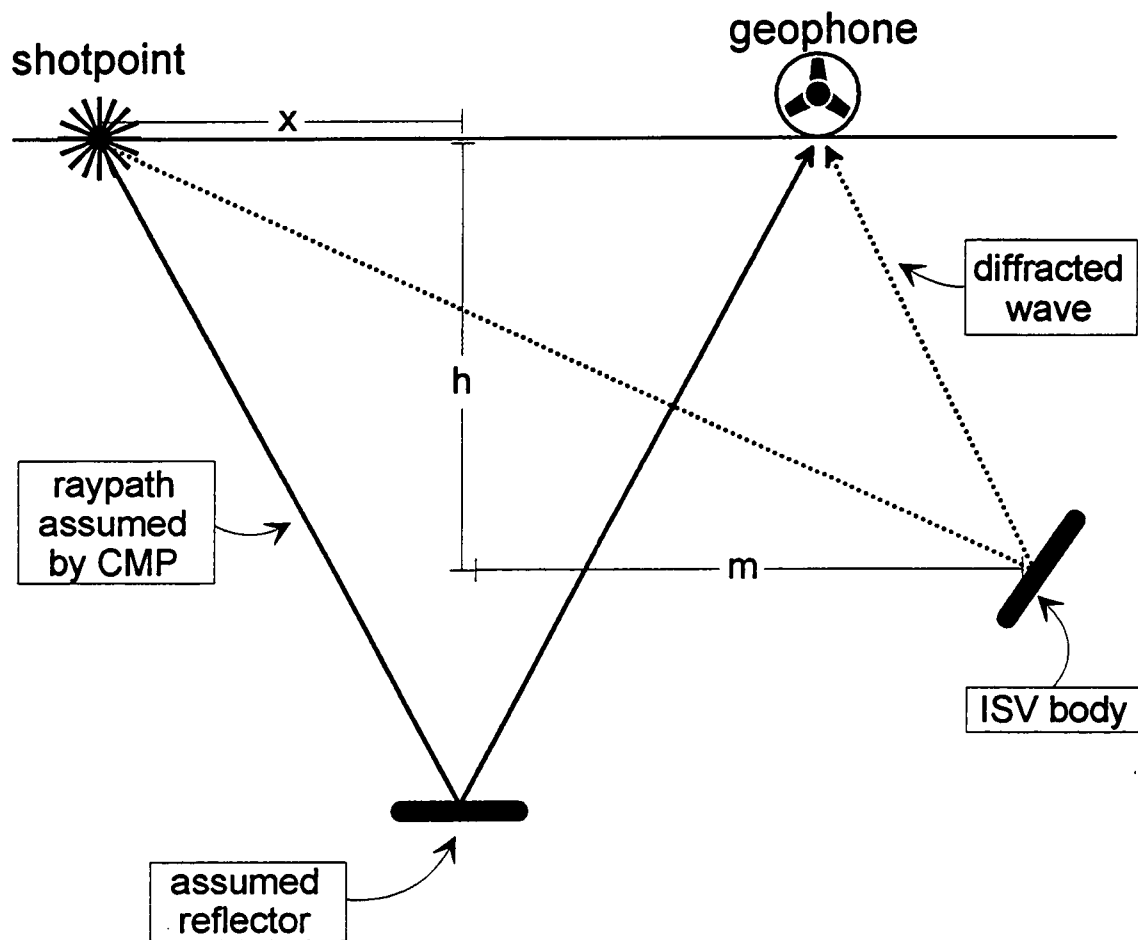


Figure 7. Reflection raypath assumed for CMP stacking versus diffracted wave path in the ISV experiment.

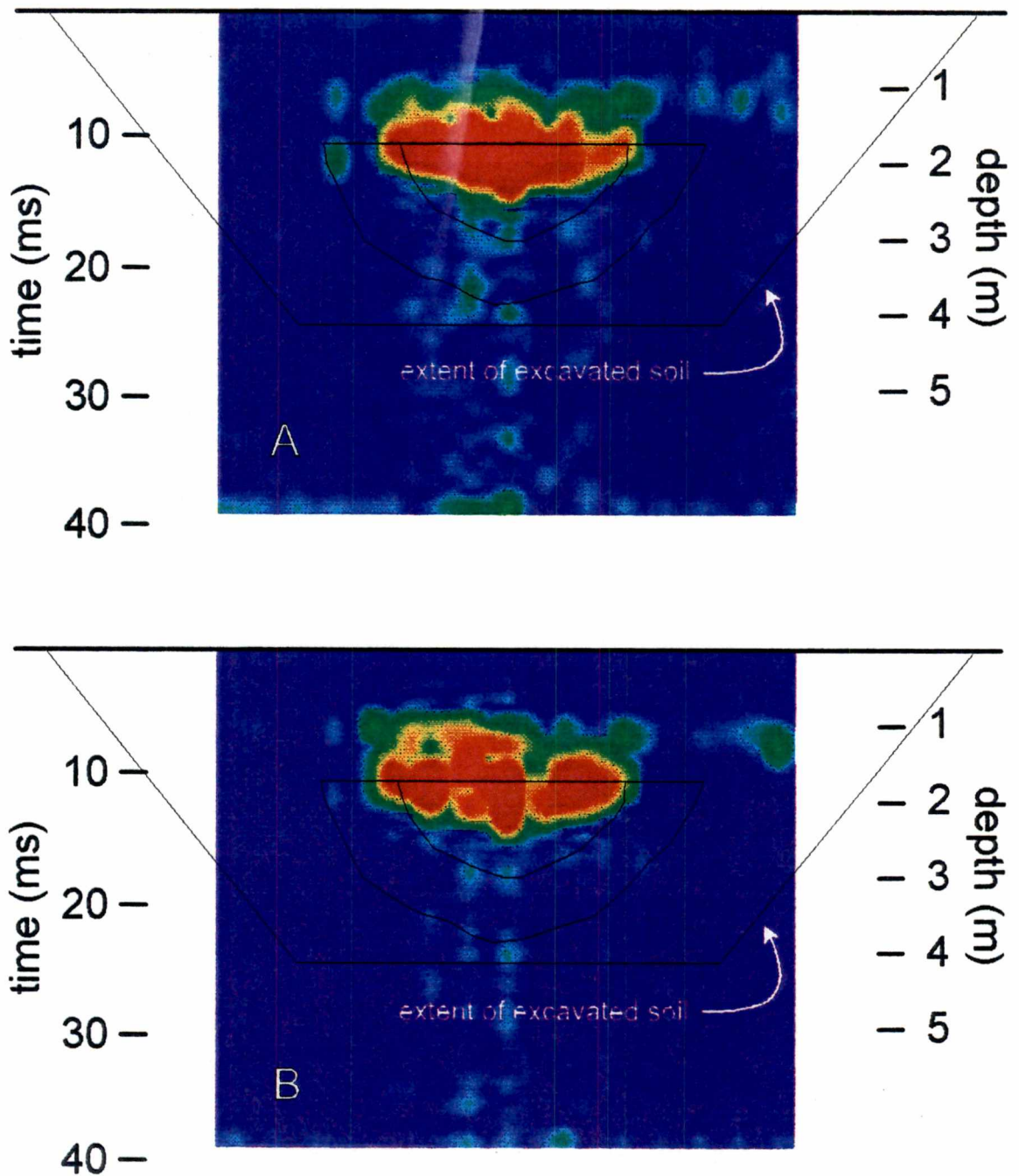


Figure 8. Comparison of reflection strength images from horizontal (radial) and vertical geophone data. (A) Horizontal. (B) Vertical. Data recorded after solidification of the ISV melt. Prestack Kirchhoff migration. Outlines of ISV body and excavated soil (Fig. 1) are shown for reference.

PART 3

**SEISMIC MASKING TO REMOVE UNWANTED
REFLECTIONS FROM KNOWN OBJECTS**

ABSTRACT

A new procedure called *seismic masking* has been developed for processing seismic reflection data and ground-penetrating radar data to reduce the effects of unwanted reflections from known objects. The procedure masks selected volumes in the earth containing the known objects prior to stacking, and is based on the seismic response of hypothetical scattering points (*masking points*) located within the volumes. Portions of the data traces in each shot gather that coincide with arrival times from the masking points are muted. The procedure involves forward modeling the traveltimes for each masking point, and thus requires an accurate velocity model.

The masking procedure was applied to seismic reflection data recorded during *in situ* vitrification (ISV) of a simulated wasted disposal trench at Oak Ridge National Laboratory. A trench containing limestone aggregate was constructed and melted by electrical heating, creating an artificial magma body. The body was well-characterized by temperature measurements during melting and core drilling the cooled, solidified rock. The masking algorithm was tested by successfully attenuating reflections from the limestone in data acquired prior to melting. Images of the melt showed unwanted reflections from a subsidence zone above the melt, which interfered with reflections from the melt itself. Masking the subsidence zone significantly improved the seismic image for the upper portion of the melt.

INTRODUCTION

Reflection seismology produces optimum results when only reflections from the desired target region are used to produce the image. The principal tools used to process seismic reflection data, however, such as stacking and migration, operate on all signals present in the data traces, including unwanted reflections from objects outside the target region. These unwanted reflections can interfere with reflections from the desired target, and degrade the resulting image. For example, traces recorded during a reflection survey to locate a cave in a karst terrane may include reflections from other, known caves. A seismic reflection survey whose purpose is to locate a magma chamber may be hindered by reflections from other known or suspected magma chambers near the target. Ground-penetrating radar (GPR) surveys often record unwanted reflections from radar-reflecting objects both above and below ground. We have developed a procedure that we call *seismic masking* to reduce the effects of unwanted reflections from objects whose locations are known or suspected. The procedure involves forward modeling to calculate the reflection traveltimes for hypothetical *masking points* (point scatterers) situated within regions where the known objects are located, and requires an accurate velocity model.

Seismic masking is fundamentally different from other types of mutes, including first-break and air wave muting, NMO-stretch muting, zeroing noisy traces, and muting noisy windows in shot files (surgical muting). In these types of mutes the underlying principle is to inspect the data traces, and attempt to remove the noise

and leave the discernible signal (Dobrin and Savit, 1988, p. 258). In contrast, seismic masking is based on zeroing all potential arrivals from a selected volume of the earth. Inspection of the field records is not part of the process. Further, the goal of masking is not to reduce seismic noise, but to selectively strip objects from the image, as an aid to interpretation or to clarify the remaining objects.

We applied seismic masking to reflection data recorded during a test of *in situ* vitrification (ISV) to stabilize old radioactive and hazardous waste disposal trenches at Oak Ridge National Laboratory (Jacobs et al., 1992). These data were acquired using closely spaced shotpoints and geophones along a profile passing over the ISV test site (Fig. 1)*. The melt was well-characterized by temperature data from a three-dimensional array of 87 thermocouples, and core drillings of the cooled, solidified rock at the end of the test. This information provided an objective standard for evaluating the seismic images. Data acquired prior to melting contained prominent reflections from limestone aggregate placed 0.8 meters deep in the disposal trench. The masking algorithm was tested by successfully suppressing these reflections. The remainder of the image was not affected by the masking except for a slight increase in background noise, which was judged to be insignificant. Images of the melt showed unwanted reflections from a subsidence zone above the melt, which interfered with reflections from the melt itself. Masking the subsidence zone significantly improved the seismic image for the upper portion of the melt, again with a slight increase in background noise.

* all figures may be found in the Appendix for Part 3

SEISMIC MASKING PROCEDURE

The seismic masking procedure mutes portions of the data using traveltime as a criterion. Seismic masking consists of:

1. Masking point definition
2. Forward modeling traveltimes
3. Time window design
4. Masking function generation

Masking point definition. A model of the survey region is created using point scatterers (*masking points*) to define selected volumes, as illustrated in Figure 2A. The model includes all those volumes that contain or are thought to contain objects causing the unwanted reflections. The number of masking points used is sufficient to encompass the full range of possible traveltimes for each volume.

Forward modeling traveltimes. Forward modeling produces a traveltime for each masking point, represented by a spike on a synthetic trace. Amplitude information is not required for masking. Any forward modeling algorithm that is satisfactory in terms of computational speed and the complexity of the velocity model may be used. Forward modeling all of the masking points produces a series of spikes on a synthetic trace for each shotpoint-geophone pair, as shown in Figure 2B.

Time window design. Each spike on a synthetic trace is replaced by a time window comparable in duration to the source wavelet. For impulsive source data, a spike represents the onset of the source wavelet, and thus marks a window's

starting position. For vibroseis and other correlated data, a spike represents the center of the wavelet after correlation, and marks the center position for a window. The time window shape may have a significant effect on the resulting image, particularly on the background noise levels. Tapered windows generally minimize the background noise observed in subsequent processing. Standard tapers, such as a hanning taper (Waters, 1981, p. 201), may be used, but the optimum choice of window shape and taper is somewhat subjective. The series of spikes generated by any one contiguous volume to be masked should be sufficiently dense to result in overlapping time windows. Figure 2C illustrates each traveltime in Figure 2B replaced by a tapered time window. Note the overlapping time windows for each trace.

Masking function generation. Masking functions are generated on a trace-by-trace basis by combining the time windows produced for each masking point, as shown in Figure 3. The masking function is multiplied sample-by-sample with the corresponding data trace. Masking functions have the same length and sample interval as the data traces, with values between zero and one. Figure 2D illustrates the masking functions generated from the time windows in Figure 2C. A shot gather where each data trace has been multiplied by the corresponding masking function is illustrated in Figure 2E.

Problems associated with seismic masking may arise from the use of an incorrect velocity model or the use of an inappropriate time window. Forward modeling traveltimes for the masking points using an incorrect velocity model may

result in elimination of reflections that occur earlier or later than the unwanted signal, while reflections from the unwanted objects may not be fully suppressed. This problem is similar to the use of an incorrect velocity model in migration, and in general a velocity model used for masking is comparable to one used for pre-stack depth migration. A time window that is too long may mask useful reflections along with the unwanted reflections, while a window that is too short may not completely mask the unwanted reflections. Tapers that are too abrupt may cause "side band" problems (Dobrin and Savit, 1988, p. 185) and additional noise in the image.

Masking may wrongly eliminate reflectors outside the volumes to be masked from the seismic image for single-fold or low-fold data. Seismic masking uses traveltimes information, and the source of a reflection based on traveltimes is not unique. If velocity is constant, the possible positions for a given reflector in the plane of the reflection profile lie on an elliptical arc (Fig. 4). Thus, while each masking point produces a single traveltimes, masking a trace at that traveltimes will eliminate information not only at the masking point but at other points as well, including points outside the volumes selected for masking. High-fold data alleviates this difficulty, as each potential reflector is recorded by numerous traces. The same masking point will produce a different traveltimes for each trace in a CDP gather, and while a point outside the selected volumes may be masked for some traces, the point should not be masked on all traces in the gather. The effective fold for gathers containing masked traces will be reduced, however, which may increase the noise level in the resulting image.

TEST USING SYNTHETIC DATA

Seismic masking was tested using synthetic data containing diffractions from two point scatterers 4 m apart and 5 m in depth, embedded in soil having a constant velocity of 350 m/s. The synthetic data simulated a profile of 31 shotpoints and geophone stations passing over the two point scatterers. The scattering points were imaged using prestack Kirchhoff time migration, with the results shown in a variable area display (Fig. 5A), and in color (Fig. 6A), using the reflection strength attribute computed for the time section by a Hilbert transform (Tanner et al., 1979).

For the test, seismic masking was applied to a circular region 0.5 m in diameter, centered on the left scatterer, with the result shown in Figures 5B and 6B. A 4 ms time window was used to generate the mask. Detailed comparison of the before and after images shows that the left scatterer was successfully masked, but that the changes were actually distributed throughout the image, with the largest effects occurring nearest the area that was masked. The reflection strength (Fig. 6) for the right scatter was noticeably reduced.

The dependence of seismic masking on the correct velocity model was examined by repeating the test with a +5% velocity error (367.5 m/s). The reflection strength image produced by masking the left scatterer as before is shown in Figure 7A. Masking failed to entirely eliminate the left scatterer in this case. As in migration, the problem is related to the absolute error in travel time rather than the percentage error in velocity (Claerbout, 1985, p. 37). A velocity error may be

partially compensated for by increasing the duration of the time window used to generate the masking function. The effect of increasing the window to 8 ms duration is illustrated in Figure 7B, where masking was successful at the expense of greater harm to other parts of the image.

APPLICATION TO AN ARTIFICIAL MAGMA AT OAK RIDGE

An artificial magma was created at Oak Ridge National Laboratory during *in situ* vitrification (ISV) of a simulated waste disposal trench (Jacobs et al., 1992). The ISV magma provided an analog to natural magmatic systems for petrologic and geophysical studies on a scale not usually available to researchers. A trench, containing approximately one cubic meter of limestone aggregate at a depth of 0.8 meters below the surface, was constructed and melted via electrical resistance heating, by applying power to graphite electrodes inserted into the soil above the melt. A roughly hemispheric magma body, approximately 2.9 m deep at the center, was produced after 127 hours of heating, with maximum temperatures reaching almost 1500°C. The upper surface of the melt subsided to a depth of 1.5 m due to volume reduction of the soil during melting. The melt ultimately cooled to form a glassy to partially crystallized rock.

The physical, petrologic, and geochemical properties of the melt and solidified rock were well-characterized by a wide range of geological and geophysical studies. A hood placed over the melt site collected gases and particulates released by the

melting process. Continuous temperature information was obtained from a three-dimensional array of 87 thermocouples installed within and around the volume to be melted. Seismic velocity measurements were made on core samples from the ISV rock (Douglas Green, written communication). Three-dimensional DC resistivity measurements were made using six vertical electrode arrays in boreholes surrounding the melt (Spies and Ellis, 1993). These data provided a comprehensive picture of both the melt and the ISV rock, allowing for an independent evaluation of images produced from seismic reflection profiles.

Seismic reflection data were obtained using 3-component, 100 hz geophones at 1.0 m intervals along a profile passing over the center of the ISV site (Fig. 1). The seismic source was a Betsy 21 mm seisgun fired into the ground at intervals of 0.5 m along the profile. An 8 meter gap in the seismic profile directly above the melt was necessary due to the presence of the gas-collecting hood and heating electrodes. A total of 8 profiles were recorded: 1 before heating, 3 during melting, and 4 during cooling and solidification. A typical data set consisted of 46 shots recorded at 24 geophones, 12 on each side of the melt. Data for the portion of the profile containing the melt ranged from 16 fold to 24 fold for each geophone component.

Seismic images of the trench, melt, and solidified ISV rock were produced using pre-stack Kirchhoff time migration. The velocity model used for imaging the trench prior to melting was based on analysis of the first arrivals in the shot gathers. A constant velocity of 350 m/s was observed for the soil surrounding the trench, and

no increase in velocity with depth in the 0 to 5 m range was apparent. Imaging the melt and ISV rock required the addition of a high velocity region to the model, corresponding to the position of the ISV body. The migrated time sections were bandpassed filtered from 120 to 600 hz. The images were displayed in color using the reflection strength attribute computed for each time section by a Hilbert transform (Tanner et. al., 1979). Traces from the horizontal (radial) and vertical components were migrated separately, and their reflection strength attributes combined using the square root of the sum of the squares. The color scale for the reflection strength images ranged from red for the strong reflections (0 db) to blue for weak or no reflections (-38 db). The image for the trench prior to melting (Fig. 8A) shows strong reflections from the limestone aggregate, and weaker (-10 to -20 db) reflections on both sides of the limestone. The weak reflections beside the limestone were attributed to soil compaction by personnel working to install the thermocouple array and other instrumentation. The image of the solidified ISV rock (Fig. 8B) shows strong reflections from both the rock and the subsidence zone.

The seismic masking algorithm was tested using data from the reflection profile over the trench before melting. The location and dimensions of the limestone were well-known, and the test was to suppress reflections from that volume. The masking points used to represent the limestone are shown in Figure 9. The time window used front and tail hanning tapers, and was 8 ms in duration, including the tapers. The image from the masked data (Fig. 10) shows no reflections from the limestone. The image for portions of the profile adjacent to the limestone aggregate

but outside the masked volume were mostly unaltered. A small amount of additional noise (-25 to -30 db) appeared in the image, concentrated between 25 ms and 35 ms two-way traveltimes.

Images of the ISV rock were improved by masking the reflections from the overlying subsidence zone. These reflections were strong (0 to -10 db), due to the velocity contrast between rubble in the subsidence zone and the surrounding soil, and partially obscured the images for the upper portion of the melt. The masking points used to represent the subsidence zone are shown in Figure 11. The series of spikes produced by forward modeling the masking point traveltimes for the first shotpoint are shown in Figure 12. Data traces for the first shotpoint before and after application of masking functions based on an 8 ms window are shown in Figure 13. Seismic masking eliminated subsidence zone reflections from the image (Fig. 14), and improved the clarity of the image for the upper portion of the melt, with little effect on the image for the lower portion of the melt. Additional low-amplitude noise was observed from 15 ms to 35 ms two-way traveltime, and mostly on the sides of the image.

Noise appearing in the image of the ISV rock after the subsidence zone was masked changed somewhat when the time window used for masking was tapered differently. Time windows having 2 ms front and tail tapers (Fig. 14) were adequate for masking reflections from the subsidence zone. Time windows having a 2 ms front taper and a 4 ms tail taper were also effective in suppressing reflections from the subsidence zone (Fig. 15A), and the longer tail taper resulted in less noise,

particularly at traveltimes greater than 25 ms. Time windows having a 4 ms front taper and a 2 ms tail taper resulted in less suppression of reflections from the subsidence zone (Fig. 15B), indicating that the more rapid (2 ms) front taper is preferred in this case.

SUMMARY AND DISCUSSION OF POSSIBLE APPLICATIONS

1. Seismic masking suppresses unwanted reflections from selected volumes based on a travelttime criterion. Masking one object can also partially suppress reflections from other portions of the profile on some traces, and cause additional noise to appear in the image. Using time windows with excessively sharp corners to generate the masking function can also cause noise in the post-masking image. These detrimental effects of seismic masking are minimized when (1) the fold of the data is sufficiently high, and (2) the duration and tapers of the time window used to generate the masking function are chosen to both suppress the unwanted reflections and minimize the noise introduced into the image.

2. Seismic masking can be used as an interpretation aid. For example, reflectors near the limestone aggregate in the simulated waste disposal trench appeared the same before (Fig. 8A) and after (Fig. 10) masking the limestone aggregate. In contrast, the high amplitude reflections interpreted to arise from the limestone aggregate itself were completely removed by masking its known position. This indicates that (1) the interpretation of the reflections from the limestone

aggregate is correct, and (2) the reflectors near it are real, not processing artifacts associated with the limestone aggregate reflections.

3. The forward modeling step in generating the masking function can be done in either two or three dimensions, even when the data are two dimensional, allowing for removal of unwanted reflections (sideswipe) from objects outside the plane of the profile.

4. An accurate velocity model is required, comparable to one used for prestack depth migration. Masking the limestone aggregate prior to melting was successful in part because the seismic velocity in the simulated waste disposal trench and surrounding soil was nearly constant and could be measured accurately, allowing accurate modeling of traveltimes for the masking points. Melting and solidification of the artificial magma resulted in a more complex velocity model, including a high velocity region occupied by the ISV rock. The high velocity rock did not have a major affect on masking the subsidence zone, however, because the important reflection raypaths were mostly within the soil, and most of the reflections from the artificial magma chamber were found in the backscattered (shotpoints and geophones on the same side of the target) data (Goldman and Williams, 1994).

5. Ground-penetrating radar was not part of the present study, but the results from masking seismic reflections from the ISV melt suggest possible applications to computer processing GPR data. GPR is susceptible to interference from radar-reflecting objects above the ground surface, such as overhead wires, trees, and fence posts. These unwanted radar reflectors are ideal prospects for masking, as their

positions can be determined from observations in the field. The velocity required to model their traveltimes is well-known, being the velocity of the radar pulse in air. Also, the duration of the radar pulse needed to design the time window used to generate the masking function may be better known than the duration of the seismic source wavelet. Thus, masking known objects above the surface in a radar survey involves fewer uncertainties than seismic masking applied to unwanted subsurface reflectors.

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APPENDIX - PART 3

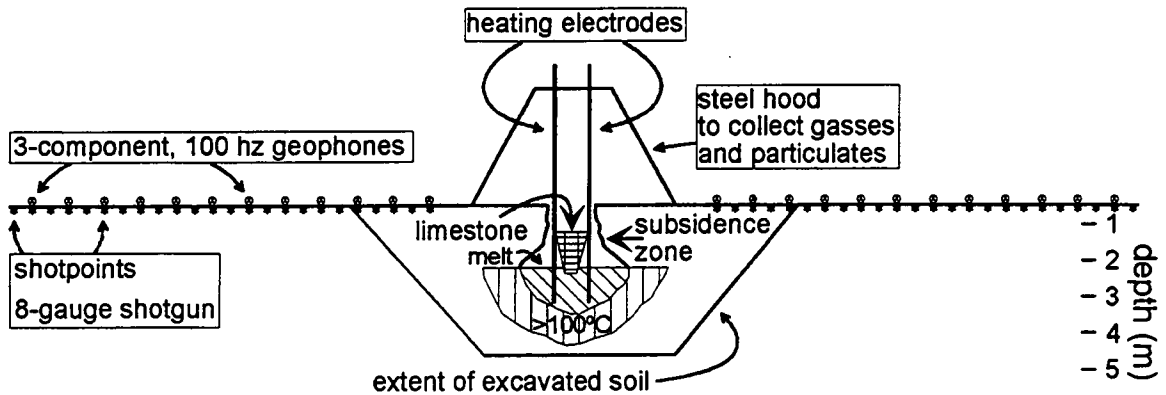


Figure 1. ISV seismic profile geometry. Simulated wasted disposal trench contained limestone aggregate. Electrical heating produced the ISV magma body and a subsidence zone. The seismic reflection profile passed over the melt and extended 15.5 m on either side. Hachures show the limestone before melting, the melt at its maximum extent, and the zone where soil temperatures exceeded 100°C.

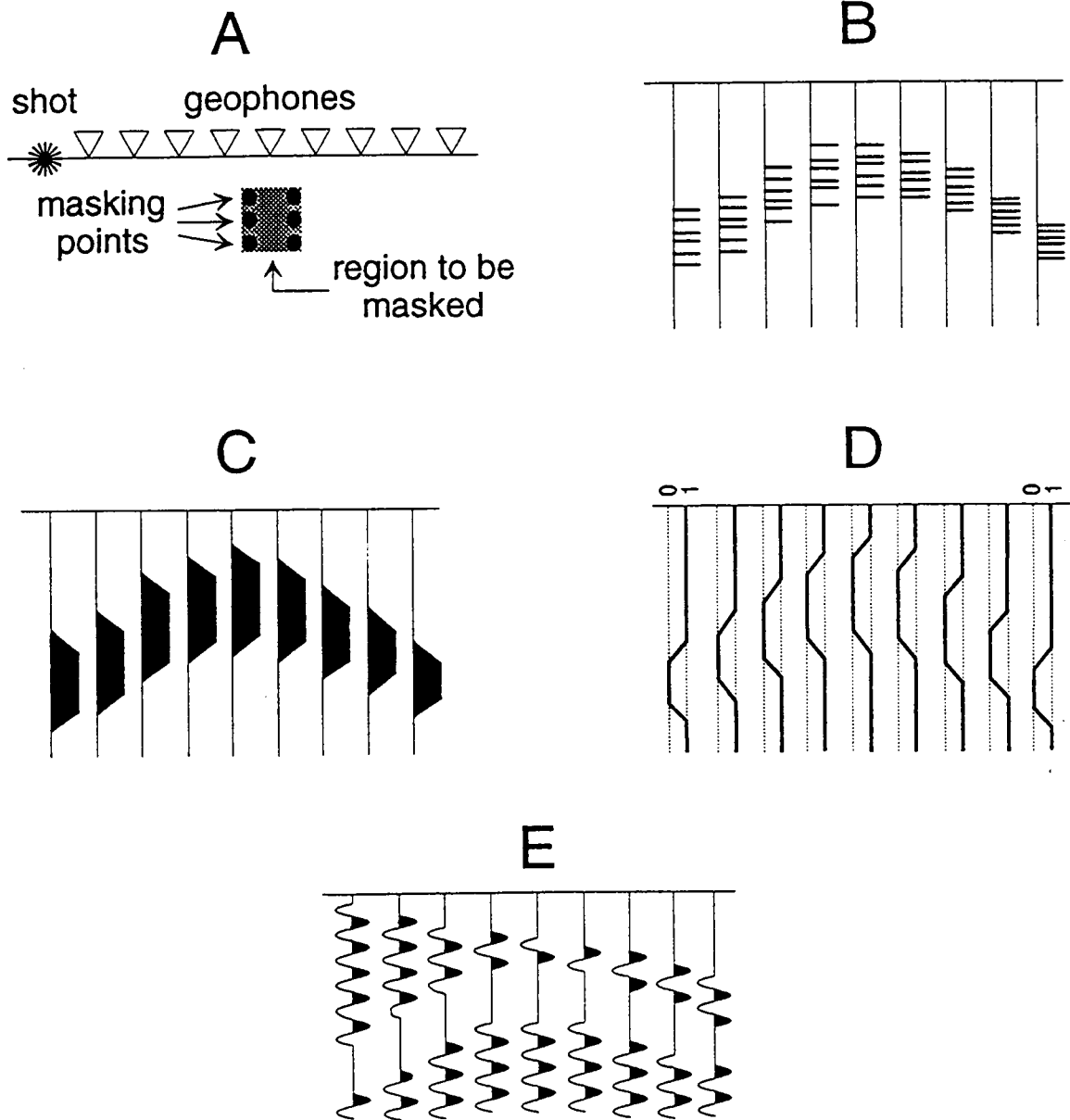


Figure 2. Seismic masking theory. (A) Survey geometry and masking points within the region to be masked. (B) Spikes representing reflection traveltimes for masking points. (C) Spikes replaced with tapered time windows. (D) Masking functions. (E) Data after masking.

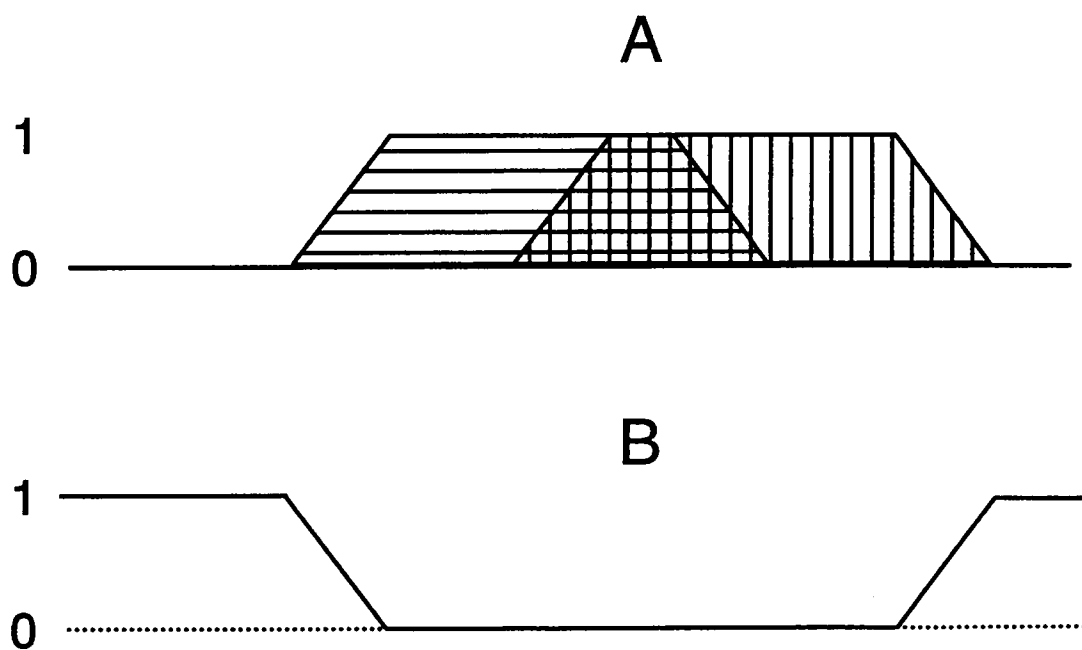


Figure 3. Construction of a masking function. The series of time windows for a single shotpoint-geophone pair (A) are combined to form a masking function for the corresponding data trace (B).

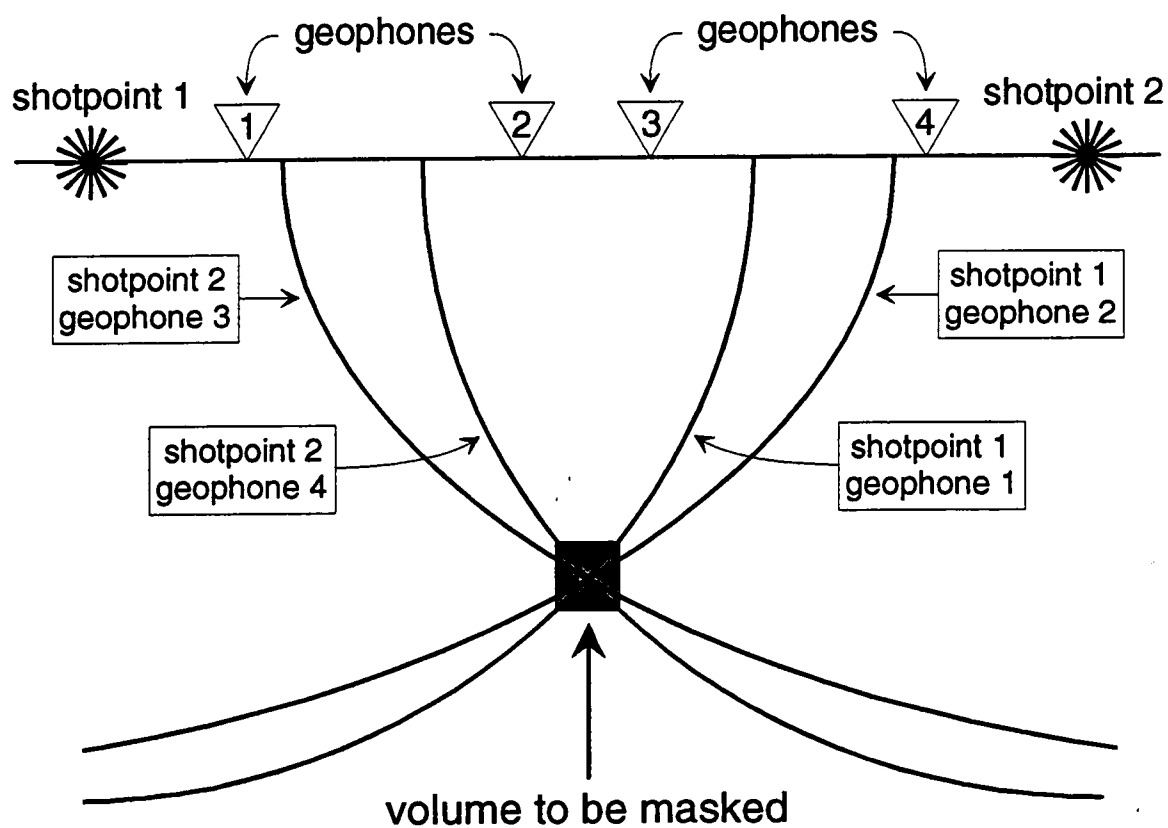


Figure 4. Possible source positions for a given reflection in a constant velocity medium, for different shotpoint-geophone pairs.

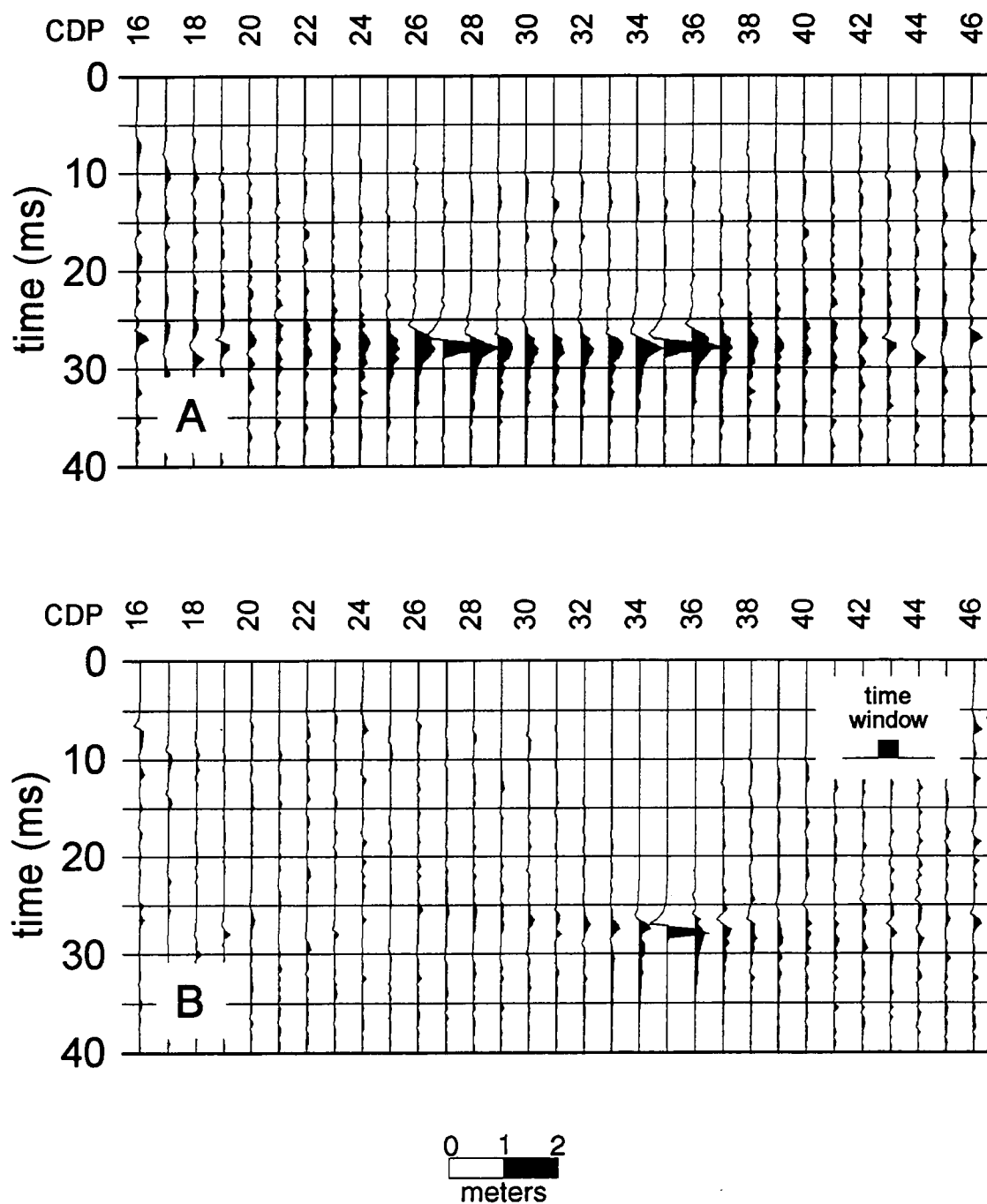


Figure 5. Migrated synthetic data for two point sources. (A) Without seismic masking. (B) Seismic masking applied to the left point source. The point sources are beneath CDP's 27 and 35, at ~28.5 ms travelt ime.

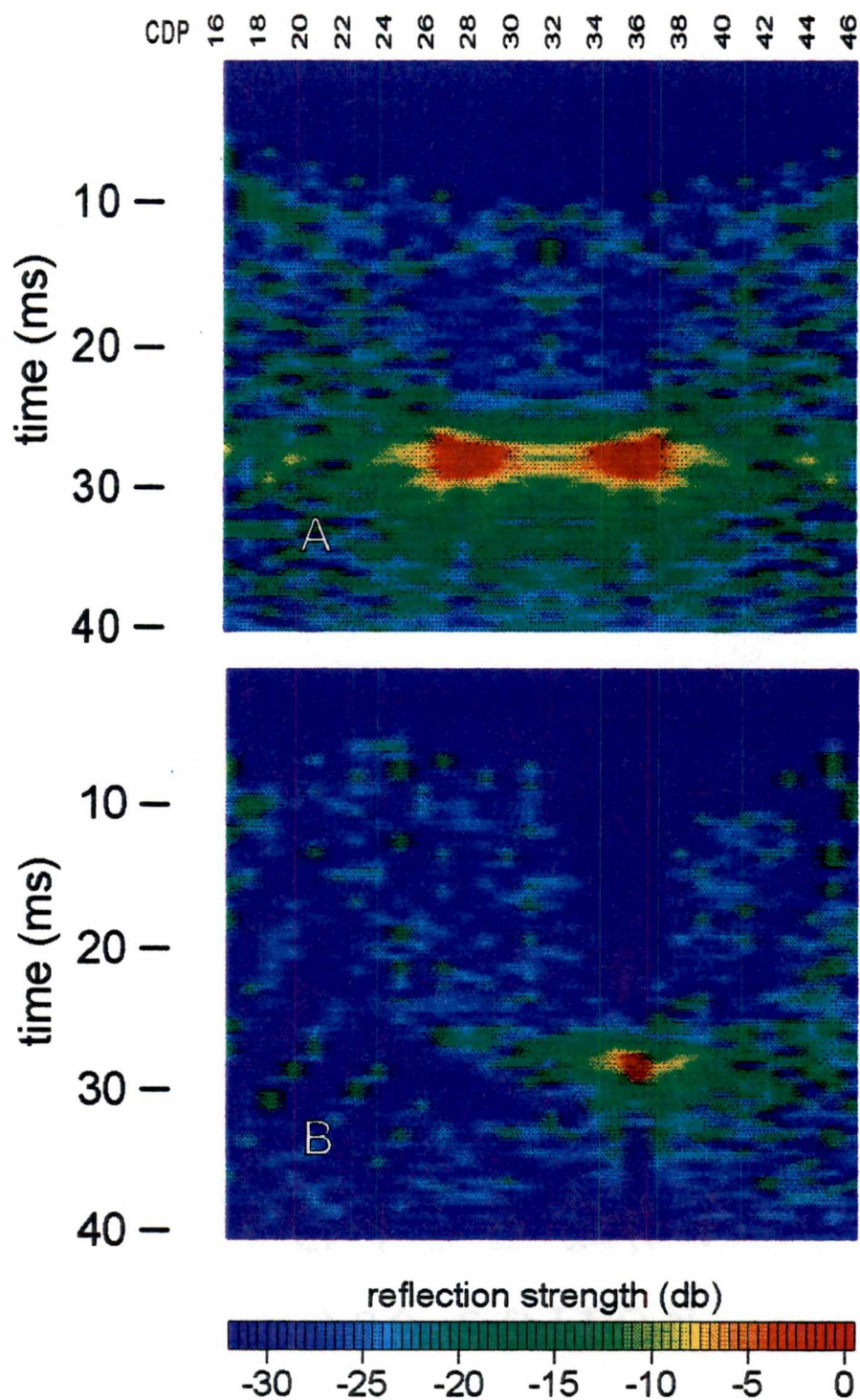


Figure 6. Reflection strength images for migrated synthetic data (Fig. 5). (A) Without seismic masking. (B) With seismic masking.

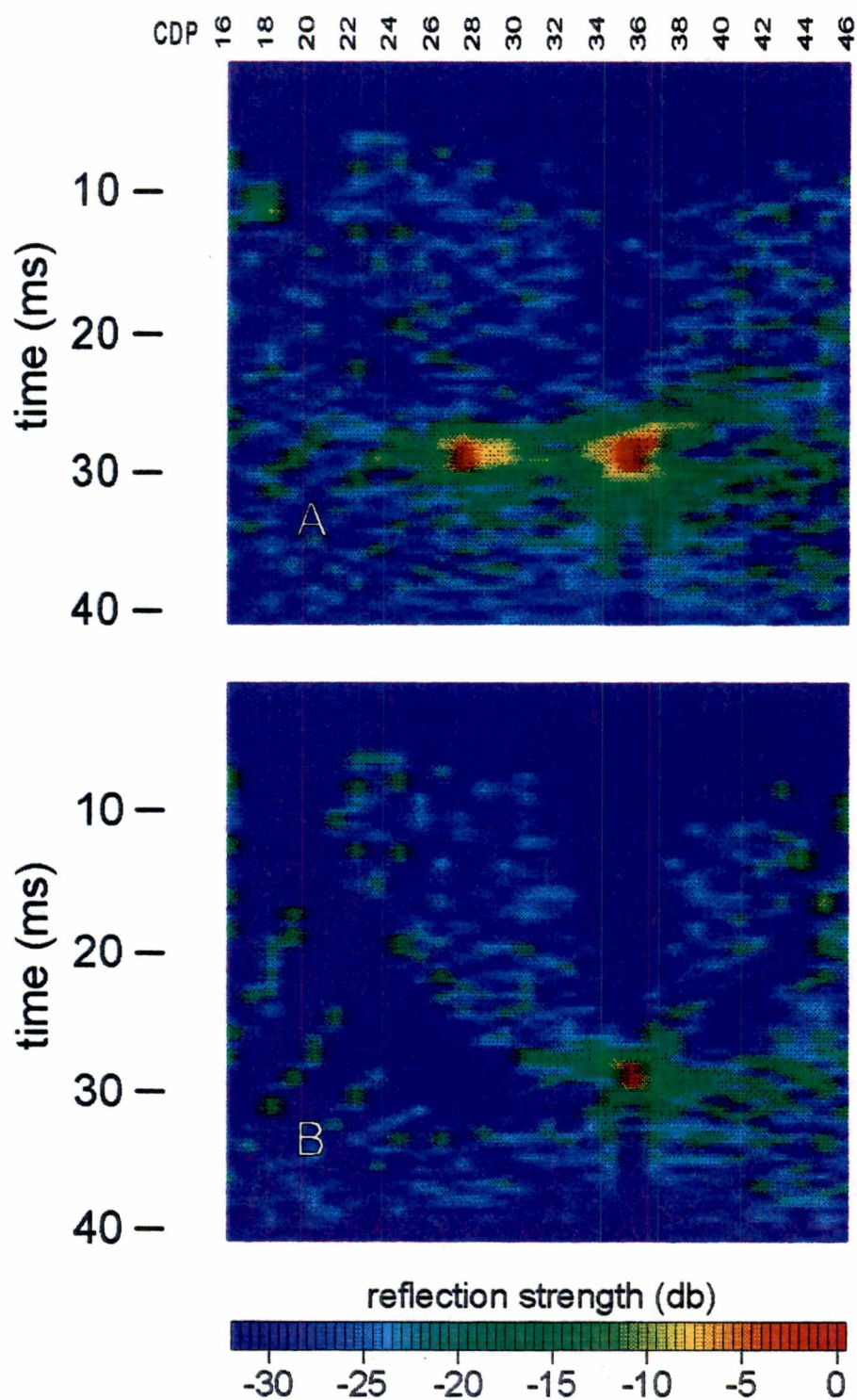


Figure 7. Reflection strength images from data masked using an incorrect velocity (367.5 m/s) 5% greater than the correct velocity (350 m/s). (A) 4 ms time window. (B) 8 ms time window.

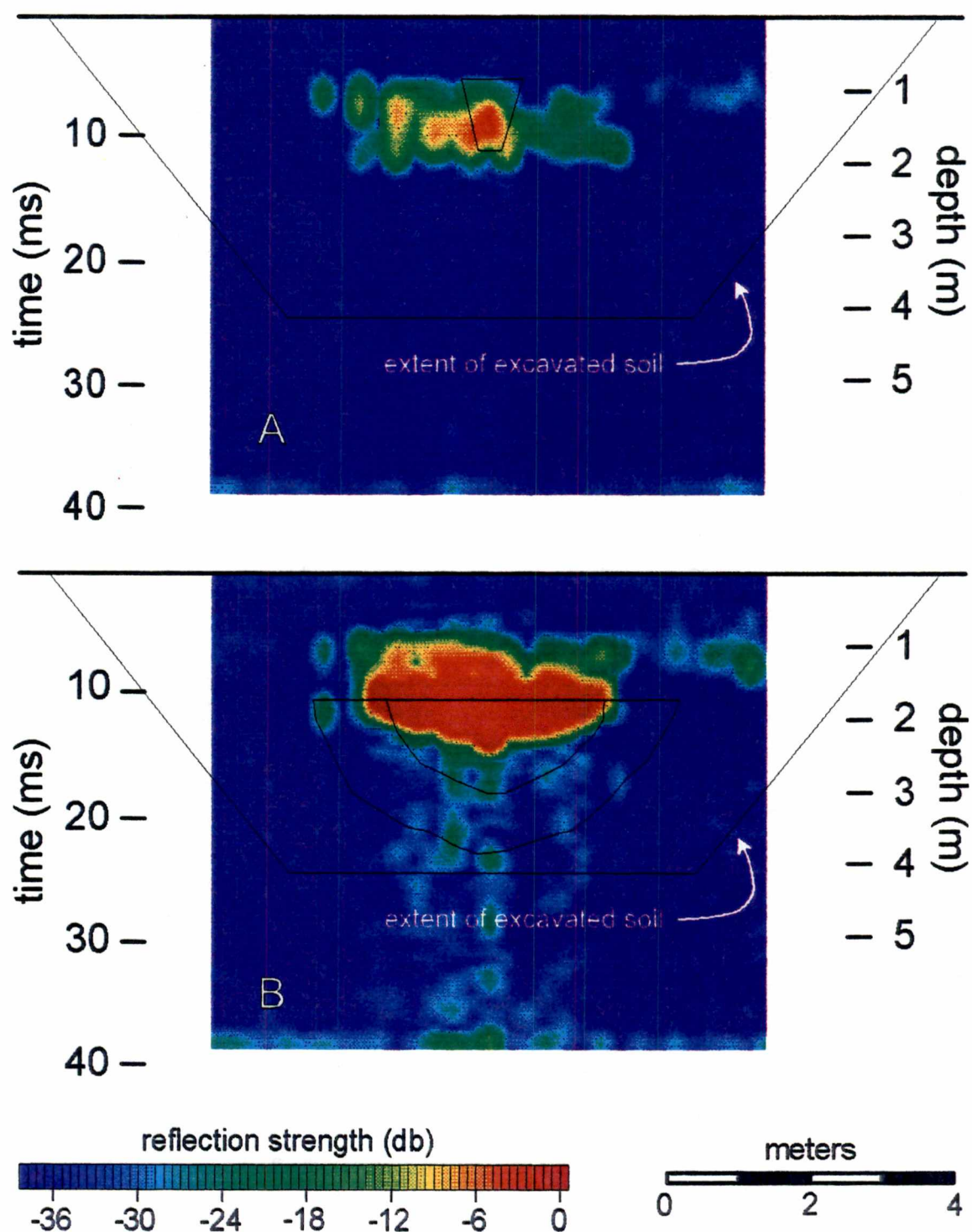


Figure 8. Reflection strength images of the ISV site, without seismic masking. (A) Limestone aggregate from data recorded before melting. (B) ISV rock and subsidence zone from data recorded after solidification of the melt.

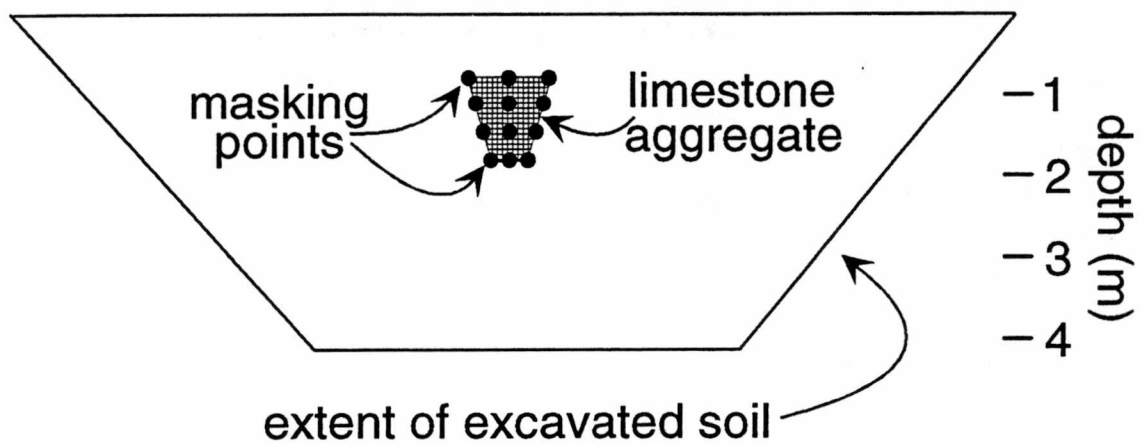


Figure 9. Locations of masking points used to represent the limestone aggregate.

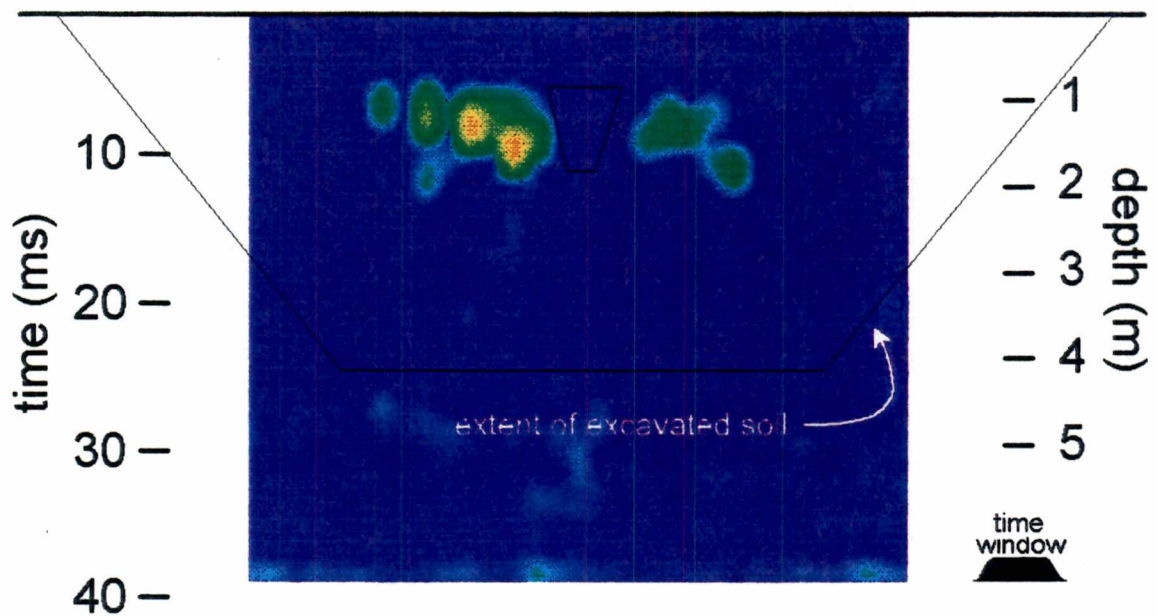


Figure 10. Reflection strength images of the ISV site before melting. Reflections from the limestone aggregate are masked. Compare to Fig. 5A.

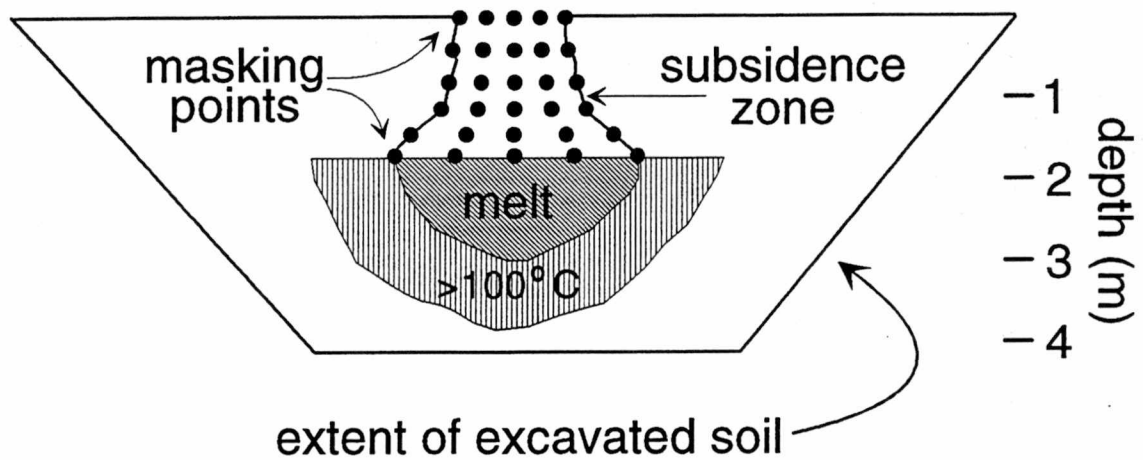


Figure 11. Masking point definition. Step 1 in the application of seismic masking to the subsidence zone.

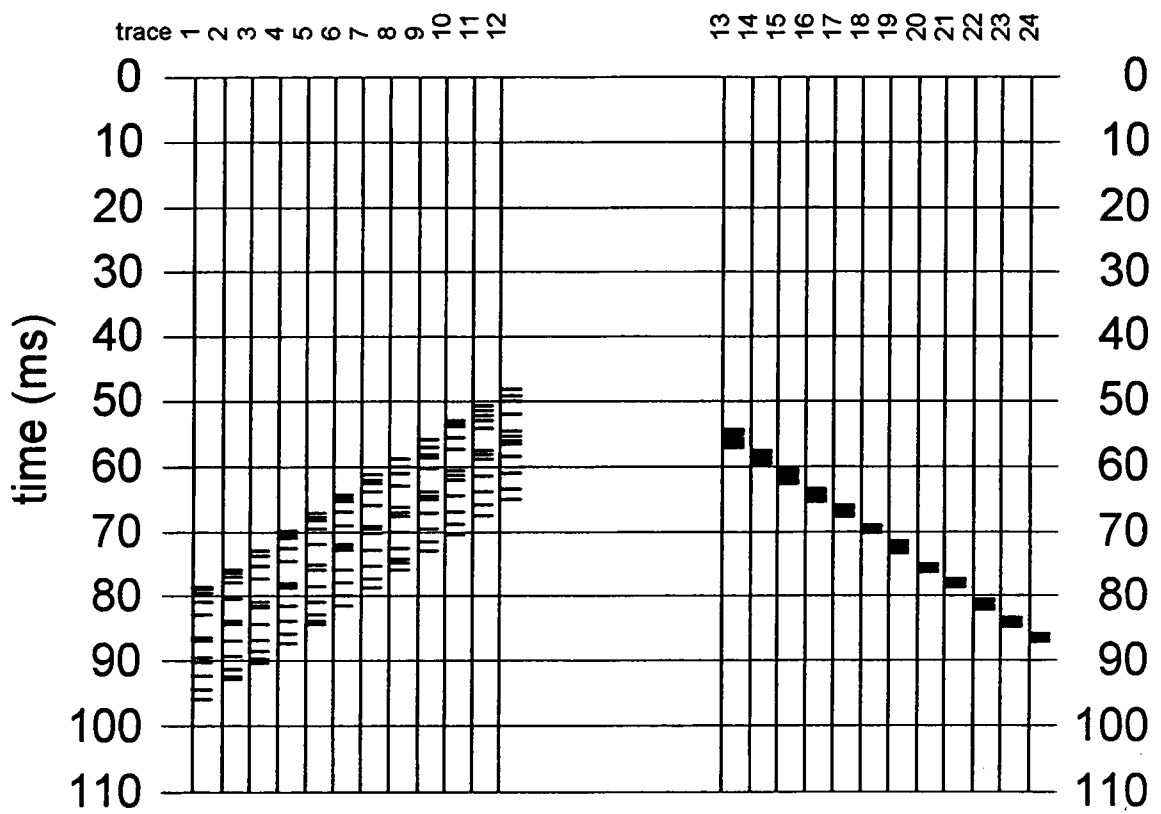


Figure 12. Step 2 in the application of seismic masking to the subsidence zone, for the first shotpoint.

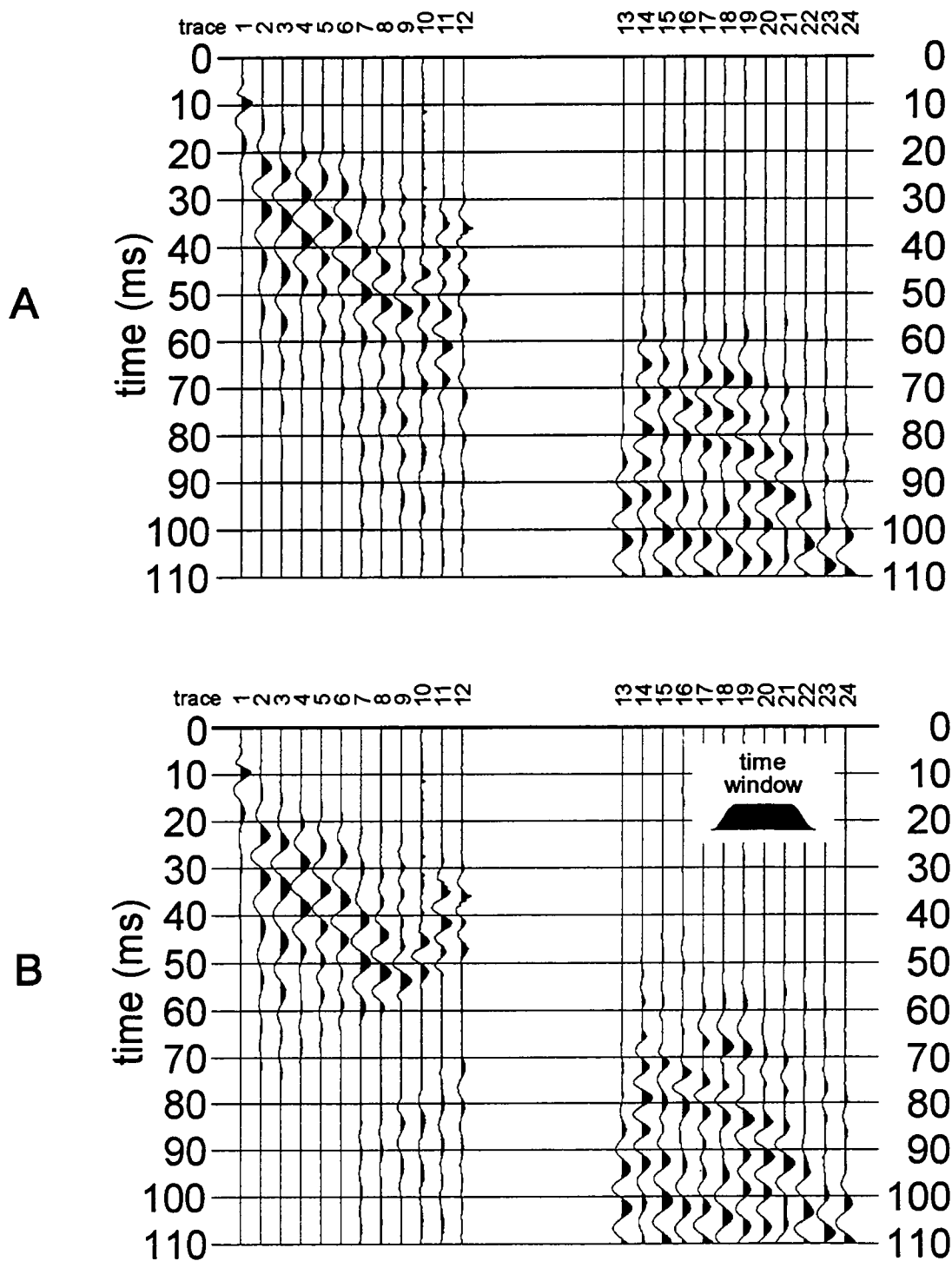


Figure 13. Shot gathers for shotpoint 1. (A) Before masking. (B) After masking.

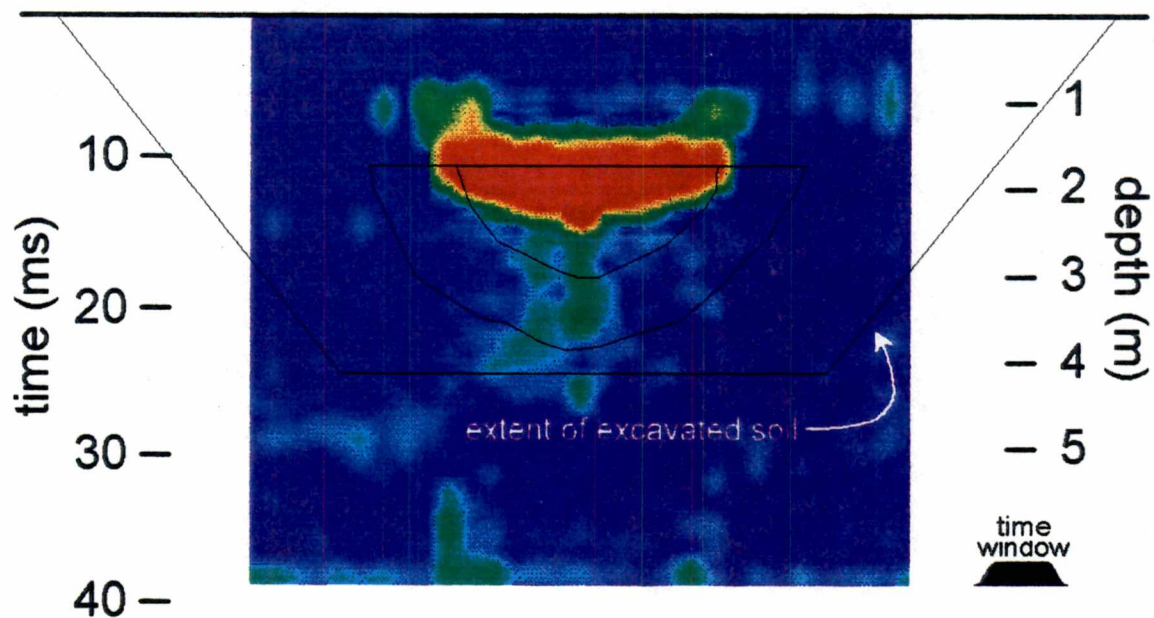


Figure 14. Reflection strength image of the ISV site after melting and solidification of the artificial magma. Reflections from the subsidence zone are masked. Compare to Fig. 5B.

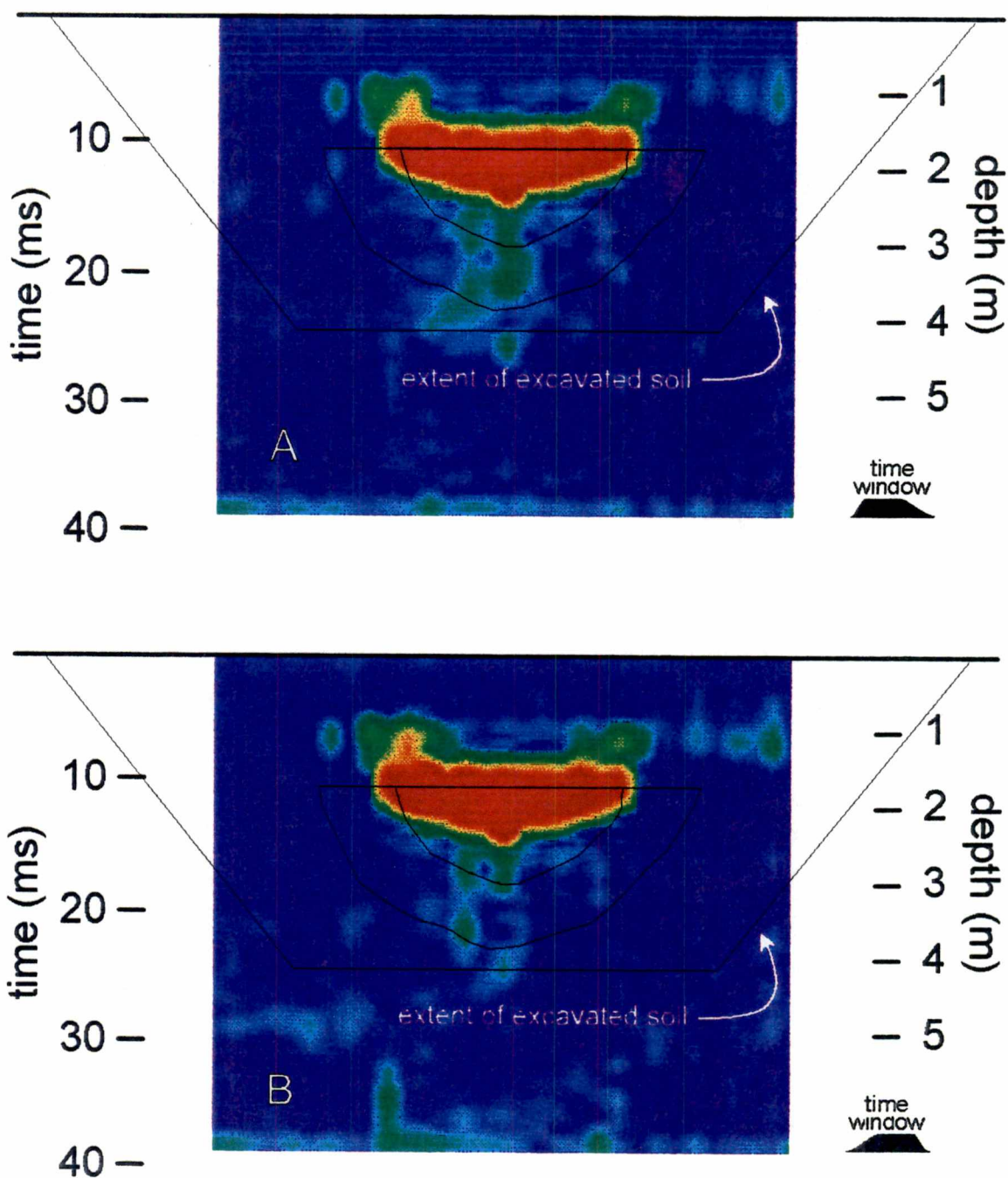


Figure 15. Reflection strength images of the ISV site after melting and solidification. Noise in the image depends on the taper of the masking window. (A) 2 ms front taper, 4 ms tail taper. (B) 4 ms front taper, 2 ms tail taper. Compare to Fig. 11, where both tapers were 2 ms.

APPENDIX

Survey Parameters and Channel Listing

The ISV experiment consisted of 8 separate seismic surveys, ranging in time from before melting to after crystallization. Each survey was recorded by 3 seismic lines, and each line comprised a distinct data set, for a total of 23 data sets (line 200 was not recorded for the survey of 5/15/91). Lines 100 and 200 consisted of 24 3-component geophones, 12 on each side of the melt. Line 300 consisted of 12 3-component geophones divided between two boreholes, one on each side of the melt. Due to the limited number of channels available for recording lines 100 and 200 required two shots at each shotpoint, with each shot recording one side of the melt. For line 300 only one shot was required to record both sides. Each data set was recorded by a combination of an MDS-10 recording system and a PC recording system. The MDS-10 recorded data on channels 1 to 12 at a sampling rate of 0.5 ms. Channels 13 to 24 on the MDS-10 were interleaved with the first 12 channels, for an approximate sampling rate of 0.25 ms. The MDS-10 also recorded 5 auxiliary channels, one of which consisted of the time break signal. The PC recorded data on channels 1 to 24 at a sampling rate of 0.16 ms. The MDS-10 channel listing for lines 100 and 200 is (for geophones on the left side of the melt):

channel 1:	geophone 1 - transverse component
channel 2:	geophone 1 - radial component
channel 3:	geophone 1 - vertical component
channel 4:	geophone 2 - transverse component
channel 5:	geophone 2 - radial component
channel 6:	geophone 2 - vertical component
channel 7:	geophone 3 - transverse component
channel 8:	geophone 3 - radial component
channel 9:	geophone 3 - vertical component
channel 10:	geophone 4 - transverse component
channel 11:	geophone 4 - radial component
channel 12:	geophone 4 - vertical component

Geophone 1 is for all cases the geophone farthest to the left. The PC channel listing for lines 100 and 200 is (for geophones on the left side of the melt):

channel 1:	geophone 5 - transverse component
channel 2:	geophone 5 - radial component
channel 3:	geophone 5 - vertical component
channel 4:	geophone 6 - transverse component
channel 5:	geophone 6 - radial component
channel 6:	geophone 6 - vertical component
channel 7:	geophone 7 - transverse component
channel 8:	geophone 7 - radial component
channel 9:	geophone 7 - vertical component

channel 10:	geophone 8 - transverse component
channel 11:	geophone 8 - radial component
channel 12:	geophone 8 - vertical component
channel 13:	geophone 9 - transverse component
channel 14:	geophone 9 - radial component
channel 15:	geophone 9 - vertical component
channel 16:	geophone 10 - transverse component
channel 17:	geophone 10 - radial component
channel 18:	geophone 10 - vertical component
channel 19:	geophone 11 - transverse component
channel 20:	geophone 11 - radial component
channel 21:	geophone 11 - vertical component
channel 22:	geophone 12 - transverse component
channel 23:	geophone 12 - radial component
channel 24:	geophone 12 - vertical component

The channel listing is the same for geophones on the right side of the melt, except that the transverse and vertical components are switched. The MDS-10 channel listing for line 300 is:

channel 1:	geophone 1 - transverse component (right borehole)
channel 2:	geophone 1 - radial component (right borehole)
channel 3:	geophone 1 - vertical component (right borehole)
channel 4:	geophone 2 - transverse component (right borehole)
channel 5:	geophone 2 - radial component (right borehole)
channel 6:	geophone 2 - vertical component (right borehole)
channel 7:	geophone 1 - transverse component (left borehole)
channel 8:	geophone 1 - radial component (left borehole)
channel 9:	geophone 1 - vertical component (left borehole)
channel 10:	geophone 2 - transverse component (left borehole)
channel 11:	geophone 2 - radial component (left borehole)
channel 12:	geophone 2 - vertical component (left borehole)

Here geophone 1 is the geophone closest to the surface. The PC channel listing for line 300 is:

channel 1:	geophone 3 - transverse component (right borehole)
channel 2:	geophone 3 - radial component (right borehole)
channel 3:	geophone 3 - vertical component (right borehole)
channel 4:	geophone 4 - transverse component (right borehole)
channel 5:	geophone 4 - radial component (right borehole)
channel 6:	geophone 4 - vertical component (right borehole)
channel 7:	geophone 5 - transverse component (right borehole)
channel 8:	geophone 5 - radial component (right borehole)

channel 9:	geophone	5 - vertical component (right borehole)
channel 10:	geophone	6 - transverse component (right borehole)
channel 11:	geophone	6 - radial component (right borehole)
channel 12:	geophone	6 - vertical component (right borehole)
channel 13:	geophone	3 - transverse component (left borehole)
channel 14:	geophone	3 - radial component (left borehole)
channel 15:	geophone	3 - vertical component (left borehole)
channel 16:	geophone	4 - transverse component (left borehole)
channel 17:	geophone	4 - radial component (left borehole)
channel 18:	geophone	4 - vertical component (left borehole)
channel 19:	geophone	5 - transverse component (left borehole)
channel 20:	geophone	5 - radial component (left borehole)
channel 21:	geophone	5 - vertical component (left borehole)
channel 22:	geophone	6 - transverse component (left borehole)
channel 23:	geophone	6 - radial component (left borehole)
channel 24:	geophone	6 - vertical component (left borehole)

Demultiplexing of Data

The first processing step for each data set was to demultiplex all recorded traces. For most of the MDS-10 tapes this was accomplished on an IBM mainframe. A README file located in the directory =demux details the procedure. The mainframe program did not output the 5 auxiliary channels. The output, in SEG-Y format, was converted to SierraSeis house format using the job listing MAINFRAME2DOUT.JOB, located in the directory =jobs and shown below. Comments are enclosed in parenthesis.

```

/IN
FORMAT VARIABLE
REEL 99999
NOMATCH
BSDICODE 1 (must be 1 for mainframe output, 0 for PC output)
FILELOC 9 4
TRLOC 13 4
HEADER 400 2
LABEL 240 241
KFLDFN 9 4
KFLDTN 13 4
KTRTYP 29 2
DATA 1 1000 0.5 24 0 (shot gathers, no geometry, 1000 milliseconds of data,
sampling rate 0.5, 24 data channels, no auxiliary channels)
BI 101 (field file numbers based on shooter's notes)
EI 155
/DOUT

```

FILENAME 'output_file'

A few of the MDS-10 tapes were unable to be read using the mainframe. These tapes were read using the program demux_MDS, written by Dr. Richard Williams of the University of Tennessee, and located in the directory =programs. Demux_MDS included the 5 auxiliary channels with the output. The output from Demux_MDS was converted to SierraSeis house format, and the auxiliary channels stripped from the output, using the job listing MDS2DOUT.JOB located in the directory =jobs:

```
/IN
FORMAT VARIABLE
REEL 99999
NOMATCH
BSDICODE 0 (must be 0 for demux_MDS output)
FILELOC 9 4
TRLOC 13 4
HEADER 400 2
LABEL 240 241
KFLDFN 9 4
KFLDTN 13 4
KTRTYP 29 2
DATA 1 1000 0.5 24 5 (demux_MDS output includes the five auxiliary traces)
BI 101
EI 155
TRACEI D1 24 1 (strips the 5 auxiliary traces from the output)
/DOUT
FILENAME 'output_file'
```

The PC data was read using the program pcseg, located in the directory =programs. Pcseg applied recording gain information to each data set. ASCII files containing recording gain information for each data set are located in the directory =files under the name pc.XXX, where XXX are the last three digits of the corresponding MDS-10 SEG-B tape. Output from pcseg was converted to SierraSeis house format using the job listing PC2DOUT.JOB. The sample rate of the PC data was changed from 0.16 to 0.5 milliseconds.

```
/IN
FORMAT VARIABLE
REEL 99999
NOMATCH
BSDICODE 0 (must be 0 for PC output)
FILELOC 9 4
TRLOC 13 4
HEADER 400 2
```

```

LABEL 240 241
KFLDFN 9 4
KFLDTN 13 4
KTRTYP 29 2
DATA 1 1000 0.16 24 0 (sampling rate 0.16 for pc data)
BI 101
EI 155
/RESAMPLE (cubic spline interpolation)
NEWRATE 0.5
/DOUT
FILENAME 'xxx'

```

Pcseggy applied additional gains to the PC data, based on sine waves recorded simultaneously by the PC and the MDS-10. These gains equalized the recorded amplitudes of the sine waves among the two recording systems, and are listed below:

channel	1:	1.766
channel	2:	1.796
channel	3:	1.852
channel	4:	1.844
channel	5:	1.892
channel	6:	1.835
channel	7:	1.845
channel	8:	1.834
channel	9:	1.696
channel	10:	1.795
channel	11:	1.876
channel	12:	1.852
channel	13:	1.819
channel	14:	1.853
channel	15:	1.817
channel	16:	1.874
channel	17:	1.735
channel	18:	1.851
channel	19:	1.869
channel	20:	1.841
channel	21:	1.814
channel	22:	1.844
channel	23:	1.848
channel	24:	1.828

The following gives the line number and date for each tape, details whether the mainframe or the program demux_MDS was used to demultiplex the MDS-10 data, and lists any missing files and traces. All missing traces were filled using zero

traces and with the SierraSeis global common variable (GCV) KFLDFN set to 999.

line	date	SEG-B tape	mainframe output?	SEG-Y tape	Missing files or traces
-----	-----	-----	-----	-----	-----
100	5/3/91	U26523	yes	U26877	PC files 22, 41, 46, all traces
100	5/6/91	U26524	yes	U26878	
200	5/8/91	U26526	no	-----	MDS files 201-207 wrong size
300	5/12/91	U26527	no	U26881	PC file 327 traces 13-24
100	5/14/91	U26530	yes	U26884	PC file 411, all traces
200	5/14/91	U26531	yes	U26885	U26531 partially erased, use demux output tape U26917, traces 4-24
300	5/14/91	U26532	yes	U26886	PC file 612 traces 4-24, PC file 628 traces 1-24, PC file 652 traces 19-24, PC file 657 traces 13-24
100	5/15/91	U26533	yes	U26887	
300	5/15/91	U26534	yes	U26888	PC file 806, traces 7-24
100	5/16/91	U26536	yes	U26890	
200	5/16/91	U26537	no	U26891	MDS-10 file 114
300	5/16/91	U26538	no	U26892	PC file 211 traces 16-24
100	5/18/91	U26539	yes	U26893	MDS-10 files 15, 20 ,67
300	5/18/91	U26540	---	U26894	MDS-10 tape blank. PC files 448, 449, all traces
200	5/18/91	U26541	yes	U26895	MDS-10 files 514-525 reversed polarity
100	5/20/91	U26542	yes	U26896	
300	5/20/91	U26543	no	U26897	
200	5/20/91	U26544	yes	U26898	
100	5/24/91	U26545	yes	U26899	
300	5/24/91	U26546	yes	U26900	
200	5/24/91	U26547	yes	U26901	
100	6/21/91	U26548	yes	U26902	MDS-10 file 12
300	6/21/91	U26549	yes	U26903	
200	6/21/91	U26550	no	U26904	PC file 156, all traces

Sorting and Categorizing of Data

All recorded shot files were categorized as either test/faulty shots, shots recorded on the left side of the melt, or shots recorded on the right side of the melt. An ASCII information file was created for each data set listing all shots in a given category. These information files, based on the shooter's notes, are given the name data.XXX, where XXX is the last three digits of the original SEG-B tape, and are located in the directory =files. Each information file has 4 lines, the first listing all

test and faulty shots. Note that the first seven or eight shots of each tape were test shots, consisting of sine waves or noise. The second line lists all shots recorded on the left side of the melt, and the third line all shots recorded on the right side. For line 300 data sets the second and third lines are identical, since geophones on both sides of the melt were recorded for each shot. The fourth line lists shotpoints in the order they were used. Standard SierraSeis delta notation is followed, where Da b c represents a series of shots from a to b in increments of c. Thus D11 17 2 represents shots 11, 13, 15, and 17. The following is a listing of all data.XXX files:

data.523:

D1 8 1 18 22 29 41 46 52
9 11 14 15 17 20 23 25 27 D30 38 2 40 43 45 48 50 53 55
10 12 13 16 19 21 24 26 28 D31 39 2 42 44 47 49 51 54 56
D1 20 1 23

data.524:

D101 107 1
D108 194 2
D109 195 2
D1 20 1 23 39 40 41 D44 63 1

data.526:

D201 207 1 213 296
208 210 212 D215 293 2 295 D298 304 2
209 211 214 D216 294 2 297 D299 305 2
1 3 2 4 5 7 6 8 9 11 10 12 13 15 14 16 17 19 18 20 21 23 22 39 41 40 42 43 45 44 46
47 49 48 50 51 53 52 54 55 57 56 58 59 61 60 62 63

data.527:

317 321 329
D311 316 1 318 319 320 D322 328 1 D330 353 1
D311 316 1 318 319 320 D322 328 1 D330 353 1
D1 20 1 D44 63 1

data.530:

D401 407 1 490
D408 488 2 D491 503 2
D409 489 2 D492 504 2
1 3 2 4 5 7 6 8 9 11 10 12 13 15 14 16 17 19 18 20 21 23 22 39 41 40 42 43 45 44 46
47 49 48 50 51 53 52 54 55 57 56 58 59 61 60 62 63

data.531:

D505 511 1 554
D512 552 2 D555 607 2

D513 553 2 D556 608 2

1 3 2 4 5 7 6 8 9 11 10 12 13 15 14 16 17 19 18 20 21 23 22 39 41 40 42 43 45 44 46
47 49 48 50 51 53 52 54 55 57 56 58 59 61 60 62 63

data.532:

610 611 636

D612 635 1 D637 658 1

D612 635 1 D637 658 1

D1 21 1 23 39 40 41 D43 63 1

data.533:

D701 707 1 735 751 756

D708 732 2 734 D737 749 2 752 754 D757 801 2

D709 733 2 736 D738 750 2 753 755 D758 802 2

1 3 2 4 5 7 6 8 9 11 10 12 13 15 14 16 17 19 18 20 21 23 39 41 40 43 45 44 46 47 49
48 50 51 53 52 54 55 57 56 58 59 61 60 62 63

data.534:

803 840

D804 839 1 D841 850 1

D804 839 1 D841 850 1

D1 21 1 23 39 40 41 D43 63 1

data.536:

D1 7 1

D8 98 2

D9 99 2

1 3 2 4 5 7 6 8 9 11 10 12 13 15 14 16 17 19 18 20 21 23 39 41 40 43 45 44 46 47 49
48 50 51 53 52 54 55 57 56 58 59 61 60 62 63

data.537:

100 101 114 165

D102 112 2 D115 163 2 D166 198 2

D103 113 2 D116 164 2 D167 199 2

1 3 2 4 5 7 6 8 9 11 10 12 13 15 14 16 17 19 18 20 21 23 22 39 41 40 42 43 45 44 46
47 49 48 50 51 53 52 54 55 57 56 58 59 61 60 62 63

data.538:

200

D201 246 1

D201 246 1

D1 21 1 23 39 40 41 D43 63 1

data.539:

D301 307 1 376
D308 312 2 314 317 319 320 323 D324 364 2 366 D368 374 2 D377 399 2
D309 313 2 315 316 318 321 322 D325 365 2 367 D369 375 2 D378 400 2
D1 21 1 23 39 40 41 D43 63 1

data.540:

D401 407 1 447 448 449
D408 446 1 D450 456 1
D408 446 1 D450 456 1
D1 21 1 23 39 40 41 D43 63 1

data.541:

D501 509 1
D510 604 2
D511 605 2
D1 23 1 D39 63 1

data.542:

D701 707 1 715 798
D708 712 2 714 D717 795 2 797 800
D709 713 2 716 D718 796 2 799 801
D1 21 1 23 39 40 41 D43 63 1

data.543:

802 803 807
804 805 806 D808 850 1
804 805 806 D808 850 1
D1 21 1 23 39 40 41 D43 63 1

data.544:

1 2
D3 97 2
D4 98 2
D1 23 1 D39 63 1

data.545:

D101 108 1 137 138 141 142 147 154 158 170 171 172 173 175 176 177 179 180 186
D109 135 2 139 144 145 149 150 152 156 157 D160 168 2 174 181 183 185 D188 210
2
D110 136 2 140 143 146 148 151 153 155 159 D161 169 2 178 182 184 187 D189 211
2
D1 21 1 23 39 40 41 D43 63 1

data.546:

D212 219 1 229 230 231 239 248 249 252 255 258
D220 228 1 D232 238 1 D240 247 1 250 251 253 254 256 257 D259 274 1
D220 228 1 D232 238 1 D240 247 1 250 251 253 254 256 257 D259 274 1
D1 21 1 23 39 40 41 D43 63 1

data.547:

D275 281 1 297 299 330 346
D282 294 2 296 D300 328 2 D331 343 2 345 D348 380 2
D283 295 2 298 D301 329 2 D332 344 2 347 D349 381 2
D1 23 1 D39 63 1

data.548:

D1 7 1 12
8 10 D13 99 2
9 11 D14 100 2
D1 21 1 23 39 40 41 D43 63 1

data.549:

D101 107 1 117 133
D108 116 1 D118 132 1 D134 155 1
D108 116 1 D118 132 1 D134 155 1
D1 21 1 23 39 40 41 D43 63 1

data.550:

D156 162 1
D163 257 2
D164 258 2
D1 23 1 D39 63 1

After demultiplexing, the MDS-10 and PC traces for each data set were combined and sorted into three disk files. These disk files were written in SierraSeis house format and named dXXX.dout, tXXX.dout, and sXXX.dout, where XXX is the last three digits of the original SEG-B tape. The file dXXX.dout contains all traces from channels 13 to 24 of the MDS-10 and consists of 12 traces per shot. The file tXXX.dout contains all test and faulty shots from the data set and consists of 36 traces per shot: channels 1 to 12 of the MDS-10 followed by channels 1 to 24 of the PC, for geophones on one side of the melt only. The file sXXX.dout contains all other shots and for line 100 and 200 data sets consists of 72 traces per shot: channels 1 to 12 of the MDS-10 followed by channels 1 to 24 of the PC for geophones on the left side of the melt, and then channels 1 to 12 of the MDS-10 and channels 1 to 24 of the PC for geophones on the right side of the melt. For line 300 data the sXXX.dout file contains 36 traces per shot: channels 1 to 12 of the MDS-10 followed by channels 1 to 24 of the PC.

Job listings named SORT.XXX and COMB.XXX were created for each tape, where XXX is the last three digits of the original SEG-B tape, and are located in the directory =jobs/=saved_jobs. The SORT.XXX listing gathers and sorts the MDS-10 and PC data, and for line 100 and 200 data reverses the trace order for geophones on the left side of the melt, giving all geophones a trace order of: vertical, radial, transverse. For line 300 data the SORT.XXX listing reverses the trace order for all geophones. The COMB.XXX listing takes the output of SORT.XXX, combines files, and rennumbers the traces in each file. The SORT.548 and COMB.548 listings for SEG-B tape U26548 are shown below. The original data set for tape U26548 consisted of 100 MDS-10 shot files and 100 PC shot files, with files 1 to 7 test shots and file 12 a faulty shot that was redone. The information file Data.548 gives the category of each shot, as described above.

/DIN

FILENAME 'MDS-10.data'

RESEQUIT 1 (rennumbers MDS-10 files to start at 1)

FILENAME 'PC.data' (appends PC files to MDS-10 files)

/GLTRANS FILES 8 10 D13 99 2 (changes trace order for renumbered MDS-10 traces)

AMP

HEADER

TRACEX 0 0 1

TRACEY 0 1 0

TRACEZ 0 0 1

/GLTRANS FILES 108 110 D113 199 2 (changes trace order for renumbered PC traces)

AMP

HEADER

TRACEX 0 0 1

TRACEY 0 1 0

TRACEZ 0 0 1

/PRMODCOM FILES 8 10 D13 99 2 108 110 D113 199 2

MODIFY 'KTRC' UPDATE 1 1 (resets trace number for reordered traces)

/AUX FILES D1 100 1 TRACES D13 24 1

/DOUT (writes out MDS-10 channels 13 to 24)

FILENAME 'd.548'

NRECS 1200

/ENDAUX

/AUX EXCLUDE FILES D1 100 1 TRACES D13 24 1 (removes MDS-10 channels 13 to 24 from further processing)

/MDPCSORT (gathers and sorts traces, outputs for each shot 12 MDS-10 traces followed by 24 PC traces)

/AUX FILES D1 7 1 12 D101 107 1 112 (writes out test and faulty files)

/DOUT

FILENAME 't.548'

NRECS 288

/ENDAUX

/AUX EXCLUDE FILES D1 7 1 12 D101 107 1 112 (removes test and faulty files from further processing)

/DOUT

FILENAME 's.548'

NRECS 3312

/ENDAUX

/ENDAUX

The job listing COMB.548 completes the gathering and sorting process:

/DIN

FILENAME 't.548'

/PRMODCOM FILES 1 101

MODIFY 'KNTR' SET 36

MODIFY 'KNSHOT' SET 8

MODIFY 'KSHOT' SET 1

/PRMODCOM FILE 1

MODIFY 'KTRC' UPDATE 1 1

/PRMODCOM FILES 2 102

MODIFY 'KNTR' SET 36

MODIFY 'KNSHOT' SET 8

MODIFY 'KSHOT' SET 2

/PRMODCOM FILE 2

MODIFY 'KTRC' UPDATE 1 1

/PRMODCOM FILES 3 103

MODIFY 'KNTR' SET 36

MODIFY 'KNSHOT' SET 8

MODIFY 'KSHOT' SET 3

/PRMODCOM FILE 3

MODIFY 'KTRC' UPDATE 1 1

.....
/PRMODCOM FILES 7 107
MODIFY 'KNTR' SET 36
MODIFY 'KNSHOT' SET 8
MODIFY 'KSHOT' SET 7
/PRMODCOM FILE 7
MODIFY 'KTRC' UPDATE 1 1

/PRMODCOM FILES 12 112
MODIFY 'KNTR' SET 36
MODIFY 'KNSHOT' SET 8
MODIFY 'KSHOT' SET 12
/PRMODCOM FILE 12
MODIFY 'KTRC' UPDATE 1 1

/DOUT
FILENAME 't.548'
NRECS 288

/DIN
FILENAME 's.548'

/PRMODCOM FILES 8 9 108 109
MODIFY 'KNTR' SET 72
MODIFY 'KNSHOT' SET 46
MODIFY 'KSHOT' SET 1
/PRMODCOM FILE 1
MODIFY 'KTRC' UPDATE 1 1

/PRMODCOM FILES 10 11 110 111
MODIFY 'KNTR' SET 72
MODIFY 'KNSHOT' SET 46
MODIFY 'KSHOT' SET 2
/PRMODCOM FILE 2
MODIFY 'KTRC' UPDATE 1 1

/PRMODCOM FILES 12 13 112 113
MODIFY 'KNTR' SET 72
MODIFY 'KNSHOT' SET 46
MODIFY 'KSHOT' SET 3
/PRMODCOM FILE 3
MODIFY 'KTRC' UPDATE 1 1

.....
/PRMODCOM FILES 97 98 197 198
MODIFY 'KNTR' SET 72
MODIFY 'KNSHOT' SET 46
MODIFY 'KSHOT' SET 45
/PRMODCOM FILE 45
MODIFY 'KTRC' UPDATE 1 1

/PRMODCOM FILES 10 11 110 111
MODIFY 'KNTR' SET 72
MODIFY 'KNSHOT' SET 46
MODIFY 'KSHOT' SET 46
/PRMODCOM FILE 46
MODIFY 'KTRC' UPDATE 1 1

/DOUT
FILENAME 's.548'
NRECS 3312

The Program process_data, located in the directory =programs, was used for line 100 and 200 data to create individual SORT.XXX and COMB.XXX files, based on input from a residing data.XXX file. Type process_data with no parameters for a summary of the command. For line 300 data the program process_data_300 was used.

For some shots geophones on the right side of the melt were recorded before geophones on the left side. The COMB.XXX listing must be modified for these shots by inserting a call to the /MSWITCH processor just before the file is output. This processor takes the last 36 traces in the specified shot file and places them ahead of the first 36 traces, thus putting all traces recorded on the left side of the melt before all traces recorded on the right side. This step is necessary for:

TAPE U26523, FILE 3
TAPE U26539, FILES 5, 6, and 8
TAPE U26545, FILES 1, 16, 18, and 21

For example, in file COMB.539 one must add the lines:

/MSWITCH FILE 5
/MSWITCH FILE 6
/MSWITCH FILE 8

Note that each file should be altered with a separate call to the /MSWITCH processor. Also note that the program process_data will not put these lines in the COMB.539 job listing. They must be manually inserted before running the job.

Editing of Traces

All traces were examined, using both normal amplitude plots and true-amplitude plots, and faulty traces were zeroed. The following lists all faulty traces found, giving the original tape number and geophone component. Borehole data also gives the particular borehole: left or right. The job listings used to edit each data set are located in the directory =jobs/=saved_jobs. Note that line 100 and 200 transverse component traces were not examined.

U26524 RADIAL:
FILES 1 TRACES 5

U26524 VERTICAL:
FILES 1 TRACES 4

U26527 TRANSVERSE LEFT:
FILES D24 30 1 TRACES 4

U26527 VERTICAL RIGHT:
FILES D1 20 1 TRACES 6 7
FILES D21 40 1 TRACES 7

U26530 RADIAL:
FILES 22 TRACES 29
FILES 45 TRACES 65

U26530 VERTICAL:
FILES 5 TRACES 10
FILES 18 TRACES 19
FILES 22 TRACES 19
FILES 23 TRACES 19
FILES 37 TRACES 49
FILES 38 TRACES 49
FILES 39 TRACES 49

U26532 RADIAL LEFT:
FILES 21 TRACES 1 2
FILES 22 TRACES 2
FILES D23 29 1 TRACES 2 5

U26532 RADIAL RIGHT:
FILES 26 27 TRACES 7

U26532 TRANSVERSE LEFT:

FILES 21 TRACES 1 2
FILES 24 TRACES 2
FILES 26 TRACES 4
FILES D29 41 1 TRACES 2
FILES D42 46 1 TRACES 1 2

U26532 VERTICAL LEFT:
FILES 21 TRACES 1 2

U26532 VERTICAL RIGHT:
FILES D1 16 1 TRACES 6
FILES 17 TRACES 4 6
FILES D18 22 1 TRACES 6
FILES 41 TRACES 2 3

U26533 RADIAL:
FILES 22 TRACES 29
FILES 43 TRACES 65

U26533 VERTICAL:
FILES 18 TRACES 19
FILES 21 TRACES 19
FILES 22 TRACES 19
FILES 34 TRACES 49
FILES 35 TRACES 49
FILES 36 TRACES 49
FILES 37 TRACES 49

U26534 RADIAL LEFT:
FILES 8 TRACES 1
FILES D22 27 1 TRACES 2
FILES 40 TRACES 2
FILES 44 TRACES 2

U26534 RADIAL RIGHT:
FILES 26 TRACES 7
FILES 29 TRACES 7
FILES 32 TRACES 7

U26534 TRANSVERSE LEFT:
FILES 8 TRACES 1
FILES 17 TRACES 4
FILES 21 TRACES 2
FILES 22 TRACES 4

FILES 32 TRACES 2
FILES 40 TRACES 2 3
FILES 44 TRACES 2 3

U26534 TRANSVERSE RIGHT:
FILES 40 TRACES 2
FILES 44 TRACES 2

U26534 VERTICAL LEFT:
FILES 8 TRACES 1
FILES 44 TRACES 2

U26534 VERTICAL RIGHT:
FILES D1 22 1 TRACES 6
FILES 32 TRACES 2
FILES 44 TRACES 2

U26536 RADIAL:
FILES 22 TRACES 29
FILES 43 TRACES 65
FILES 46 TRACES 65

U26536 VERTICAL:
FILES 18 TRACES 19
FILES 19 TRACES 19
FILES 20 TRACES 19
FILES 21 TRACES 19
FILES 22 TRACES 19
FILES 34 TRACES 49
FILES 35 TRACES 49
FILES 36 TRACES 49
FILES 37 TRACES 49

U26538 RADIAL LEFT:
FILES D21 28 1 TRACES 2

U26538 TRANSVERSE LEFT:
FILES 30 31 32 TRACES 2
FILES 36 TRACES 2

U26538 VERTICAL LEFT:
FILES 36 TRACES 2

U26538 VERTICAL RIGHT:

FILES D1 22 1 TRACES 6

U26539 RADIAL:

FILES 44 TRACES 65

FILES 46 TRACES 65

U26539 VERTICAL:

FILES 18 TRACES 19

FILES 19 TRACES 19

FILES 20 TRACES 19

FILES 21 TRACES 19

FILES 22 TRACES 19

FILES 34 TRACES 49

FILES 35 TRACES 49

FILES 36 TRACES 49

FILES 37 TRACES 49

U26540 RADIAL LEFT:

FILES 4 TRACES 4 5 6 7

FILES 27 TRACES 4 5 6 7

U26540 RADIAL RIGHT:

FILES 4 TRACES D1 7 1

U26540 TRANSVERSE LEFT:

FILES 4 TRACES 4 5 6 7

U26540 TRANSVERSE RIGHT:

FILES 4 TRACES D1 7 1

U26540 VERTICAL LEFT:

FILES 4 TRACES 4 5 6 7

FILES 27 TRACES 4 5 6 7

U26540 VERTICAL RIGHT:

FILES 1 2 3 TRACES 6

FILES 4 TRACES D1 7 1

FILES D5 22 1 TRACES 6

U26542 RADIAL:

FILES 22 TRACES 29

FILES 44 TRACES 65

FILES 45 TRACES 65

FILES 46 TRACES 65

U26542 VERTICAL:
FILES 3 TRACES 31
FILES 4 TRACES 31
FILES 5 TRACES 31
FILES 6 TRACES 31
FILES 7 TRACES 31
FILES 17 TRACES 19
FILES 18 TRACES 19
FILES 19 TRACES 19
FILES 20 TRACES 19
FILES 21 TRACES 19
FILES 22 TRACES 19
FILES 34 TRACES 49
FILES 35 TRACES 49
FILES 36 TRACES 49

U26543 RADIAL LEFT:
FILES 21 TRACES 1
FILES D22 25 1 TRACES 2
FILES 26 TRACES 2 5
FILES 27 TRACES 2 4 5 6 7
FILES 28 29 TRACES 2

U26543 RADIAL RIGHT:
FILES 25 TRACES 2

U26543 TRANSVERSE LEFT:
FILES 21 TRACES 1

U26543 VERTICAL LEFT:
FILES 21 TRACES 1
FILES 26 TRACES 7
FILES 27 TRACES 5 6 7

U26543 VERTICAL RIGHT:
FILES D1 22 1 TRACES 6

U26545 RADIAL:
FILES 1 TRACES 5
FILES 15 TRACES 35
FILES 16 TRACES 35
FILES 17 TRACES 35
FILES 18 TRACES 35

FILES 19 TRACES 35
FILES 20 TRACES 35
FILES 21 TRACES 35
FILES 44 TRACES 65

U26545 VERTICAL:
FILES 19 TRACES 19
FILES 20 TRACES 19
FILES 21 TRACES 19
FILES 22 TRACES 19
FILES 36 TRACES 49

U26546 RADIAL LEFT:
FILES 21 TRACES 2
FILES 22 TRACES 1 2
FILES 23 24 TRACES 2
FILES 25 26 TRACES 2 3 4 5 6 7
FILES 27 28 TRACES 2

U26546 TRANSVERSE LEFT:
FILES 22 TRACES 1
FILES 33 TRACES 2
FILES 43 TRACES 2
FILES 44 TRACES 1 2
FILES 45 TRACES 2

U26546 TRANSVERSE RIGHT:
FILES 43 44 45 TRACES 2

U26546 VERTICAL LEFT:
FILES 22 TRACES 1
FILES 44 TRACES 1

U26546 VERTICAL RIGHT:
FILES D1 22 1 TRACES 6
FILES 26 TRACES 6

U26548 RADIAL:
FILES 1 TRACES 5
FILES 44 TRACES 65
FILES 46 TRACES 65

U26548 VERTICAL:
FILES 1 TRACES 4

FILES 17 TRACES 19
FILES 18 TRACES 19
FILES 19 TRACES 19
FILES 20 TRACES 19
FILES 21 TRACES 19
FILES 22 TRACES 19
FILES 34 TRACES 49
FILES 35 TRACES 49
FILES 36 TRACES 49

U26549 RADIAL LEFT:
FILES 21 TRACES 2
FILES D23 26 1 TRACES 2
FILES 27 TRACES 2 6
FILES D28 30 1 TRACES 2

U26549 TRANSVERSE LEFT:
FILES 25 26 27 TRACES 4 5 6 7

U26549 VERTICAL LEFT:
FILES 21 TRACES 2

U26549 VERTICAL RIGHT:
FILES D1 22 1 TRACES 6

Creating Geometry Files

Trace editing is the last procedure for line 300 data. Line 100 and 200 data, however, requires for further processing a geometry file to record the spatial position of each shotpoint and geophone. All spacing and distance units were multiplied by 100 to create integer distances. Thus shotpoint spacing became 50 m instead of 0.5 m, and the background velocity became 35000 m/sec instead of 350 m/sec. This was necessary since SierraSeis, when creating common-offset gathers, rounds all spacing units to the nearest integer. An example geometry listing for SEG-B tape U26548 is shown below:

```
/GEOMETRY  
GEOMFILE 'GEO.548'  
PRINTALL  
SURVEY  
STBASE 1  
SPLIST D1 46 1  
STATION 1 -1550 0, 2 -1500 0
```

SHOT 1 AT 1 INTO 2 2 2 4 4 4 6 6 6 8 8 8

10 10 10 12 12 12 14 14 14 16 16 16

18 18 18 20 20 20 22 22 22 24 24 24

40 40 40 42 42 42 44 44 44 46 46 46

48 48 48 50 50 50 52 52 52 54 54 54

56 56 56 58 58 58 60 60 60 62 62 62

SHOT 2 AT 2 INTO 2 2 2 4 4 4 6 6 6 8 8 8

10 10 10 12 12 12 14 14 14 16 16 16

18 18 18 20 20 20 22 22 22 24 24 24

40 40 40 42 42 42 44 44 44 46 46 46

48 48 48 50 50 50 52 52 52 54 54 54

56 56 56 58 58 58 60 60 60 62 62 62

.....

SHOT 21 AT 21 INTO 2 2 2 4 4 4 6 6 6 8 8 8

10 10 10 12 12 12 14 14 14 16 16 16

18 18 18 20 20 20 22 22 22 24 24 24

40 40 40 42 42 42 44 44 44 46 46 46

48 48 48 50 50 50 52 52 52 54 54 54

56 56 56 58 58 58 60 60 60 62 62 62

SHOT 22 AT 23 INTO 2 2 2 4 4 4 6 6 6 8 8 8

10 10 10 12 12 12 14 14 14 16 16 16

18 18 18 20 20 20 22 22 22 24 24 24

40 40 40 42 42 42 44 44 44 46 46 46

48 48 48 50 50 50 52 52 52 54 54 54

56 56 56 58 58 58 60 60 60 62 62 62

SHOT 23 AT 39 INTO 2 2 2 4 4 4 6 6 6 8 8 8

10 10 10 12 12 12 14 14 14 16 16 16

18 18 18 20 20 20 22 22 22 24 24 24

40 40 40 42 42 42 44 44 44 46 46 46

48 48 48 50 50 50 52 52 52 54 54 54

56 56 56 58 58 58 60 60 60 62 62 62

SHOT 24 AT 40 INTO 2 2 2 4 4 4 6 6 6 8 8 8

10 10 10 12 12 12 14 14 14 16 16 16

18 18 18 20 20 20 22 22 22 24 24 24

40 40 40 42 42 42 44 44 44 46 46 46

48 48 48 50 50 50 52 52 52 54 54 54

56 56 56 58 58 58 60 60 60 62 62 62

SHOT 25 AT 41 INTO 2 2 2 4 4 4 6 6 6 8 8 8
 10 10 10 12 12 12 14 14 14 16 16 16
 18 18 18 20 20 20 22 22 22 24 24 24
 40 40 40 42 42 42 44 44 44 46 46 46
 48 48 48 50 50 50 52 52 52 54 54 54
 56 56 56 58 58 58 60 60 60 62 62 62

SHOT 26 AT 43 INTO 2 2 2 4 4 4 6 6 6 8 8 8
 10 10 10 12 12 12 14 14 14 16 16 16
 18 18 18 20 20 20 22 22 22 24 24 24
 40 40 40 42 42 42 44 44 44 46 46 46
 48 48 48 50 50 50 52 52 52 54 54 54
 56 56 56 58 58 58 60 60 60 62 62 62

SHOT 46 AT 63 INTO 2 2 2 4 4 4 6 6 6 8 8 8
 10 10 10 12 12 12 14 14 14 16 16 16
 18 18 18 20 20 20 22 22 22 24 24 24
 40 40 40 42 42 42 44 44 44 46 46 46
 48 48 48 50 50 50 52 52 52 54 54 54
 56 56 56 58 58 58 60 60 60 62 62 62

The program create_geometry, located in the directory =programs, creates a geometry file called GEO.XXX, based on a residing data.XXX file. Line 300 tapes do not have a geometry file. All GEO.XXX files are located in the directory =jobs/=saved_jobs. The GEOMETRY.JOB listing, located in the directory =jobs, was used to apply geometry information to each data set.

Processing of Data

Several SierraSeis job listings, all located in the directory =jobs, were used to process and migrate the data. The first processing step was to separate the geophone components in each data set. The job listing SEPARATE.JOB creates 3 data sets, each containing one geophone component:

```
/DIN
FILENAME 'sXXX.dout'
/PRMODCOM
MODIFY 'KNTR' SET 24
/DOUT TRACES D1 70 3 (vertical component)
FILENAME 'sXXXv.dout'
NRECS 1104
/DOUT TRACES D2 71 3 (radial component)
```

```
FILENAME 'sXXXr.dout'  
NRECS 1104  
/DOUT TRACES D3 72 3 (transverse component)  
FILENAME 'sXXXt.dout'  
NRECS 1104
```

The next step was to remove the direct wave from the data. Analysis of the direct wave on shot and receiver gathers established a background velocity of 350 meters/sec. The velocity used in the following job listing was 35000 m/sec, since as described above all distance measurements were multiplied by 100. The listing performs a surgical mute on the data, with amplitudes decreased by 40 dB at the time calculated, based on the source-receiver offset (GCV variable RANGE) and the velocity of the direct wave. A delay of .001 seconds was used to compensate for the recording delay time. The width of the surgical mute zone was 0.5 milliseconds, with a 5 millisecond cosine taper on either side of the mute zone.

```
/AIRWVMUT  
AIRVEL 35000  
DBLEVEL 40  
MUTWIDTH 0 0.5  
TPRWIDTH 5  
DELAY .001
```

(note: for data resampled to .05 sampling rate use DELAY 0.0)

The processor /SRPOL was run for all radial component traces. This processor reverses the polarity of all traces whose corresponding geophone is to the left of the shotpoint. This ensures phase continuity of shot gathers when a shotpoint is located within a seismic array, rather than on an endpoint.

```
/SRPOL
```

The next job listing creates a velocity model composed of stacking (RMS) velocities as a function of two-way traveltime. This listing was combined with subsequent processors to provide a velocity model. A constant background velocity of 350 meters/sec was used, while the melt area is often given a higher velocity. All velocities, as described above, were multiplied by 100 in the actual job listings. The program VD2VT.EXE, located in the directory =programs, was used to help create this job listing. VD2VT.EXE first creates a pseudo job listing comprised of interval velocities as a function of depth. VD2VT.EXE then runs a program called VD2VT, which converts the pseudo-listing to a SierraSeis job listing containing stacking velocities. Thus for example, to create a job listing with a melt velocity of 700 meters/sec, one must first write a pseudo job listing using interval velocities as a function of depth. Typing VD2VT.EXE 700 will produce the pseudo-listing:

/VELOCITY

UNITS M MSEC '

CMP 1 100 35000 10000 35000
CMP 56 100 35000 10000 35000
CMP 57 190 35000 220 70000 1000 35000 10000 35000
CMP 58 190 35000 250 70000 1000 35000 10000 35000
CMP 59 190 35000 270 70000 1000 35000 10000 35000
CMP 60 190 35000 290 70000 1000 35000 10000 35000
CMP 61 190 35000 300 70000 1000 35000 10000 35000
CMP 62 190 35000 310 70000 1000 35000 10000 35000
CMP 63 190 35000 320 70000 1000 35000 10000 35000
CMP 64 190 35000 310 70000 1000 35000 10000 35000
CMP 65 190 35000 300 70000 1000 35000 10000 35000
CMP 66 190 35000 290 70000 1000 35000 10000 35000
CMP 67 190 35000 270 70000 1000 35000 10000 35000
CMP 68 190 35000 250 70000 1000 35000 10000 35000
CMP 69 190 35000 220 70000 1000 35000 10000 35000
CMP 70 100 35000 10000 35000
CMP 124 100 35000 10000 35000

Here the melt is defined as starting at a depth of 1.9 meters, with a maximum depth of 3.2 meters, and extending from CDP 57 to 69. This pseudo job listing is input into the program VD2VT, which outputs the actual job listing using stacking velocities as a function of two-way traveltimes:

/VELOCITY

UNITS M MSEC '

CMP 1 5.80 35000 571.40 35000
CMP 56 5.80 35000 571.40 35000
CMP 57 10.80 35000 11.80 38451 56.20 35740 570.60 35074
CMP 58 10.80 35000 12.60 41833 55.40 36666 569.80 35166
CMP 59 10.80 35000 13.20 42976 54.80 37048 569.20 35202
CMP 60 10.80 35000 13.80 44515 54.20 37615 568.60 35258
CMP 61 10.80 35000 14.00 45442 54.00 37984 568.20 35294
CMP 62 10.80 35000 14.20 45880 53.80 38185 568.00 35313
CMP 63 10.80 35000 14.60 46707 53.40 38555 567.80 35350
CMP 64 10.80 35000 14.20 45880 53.80 38185 568.00 35313
CMP 65 10.80 35000 14.00 45442 54.00 37984 568.20 35294
CMP 66 10.80 35000 13.80 44515 54.20 37615 568.60 35258
CMP 67 10.80 35000 13.20 42976 54.80 37048 569.20 35202
CMP 68 10.80 35000 12.60 41833 55.40 36666 569.80 35166
CMP 69 10.80 35000 11.80 38451 56.20 35740 570.60 35074
CMP 70 5.80 35000 571.40 35000
CMP 124 5.80 35000 571.40 35000

It may be necessary to manually alter the final job listing, since SierraSeis may abort if there is less than 0.5 ms difference between two-way traveltimes on a single line. CMP's with less than 0.5 ms difference were either extended to 0.5 ms or else given a constant velocity of 35000 m/sec.

The next step was to compute amplitude corrections. Two separate corrections were used: one for spherical divergence, and one for attenuation. The spherical divergence processor was preceded by a velocity model as described above:

```
/SPHDIV  
ETIME 0 1000
```

The attenuation processor applied an exponential gain function to the data, in decibels per second:

```
/EXPGAIN  
BTIME 0 0  
ETIME 0 1000  
EXPFUNC 89
```

The attenuation value of 89 was determined through plots of amplitude vs. time using the /AMPVT function.

Next, geophones within 1 meter of each shotpoint were zeroed:

```
/ZERO RANGE 0 100
```

The final step before migration was a tail mute of the data. All samples past 150 milliseconds were muted using an inclusive cosine taper 32 milliseconds long:

```
/MUTE  
TMUTE 0 0 150
```

The job listing CORRECT.JOB performs the above-mentioned tasks.

Resampling of Data

The RESAMPLE.JOB listing was run to resample the data using a cubic spline interpolation. This job resamples data to a .05 millisecond sampling rate. It changes the GCV variable 'SR' to .00005 (SR is in seconds). It was necessary to resample the data to a higher sampling rate when migrating or using very high velocities for the melt. To save disk space the resampled traces were truncated to 200 ms. in length.

```
/NULENGTH  
  NEWTIME 200  
/RESAMPLE  
  NEWRATE 0.05
```

Kirchhoff Pre-Stack Migration

Kirchhoff pre-stack migration was performed by the job listing MIG_P.JOB, which migrates using constant offset panels. The output was resorted into CDP gathers, and was limited to a range of CDP's from 48 to 78, and a maximum of 40 milliseconds in time. The migrated gathers were then stacked.

```
/GATHER  
  OUTSORT 3  
  NODUMMY  
/KIRTWO  
  COFFSET  
  CDPSPACE 25  
  APERTURE 1 0 79  
  APTAPER 100  
  AVEFREQ 500  
  NOSCALE  
  FIRSTCDP 48  
  LASTCDP 78  
  ETIME 40  
/GATHER  
  OUTSORT 2  
  NODUMMY  
/STACK
```

Kirchhoff Post-Stack Migration

Kirchhoff post-stack migration was performed by the job listing MIG_K.JOB, which migrates after sorting into CDP gathers, performing normal moveout, and stacking. The output was limited to a range of CDP's from 48 to 78, and a maximum of 40 milliseconds in time.

```
/GATHER  
  OUTSORT 2  
  NODUMMY  
/NMO  
/STACK  
/KIRTWO  
  CDPSPACE 25
```

APERTURE 1 0 79
APTAPER 100
AVEFREQ 500
NOSCALE
FIRSTCDP 48
LASTCDP 78
ETIME 40

Stolt FK Post-Stack Migration

Stolt FK post-stack migration was performed by the job listing MIG_SJOB. The actual migration was performed after sorting into CDP gathers, normal moveout, and stacking. An /AUX processor was used to limit the output to CDP's 48 to 78:

/GATHER
OUTSORT 2
NODUMMY
/NMO
/STACK
/FKMIG
SPACING 25
/AUX CDPS D48 78 1
.....

Finite-Difference Post-Stack Migration

A finite-difference post-stack migration was performed by the job listing MIG_FJOB. The BOTDEP 400, NDEP 81, and TIMESEC parameters forced the output to coincide with the sampling rate of the input data. As with the Stolt migration, sorting by CPD's, normal moveout, and stacking was performed prior to the actual migration. An /AUX processor was used to limit the output to CDPS 48 to 78:

/GATHER
OUTSORT 2
NODUMMY
/NMO
/STACK
/FDMIG
TRSP 25
NDEP 81
BOTDEP 400
LOWFRQ 120
HIGFRQ 900

TIMESEC
/AUX CDPS D48 78 1
.....

Filtering of Data

After migration the data was frequency filtered, using the job listing FILTER.JOB. A notch filter was first used to remove noise in the 120 Hz range, with an 8 Hz frequency gap on either side for the 50 percent down points. The second filter was trapezoidal with corners of 120, 180, 600, and 900 Hz. The cutoff frequencies for this filter were 100 dB below the band-pass frequencies.

/NOTCH
FREQ 120
GAP 8
/STVF
OVERRIDE
BYFILE
ZERO
TRAPZOID
FILT 1 120 180 600 900 100
APPLY 1 2 1 0 999 0

Plotting of Traces

Traces were plotted in two ways. Normalized plots were made with each trace scaled so that either it's maximum absolute value (NORM option) or it's average absolute value (TR option) was set equal to one-half the trace width. The PLOT.JOB listing gives an example of normalized plotting of traces:

/MUTE (mutes first millisecond of each trace to remove the effect of front-end spikes)
FMUTE 0 0 1
TAPER 0
/DISPLAY
SCALE NORM OVER WINDOW 0 160 (may use TR option instead of NORM)
ANNOTATE TOP EVERY 1
ANNOTATE TRC
ANNOTATE FILE
TIMELINE 10 160 160
ANNOINTV 20
GAPS 7 12
GAIN 0.0
CLIP 400

```
HORZ 10
VERT 20 (use VERT 70 if plotting only 40 ms. of data)
MODE VAW
DOTS 200
```

True_amplitude plots were made using the SECT option. The SECT option scales all traces according to the expected average absolute amplitude of the data, given by the AVGAMP parameter. Increasing the value of the AVGAMP parameter decreases the scale of the plotted traces. The PLOT_TRUEJOB listing gives an example of true-amplitude plotting of traces:

```
/DISPLAY
AVGAMP .001 (expected amplitude of traces)
SCALE SECT
WINDOW 0 160
ANNOTATE TOP EVERY 1
ANNOTATE TRC
ANNOTATE FILE
TIMELINE 10 160 160
ANNOINTV 20
GAPS 7 12
GAIN 0.0
CLIP 400
HORZ 10
VERT 20 (use VERT 70 if plotting only 40 ms. of data)
MODE VAW
DOTS 200
```

Computation and Plotting of Reflection Strength Attribute

The ATTRIBUTE.JOB listing was run to compute a reflection strength attribute for each trace, using the Hilbert transform. Attribute values are appended to the end of each trace, increasing trace length by an approximate factor of two:

```
/ATTRAN
DATATYPE 'STRENGTH'
```

The DISPLAY.JOB listing was used to plot the final reflection strength image using contour color numbers, and assumes an original trace length (before appending the reflection strength attribute information) of 40 ms. This initial 40 ms. is muted, leaving only the reflection strength attribute data. Each reflection strength attribute value is converted to decibels, with a zero decibel reference value of 0.0035. A contour color number is assigned for every 0.6 dB decrease in reflection strength from this reference value, starting at 0.0 dB and reaching a minimum at -37.8 dB.

There were a total of 65 contour numbers, with 63 numbers between the minimum and maximum dB levels plus 2 additional contour numbers for reflection strengths above 0 dB or below -37.8 dB. The output is a color raster file having a .CRS suffix.

```
/MUTE
FMUTE 0 0 40
TAPER 0
/DISPLAY
! for data migrated using MIG_PJOB:
COLORLVL -37.8 0.0 0.6 .00035
! for data migrated using MIG_KJOB:
COLORLVL -37.8 0.0 0.6 .0025
! for data migrated using MIG_SJOB:
COLORLVL -37.8 0.0 0.6 .00008
! for data migrated using MIG_FJOB:
COLORLVL -37.8 0.0 0.6 .35
!
! alternate values for data migrated using MIG_PJOB:
! COLORLVL -44.1 0.0 0.7 .004
! COLORLVL -40.95 0.0 0.65 .003
! COLORLVL -50.4 0.0 0.8 .008
!
! for SR = .00005 instead of .0005
! multiply last parameter by 10
! ex: COLORLVL -37.8 0.0 0.6 .00035
!
COLORRES 4
SCALE NORM OVER WINDOW 0 40
ANNOTATE CDP EVERY 2
TIMELINE 5 40 40
ANNOINTV 10
CLIP 400
HORZ 10
VERT 70
MODE VA
DOTS 200
```

The program CRSRAS was run to convert the color raster files (.CRS file) to directly-plottable files (.RAS file). A color assignment file, COLOR.DAT, was used to translate the contour color numbers in the .CRS file to specific colors. The COLOR.DAT file is an ASCII file containing one line of three color intensities (cyan, magenta, yellow) for each color number. The colors in COLOR.DAT form a spectrum from red (high reflection strength) to blue (no reflection strength). The COLOR.DAT file is shown below:

16	16	0
16	15	0
16	14	0
16	13	0
16	12	0
16	11	0
16	10	0
16	9	0
16	8	0
16	7	0
16	6	0
16	5	0
16	4	0
16	3	0
16	2	0
16	1	0
16	0	0
16	0	1
16	0	2
16	0	3
16	0	4
16	0	5
16	0	6
16	0	7
16	0	8
16	0	9
16	0	10
16	0	11
16	0	12
16	0	13
16	0	14
16	0	15
16	0	16
15	0	16
14	0	16
13	0	16
12	0	16
11	0	16
10	0	16
9	0	16
8	0	16
7	0	16
6	0	16
5	0	16

4	0	16
3	0	16
2	0	16
1	0	16
0	0	16
0	1	16
0	2	16
0	3	16
0	4	16
0	5	16
0	6	16
0	7	16
0	8	16
0	9	16
0	10	16
0	11	16
0	12	16
0	13	16
0	14	16
0	15	16
0	16	16

Reflection strength attributes were also plotted on a PC. The job listing RAW.JOB writes a binary file containing only the reflection strength attribute information. The listing assumes an original trace length (before appending the reflection strength attribute information) of 40 ms.

```

/BULKSHFT
SHIFTMS -41.0
NULENGTH
NEWTIME 40.0
/UNIXIO
FILENAME 'output_file'
WRITE
NOGCV

```

Each output file from the RAW.JOB listing was converted to a grey scale, with values ranging from 0 to 255, using the program raw_grey located in the directory =programs. Output files were also converted using an RGB scale, with RGB values ranging from 0 to 255, using the program raw_color. The output of raw_grey may be examined using the program raw_grey_dump, and the output of raw_color may be examined using the program raw_color_dump.

For data resampled to SR=.00005, CDP's may be interpolated from 31 to 301 using

the programs `rlate`, located in the directory `=programs`. Using this programs gives you an image of 801 vertical points to 301 horizontal points, which may then be inputed to `raw_grey` or `raw_color`.

Merging Two Reflection Strength Attribute Files

Combined vertical and radial reflection strength attribute images were created using the `MERGE.JOB` listing. A square root of the sum of squares algorithm was used to combine each sample value of two attribute files. The processor `/MWEAVE` in the `MERGE.JOB` listing resorts the two attribute files by physically placing each trace from file 2 after the corresponding trace from file 1, enabling them to be summed using the `/TSUM` processor.

```
/DIN
FILENAME 'file_1'
FILENAME 'file_2'
/TRCSQR (squares each sample)
/MWEAVE
/TSUM
NSUM 2 (combine every 2 traces, and divide by 2)
/AMPMATH
MULTA 2 (negate previous division by 2)
/EXP
POWER .5 (take square root)
/PRMODCOM
MODIFY 'KNSHOT' SET 31
MODIFY 'KNCDP' SET 31
/DOUT
FILENAME 'combined_file'
```

Creating Binary Data Files

Binary files containing only trace samples were created using the `/UNIXIO` processor. The processor's `NOGCV` option writes a binary file containing only trace samples, 4 bytes per value, with no accompanying GCV header information.

```
/UNIXIO
FILENAME 'output_file'
NOGCV
WRITE
```

`NOGCV` binary files may also be read using the `/UNIXIO` processor, in which case a `DATA` line is necessary to provide trace length and sampling rate information. The first and last files to be read must also be specified, using either the `BI EI`

parameters or the NI parameter. In addition, a bug in the /UNIXIO processor requires that the SR variable be set manually using /PRMODCOM, after the data has been read in:

```
/UNIXIO
FILENAME 'input_file'
NOGCV
READ
DATA 1 1000 0.5 24
BI 1
EI 100
/PRMODCOM
MODIFY 'SR' SET 0.0005
(note: SR is in units of seconds)
(note: for resampled data use 0.00005)
```

Wide-Angle Reflection and Backscattered Subsets of the Data

Portions of the data were zeroed, using the /AMPMATH processor to multiply particular traces by .000001. A subset of the data containing only wide-angle reflections was created by zeroing all traces containing backscattered data:

```
/AMPMATH FILES D1 22 1 TRACES D1 36 1
          FILES D23 46 1 TRACES D37 72 1
MULTA 0.000001
```

Similarly, traces containing wide-angle reflection data were zeroed using:

```
/AMPMATH FILES D1 22 1 TRACES D37 72 1
          FILES D23 46 1 TRACES D1 36 1
MULTA 0.000001
```

This method of zeroing traces gives better results than the SierraSeis processor /ZERO, which marks traces as having been zeroed, with unpredictable results when passing these marked traces to subsequent processors.

Masking of Data

A masking procedure was used to reduce reflections from a subsidence zone located directly above the melt. The first step of the masking procedure was to place hypothetical masking points in the area producing the unwanted reflections. The seismic response of these masking points was calculated using the GENERATE.JOB listing, located in the directory =mask, which creates an output file with identical parameters as the data file (same trace length and sampling rate) but containing only

reflections from the masking points. Due to a design flaw the SierraSeis processor /GENDIF uses the GCV TRCX instead of RCVRX for receiver location. This problem was overcome by copying the RCVRX value to TRCX. Note that GENERATE.JOB outputs a file using /UNIXIO but keeps the GCV's by using the USEGCV parameter:

```
/GENSCR
BI 1
EI 46
KNTR 24
KNSAMP 2001
SR 0.5
! SR 0.05 if data resampled
/GEOMETRY GEOMFILE 'GEO548.LGM' USE
/HEADEQL
HEADIN RCVRX
HEADOUT TRCX
/GENDIF
VELOCITY 35000
POINTS -60 0.0 10 1
        60 0.0 10 1
       -100 0.0 90 1
        100 0.0 90 1
       -130 0.0 140 1
        130 0.0 140 1
       -150 0.0 180 1
        150 0.0 180 1
         0 0.0 10 1
         0 0.0 90 1
         0 0.0 140 1
         0 0.0 180 1
/UNIXIO
FILENAME 'file.uio'
WRITE
USEGCV
```

The output from GENERATE.JOB was converted to a masking file using the program create_mask. This program substitutes a tapered time window for each spike in the output file. The mask used was 8 ms. long, with various inclusive tapers on both the front and tail ends ranging from 2 ms. to 4 ms. Spikes should be sufficiently dense so that the time windows for each spike overlap. The density of spikes was tested using the program test_spike, which lists all spikes separated by more than a given number of samples. Once a masking file was created the program apply_mask multiplied, sample by sample, the masking file with a data file that has

been converted to /UNIXIO USEGCV format. The output of this program was a /UNIXIO USEGCV format masked data file, which was converted back to a SierraSeis house format file. All three of the above-mentioned programs are located in the directory =mask.

VITA

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