Chapter D

Preliminary Results from the NPE-Ryan Reversed Refraction Profile

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Contents

Abstract 2
Introduction 2
Acknowledgments 3
Record Sections 3
Reference Model 3
Interpretation and Early NPE Arrivals Through Crater Flat 7
Conclusions 9
References Cited 9

Figures

1. Map of study area showing locations of portable instrumentation, Southern Great Basin Seismic Network stations, and USGS seismic profiles 2
2. Record section from NPE shot south 4
3. Record section from Ryan shot north 5
4. Cross sections showing starting velocity structure from Ryan to NPE shot point and arrival times compared to predicted arrival times 6
5. Diagram showing *P*-wave particle motion for station DV03 7
6. Cross sections showing modified velocity structure from Ryan to NPE shot point and arrival times compared to predicted arrival time 8

[For table of abbreviations and conversions, click here]

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Abstract

A reversed seismic-refraction profile was recorded along an approximately 100-kilometer-long line between the Non-Proliferation Experiment (NPE) (a 1-kiloton conventional test) on the northern Nevada Test Site and a smaller shot (a 3,200-pound conventional test) at Ryan, California, in September 1993. First-arrival times from these tests are used to model the velocity structure of the upper crust in and around Yucca Mountain, a potential site in southwestern Nevada for a high-level radioactive-waste repository. The *P*-wave velocity structure could be measured to greater depths than in previous refraction studies in the Yucca Mountain area because of the wide shot-point separation. We have applied existing velocity models for the Yucca Mountain area as starting models and modified these to fit the first-arrivals from the NPE and Ryan shots. Relatively early first-arrivals in the Yucca Mountain area from the NPE suggest a block of high-velocity material in eastern Crater Flat. This high-velocity material may be a cooled block or zone of Tertiary basaltic magma within the upper crust in eastern Crater Flat.

Introduction

On September 22, 1993, the U.S. Department of Energy detonated a 1-kiloton (1,000 tons) chemical (conventional) test in Rainier Mesa on the northern part of the Nevada Test Site

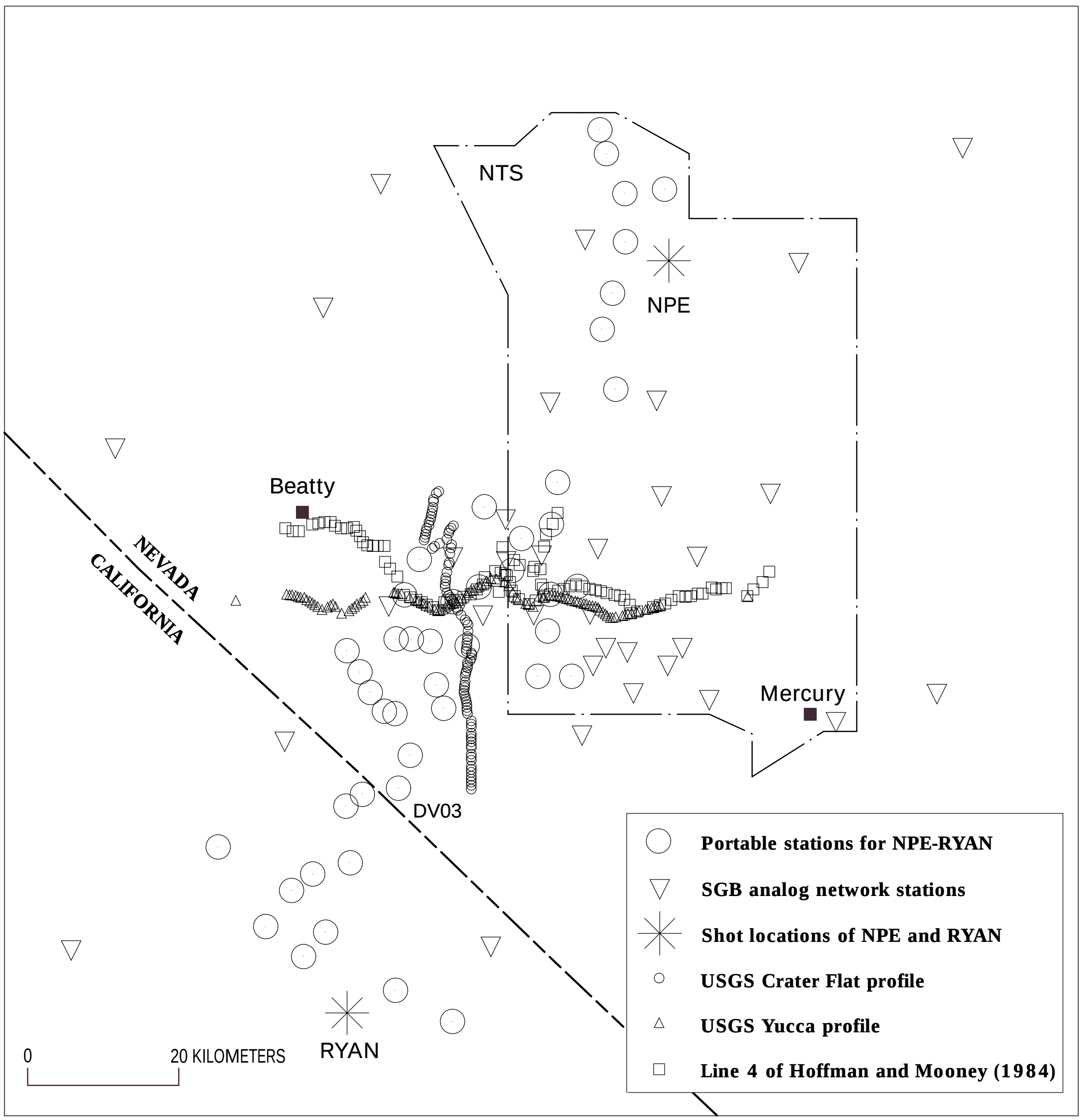

Figure 1. Study area, showing location of portable instrumentation, Southern Great Basin Seismic Network stations, and locations of USGS seismic profiles from the early 1980's (Sutton, 1985). NTS, Nevada Test Site; DV03, station represented in figure 5.

(NTS) in southwestern Nevada (fig. 1). The test, designated the Non-Proliferation Experiment (NPE), was part of an international effort to better understand the seismic radiation characteristics of conventional compared to underground nuclear detonations. In conjunction with a large-scale seismic experiment conducted in southern Nevada and southern California by the Southern Sierra Continental Dynamics Consortium (SSCDC) during the fall of 1993, another conventional explosive (3,200 pounds) was detonated at Ryan, Calif., on the east edge of the Death Valley National Monument. This shot point essentially reversed the NPE shot line through Yucca Mountain, although the source was much smaller than the NPE. The University of Nevada-Reno Seismological Laboratory (UNRSL) deployed 46 portable digital seismographs in the region to collect seismic data from these tests that would help to better determine the shallow velocity structure in and around Yucca Mountain. Yucca Mountain is the potential site for a high-level radioactive-waste repository.

The ray paths for this experiment pass beneath Yucca Mountain and Crater Flat at a depth of about 5 km. They provide important constraints on the velocity structure in the upper crust near the Yucca Mountain site and on the velocity structure of Crater Flat, particularly with respect to identifying potential magma sources within the upper crust. The shallow structure of the crust (to depths of about 4 km) in the region of Yucca Mountain and Crater Flat had previously been constrained by five detailed seismic refraction profiles collected by the U.S. Geological Survey (USGS) that have been reported in several studies (Sutton, 1984, 1985; Hoffman and Mooney, 1984; Ismail, 1986; Ackermann and others, 1988; Mooney and Schapper, 1995). We have used the velocity structures developed in these studies as a starting model and have made adjustments necessary to fit the first-arrivals from the NPE and Ryan shots.

The 46 portable digital seismic recorders installed by UNRSL (fig. 1) were deployed along the reversed refraction line as well as in a fan geometry through Crater Flat, Jackass Flat, Amargosa Valley, and Death Valley. Permanent stations of the Southern Great Basin Seismic Network (SGBSN) operated by the UNRSL provided additional coverage (fig. 1). Portable instruments were configured almost exclusively with three-component seismometers. A number of portable recorders were on temporary loan from the SSCDC and were operated by that group.

Acknowledgments

We thank Peter Malin, Stan Ruppert, Tim Cartwright, and the 1993 SSCDC for operating and providing a number of portable instruments for the experiment. They were also responsible for arranging and detonating the shot at Ryan, Calif. Mike Sleeman, John Torrisi, Steve Satterfield, Lorenzo Trimble, Bill Hendrix, and Bill Honjas, among others, helped in the portable deployment. Refraction Technology, Inc., provided a technician onsite, Dennis Pavell, as well as six portable recorders.

Record Sections

Record sections from the NPE and Ryan shots are shown in figures 2 and 3. Note that the geometry of the line is such that the most northern station is 10–20 km north of the NPE shot point in northern Pahute Mesa (fig. 1). The record section for the NPE shot (fig. 2), with distances referenced to the NPE shot point, shows clear first-arrivals at all stations. However, at greater distances (more than 50 km) the Ryan records (fig. 3) show relatively weak and emergent first-arrivals, raising some doubt as to whether the true first-arrival is resolvable from the Ryan records at long distances. In the distance range of 58–81 km, the records from the NPE show a clear but weaker first-arrival, followed by a stronger and more impulsive second-arrival. At distances greater than 110 km (fig. 2), first-arrivals are those from SGBSN stations PANS and QSMS which are beyond the area where portable instruments were deployed.

Reference Model

The results of Hoffman and Mooney (1984) and Mooney and Schapper (1995) were used to derive a starting model. The NPE-to-Ryan line intersects three previous USGS refraction profiles at distances of 45–55 km from the NPE shot point (fig. 1). These surveys (Line 4, Yucca, and Crater Flat) had much denser arrays of sources and receivers and thus had better control of the velocity structure at shallow depths; the results were used with the NPE shot line to derive our starting structure. The velocities that Mooney and Schapper (1995) found at 4 km depth are assumed to extend to 10 km, although ray paths from the NPE-Ryan shots did not actually sample to these depths. The relatively high velocities in the starting model at depths of 5 km (*P*-wave velocity equal to 6.3 km/s rather than the more typical 6.1 km/s) beneath Yucca Mountain and Crater Flat (Hoffman and Mooney, 1984) are probably restricted to the local area, as refraction studies from NTS show a consistent regional *P*g velocity of 6.0 km/s. Therefore, we have used an upper crustal velocity of 6.0 km/s in the model outside of the Yucca Mountain–Crater Flat area. Vidale's method (Vidale, 1988) was used to calculate the predicted arrival times from the velocity models in this study. This method solves the Eikonal equation with a finite difference scheme for travel times to all grid points.

The starting model with the ray paths for the NPE and Ryan shots is shown in figure 4*A*. Ray paths from each traveltime field were generated by following time gradients up from each receiver to the source. To compute the gradients, we linearly interpolate between grid points (spaced at 0.2 km for all of our time fields) to form linear contour-line segments at 0.5 second (s) contour intervals. We traced the ray from each receiver by finding the nearest perpendicular intersection to successive contours. Although each time field was smoothed with a 3×3 five-point uniform average filter before ray tracing, ray locations and the maximum depth of penetration are assumed to be accurate to within three grid points, or 0.6 km.

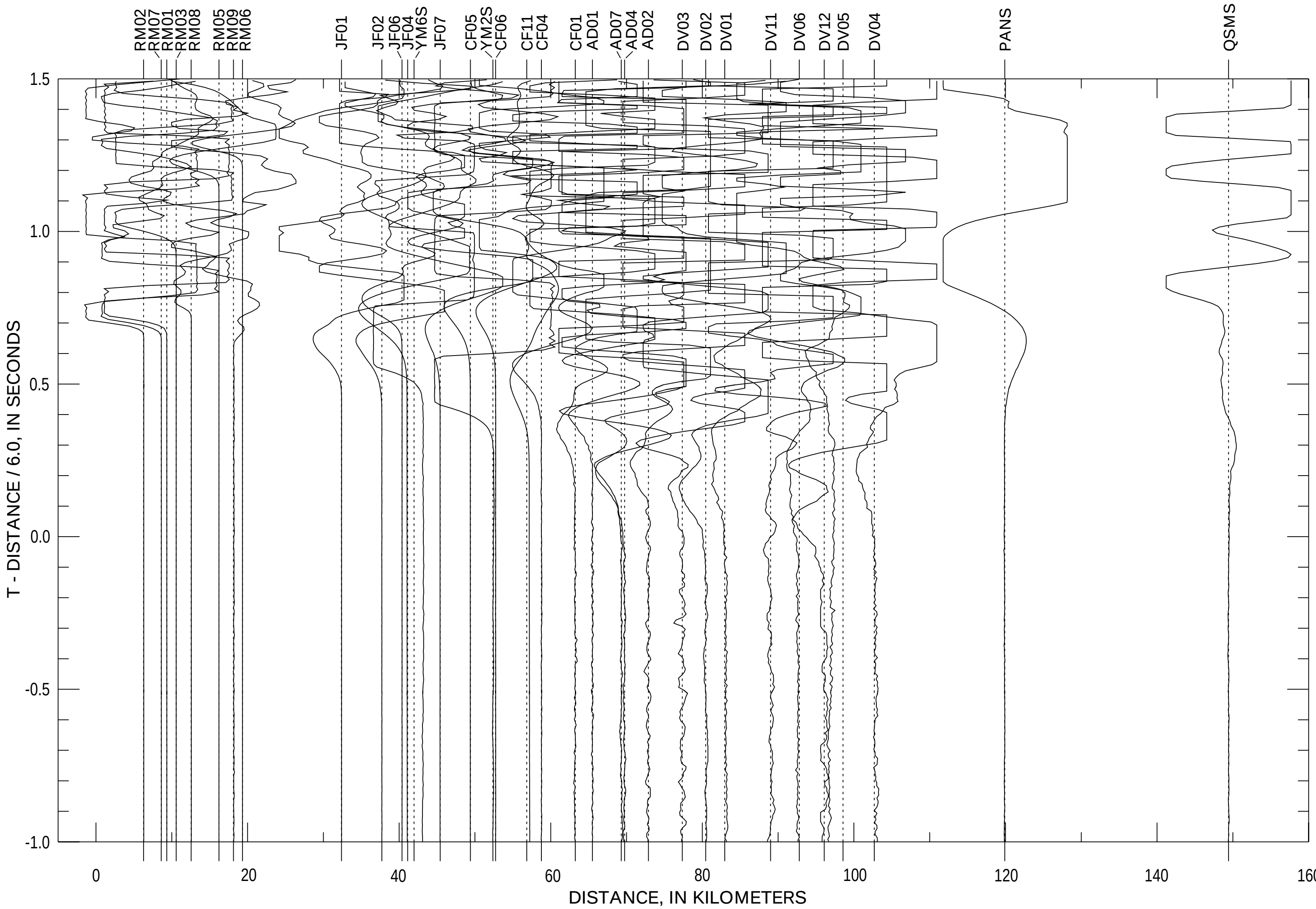

Figure 2. Record section from NPE shot toward south; scaled to maximum trace amplitude with a reduction velocity of 6.0 km/s.

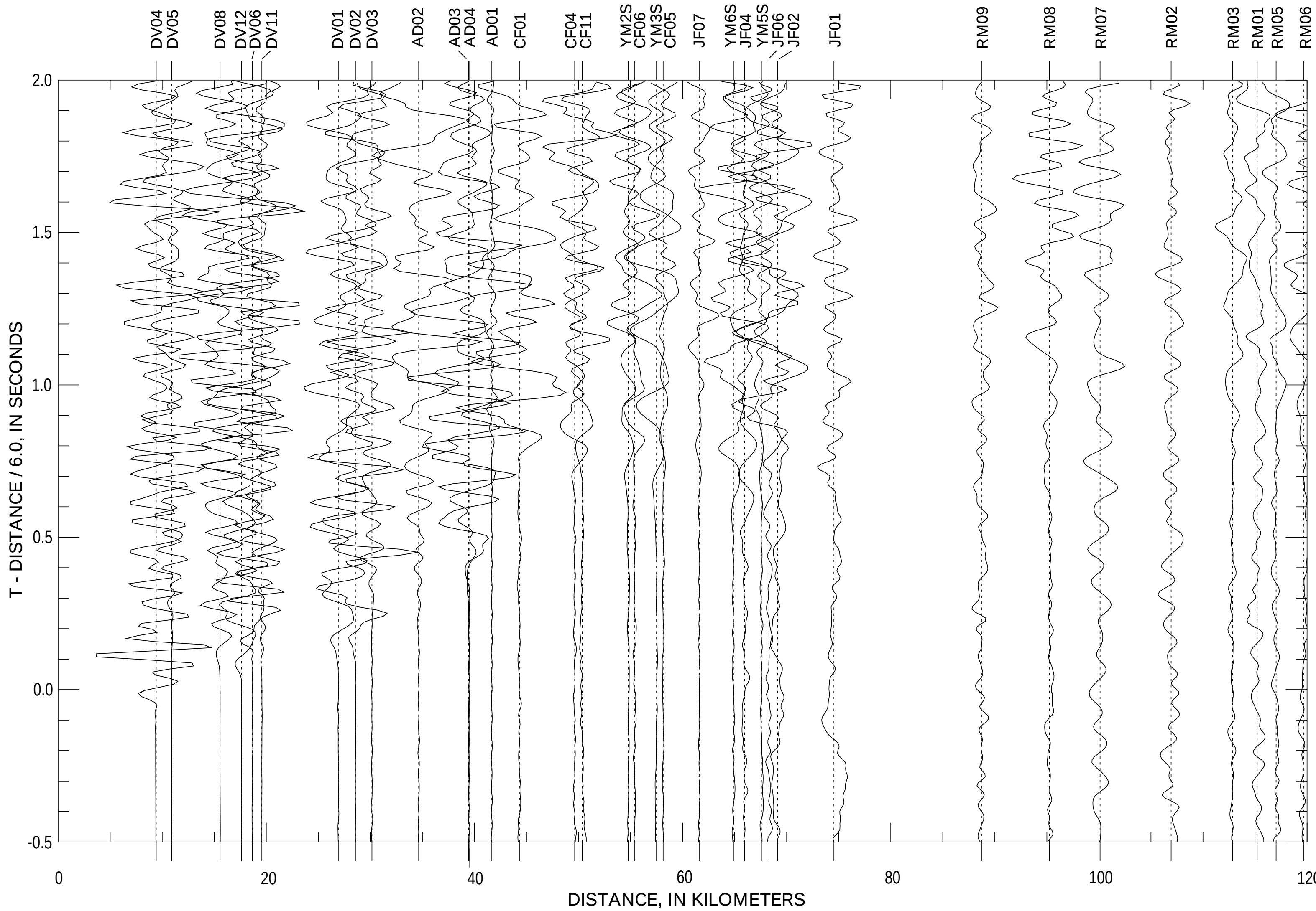

Figure 3. Record section from Ryan shot toward north; scaled to the maximum trace amplitude with a reduction velocity of 6.0 km/s.

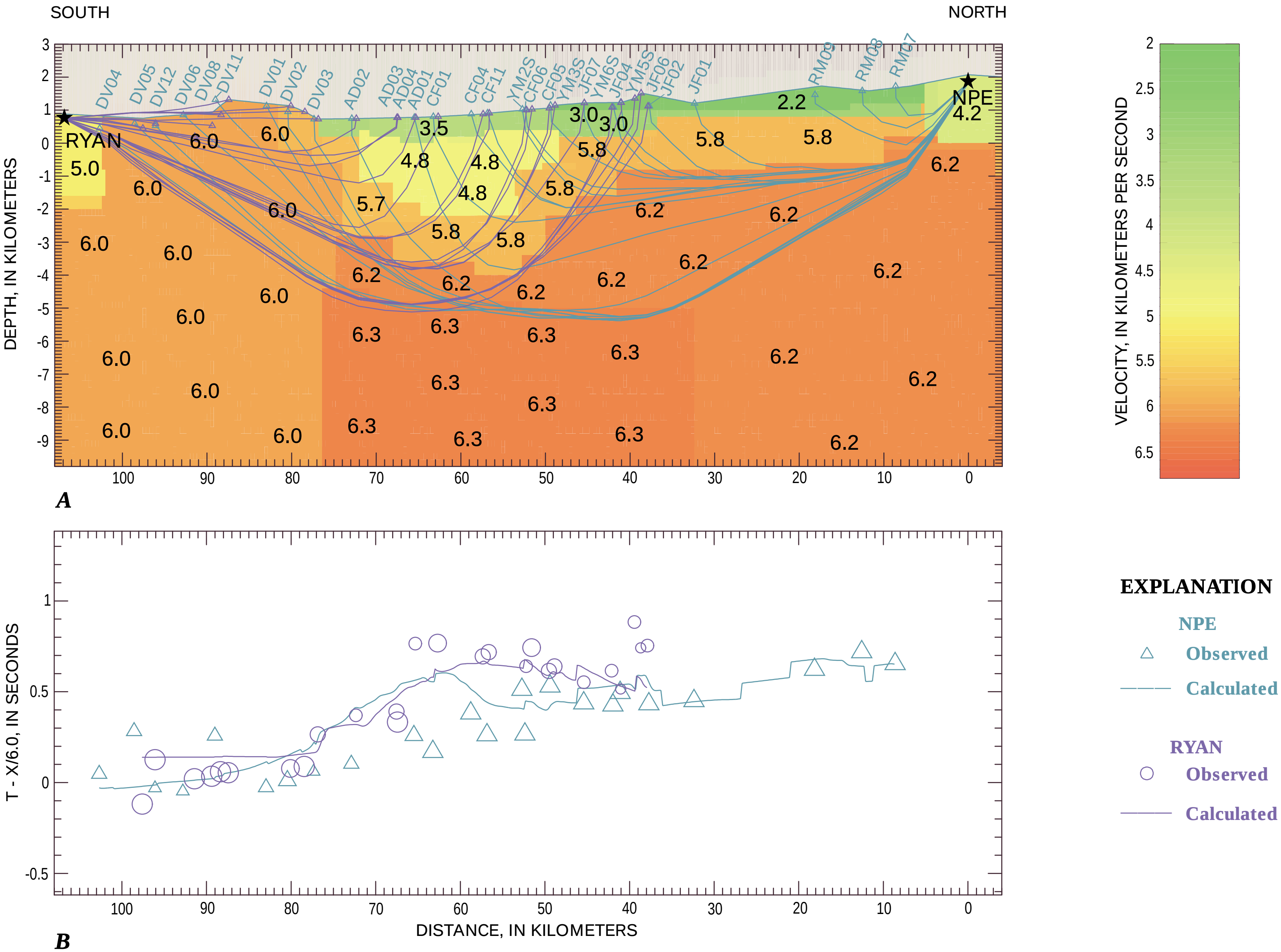

Figure 4. Starting velocity structure from Ryan to NPE shot point (*A*), and arrival times as compared to predicted arrival times based on velocity model (*B*). *A*, Station locations are shown (triangles) above topographic surface; block velocities are labeled on model. Depth is related to mean sea level. *B*, Larger symbols represent higher quality first-arrivals.

Reduced first-arrival times (reduction velocity of 6 km/s) are plotted against calculated arrival times in figure 4*B*. Clear first-arrivals are indicated by large symbols; less certain first-arrivals are indicated by smaller symbols, and the continuous line is the calculated travel time based on the model. The data agree relatively well (within 0.2 s) with corresponding values in the starting model. However, the clear first-arrivals from the NPE in the distance range of 58–81 km are a few tenths of a second too early (negative residual) with respect to the predicted arrival times, indicating relatively high velocities at a depth of about 5 km beneath Yucca Mountain and southern Crater Flat.

Interpretation and Early NPE Arrivals Through Crater Flat

Particle motions for the early *P*-wave arrivals from the NPE shot in the distance range of 58–81 km, and the post-*P*-wave large-amplitude arrival, indicate that they both consist of *P*-wave energy that follows a direct path and is not strongly refracted laterally (fig. 5). The recording sites for these arrivals lie in an area with the best control on the shallow structure (derived from previous USGS studies), providing confidence in our observations. Although no evidence exists of early *P*-wave arrivals at corresponding distances from the Ryan profile, the arrivals from the Ryan shot are weak, and we may not be observing the true first-arrivals.

Following a preliminary interpretation of our results, we modified the starting model by inferring a block of high-velocity material below a depth of 3 km at a distance of about 60 km from the NPE shot point (fig. 6). This high-velocity material improves the fit of the calculated to the observed first-arrivals from the NPE shot and accounts for the advance of NPE first-arrivals relative to Ryan arrivals around the 60-km distance mark (fig. 6). Thus, in this preliminary interpretation the NPE results appear to support the existence of a block of high-velocity material beneath the western part of Yucca Mountain and the eastern part of Crater Flat. Determining the exact geometry and nature of the materials responsible for these early *P*-wave arrivals is difficult; the high velocities could represent a local, nearly equidimensional body of cooled basaltic material, vertical dike structures, or a nearly flat lying stratified high-velocity body of pre-Tertiary basement.

A block of high-velocity material in this region is consistent with the results of Mooney and Schapper (1995), who found evidence for high-velocity material at shallow depths on their north-south line but not, however, on their east-west line. They suggested that this inconsistency may result from the presence of anisotropic Tertiary-age carbonates. All the first-arrivals used by Mooney and Schapper (1995) were weighted as uncertain arrivals in their models. Weak

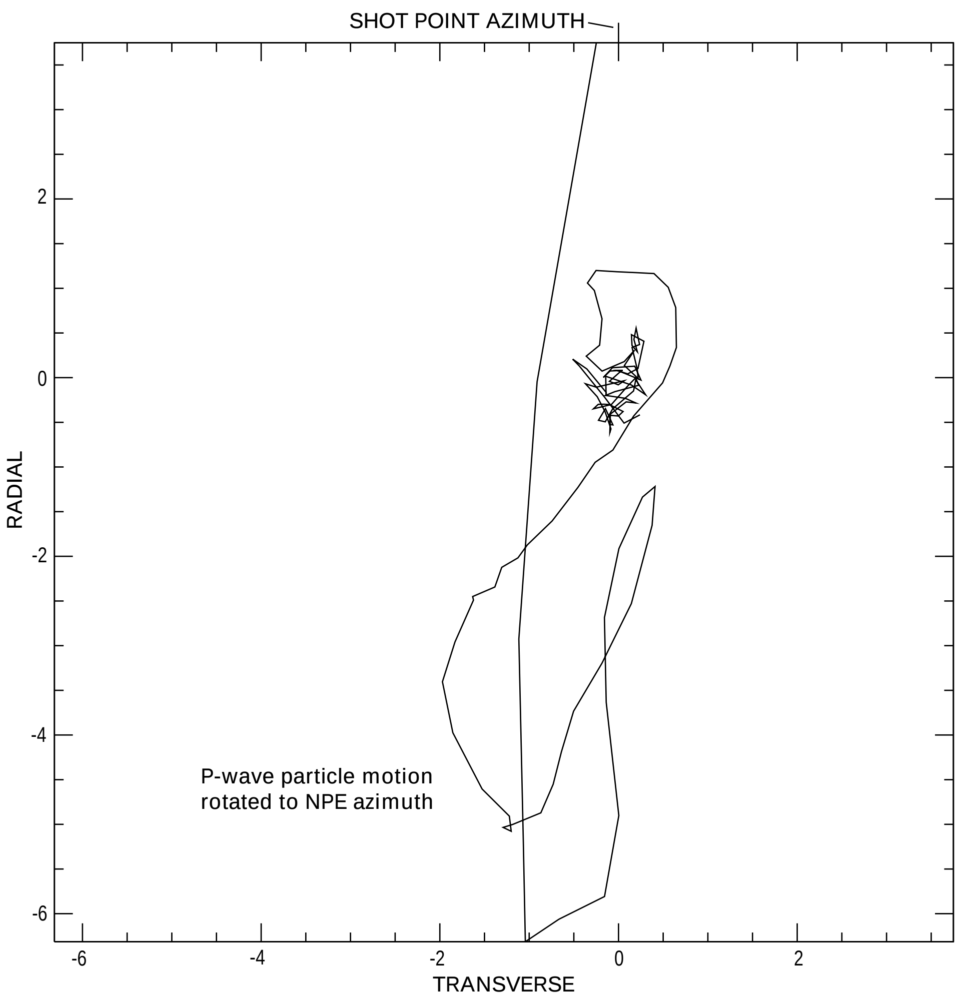

Figure 5. *P*-wave particle motion relative velocity diagram for station DV03 at a distance of 60 km from the NPE shot point (station location labeled in fig. 1; numbers refer to relative velocities).

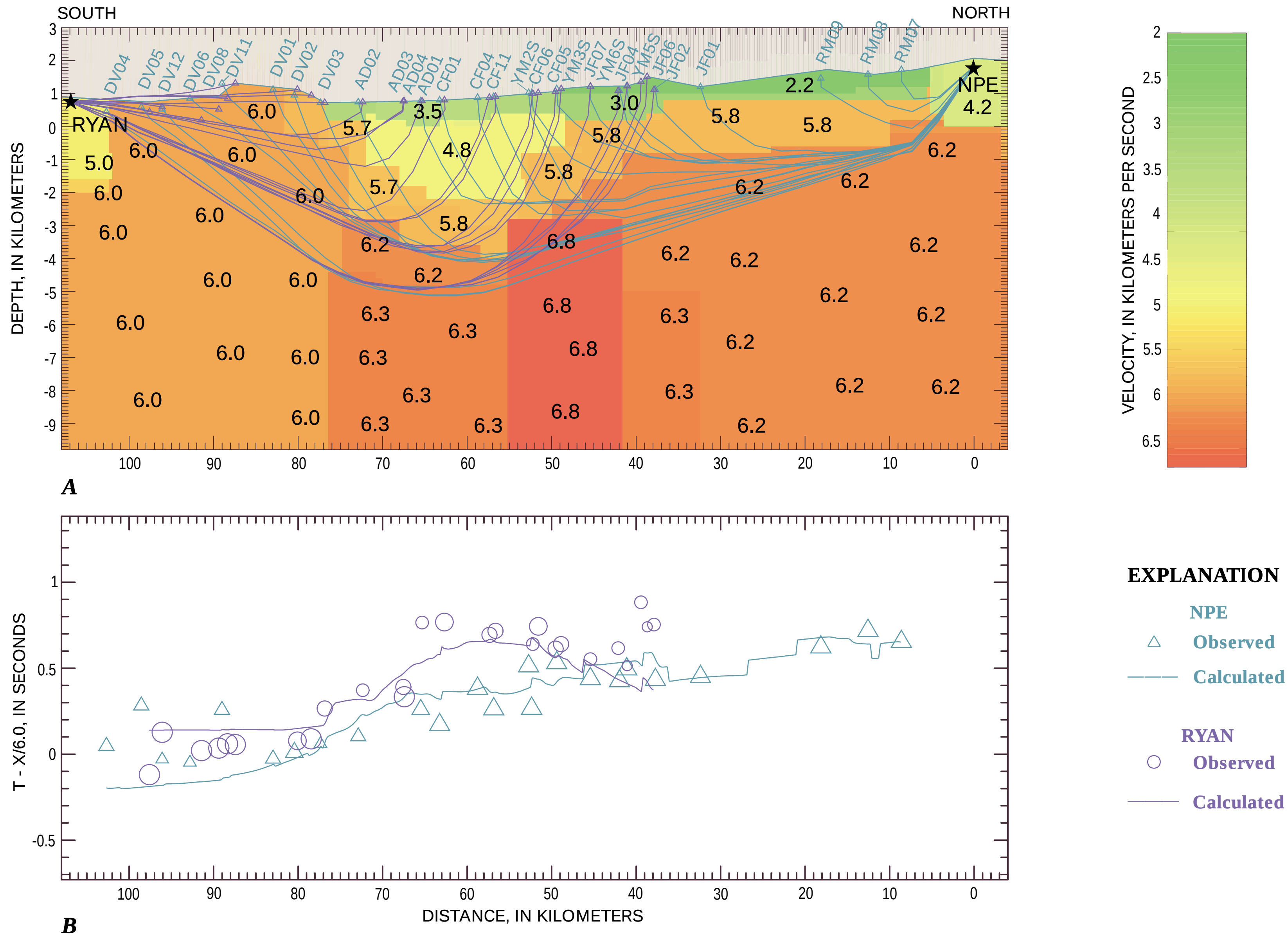

Figure 6. Modified velocity structure from Ryan to NPE shot point, including high-velocity material in Crater Flat (*A*), and arrivals time as compared to predicted arrival time based on velocity model (*B*). *A*, Station locations are shown (triangles) above topographic surface; block velocities are labeled on model. Depth is related to mean sea level. *B*, Larger symbols represent higher quality first-arrivals.

precursory first-arrivals not observed on their east-west line may have been seen on the NPE profile because of the size of the shot. Also, their east-west line may not have extended far enough to observe these arrivals.

The data from this study do not indicate the presence of very low velocity material beneath Yucca Mountain and Crater Flat. If anything, the simulated velocities are somewhat high. These velocities argue against the presence of large volumes of extremely hot or molten materials at shallow depths under Yucca Mountain and east-central Crater Flat (the tests did not generate clear enough *S*-wave arrivals to be useful). This does not rule out the possibility that a molten magma source does exist at greater depths in the crust, inasmuch as ray paths from the NPE-Ryan and other USGS controlled-source experiments have only sampled the upper few kilometers of the crust.

Conclusions

Observational data, preliminary interpretations, and observations of refracted *P*-wave arrivals are presented along a reversed refraction line from the NPE and Ryan shots. A preliminary velocity model along the north-northeast to south-southwest line beneath Yucca Mountain and southern Crater Flat is generally consistent with the shallow velocity structure inferred by earlier studies (Hoffman and Mooney, 1984; Mooney and Schapper, 1995). However, early arrivals from the NPE shot in the distance range of 58–81 km indicate a local body of higher velocity material, near 6.8 km/s, extending to several kilometers depth, which may be the same body of high-velocity material inferred by Mooney and Schapper (1995). This body may be cooled magmatic material. There is no indication of anomalously low velocity material, which would indicate molten or near-molten magmas, at shallow depths below Yucca Mountain or in southern Crater Flat.

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