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Sandia National Laboratories

Operated for the U.S. Department of Energy by
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Albuquerque, New Mexico 87185-

date: January 22, 2001

to: Frank Hansen

Mario Chavez for

from: David Holcomb and Robert Hardy, Org. 06117, MS 0715

subject: Status of ultrasonic wave speed measurements undertaken to characterize the DRZ in the access drift to Q room.

Introduction:

There is a need to understand the spatial and temporal development of the disturbed rock zone (DRZ) around openings at the Waste Isolation Pilot Plant (WIPP). Possible leakage paths around seals, effects on closure rates and safety issues related to deterioration of the salt mechanical properties are issues affected by the DRZ. An access drift to Room Q, constructed about 10 years ago, provided an opportunity to conduct geophysical investigations of the damage that has developed in the salt for a nearly perfect 2 dimensional configuration removed from the disturbances of other excavations. As part of a suite of measurements designed to study the hydrological and mechanical properties of the salt around the drift, an array of ultrasonic transducer emplacement holes was drilled in the rib to a depth of about 7 meters. The mature DRZ is the macroscopic manifestation of grain-scale and larger cracks that form as a result of the instantaneous shear stress around the newly-created opening, and as a result of creep-related failures over a period of years. Velocity and attenuation of elastic waves in the salt are a function of the density of cracks, as is the permeability. The design of the hole array and the transducer assemblies allows the measurement of elastic wave velocities and amplitudes (for attenuation studies) along vertical and horizontal paths tangential to the drift walls and, within the same hole, perpendicular to the rib. Orthogonal paths are necessary in order to detect the anisotropy of the cracking in the DRZ. Transducer positions were carefully surveyed, allowing absolute velocity measurements. Measurements were completed at roughly 30 cm intervals over paths vertical, horizontal and perpendicular to the drift axis, giving a complete and redundant data set. Measurements were done using paths through the salt near the back, floor and center rib, allowing us to detect the effect of the varying stress state on the development of the DRZ in these locations.

Previous work at the WIPP, (Munson et al., 1995, Holcomb, 1999, and Hardy and Holcomb, 2000) delineated the DRZ as a function of depth from the drift wall and as function of the varying stress state around the roughly rectangular drift cross section. Using results published by Brodsky (1995), changes in velocity can be related to the damage, due to microcracking, required to produce the observed changes. It is expected that the results will be useful to other studies of the long-term deformation characteristics of salt. The significance of the results lies in the length of time the DRZ has had to develop (approximately 10 years), the geometrical simplicity of the drift which eases the task of relating the results to models, and the hydrological measurements to be made in conjunction with the velocity and attenuation measurements. Understanding the time-dependent changes in damage, and thus permeability, as the DRZ develops is important because these changes strongly affect the sealing of underground openings at the WIPP.

Approach:

Elastic moduli and therefore, elastic wave velocities are decreased by open cracks and loosened grain boundaries. The effect on elastic wave velocities is strongest for cracks oriented perpendicular to the particle motion induced by the wave. Thus the physical extent of the disturbed zone can be determined by propagating elastic waves through successive portions of the formation until an undisturbed zone is reached, as indicated by a constant velocity with increasing depth from the rib. In this case, the cracking responsible for the disturbed zone is expected to vary as a function of distance from the wall of the Room Q access drift and to depend on the position of the measurement path relative to the back and floor. Measurements were made between pairs of holes cored perpendicular to the axis of the drift along horizontal and vertical paths lying in vertical planes parallel to the rib. Between each pair of holes, travel time measurements were made at 30 cm intervals to a depth, measured from the rib, of about 7 meters. In addition, measurements were made within one hole along paths perpendicular to the drift wall. The cross-hole measurements paths were nominally one meter long, while the same-hole measurements all had the same fixed path length of 33 cm. Figure 1 shows the arrangement and naming scheme for the measurement holes, QGU10, QGU11, … QGU18. Travel time measurements were made using the technique commonly used for laboratory determinations of sound speed in rock; a sound pulse is applied to the rock at a known time and place and, after traveling through the rock, is received by a transducer at a known distance. The travel time and distance combine to give the average velocity over that path.

Lithology and Hole Layout

Nine holes were cored (see Figure 1) to sample the lithologies exposed in the access drift and the stress state from top to bottom of the rib. Each hole was 10.16 cm (4 inches) in diameter, 6 meters deep and as nearly horizontal as possible. Great effort and care was taken by the surveying and drilling crews to align the holes parallel and horizontal and their efforts were rewarded with the best set of holes we have worked with at the WIPP. Hole-to-hole separation varied by less than 10 cm over the 6 m depth, indicating very good control on the starting angle and carefully controlled drilling.

Hole locations were chosen that sampled the three map units present (labelled argillaceous, halite, and argillaceous in Fig. 1), and also the expected variation in damage along the height of the rib. Redundancy was included by adding a third column of holes (QGU12, 15 and 18). Measurements between 10 and 11 should be similar to the results observed between 11 and 12, with the exception of small scale variations in the lithology due to fluctuations in the boundary between the map units.

Measurement System:

Piezoelectric transducers were used as both the transmitter and receivers of the ultrasonic elastic waves. In the current work only compressional mode transducers were used, although in certain configurations, a shear mode can be generated. A 300 kHz, PZT-5A piezoelectric disk was the basic element; four of these were used, two as transmitters and two as receivers. Each disk was mounted inside of a housing that could be pressed against the side of the 4 inch boreholes using air pressure. Suitably curved faces on the aluminum housing increased the area of contact when the housing was extended by pressurization to, typically, 60 psi. To further, and very substantially, increase the energy transmission across the housing-rock interface, a couplant was extruded between the housing face and the rock. Corn syrup was used for this work; it is cheap, cleans up easily and provides good coupling for both compressional and shear elastic waves.

Two transducer housings were coupled together (Figure 2) to form the tool inserted into the borehole. Each transducer was electrical independent, meaning that either could be driven and/or act as a receiver. One advantage of this approach is the ability to make two measurements at one tool position; repositioning the tool occupied about half the measurement time, so cutting the number of repositionings in half accelerated the measurement pace. An additional capability is gained by placing two transducers in one hole; one transducer can be driven as a transmitter while the other acts as a receiver. In this way, measurements can be made along paths normal to the rib face and orthogonal to the cross-hole measurements. As the orientation of the damage is expected to be anisotropic, it adds information to be able to measure the effects of damage along orthogonal paths. In particular, it is expected that the cracking planes will be preferentially parallel or sub-parallel to the rib, resulting in the largest changes in velocity along paths normal to the rib.

In addition to measurements of compressional mode (P) velocity, this technique allows the generation and propagation of shear (S) waves through the material parallel to the hole axis. A similar technique is discussed by Maxwell et al., 1998. Although it is common to talk about P and S mode transducers, it is a misnomer. All PZT-5 ceramic transducers expand and contract along the axis parallel to the direction of polarization when an electrical field is applied, and generate an electrical field when an impinging mechanical disturbance causes strain along the axis of polarization. A disk of PZT-5, a so-called P mode transducer, is polarized parallel to the axis of the disk; application of an electrical field results in the disk getting thicker or thinner, according to the sense of the electric field. When coupled mechanically to the surrounding medium, as discussed above, the rapid change in shape causes a wave to propagate into the rock, much as if a tiny hammer had struck the side of the hole. In the direction parallel to the disk axis, the result is a wave where the particle motion is parallel to the propagation direction—a P wave, analogous to a sound wave in air. However, at right angles to the disk axis, a disturbance propagates also, with the particle motion still parallel to the disk axis, but the propagation direction is now orthogonal. This is a shear wave, characterized by particle motion perpendicular to the direction of propagation, and has no analogue in fluids such as air. Thus a ``P`` transducer can in fact generate and detect S waves and this was done using the pair of transducers in a single hole.

Once positioned and pressurized, the chosen transducer was excited by a 100 volt square pulse, with a rise time of about 200 nsecs. The resulting wave was detected by the chosen receiver, amplified by 60 db and recorded on a digital oscilloscope to 16 bit precision, at a sampling rate of 10 or 20 MHz. Each data set, consisting of the recorded driving pulse and received pulse was transferred to computer storage for later analysis. To enhance signal quality, 100 signals were averaged at each position. For cross-hole measurements, only P waves were recorded, with measurements made at approximately one foot intervals from the full depth of the holes to the surface, or as nearly as possible. Positioning was done by measuring the tool depth relative to surveyed marks on reference plates affixed as a collar at the hole's entrance. Calculating velocities requires an accurate knowledge of the transmitter and receiver positions.

Surveying

Our goal was to determine wave speeds with an accuracy of 0.5% percent or better. Path lengths ranged from about 1 meter for the cross-hole measuremets to a fixed 0.3 meters for the same-hole easurements and the wave speed for P waves in salt is approximately 4500 m/sec for undisturbed salt. Thus travel times were expected to be in the range of 200 to 70 microseconds. To maintain the desired accuracy, the path length had to be known to substantially better than 0.5%, or 5 mm for the cross-hole paths. No direct measurement of path length was possible, so the path had to be determined indirectly by determining the 3-D position of each transducer as a function of depth in the hole.

A survey was carried out by Westinghouse to locate the center line of each of the measurement holes to an accuracy of 1mm. A repeated survey showed, by repeatability, that this accuracy was attained, and surpassed.

Data Analysis

Calculating the velocity was a several step process involving coordinate determination, corrections for various offsets and choosing the arrival time for the P or S wave at the receiver. Coordinates were determined by parameterizing the North, East and vertical coordinates (N,E,Z) of the surveyed center line of each hole as a function of depth into the hole. Three, second order-fits for N, E, and Z as functions of depth was determined and found to reproduce the surveyed coordinates within the required precision. For each measurement set, the measured depth of emplacement for the transducer was used in the second-order fits to calculate the coordinates of the transducer in space. Offsets were applied to account for the actual position of the transducer against the wall, instead of the centerline of the hole. Knowing the coordinates of the transmitter and receiver, the path length could be calculated. Non-systematic errors are estimated to make the uncertainty in cross-hole path length be less than 3 mm.

Determining the travel time requires knowing the difference between the time of the initiating electrical pulse applied to the transmitter and the time of arrival of the P or S wave at the receiver. Pulse time, which is easily determined from the recorded rapidly rising square wave to an accuracy limited only by the typical sample interval of 50 or 100 ns, contributed a negligible amount to uncertainty in velocity. It is much more difficult to fix the arrival time of the wave at the receiver. The waveform is an emergent sinusoid, not a square wave pulse, whose unsharp beginning is additionally obscured by electrical noise in the highly amplified signal. S waves, which travel slower and arrive later than P waves, are additionally muddied by the coda of the P wave that extends into the S wave signal.

Although signal quality was improved by signal averaging, the determination of arrival times could still be difficult especially for measurement paths that passed close to the surface where damage was greatest, resulting in high attenuation of the signal. Typically the first arrival is small in amplitude, making it easy to miss the first cycle or more in a highly attenuated signal. This would result in unacceptable errors in the travel time and velocity. Visual comparison of the signals in a given data set can be used to minimize the risk of missing first arrivals.

An interactive Matlab program has been developed that allows the signals from a given data set to be plotted, offset so that the arrival times are aligned. When arrival times are correctly chosen, the similarity of the signals is usually obvious. The program allows the arrival times to be adjusted interactively until the signal-to-signal correlation is good. For the measurement paths at some distance from the free surface, the actual arrival time is easily determined, allowing these signals to be used as a guide for choosing the arrival time for the less distinct signals from paths near the free surface. Typically one clear arrival is used as a reference and all the other signals are adjusted to correlate well with that reference. This builds in a systematic error corresponding to the error in picking the reference signal, but reduces the scatter between measurements, making it much easier to see trends in the velocity with depth. The systematic error is determined by the error in picking the arrival time of the reference, which for the cross-hole P waves, is less than 200 ns, a negligible amount. Same-hole P waves are much lower amplitude because of the unfavorable geometry of the transmitter and receiver. As a result the errors are larger, and the effect more significant due to the shorter path lengths. The systematic error is close to 1% for these paths, but of course, that is a constant error for all measurements. Trends are not obscured as a result.

Shear waves travel slower than P waves and there is always energy emitted as P waves. Thus the S wave arrival must be detected while the P wave is still influencing the transducer. Typically a large, fairly sharp sinusoid emerging from the P wave coda is taken as the S wave arrival. The technique of comparing waveforms is essential to get consistent results for S waves as determining the actual arrival time is usually difficult. A reference signal with the sharpest S arrival is chosen and a particular peak within the signal is used to align the other signals. Inevitably this introduces a systematic error of 1 or 2% in the S velocity, but the trends are unaffected as the error applies to all the referenced signals.

Results and Discussion

Measurements were made horizontally for all 6 cross-hole possibilities, vertically for 4 of 6 cross-hole possibilities and perpendicular to the rib (same hole) in 4 of the 9 holes. All of the data plots follow the same format, consisting of a title giving the location data and the wave type, P or S, and the data plotted as the measured velocity plotted at the depth of the transmitter. A typical title would be

Q ROOM ACCESS, QGU13 → QGU10, P Wave

For the current work all data are from the Q room access drift, at location 1. This title would correspond to a cross-hole measurement set, transmitting the signal from QGU13 to QGU10 and plotting the velocity of the P wave.

Horizontal Paths

Vp , the P wave velocity, was measured at 30 cm intervals for the six possible horizontal paths (Figure 3). Figure 3 summarizes all the measurements with six sub plots arranged in the same way as the physical arrangement of the holes in the rib. Beginning at panel a of Figure 3, Vp is plotted for the horizontal path between the left and center holes drilled in the rib near the back (Figure 1). At the upper right of Figure 3 (panel b), results for the measurements made between the center and right hand holes (QGU11 and QGU12) are plotted and similarly for the center row of holes (panels c and d) and the bottom row of holes (panels e and f).

Overall, the velocity is 4.4 km / sec + / - 0.1 km / second for all three levels at depths greater than 2 metes from the rib. A variation of less than + / - 2% indicates several things. First, the surveying and corrections for non-parallelism of the holes has been correctly handled. Even with the excellent control on drilling the holes, the runout between any given pair of holes frequently exceeded 10% of the hole spacing. If not corrected for, the cross-hole velocities would show a significant trend with depth, and indeed, several errors in the analysis were revealed by such trends. Second, the velocity differences between the two argillaceous layers (Map units 0 and 4, Powers, 2000) and the clear halite in Map unit 3 are small, indicating little difference in the elastic moduli, despite the visual differences. There is a small but significant difference between Vp in clear halite (QGU13, 14, 15, Map unit 3) where Vp = 4.5 km / sec and the other two units where the Vp at depth is closer to 4.4 km/sec.

Panels c and d show how consistent the velocity measurements can be at depth. Variations from the mean are less than 0.5% which is getting close to the attainable accuracy. Powers (2000, p. 7) describes the core from these holes as being more homogeneous than the core from the other rows of holes. This is consistent with the almost constant cross-hole velocity observed for QGU13 to QGU14, and QGU14 to QGU15. Given the consistency achieved with this data set, it is reasonable to argue that the variations of Vp measured in the top and bottom row of holes are probably real. Powers (2000, p 6), describes significant variations in lithofacies for the core from the bottom row of holes (QGU16, 17 and 18) and speculates that the differences may be of such magnitude as to influence the elastic wave velocity. We believe that to be the case. Further work will be required to correlate the velocity results with the core logging.

All 6 data sets for the horizontal cross-hole Vp measurements indicate a constant value, subject to local variations as the lithology fluctuates, as the measurement depth approaches 6 meters. In the first two meters, there is clear evidence of the disturbed zone for the center row of holes. A slightly different picture is seen for the top and bottom row of holes; a shallower DRZ, extending in perhaps 1 m and between QGU10 and QGU11, no real evidence for a disturbed zone.

The center row of holes (QGU13,14 and 15) is at approximately the mid-height of the rib where the shear stress is expected to be greatest because σ_{11} , the maximum compressive stress, vertical and amplified by the stress concentration around the drift, σ_{22} , the intermediate stress, parallel to the drift and equal to the far field value, and σ_{33} , the minimum compressive stress, equal to zero at the rib and, in general, increasing with depth. Thus at the rib, the maximum shear stress, which is proportional to $\sigma_{11} - \sigma_{33}$, is large and decreases with depth. As both creep and quasistatic damage are driven by shear stress, it is expected that high shear stress will produce high levels of damage and low velocities near the rib, with decreasing effect as increasing distance from the rib, decreases the shear stress.

Panels c and d, Figure 3, show exactly the expected pattern. V_P is lowered to by 9% to 4.1 km / sec near the surface, rising over the first two meters to about 4.5 km / sec and remaining nearly constant over the rest of the measurement interval. There are two points of increasing velocity right at the surface for the measurement path QGU14 to QGU13. Previous studies (Knowles, et al. , 1996, Figure 7) have found a similar result in some cases at the WIPP. It is possible that a slab of salt, has essentially been unloaded by splitting , allowing cracks to close or avoiding their formation. The point at a depth of 0 meters, nominally right along the rib surface, seems excessively fast at 4.65 km/sec, which is faster than the far field value. Further measurements at closely space intervals will be necessary to judge the validity of this one point. Although not shown, a superposition of the measurements sets for QGU13 to QGU14 and QGU14 to QGU15 shows them to be virtually identical, consistent with Powers' (2000) observation that core from these holes was particularly homogeneous.

Near the back (Panels a and b, Figure 3), V_P along the horizontal paths between QGU10, 11 and 12 shows a much shallower disturbed zone and the effect on V_P is lessened. In fact, for QGU11 to QGU10, the data show no DRZ effect at all. One data point is missing at 0.3 meters due to equipment problems, but there is no indication of a downtrend in the data, implying that the DRZ is non-existent or extends in less than 0.5 meters. Between QGU11 and QGU12, nominally in the same lithology, there is evidence of a shallow DRZ, causing V_P decrease from 4.35 km/ sec in the far field to 4.15 km / sec at 0.3 meters. The decrease of 5% occurs over about 1 meter.

A similar picture is seen at the bottom of the rib, holes QGU16, 17 and 18, in panels e and f of Figure 3. We were able to make measurements at a depth of about 0.15 m in these holes, but the minimum value for V_P was still 4.1 to 4.15 km / sec, as compared to a far field value of 4.4 km / sec. The DRZ appears to extend in less than 1 meter from the surface, lowering V_P by 6 to 7 %.

P waves travelling in the plane parallel to the rib are not expected to be strongly influenced by the DRZ as the cracks that are the microscopic manifestation of the DRZ are expected to have their planes subparallel to the rib and thus parallel to the particle motion in the P wave. Despite the unfavorable alignment, it is clear that the DRZ is seen, extending between 1 and 2 meters into the rib. A spatial variation in the extent of the DRZ is expected as the stress concentration around the rectangular drift produces a varying shear stress field. From elementary elastic considerations, the shear stress is expected to be at a maximum near the mid-height of the rib and decrease towards the upper and lower corners of the drift. However, salt is anything but elastic, with time-dependent phenomena playing a dominant role in determining the long term behavior. From this one set of measurements it is impossible to say how much of the DRZ should be attributed to instantaneous, brittle, cracking and how much to creep-driven fracturing.

Given the large length to width and height ratio of the drift, the stress state should be independent of displacements along the drift. Thus all of the horizontal paths experience nominally constant stress and lithology along their length and the results can be treated as representative of the salt at a given height and depth. This is not true of the vertical paths, which pass through changing lithology and varying stress states.

Vertical Paths

Four of the six possible vertical cross-hole pairs were tested, giving one-fold redundancy for the results. Figure 4, using the same plotting conventions as Figure 3, shows the results. A very simple picture emerges; all four paths indicate an average far field velocity of 4.4 to 4.5 km / sec and a DRZ beginning at about 1.5 to 2 meters from the rib that lowers the average V_P by 8% to 4.1 km / sec at the surface. Results are described as averages because, unlike the horizontal paths, the vertical paths cross lithologies and pass through salt exposed to a spatially-varying stress state. Thus the magnitude of the damage is not expected to be the same at each point of the path traveled by the elastic wave.

At small depths, the minimum velocity observed for both horizontal and vertical paths is about 4.1 km per second, implying that the damage near the rib surface is similar when viewed horizontally or vertically, regardless of the position of the measurement. At greater depths of course this is not true as discussed in the previous section on horizontal paths.

Assuming that the observable changes in lithology do not have a large effect on the mechanical properties, as seems reasonable from the near equality of the far field velocities, then the symmetry of the vertical paths about the midheight of the rib leads to the expectation that the results should be nearly identical for the four paths. As Figure 4 shows, this was the case.

Same-hole paths

Same-hole paths, where the transmitter and receiver are in the same hole offer a number of advantages: maximum sensitivity of V_P to the expected orientation of cracks, fixed path length to eliminate surveying as a source of error, and the ability to measure both P and S waves with one set of transducers. To offset these advantages there is the poor quality of the P wave signal due to the geometry of the transducer arrangement and the lower sensitivity of V_S. In this arrangement the shear wave is propagating perpendicular to the expected crack orientation, but the particle motion is parallel to the plane of the cracking, thus reducing the effect of the DRZ on the velocity of the shear wave.

Three sets of data suitable for determining V_P and V_S were obtained using holes QGU12, QGU14 and QGU17. Results are shown in Figure 5, where P and S wave velocities are plotted in two columns. Note that the scale for V_P has been increased to cover the range from 3 to 5 km / sec, twice that used for the earlier plots, to accommodate the greater range of velocities observed in these measurements. A greater scatter was seen, particularly for V_P, as compared to the cross-hole measurements. Partly this is due to the lower quality of signals that made choosing the arrival time difficult, but much of the variation appears to be real. This is probably a result of the shorter path length used for these measurements, 0.3 meters versus 1.2 to 1.4 meters for the cross-hole measurements. Velocity changes due to variations in the lithology would be emphasized by the short path length that could lie entirely within one of the subunits described by Powers (2000). V_P is unusually high, averaging 4.7 km / sec which is not consistent with the other measurements. Repeated checks of the data found the value to be correct, leaving us with no explanation for the result.

Panel a, Figure 5, shows V_P for QGU12, located in the upper row of holes and cored through argillaceous halite (Map Unit 4, Powers). There appears to be no DRZ at this hole location, although the scatter in velocities might obscure a small decrease near the rib. Powers (2000) discusses the variability of the lithology for QGU12, pointing out the variation both along and even across the core. This no doubt accounts for the range of values for V_P observed in this hole. Panel b similarly shows V_S measured in QGU12. Again, there is no sign of the signature decrease in velocity due to a DRZ near the rib surface. Measured values showed considerable variation along the length of the hole, that, in light of the relatively consistent values observed in QGU14 and QGU17, are attributed to material variation.

Hole QGU14 (panel c, Figure 5), at mid-height of the rib, shows a strong response to the DRZ that was observed in the cross-hole measurements at this location. Velocities at the surface were in the neighborhood of 3.5 km / sec, a 22% decrease from the far field value of 4.5 km / sec. It is worth noting that the far field value measured here is the same as the value obtained in the cross-hole measurements between QGU13 and 14 (panel c, Figure 3). The core from QGU14, along with 13 and 15, was described by Powers as the most homogeneous of all the units sampled. Therefore it would be expected that the velocity measured should be independent of path length or orientation in the far field, beyond the influence of the DRZ. The DRZ is definitely detectable at depths up to 2 meters and the far field velocity is not truly reached until nearly 4 meters. Given the described homogeneity of the salt in this hole, it is less likely that the changes between 2 and 4 meters are due to lithology and more likely that the changes are the result of damage. Compressional waves travelling perpendicular to the rib should be the most sensitive to the oriented cracking of the DRZ, much more so than P waves travelling parallel to the rib as in the cross-hole measurements.

Shear wave data (panel d, Figure 5) also indicate a decrease in velocity extending about 2 meters from the rib. The magnitude of the decrease is difficult to estimate due to the high velocity observed at 0.3

meters. Picking the arrival time for S waves is chancy enough, but in the DRZ the attenuation is so high that signal quality is degraded, making a reliable pick even more difficult. In the absence of adjacent measurements that are in accord, it is likely that this data point is not the actual velocity, but no other choice of arrival time was defensible.

Near the floor, V_P in QGU17 was found to be relatively constant beyond 1 meter depth at 4.5 km / sec, with significant variations that are attributed to lithology changes (panel e, Figure 5). A shallow DRZ, extending less than one meter in depth is seen, with V_P decreasing by 15% near the surface. A similar DRZ pattern is observed in the shear velocity (panel f, Figure 3), which decreases abruptly by 15 % in less than one meter.

Conclusion:

Cross-hole and same-hole velocity measurements give a consistent picture of the DRZ that has developed in Q room access drift since it was constructed. The DRZ is well developed at mid-height on the rib, extending in 2 meters and possibly as much as 4 meters. Near the back and floor, the DRZ is shallower (1 meter or less) or not detectable. The lithology plays a role in determining whether the DRZ develops in the zones near back and floor, with some holes showing a DRZ and their neighbors a meter or two away, showing little or nothing.

P waves in same-hole measurements are most sensitive to the DRZ because of favorable orientation of particle motion perpendicular to the cracking. Changes in V_P as large as 22% were observed for P waves propagating at perpendicular to the drift axis at room mid-height. Using results from Brodsky (1995 Figure 4-2), this would correspond to the velocity changes observed in salt loaded nearly to failure in triaxial compression.

References

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Figures

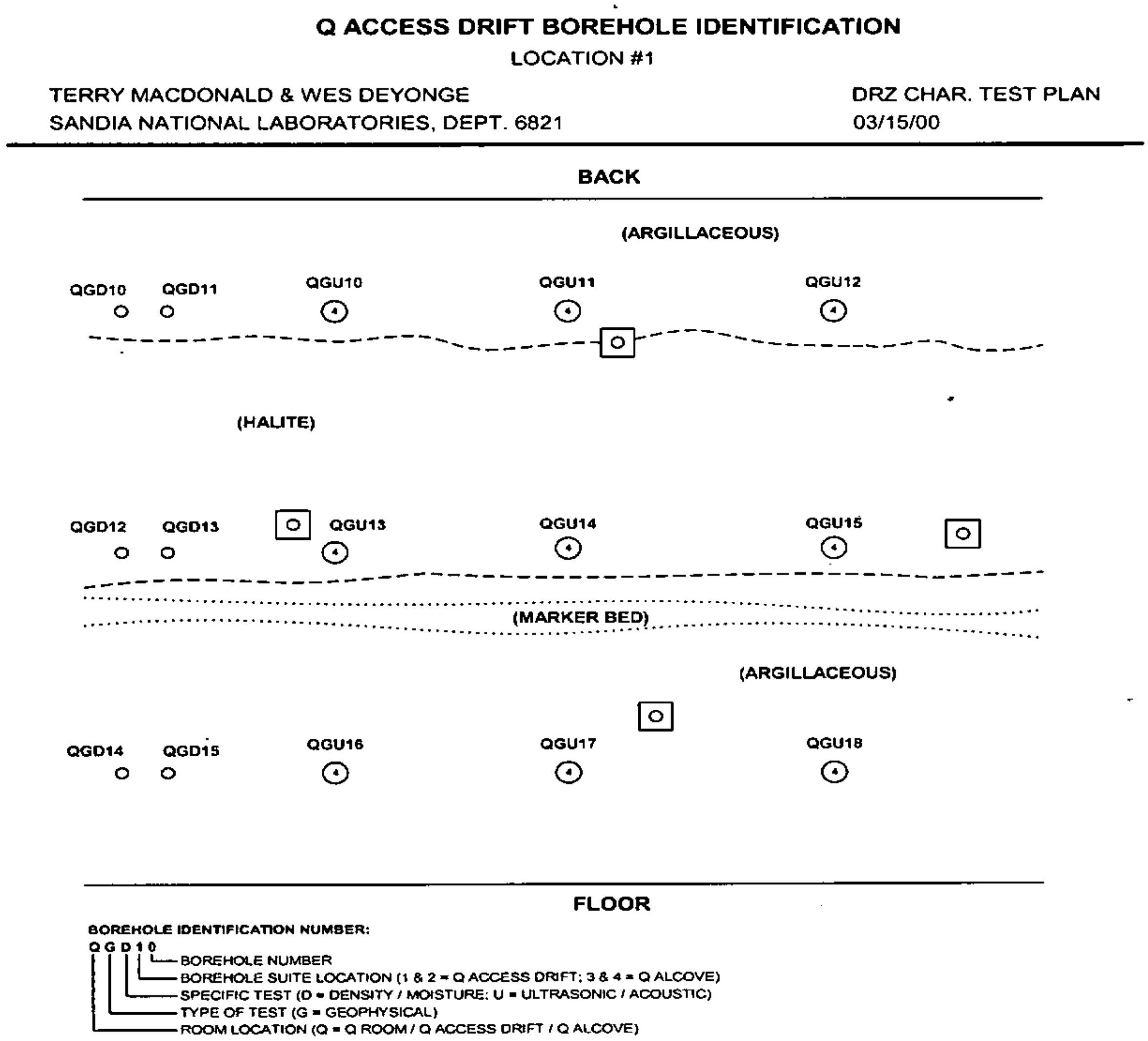

Figure 1 Layout of holes

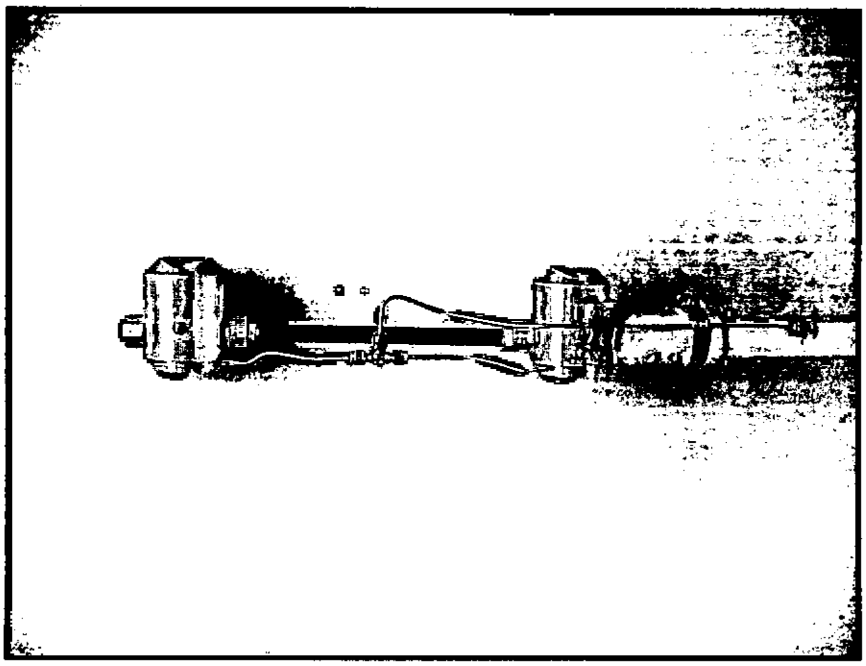

Figure 2 One of the measurement tools, showing the two transducer heads and the plumbing for the couplant transport and pressurizing the air cylinders.

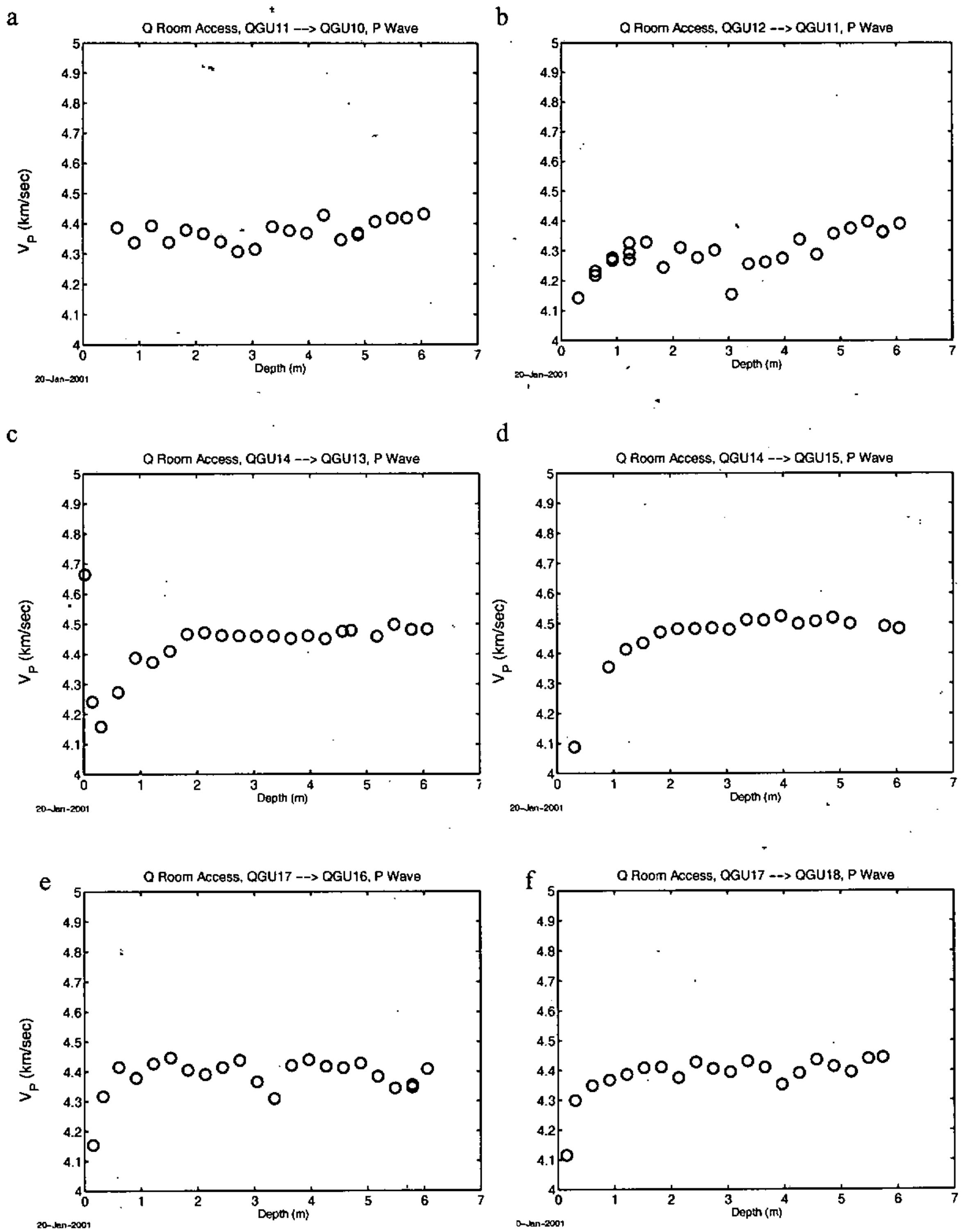

Figure 3: Vp for all horizontal cross-hole paths arranged in the same order as the physical arrangement of holes in the rib.

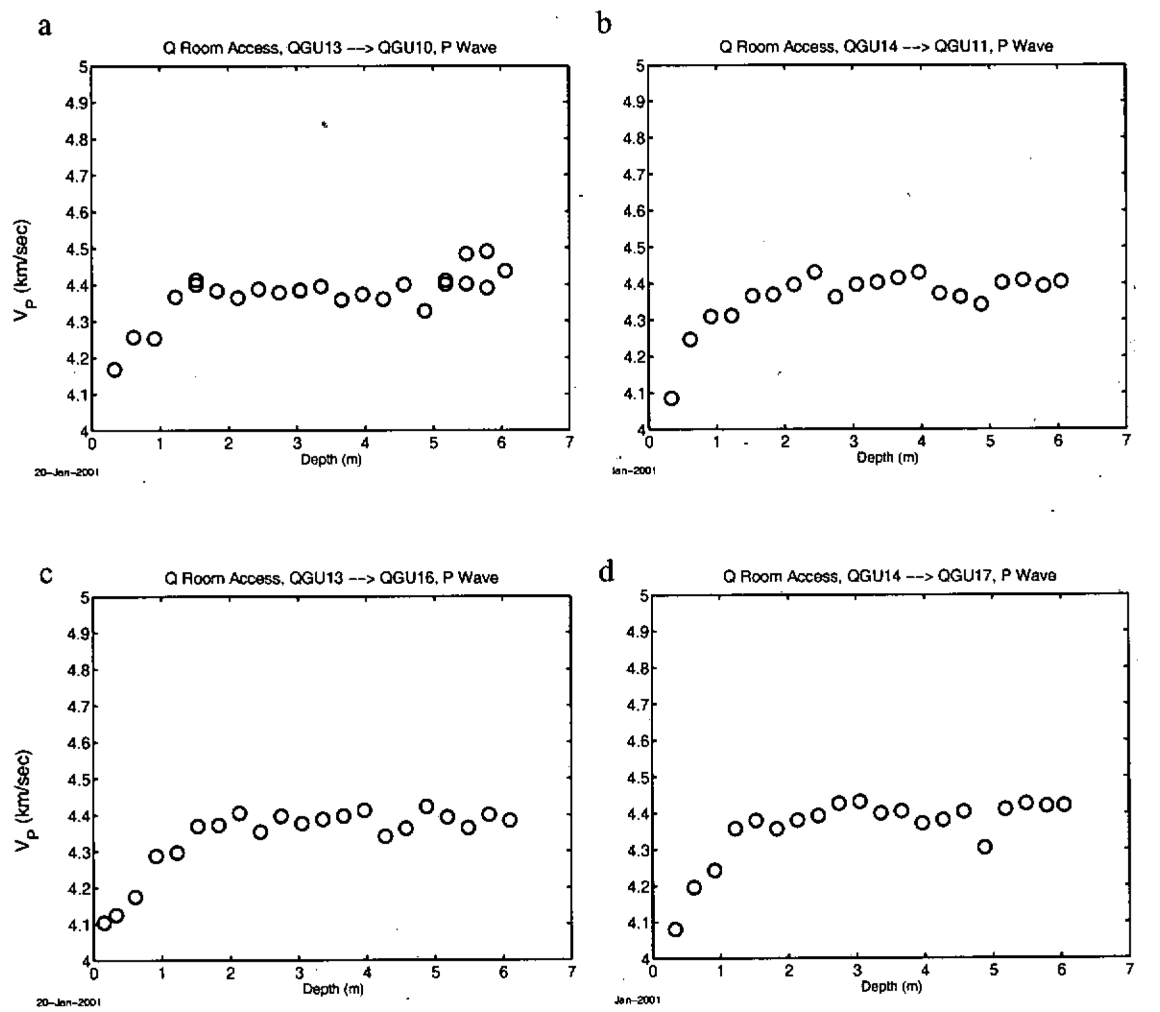

Figure 4 Vp for all vertical cross-hole paths arranged in the same order as the physical arrangement of holes in the rib.

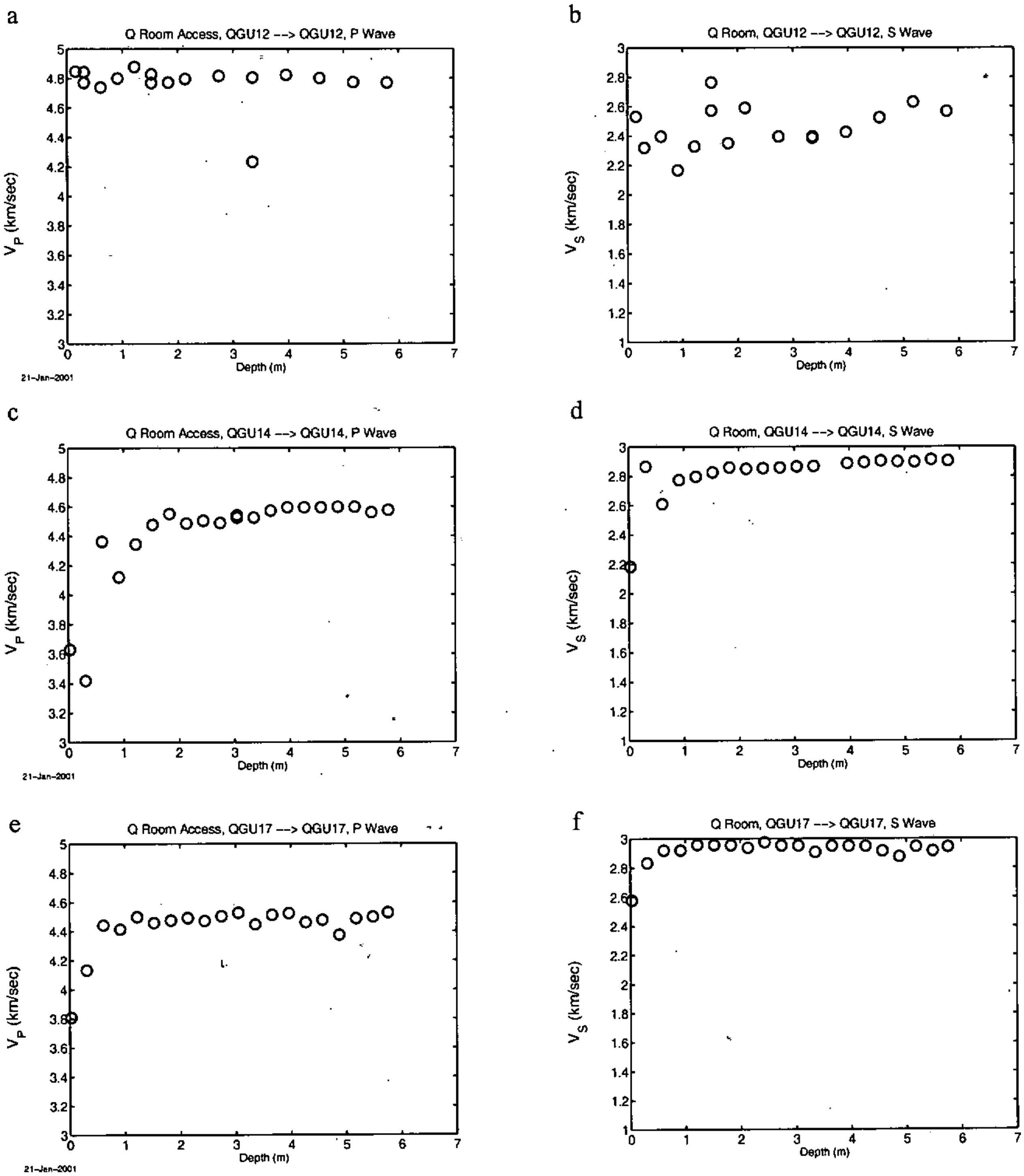

Figure 5 V_P and V_S for same-hole paths. Paths are perpendicular to the rib and of fixed length, determined by the transducer spacing on the tool.

Chavez, Mario Joseph Mario Chavez 2/28/07

Subject: FW: Signature Authority

From: Holcomb, David J
Sent: Wednesday, February 28, 2007 11:00 AM
To: Chavez, Mario Joseph
Subject: RE: Signature Authority

Mario-

As long as it doesn't involve my money, as on a check, feel free to sign for me. More formally, you have my authorization to sign the three documents.

I am pretty much fully committed to a field test for the next 2-3 weeks, but will try to stay aware of other things.

David J. Holcomb
Geomechanics
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Phone: 505-844-2157
Fax: 505-844-7354

-----Original Message-----
From: Chavez, Mario Joseph
Sent: Wednesday, February 28, 2007 10:17 AM
To: Holcomb, David J
Subject: Signature Authority

David,

For Records purposes I need your signature to authenticate the following three (3) records.

1. Data set notes for S90 drift and Q Room Annex, Prepared by David Holcomb, February 2007
2. Status of ultrasonic wave speed measurements undertaken to characterize the DRZ in the access drift to room Q, Memo form Holcomb and Hardy to Frank Hansen, dated January 22, 2001.
3. Using Ultrasonic Waves to Assess the Disturbed Rock Zone (DRZ) in the Q room Alcove, WBS 1.3.5.4.4.1, memo from Holcomb,Hardy, and MacDonald to Frank Hansen, dated October, 24 2001.

You can either print the first page of each attached document sign it and fax (234-0061) back to me or you can give me signature authority for the three attached documents.

Mario