# Near-surface seismic imaging and reflectivity studies of the Melton Valley waste areas, Oak Ridge Reservation

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## Summary

During 1996, eight surface seismic reflection lines and one multicomponent VSP were collected south of Oak Ridge National Laboratory, Tennessee adjacent to the Melton Valley waste areas. The primary goals of this project are to determine the in-situ causes of local seismic reflectivity and to provide more detailed interpretations of subsurface geologic structures within the waste areas. Prior to this survey, reflection images of these sequences were limited to a single 1981 exploration data set and a 1993 source test line, so local understanding of in-situ causes of reflectivity was limited. The new data set: 1) illustrates previously suspected duplex structures above the Copper Creek Thrust zone (CCT) beneath many of the waste areas, 2) images folded/faulted sequences above the CCT, 3) provides additional evidence for remapping a few inferred geological contacts, and 4) shows that observed seismic reflectivity is principally caused by intraformational lithologic contacts and intraformational brittle fracture zones (some of which have connective ground water flow). This new data provides important structural information for those doing hydrologic modeling in the area and provides a detailed analysis on the nature of seismic reflectivity in this region which could aid future near-surface or exploration surveys in the Valley and Ridge province.

## Introduction

The Oak Ridge Reservation (ORR), situated about 15 mi. (~ 25 km) west of Knoxville, Tennessee is a 35,000 acre (143 $km^2$) U.S. Department of Energy operation which contains research facilities, production plants, waste disposal areas, and forests. ORR geology consists principally of interbedded shales and carbonates that strike approximately N 55° E and dip between 20-60° S and lies within the Valley and Ridge province of the western Appalachians. The units of specific interest are the mid/upper Cambrian Conasauga group (Nolichucky shale, Dismal Gap Fm., Rogersville shale, Friendship Fm., and Pumpkin Valley shale), and the lower Cambrian Rome Formation. Hydrologically, these units are considered an aquitard. In this aquitard, the groundwater flow is controlled by fractures since the rock permeabilities are extremely low (Hatcher et al. 1992).

The seismic reflection project was planned as part of a remedial investigation of the eight Waste Area Groupings (WAGs 3-10) of Melton Valley on the ORR ( Fig. 1). Contaminants in the WAGs include radioisotopes and solvents. These waste sites and adjacent contaminated areas are currently operated under environmental regulations. The eight seismic reflection lines (Fig. 1; labeled XA, XB, XC, XD, XE, XF, XG, and XH) were expected to provide images of the large-scale geologic structures (basic stratigraphy, thrust plane surfaces, etc.) and smaller geological features such as faults and fracture zones. These could act as pathways for contaminant migration from the surface WAGs and the injected grouts of the new and old Hydrofracture waste facilities (NHF and OHF, Fig. 1). The NHF and OHF facilities were used for injection of low-level radioactive wastes mixed with cement grout into shales at a depth of approximately 940 ft. (-286 m) from 1963 to 1984.

In addition to the surface seismic profiles, multicomponent, vertical incidence P- and SH-wave Vertical Seismic Profiles were collected in a borehole (WOL-2, Fig. 1) near the western end of Melton Valley. These data in combination with previous borehole geological and geophysical information (Fig. 1; wells WOL-2, HHMS-12, HHMS-13, HHMS-14, 1953, 1943, 1920, C-l, C-2, and C-3) provide the basis needed to analyze the basic geologic structure in Melton Valley, and to evaluate the nature and causes of observable reflectivity in this region.

## Data Acquisition and Processing

Due to surface contamination surrounding the WAGs, acquisition was restricted to available roads (Fig. 1). Data were recorded by the Kansas Geological Survey with two 48 channel Geometries Strataview seismographs which sampled at lms for 12 seconds. Stations spacing was 8 ft (-2.4 m) with three 40 Hz geophones at each station. The source was a single Industrial Vehicles Inc. Minivib which fired 10s, linear-upsweeps from 30-300 Hz at each station in an end-on configuration. Three uncorrelated records were recorded for every shot point resulting in 13,300 uncorrelated shots (roughly 110 Gbyte). Data were stored uncorrelated to disk in the field, then transferred nightly to 4mm tape for archiving and pre-correlation, vibroseis whitening processing (Çoruh and Costain, 1983) on a UNIX workstation.

Data processing followed a standard seismic processing scheme with a few notable deviations. Specifically, pre-correlation vibroseis whitening (VSW) was implemented on all of the data based on the previous work of Doll, et al. 1997; where it was found that for the IVI Minivib source, prewhitening provided the best combined image of the very shallow (~ 200-700 ft (61-213 m)) and deeper (700-2000 ft (213-609 m)) intervals and structures of interest. In addition to VSW, it was found that time-invariant spectral balancing applied to the correlated shot records improved the high frequency response and reduced the relative amplitude of near-surface source-generated noise (i.e. air wave, and ground roll). It was observed in the early stages of processing that only one line (XA) was severely contaminated by multiple energy. The other lines did, however, exhibit a more subtle "ringing". At this stage, the vertical incidence, P-wave VSP data from the WOL-2 borehole was analyzed for multiples. It was discovered from autocorrelation analysis of the downgoing (transmitted), and inside/outside corridor stack analysis (Hinds et al., 1996) that few multiples (surface or interbed) exist in the VSP data. Consequently, a predictive deconvolution operator for line XA was designed and applied in the CDP domain with success. The other lines had no additional deconvolution applied. Lastly, prestack time and depth migrations were implemented for those lines which parallel the lithologic dip (i.e. XA, XB, XD, XF, and XG) to better resolve the geologic structures. Previous success using prestack migration for near-surface data was shown by Carr et al., 1997. With the available prestack migration algorithms, we have had some success for times > 100 ms (-700 ft (213 m)). Above this time, migration has mixed success. The combination of high frequencies, and lack of extremely detailed velocity field in this range makes it difficult to image the upper 100 ms well. Efforts are ongoing to understand the practical limits to prestack migration for this and other near-surface data sets.

## Discussion

To assist in data analysis and interpretation, VSPs from boreholes WOL-2, 1943, and 1920 and ten sonic log derived synthetic seismograms (WOL-2, HHMS12-14, 1953, 1943, 1920, and Cl-3; Figure 1) were studied to evaluate the nature of the observed reflectivity in the CDP profiles. The VSP from WOL-2 was collected at the end of the last acquisition phase in August of 1996. Earlier VSPs were collected by hydrophone strings and geophones deployed in boreholes 1943, and 1920 during the 1993 source test (Doll et al., 1997).

The 1996 WOL-2 P-wave VSP, and CDPs exhibit a dominant frequency of 150 Hz. For an average velocity (14 kft/s or 4.2 km/s), vertical resolution is on the order of 23 ft (7 m) based on l/4 wavelength criteria. To develop an understanding of local reflectivity, synthetic seismograms were generated for the available Melton Valley sonic logs with a 150 Hz, zero-phase Ricker wavelet. This showed reflections generated at all formation boundaries (including one at the top of the Copper Creek Thrust zone), and at internal boundaries within the Dismal Gap Fm., Rogersville Shale, Friendship Fm., Pumpkin Valley Fm., and Rome Fm. Further analysis of logs in HHMS 12-14, and 1920 identified reflections from 16 of 17 hydrologically identified fracture zones. Of these 16 fracture zone reflections, seven correspond with mapped lithologic contacts and four of these contain brine and are inferred to be hydraulically connective. Interestingly, these "wet" zones correspond to a zone within the lower Dismal Gap Fm., the Dismal Gap Fm./Rogersville Shale contact, the upper Rome Fm., and the Copper Creek Thrust zone. Clearly, from synthetic seismograms alone, the reflectivity is much more complex than we initially expected.

Within the 1996 WOL-2 VSP (recorded from 45 - 855 ft (14-260 m)), P-wave reflectivity is observed from three depths within the Nolichucky shale, the contact between the Nolichucky shale and the Dismal Gap Fm., four depths within the Dismal Gap Fm., and the contact between the Dismal Gap Fm. and the underlying Rogersville shale. Below the recorded VSP interval, reflections are observed from 151 ms, 167 ms, 180 ms, 200 ms, and 210-220 ms (Two-way travel time). Based on thickness-travel time estimates for the underlying units, these reflections are interpreted to originate from the Rogersville shale/Friendship Fm. contact, the Friendship Fm./Pumpkin Valley contact, an upper contact in the Rome Fm., and the Copper Creek fault zone.

Surface seismic sections show less reflectivity than either the VSP or the synthetics. Clearly, some of this is a result of the expected differences in sensitivity between surface and downhole methods and the fact that some reflections are not as laterally continuous, making interpretation more subjective. A number of reflection intervals have been identified in the data by using 1) the coincident VSP and various synthetics, 2) the known (or predicted) surface location of contacts, 3) thickness-travel time estimates, and 4) ties between lines. For all lines, laterally traceable reflection events originate from: 1. Two (middle) depths within the Dismal Gap Fm., the contact between the Dismal Gap Fm. and the Rogersville Shale, the Rogersville Shale/Friendship Fm. contact, an event internal to the Pumpkin Valley Shale, upper internal Rome Fm., and the CCT. Figure 2 displays some of these events recorded on dip line XG.

Reflections within the Conasauga Group and Rome Formation originate from internal as well as lithologic boundaries. It is also probable that some of the reflections are affected by the presence of fractured zones and fluids. Of the reflectors interpreted on the surface data, the two internal Dismal Gap Fm. and the Dismal Gap Fm./Rogersville shale events correspond to zones in the sonic logs of boreholes 1920, and WOL-2 where the velocity is low relative (-18%) to the surrounding rocks. From borehole hydrophone VSP measurements in borehole 1920, the internal Dismal Gap Fm. and Dismal Gap Fm./Rogersville shale events imparted strong secondary pulses into the recorded data. It is indicated by Cicerone and Tösoz (1995) that this phenomena is a result of elastic compressional energy forcing (or squirting) fluid in connective fractures into the well bore, thereby creating a secondary source recorded in the hydrophone VSP. At this depth, the Dismal Gap Fm. is divided into a lower and upper part based on a gamma-ray log shift caused by a decreased limestone content in the lower unit. Both upper and lower members of the Dismal Gap Fm. are interpreted to contain intraformational thrust faults and buckle folds (Hatcher et al., 1992), but details on these particular fracture zones from core or hydrogeologic flow data do not exist. The upper Rome Fm. and the CCT are reported (Dreier et al., 1992) to produce measurable fluid inflow into HHMS-12, HHMS-13, and HHMS-14 (which lie along line XC). Yet, these zones also contain the largest percentage of sand/dolomite within the lower Paleozoic section of the area. Therefore, it would be difficult to attribute the reflectivity exclusively to either lithology changes, or porosity. However, both factors are likely contributing to the large amplitude reflectivity seen from these units.

The new seismic data have confirmed the presence of duplex structures along the **décollement** surface of the CCT. One of these features is mapped at the surface between ORNL and Melton Valley. Previously it was assumed that this duplex continued further to the west, but would be unexposed at the surface. Between lines XA, XB, and XD, this duplex is followed in the subsurface further to the west. Additionally, a different duplex lies beneath most of Melton Valley. It can be identified on all of the Melton Valley lines (e.g. D on Fig. 2). These lines also display indications of the inferred Conasauga Group intraformational faults (Fig. 2 - F) or alternatively, mesoscopic buckle folds (Hatcher et al., 1992). Although the tight axis of the inferred folds is beyond the imaging capabilities of this survey, a series of folds are observed in both dip lines XF, and XG (Fig. 2) in the lower (internal) Dismal Gap Fm. reflection event.

## Conclusions

The 1996 Melton Valley reflection data provides a detailed view at duplex structures, tear faults, and the causes of reflectivity within the waste sites south of ORNL. Importantly, reflections are found not only from lithologic contacts, but fault zones (e.g. Copper Creek Thrust) and lithologic units that have fracture zone porosity within particular formations. Therefore, this data set will provide better structural control, and indications of hydraulically connected fracture zones for those engaged in hydrogeologic modeling of the waste areas.

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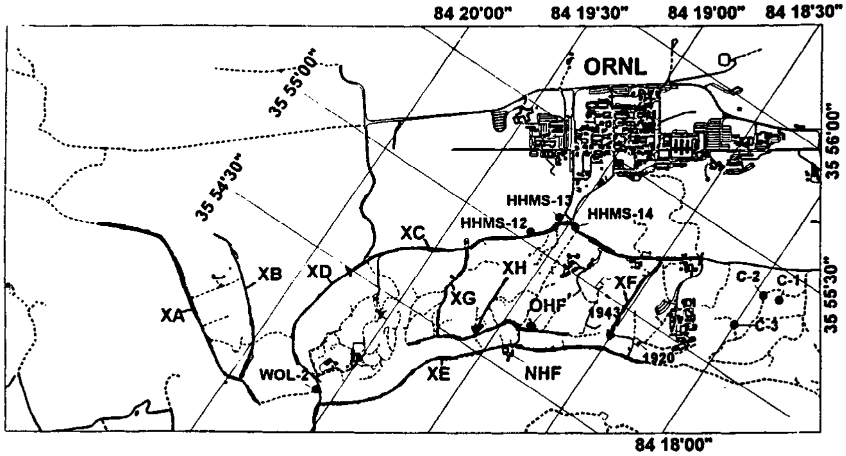

Figure 1. Location of the Melton Valley seismic lines (e.g. XA, XB,...), NHF/OHF = new and old Hydrofrac facilities, boreholes (e.g. WOL-2, HHMS 12,...) in relation to ORNL. Grid lines are latitude and longitude.

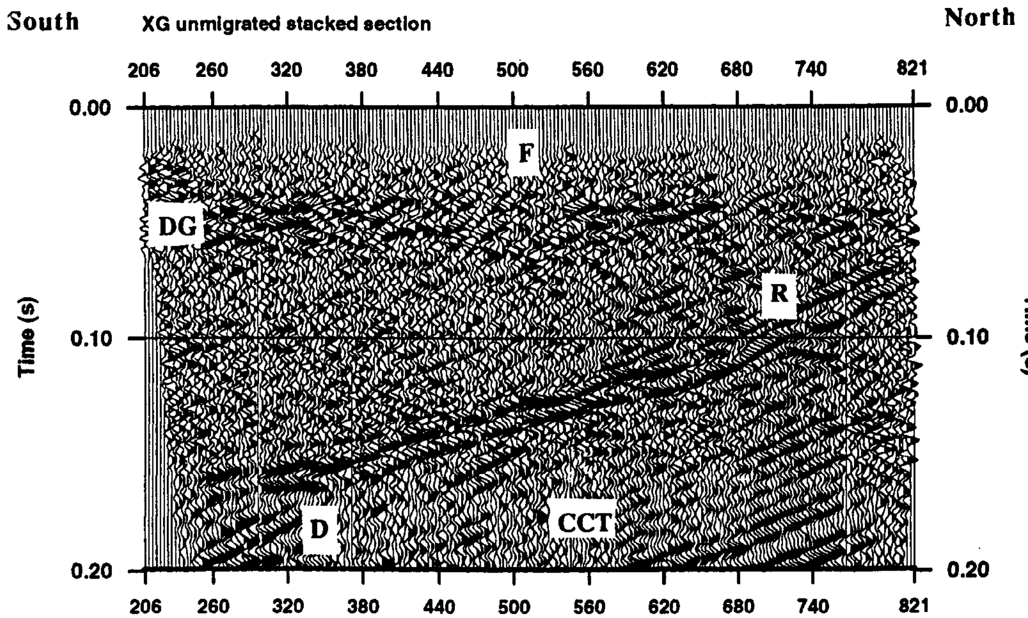

Figure 2. Unmigrated stack of Melton Valley line XG. D = updip edge of the Melton valley duplex structure; CCT = Copper Creek Thrust Fault; R = upper Rome Fm. reflector; DG = the lower Dismal Gap Fm. reflector, notice folding in this event (see text for details); F = fault zone.