High Frequency Electromagnetic Impedance Imaging for Vadose Zone and Groundwater Characterization

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RESEARCH OBJECTIVE

Accurate description of transport pathways on the gross scale, the location of contamination, and characterization of heterogeneity within the vadose zone, are now realized as vital for proper treatment, confinement and stabilization of subsurface contamination at Department of Energy (DOE) waste sites. Electromagnetic (EM) methods are ideal for these tasks since they are directly sensitive to the amount of fluid present in porous media, as well as fluid composition. At many DOE sites it is necessary to employ lower frequency (<1 MHz) or diffusive electromagnetic fields because of the inability of ground penetrating radar (GPR) to penetrate to sufficient depths. The high frequency impedance method, which operated in the diffusive frequency range (10 Hz to 1 MHz), as well as the low end of the spectrum employed by GPR (1MHz – 10 MHz), is an ideal technique to delineate and map the aforementioned targets. The method has clearly shown the potential to provide needed information on variations in subsurface saturation due to local storage tanks and perched water zones, as well as mapping geological structures related to the subsurface hydrological properties and heterogeneity within the vadose zone.

Although it exhibits certain advantages over other EM methods, the impedance method comes with a set of assumptions and practices that can limit its potential. The first is the desire to locate receivers in the far-field of the transmitter which allows the use of magnetotelluric (MT) inversion codes to interpret the data. Unfortunately, one does not precisely know when one is in the far-field of the transmitter, because this depends on the geology we wish to image. The second limiting factor is the scarcity of complete 2D and 3D inversion schemes necessary to properly invert the data. While approximate 2D schemes are now emerging, rigorous 2D and 3D inversion codes are needed to bound the range of applicability of the approximate methods. We propose to address these problems in the following manner: (1) implement full non-linear 2D/3D inverse solutions that incorporate source coordinates and polarization characteristics, (2) use these solutions to study improvements in image resolution that can be obtained by making measurements in the near- and mid-field regimes using multiple source fields, (3) collect data at the Hanford Reservation with recently developed earth impedance measurement systems, and (4) interpret the field data with the newly developed inversion capability, as well as with additional and independent information such as well logs from boreholes. The benefit of this research to the DOE would be a combined measurement/interpretation package for non-invasive, high-resolution characterization of larger transport pathways, certain types of contamination, and heterogeneity within the vadose zone at the Hanford reservation, as well as other DOE facilities.

RESEARCH PROGRESS AND IMPLICATIONS

As of June 15, 2001, this report summarizes work for the last twelve months of the project. The project received initial funding in September of 1999. Over this period a prototype 3D inversion code has been developed for impedance data that incorporates source characteristics and coordinates. It has undergone testing and development, which indicated that is was not of sufficient accuracy to invert impedance data with confidence. The cause of the problem has been traced to the algorithm, which computes the predicted data values. A remedy to the problem has now been found. A new algorithm is now under development, which is reformulated using a scattered-field solution approach. Here the background fields, used to source the impedance fields, are given by a layered half space medium.

Analysis has started on an impedance data set, acquired by Electromagnetic Instruments incorporated (EMI) using the IMAGEM impedance field measurement system at the Hanford Reservation clastic dike site (see figure below). This site was selected because the dikes act as a conduit for the transport of fluids, and exhibit a significant contrast is electrical conductivity, compared to the surrounding geological formations. These data were first analyzed using 2D magnetotelluric inversion algorithms, where a compost 3D earth model was constructed from the 2D earth models along the different data profiles. Analysis of the data also clearly indicated that source effects are clearly present in the data. We next used the 3D model of the clastic dike site and computed impedance responses, which included the source effects. The point was to compare the predicted impedances with the observations, to 1) see is we could accurately model the source effects and 2) proceed to full 3D inversion of the data set, which considers source characteristics. Results on this analysis indicated that the algorithm used to compute predicted impedance data values did not have the required accuracy to proceed to inversion of the data. This lead to the development of the new algorithm described above.

PLANNED ACTIVITES

Because of the lack of a robust inversion code needed to analyze the data already acquired at Hanford, we have decided to delay the surveys for new data sets until a more robust algorithm has been implemented. This implementation is now underway, and should be finished in the next 6 weeks. At this point we have also decided to concentrate our efforts on the IMAGEM system and data and no longer proceed with acquiring and interpreting data using the EMI ZHF system. This latter system acquires data in the 10 MHz to 100 kHz frequency range, while the IMAGEM system is designed for data acquisition below 70 kHz. Our motivation is to better focus our efforts on the data already acquired and use our experience with the IMOGEM system in the acquisition of new data sets. After the development of the new inversion algorithm, plans call for the clastic dike data set to be reanalyzed in the next three months. In the fall, a new impedance survey at Hanford will be then carried out. The proposed second site is a buried waste site, where we anticipate a significant electrical contrast between the waste and host formation. The goal of the survey is to map the base of the waste pit and to determine if contaminants are leaking into the lower geological horizons via transport pathways.

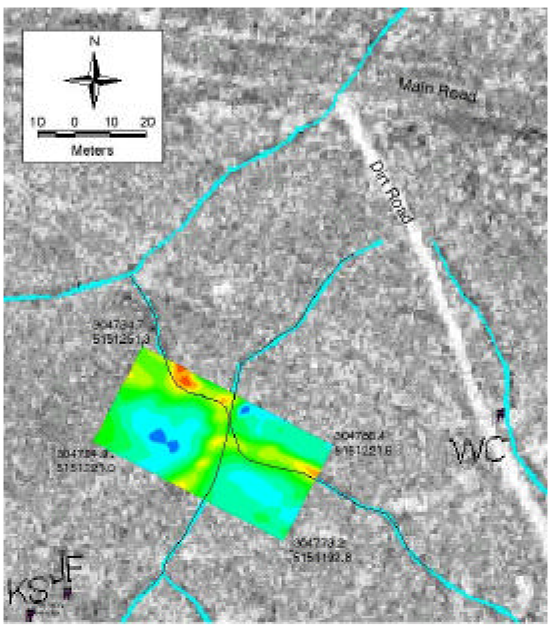

Figure shows survey data collected by the IMOGEM impedance system acquired over the clastic dike site at the Hanford Reservation. The data consist of apparent resistivity at 66 kHz The dikes are clearly indicated by the yellow bands in the figure. The measurement site is 60 x 30 m, where data were acquired at 3 m intervals along multiple profiles.