High Resolution Seismic Profile in Permafrost, at the Mallik Scientific Wellbore, MacKenzie Delta, NWT

Douglas R. Schmitt, Marek Welz, and C. Dean Rokosh, Institute for Geophysical Research, University of Alberta, Edmonton.

Introduction

The JAPEX/JNOC/GSC et al. Mallik 3L-38, 4L-38, and 5L-38 scientific wells were drilled in the MacKenzie Delta, NWT (69°27'39.30"N, 134°39'38.90"W) in early 2002 primarily for carrying out initial tests of the feasibility of producing methane gas from the large gas hydrate deposits there[1]. Briefly, gas hydrates are an interesting 'ice' like material in which CH_4 molecules are trapped in a framework of bonded H_2O; it is produced and stable under a certain range of pressures and temperatures. Such material forms in the pore space of rock when these conditions are encountered. While there is disagreement as to the extent of this producible potential of this CH_4 resource, Research projects included nearly continuous coring, cross-well tomography, vertical seismic profiling, and mud and geophysical logging beneath the ice bonded permafrost zone in the main well 5L-38; an overview of this project may be found in Dallimore et al. (2005). As part of this study, a high resolution seismic profile and a pseudo-3D single fold seismic volume were acquired over Mallik 5L-38. Here, we provide details on the acquisition program, present the results of the 2D field profile, and discuss the potential implications of these observations for the structure of the permafrost. The permafrost has gained substantial interest both from both purely scientific points of view as an analog to geologic development on other planets and from engineering perspectives in that it can be hazardous to drill through. Indeed, although a sizeable fraction of the earth's surface is covered with permafrost, there remains much to be understood with regards to its structure.

Geology and Prior Work at the Site

Broadly, the scientific wells overlie a large anticlinal feature consisting of sand-dominated Tertiary strata representative of northward- or northeastward-progradingdeltaic facies. Quartenary deltaic deposits are above recent glacial and fluvial deposits to depths above 100 m. Below this, log and core examinations have identified three Tertiary sequences: the Iperk, the Mackenzie Bay (top at ~ 350 m), and the Kugmallit (top at ~900 m). In the nearby well 2L-38, gas hydrates were found in 4 layers with maximum thicknessess of 35 m between 810 m and 1102 m depth. The permafrost zone extends to approximately 640 m depth but no open hole logs were obtained in this section.

A number of seismic studies have been carried out in this location. Collett et al. (1999) interpret earlier exploration data that show the Mallik site to lie immediately above a large anticlinal structure at greater depth; methane escaping from this structure likely provided the gas that migrated to become trapped in hydrate. In 1999, Miller et al. (2003, 2005) acquired two orthogonal high resolution lines near the site (Figure 1) using a 6000-lb force high frequency vibrator and a 96-channel acuisition system. These authors observed high-amplitude but laterally discontinuous reflections within the gas hydrate zone. They interpreted this character to be related to variations in gas hydrate concentration or changes in clay content rather than to rock types.

Permafrost zones have long been problematic in seismic imaging due to the lateral heterogeneities and the unusually high velocities of the ice bonded materials (up to 4000 m/s). Seismic wellbore tests (Milkereit et al., 2005) yield VSP interval velocities between 2400 m/s and 3400 m/s from 250 m to 600 m depth. The general

[1] See http://gashydrate.nrcan.gc.ca/mallik2002/ for more information

velocities drop to as low as 2000 m/s below this zone. As noted, no open hole geophysical logs are available within the permafrost zone for more detailed comparison of the velocity structure.

Acquisition and Processing

The seismic data were acquired using the University of Alberta 240 channel Geode® semi-distributed system with 14-Hz Oyo® vertical geophone singles at a 4-m spacing. The geophones were planted into small holes drilled into the surface ice. A truck mounted, 6000-lb force IVI Minivibe (Figure 2) was used as the seismic source with a 7 second linear sweep from 12 Hz to 180 Hz., shaking was only allowed on the ice road (Figure 1) leading into the camp and directly towards well 5L-38. Environmental restrictions also limited deployment of the geophones to a T-array consisting of 192 crossline and 48 inline receivers; this arrangement provided both a short high resolution 2D profile and a pseudo-3D data volume over the well.

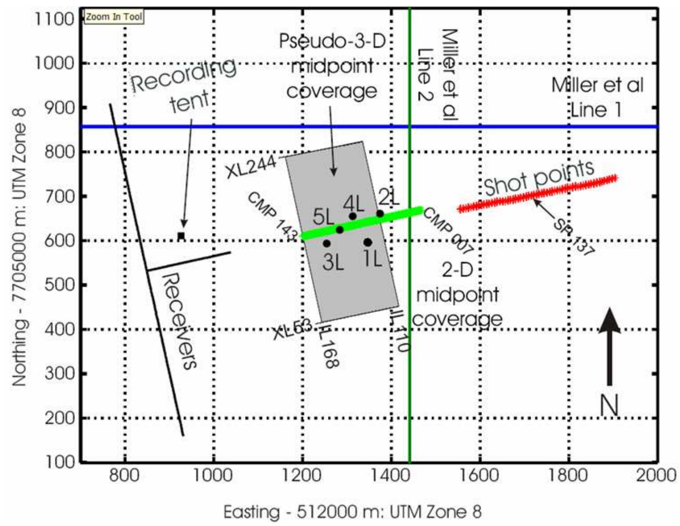

Fig. 1. Map of site. Red and green lines are the shot point and 2D profile CMP coverage, respectively. 'T-array' and recording tent locations to the left. Grey rectangle is the coverage of the pseudo-3D single fold data volume. Locations of the 1999 Miller et al. lines also shown.

A number of problems were encountered in the processing of these data. Noise sources included 1) the high velocity direct waves and surface waves, 2) coherent rig noise, and 3) wind noise. A standard processing routine was employed that used stacking velocities derived directly from the VSP observations and a number of coherent filtering techniques to reduce noise. Despite this, good coupling with the ice surface was achieved at nearly all shot points with constant force levels out to the maximum frequency observed. Fourier transforms of the traces show that these higher frequencies were transmistted to the receivers even with maximum offsets up to 1 km. Additional details of the processing of these data may be found in Schmitt et al., 2005.

Fig. 2. Photograph of U of Alberta IVI Minivibe unit on ice road at site, February, 2002.

Results and Discussion

The resulting seismic section is diplayed in both variable area wiggle and color raster plots in Figure 3 with a 250 ms AGC applied. Time to depth estimates place the bottom of the permafrost at ~470 ms two-way time. The perpendicular location to well 5L-38 is shown also.

An interesting observation in Figure 3 is the lateral seismic amplitude variations along a given horizon. These bright spots appear at all times in the section. Some examples of these zones include one at 300 m to the left of the centre of the image, and another at 550 ms immediately to the left of the Mallik 5L-38 well.

While at this time the origin of the bright spots is not known and is made more difficult by the lack of geophysical logs through such a formation, it is interesting to speculate on what produces them (Schmitt et al., 2005). Permafrost is not simply rock and soil with ice in the pore spaces. There are also 'unfrozen water' zones consisting of brines that have been progressively concentrated as dissolved solids leave the ice matrix during the freezing process. In the current context, there appear additionally to be zones of free gas that have been detected in the mud logs and via surface locations where open water exists year round due to the natural release of methane. The point is that for a given rock type such as a porous and weakly consolidated sand, there will be changes in the compressional wave velocity in such materials that can be on the factor of 2 as one goes from ice to water to gas saturation. As such, small variations in saturation in the materials provide opportunity for large impedance contrasts and changes in seismic reflectivity. Future work will examine modeling of the subresolution structures under different saturation conditions. Future work may also include a more in depth study of the permafrost by scientific drilling.

Acknowledgements
This work could not have occurred without the assistance in field deployment of M. Lazorek and L. Tober, and infrastructural assistance at the field site by M. Riedel. Additional field assistance was provided by D. Bannerjee, B. Milkereit, E. Adam, G. Pratt, and K. Bauer. The support of the staff both at the Mallik drill site and in Inuvik was also critical to the success of the project. The authors acknowledge the international partnership that undertook the Mallik 2002 Gas Hydrate Production Research Well Program: Geological Survey of Canada (GSC), Japan National Oil Corporation (JNOC), GeoForschungsZentrum Potsdam (GFZ), United States Geological Survey (USGS), India Ministry of Petroleum and Natural Gas (MOPNG), BP-ChevronTexaco-Burlington joint venture parties, and United States Department of Energy (USDOE). The program received financial support from the International Continental Scientific Drilling Program (ICDP). The authors also acknowledge Seismic Image Software Ltd. for access to the Vista™ seismic-data-processing program. This work was primarily funded by the senior author's NSERC discovery grant and the Canada Research Chairs program.

References

Baltimore, S.R., Collett, T.S., Uchida, T., and Weber, M., 2005, Overview of the science program for the Mallik 2002 Gas Hydrate Production Research Well Program; *in* Scientific Results from Mallik 2002 Gas Hydrate Production Research Well Program, Mackenzie Delta, Northwest Territories, Canada, (ed.) S.R. Dallimore and T.S. Collett; Geological Survey of Canada, Bulletin 585, in press.

Miller, R.D., Hunter, J.A., Doll, W.E., Carr, B.J., Good, R.L., Burns, R.A., Laflen, D.R., and Douma, M. 2003: High-resolution seismic imaging of the hydrate stability zone: Mallik, Canada (poster at the AAPG, Annual Meeting, May 2003, Salt Lake City, Utah); United States Geological Survey, Open File Report 2003-36.

Milkereit, B., Adam, A., Li, Z., Qian, W., Bohlen, T., Banerjee, D., and Schmitt, D.R., 2005, Multi-offset vertical seismic profiling: an experiment to assess petrophysical-scale parameters at the JAPEX/JNOC/GSC et al. Mallik 5L-38 gas hydrate production research well; *in* Scientific Results from Mallik 2002 Gas Hydrate Production Research Well Program, Mackenzie Delta, Northwest Territories, Canada, (ed.) S.R. Dallimore and T.S. Collett; Geological Survey of Canada, Bulletin 585, in press.

Schmitt, D.R., M. Welz, and C.D. Rokosh, 2005**,** High-resolution seismic imaging over thick permafrost at the 2002 Mallik drill site, *ibid.*

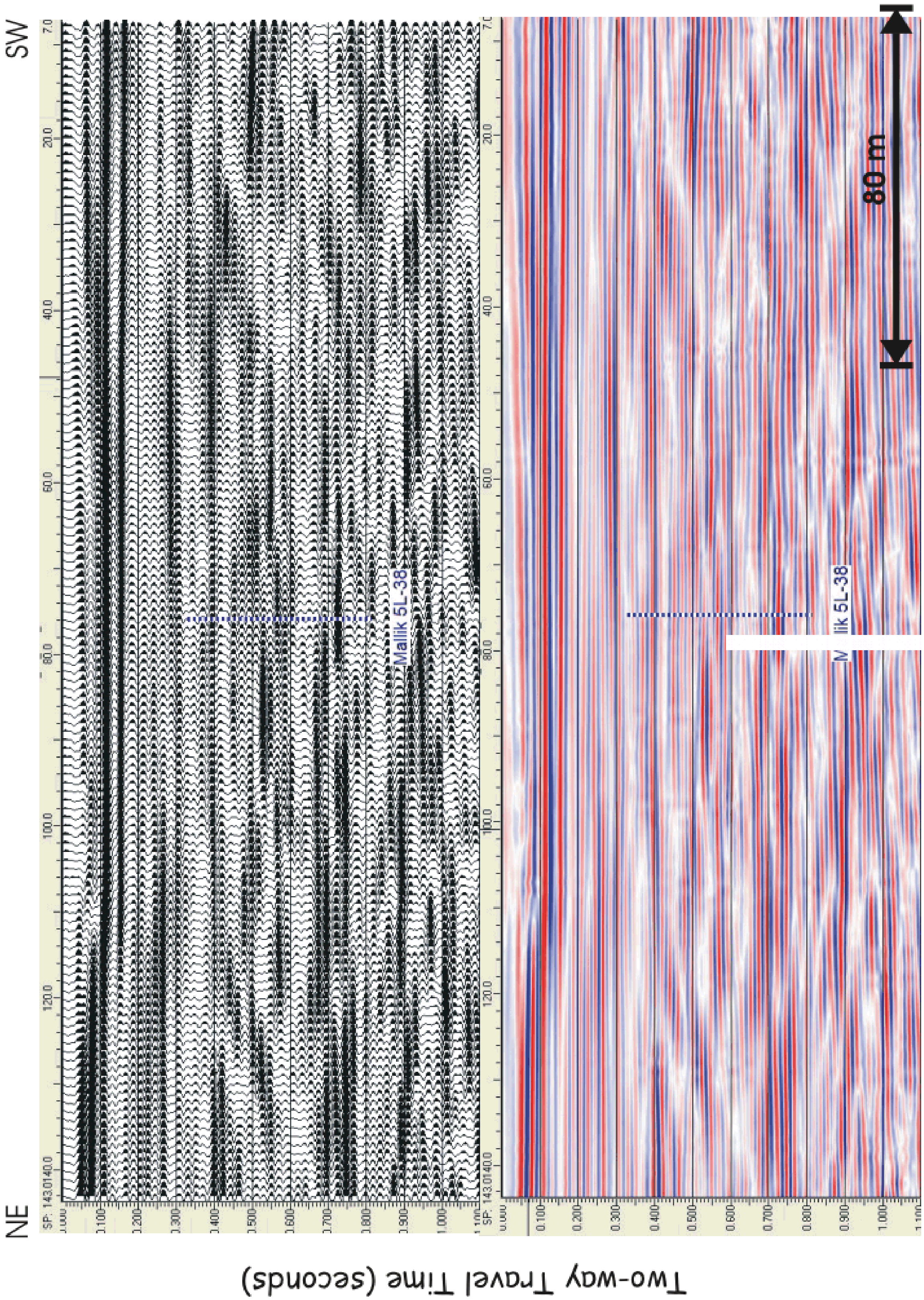

Figure 3. Images of high resolution seismic profile in variable density and color raster images. Note location of the open-hole logged sections of the Mallik 5L-38 well below 600 m depth. Red and blue colors represent positive and negative polarities, respectively.