Geomapping for Energy and Minerals (GEM): New Teleseismic and Magnetotelluric Arrays in Alberta

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Summary

The GEM focus in Alberta is on the 'diamond fairway' a broad region between the kimberlite fields of Buffalo Head Hills, Alberta and Fort A la Corne, Saskatchewan. Regional geophysical studies of the crust and mantle structure in the region provide important clues on the Early Proterozoic tectonic assembly of western Laurentia, the nature and vertical extent of the controversial boundaries between previously inferred basement domains, as well as information on more recent interactions between the North American craton and the Cordilleran orogen. Teleseismic and magnetotelluric arrays involving the University of Alberta, the Geological Survey of Canada (GSC) and Alberta Geological Survey (AGS) have acquired new sets of data on the upper mantle and crust in southern and central Alberta to examine possible diamond source regions and structural controls on kimberlite emplacement. The results of the project contribute to the broad goal of the Northern Diamond project to map and understand the lithosphere of the Canadian Shield and potentially provide local exploration guidance. In addition, work in this project assists with training of highly qualified geophysics personnel.

Introduction

Evidence from regional magnetic, electromagnetic, gravity and seismic surveys (e.g., Ross, 2000; Eaton et al., 1999; Van der Lee and Frederiksen, 2004; Marone and Romanowicz, 2007) suggests that the Alberta crust in the investigated region consists of various crustal domains (e.g., Buffalo Head, Wabamum, Thorsby, Lacombe, Hearne), as well as major mantle seismic velocity gradients, shear wave and conductivity structure anisotropy. The nature of the boundaries between the basement domains and their vertical extents remained however controversial, due to the lack of exposed geology and limited seismic and electromagnetic (magnetotelluric, MT) receiver coverage. Seismic and MT imaging methods have the potential of addressing these issues and could delineate large structures such as subduction related mantle layering, possibly indicative of diamond reservoirs or transition zones from very old, stable lithosphere into the tectonically active southern Cordillera. University of Alberta faculty and research assistants, with financial, logistical and scientific support from the GSC and AGS have started to develop 3D seismic and MT grids for an unprecedented coverage of the crust and mantle beneath Alberta.

Beginning in late 2005, the first broadband seismic array named Canadian Rockies and Alberta Network (CRANE) took a major step forward in improving the 3D seismic data coverage in central and southern Alberta. This array now consists of 11 broadband stations (13 sites in total) that, in addition to providing nearly uniform coverage, enable a detailed examination of seismic structures down to great depths. During the past 2+ years, CRANE stations successfully recorded continuous earthquake records from more than 300 earthquakes with M > 5.5, as well as numerous low-magnitude events (or microseismicity) in and around central Alberta. As part of GEM, a number of teleseismic sub-projects investigate the regional seismic source, crust/mantle seismic structure and mantle flow beneath Alberta.

Previous long period MT measurements were made during the 1990's at a number of locations in the province as part of the Lithoprobe Alberta Basement Transect project and through ongoing research at the University of Alberta. The data sets were used for 2D data analysis and showed that in some areas the conductivity structure beneath Alberta was anisotropic. Previous long period MT studies in northern Alberta have mapped the depth to the lithosphere – asthenosphere boundary (LAB) below Alberta (e.g., Turkoglu et al., 2009). This project attempts to fully define the 3D structure of the crust and upper mantle beneath Alberta. Recent work under GEM benefits from and contributes to the ongoing regional electromagnetic (EMSCOPE) studies across the border in the United States which are part of the Earthscope initiative.

Data and Methods

Teleseismic imaging of the crust and upper mantle is based on continuous earthquake and micro-seismicity records. MT imaging uses natural radio waves to image the rock properties from the surface to a depth of more than 300 km.

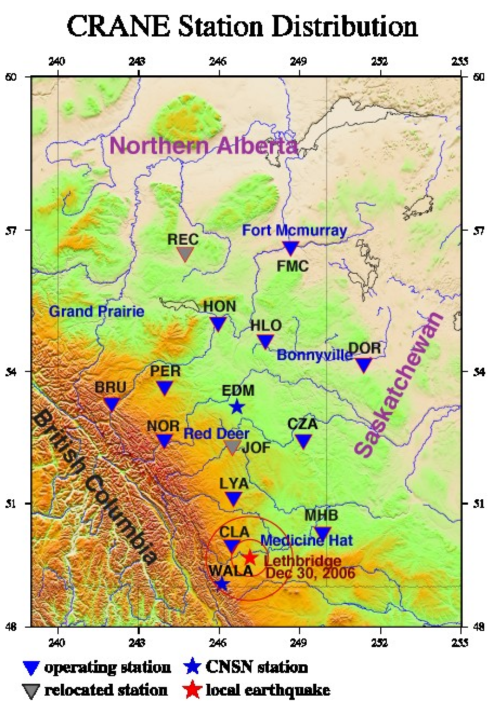

Figure 1: Distribution of CRANE and nearby CNSN stations. Two of the CRANE stations (shown in gray) have been relocated. The red circles mark the wavefield generated by a recorded Mb=3.5 local earthquake.

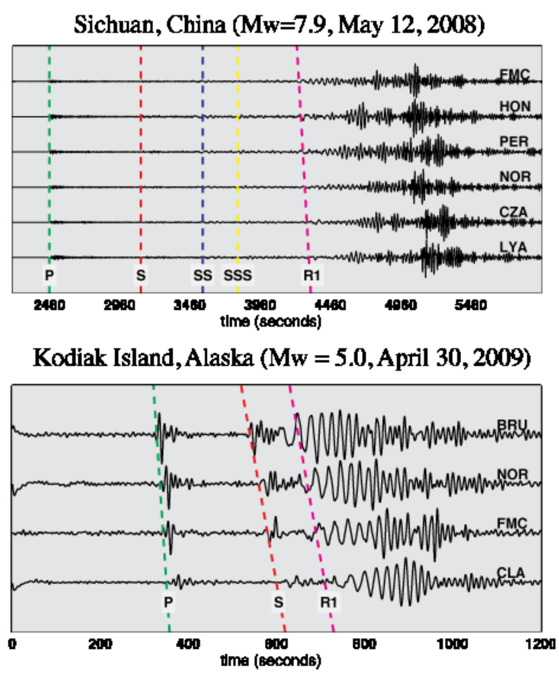

Figure 2: Vertical-component waveforms at selected CRANE stations. The predicted arrival times and phase names are as indicated. Data from the Alaska event have been band-pass filtered to the frequency range of 0.03-0.06 Hz (after Gu et al., 2010)

Results of regional shear wave splitting measurements suggest a significant east-west change of mantle flow pattern, consistent with present-day plate motion and the dynamic effect associated with a migrating continental root east of the province. Novel approaches have also been developed and benchmarked for 3-D seismic tomographic inversions and receiver function migration. More than 4000 travel time measurements from M>5.5 teleseismic events enable 3D inversions for P wave models with a lateral resolution of 40 km and a vertical resolution of 25-40 km (Shen et al., 2010). In southern Alberta, a high velocity anomaly is identified near the foothills of the Canadian Rockies down to 50 km depth, potentially extending eastwards and approximately coinciding with the controversial Vulcan structure. In central Alberta, our model shows interweaving low and high crustal velocities at the depth corresponding to the crust/shallow mantle interface and underscores a complex (and likely reworked) crust beneath Alberta. The northeastern part of the station array (at latitudes higher than 55°N) appears to be underlain by relatively uniform, fast P velocities in the top 40 km. Though preliminary, these results and the inferred reflectivity structures based on receiver functions may have significant implications for the understanding of ground motion, tectonic history and mantle dynamics beneath central and southern Alberta.

During 2008 and 2009, long-period MT data from forty MT sites were collected on a grid throughout southern Alberta, filling in gaps between the Lithoprobe MT profiles with a twofold objective: a) to improve knowledge of the conductivity structure of the crystalline Precambrian basement, and b) to map the depth of the lithosphere – asthenosphere boundary (LAB) beneath Alberta. Deployments of 15 stations at a time, each lasting a month, resulted in a new, relatively dense grid that has allowed 3D modelling of long period MT data without spatial aliasing. Preliminary results from the 3D modeling have confirmed the presence of the Red Deer Conductor (RDC) originally identified on the Lithoprobe transect in the northern portion of our grid. Our new data suggest that the RDC is a shallow basement conductor and that its continuation to the south west across southern Alberta differs substantially from the previously speculated location (Boerner et al, 1995) . This preliminary 3D model has also defined a much deeper (ca. 40 km depth) conductor, which appears to coincide with RDC in the northern part of the grid but deviates greatly southward to partly overlap the north-central part of the Vulcan structure. Our preliminary 3D model suggests a LAB in the depth range of 200 to 250 km.

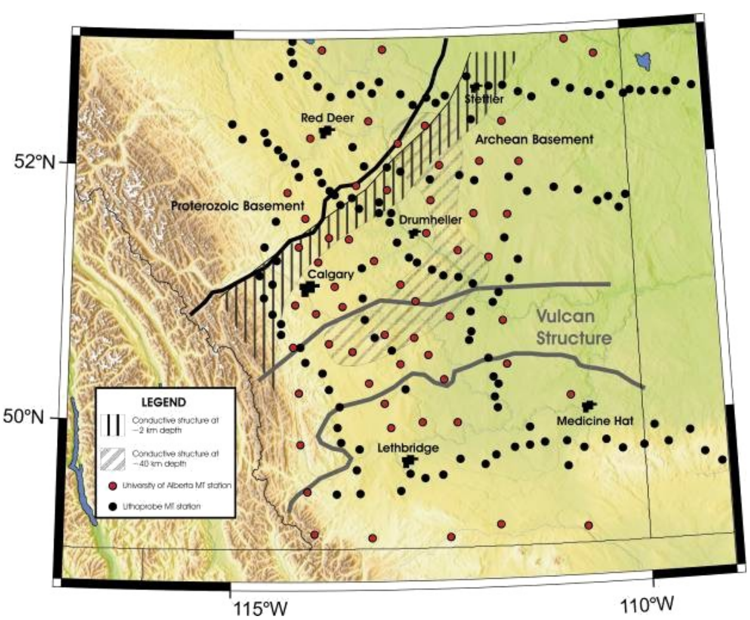

Figure 3: Map of MT stations in Southern Alberta with prominent conductivity structures defined by preliminary 3D modelling. The dark black line represents the boundary between the Proterozoic Lacombe domain, and the Archean Hearne Province. The grey lines show the boundaries of the Vulcan structure (after Nieuwenhuis et al, 2010)

Work plans under GEM for the coming year include the continuation of the ca. 30 km spacing grid to the north, in Central Alberta, to cover conductivity anomalies associated with the Snowbird Tectonic Zone.

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