SEISMIC EXPLORATION OF THE MANITOUWADGE GREENSTONE BELT, ONTARIO

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ABSTRACT

High resolution seismic data acquired in 1995 in the Manitouwadge greenstone belt in Northern Ontario have provided detailed information on the extent and structure of key horizons defining the Manitouwadge synform. This unusually high quality seismic data from the Canadian Shield, extends geological models of the Manitouwadge synform and identifies potentially important marker horizons. As predicted from rock property studies, the contact of the Inner Volcanic Belt with overlying plutonic rocks is a strong reflector indicating that this structurally important horizon can be further mapped with future seismic studies.

INTRODUCTION

The Geological Survey of Canada, in collaboration with Noranda Mining and Exploration and the Ontario Geological Survey, has undertaken an integrated study of the Manitouwadge greenstone belt (MGB). The objectives of this program are to advance our understanding of the deep geology of the MGB and to establish a case history to foster the technology transfer of seismic methods for mineral exploration. Since 1995, three seismic profiles have been acquired in the Manitouwadge synform, one of which (Line 1) will be reported on here (Figure 1). A number of factors in the MGB make it a favourable environment for seismic techniques aimed at regional reconnaissance and direct detection of massive sulphide bodies. The belt is host to major volcanogenic Cu-Zn deposits, including Noranda's Geco mine, which had a total lifetime production of nearly 60 million tonnes. All the known economic deposits were found in the 1950s, on the basis of surface exposures and geophysical anomalies from near-surface sources. Within the Manitouwadge synform, drilling data suggest that the favourable horizon for mineralization lies at depths feasible for present-day mining methods, but out of reach of conventional geophysical methods.

The multiphase seismic exploration program included: subsurface projection of mapped surface geology, comprehensive physical rock property studies, forward modelling, design of an appropriate seismic survey to image structures and contacts at depth, acquisition of high frequency seismic profiles across the MGB, and integration of seismic with drill hole and geological data. Interpreted results indicate seismic methods are a valuable tool for mineral exploration in the Manitouwadge area.

GEOLOGICAL SETTING

The MGB is a highly deformed remnant of upper amphibolite facies supracrustal rocks in the volcano-plutonic Wawa subprovince of the Archean Superior Province, immediately south of the major tectonic boundary with the metasedimentary-migmatitic Quetico subprovince (Figure 1, inset). The granulite-facies orthopyroxene isograd lies immediately to the north of the subprovince boundary. The MGB comprises a single mafic-to-felsic volcanic succession of 2720 Ma, that includes a large synvolcanic trondhjemite body inside the Manitouwadge synform (Zaleski and Peterson, 1995a,b) (Figure 1). Felsic volcanic rocks are intercalated with iron formation and associated volcanogenic massive sulphide deposits. The volcanic rocks are stratigraphically overlain by greywackes which lie in an early fold (Agam Lake syncline) along the southern limb of the Manitouwadge synform.

Within the Manitouwadge synform there are two additional zones of mafic rocks known as the Dead Lake suite, comprising an enigmatic package of interleaved foliated gabbro, diorite, and layered mafic to intermediate rocks of probable supracrustal origin, as well as magnetite-garnet-rich rocks (Zaleski *et al.*, 1996).

Volcanic rocks of the MGB have undergone high-grade metamorphism and four phases of ductile deformation, including the D3 Manitouwadge synform which forms the major regional fold (Zaleski and Peterson, 1995a). Plutonic and sedimentary rocks experienced some or most of the same tectono-metamorphic history. Metamorphic grade increases toward the north such that the Manitouwadge metagreywackes have sillimanite-biotite-garnet assemblages characteristic of

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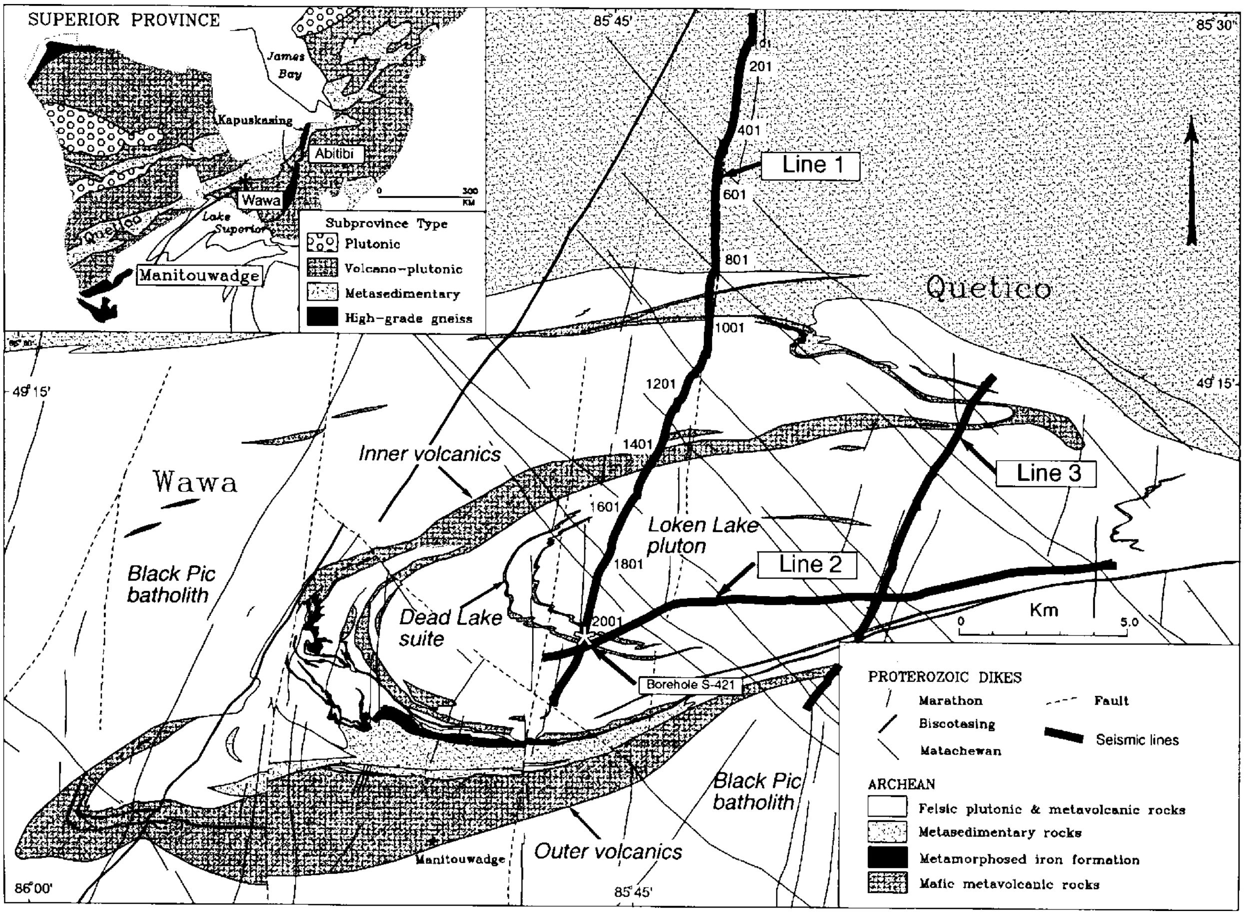

Figure 1: *Geological map of the MGB and Wawa-Quetico boundary (modified from Zaleski et al., 1997).*

upper amphibolite facies, without evidence of melting, whereas the Quetico metagreywackes are migmatitic. The MGB is enclosed by foliated multiphase dioritic to granitic rocks of the Black Pic batholith. The related Loken Lake pluton is outlined by the Dead Lake suite in the core of the Manitouwadge synform. The regional structure of the MGB and the Black Pic batholith is dominated by shallow easterly plunging D3 folds, with axial surfaces that dip moderately to the south. Toward the north, the structural grain is progressively tightened and transposed into steeply dipping east-west trends typical of the Wawa-Quetico boundary and the Quetico subprovince.

PHYSICAL ROCK PROPERTIES

Laboratory measurements of compressional wave velocity (Vp) and density were made at elevated pressures on a representative suite of ore and host rock samples in order to determine the impedance contrasts and estimated reflection coefficients at contacts between known lithologies. Velocity and density logs were obtained in two deep drill holes to compare impedances measured in the lab with *in situ* observations at map-scale. Synthetic seismic reflection models, based on the lab measurements, logging results and subsurface projections of the known geology, were then used to aid geological interpretation of the seismic sections. Since reflection coefficients of .06 and greater should generate strong reflections (e.g., Salisbury *et al.*, 1996), the physical rock property studies indicate that the MGB should be very reflective. With the exception of contacts between mafic units and iron formation or Fe-rich Dead Lake Suite rocks (reflection coefficient of .02) the major lithologies present in the MGB generate reflection coefficients of .06 or greater. Mafic-felsic contacts should be marked by strong semi-continuous reflections, making the Geco mine camp and Manitouwadge synform a good location for seismic mapping of stratigraphy and structure at depth. Significant concentrations of massive sulphides may appear as bright spots along mafic-felsic contacts, but they are equally likely to be masked by interference effects.

FORWARD MODELLING

For the purposes of modelling, the MGB was represented as three layers, essentially comprising: 1) the Black Pic batholith and plutonic rocks inside the Manitouwadge synform (Loken Lake pluton), 2) dominantly mafic volcanic rocks (inner and outer volcanic contacts on Figure 2) and 3) greywacke (including tonalite and felsic volcanic rocks without inter-

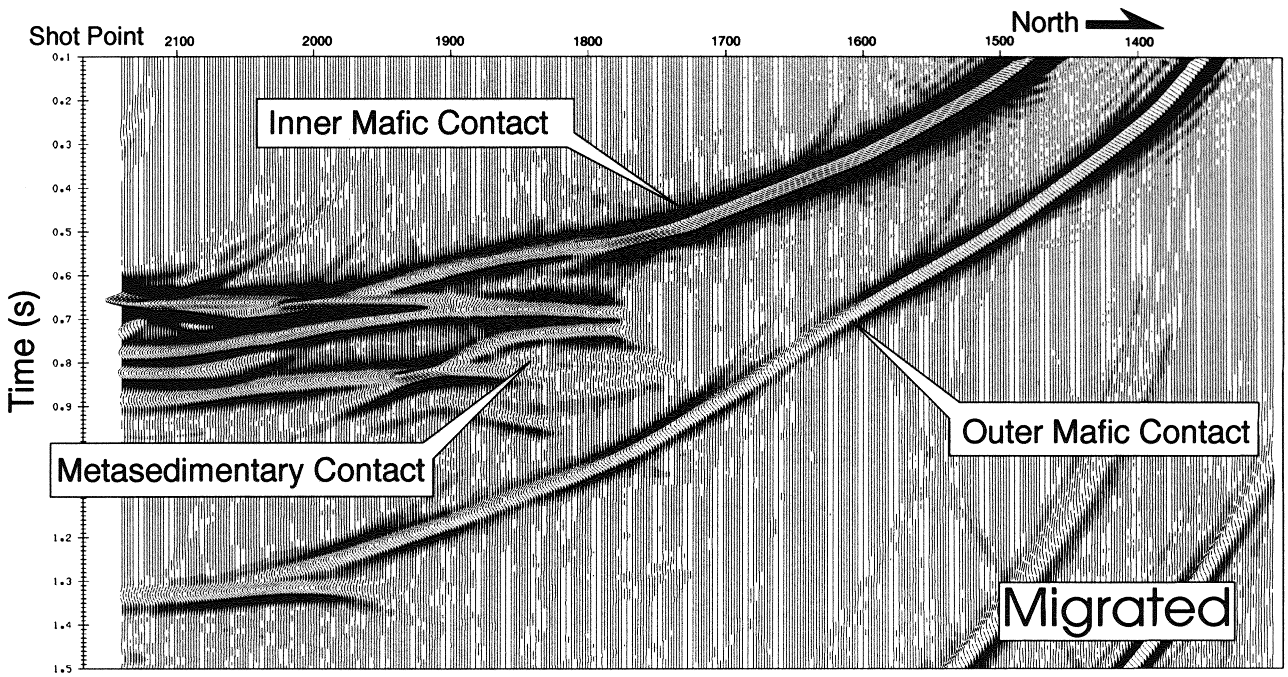

Figure 2: *Synthetic seismic section for the Manitouwadge synform (1:1 @ 6.0 km/s).*

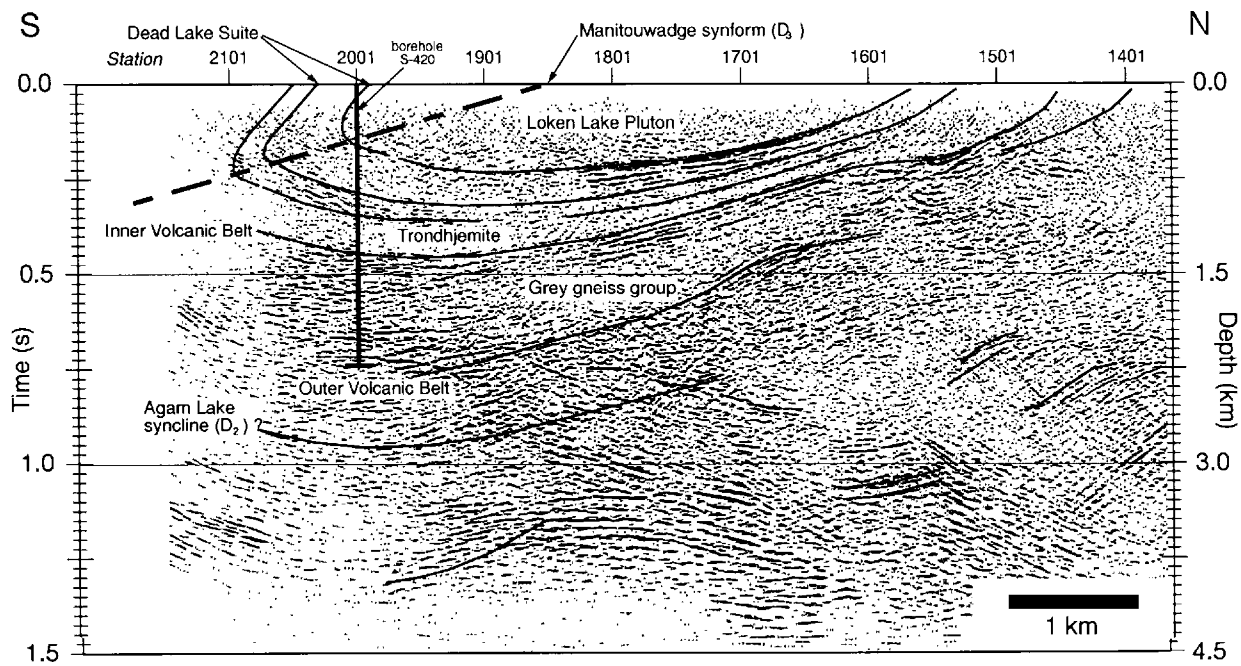

Figure 3: *South end of Line 1 over the Manitouwadge synform. The section is migrated and some interpreted horizons are indicated.*

layered iron formation). A 2-D seismic model was generated for the southern part of Line 1 using a Born scattering algorithm (Eaton, 1996) (Figure 2). The synthetic model shows that the inner mafic contact should appear as a gently dipping synformal reflection that surfaces near station 1450. The utility of the synthetic section is mainly in constraining the interpretation of the observed data rather than in attempting to reproduce it.

SEISMIC DATA ACQUISITION AND INTERPRETATION

High resolution surface seismic data have been acquired along three transects in the Manitouwadge synform (Figure 1). Line 1 crosses the Manitouwadge synform and the Wawa-Quetico subprovince boundary, and was acquired in 1995. Lines 2 and 3 were acquired in the fall of 1996 and are presently undergoing processing and interpretation. Three seconds of data were recorded along Line 1 using a sample rate of 1 ms and a 480-channel receiver spread with a 10-m spacing between geophone groups. The source used was a dynamite charge (.34 kg) in drilled shotholes with a shotpoint interval of 40 m. The processing of line 1 followed a conventional sequence with special attention given to some key steps which are critical to producing a high quality stack section in crystalline rocks. The key processing steps were: 1) refraction statics, 2) spectral balancing, 3) front mute, 4) dip moveout correction (DMO), and 5) migration.

The shallow levels of the Manitouwadge synform are clearly imaged by the seismic data (Figure 3) and confirm this part of the geological model. Reflections from the Dead Lake suite define the gently dipping northern limb of the synform. The high amplitude reflections and lateral extent of the Dead Lake suite make it a seismic marker throughout the Manitouwadge synform. Beneath the Dead Lake suite, a gently dipping reflective package projects to surface exposures of mafic rocks on the northern limb of the Manitouwadge synform. From drill hole data we interpret the top of this package as the contact between the trondhjemite and the inner volcanic belt, labelled on the synthetic section as the Inner Mafic Contact (Figure 2). The known massive sulphide deposits lie in volcanic rocks below this contact. The lower limit of the reflective package is not clearly defined, likely due to complex geology and interference from off-line reflections. There is much detail in this high quality section, including many reflections which may originate from subvertical diabase dykes crossing or subparallel to line 1 (Zaleski *et al.,* 1997).

CONCLUSIONS

Integrated studies in the MGB have shown that high resolution seismic reflection data, constrained by physical rock property, modelling, and geological analysis, can substantially increase our understanding of the MGB and its potential for hosting massive sulphides. Further seismic work to image prospective targets is warranted and highly recommended. To better image the detailed structures and remove ambiguity over the true orientation of reflectors, 3-D seismic methods should be considered at Manitouwadge.

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