SEISMIC METHODS IN
MINERAL EXPLORATION

PAPER 59

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SEISMIC REFLECTION IMAGING OF A SHALLOW, FAULT-CONTROLLED VMS DEPOSIT IN THE MATAGAMI MINING CAMP, QUÉBEC

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ABSTRACT

A 2-D seismic reflection profile was shot across the southern flank of the Matagami mining camp, and directly above the recently discovered Bell Allard VMS deposit, now estimated at over 6 Mtonnes. The survey images high amplitude reflections from the gabbro sills that intrude much of the volcanic stratigraphy, which is generally characterised by weaker reflections. A strong reflection from the top of the ore body is clearly visible in a seismic section processed to preserve relative amplitude information, but the reflection does not extend over the full width of the deposit as defined by drilling.

Faulting can be interpreted from discontinuities in the observed reflections, and appears to have controlled the formation of the Bell Allard deposit. If the interpreted gabbro sills are accepted as iso-time markers, then faulting of the deeper sill complex defines a series of half-grabens within the rhyolitic Watson Lake group. The Bell Allard deposit is found at the intersection of one of these apparently low-angle normal faults with the top of the Watson Lake Group, indicating that sulphide mineralisation may have been associated with fluid flow along the fault which likely penetrates to the underlying mafic intrusion. Although the precise geometry of subsurface faulting cannot be estimated from a single 2-D seismic profile, these results indicate that a full 3-D seismic survey should allow the mapping of many of the subsurface fault systems, and the verification of hypotheses of fault controlled deposit formation.

INTRODUCTION

Many volcanogenic massive sulphide (VMS) deposits have been identified at the contacts of bimodal volcanic sequences in the Archean-age Abitibi greenstone belt of Canada. Mineral exploration in the Abitibi is at a mature stage, and many of the shallower ore bodies have been located and mined. With a great deal of exploitation infrastructure in place, it is often economic to mine deeper ore bodies if they can be found. As part of the Canadian Lithoprobe program, and in conjunction with a number of mining companies, several high resolution seismic reflection profiles have been acquired over mining camps with the objective of imaging directly the contacts between the bimodal volcanic units, the fault systems that exist, and if possible the VMS deposits themselves. Faulting can be inferred from discontinuities in, and truncations of, imaged seismic reflections, which often arise from changes in subsurface lithology. Typically, lithologic contrasts are themselves linked to changes in the composition of erupted volcanics, for example from rhyolite to basalt as is commonly found in the Abitibi bimodal suites, or to mafic sill intrusion. The changes in both density and seismic P-wave velocity can be quite abrupt, and may cause strong seismic reflections. Recent work has also shown that many sulphide ores are likely to exhibit highly anomalous physical properties, implying that VMS deposits may also be characterised by a strong response on seismic profiles (Salisbury *et al.*, 1996).

Seismic reflection profiling thus has the potential to aid mineral exploration in two ways: first, by imaging directly massive sulphide deposits; second, by defining the fault systems that can control the formation of many types of ore deposit, not only massive bodies. In 1993, Noranda and Lithoprobe collaborated to shoot an 8 km seismic profile directly above the recently discovered Bell Allard VMS deposit on the south flank the Galinée anticline at Matagami. The survey objective was to determine whether a response from the ore body could be recorded, and to define more precisely the structural interpretation of the camp by mapping known contacts between, and beyond, existing boreholes.

GEOLOGICAL SETTING

The Bell River intrusion (Freeman, 1939), which underlies the town of Matagami, is one of a number of mafic-ultramafic layered complexes found in the northernmost part of the Abitibi greenstone belt (Figure 1). Associated granophyric rocks have been dated at 2724.6 ± 2.5 Ma using U-Pb methods (Mortensen 1993). The Bell River Complex stratigraphically underlies a suite of bimodal volcanic rocks; the deepest volcanic unit, the Watson Lake Group, is largely felsic, and is overlain by the intermediate to mafic rocks of the Wabassee Group (Roberts, 1975; Beaudry and Gaucher, 1986). Rhyolites of the Watson Lake group have

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been shown to have an age similar to that of the Bell River mafic intrusion, and it has been suggested that the Bell River intrusion represents the magma chamber from which the overlying volcanic units were erupted (Sharpe, 1968; MacGeehan, 1978); however, a more complex evolution, in which the Bell River units subsequently intrude the overlying volcanics, has also been proposed (Maier *et al.*, 1996).

The Bell River Complex, together with its associated volcanics, is considered to have been folded into the Galinée anticline, whose southwestern flank dips at around 45°. On this flank, the Watson Lake group comprises a dacite unit overlain by rhyolite, and is separated from the overlying basaltic Wabassee group by a 1–3 m thick cherty, tuffaceous horizon known as the Key Tuffite (Jenney, 1961). Several VMS deposits have been located around the northwestern edge of the Bell River intrusion. Most of the deposits occur at the stratigraphic level of the Key Tuffite horizon, and indicate that formation of the ore bodies is linked to the underlying Watson Lake group. MacGeehan *et al.* (1981) and Piché *et al.* (1991) have suggested that metals may have been leached from submarine basalts, and subsequently precipitated at the overlying siliceous tuffite, with the fluid circulation driven by heat from the deeper Bell River intrusion. The Bell Allard deposit was located by drilling and borehole electromagnetic surveys; it lies at a depth of 900–1150 m beneath the main highway to the town of Matagami (Figure 1). With an estimated size of over 6,000,000 tonnes, the deposit is the largest identified on the southern flank of the Galinée anticline.

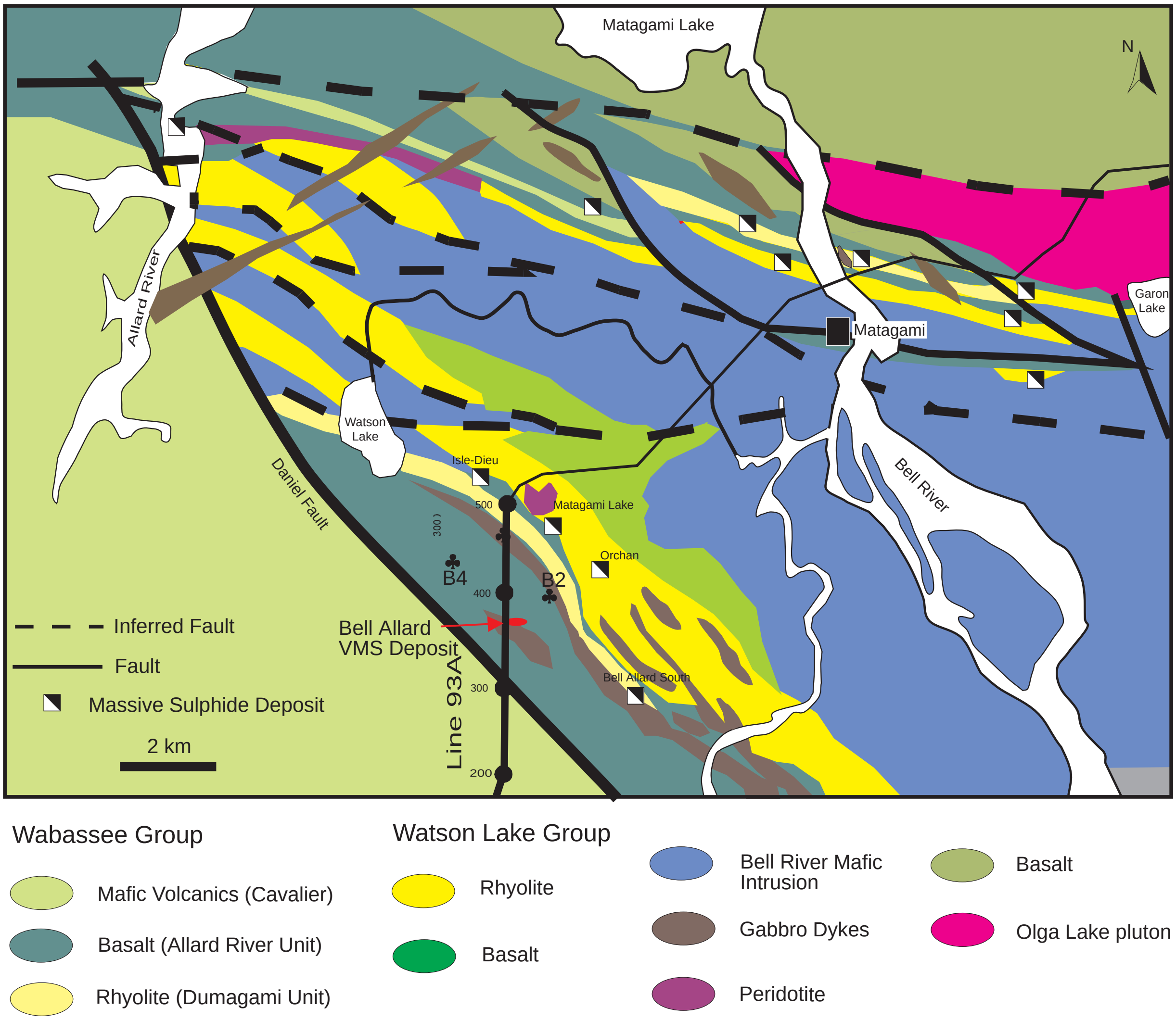

Figure 1: *Geological map of the Matagami mining camp. High resolution seismic profile 93a was shot along the north-south section of the main highway over the south flank of the Galinée anticline, which is cored by the Bell River mafic intrusion. The Bell Allard VMS deposit lies almost directly beneath the highway. Gabbro sills, which intrude the volcanic units of the Wabassee and Watson Lake Groups, are exposed across the area.*

SEISMIC REFLECTION PROFILE

Prior to the start of any mine development, an 8-km long, 120-fold Vibroseis seismic reflection profile was shot in 1993 along the highway, and above the Bell Allard deposit. The seismic line was recorded with a 240-channel telemetry acquisition system using 8 m long linear arrays of nine 30 Hz geophones deployed every 20 m. Two vibrators, each with a peak force of 22,800 kgf (50,160 lbf) were deployed in an eight sweep, 20-m source array; the vibration point spacing was 20 m. In order to obtain the greatest possible resolution, but also to eliminate interfering low frequency ground roll, a linear 30–140 Hz, 12 s long upsweep was employed. The recorded vibroseis data were correlated in the field.

First breaks were picked and a refraction statics solution derived using a generalised linear inversion approach. Although the ground roll proved to be negligible with the use of the 30–140 Hz sweep, a strong shear wave arrival was usually recorded. The shear wave was attenuated by applying a 15 trace median filter along the shear arrival in the shot domain, and then subtracting the result from the original data. Other prestack processing included zero phase spiking deconvolution, two passes of stacking velocity estimation plus surface consistent residual statics, and a 200 ms automatic gain control (AGC) trace equalisation. Because of the highly heterogeneous nature of the subsurface, reflections and diffractions with conflicting apparent dips are present on the stacked seismic section. These arrivals were imaged by applying a log-stretch dip moveout (DMO) correction in the constant offset domain, followed by a Stolt migration using a constant velocity of 6200 m/s, also in the constant offset domain. A final velocity analysis was carried out after sorting back to common midpoint (CMP) gathers in order to optimise the summation of the migrated constant offset sections (Figure 2a). The highly anomalous physical properties of massive sulphides suggests that sulphide mineral deposits may be characterised by strong reflection amplitudes, which are not preserved by the time variant AGC. Thus the processing flow was repeated with no AGC, but with a geometric spreading correction prior to deconvolution and a whole trace equalisation before DMO correction. This had the effect of preserving better the relative amplitudecharacter of the reflection data, and part of the line processed in this manner is shown in Figure 3.

GEOLOGICAL INTERPRETATION

The advantage of a straight 2-D seismic profile such as line 93a is that both in-plane and out-of-plane arrivals can be accurately imaged by prestack migration processing; however, out-of-plane reflections can only be migrated to their true subsurface position when cross-line data is available as part of a full 3-D survey. As a result, the interpretation of this 2-D seismic line is limited to some extent by the fact that many of the stronger reflections originate out of the plane of the profile. Thus, although it is possible to identify faulting from discontinuities in strong reflections packages, it should be borne in mind that the location may not be below the surface location of the seismic line.

Line 93a is characterised by two strong convergent reflective packages which have an apparent dip towards the south end of the line. Correlation of line 93a with the earlier Phase I Lithoprobe/Noranda line, 29-3, and borehole logs obtained by the GSC indicates that the upper reflective package probably corresponds to primarily gabbroic lithologies. Gabbro sills are known to occur widely within the volcanic stratigraphy of the Galinée anticline, and this is the likely origin of the strongest of these reflections. Sills usually cut through existing lithologies creating the relatively smooth, areally extensive surfaces necessary to cause strong seismic reflections. The lower reflective package has not been penetrated by drilling, and its origin is uncertain, but is also tentatively interpreted as another gabbro sill.

The strong reflections from the gabbro sills are superimposed on a weaker reflectivity attributable to the volcanic stratigraphy. The contact between the essentially basaltic Wabassee Group and the largely rhyolitic Watson Lake group is located at the Key Tuffite, the cherty exhalite horizon, at which many of the area's VMS deposits are located. The approximate location of this contact is shown by KT in Figure 2b. Subparallel overlying reflections (DR) are likely associated with the Dumagami rhyolites located within the Wabassee Group, and are truncated unconformably by the shallow gabbro sill complex. Faulting of both the gabbro sills and volcanic stratigraphy can be identified from discontinuities in the observed reflections and is represented in Figure 2b. There are at least two fault systems present: the lower is associated with faulting of the underlying Watson Lake Group and does not appear to penetrate far into the Wabassee Group. The upper faulting is largely confined to the Wabassee Group, but probably cuts some of the deeper faults; however, this is difficult to identify clearly on the seismic section as both sets of reflections originate out of the vertical plane of the profile. It is also possible to discern a concentration of faulting around SP 350 where the Bell Allard ore body is located.

The Bell Allard deposit lies between 900 and 1150 m depth, and dips to the south at around 50 degrees (Adam *et al.*, 1996), allowing it to be accurately located within the plane of the north-south seismic profile. Figure 2b indicates the short reflection segment, which is interpreted as being from the top of the Bell Allard VMS deposit because of its appropriate position and dip. However, the reported lateral extent of the deposit is actually longer than the observed reflection, and the seismic response may be attributable either to the thickest zone of mineralisation, or perhaps to the highest concentration of sulphides, issues which require further investigation. No separate reflection from the base of the deposit can be clearly identified. Figure 3 shows another reflection amplitude anomaly at the same stratigraphic level, the Key Tuffite, but of unknown origin. If the interpreted gabbro sills are accepted as iso-time markers, then the deformation of the lower sill complex suggests that half-graben structures have evolved, allowing the rhyolitic lavas of the Watson Lake Group to accumulate. The Bell Allard deposit is found at the southern edge of this structure, and the sulphide mineralisation may have been caused by fluid flow along one of these faults. The lower level of disruption of the upper gabbro sill complex suggests that it was emplaced at a later stage after deposition of the upper basalts of the Wabassee Group.

CONCLUSIONS

Seismic profile 93a, shot with Noranda as part of the Abitbi-Grenville Lithoprobe project, provides a detailed image of the south flank of the Galinée anticline of the Matagami mining camp. We interpret the strongest reflections as arising from mafic intrusions within the volcanic stratigraphy, which is characterised by somewhat weaker reflections. The seismic profile images well much of the faulting across the camp, and suggests that these fault systems can be mapped in detail. We also identify in line 93A the strong seismic reflection, which originates from the top of the 6 million tonne Bell Allard deposit, but note that its lateral

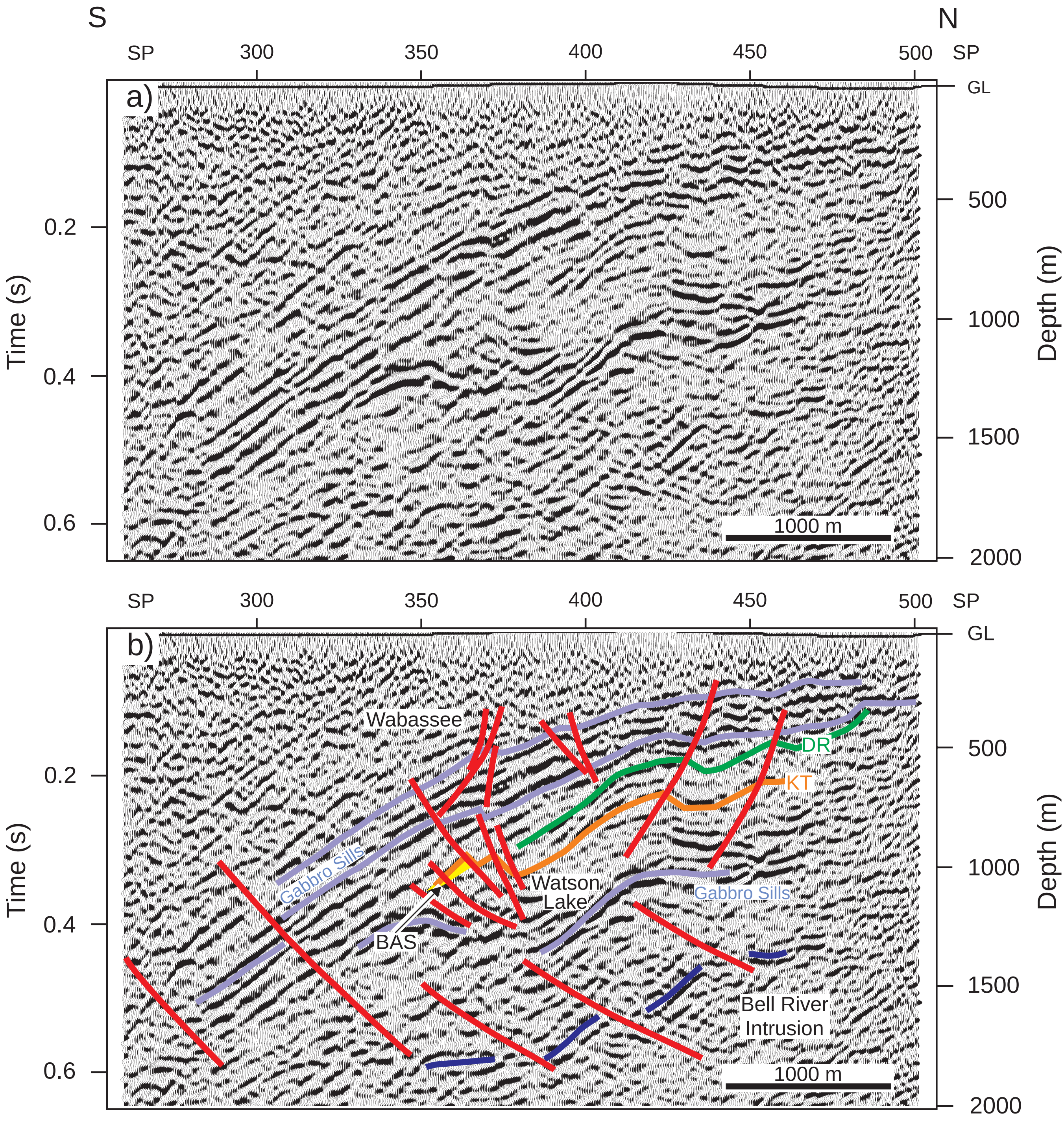

Figure 2: *Seismic profile 93A across the southern flank of the Matagami mining camp. (**a**) Prestack migration. (**b**) Interpretation. The strongest reflections visible are likely associated with two gabbro sill complexes which converge just to the south of the Bell Allard Sulphide deposit (BAS). The Key Tuffite contact between the primarily basaltic Wabbassee group and the felsic Watson Lake Group is denoted by KT. DR marks the approximate position of Dumagami rhyolite within the Wabbassee group. Interpreted faulting is shown in red. The blue horizon may be the top of the Bell River gabbro-anorthosite.*

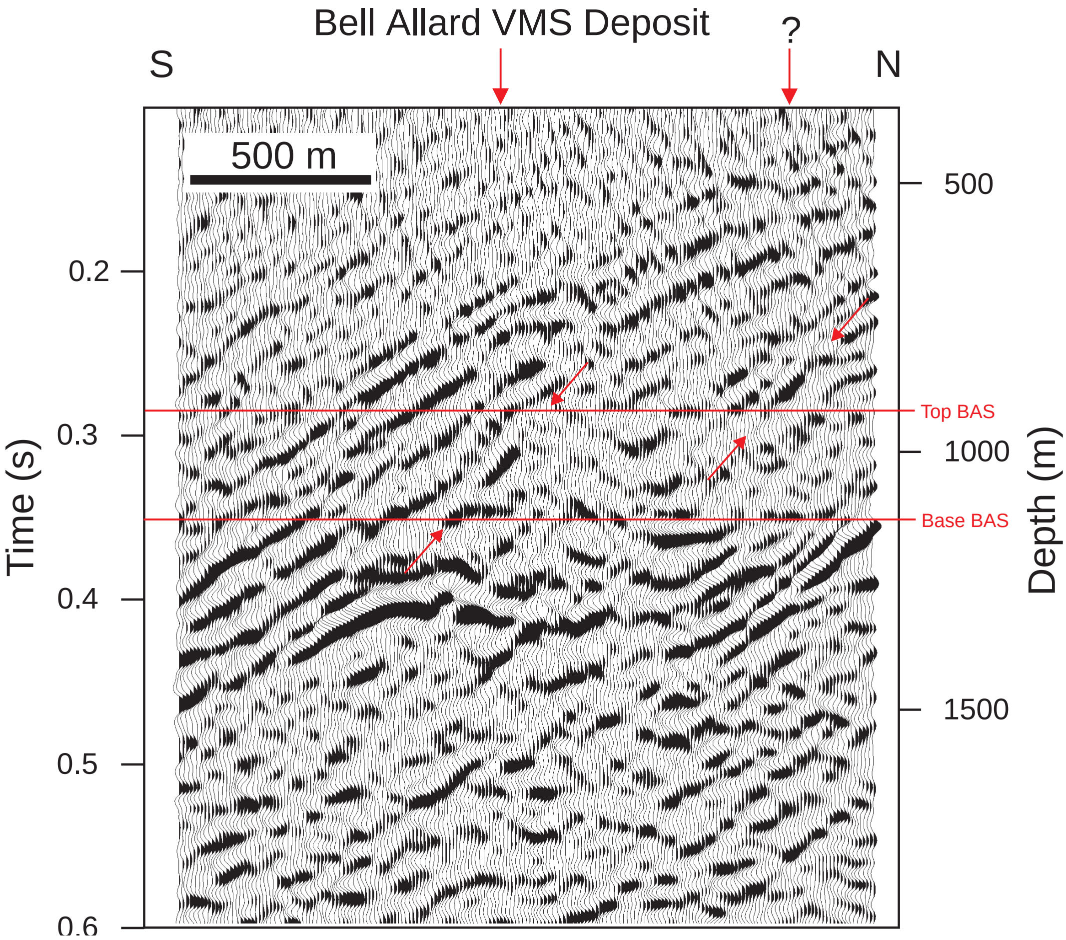

Figure 3: *Prestack migrated profile after relative amplitude preservation. The leftmost arrows indicate the reflection from the top of the Bell Allard VMS deposit. The horizontal lines mark the depth range of known sulphide mineralisation estimated from drill core. The question marks indicates a second amplitude anomaly at the top of the Watson Lake group.*

extent does not correlate precisely with the known size of the ore body. The Bell Allard deposit, which occurs at the top of the Watson Lake group, appears to be associated with faulting that extends to depth within this unit. These results suggest that identification of seismic amplitude anomalies linked to faulting in the Watson Lake group may prove to be a useful avenue for future exploration on the southern flank of the Matagami mining camp.

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REFERENCES

Adam, E., Milkereit, B., Arnold, G., Pineault, R., 1996, Seismic response of the Bell Allard orebody, Matagami, Quebec, 66th International annual meeting of the SEG, Denver, expanded abstracts, 634-637.

Beaudry, C., and Gaucher, E., 1986, Catographie géologique de la région de Matagami. Ministére d' Energie et des Ressources du Québec, report MB 86-32.

Freeman, B.C., 1939, The Bell River Complex, northwestern Québec, J. Geology, **47**, 27-46.

Jenney, C.P., 1961, Geology and ore deposits of Matagami area, Québec, Economic Geology, **56**, 740-758.

MacGeehan, P.J., 1978, The geochemistry of altered volcanic rocks at Matagami, Québec: a geothermal model for massive sulphide genesis, Can. J. Earth Sci., **15**, 551-570.

MacGeehan, P.J., MacLean, W.H., and Bonenfant, A.J., 1981, Exploration significance of the emplacement and genesis of massive sulphides in the Main Zone at the Norita Mine, Matagami, Québec. CIM Bulletin, 74, 59-75.

Maier, W.D., Barnes, S.-J., and Pellet, T., 1996, The economic significance of the Bell River Complex, Abitibi subprovince, Quebec, Can. J. Earth Sci., **33**, 967-980.

Mortensen, J.K., 1993, U-Pb geochronology of the eastern Abitibi Subprovince. Part 1: Chibougamau-Matagami-Joutel region, Can. J. Earth Sci., **30**, 11-28.

Piché, M., Guha, J., Daigneault, R., Sullivan, J.R., and Bouchard, G., 1990, Les gisements volcanogénes du camp minier de Matagami: structure, stratigraphie et implications métallogéniques, *in* The northwestern Québec polymetallic belt. M. Rive *et al. eds.*, Can. Inst. Min. and Metallurgy, Special Volume 43, 327-335.

Roberts, R.G., 1975, The geological setting of the Mattagami Lake Mine, Québec: a volcanogenic massive sulphide deposit. Economic Geology, **70**, 115-129.

Salisbury, M., Milkereit, B., and Bleeker, W., 1996, Seismic imaging of massive sulfide deposits: Part I. Rock properties. Economic Geology, **91**, 821-828.

Sharpe, J., 1968, Geology and sulfide deposits of the Matagami area, Abitibi–East county. Quebec Department of Natural Resources, geological report 137.