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A new look at the geological framework of the central Noranda camp, Quebec from industry high-resolution seismic profiles

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Abstract: As part of the Targeted Geoscience Initiative, the Geological Survey of Canada obtained access to industry-owned seismic-reflection data along two profiles crossing the volcanic rocks of the Noranda mining camp. A detailed 3-D geological model covering the central Noranda camp was also provided to the TGI-3 Abitibi Project by Xstrata Copper Canada. The model is primarily based on exploration drill cores and allows precise comparison between seismic reflections and subsurface geology. The Amulet seismic section reveals several prominent east-dipping reflections originating from the Flavrian pluton. The diorite mapped within the Flavrian pluton could explain the strong reflections. The volcanic rocks of the Noranda Formation are characterized by short, crossing reflections with different dips that complicate reconciliation with the faulted rhyolitic-andesitic sequences in the area. The integration of seismic data and 3-D geological model provides new constraints on the deep geological framework that may help exploration in the Noranda camp.

Résumé : Dans le cadre de l'Initiative géoscientifique ciblée, la Commission géologique du Canada a obtenu accès à des données de sismique réflexion acquise par l'industrie le long de deux profils recoupant les roches volcaniques du camp minier de Noranda. Un modèle géologique tridimensionnel détaillé du camp minier central de Noranda a aussi été fourni au projet IGC-3 Abitibi par la Xstrata Copper Canada. Ce modèle est fondé principalement sur des carottes de forages d'exploration et permet une comparaison précise des observations sismiques par réflexion et de la géologie de la subsurface. Le profil sismique Amulet montre plusieurs fortes réflexions à pendage est provenant du pluton de Flavrian. La diorite cartographiée dans le pluton de Flavrian pourrait en être la source. Les roches volcaniques de la Formation de Noranda sont caractérisées par de courtes réflexions croisées aux pendages différents, ce qui complique le rapprochement de ces roches et des séquences rhyolitiques-andésitiques faillées de la région. L'intégration des données sismiques et du modèle géologique tridimensionnel fournit de nouvelles données sur le contexte géologique en profondeur qui pourraient aider l'exploration dans le camp de Noranda.

INTRODUCTION

As part of phase 3 of the Targeted Geoscience Initiative (TGI-3), the Geological Survey of Canada obtained access to industry-owned seismic-reflection data along two profiles in the eastern Blake River Group. The two seismic lines (Amulet-001 and Ribago-001) were shot by Noranda during the summer of 2000. The Amulet and Ribago seismic profiles run approximately from east to west and cross the volcanic rocks of the Noranda Formation, which host most of the ore deposits in the central Noranda camp (Fig. 1). The two seismic profiles were reprocessed to improve the reflectivity in the shallow part of the section and imaging of dipping reflectors. The seismic profiles, not previously shown publicly, provide new information about the geology at depth and complement information obtained from the high-resolution LITHOPROBE seismic profile 21-1 (Fig. 1). Here the authors present initial results from the reprocessing and interpretation of the Amulet profile based on petrophysical and geological information available in the central Noranda camp. In particular, the interpretation relies on a detailed 3-D geological model built from an extensive number of exploration boreholes available in this area. The integration of seismic sections into this model helps to further define the deep geological framework in the Noranda camp.

GEOLOGICAL SETTING

The Blake River Group is located within the southern part of the Abitibi Subprovince and is delimited to the south by the Cadillac tectonic zone and to the north by the Porcupine Destor fault. The Blake River Group is composed of an andesite-rhyolite volcanic complex, felsic intrusions and diorite-gabbro sills and dykes. More specifically, the two industry-owned seismic profiles were acquired over the volcanic rocks of the Noranda Formation, which hosts the majority of the volcanogenic massive-sulphide deposits of the Noranda camp (Gibson and Watkinson, 1990). Felsic intrusive rocks are also significant rock types in the vicinity of the

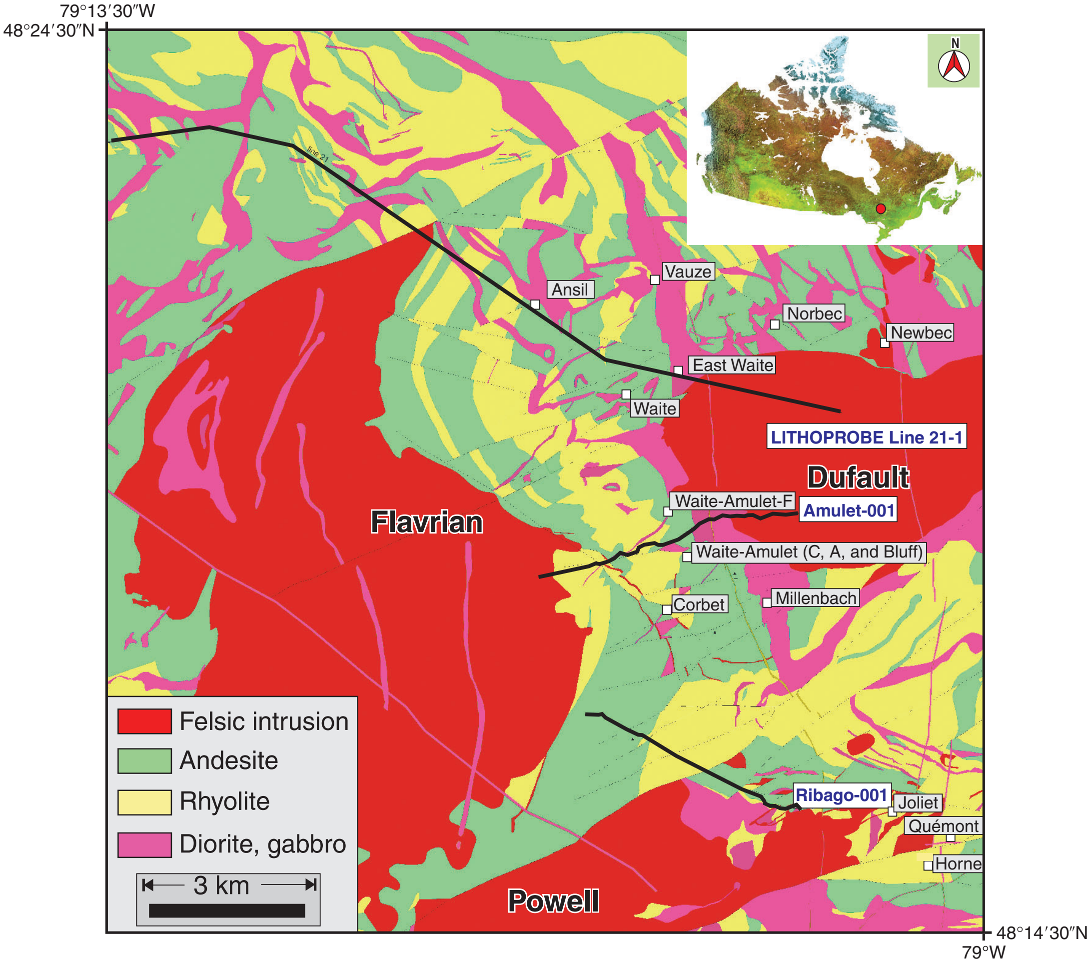

Figure 1. Geological map of the central Noranda camp showing the volcanic rocks of the Noranda Formation and felsic intrusive rocks. The location of the two industry-owned seismic profiles (Amulet-001 and Ribago-001) and common depth points (CDP) of LITHOPROBE line 21-1 are also shown.

seismic profiles. The Flavrian and Powell plutons (Fig. 1) are synvolcanic and are considered to represent the magma chamber that fed in part the Noranda Formation. The Dufault pluton, located east of the Amulet profile (Fig. 1), is postvolcanic and crosscuts the volcanic rocks of the Noranda Formation. This formation is cut by several dykes and sills composed of diorite and gabbro representing approximately 20% of the surface rocks. The geometry at depth of the Blake River Group is poorly known except in the Noranda Formation, where a significant number of exploration boreholes provide some information down to approximately 1.5 km; however, the numerous faults mapped in this area complicate the correlation between rock types (Peloquin et al., 1990).

PREVIOUS SEISMIC-REFLECTION WORK

The two Noranda seismic profiles were acquired after the LITHOPROBE Abitibi transect, which included two regional seismic profiles (14 and 21) and a high-resolution profile (21-1) in the eastern part of the Blake River Group. The LITHOPROBE lines were previously analyzed and interpreted by Verpaelst et al. (1995), Perron and Calvert (1998), and Adam et al. (2000). The high-resolution profile 21-1 runs from southeast to northwest north of the Amulet seismic profile (Fig. 1). Several observations and conclusions from line 21-1 are likely applicable to the Amulet and Ribago study areas because the same geological units are found beneath the three seismic profiles. The interpretation and assessment of reflectivity on line 21-1 is supported by a petrophysical analysis of borehole-log data and detailed geological section close to the Ansil mine (Perron and Calvert, 1998). The sonic and density logs were acquired in a 1.6 km deep borehole located in the vicinity of the Ansil mine. This petrophysical analysis shows that diorite units are likely to cause strong reflections when in contact with tonalite or rhyolite. Several reflections on line 21-1 were associated with dioritic intrusions that form laterally continuous, shallow-dipping surfaces prone to reflect seismic waves. Results from LITHOPROBE studies show that contacts between volcanic units, including rhyolite-andesite contacts, are mostly nonreflective, possibly because they are laterally heterogeneous at the scale of the seismic waves (Perron and Calvert, 1998). This suggests that the seismic-reflection method is not the most appropriate to map exhalite horizons often observed at rhyolite-andesite contacts. A narrow part of the northern tip of the Flavrian pluton is also intersected by line 21-1. The interpretation of Perron and Calvert (1998) suggested that the Flavrian pluton is an east-dipping tabular body crosscut by diorite sills.

SEISMIC DATA ACQUISITION AND PROCESSING

The Amulet and Ribago profiles were acquired by Noranda Inc. to assess the applicability of seismic methods in the central camp and to help define potential exploration targets in a highly productive mining area. The Amulet seismic profile is 5.6 km long and located between the Dufault and Flavrian plutons. The Waite-Amulet-F and Waite-Amulet (C, A, and Bluff) deposits are located at a maximum distance of 500 m on each side of this profile. The Amulet profile is almost parallel to the northeast-trending faults mapped in the Noranda Formation. The Ribago line is 4.9 km long and located east of the Flavrian pluton, just north of the Powell pluton. There are no known major massive-sulphide deposits in this area; however, sulphide minerals were intersected in boreholes located near this profile. Both profiles were acquired with explosive sources (500 g) placed in 6 m deep borehole located every 40 m along the seismic lines. The receiver groups were spaced every 10 m along the lines. Each receiver group consisted of six 10 Hz geophones linearly distributed over a distance of 10 m. The entire receiver spread was active during acquisition. The data were acquired with a Sercel SN388™ seismograph using a sampling rate of 2 ms and a record length of 3 s.

The Amulet and Ribago lines are mostly straight, especially in their centre part, and they are mostly orthogonal to the main lithological contacts they intersect. Some significant parts of these profiles were acquired along cut lines. In comparison, the LITHOPROBE profiles were acquired with a vibroseis source along existing roads. Although these roads were carefully selected, they are often crooked and not necessarily orthogonal to lithological units. In general, such crooked-line geometry complicates data processing and in some cases interpretation. The quality of the field data from the Amulet line is excellent and may partly result from the moderately dipping stratigraphy found in this area of the Blake River Group. A raw shot gather from this profile is shown in Figure 2. The record shows strong direct and refracted P- and S-waves and ground roll. Some short and discontinuous reflections are also observed. The curvature of many reflections on this record indicates dipping reflecting interfaces. The strength and number of reflections are lower on the Ribago raw field gathers, but data quality is generally good. This profile runs over stratigraphy with steeper dips. Both profiles were reprocessed to improve the imaging of dipping reflectors and to preserve as much as possible shallow reflections that can be correlated with information contained in the 3-D geological model. Key processing steps included refraction static corrections, soft first-break mute functions, and dip moveout (DMO) corrections. Figure 2b shows improved reflection continuity on a shot gather after refraction static corrections.

3-D GEOLOGICAL MODEL

Interpretation of seismic data acquired in hard-rock environment is often seen as highly speculative due to the lack of laterally extensive geological information at depth. This is not the case here as a detailed 3-D geological model covering the central Noranda camp was also provided to the TGI-3 Abitibi Project by Xstrata Copper Canada. The model is primarily based on exploration drill cores and comprises 3-D surfaces of main rock units (including exhalite horizons) and a detailed fault network (Fig. 3). Control points used to define these surfaces are also part of the model. These points provide hard geological constraints that can be used to validate interpretation of the two industry-owned

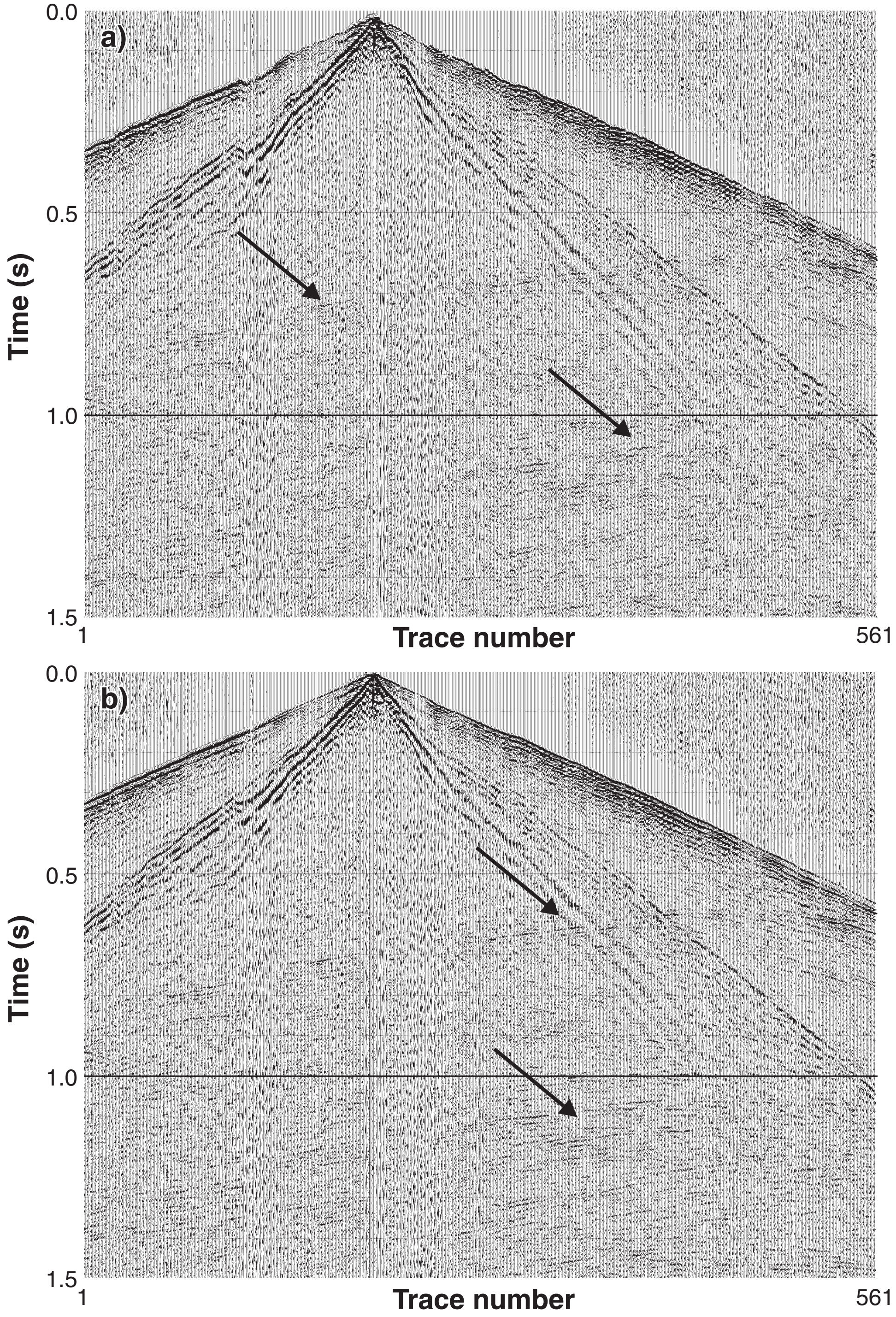

Figure 2. a) Shot gather from the centre of the receiver spread on the Amulet seismic profile. **b)** Same shot gather after only static corrections. Arrows point to the reflections, the continuity of which are improved in Figure 2b.

seismic profiles and to revisit interpretation of LITHOPROBE line 21-1. The model allows precise comparison between seismic-reflection data and subsurface geology. The 3-D geological model can be used to locally confirm the reflectivity of specific lithological contacts or faults. The seismic data provides additional control in areas with no boreholes and can extend geological information at depth. Furthermore, the seismic data can help to upscale detailed geological information to a regional scale.

Some localized discrepancies are observed between the model and the seismic data. They can be explained by the lack of geological information to constrain specific area of the model, particularly at depth. Another explanation is the imaging of off-line lithological contacts or structures on a 2-D profile. Those off-line reflections will likely be mispositioned on the seismic sections and will therefore not coincide with information within the 3-D model. The constant velocity

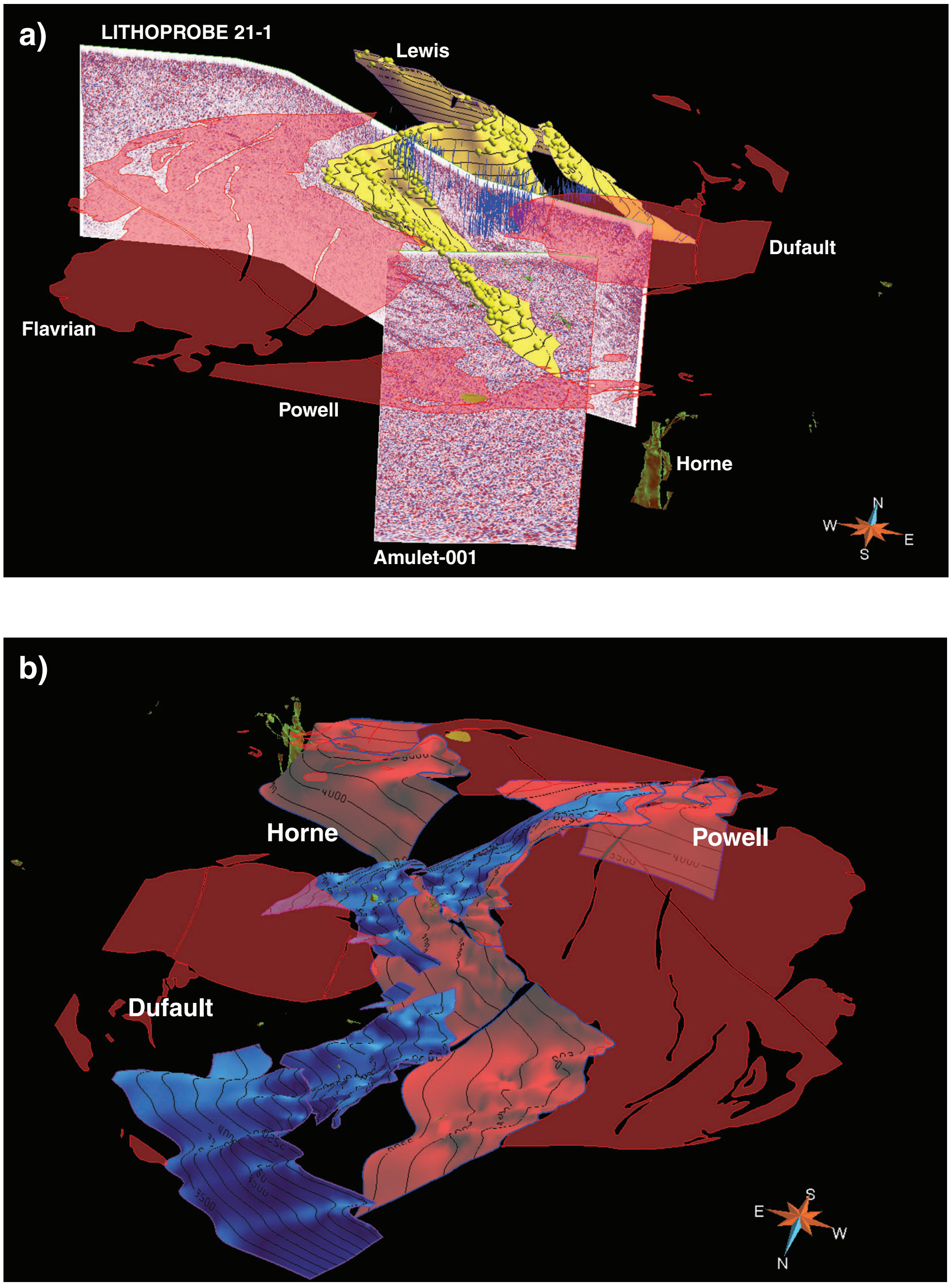

Figure 3. a) Perspective view of the 3-D Noranda camp model (looking north-northwest), showing the Amulet and LITHOPROBE 21-1 seismic profiles, three felsic intrusions, the Lewis exhalite horizon (in yellow with control points), the sulphide ores (in green, some are small at that scale), and some borehole trajectories on either side of line 21-1 (blue lines). **b)** Crossplunge view of the model with the Flavrian pluton and C-contact (exhalite) 3-D surfaces (looking south-southeast). The green surfaces correspond to sulphide ore.

approximation used for time-to-depth conversion can also cause mismatches. Some boreholes with logging measurements are also available close to the Amulet and Ribago profiles. The logs contribute in assessing the nature of reflections on the seismic data.

INTERPRETATION OF THE AMULET PROFILE

Changes in seismic-reflectivity characteristics are used to define several geological domains. On the Amulet profile, one of these domains corresponds to the Flavrian pluton. The profile barely intersects the eastern part of the pluton at surface and can provide limited information where felsic rocks outcrop; however, it is well located to image parts of the pluton that extend underneath the volcanic rocks of the Noranda Formation. The Amulet profile reveals several prominent east-dipping reflections embedded in a relatively low-reflectivity background originating from lithological contacts or structures within the pluton (Fig. 4). In particular, a strong, shallowly dipping reflection shows a vertical separation along another reflection with a steeper dip to the east. Unfortunately, the 3-D geological model provides almost no control within the Flavrian pluton and cannot help to determine the origin of the strong reflections. According to previous physical rock-property studies, diorite in contact with felsic intrusive rocks should produce significant reflections. The diorite mapped within the Flavrian pluton could likely explain the strong reflections on the section, since some diorite was emplaced in fracture zones that trend north and dip 0–30° east (Richard et al., 1990).

At the Pierre-Beauchemin gold mine located in the Flavrian pluton, mineralization is associated with concordant-layered dioritic intrusions (Richard et al., 1990). Some ore lenses are hosted in diorite zones dipping 10–40°E. Thus, the

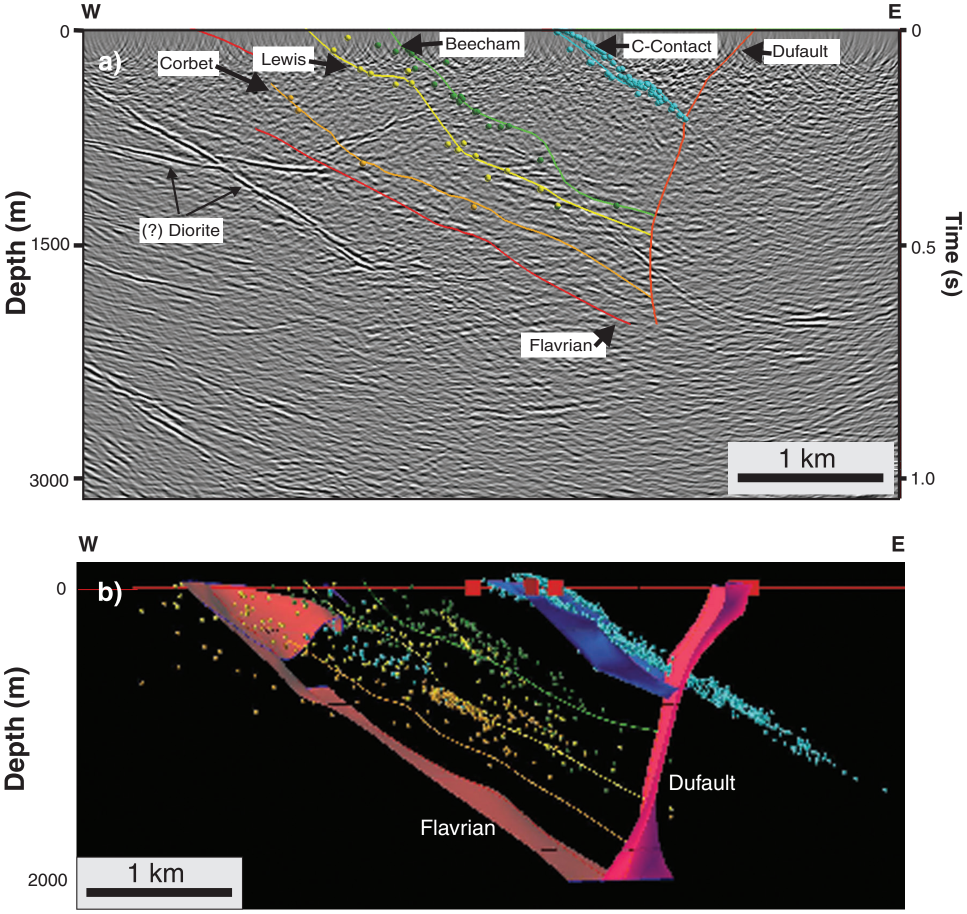

Figure 4. a) Migrated data from the Amulet-001 seismic profile. Intersections with major lithological contacts from the 3-D geological model are also shown. **b)** The control points used to define the lithological contacts (3-D surfaces) are shown in a perspective view. Depth axis in Figure 4a assumes a constant velocity of 6 km/s. There is no vertical exaggeration in Figures 4a and b. Scale on the perspective view Figure 4b is approximate.

imaging of diorite intrusions could provide new insights for gold exploration in the Flavrian pluton. The two strong crosscutting reflections on the seismic profile suggest two phases of dioritic intrusion. The termination of one of these reflections at the Flavrian pluton–Noranda Formation contact also suggests that these dioritic intrusions may have occurred only within the pluton. The contact between the Flavrian pluton and overlying volcanic rocks produces a weak, but locally detectable reflection.

The volcanic rocks of the Noranda Formation are characterized by short, crossing reflections with different dips that complicate reconciliation with the faulted rhyolitic-andesitic sequences in the area. The andesite-rhyolite contacts are often disrupted along faults, creating blocks that may not have a sufficiently continuous surface to generate extensive reflections. A package of short, subhorizontal reflections is found between the Lewis and Beecham exhalite horizons near 0.4 s. Some of these reflections could likely originate from subhorizontal dykes and sills of gabbro and diorite mapped in the Noranda Formation. The four exhalite horizons do not produce clear reflections except the Lewis horizon, which can be associated with short reflections near 0.4 s (Fig. 4). This can be seen as a limitation of the method for exploration of massive-sulphide deposits in the Noranda camp; however, anomalous seismic reflectivity (strong and localized seismic amplitudes) along the exhalite surfaces of the 3-D model could be a direct indication of massive mineralization.

The western contact between the Dufault intrusion and the volcanic rocks is not imaged on the seismic section. The reflectivity in this part of the profile is low except near a depth of 1500 m, where some east-dipping reflections within the volcanic rocks intersect the interpreted location of the Dufault contact on the 3-D model. This suggests that this contact does not extend as far west as shown in the model.

SUMMARY

The reconciliation of the detailed 3-D geological model and seismic data is not necessarily a straightforward task. A significant complication results from the inaccuracies related to the 2-D seismic imaging of a 3-D geological environment. Nevertheless, the integration of seismic data and the 3-D geological model locally provides new constraints on the deep geological framework that may help exploration in the Noranda camp. Future work will include the interpretation and integration of the Ribago profile in the 3-D geological model and additional physical rock-property measurements to better understand the origin of the reflectivity on the two industry-owned seismic profiles.

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