GPR-Based Mapping Silurian Grainstone Megashoals

Brian Pratt*
University of Saskatchewan, Saskatoon, SK
brian.pratt@usask.ca

Gregory De Pascale
William Lettis & Associates, Walnut Creek, CA, United States

and

Bruce Hart and Wayne Pollard
McGill University, Montreal, QC, Canada

Summary

We evaluated the use of ground-penetrating radar to study grainstone megashoals of the Silurian Amabel Formation in a southern Ontario quarry. The quarry test allowed us to compare the GPR images to the stratigraphy exposed in adjacent quarry walls. These units are potential analogues for prolific carbonate grainstone reservoirs elsewhere. We tested GPR antennae operating at 50 and 250 MHz, and weather and other conditions permitted us to penetrate to depths of 10–14 m using the lower frequency antenna. The crinoidal grainstones are shoal deposits with large-scale oblique bedding that can approach 10 m in height. This cross-stratification is visible in both the quarry walls and 2-D GPR profiles. Horizons mapped in the GPR data were strongly correlated with stratigraphy seen in the quarry wall exposures showing that these techniques work well in this system.

Introduction and Geologic Setting

Many reservoirs around the world consist of carbonate grainstones. Some of these reservoirs are oolitic, while others are bioclastic. These facies represent shallow, shoal-water deposition in tropical to subtropical settings. They can form accumulations of considerable stratigraphic thicknesses located adjacent or connected to source rocks. Ooidal shoals in the Bahamas are the classic modern analogue (Rankey et al., 2006; Qi et al., 2007). However, there are few bioclastic examples to serve as reservoir analogues. In the parade of carbonate facies models, shoal-water deposits are probably the least well characterized.

In this study we return to a bioclastic grainstone unit of Paleozoic age that was explored in a reconnaissance fashion by Pratt and Miall (1993). The outcrop selected for study belongs to the middle Silurian Amabel Formation of southern Ontario, west of Toronto. This pervasively dolomitized unit is composed of coarse crinoidal grainstone (Fig. 1) and is well exposed in the Niagara Escarpment and in nearby quarries, where it reaches some 25 m in thickness.

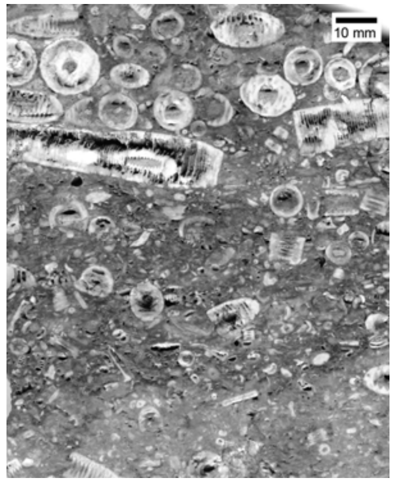

Figure 1: Close-up of Amabel Formation, showing dolomitized skeletal grains.

Regionally, the high-energy grainstones we studied pass basinward (west and southwest) into thin-bedded, dolomitized packstones, wackestones and grainstones that are finer grained and were deposited in a lower energy subtidal setting. Many of the grains in the Amabel grainstones are stem segments up to 10 cm long and 1 cm wide. The environment is envisaged as a carbonate sand shoal covered with a host of crinoids up to about 1 m in length. It was well winnowed by quotidian turbulence and perhaps minor storms. Bars accreted and migrated laterally. However, outcrop faces show numerous spectacular scour surfaces up to 15 m deep, presumably made by extreme storm events that wiped out local benthic populations. The resulting hollows were filled by laterally accreting grainstone with large-scale oblique bedding or cross-bedding (Fig. 2).

GPR is geophysical tool that has been used increasingly for a wide range of subsurface mapping applications. GPR antennae transmit an electromagnetic pulse into the ground and record the travel time of reflections caused by contrasts in dielectric properties GPR measurements. Many applications use 250 MHz or higher frequencies which limit depth of penetration to less than 4 or 5 m. Using a lower frequency proved its use immediately to image the stratigraphy and structure of unlifithifed sediments. Pratt and Miall (1993) were the first to show that it can be reliably used also to show the crude stratal architecture of lithified sedimentary rocks because it picks up large-scale stratigraphic contacts and discontinuties. Since then numerous studies have employed GPR for 2-D and 3-D analyses (e.g. Lee et al., 2005; Grasmueck et al., 2004).

Methodology

Our surveys were conducted in February 2006 with air temperatures between -10 and 0 °C, and the ground surface was covered by ice and wind-crusted snow. The GPR system used was a MALA controller with antennae operating at 50 MHz and 250 MHz. The controller triggers pulses of energy that are transmitted into the ground by the antenna which acts as a band-pass filter emitting sine waves with the center frequency determined by the antenna. Some 2-D GPR transects were collected above the quarry (for comparison with quarry wall exposures) and both 2-D and 3-D data were collected on the floor of the quarry. Here we focus on the 2-D profiles.

GPR data were processed using the *Reflexw* software package. Processing involves time-zero surface correction and horizontal filtering of the direct coupling wave. This processing is standard for GPR data and removes system noise that could mask real data. Because of the lithologies found at the field site (dolomite overlying shale), penetration depth estimates are made assuming velocities of ~0.10 m/ns for dolomite and 0.09 m/ns for shale. Due to the relative lack of topography at the site, static corrections were deemed to be unnecessary. After processing of these data, continuous horizons were picked from the dataset. These horizons were then compared with outcrop data. These quarry walls and surfaces permitted excellent stratigraphic control for the radar data.

Figure 2: Oblique view of part of quarry during data acquisition, with large-scale lateral-accretion bedding in the wall.

Results

The results of our profiling are shown in Figure 3. Strong reflections were found both at joints and on bedding planes in the GPR data. There is a strong correlation between the mapped stratigraphy in the GPR data and structures found in the quarry wall. Penetration depth of GPR signals depend on the antenna frequency and the electromagnetic properties of the subsurface materials, and in the dolomite we obtained high resolution data up to 14 m below ground surface. The dips of cross-stratification seen in the quarry wall and the associated GPR profile in Figure 3 are not as great as the dips of cross-stratification seen in the quarry wall shown in Figure 2. The two quarry walls are oriented nearly at right angles, and so these observations suggest that the shoals' internal structure is highly three-dimensional. We conclude that it will be necessary to observe the shoals using a 3-D grid of GPR data in order to truly understand their shape and internal architecture.

Conclusions

Our tests indicate that the 50 MHz GPR system was able to penetrate 10–15 m into the dolomitized grainstones of the Silurian Amabel Formation. The stratigraphic geometries we observe in the GPR data are directly comparable to those seen in adjacent outcrops. In particular, we note the presence of large-scale oblique bedding at least 10 m high produced by carbonate sand-body migration. These observations will help us to define the internal architecture of the shoal system, and enhance our confidence that features observed in 3-D GPR grids beneath the floor of the quarry (where adjacent quarry wall exposures are lacking) are indeed stratigraphic in nature.

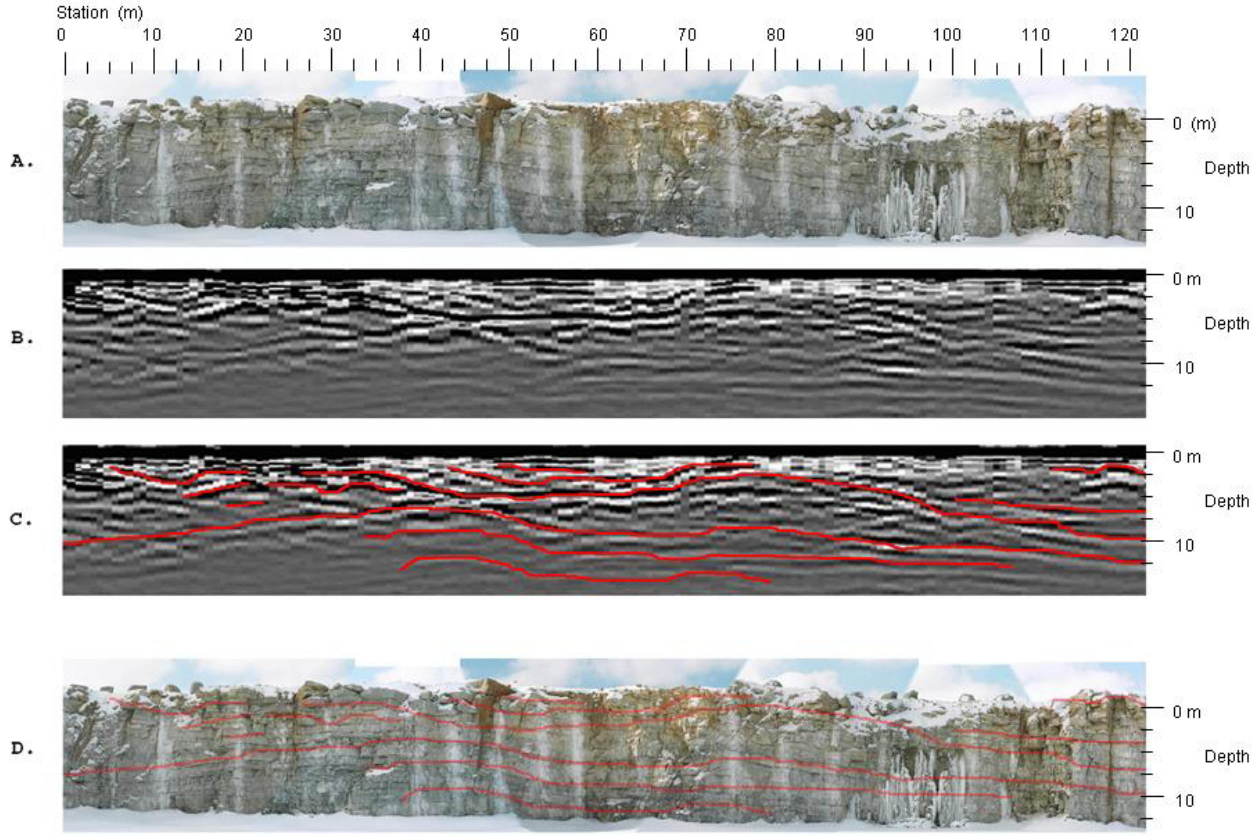

Figure 3: Comparison of quarry wall and GPR images. The GPR profile was collected approximately 5 m behind the quarry wall. A. Photomosaic of SW quarry exposure in Febuary 2006. B. 50MHz GPR data. C. 50MHz GPR data with mapped horizons. D. Photomosaic of SW quarry exposure with horizons as mapped in the GPR data (horizons from C).

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