Talc, the softest mineral in the world, is a hydrated magnesium sheet silicate, formed by transformation of existing rocks under hydrothermal activity. Properties of talc—including its resistance to heat, electricity, and acids, its platyness and its insolubility—make it a very important industrial mineral. The open-cut mining of talc can therefore be an attractive and profitable industry, provided exploration and production costs are not excessive.

WMC Resources first became involved in talc exploration at Three Springs, Western Australia, in 1960. There, talc mineralization is hosted in the Proterozoic Moora Group dolomite, which unconformably overlies Archaean basement and is intruded by numerous dolerite dykes and sills. The location of the talc mineralization is closely related to the structural setting. In the late 1980s, WMC investigated the physical properties of the talc mineralization and its dolerite/dolomite contacts, and concluded that the acoustic contrasts between talc and the host rock should be sufficient to produce a reflection. However, it was recognized that there may be difficulties associated with the seismic imaging of the talc mineralization because the talc bodies are shallow, have a complex geometry, and are intersected by many faults. Such conditions could significantly scatter the seismic energy, resulting in a deteriorated image of the subsurface.

In 1993, following the results of the wireline logging, a 700-m seismic line was recorded over a known talc deposit, in order to test the applicability of seismic methods for talc exploration at Three Springs. A Betsy gun system was the energy source. Shots were fired in 1-m holes, 2.4 m apart; receiver stations were 1.2 m apart. A 24-channel Bison recording system was used to stack repeated shots. Average fold was six. The line was over a shallow talc mineralization in the form of domes. The near-surface geology consists mainly of crusty, highly heterogeneous lateritic material.

Initial processing of the data in 1993 produced a poor result. Minor reflections were observed in the field records, but the resulting seismic section was uninterpretable and the talc mineralization could not be imaged. In 2000, the data was reprocessed at Curtin University. The major prestack processing effort was spent on obtaining a precise statics solution required for data with high-frequency content. After this was achieved, good quality final time and depth images were produced. The results of this study suggested that seismic methods could be a valuable exploration tool for talc exploration in this area.

Data processing. Inspection of the shot records revealed that 1-2 traces nearest to the shot have to be edited due to amplitude clipping. This resulted in further lowering nominal fold from 6 to around 5. However, weak reflections in several field shot records (Figure 1) encouraged further reprocessing. A two-layer model was used to compute refraction statics. Subsequent processing steps involved signal to noise ratio (S/N) improvement through amplitude compensation (including Q-compensation), f-k filtering, and deconvolution (Figure 2). Figure 3a shows a brute stack, after application of refraction statics and S/N ratio improvement. Figure 3b is a final time stack with surface consistent resid-
ual statics, residual NMO corrections, and trim statics (maximum shift limited to 0.5 ms).

Poststack processing started with f-x deconvolution to further improve S/N ratio while preserving signal integrity (Figure 4a). To generate the velocity field for migration, we carried out a preliminary interpretation and then assigned velocities measured in the laboratory to selected layers. Two different migration techniques were tested: phase shift and finite difference. In this case, these two techniques produced practically equivalent results. Figure 4b is the final time-migrated image. A second phase of interpretation was carried out on the migrated seismic data and included log data and local geologic information. Velocities measured on core samples were subsequently assigned to this refined geologic model. The derived velocity field, after smoothing, was used for time-to-depth conversion. Figure 5 shows an expanded portion of the final seismic line covering the talc mineralization. The time-migrated section is Figure 5a and the equivalent depth section is Figure 5b.

Interpretation of results. Final interpretation of the data was based on physical property results, geologic knowledge at the mine site, and seismic data. The vicinity of the open-cut pit was certainly helpful in this process (Figure 6). The photograph shows two talc domes in the open-cut pit, after mining. The road ways (benches) around the pit and the excavation truck give a sense of relative size. The seismic line was recorded 100 m away from the pit, at a slight angle to the open cut, but a comparison shows a remarkable similarity. It was certainly very encouraging to see good agreement between the seismic data and the main geologic features exposed in the open cut. Clearly, the seismic method worked.
The 700-m seismic line crossed two known talc mineralizations of dome shape. Two parts of the final depth section covering the eastern and western extensions of the talc mineralization are enlarged in Figures 7a and 7b, respectively. The main faults and the boundaries of the talc domes have been interpreted with the help of borehole data and geologic cross-sections. Reflection amplitudes were used in the interpretation process according to the impedance contrast, measured on core samples, between massive talc/dolomite and talc/dolerite rocks.

**Conclusions.** We have shown that talc mineralization can potentially be imaged with high-resolution seismic methods.

**Figure 5.** An enlargement surrounding the domed feature is shown (a) as a migrated time section and (b) as a depth section after time-to-depth conversion was performed. The possible extent of mineralization is marked in (a).

**Figure 6.** The seismic profile recorded about 100 m from and parallel to the open-cut pit, closely resembles observed local geological features.
providing that a reasonable effort, time, and care are put into data processing. One of the most important steps in high-resolution data processing is accurate computation of refraction and residual static corrections. This step was also crucial for successful reprocessing of the Three Springs seismic data. Interactive velocity analysis was carried out before and after residual static computations. The estimate of the best stacking velocities was not reliable because of the very short spread used during data acquisition (28.8 m). To overcome these problems, at least partially, we adjusted stacking and migration velocities according to the laboratory measurements of ultrasonic velocities on core samples.

The quality of the final seismic section enabled mapping the extent of talc mineralization. A subsequent survey was commissioned, using survey parameters adjusted in accordance with the analysis of 1993 data set. These results will be reported in the future.

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Figure 7. Seismic interpretation of talc mineralization: (a) talc-east and (b) talc-west.