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REFLECTION SEISMICS FOR GOLD, PLATINUM AND BASE METAL EXPLORATION AND MINING IN SOUTHERN AFRICA

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ABSTRACT

Reflection seismology has been widely used for gold, platinum and base metal exploration in southern Africa, and has also proven useful for mine planning. Several case histories are presented. (i) A seismic section from the northwestern margin of the Witwatersrand Basin shows the disposition of the Archean and Early Proterozoic supracrustal. The positions of the stratiform gold-bearing "reefs" are inferred by mapping marker horizons. (ii) The use of reflection seismics to map slump structures (known as "potholes") which disrupt the main platinum ore body of the Bushveld Complex and cause mining problems is described. (iii) Some Namibian base metal deposits are associated with paleokarst features. Seismic surveys were carried out in an attempt to locate these features beneath younger cover rocks. (iv) The use of reflection seismology to map the down-dip extension of massive sulphide "shoots" in the Matchless Amphibolite Belt is described.

INTRODUCTION

Since the early 1980s reflection seismology has found wide application for gold, platinum and base metal exploration in southern Africa, and has also proven useful for mine planning. Acquisition and processing parameters have had to be adapted to new environments and targets. In this paper several case histories are presented. The model of the target ore body, the design and execution of the seismic surveys, and the interpretation of the results are described.

GOLD EXPLORATION, WITWATERSRAND BASIN

Gold was discovered in Archean conglomerates near Johannesburg in 1886, and since then the Witwatersrand Basin (Figure 1) has produced about half the gold ever mined, worldwide. During the 1930s the gravity and magnetic methods proved very successful in locating new gold-bearing strata concealed beneath cover rocks. However, the resolution of these methods is inadequate for detailed structural mapping of deeply buried strata, and the implementation of reflection seismics in 1982 initiated a new phase of exploration (Campbell and Peace, 1984; Durrheim, 1986; Pretorius *et al.,* 1989; Campbell, 1990; Campbell and Crotty, 1990; Durrheim *et al.,* 1991; Campbell, 1994; De Wet and Hall, 1994; Pretorius *et al.,* 1994; Weder, 1994). Reflection seismics has contributed to the discovery of major new deposits such as the South Deep Project, contiguous to Western Areas Gold Mine and reputed to be one of the largest unexploited gold deposits known on earth (Haslett, 1994), and the Sun Project, a major new goldfield in the Bothaville Gap—a name given to the area by prospectors who had concluded that there was no "entry point" for gold into the Witwatersrand Basin in this region (Gray *et al.,* 1994; Tucker *et al.,* 1994).

A typical seismic section from the northwestern sector of the Witwatersrand Basin is shown in Figure 2. The geologically mapped contacts between formations were projected down dip to identify the reflections marking these interfaces. Where possible, the interpretation was constrained by drill hole information. The basement granite is generally seismically transparent, although continuous zones of strong reflection occur in some areas. The alternating shales, lavas and quartzites of the overlying Dominion and West Rand Group rocks give rise to strong continuous reflections. The quartzites of the Central Rand Group and the basaltic lavas of the Ventersdorp Supergroup are essentially seismically transparent, although the contact between these units is marked by a strong reflection. An important gold-bearing horizon (the Ventersdorp Contact Reef) can thus be directly mapped. The gold-bearing conglomerate horizons within the Central Rand Group have no significant acoustic impedance contrast with the enclosing quartzites, and cannot be directly detected. The dolomitic rocks at the base of the Transvaal Sequence give rise to low amplitude reflections with poor continuity, although the contact with the underlying Ventersdorp lavas is marked by a strong reflection. The upper formations of the Transvaal Sequence are shales, characterised by strong continuous reflections, divided by a seismically transparent andesitic lava formation.

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MAPPING OF "POTHOLES" IN MERENSKY REEF, BUSHVELD COMPLEX

The 2.1 Ga Bushveld Complex is a large igneous intrusion, roughly oval in shape with an east-west axis of about 400 km (Figure 1). It is estimated to contain about 70% of the world's reserves of platinum group elements (PGEs), and substantial reserves of chrome, copper, nickel and vanadium. The ore minerals occur in bands within the layered pyroxenites, anorthosites, norites and gabbros that constitute the bulk of the intrusion. Reflection seismics was introduced following the success of the method in the Witwatersrand Basin, and has proven useful both for exploration and for mine planning (Campbell, 1990; Durrheim and Maccelari, 1991; Odgers *et al.,* 1993; Campbell, 1994).

In this paper we describe the use of the reflection seismic method to map slump structures (known as *potholes*) that disrupt the main platinum ore body. Potholes occur when the reef crosscuts its own unlithified footwall, resulting in the reef occurring unconformably at a lower horizon. Potholes are roughly circular in shape, and may vary from tens to hundreds of metres in diameter with depths of up to 100 m. There is generally a close relationship between reef thickness and the abundance of potholes (Viljoen, 1994). The origin of these structures has been the subject of considerable theorizing. A current view is that the potholes developed as a result of a density disequlibrium where a heavy pyroxenite or chromitite layer was positioned above a lighter, partly consolidated, anorthosite footwall. The lighter rocks were locally mobilized and became buoyant, "floating off" and mixing with the pyroxenitic liquid of the succeeding unit (Hahn and Ovendale, 1994).

Northam Platinum Mine is situated in the northwestern limb of the Bushveld Complex. Exploration commenced in the early 1980s. The principal ore body is the PGE-enriched Merensky Reef, which dips to the southeast at 20° at depths between 1400 and 2500 m, and is disrupted

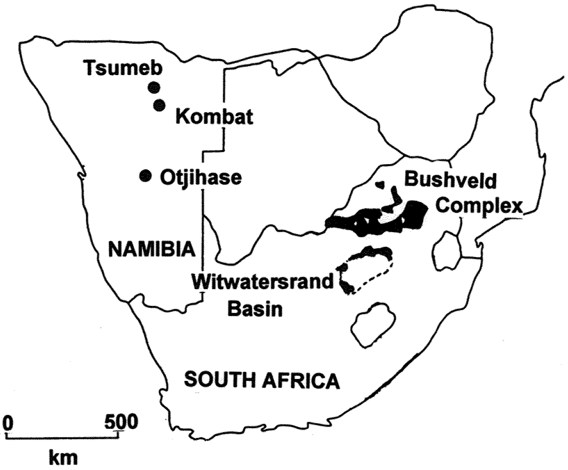

Figure 1: *Map of southern Africa showing the locations of the seismic surveys for gold (Witwatersrand Basin), platinum (Bushveld Complex), and base metals (Tsumeb, Kombat and Otjihase) described in this paper.*

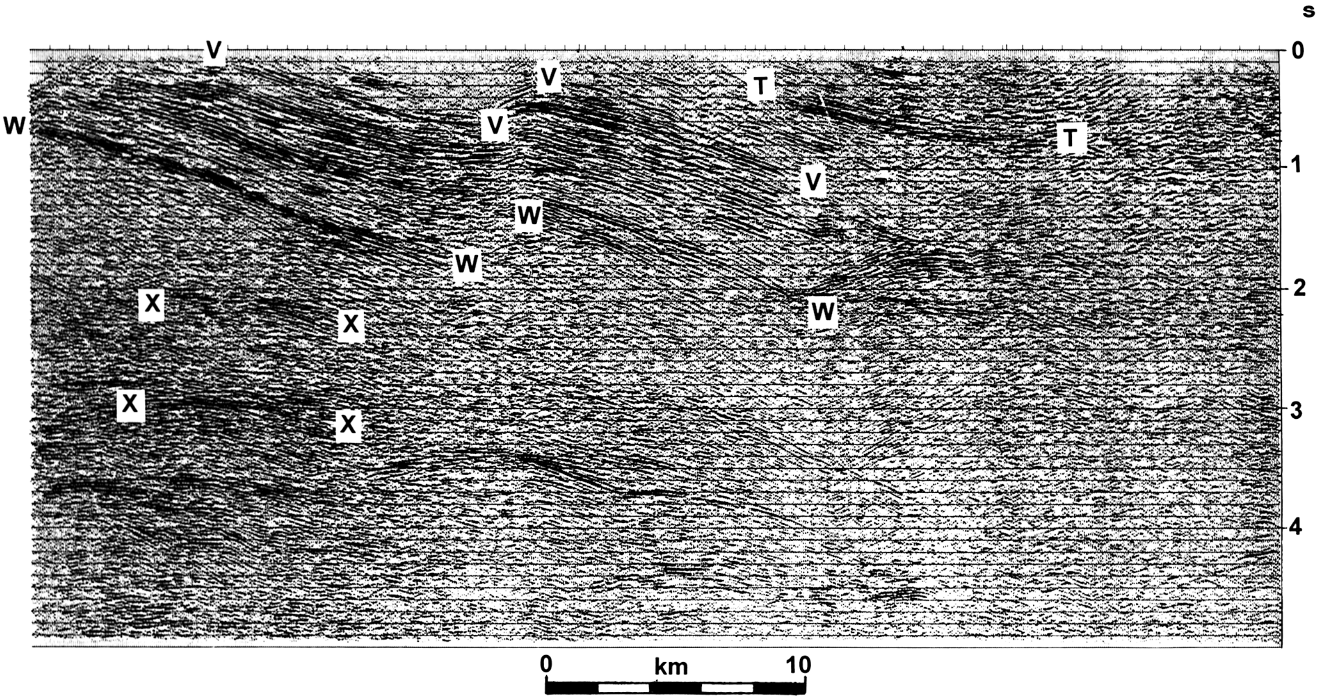

Figure 2: *Seismic section across the northwestern margin of the Witwatersrand Basin. X: reflectors within the Basement Complex; W: base of Dominion or West Rand Group; V: base of Ventersdorp Supergroup; T: base of Transvaal Sequence. Vertical = horizontal scale.*

by large potholes. The total PGE reserve is estimated to be 481 Mt @ 7.7 g/t. The "Normal reef" is a pegmatoidal feldspathic pyroxenite sandwiched between two thin chromitite layers, varying in thickness from 2.5 m to a few centimetres on the edge of potholes. "Contact-type reef" is present on the periphery of potholes and represents the transition between normal and "pothole-type reef", and truncates the footwall succession. In its typical form it is a silicate contact or a single chromitite layer a few centimetres thick. "Pothole-type reef" commences at the point where contact reef settles onto a pseudo-marker layer, and is termed either "first-order pothole reef" or "second-order pothole reef" depending on the footwall rock. "Lens-type reef" occurs where there has been incomplete removal of the sequence between normal Merensky Reef and the pseudo-marker layer (Viljoen *et al.,* 1986). The presence of potholes presents mining difficulties due to a sudden change in the dip of the strata, a change in the composition of the hanging- and footwall strata, increased numbers of joints and fractures which may be filled by talc, serpentine or chlorite, and the appearance of crosscutting pegmatite veins. Prior knowledge of the Merensky Reef types is thus extremely important for effective mine planning

The first geophysical surveys to be conducted at the Northam Platinum Project (in 1983) were a high resolution aeromagnetic survey and a gravity survey. The physical properties of borehole core were measured to assist in the interpretation of the magnetic and gravity surveys. These results also indicated that several formations had a sufficient contrast in acoustic impedance for the reflection seismic method to be used to map geological structure. Reflection seismic surveys were conducted in 1985 and 1986. The quality of the seismic image was found to be strongly dependent on the near-surface rock type. It was found that the zone surrounding the Merensky Reef (the exploration target) consistently produced clear reflections if the outcropping rock was Main Zone norite. Poorer results were obtained in areas where Nebo Granite or Upper Zone magnetite gabbro crops out. It is thought that the large number of magnetite bands occurring in the Upper Zone absorbs much of the higher frequency energy.

The objective of the seismic survey described below was to map the different types of Merensky Reef. Preliminary modelling studies (Figure 3a) indicated that the different reef types could only be distinguished if the reflections contained significant energy at frequencies above 100 Hz. Compared to earlier surveys conducted for structural mapping, the vertical resolution was improved by increasing the bandwidth of the sweep (to 30-120 Hz). Lateral resolution was improved by reducing the station interval to 25 m, and by shortening the length of source and receiver arrays to approximate point sources and receivers while still reducing ground roll. The signal to noise ratio was improved by increasing the sweep time to 22 seconds (with 2 seconds listening time), and by using an additional vibrator. Five profiles totalling 30 line-km were surveyed. The processing sequence was similar to that used for the earlier surveys, with the exception that all processes that modify the shape of the wavelet (e.g., spiking deconvolution) were excluded, and spectral balancing was added to enhance the high frequency content of the signal, thereby assisting in the identification of reef types.

The geology mapped in several boreholes was of crucial importance in determining the seismic signature of the different reef types (Figure 3a). An example of a seismic section is shown in Figure 3b. Normal, first-order and second-order pothole reef were successfully identified. Conditions such as lens and contact reef were less clearly imaged, but by combining geological reasoning with a close inspection of the seismic character within areas of pothole reef, their existence could be inferred. The interpretation of the five seismic lines was combined with borehole data to produce a map showing the distribution of the different reef types. This information was used to improve the estimates of ore reserves and to plan mining operations.

BASE METAL EXPLORATION, NAMIBIA

The success of reflection seismics in delineating potholes in the Merensky Reef led to conjecture that the method may be useful for other exploration activities. Large parts of Namibia are covered by recent sands and calcrete. Consequently remote sensing techniques are required for mineral exploration. Two areas with proven economic base metal deposits are the Otavi Mountainland near Tsumeb and the Matchless Amphibolite Belt (Figure 1). The problem of delineating karst features on the contact between the carbonate and clastic formations in the Otavi Mountainland is analogous to the mapping of potholes. In this paper we describe a trial survey carried out to test the viability of using the reflection seismic method to search for synsedimentary fracture systems linked to basement faulting. A second case history describes the use of reflection seismology to map the downdip extension of mineralized "shoots" at Otjihase Mine in the Matchless Amphibolite Belt.

Tsumeb, Tschudi and Kombat surveys, Otavi Mountainland

The Tsumeb and Kombat ore deposits are amongst the most important mineral deposits in Namibia. The Tsumeb Pb-Cu-Zn ore body is a polymetallic pipe-like deposit located within the moderately folded, predominantly dolomitic succession of the Otavi Group (Lombaard *et al.,* 1986). The pipe is associated with a paleokarst feature at the interface between the Mulden and Otavi groups. Synsedimentary fracture systems linked to basement faults acted as conduits for mineral-rich hydrothermal fluids which chemically eroded the limestone host rock of the Otavi Group and deposited a wide range of lead and copper minerals. The body is roughly elliptical in plan (about 150 m x 70 m), with the long axis oriented east-west parallel to the strike of the sedimentary strata. In cross-section, the pipe dips from the surface steeply southward, parallel to the dolomite strata, to a depth of about 600 m. At this point the ore body changes attitude to near-vertical, transgressing the strata. The ore body extends to a depth in excess of 1500 m, narrowing with depth. The pipe is filled with feldspathic sandstone originating from the overlying Mulden Group and dolomite breccia. The high grade ore is generally found around the periphery of the pipe, with irregular veins and pods towards the core. Tsumeb mine is nearing the end of its reserves, which totaled some 22 Mt grading 11.9% Pb, 4.8% Cu, and 4.3% Zn (Lombaard *et al.,* 1986). Kombat Mine is situated near the southern limit of the Otavi Mountainland. The Kombat Cu-Pb-Ag ore bodies are located below a monoclinal flexure in the carbonates (Innes and Chaplin, 1986). The ore bodies are discrete pods, with typical dimensions of 100 m x 100 m x 50 m. Total ore reserves, including past production, amount to some 8 Mt grading 2.5% Cu, 1.9% Pb, and 19 g/t Ag.

The Otavi Mountainland has been extensively explored for ore bodies similar to Tsumeb and Kombat. The potential host rock, the dolomitic formation of the Otavi Group, is concealed by younger clastic sediments of the Mulden Group over a broad area. Geophysical methods have been used to probe beneath this cover. Magnetic and electromagnetic methods have been used to explore for Kombat-type mineralisation (Lubbe *et al.,* 1994). Remanently magnetized pyrrhotite within the Mulden Group gives rise to significant magnetic anomalies. Fe/Mn assemblages are associated with Kombat-type ore bodies and produce small deviations in the magnetic field. Deep electromagnetic soundings are then used to locate the position of the monoclinal flexure to site exploration boreholes. However, the potential of magnetic, electrical and electromagnetic methods to explore beneath the Mulden Group is considered to be limited as the ore is generally non-magnetic, substantial oxidation has occurred from the surface to a depth of 400 m, and pyrite and pyrrhotite are ubiquitous within the Mulden Group sediments. The use of the gravity method to detect a Tsumeb-like ore body concealed beneath cover rocks was investigated by Fuller (1977). The feldspathic sandstone and dolomitic breccia filling the pipe has a negative density contrast compared to the dolomitic host rock, while the metal sulphide veins and pods have a positive density contrast. A Tsumeb-like pipe buried at depths of 100 m and 200 m would give rise to gravity anomalies with peak amplitudes of 0.10 mGal and 0.076 mGal, respectively. A 0.10 mGal anomaly is considered to be marginally detectable with very careful observations in flat terrain with minimum geological noise. However, physical property measurements indicated that the Otavi Group rocks have P-wave velocities between 3800 m/s (highly fractured and altered dolomite) and 5130 m/s (unaltered dolomite), while the average velocity for the Mulden Group is 3360 m/s. The reflection coefficient of the target horizon (the Otavi/Mulden contact) was estimated to be relatively high, in the range 0.1 to 0.2, suggesting that reflection seismology could be used to map the Otavi/Mulden contact and search for karst features.

Two profiles were surveyed near Tsumeb in June 1988. The seismic sections show a strong persistent reflection at the Otavi/Mulden contact (Figure 4). Other persistent reflections within the Otavi Group were used to map faults that could have acted as conduits for hydrothermal fluids. This trial survey demonstrated that the reflection seismic method is capable of detecting paleokarsting along the interface between the Mulden and Otavi Groups at depths in excess of 300 m.

A trial survey was also conducted near the Tschudi deposit (25 km west of Tsumeb), and provided reasonable evidence that no pipe-like feature comparable to the Tsumeb ore body exists beneath the survey area. This survey also detected block faulting below the Mulden Group. The faults could have been the conduits for the mineralising fluids.

A reflection seismic trial survey was also conducted near Kombat Mine where the dolomitic rocks of the Otavi Group and the clastic sediments of the Mulden Group are folded into a narrow, deep, double plunging syncline approximately 50 km in length. This was the least successful of the trial surveys. The steeply dipping sides of the syncline were not well imaged, but one potentially useful result did emerge: it appears

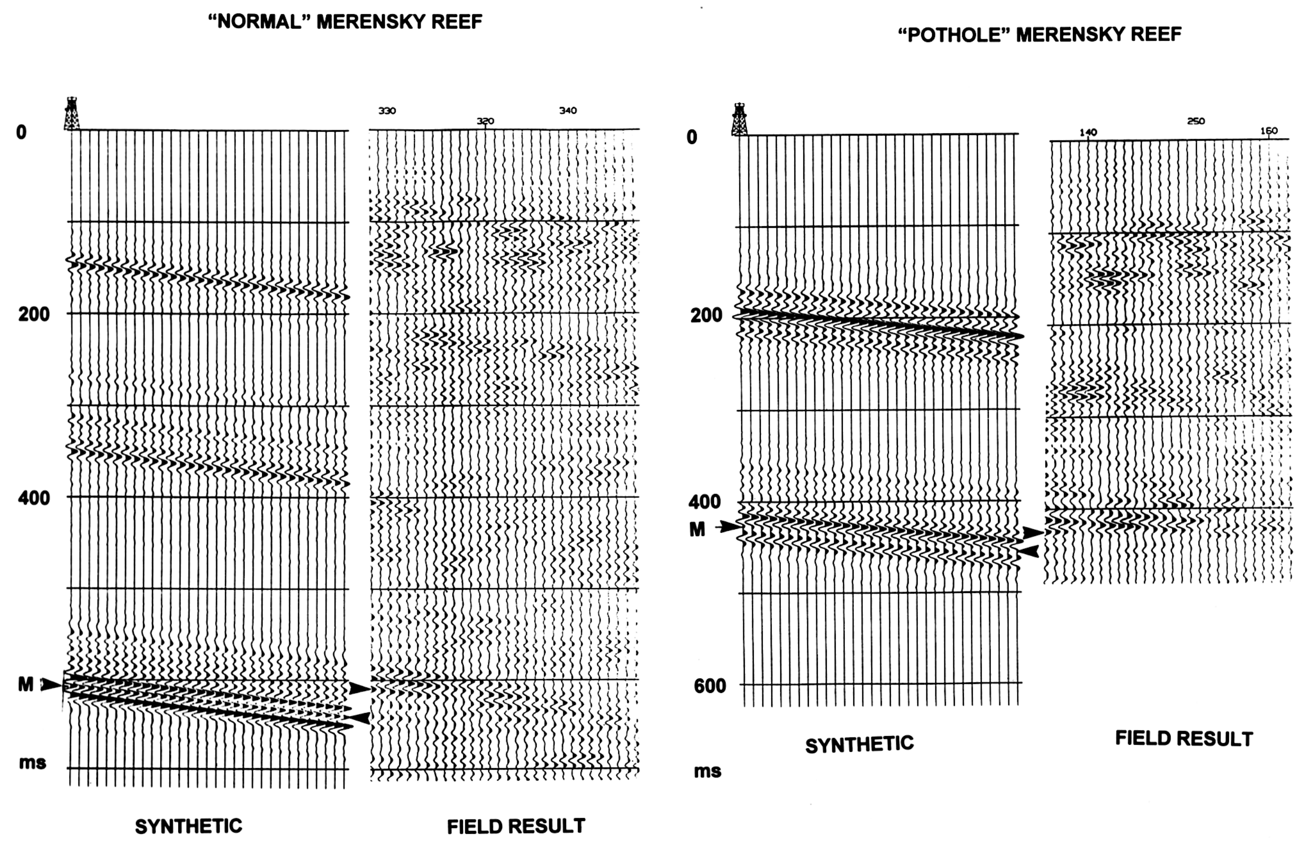

Figure 3a: *Synthetic seismograms and field results for "Normal" and "Pothole" Merensky Reef, indicated by "M".*

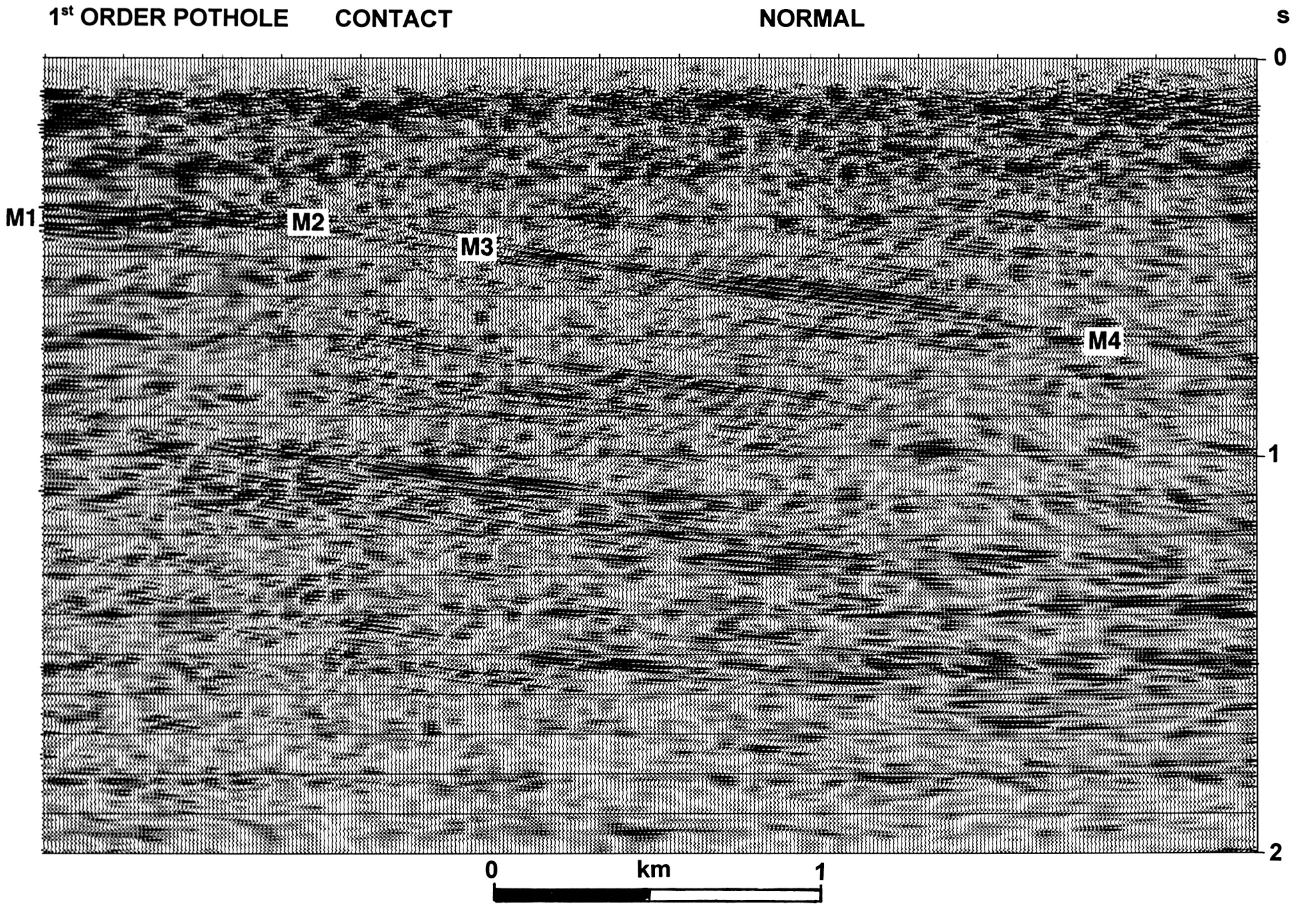

Figure 3b: *Seismic section from Northam Platinum Mine showing the identification of different types of Merensky Reef: First-order reef, M1-M2; Contact reef, M2-M3; Normal reef, M3-M4. Vertical = horizontal scale.*

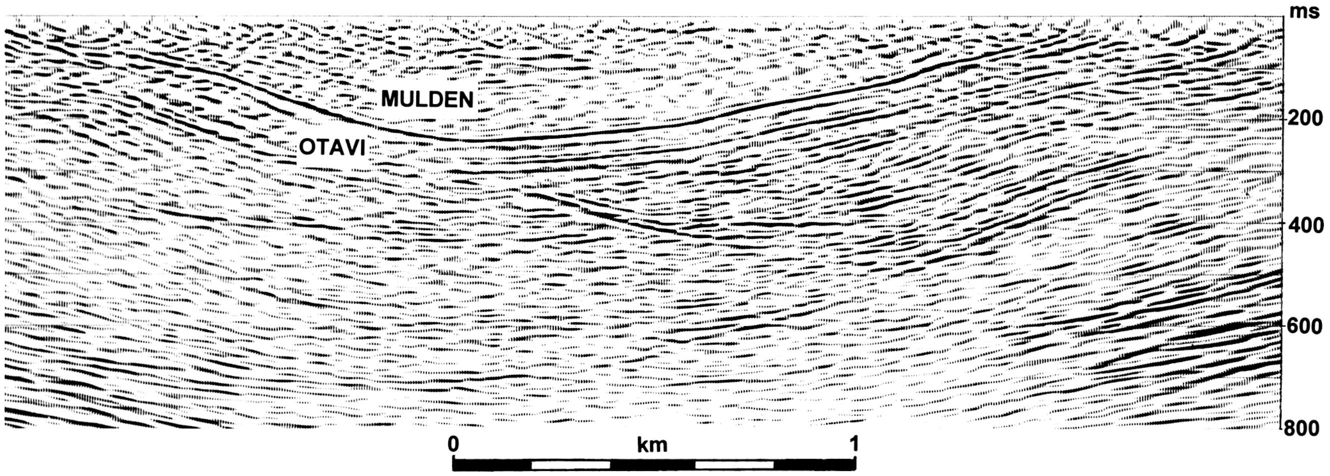

Figure 4: *Seismic section from the Tsumeb area. Mineralisation occurs in paleokarst features within the dolomitic rocks of the Otavi Group. In this area the potential host rock is concealed by clastic sediments of the Mulden Group. The contact between the Otavi and Mulden groups was mapped in an attempt to locate these features. Vertical = horizontal scale. Sweep 25–120 Hz, 48-fold.*

that the horizon forming the trap for the mineralising fluids is at a shallower depth than was previously thought, opening up new areas for exploration. It was recommended that existing gravity and magnetic data be reinterpreted using the structural constraints provided by the seismic survey.

Otjihase Mine, Matchless Amphibolite Belt

The Matchless Amphibolite Belt is a 350-km long northeast-trending belt in central Namibia consisting mainly of mafic lavas and meta-intrusives with associated massive sulphide deposits (pyrite, pyrrhotite, chalcopyrite, and sphalerite) within the schists of the Kuisib Formation of the Damara Orogen (Smalley, 1988). The sulphide layer is an excellent target for the electromagnetic method due to the high resistivities of the surrounding Kuisib Formation schists, lack of conductive overburden, and integrity of the semi-massive sulphide bodies. A magnetite quartzite horizon is associated with the sulphide layer, and is used to prioritize conductivity anomalies (Lubbe *et al.*, 1994; Campbell and Mason, 1979).

The Otjihase deposit, which is situated about 30 km east of Windhoek, consists of four subparallel pencil-shaped mineralised shoots. Only the Main Shoot is mined. It is typically 250 m wide and 5 m thick, and has been proven to have a down-plunge extent in excess of 4 km, reaching depths greater than 1 km below surface. Major normal faulting has subdivided the Main Shoot into discrete ore bodies. Surface diamond drilling is normally used to delineate the ore shoots and to provide information on major faulting and footwall elevations. In certain areas poor ground conditions caused significant delays to mining. The use of the reflection seismic method to map the structure of the ore shoots was proposed as information was urgently needed for planning purposes.

Seismic modelling was carried out as part of the feasibility study. The density contrast between the ore body and country rock was estimated to be greater than 0.35 g/cm^3. It was concluded that the ore body would produce a significant reflection, and that it would be possible to map the broad outline of the deposit and faults with a throw greater than 15 m.

A reflection seismic survey consisting of four profiles totalling 10 line-km was conducted in 1988. The selection of 24-fold coverage proved to be optimistic as the signal-to-noise ratio was reduced by noise emanating from mining operations and vibrations induced in a water pipe. An optimum image was obtained by careful editing of noisy traces and weighted averaging of adjacent traces. The Main Shoot gave rise to a recognisable reflection (Figure 5). While faulting of the ore zone was clearly visible, it was not possible to discriminate between different facies within the ore zone.

CONCLUSIONS

Case histories from southern Africa demonstrate that reflection seismology can play an important role in the exploration for precious and base minerals in a wide variety of environments, and can also be used to solve mine-planning problems. The effective use of reflection seismology for

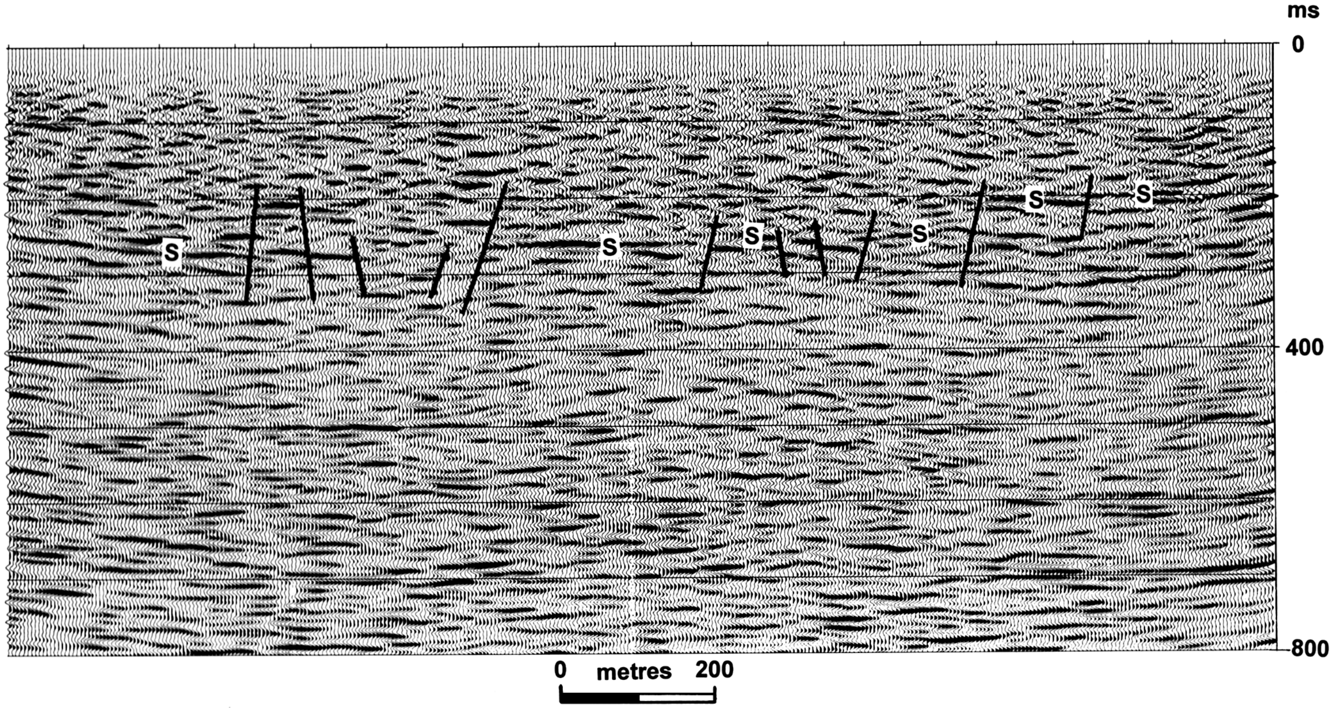

Figure 5: *Migrated seismic section from the Otjihase Mine. The Main Shoot of the massive sulphide ore body is directly mapped (indicated by "S" on the section), showing disruptions due to faulting. Vertical = horizontal scale. Sweep 25–120 Hz, 24-fold.*

mineral exploration requires a clearly defined model of the target ore body. Direct detection from the surface of stratiform ore bodies only a few metres thick (such as the gold-bearing conglomerate of the Witwatersrand Basin) is often impossible, and reflection seismology is used to seek favourable structures where the strata have been preserved from erosion, or are at mineable depths. The PGE-bearing pyroxenite of the Bushveld Complex can be directly detected, and it is even possible to map different reef types, which is important for mine planning. Base metal ores often have a significant acoustic impedance contrast with the host rock allowing direct detection, but the ore bodies are often irregular in shape and relatively small in extent. However, the use of reflection seismics to search for ore bodies associated with paleokarst features concealed beneath younger cover appears viable. Reflection seismics has also been used successfully to map the faulting of a massive sulphide ore body, providing valuable information for mine planning.

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REFERENCES

Campbell, G., 1990, The seismic revolution in gold and platinum prospecting: South African Geophysical Association Yearbook, South African Geophysical Association, 37-45.

Campbell, G., 1994, Geophysical contributions to mine-development planning: a risk reduction approach, *in* Anhaeusser, C.R., ed., Proc. XVth CMMI Congress: SAIMM Symposium Series S14, 3, 283-325.

Campbell, G., and Crotty, J.H., 1990, 3-D Seismic mapping for mine planning purposes at the South Deep Prospect, *in* Ross-Watt, D.A.J. and Robinson, P.D.K., eds, Proc. International Deep Mining Conf.: SAIMM Symposium Series S10, 2, 569-597.

Campbell, G., and Mason, R., 1979, The application of airborne and ground geophysical techniques to search for magnetite-quartzite associated base-metal deposits in Southern Africa, *in* Hood, P.J., ed., Geophysical and Geochemistry in the Search for Metallic Ores: Geological Survey of Canada, Economic Geology Report 31, 757-777.

Campbell, G., and Peace, D.G., 1984, Seismic reflection experiments for gold exploration, Wits basin, Republic of South Africa: Presented at the 46th Ann. Int. Mtg, Eur. Assn. Expl. Geophys.

De Wet, J.A.J., and Hall, D.A., 1994, Interpretation of the Oryx 3-D Seismic Survey, *in* Anhaeusser, C.R., ed., Proc. XVth CMMI Congress: SAIMM Symposium Series S14, 3, 259-270.

Durrheim, R.J., 1986, Recent reflection seismic developments in the Witwatersrand Basin, *in* Barazangi, M. and Brown, L., eds, Reflection Seismology: a global perspective: Am. Geophys. Union, Geodynamics Series, 13, 77-83.

Durrheim, R.J., and Maccelari, M.J., 1991, Seismic exploration for precious metals in the hard rock environment, 61st Ann. Int. Mtg., Soc. Expl. Geophys., Expanded Abstracts, 159-162.

Durrheim, R.J., Nicolaysen, L.O., and Corner, B., 1991, A deep seismic reflection profile across the Archean-Proterozoic Witwatersrand Basin, South Africa, *in* Meissner, R., Brown, L., Dürbaum, H-J., Franke, W., Fuchs, K., and Seifert, F., eds., Continental Lithosphere: Deep Seismic Reflections: Am. Geophys. Union, Geodynamics Series, 22, 213-224.

Fuller, B.D., 1977, Calculation of the gravity anomly at Tsumeb Mine: Geophysics, 42, 778-787.

Gray, N.K., Tucker, R.F., and Kershaw, D.J., 1994, The Sun Project–I. Discovery of a major new Witwatersrand goldfield: *in* Anhaeusser, C.R., ed., Proc. XVth CMMI Congress: SAIMM Symposium Series S14, 3, 95-102.

Hahn, U.F., and Ovendale, B., 1994, UG2 Chromitite Layer Potholes at Wildesbeestfontein North Mine, Impala Platinum Limited, *in* Anhaeusser, C.R., ed., Proc. XVth CMMI Congress: SAIMM Symposium Series S14, 3, 195-200.

Haslett, M. J., 1994, The South Deep Project: geology and planning for the future: *in* Anhaeusser, C.R., ed., Proc. XVth CMMI Congress: SAIMM Symposium Series S14, 3, 71-83.

Innes, J., and Chaplin, R.C., 1986, Ore bodies of the Kombat Mine, South West Africa/Namibia, *in* Anhaeusser, C.R. and Maske, S., eds., Mineral Deposits of Southern Africa: Geol. Soc. South Africa, 2, 1798-1805.

Lombaard, A.F., Günzel, A., Innes, J., and Krüger, T.L., 1986, The Tsumeb lead-copper-zinc-silver deposit, South West Africa/Namibia, *in* Anhaeusser, C.R. and Maske, S., eds., Mineral Deposits of Southern Africa: Geol. Soc. South Africa, 2, 1761-1787.

Lubbe, B.L., Krüger, T.L., and Symons, G., 1994, Geophysical exploration techniques employed by Gold Fields Namibia in search for base metals and some exploration results, *in* Anhaeusser, C.R., ed., Proc. XVth CMMI Congress: SAIMM Symposium Series S14, 3, 243-246.

Odgers, A.T.R., Hinds, R.C., and Von Gruenewaldt, G., 1993. Interpretation of a seismic reflection survey across the southern Bushveld Complex: South African J. Geol., 96, 205-212.

Pretorius, C.C., Jamison, A.A., and Irons, C., 1989, Seismic exploration in the Witwatersrand Basin, Republic of South Africa, *in* Garland, G.D., ed., Proc. Exploration 87, 3rd Decennial Int. Conf. on Geophysical and Geochemical Exploration for Minerals and Groundwater: Special Publication, Ontario Geol. Surv., 3, 241-253.

Pretorius, C.C., Steenkamp, W.H., and Smith, R.G., 1994, Developments in data acquisition, processing, and interpretation over ten years of deep vibroseismic surveying in South Africa, *in* Anhaeusser, C.R., ed., Proc. XVth CMMI Congress: SAIMM Symposium Series S14, 3, 249-258.

Smalley, T.J., 1988, A genetic model for part of the Matchless Amphibolite Belt and its exploration significance: Extended Abstract, Geocongress '88, Geol. Soc. South Africa, 563-566.

Tucker, R.F., Schlegel, G. C-J., Wagener, J.H.F., and Gray, N.K., 1994, The Sun Project–II. Scientific and technological innovations in a Witwatersrand exploration venture, *in* Anhaeusser, C.R., ed., Proc. XVth CMMI Congress: SAIMM Symposium Series S14, 3, 103-116.

Weder, E.E.W., 1994, Structure of the area south of the Central Rand Gold Mines as derived from gravity and vibroseis surveys, *in* Anhaeusser, C.R., ed., Proc. XVth CMMI Congress: SAIMM Symposium Series S14, 3, 271-281.

Viljoen, M., 1994, A review of regional variations in facies and grade distribution of the Merensky Reef, Western Bushveld Complex, with some mining implications, *in* Anhaeusser, C.R., ed., Proc. XVth CMMI Congress: SAIMM Symposium Series S14, 3, 183-194.

Viljoen, M.J., De Klerk, W.J., Coetzer, P.M., Hatch, N.P., Kinloch, E., and Peyerl, 1986, The Union Section of Rustenburg Platinum Mines Limited with reference to the Merensky Reef, *in* Anhaeusser, C.R. and Maske, S., eds., Mineral Deposits of Southern Africa: Geol. Soc. South Africa, 2, 1061-1090.