First use of geological radar to assess the conservation condition of a South African rock art site: Game Pass Shelter (KwaZulu-Natal)

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WE PRESENT THE RESULTS OF A SURVEY of the main panels of Game Pass Shelter, a major painted rock art site in the KwaZulu-Natal Drakensberg mountain range, using ground penetrating radar. The investigation depth in the Clarens Formation sandstones lies between four and 80 cm, adequate to determine whether the rock wall presents any potentially unstable discontinuities. By identifying such areas and determining the depth of alteration zones at the major discontinuities, the radar helps in the precision mapping of the state of conservation of the rock art panels. The best results are obtained when discontinuities consist of thin clayey layers and are saturated with infiltrating water or are open widely. The radar analysis demonstrated the major role of the thin clayey sedimentary joints as potential source of instability and damage to the art. Thus, non-destructive and technically simple ground penetrating radar is especially useful for the investigation of the stability of rock art sites.

Introduction

For many years, the conservation of rock art in South Africa has been a major challenge and many studies on both natural and anthropogenic damage have been carried out.[1–6] If today we can reasonably expect to limit human vandalism at public sites, natural weathering still remains an important threat to rock art. In the KwaZulu-Natal (KZN) Drakensberg, well known for its high concentration of painted San rock art, it is known[7–10] that the art is susceptible to the natural weathering of the Clarens Formation sandstone.[11] Together with the usual chemical, physical and biological weathering processes, the fracture system of the rock at the origin of the shelters, comprising the Clarens Formation (previously called Cave Sandstone), often jeopardizes the integrity of the rock art. The visual identification of discontinuities apparent on the rock surface is, however, insufficient to assess the potential risks of instability. Knowledge of the spatial extension of the discontinuities within the rock and of their width is required for an accurate assessment of the risk.

The lack of efficient and non-destructive tools to assess the structural stability of painted panels encouraged us to test the applicability of ground penetrating radar (GPR). This technique is mostly used for ground geological investigations and the identification of discontinuities within rock beds.[12,13] GPR localizes and evaluates the development of discontinuities in depth, behind the rock wall, and gives a three-dimensional visualization of potential instability sources. Although it has never been attempted before, the GPR thus seems particularly suitable for investigating the stability and helping in the design of efficient and proactive conservation measures for painted rock shelters.

The investigations were carried out at Game Pass Shelter (GP), one of the principal public rock art sites in the KZN Drakensberg (Kamberg Nature Reserve, uKhahlamba-Drakensberg Park). The site was chosen for its significance in the understanding of San rock art[14,15] and its excellent management, making it a potential model site of conservation against damage of natural origin. Moreover, feasibility tests carried out at this site are applicable to the numerous other sites within the Clarens Formation.

The Clarens Formation consists of sandstones dated from the Late Triassic. These sandstones[16,17] are of aeolian origin, their thickness ranges from 100 m to more than 230 m and they are covered, at a regional scale, by important basalt flows dating from the Early Jurassic forming the Drakensberg Massif. Petrographically speaking, the Clarens sandstones are composed of quartz grains marginally associated with feldspars. They appear as layers of finely sorted sandstones of colours ranging from ochre to rust.[18] Between these layers, there are joints of bluish clay that can reach a few decimetres in thickness. Some sandstone layers show abundant sedimentary figures of cross-layered stratification that indicate a partly alluvial origin.

The Clarens layers are also widely fractured, which causes the broken aspect of the main scarp. In the Kamberg area, the fracturing is mainly orientated 60° from north and is, therefore, orthogonal to the orientation of the scarp at GP (orientated mainly between 120° and 150° from north). The dip of the sandstone layers is relatively small, varying around three and five degrees to the north-west. This gives a pseudo-tabular and monocline structure to the sedimentary ensemble. The massive structure of the sandstone layers and their tendency to break out in metre-sized blocks constitutes a major risk to the conservation of the rock art, confirmed by the accumulation at the base of the scarp of sandstone blocks amounting to 50 cubic metres.

Discontinuities observed at GP are either of geological origin or result from weathering processes. Geological discontinuities comprise, for instance, fractures, extension joints, and clayey stratification joints. Weathering processes include a combination of thermal stress fatigue and variations in the rock moisture regime, said to affect mostly the aeolian sandstones of the Clarens Formation.[11] The development of large scales and many flakes on the surface of the main panel at GP may be attributed to these phenomena. Although climatic variables are reported as important parameters controlling deterioration of rock art,[11,19–21] the impact of animal burrowing and mineral crystallizations caused by the circulation of percolating water should not be underestimated.

At a larger scale, the intense vertical fracturing of the whole cliff at GP is associated with at least four stratification joints (thin and weak clayey layers) that are responsible for the cutting of the painted wall into many blocks of several metres. Some of these blocks are highly unstable and the evaluation of their connection with the whole scarp is a priority to assess conservation threats.

Methods

GPR is a survey method using the properties of electromagnetic waves and their interactions with the ground or the rock. The propagation of electromagnetic waves is described by the Maxwell equation, where two regimes can be distinguished: a diffusion regime associated with conduction phenomena and a propagation regime linked to polarization phenomena. The GPR belongs to the high-frequency (ranging from less than 100 MHz to several GHz) electromagnetic methods in which polarization phenomena predominate.

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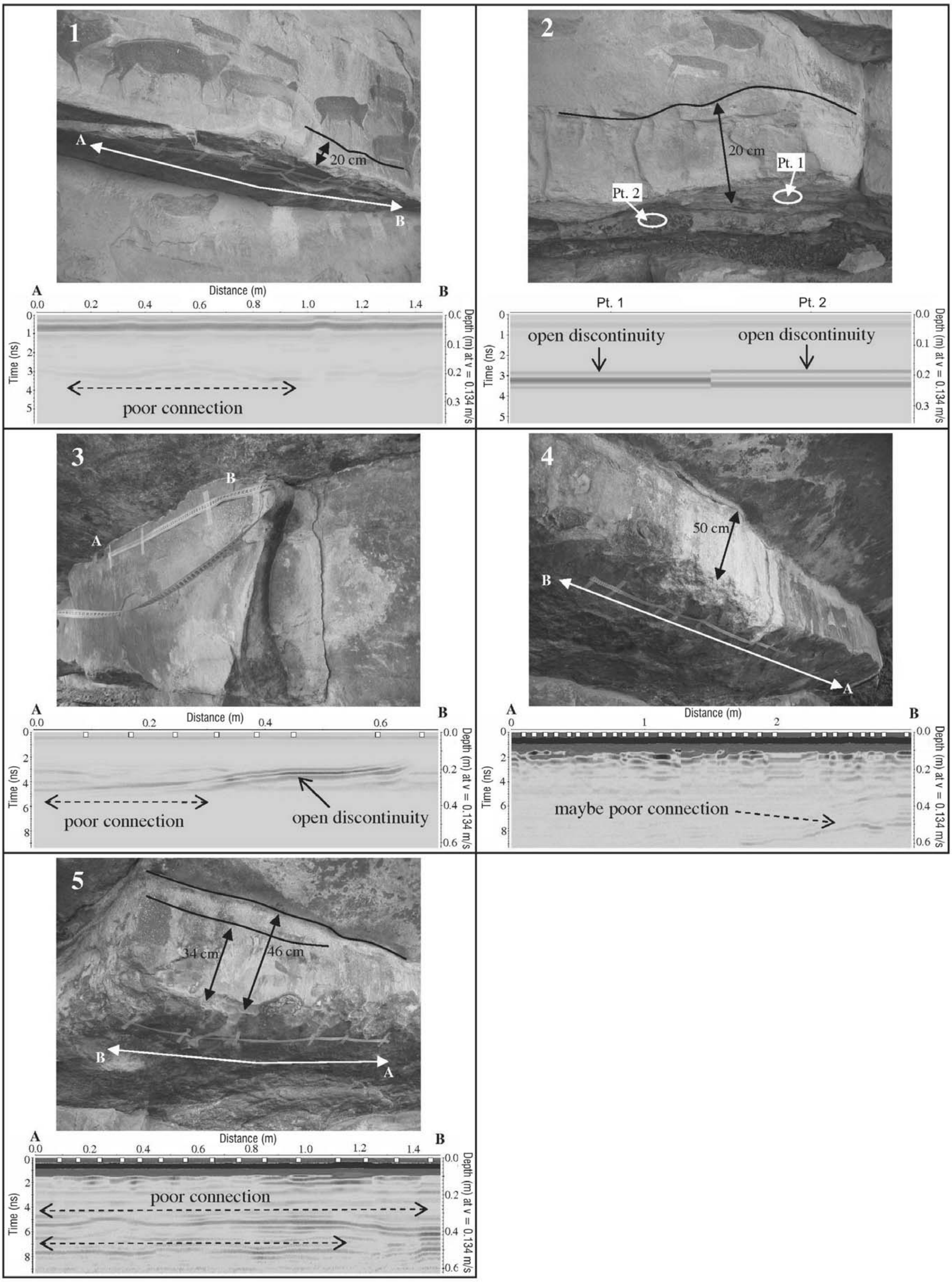

Figs 1–5. **1**, View of the Main Panel and radargram showing the extension in depth of a discontinuity apparent on the surface; **2**, view of the Main Panel and two point measurements showing the opening in depth of a discontinuity that appears closed on the surface; **3**, view of a large slab with several paintings and radargram confirming the detachment of this slab over most of its length; **4**, view of the Dying Eland Panel. Although water seepage (it was dry at the time of the survey) suggests a discontinuity, the radargram fails to show any; **5**, view of the far left of the Dying Eland Panel. The radargram shows two parallel discontinuities developing in depth, and the probable poor attachment of the left part of this overhanging panel. A 2-m measuring tape is shown on all the figures.

On the surface, an emitter antenna sends waves into the ground as very short time pulses. On encountering a discontinuity in the dielectrical properties of the soil, the waves are partially reflected back to the surface where the amplitudes of the reflected waves are measured by a receiver antenna. These readings are a measure of the amplitude of the electrical field resulting from the reflections and diffractions on the dielectrical interfaces, and are a function of the propagation time of the waves. Their analysis gives access to the electromagnetic and physical properties of the soil.

The results are first given as a raw radargram (or time section), in which the amplitude of each signal, coded as colour levels, is shown as a function of the propagation time (vertical scale). The horizontal scale shows where the signals are recorded on the surface. The first step in the processing of these raw data is to build an interpreted radargram (or depth section), where the vertical scale of time is replaced by a scale of depth (e.g. Fig. 1). This is implemented from the knowledge of the speed of propagation of electromagnetic waves in the studied medium.

A Geophysical Survey Systems Inc. Subsurface Interface Radar 2000 (GSSI SIR-2000) detector (model DC-2A/3400) was used in this study. The frequencies used are around 1.5 GHz, which allow investigation depths varying between one and 80 cm, depending on the resistivity of the soil. The electromagnetic waves have no harmful effects on the rock or the paints. Measurements can be made as continuous sections or on a point, according to the fragility of the rock studied or the presence of art.

Before any investigation of the stability of painted rock walls, tests (not reported here) were made to determine whether the equipment could be used on Clarens sandstones. These preliminary tests, to determine the depth of penetration of the electromagnetic waves and the possibility of identifying the discontinuities of interest for conservation, showed that the GPR can detect: (i) rock scales of small width (10–20 cm), (ii) the presence of moisture in clayey joints, and (iii) at greater depths the presence of open cracks which might destabilize entire rock blocks.

Results

A wave of high amplitude, nearly continuous over the entire profile, is clearly shown between 20 and 25 cm (Fig. 1), consistent with a thin clay joint locally visible on the surface. This important discontinuity is a risk for the conservation of the panel located just above which carries most of the paintings of the site. Although no sign of short-term instability is so far visible on the surface, the radargram indicates that the joint lacks cohesion. It also shows that infiltration water passes through this joint, thus potentially increasing the instability of the panel.

Because the rock geometry does not allow a continuous profile under this layer, two point measurements were made instead. These measurements show the presence of an interface between 18 and 25 cm (also visible on the surface) that goes deep into the rock (Fig. 2). Although it appears closed on the surface, where no sign of short-term instability has yet appeared, the radar image shows that the interface is clearly discontinuous in depth.

Figure 3 shows a slab with a significant detachment visible to the naked eye. The aim of the radar measurement was to evaluate the detachment in depth and over the entire length of the slab. The radargram shows that the slab is detached over its entire length and with potential short-term instability. A radargram recorded of an area with water seepage, suggesting the possibility of an open discontinuity, failed to confirm, after processing, a clear discontinuity (Fig. 4). The blurred shape of the radargram results from strong amplification of the waves that increases measurement noise. Nevertheless, the strong amplification on part B (the zone with maximal oozing) possibly shows a discontinuity at about 50–60 cm. At the time of the measurement (during austral spring), the surface was dry and no water was seeping, which may explain the poor contrast.

The aim of the measurement depicted in Fig. 5 was to confirm the presence of an open discontinuity (at the layer upper joint) possibly causing instability of the overhanging slab. When the signal is strongly amplified, the radargram shows the probable presence of two interfaces, detected at 35 and 50 cm. The joints observed on the surface are, therefore, continuous in depth and contain moisture, as they are easily detected by radar.

Discussion

The radar investigations carried out at GP have demonstrated the usefulness of GPR in assessing the conservation condition of a rock art site. The best results are obtained with: (i) clayey sedimentary joints, (ii) open tension joints, (iii) joints saturated with percolating water. The GPR is, however, not able to show shallow discontinuities such as superficial scales because the signal from the first centimetres of the ground are perturbed by direct waves of strong amplitude ('near-field zone').

The contrast on the radargrams is increased by the presence of water or air within the discontinuities. This preliminary investigation was carried out during the dry season. Better results might be expected during the wet season when percolating waters may circulate along major cracks or saturate argillaceous joints and allow a stronger contrast in the reflection of the electromagnetic waves. This is likely to be the case where marks left by seeping water were observed but that were dry at the time of the investigation.

Most of the sources of instability investigated at GP with ground penetrating radar are more related to the geological characteristics of the site than to weathering processes. From this point of view, the vulnerability of the numerous thin bluish clayey joints can be considered as a potential short-term risk to the conservation of the rock art. The GPR clearly underlines the poor cohesion of these sedimentary joints and the risk of damage to painted panels that they represent.

Conclusion

Tests and measurements made at GP demonstrate that the GPR met its objectives; namely, to determine the existence of scale detachments behind the surface and the deeper opening of discontinuities between layers without any danger to the paintings. This technique complements information obtained by a visual observation of the walls.

It is now possible to undertake precise monitoring focusing on the most unstable parts of the painted panels. At GP special attention should be paid to the evolution of the thin clayey joints, as they constitute the main source of instability of the rock layers. Gauges may be installed to follow the opening of the discontinuities identified as potential sources of instability, thus allowing for timely remedial action.

We thank for their financial support the French Ministry of Foreign Affairs, Suzanne Ward (Xharo Award 2004) and the Faculty of Science, University of the Witwatersrand (individual research grant 2004). This project also benefited from the help of Amafa aKwaZulu Natali and Ezemvelo-KZN Wildlife, which granted the required permits, and would not have been possible without the collaboration of all the staff from Kamberg Nature Reserve.

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