Electrical imaging of peridotite weathering mantles as a complementary tool for nickel ore exploration in New Caledonia

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SUMMARY

The first 2-D electrical resistivity tomography (ERT) survey on the well explored (for Nickel ore) lateritic mantle of a new Caledonian ultramafic massif shows a good fit between the geoelectrical sections and the core loggings.
Data collected along several 1 km long profiles, with 10 m electrode spacing to reach about 100 m penetration depth, are reliable and the preliminary interpretation of resistivity models indicates :
- well-defined geoelectrical layers with significant resistivity contrast,
- a very good fit of the above layers with the various units of a weathering mantle, i.e. ferricrete, saprolite and bedrock,
- the suspected geometry of horizons, deduced from core logs, is better defined by the continuous ERT imaging,
- a transverse (section to section) continuity of saprolite troughs and bedrock ridges along N140° strike, which is the main structural feature of Tiebaghi ultramafic massif.
2D Electrical Resistivity Tomography appears to be an appropriate geophysical method to investigate the structure of weathering mantles of ultramafic massifs in New Caledonia. It should become a useful complementary tool to locate favourable zones, i.e. the saprolite horizon where Ni accumulation can be found, or, at least, to economize on drillings.

Key words: Electrical Resistivity Tomography, Weathering profile, Ore nickel site, New Caledonia.

INTRODUCTION

In New Caledonia, the overburden cover of ultramafic massifs mostly consists of a more or less thick and complete weathering mantle. A knowledge of the weathering lateritic horizons is important for groundwater and mineral investigations. On the average, ore extracted from both saprolite and limonite contains about 2.6 and 1.5 wt% nickel (dry ore), respectively. The contact between barren ultramafic fresh rock and the various mineralized weathering units is very irregular and consequently a good knowledge of the fresh rock topography is needed to investigate the geometry of the units.
Surface electrical measurements have been used for many years to identify and delineate the sub-surface features in areas of complex geology (Palacky and Kadekaru, 1979; Van Overmeeren, 1989) where the use of other techniques is unsuitable. Electrical resistivity tomography, or ERT, (Griffiths and Barker, 1993) differs from the conventional electrical approach in using a large array of electrodes and in recording the maximum number of independent measurements on the array. The apparent resistivity data set can then be directly imported into a computer-inversion program that generates images of resistivity distribution. Bulk resistivity as measured by ERT is strongly dependent on the presence and the abundance of mineral particles and fluids. If other factors (pressure and temperature, for example) controlling the bulk resistivity are static in time, a sequence of resistivity images can provide possibly quantitative information on the different degrees of weathering of a rock. ERT already gave a good image of the geometry of the weathering horizons in the African geological context (Ritz et al., 1999; Beauvais et al., 1999).
In this paper, we explore the possibility of using ERT at the Tiebaghi minesite (Northern New Caledonia) in detecting potential mineralized geological structures. The main aim of this work is to provide valuable information to mineral exploration that previously had to be distilled from drilling alone. Our purpose here is to present examples and applications of the method on weathering mantles related to nickel concentration and to compare the ERT images with drilling results.

GEOLOGICAL SETTING

More than one third of the surface of the main island of New Caledonia (SW Pacific) consists of ultramafic (UM) rocks. They were emplaced as a giant ophiolitic nappe by obduction of oceanic mantle over the New Caledonia - Norfolk continental ridge during the upper Eocene orogenic phasis. Due to the combined effects of isostatic post-orogenic uplift, gravity, erosion and neotectonics, UM rocks are now distributed in many massifs having various elevations: a large southeastern massif and smaller ones along the northwestern coast (fig. 1).
A thick lateritic mantle (10 to 100 m) more and less eroded, depending on the geomorphological location, overlies UM rocks. Lateritization processes induce drastic chemical transformation of the peridotite; magnesia and part of silica are progressively leached when Fe, Cr, Al and Ni accumulate, usually in the upper part of saprolite. The quality of the Ni ore and consequently its industrial process depends on the nature of the weathering horizons. Four main horizons form the complete weathering profile: At the base, within the saprolite (coarse grain saprolite, Trescase, 1975), the peridotite is partially weathered, Ni is mainly associated to residual serpentine, subamorphous oxy-hydroxides and neoformed smectite. This "saprolite ore" presents average Ni content of 2 to 3%. Above, the limonite (fine grain saprolite, Trescase, 1975) is mainly formed of Fe-oxy-hydroxides; the silicate minerals are completely leached. Within this "limonite ore"

the average Ni+Co content fluctuates between 1 to 2%. The ferricrete zone caps the profile.

Tiebaghi UM massif is located in the north of New Caledonia. It is a west dipping klippe of peridotite, resting eastwards on the Cretaceous Poya basaltic terrane and westwards on the low grade metamorphic (HP) Eocene Paleocene sediments. Harzburgite is the main peridotite "facies" (lithology) with abundant dunite, pyroxenite and gabbro layering or intrusive bodies; but lherzolite is also found in some parts of the massif. Apart from the initial mantle structures, UM rocks are crossed by numerous serpentinized thrusts and late N140 steep normal faults. Tiebaghi massif forms a westwards gently sloping plateau of 12 x 7 km culminating at 584 m. The studied area called "Dôme" is located on the western side of the plateau and presents a complete lateritic weathering profile. According to geological mapping and the numerous drill data, the bedrock topography is very undulated.

The aim of this study is to validate the ERT method to obtain a 2D image of the lateritic mantle with its various weathering horizons and consequently to get a better knowledge of the special distribution of saprolite where ore is found.

SURVEY RESULTS AND INVERSION OF THE DATA

Electrical measurements were performed using the ABEM Lund Imaging System with an array of 64 stainless steel electrodes spaced at a 10 m interval. Data have been collected along the five lines labelled T1, T2, T3, T4, and T5 in the figure 1. Lines are over 1 km long, 40 m spaced, and were surveyed using a Wenner electrode configuration. The field data, transferred to an external PC, were classically presented in the form of pseudo-sections (Edwards, 1977) that give an approximate picture of the subsurface resistivity below the survey lines.

Field data are then inverted using the interpretation software RES2DINV (Loke, 1999) that generates a detailed two-dimensional (2D) true-resistivity section. The program uses a nonlinear least-squares optimization technique to obtain the inversion of apparent resistivity (Loke and Barker, 1996). Furthermore, the topographic variations have been incorporated in the inversion processing.

Results of the inversion along the 5 lines, as shown in the figure 1, indicate the following common resistivity properties: (i) a highly resistive (800-1500 Ω.m) surface layer from 5 to 20 m thick; (ii) a conductive zone (10 to 80 Ω.m) characterized by the blue colour in the figure 1, which can reach a thickness of 50 m, and (iii) a resistive basement with an undulated surface topography, from 20 to 70 m depth, the resistivity of which increasing with depth. Note that between the resistive "red" surface layer and the conductive "blue" one, a thin "yellow-green" intermediate resistive (100 – 300 Ω.m) zone can be distinguished, which thickens when the conductive zone get thinner.

The electrical structure along the 5 lines describes low resistivity troughs and high resistivity ridges. Note that the resistive surface layer thickness is well-correlated with these troughs and ridges, increasing and decreasing respectively.

Finally, the figure 1 clearly indicates a transverse (section to section) continuity of "troughs and ridges" structures along a N140° strike.

DISCUSSION AND CONCLUSION

"Dôme" area has been intensively drilled by SLN mining company since 70's. Most of ERT lines correspond to drillholes lines. Then, a comparison between resistivity distribution results and core logs can be done, as shown in figure 2 for line T1. A very good fit can be observed between the electrical layers and the four main horizons forming the complete weathering profile. Then, the weathering profile can be interpreted in term of resistivity. From the bottom to the top, we can identify:

-The bed-rock, which the resistivity ranges from 100 to 3000 Ω.m, increasing with depth. Note that the great range of resistivity values inside the bed-rock can be interpreted in term of serpentinisation and fracturation of the peridotite, that is confirmed by core logs in the area.

-The saprolite horizon, with a resistivity ranging from 10 to 300 Ω.m. The distinction between limonite and saprolite is well evidenced by core logs (Diamond Drilling Hole) in the figure 1 but is also well defined by in-situ resistivity measurements in these area, from which the resistivity of the limonite ranges from 100 to 300 Ω.m in the survey area. Nevertheless, the boundary between limonite and saprolite is blurred along a continuous gradient and not fixed. In fact, the saprolite is less resistive than the limonite. The very low resistivity of the saprolite (< 30 Ω.m) can be explained by a higher clay (smectite) content or a high groundwater content, or any combination of both.

-The ferricrete zone, with a resistivity ranging from 600 to 1500 Ω.m. Although its soft lower part is less resistive than the ferricrete, it is difficult to electrically distinguish the boundary between these two units.

To conclude, the first 2-D electrical resistivity tomography (ERT) survey on the well explored lateritic mantle of Tiebaghi ultramafic massif indicates well-defined geoelectrical layers with significant resistivity contrast. There is a good fit between the geoelectrical sections and the core loggings of the weathering mantle horizons, i.e. ferricrete, saprolitic horizons and bedrock.

All ERT lines show low resistivity troughs and high resistivity ridges, corresponding to saprolite deepening and bedrock highs respectively. A transverse (section to section) continuity of the trough and ridge structures appears along a N140° strike, which is the main structural feature of "Dome" as well as for Tiebaghi massif and even of the New-Caledonia island itself (see figure 1). Well-known N140° extensional structures is a factor controlling the weathering process: open fracturing favors meteoric fluid circulation and thickens the weathering profile, the ferricrete horizon and particularly the saprolitic horizons. Saprolite troughs are probably located above the major N140 normal faults cutting across Tiebaghi massif, which are also sites of most important fluid circulation.

Then, 2D Electrical Resistivity Tomography appears to be an appropriate geophysical method to investigate the structure of weathering mantles of ultramafic massifs in New Caledonia. It should become a useful complementary tool for mining exploration. In preliminary phases, to better emplace exploration wells and later, when ore contents are confirmed, to help imaging ore deposits for better driving the exploitation.

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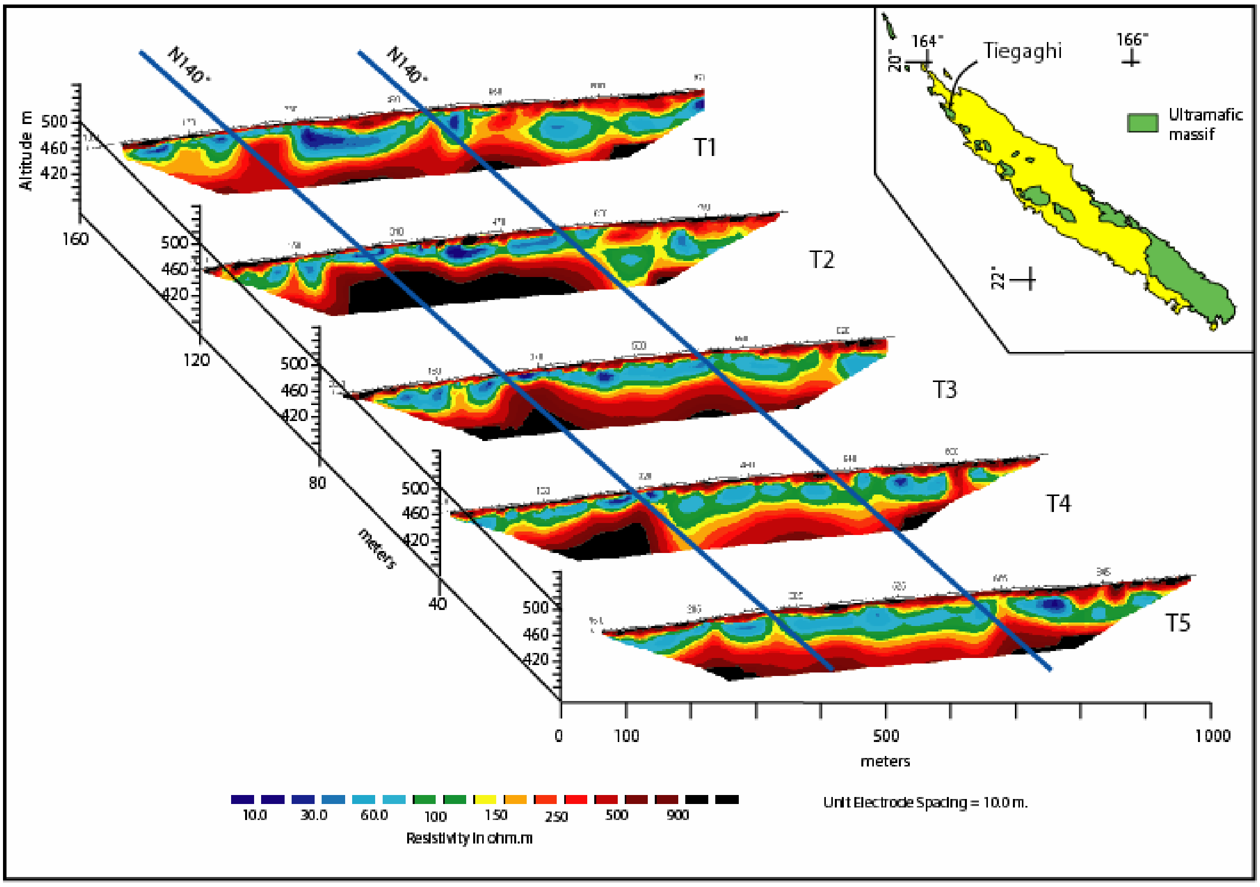

Figure 1. Five Electric Resistivity Tomography (ERT) parallel geoelectrical section, 1 km long and 40 m spaced, on the Tiebaghi ultramafic massif (northern New Caledonia, see location on map) covered by a "complete" lateritic mantle.

Figure 2: Comparison between ERT results and associated core logs along line T1. Concerning core logs, white lines represent the ferricrete/limonite boundary, pink lines the limonite/saprolite one and black lines the saprolite/bed-rock boundary.