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New Method in Telluric Prospecting for Detecting Deep Conductors, Not Intersecting with Wells: Application in the Rouez Region (France)

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ABSTRACT. This research introduces a recent telluric logging methodology in the field of mineral prospecting for the detecting of deep conductors, not intersecting with well. This method is characterized by its big deep penetration, compared with the conventional surface geoelectrical methods and through boreholes. The proposed telluric method consists of measuring two telluric fields. The first one is horizontal and obtained at the surface using a reference line (E_{EW} & E_{NS}). The second one is vertical (E_V) and obtained in the well between two mobile electrodes *M* and *N*. The ratio between the horizontal and vertical telluric fields (E_V/E_{EW} & E_V/E_{NS}) is of interest in this research work. The application of this method at the Rouez Mine in France permits a location of several conductors not intersecting with the studied well No. 32. The presence of these conductors is approved by morphological and lithological description. The well-known macroanisotropy phenomenon is demonstrated in the studied area, where it has been found that longitudinal resistivity ρ_{EW}, obtained according to the reference line of EW direction is less than transverse resistivity ρ_{NS}, obtained according to the reference line of NS direction. A wide telluric anomaly at the depth of 140 m has been detected, which could be related to an equivalent conductor sphere. The horizontal distance between this conductor and well No. 32 is estimated to be 70 m. The new telluric configuration is important in mining prospecting, since its application decreases considerably the well number needed for the detecting of spreaded conductors and gives rapidly an idea about the distribution of the conductors in the plan. More tests at the theoretical and practical levels are still needed to make this configuration adapted and easily used in geophysical prospecting.

Introduction

Since not long time ago, the used techniques for mineral prospecting allowed only to discover surfacial mines. Recently, the development of structural and applied geophysics has made the exploiting of very deep mines possible. Today, it is necessary to develop several methods to investigate very deep mines, but unfortunately the physical nature of phenomenon, which allows the detection from surface, has raised a real problem related to the penetration depth. In fact, it is impossible in most cases to conduct and to determine mineral body, having more depth than its dimension. Thus, it is urgent to use few drill holes to know and to evaluate such mineral body. Wells drilling stage comes after the application of surface geoelectrical measurements. Usually, geophysicists interpret the results by trying to get the highest quantity information as possible as they could. This will lead finally to determine the location of the well that should be drilled. Unfortunately, the first well can not reach the objective body due to the existence of many bodies or overburden having a high conductivity. Morefurther, the high depth of the body complicates the problem from an interpretation point of view. In attempt to obtain accurate results regarding the identification of mineral body, the geophysicists have been trying for a long time to use the wells for conducting geophysical measurements through them. In fact, the using of wells allows obtaining more depth penetration than that obtained by surface geoelectrical methods. The reached depth penetration is not expected to be more than 30 cm around the well. However, and with a good accuracy, it is enough to know the nature of the penetrated formation by the well. But the adjacent and far formation from the well can not be indicated by the conventional resistivity well logging. Recent geophysical researches are directed towards the development of new methods to investigate mainly deep conductive bodies existed nearby but not intersected with the studied well, and concentrating on reducing the well number and here lies the importance of such methods from an economic point of view.

The main purpose of this paper is to use the natural electric field to obtain the necessary information about the vicinity of drill holes. Field experiences have shown that the signal neither requires any amplification nor impedance adaptation between 1 and 2500 Hz. In other words, the galvanic response for the previous frequencies is always preponderant with respect to the inductive one, and thus D.C. consideration is applied to such measurements. Herewith, a new telluric configuration using, a reference line at the surface, is theoretically investigated to specify the characteristics of obtained anomaly, in the case of a conductive sphere, not intersecting with the well, and undergoing to uniform electrical field. The proposed configuration is tested and applied in the Rouez mine in France (Asfahani, 1989), where sulfurous mineralisations are known to be occurring in this region.

Characteristics of the New Telluric Configuration

The new telluric method through wells, introduced in this research, is derived from the telluric-telluric methods, applied from the ground surface (Slankis *et al.,* 1972). In general, the telluric method is based on the comparison between two telluric fields, measured simultaneously at two points. In this new method applied in the wells, two horizontal and vertical telluric fields are measured (Asfahani, 1989):

1 – The horizontal telluric field is measured at the surface, using a reference line.

2 – The vertical telluric field is measured in the well between two movable electrodes.

The telluric probe, used in the field, contains several electrodes for measuring the potential, which permits to choose the suitable electrode configuration to be applied.

A theoretical study was carried out to know the characteristics of telluric curves obtained in the case of presence of a conductive sphere not intersecting with the well, and undergoing to the uniform and horizontal field. The induction phenomenon in low frequencies is widely negligible comparing with galvanic one. Therefore, this simplicity allows using the consideration of D.C. during this theoretical study. The potential expression at the exterior of a conductive sphere has the following formula (Asfahani, 1989).

$$V(z) = -E_0 r \operatorname{Cos}(\theta) \left[1 - \frac{\rho_2 - \rho_1}{\rho_2 + 2\rho_2} \cdot \frac{a^3}{(d^3 + z^2)^{3/2}} \right] \tag{1}$$

Where

$$d = r \operatorname{Cos}(\theta) \tag{2}$$

and d, being constant; the potential expression can be, therefore, written as follows

$$V(z) \approx K \frac{d}{(d^2 + z^2)^{3/2}} \tag{3}$$

where

$$K = E_0 \frac{\rho_2 - \rho_1}{\rho_1 + \rho_2} \cdot a^3 \tag{4}$$

It is obviously clear, that the telluric response depends on the geometric of the chosen configuration. Therefore, the potential can be computed as a function of depth $V(z)$, by using the relationship (3). The gradient of the resulting potential is determined, taking in consideration the distance between the two movable electrodes M and N, by which the potential difference is measured.

The geometry of the studied model and the parameters used in this research are shown in Fig. 1. This figure indicates the following:

1 – The presence of two maximum points.

2 – The distance between these two points is the same theoretical distance supposed between the well and the sphere center "*d*".

3 – $\frac{E_v}{E_0}$ at the depth, which corresponds to the theoretical depth of the sphere, center "z" is equal to zero.

4 – The results presented in 2 and 3 are very important to interprete the obtained telluric field curves later on.

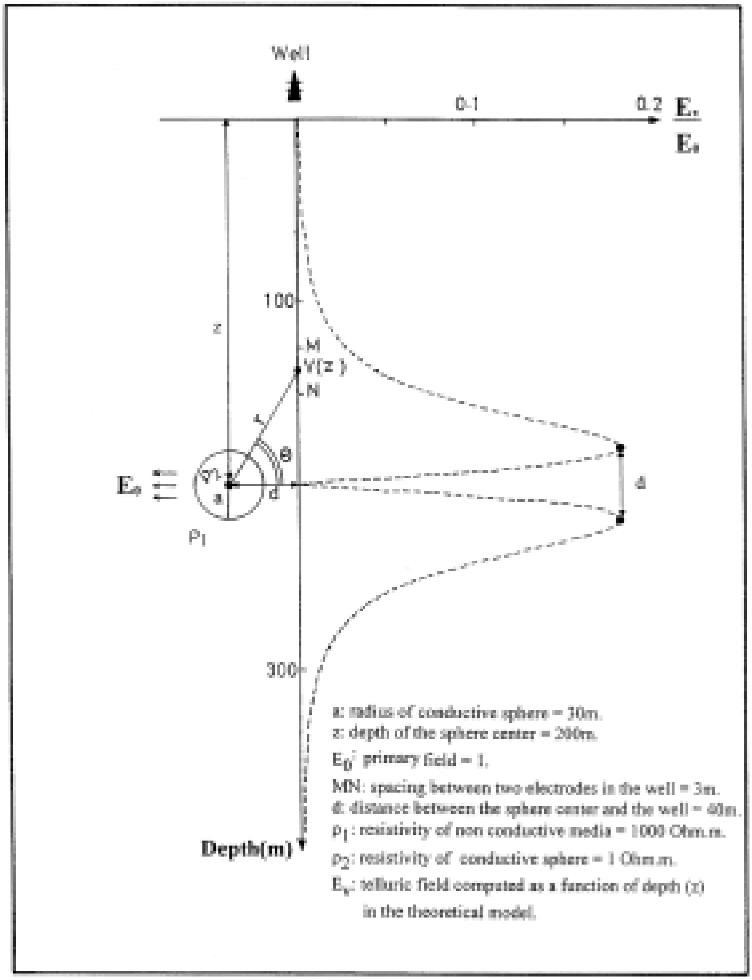

FIG. 1. Geometry of a conductive sphere and its telluric gradient response.

Geological Setting

The massive sulfurous ore body of Rouez region, which occurs in the clastic formations of Upper Prioverian, is ouctropping among Coevron synclines in North and Laval syncline in South. These synclines are of Paleozoic age. This zone is related to the southern-eastern margin of Mancelian, that characterized by granodiorite intrusive of cadomian. Figure 2 shows the study area and its geology. On local and regional scale, the Prioverian Formations consist of alternation of greywacke-silt-argilosilt and interbedding of scattered lenses of infratraformational conglomerates observed in Rouez. These formations have undergone a moderate deformations accompanied by low-grade metamorphism, which may be attributed to varsique orogeny.

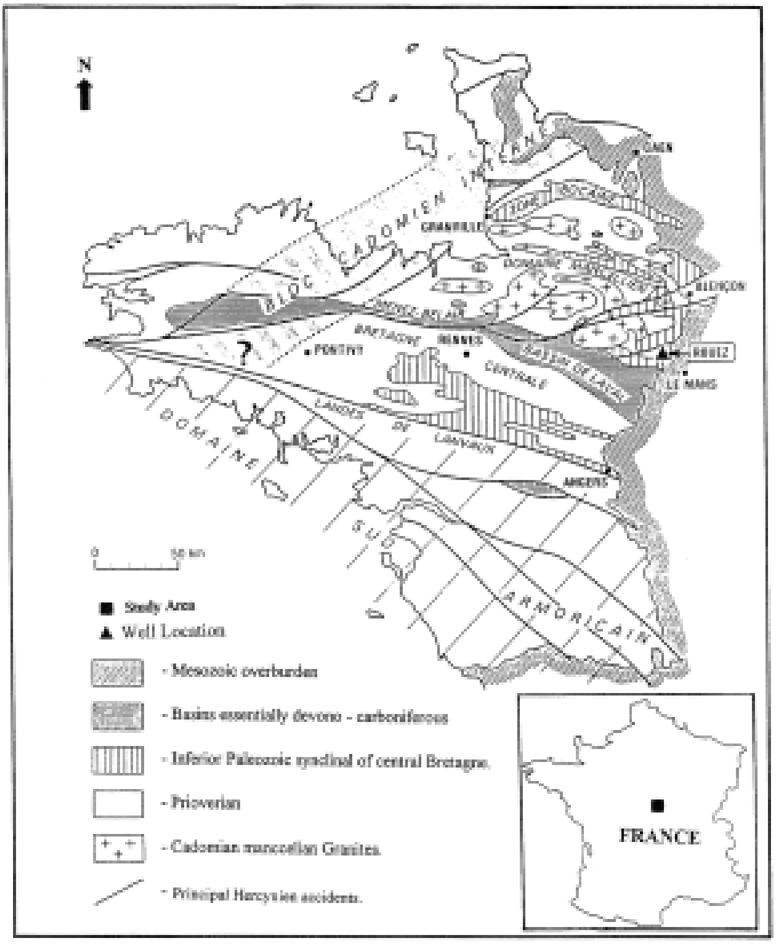

FIG. 2. Study area and its geological features.

Geological data acquisition of the mineralized zone and adjacent formations have been achieved through the boreholes that allowed performing geometric and stratigrapbic study for 30 to 40 m depth in these formations. These mineralizations are stratiform type encountered in the lithological succession of argilo-silt, Grey-wacke and schist, along with hydrothermal facies of laminated sericite arglite-sandstone-argilite comprising pyrite. Major components of the ore body are pyrite-peridotite sedirite-sphalerite-chalcopyrite and galena. Schistosity-stratigraphy interrelation study applied to core samples and correlation among the boreholes have contributed to the determination of the ore body, its morphology and the adjacent formations. This ore body consists of 100-300 m lengths of lenses with an estimated thickness of 10 m lying conformably with the bedding planes.

Measurements Executed

The objective of this research work is to develop geophysical prospecting methodologies for the detecting of deep conductors around and not intersected with wells. Therefore, several kinds of geoelectrical survey are executed in well 32. These are:

1 – Resistivity measurements, using different electrode configurations.
2 – Induced polarization measurements in time and frequency domains.
3 – Hole to surface measurements.

Figure 3 shows the locality of this well on the gravimetric map, which indicates clearly the presence of positive remarkable zone of 2.6 milligals. The average density of the host rock is 2.7 g/cm^3, while the density of the sulfurous mass is 4.9 g/cm^3 (*i.e.*, the contrast is in order of 1.9 g/cm^3). The residual value derived from Bouger anomaly by simple eliminating of plan indicates a mineral body with inclination towards the North. The position of well 32 related to the mineral body is shown in Fig. 4 (Fromaigeat, 1985).

The studied depth in this well is still vertical until 300 m, therefore, no corrections for the executed measurements are needed to be carried out.

- Beyond 300 m, the well begins its deviation; so the measurements are stopped at this depth. In this research, the focus is only on the telluric measurements obtained by using the TT12 instrument. It is the same that can be used in the telluric-telluric profiling executed on the surface (Pham *et al.,* 1978). This sophisticated equipment is originally manufactured for the simple type magnetotelluric measurements. It allows the amplitude measurement of electric and magnetic component fields to be obtained, at 12 discrete frequencies, ranged between 3 Hz and 2.5 kHz. This wide range of frequencies can be used for several applications depending on the chosen frequency. Therefore, this equipment is a powerful tool in the mineral, volcanic, and geothermic domains. It is easily used in the field, and its originality is related to the fact that it can be used at the same

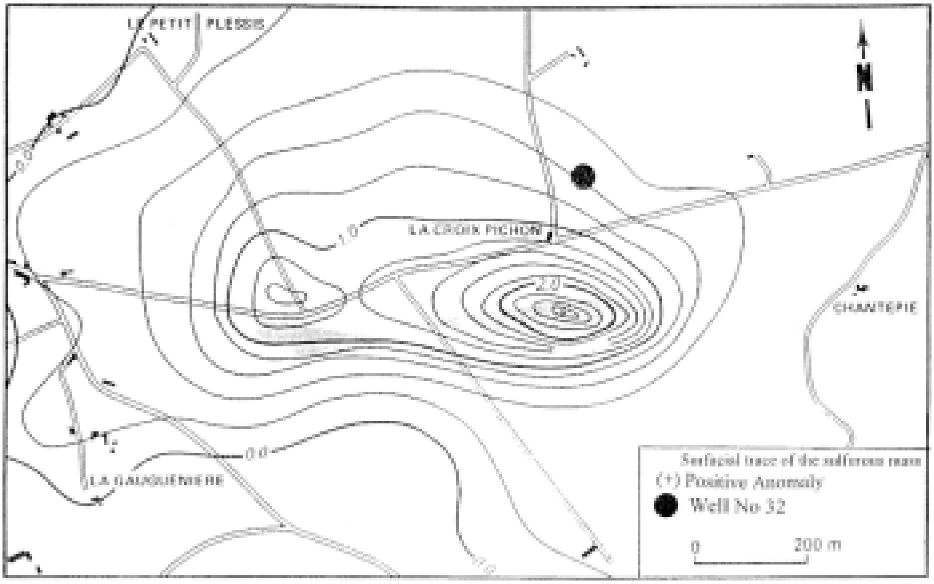

FIG. 3. Well location on gravimetric contour map (Fromaigeat, 1985).

time for the magnetotelluric and telluric-telluric profilings. This equipment is composed of two identical boxes; each of them treats only one component (magnetic or electric). In this research, one box is used for collecting the telluric measurements at the surface, using a reference line and the other one is used for measuring the vertical telluric field in the borehole. The two components could be obtained simultaneously for the four gammes of frequencies, ranged as the following:

Gamme 1: 3Hz, 5Hz and 8Hz.
Gamme 2: 13Hz, 21Hz and 34Hz.
Gamme 3: 90Hz, 200Hz and 400Hz.
Gamme 4: 700Hz, 1200Hz and 2500Hz.

The first gamme has been used for collecting our telluric measurements in the Rouez mine.

Results and Discussions

In the field of Rouez mining, two kinds of directional telluric measurements were executed:

1 – The first is by using a telluric reference line taking EW direction. According to this direction, both the horizontal telluric field (E_{EW}) at the surface and the vertical telluric field in the well (E_V) are measured.

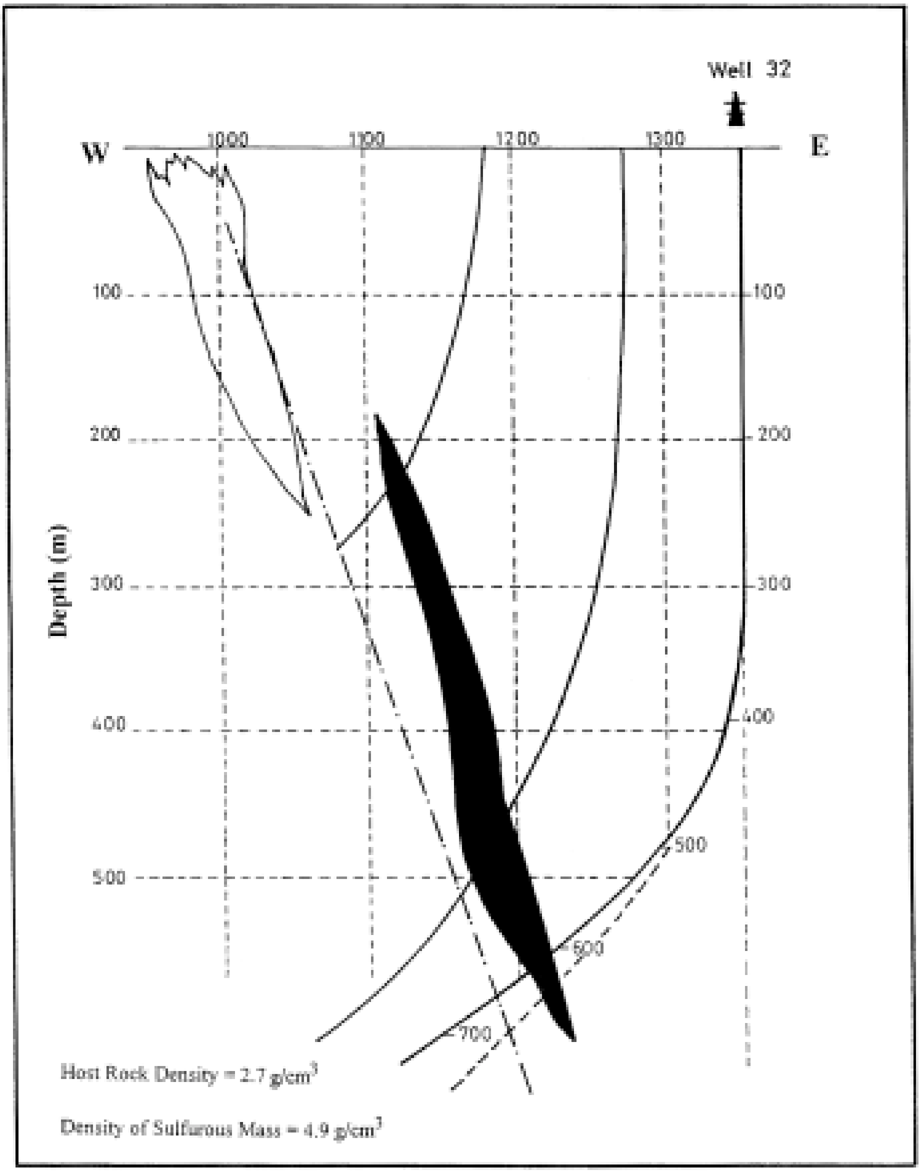

FIG. 4. Bore hole 32 relative to the detected ore body (Fromaigeat, 1985).

2 – The second is by using a telluric reference line taking NS direction. According to this direction, both the horizontal telluric field (E_{NS}) and vertical telluric field in the well (E_V) are also measured.

The ratio between the horizontal and vertical fields (E_V/E_{EW} & E_V/E_{NS}) is interesting in this work. The telluric field in the homogeneity media is horizontal and uniform, because the sources of the telluric field are considered to be too far (Cagniard, 1953). Therefore, the obtainment of vertical component of this field indicates the presence of inhomogenous underground. The role of the proposed telluric method is to determine its characteristics, including essentially the depth and the distance between the center of this inhomogeneity and the studied well.

The distance between the two electrodes of telluric measurements at the surface is chosen to be 100 m, while the spacing *M N* between the two movable electrodes in the well, is chosen to be 10 m. Figure 5 shows the obtained telluric measurements in well 32, presented as (E_V/E_{EW} & E_V/E_{NS}) for the three frequencies used 3Hz, 5Hz and 8Hz.

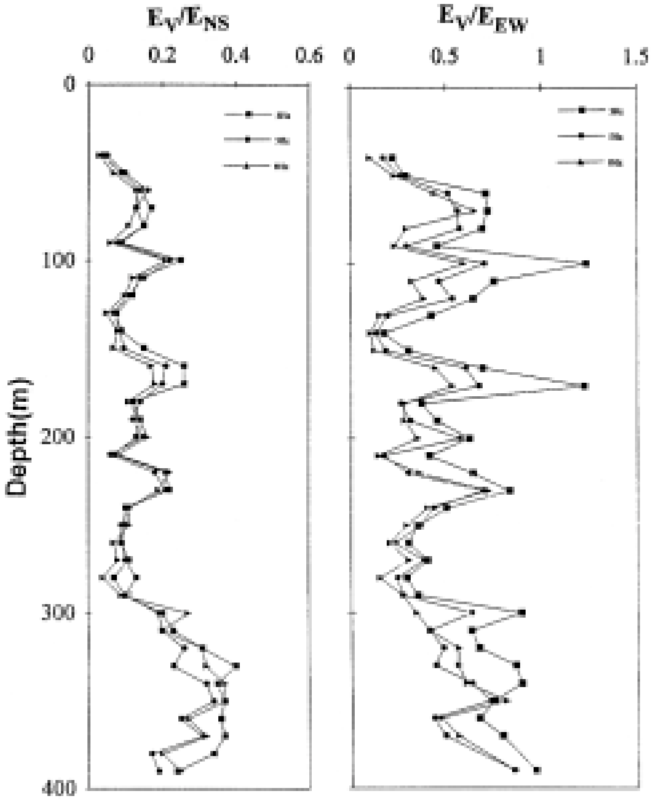

FIG. 5. NS & EW telluric-telluric measurements through well 32 for 3, 5 and 8 Hz.

For all the telluric curves obtained according to the two directions EW and NS for the three frequencies, it is immediately observed that:

$$\frac{E_v}{E_{NS}} \langle \frac{E_V}{E_{EW}} \Rightarrow E_{NS} \rangle E_{EW} \tag{5}$$

This result reflects the anisotropy characteristics of host rocks, which take vertical position and are parallel to the EW direction. According to this direction, the resistivity nominated longitudinal ρ_{EW} is less than the resistivity nominated transversal ρ_{NS}, which indicates the well-known macro-anisotropy phenomenon.

All the telluric field curves take the same shape for all the used frequencies. This result is very important, because it enhances the confidential of the measurements. The comparison between the points of minimum values on the telluric curves and the results of conventional resistivity logging at the sites of the same points indicates the following:

1 – The minimum points indicated on the telluric measurements at depths 180, 210 and 280 m are characterized by decreasing the resistivity values on the conventional resistivity logging, short normal (RLN) and long normal (RLN), (Fig. 6). This indicates the presence of conductive paths at these depths. Another clear anomalies were also obtained, by using the induced polarization method in the frequency and time domains (Asfahani, 1989). The induced polarization measurements are carried out by applying a special geoelectrical configuration with a geometrical factor of 2.67 m. This configuration consists of injecting the electric current between two electrodes A and B spaced 10 m, and measuring the potential difference between other two electrodes M and N spaced 3 m, all the four mentioned electrodes are logged in the well. Figure 7 shows a clear anomaly of chargeability at the 5*th* window (CH5) and percent frequency effect (PFE). The resistivity measurements conducted by the same configuration indicate a low resistivity value at the depth of 210 m.

2 – At the depth of 140 m, a wide anomaly is detected in all telluric curves (Fig. 5). At the same time, no decreasing of resistivity is noticed at this depth in the conventional resistivity logging, which can be interpreted only by the presence of a conductor, not intersecting with the well under study. The telluric-telluric method described above could detect this conductor, due to its high depth penetration compared with conventional resistivity logging. It is possible to represent this conductor as an equivalent sphere, not intersecting with the well. The distance between the center of this equivalent sphere and well No. 32 is estimated as equal to 70 m. This result is obtained according to the distance between the two maximum points observed in the telluric field curves on one hand, and depending on the modeling results of the theoretical study discussed in this paper, on the other hand.

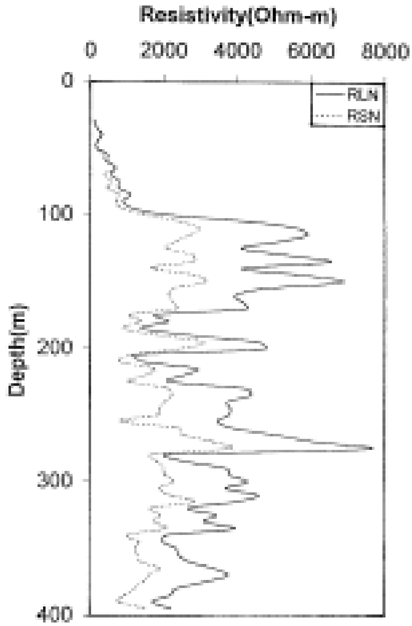

FIG. 6. Conventional electrical resistivity well-logs (RLN, RSN).

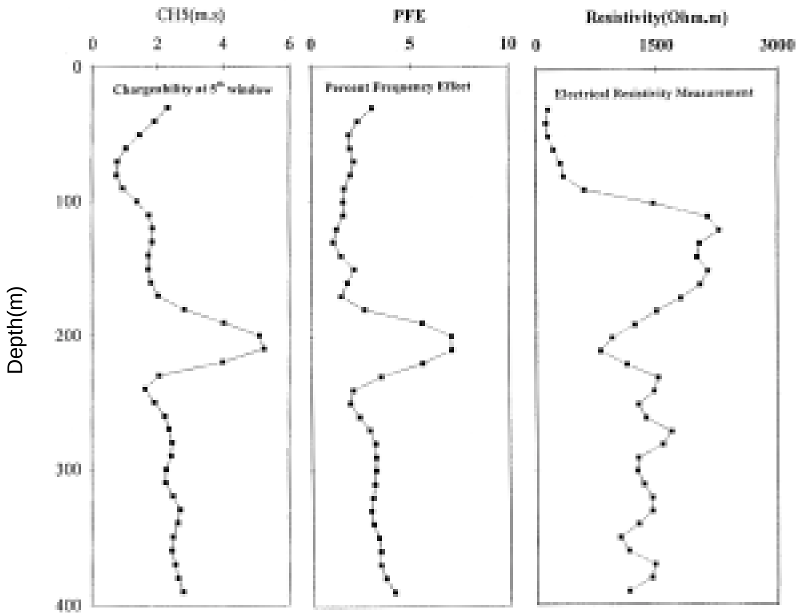

FIG. 7. Chargeability, percent frequency effect and electrical resistivity measurement through well No. 32.

3 – All the detected conductors by both the telluric-telluric method and the conventional resistivity logging, indicate probably that these conductors have lateral extension more important than the conductors detected only by conventional resistivity logging.

Figure 8 indicates the conductors detected by the telluric-telluric and other geoelectrical methods applied in this research. These conductors are:

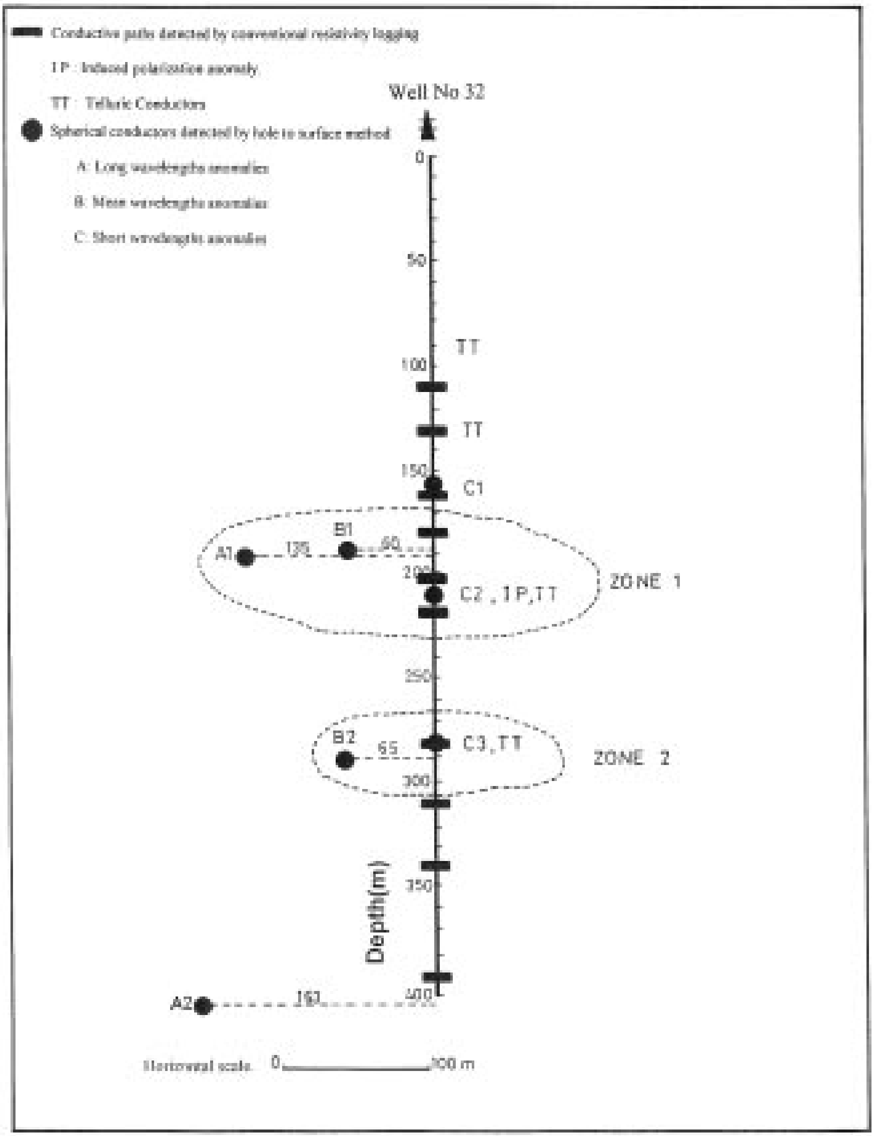

FIG. 8. Detected conductive bodies.

- The ten conductive paths, which are intersected with well 32, at the depths of (110, 130, 165, 180, 200, 220, 280, 310, 340 and 390 m) and are detected by conventional resistivity short normal (RSN) and long normal (RLN).
- The conductor "IP" detected by the induced polarization method at the depth of 210m.
- The conductors detected by the telluric-telluric method at the depths of (140, 180, 210 and 280 m) discussed previously.
- Three types of conductors detected by the application of hole to surface method are also presented. The first type of these conductors is identified as C1, C2 and C3 at the depths of 180, 210 and 280 m respectively. These conductors are characterized by short wavelengths, and their existence is confirmed by geoelectrical well logging short and long normal (RSN, RLN). The second type of these conductors characterized by mean wavelengths is identified as B1 and B2 at the depths of 190 and 285m respectively. The third type of these conductors characterized by long wavelengths is identified as A1 and A2 at the depths of 190 and 413m respectively. These two conductors have an origin, which is difficult to be precisely determined, or could be related to the tectonic effect. The hole to surface method which is characterized by its deep penetration and directional effect will be introduced by another paper, including theoretical and practical study (Asfahani, 2001). Figure 8 shows also two separated mineralization zones, (Zone 1 and Zone 2) distinguished at the depths of 200 and 280 m respectively. The conductors in these zones are detected by several geoelectrical methods. In fact, each of these methods is characterized by its specific depth penetration. Thereby, these two separated zones correspond probably to the conductors, having big lateral extension. Therefore, the integration of these geoelectrical methods together permits a clear idea about the distribution of conductors around the well.

Conclusion

The importance of the new telluric electrode configuration, proposed in this researsh for detecting of deep conductors not intersecting with well is demonstrated. This configuration is characterized by its high depth of penetration, compared with conventional resistivity logging. Its economic importance is approved, since it decreases the well number, which is necessary for the detecting of spreaded conductors. The application of this configuration gives an idea about the sites of conductors in the plan, which allows proposition of a suitable plan to extend the prospecting zone in the studied area. This telluric configuration is considered to be in a test stage; therefore, several researches have to be conducted at two levels. At the theoretical level, the treatments of telluric signals, and the interpretation of the results obtained in the field have to be concerned. At the practical level, this configuration shoud be applied in the well-known mining zones for the determination of its effective detection and making it an active configuration, easily used in mining and prospecting fields.

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طرق جديدة في التنقيب التلوري ، لتحديد الموصلات العميقة ، التي لم تخترقها الآبار مع التطبيق في منطقة روز (فرنسا)

جمال أصفهاني

هيئة الطاقة النووية ، قسم الجيولوجيا ، دمشـــق - ســـوريـة

المستخلص. يقدم هذا البحث طريقة حديثة لتسجيل التيارات الأرضية (تيلوري) في مجال التنقيب عن المعادن لتحديد الموصلات العميقة ، التي لم يخترقها البئر . تتميز هذه الطريقة بسبرها لأعماق كبيرة بالمقارنة بالطرق الجيوكهربية السطحية ومن خلال الآبار المعروفة . تشمل طريقة التيارات الأرضية (التيلورية) المقترحة قياس المجالين الأرضيين الأفقي والرأسي ، الأول يقاس على السطح على طول خط مرجعي (E_{EW} & E_{NS}) ، والثاني (الرأسي E_V) يقاس في بئر بين قطبين متحركين M, N . النسبة بين المجالات الرأسية والأفقية (E_V/E_{EW} & E_V/E_{NS}) هي محل اهتمام هذا البحث . وبالتطبيق في منجم روز في فرنسا أمكن تحديد أماكن موصلات عديدة لا يخترقها البئر الذي تم منه القياس رقم ٣٢.

هذه الموصلات معروفة مسبقًا من خلال الوصف المورفولوجي والصخري . ولقد وضح جليًا في هذه الدراسة ، مفهوم عدم التماثل المعروف حيث وجد أن المقاومة الطويلة ρ_{EW} المسجلة على الخط المرجع E-W هي أقل من المقاومية المستعرضة ρ_{NS} المسجلة على الخط المرجعي NS. بناءً على ذلك تم التعرف على شاذة واسعة عند عمق ١٤٠ متر تتعلق بموصل كروي الشكل . المسافة بين هذا الموصل والبئر ٣٢ قدرات بحوالي ٧٠ متر . لذلك ترجع أهمية هذه الطريقة الجديدة في التنقيب المعدني ، حيث يؤدي تطبيقها إلى التقليل من حفر الآبار لتحديد الموصلات الموجودة ، كما تعطي هذه الطريقة فكرة سريعة عن توزيع الموصلات في المنطقة . ومع ذلك يحتاج الأمر إلى اختبارات نظرية وعملية أكثر لجعل هذه الطريقة مناسبة وسهلة الاستخدام في مجال التنقيب الجيوفيزيائي .