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Application of electrical tomography technique for landslide investigation: Case of the Kef Essenoun phosphate deposit, Djebel Onk (Northeastern Algeria)

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The enormous development of the technology of raw material extraction drives the economic companies and technicians to make efforts to meet the needs of consumers. These efforts directly influence the nature, creating voids or cavities in the soil and subsoil inducing a structure disturbance and subsequently giving damages. A landslide of the Kef Essenoun phosphate deposit occurred in 2007 when large mass of rocks detached caused a number of undesired and negative effects. To analyze this deformation, a two-dimensional (2D) electrical tomography with the Wenner and Schlumberger device was deployed, using equipment of Syscal Pro 48 type for the implementation of an electrical profile, through a transect length of 140 m with electrode spacing of 3 m and a depth of investigation that measures 32 m to the center. Data processing was performed using RES2DINV software and the results allowed mapping visible cracks with a high resistivity value of 890 Ω m as well as low values of 6 Ω m for marls and clay. In addition, to predict the extent of cracks (slip) and geological formations. These phenomena have been evidenced due to tectonic (rough terrain) on one side and sliding on the other.

Keywords: landslide, Kef Essenoun, electrical tomography, resistivity, crack

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1 Introduction

Undesirable effects have been often left due to the abusive exploitation of mineral resources, conducted to meet the increasing demand of the world market. The extraction of these resources, which is generally the result of damaging the ground, is accompanied with the collapse of underground structures or landslides in open pit mining [*Nouioua et al.*, 2015].

The complexity of the geological phenomena plays a crucial role in causing landslides that negatively affect the environment [*Perrone et al.*, 2014]. A landslide is essentially the sudden or gradual release of rocks under the effect of gravity [*Israil and Pachauri*, 2003].

The geological and hydrological conditions generally characterize landslide phenomena [*Sastry et al.*, 2006]. The intrinsic state or internal behavior of the landslide plays a primordial role, and the complex state of many landslides requires detailed knowledge of their characteristics in order to determine the actual conditions of their stability [*Bichler et al.*, 2004].

Estimating the creation of the landslide requires a deep understanding of the geological and geotechnical conditions of the landslide. Therefore, the non-invasive geophysical methods are very effective and accurate in the study of landslides [*Pasierb et al.*, 2019]. The information obtained from the geophysical surveys is used as input data to define landslide terrain models and consequently to perform slope stability assessment [*Hussain et al.*, 2019].

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In applied geophysics, different tools that can be deployed to gather valuable subsurface data, namely seismic reflection and refraction [*Hack*, 2000], gravimetry [*Gaudio et al.*, 2000; *Perrone et al.*, 2012], georadar [*Borecka et al.*, 2015; *Jongmans and Garambois*, 2007] and electrical resistivity tomography [*Fehdi et al.*, 2011]. The latter is considered the most used in landslides investigation [*Sigdel and Adhikari*, 2020].

The electrical resistivity tomography or electrical imaging [*Boubaya et al.*, 2017] is a geophysical prospecting technique which is well adopted in the structural study of landslides and in the attempts to understand their internal mechanisms of deformation and rupture [*Bouaziz and Melbouci*, 2015]. It provides high-resolution 2D or 3D electrical resistivity variation images of geologic formations [*Jomard et al.*, 2010]. This technique is based on the assumption that subsurface geological materials exhibit significant resistivity contrasts that can be identified on the bases of surface measurements [*Arjwech and Everett*, 2015].

The Kef Essenoun landslide (Northeastern of Algeria) that occurred in 2007 is a fait accompli, but the cracks that appear in the perimeter of the mine's operations remain an unpredictable risk and are probably a sign of another possible landslide. The aim of this study is to present the results of a geophysical survey in order to map the different geological formations of the landslide (fissures, marl, phosphate, limestone) on the basis of their resistivities, obtained using electrical tomography.

2 General setting

Algerian phosphates in the Djebel Onk basin are related to Tertiary marine deposits. This mining basin contains five phosphate deposits: the Djemi-Djema deposit, Djebel Onk North, Kef Essenoun, Bled El Hadba and Oued Betita. The Kef Essenoun deposit is located in southeastern Algeria, 9 km south-east of the city of Bir El Ater and 20 km to the Algerian-Tunisian border (Figure 1) [*Dassamiour et al.*, 2013]. The phosphate deposits in Jebel Onk region are of Upper Thanetian age. A series of three major faults of NNO–SSE direction cross the Jebel Onk deposit with no major deformations in the geometry of the phosphate layer [*Dassamiour et al.*, 2021].

The Kef Essenoun deposit is located at the southern bottom of the Djebel Onk mountain series. The latter is in the form of a limestone massif of 20 km lenght and 3 km width, oriented from E–W to ENE–WSW and culminates at 1192 m altitude at Djebel Tarfaya. The maximum height of the crest of the Kef Essenoun deposit exceeds 900 m. It is made up mainly of limestone rocks, from which the slope gradually decreases down to the mining site (700 m). This ridge is dominated by a massive Maastrichtian limestone escarpment nearly of

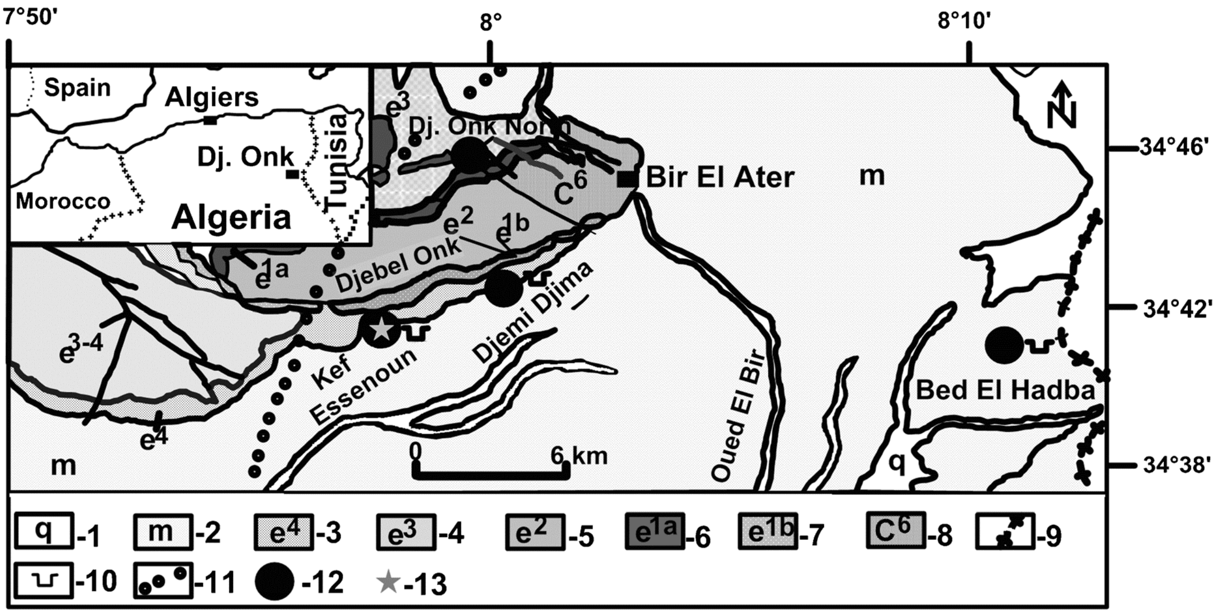

Figure 1: Schematic geological map and location of Djebel Onk phosphate deposits [*Dassamiour et al.*, 2021; *Kassatkine et al.*, 1980]. 1 – alluvial deposits (Quaternary); 2 – sand and clay (Miocene); 3 – marl and limestone (Lutetian); 4 – marl and limestone with phosphate level (Ypresian); 5 – marl, limestone, dolomite and main phosphate layer (Thanetian); 6 – coquina limestone and marl (Montian); 7 – marl and limestone (Danian); 8 – limestone (Maastrichtian); 9 – Algerian-Tunisian border;10 – open pit; 11 – Shallow of Ain Fouris: western limit of the main phosphatic layer;12 – phosphate deposits; 13 – Kef Essenoun phosphate deposit (study area).

Figure 2: Landslide of the study area.

100 m high [*Mezam and Assed*, 2017]. The geology of this deposit is mainly composed of a succession of Ypresian flint dolomitic limestone, locally overlain by Lutetian limestone, Miocene sands and Quaternary Alluvium [*Fredj et al.*, 2019; *Rais et al.*, 2017].

In 2007, the Kef Essenoun landslide contained the most dangerous open pit mining activity in Algeria (Figure 2) [*Fredj et al.*, 2017]. A rock mass that has fallen completely into the pit is estimated at around 11 ha, including 30 m of the productive layer and 40 m of the waste rock cover [*Fredj et al.*, 2018] Depending on the shape of the rupture surface, the slip first appears as a circular landslide (Figure 3). However, the rupture mode that occurred in the Kef Essenoun pit is classified as a structural (planar) landslide [*Gadri et al.*, 2015].

3 Electrical resistivity tomography technique

The electrical resistivity tomography technique (ERT) is based on the measurements of the distribution of apparent resistivity and the variations in the electric field. These have been artificially generated through a system of electrodes [*Mita et al.*, 2018]. The measurement of the resistivity of a structure is carried out through injecting an electric power into it by means of injection electrodes (electric power electrodes) and through measuring the potential difference created by the passing of the electric power by means of potential measuring electrodes (potential electrodes). The number of electrodes, as well as their arrangement defines the electrical device used. The configuration of the device is chosen according to the problem of the study and the electrodes can be used on or below the ground surface [*Marescot*, 2006].

In tomography, the main devices commonly used are the Wenner, pole-pole [*Berge and Drahor*, 2009], the Wenner-Schlumberger dipole-dipole [*Hermawan and Putra*, 2016]. In Figure 4: an example that shows the possible sequence of measurements for the Wenner Schlumberger configuration with 20 electrodes. The distance between two electrodes, n is the number of measurement level, (C1 and C2) are two electric power electrodes and (P1 and P2) are two potential electrodes.

The apparent electrical resistivity ρ_a can be expressed on the basis of the potential difference (ΔV) and the electric power intensity (I), with a geometric coefficient (K) linked to the configuration of the electrodes [*AL-Hameedawi et al.*, 2021; *Bellanova et al.*, 2016]:

$$\rho_a = K\frac{\Delta V}{I}$$

The obtained values of the apparent resistivity provide a first tomographic image of the electrical structure of the subsoil, called "pseudo-section". Then, the measurements of apparent resistivity are processed using inversion methods to obtain a synthetic model of the real electrical resistivity [*Perrone et al.*, 2006]

4 2D tomography acquisition

A 2D tomography requires a number of electrodes connected to a multi-conductor cable and placed in a profile. A laptop, in which the measurement sequence is programmed, is connected to the electronic switch box and automatically selects the electrodes used for electric power injection and potential measurement. Each electrode has a unique numerical address in the device, which allows it to be identified by the computer [*Loke*, 1999].

In our case study, we used the Wenner-Schlumberger device. The latter was preferred to other configurations due to its good vertical resolution and wider horizontal data coverage [*Aigbogun et al.*, 2020].

The sequence is developed using the Electre Pro software. The profile is carried out in a way perpendicular to the axis of the movement of the ground from south-east to the North-west over a length of 140 m with 48 electrodes and a spacing of 3 m of which the depth of investigation is around 32 m (Figure 5). The Syscal Pro Switch 48 is the device to carry out the profile. The results being transferred to Prosys II, the data obtained is processed and interpreted using the RES2DINV software.

5 Results and Discussion

The analysis of the geophysical profile (Figure 6) have confirmed the presence of cracks in the depth

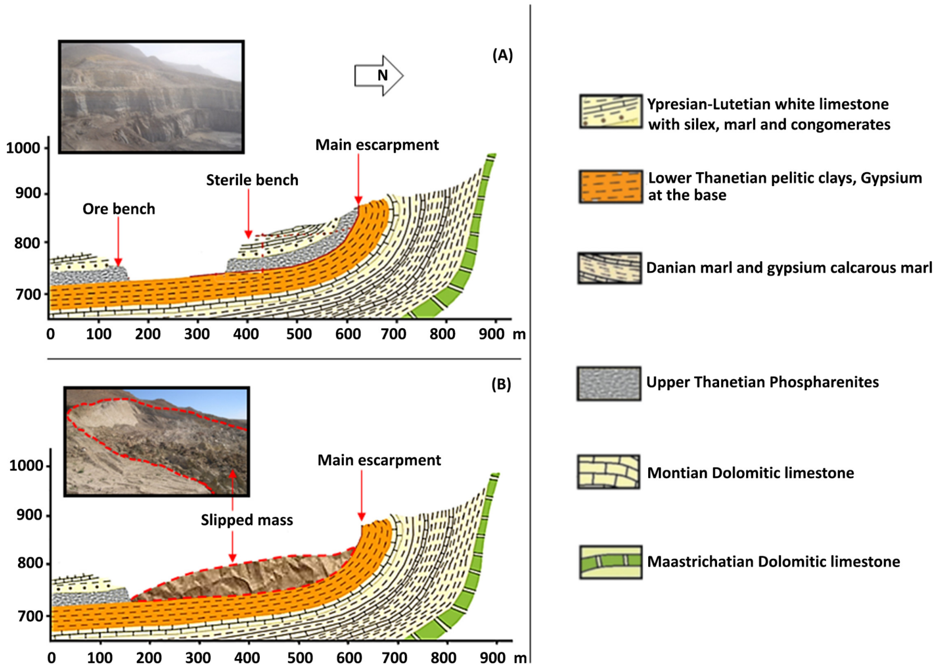

Figure 3: Geological section of Kef Essenoun deposit before (A) and after sliding (B) [*Fredj et al.*, 2020].

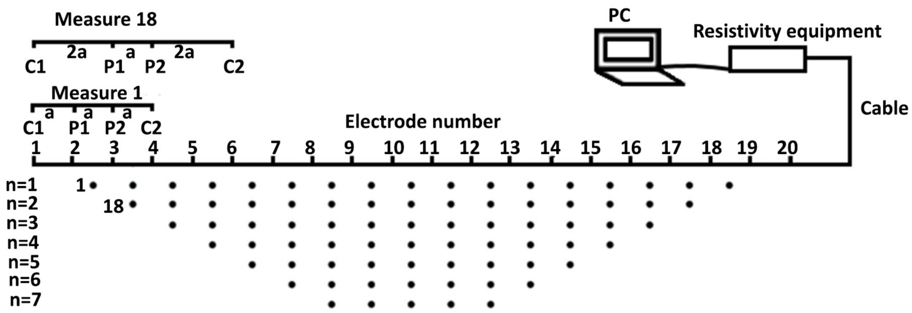

Figure 4: The Wenner–Schlumberger configuration and the sequence of measurements collected [*Jiang et al.*, 2020].

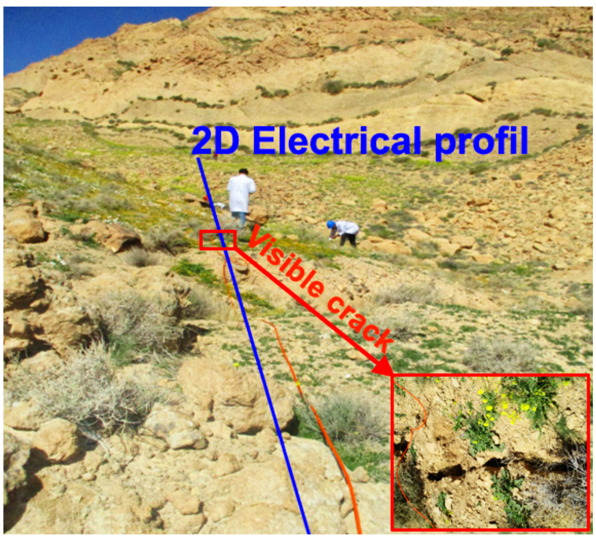

Figure 5: Photo showing the realized profile through the crack.

attributed to faults of tectonic origin resulting from the rugged terrain of the region in the northern flank which is called the dressers of Kef Essenoun. The faults might be also resulting from landslide which probably triggers new fault post. As of the large gap between electrode 3 and 8 on the left side of the profile, it was filled by a foreign body. This body is probably Thanitien marls penetrating into the cavity left by the marly limestones.

For the second fault between electrode 22 and 24, two phenomena appear in the center of the profile, one is the collapse caused by two parallel faults and the other is the penetration of the marl into the void created by the marly limestone. The resistivity of 890 Ωm was obtained at the level of the cracks observable on the surface corresponds to voids created under the effect of landslide, the phosphate layers have a resistivity value of 222 to 445 Ωm; the marly limestones have a value of 55.6 to 111 Ωm; and the marly clays have a value of 6.95 to 27.8 Ωm.

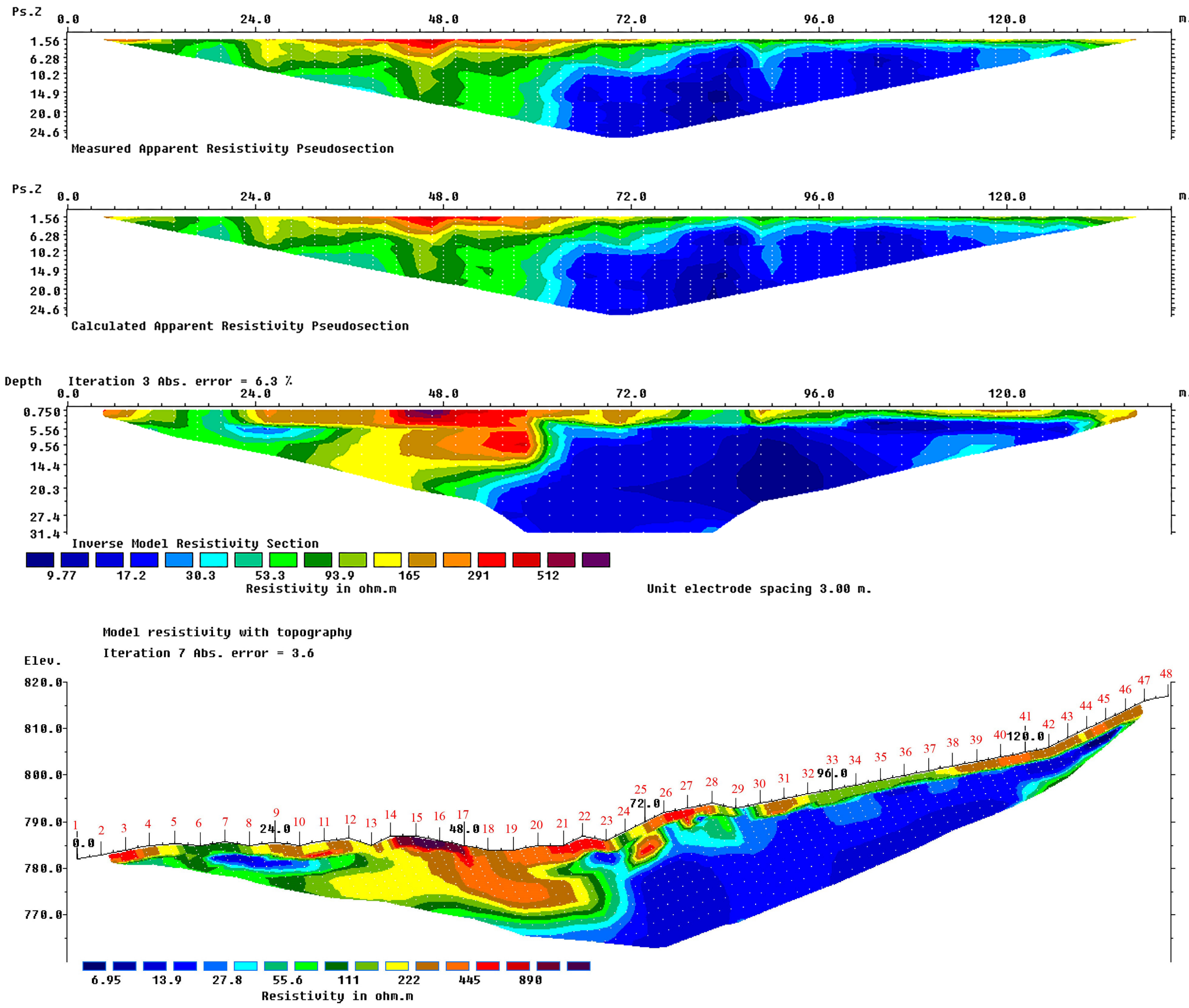

Figure 6: Results of a geophysical survey (ERT) carried out on a landslide of the Kef Essenoun Phosphate deposit.

The surface alluvial layer overlies a significant thicker one of marl, where cracks become less detectable by resistivity, probably due to the nature of the rock. Landslides usually occur suddenly, but the essential clues are the cracks that appear on the surface, which give the idea to do a geophysical survey to know the continuation and the level of the landslide risk.

6 Conclusion

In order to analyze the soil and the subsoil deformations, a geophysical investigation using electrical tomography was conducted in the Kef Essenoun phosphate deposit (Northeastern of Algeria), This which gives resistivities in the faults or cracks positions that go up to 890 Ω m which is considered as a conductive formation against marly and clayey formations with a resistivity of low conductivity (6 Ω m). The faults detected either on the surface or in depth are attributed to the tectonics of the region (very rugged terrain). However, it must be noted that the landslide caused in 2007 plays a major role in triggering these faults, which are ready to wake up at any time.

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References

Aigbogun, C. O., D. A. Babaiwa, and B. J. O. Mujakperuo (2020), Application of 2-dimensional tomography to investigate subsurface lithology in Auchi polytechnic, auchi, Edo state, nigeria, *Nigerian Journal of Technology*, *39*(3), 905–910, doi:10.4314/njt.v39i3.32.

AL-Hameedawi, M. M., J. M. Thabit, and F. H. AL-Menshed (2021), Some notes about three types of inhomogeneity and their effect on the electrical resistivity tomography data, *Journal of Applied Geophysics*, *191*, 104,360, doi:10.1016/j.jappgeo.2021.104360.

Arjwech, R., and M. Everett (2015), Application of 2D electrical resistivity tomography to engineering projects: Three case studies, *Songklanakarin Journal of Science and Technology*, *37*(6), 675–681.

Bellanova, J., G. Calamita, A. Giocoli, R. Luongo, A. Perrone, V. Lapenna, and S. Piscitelli (2016), Electrical Resistivity Tomography surveys for the geoelectric characterization of the Montaguto landslide (southern Italy), *Natural Hazards and Earth System Sciences Discussions*, pp. 1–17, doi:10.5194/nhess-2016-28, (preprint).

Berge, M. A., and M. G. Drahor (2009), Optimum Electrical Resistivity Tomography (OERT) approach using combination of different arrays in archaeological investigations, *ArcheoSciences*, (33 (suppl.)), 263–265, doi:10.4000/archeosciences.1667.

Bichler, A., P. Bobrowsky, M. Best, M. Douma, J. Hunter, T. Calvert, and R. Burns (2004), Three-dimensional mapping of a landslide using a multi-geophysical approach: the Quesnel Forks landslide, *Landslides*, *1*(1), 29–40, doi:10.1007/s10346-003-0008-7.

Borecka, A., J. Herzig, and M. Durjasz-Rybacka (2015), Ground penetrating radar investigations of landslides: a case study in a landslide in Radziszów, *Studia Geotechnica et Mechanica*, *37*(3), 11–18, doi:10.1515/sgem-2015-0028.

Bouaziz, N., and B. Melbouci (2015), The supply of electrical tomography in the study of the landslides in Great Kabylia, Algeria, in *Rencontres Universitaires de Génie Civil*, pp. 1–8, HAL, Bayonne, France.

Boubaya, D., K. Hebbache, L. Gouaidia, F. Baali, C. Fehdi, and O. Guefaifia (2017), 2D Electrical Resistivity Tomography Of An Active Landslide: A Case Study From Ain Torki, Algeria, in *9th Congress of the Balkan Geophysical Society*, pp. 1–5, EAGE Publications BV, doi:10.3997/2214-4609.201702568.

Dassamiour, M., H. Mezghache, and B. Elouadi (2013), The use of three physico-chemical methods in the study of the organic matter associated with the sedimentary phosphorites in Djebel Onk Basin, Algeria, *Arabian Journal of Geosciences*, *6*(2), 309–319, doi:10.1007/s12517-011-0381-9.

Dassamiour, M., H. Mezghache, O. Raji, and J.-L. Bodinier (2021), Depositional environment of the Kef Essennoun phosphorites (northeastern Algeria) as revealed by P2O5 modeling and sedimentary data, *Arabian Journal of Geosciences*, *14*(12), 1–17, doi:10.1007/s12517-021-07400-z.

Fehdi, C., F. Baali, D. Boubaya, and A. Rouabhia (2011), Detection of sinkholes using 2D electrical resistivity imaging in the Cheria Basin (north-east of Algeria), *Arabian Journal of Geosciences*, *4*(1–2), 181–187, doi:10.1007/s12517-009-0117-2.

Fredj, M., A. Hafsaoui, Y. Khadri, B. Riadh, R. Nakache, A. Saadoun, and K. Menacer (2017), Study of bench stability in the phosphate mine (Algeria), in *Engineering Geology and Geological Engineering for Sustainable Use of the Earth's Resources, Urbanization and Infrastructure Protection from Geohazards*, pp. 101–114, Springer International Publishing, Cham, doi:10.1007/978-3-319-61648-3_7.

Fredj, M., A. Hafsaoui, Y. Khadri, and R. Boukarm (2018), Influence of the failure surface choice on the safety factor value during slope stability studies, *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (3), 30–35, doi:10.29202/nvngu/2018-3/3.

Fredj, M., A. Hafsaoui, R. Boukarm, R. Nakache, and A. Saadoun (2019), Numerical Modelling of Slope Stability in Open Pit Phosphate Mines, Algeria: A Comparative Study, in *World Multidisciplinary Earth Sciences Symposium (WMESS 2018) 3–7 September 2018*, vol. 221, p. 012020, IOP Publishing, Prague, Czech Republic, doi:10.1088/1755-1315/221/1/012020.

Fredj, M., A. Hafsaoui, H. Riheb, R. Boukarm, and A. Saadoun (2020), Back-analysis study on slope instability in an open pit mine (Algeria), *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (2), 24–29, doi:10.33271/nvngu/2020-2/024.

Gadri, L., R. Hadji, F. Zahri, Z. Benghazi, A. Boumezbeur, B. M. Laid, and K. Raïs (2015), The quarries edges stability in opencast mines: a case study of the Jebel Onk phosphate mine, NE Algeria, *Arabian Journal of Geosciences*, *8*(11), 8987–8997, doi:10.1007/s12517-015-1887-3.

Gaudio, V. D., J. Wasowski, P. Pierri, U. Mascia, and G. Calcagnile (2000), Gravimetric study of a retrogressive landslide in southern Italy, *Surveys in Geophysics*, *21*(4), 391–406, doi:10.1023/a:1006793009054.

Hack, R. (2000), Geophysics for slope stability, *Surveys in Geophysics*, *21*(4), 423–448, doi:10.1023/a:1006797126800.

Hermawan, O. R., and D. P. E. Putra (2016), The effectiveness of wenner-schlumberger and dipole-dipole array of 2d geoelectrical survey to detect the occurring of groundwater in the gunung kidul karst aquifer system, Yogyakarta, Indonesia, *Journal of Applied Geology*, *1*(2), 71–81.

Hussain, Y., M. Cardenas-Soto, S. Martino, C. Moreira, W. Borges, O. Hamza, R. Prado, R. Uagoda, J. Rodríguez-Rebolledo, R. Silva, and H. Martinez-Carvajal (2019), Multiple geophysical techniques for investigation and monitoring of Sobradinho landslide, Brazil, *Sustainability*, *11*(23), 6672, doi:10.3390/su11236672.

Israil, M., and A. K. Pachauri (2003), Geophysical characterization of a landslide site in the Himalayan foothill region, *Journal of Asian Earth Sciences*, *22*(3), 253–263, doi:10.1016/s1367-9120(03)00063-4.

Jiang, F., L. Dong, and Q. Dai (2020), Electrical resistivity inversion based on a hybrid CCSFLA-MSVR method, *Neural Processing Letters*, *51*(3), 2871–2890, doi:10.1007/s11063-020-10229-4.

Jomard, H., T. Lebourg, Y. Guglielmi, and E. Tric (2010), Electrical imaging of sliding geometry and fluids associated with a deep seated landslide (La Clapière, France), *Earth Surface Processes and Landforms*, *35*(5), 588–599, doi:10.1002/esp.1941.

Jongmans, D., and S. Garambois (2007), Geophysical investigation of landslides: A review, *Bulletin de la Société Géologique de France*, *178*(2), 101–112, doi:10.2113/gssgfbull.178.2.101.

Kassatkine, Y., A. Yahyaoui, and S. Chatilov (1980), The works of prospecting and assessment on phosphate executed in 1976–1978 in the mining district of Djebel Onk, *SONAREM (Société Nationale de Recherche et d'Exploration Minière) Internal report*, *2*, 140.

Loke, M. H. (1999), *Electrical imaging surveys for environmental and engineering studies*, vol. 2, 70 pp., Apractical Guide to 2D and Surveys, Austin.

Marescot, L. (2006), An introduction to electrical imaging, *Bulletins des séances de la Société vaudoise des sciences naturelles*, *90*(1), 23–40.

Mezam, M. C., and M. A. B. Assed (2017), Etude Retro-analytique du glissement du bord Nord de la mine a ciel ouvert de Kef Essenoun (Djebel Onk), Algerie, *Bulletin of Engineering Geology and the Environment*, *76*(4), 1307–1320, doi:10.1007/s10064-016-0988-x.

Mita, M., M. Glazer, R. Kaczmarzyk, M. Dąbrowski, and K. Mita (2018), Case study of electrical resistivity tomography measurements used in landslides investigation, Southern Poland, *Contemporary Trends in Geoscience*, *7*(1), 110–126, doi:10.2478/ctg-2018-0007.

Nouioua, I., C. Fehdi, D. Boubaya, B. Serhane, and A. Djellali (2015), Mapping underground cracks using 2D electrical resistivity tomography: the case of the landslide of Kef Essenoun phosphate deposit, Djebel Onk (northeast of Algeria), *Arabian Journal of Geosciences*, *8*(10), 7731–7738, doi:10.1007/s12517-014-1769-0.

Pasierb, B., M. Grodecki, and R. Gwóźdź (2019), Geophysical and geotechnical approach to a landslide stability assessment: a case study, *Acta Geophysica*, *67*(6), 1823–1834, doi:10.1007/s11600-019-00338-7.

Perrone, A., G. Zeni, S. Piscitelli, A. Pepe, A. Loperte, V. Lapenna, and R. Lanari (2006), Joint analysis of SAR interferometry and electrical resistivity tomography surveys for investigating ground deformation: the case-study of Satriano di Lucania (Potenza, Italy), *Engineering Geology*, *88*(3–4), 260–273, doi:10.1016/j.enggeo.2006.09.016.

Perrone, A., S. Piscitelli, and V. Lapenna (2012), Electrical resistivity tomographies for landslide monitoring: a review, pp. 129–134, Geologische Bundesanstalt, Wien.

Perrone, A., V. Lapenna, and S. Piscitelli (2014), Electrical resistivity tomography technique for landslide investigation: A review, *Earth-Science Reviews*, *135*, 65–82, doi:10.1016/j.earscirev.2014.04.002.

Rais, K., M. Kara, L. Gadri, R. Hadji, and L. Khochmen (2017), Original approach for the drilling process optimization in open cast mines; case study of Kef Essenoun open pit mine northeast of Algeria, *Mining Science*, *24*, 147–159, doi:10.5277/MSC172409.

Sastry, R. G., S. K. Mondal, and A. K. Pachauri (2006), 2D electrical resistivity tomography of a landslide in Garhwal Himalaya, in *6th International Conference & Exposition on Petroleum Geophysics "Kolkata 2006"*, pp. 997–1001, SPG, Kolkata.

Sigdel, A., and R. K. Adhikari (2020), Application of Electrical Resistivity Tomography (ERT) survey for investigation of the landslide: a case study from Taprang landslide, Kaski district, west-central Nepal, *Journal of Nepal Geological Society*, *60*, 103–115, doi:10.3126/jngs.v60i0.31261.