Detecting Lithium Mineralizations from Space

Subjects: Others

Contributor: Joana Cardoso-Fernandes, Ana C. Teodoro, Alexandre Lima, Mônica Perrotta, Encarnación Roda-Robles

Optical and thermal remote sensing data have been an important tool in geological exploration for certain deposit types. However, the present economic and technological advances demand the adaptation of the remote sensing data and image processing techniques to the exploration of other raw materials like lithium (Li). A review of the application studies and developments in this field was also made. The addressed topics include: (i) achievements made in Li exploration using remote sensing methods; (ii) the main weaknesses of the approaches; (iii) how to overcome these difficulties; and (iv) the expected research perspectives. We expect that the number of studies concerning this topic will increase in the near future and that remote sensing will become an integrated and fundamental tool in Li exploration.

Keywords: satellite data ; image processing algorithms ; pegmatite ; brine ; lithological mapping ; mineral alteration mapping ; geobotanical mapping

1. Introdcution

Optical and thermal remote sensing data, namely satellite-acquired images, have been an important tool in geological exploration allowing to target exploration areas for more than four decades. The major contribution that remote sensing offers to mineral exploration was reviewed in several works dedicated to this topic [[1][2][3][4][5]]: it provides information in a fairly quick, inexpensive, and non-intrusive way, which favors mining and exploration companies especially in inaccessible remote areas. However, Rajesh [3], in an overview of the use of remote sensing and Geographic Information Systems (GIS) in mineral exploration, points out the difficulty of directly pinpointing mineralizations using only remote sensing data, highlighting the importance of the integration with other types of geological data.

Sabins [[6]], in one of the first reviews about the types of data and image processing methods for mineral exploration, describes two main approaches to target mineral deposits: (i) structural and lithological mapping; and (ii) hydrothermal alteration mapping. Later, Rajesh [[3]] proposed three approaches: (i) lithological mapping; (ii) structural mapping; and (iii) alteration mapping. These approaches have been applied since the 1970s to identify very distinct types of mineral deposits. The more common applications include porphyry copper [[7][8][9][10][11][12][13][14][15][16][17]] and gold [[18][19][20][21][22][23][24][25][26][27][28]] deposits. Other applications may include: iron ore deposits [[19],[29][30][31][32]], volcanogenic massive sulfide ore (VMS) deposits [[33][34][35]], several skarn-hosted deposits [[36][37][38][39]], chromite deposits [[40][41][42][43]], uranium deposits [[39],[44]], rare earth elements (REE) exploration [36][45], brine and evaporite deposits [[46][47]], porphyry molybdenum deposits [[48][49]], zinc-lead (Zn-Pb) deposits [50], diamond [[51]] and bauxite exploration [[52]].

Regarding the types of data used, multispectral products, namely Landsat and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor imagery, played an important part in geological remote sensing [[4],[5][53]. Abrams and Yamaguchi [[54]] reviewed ASTER's contributions to mineral exploration and lithological mapping. The success of the ASTER sensor in geological exploration was mainly due to a higher spectral resolution in the short-wave infrared (SWIR) and thermal infrared (TIR), specially designed for geological applications, which improved its lithological and mineral mapping capabilities, particularly in the identification of alteration minerals [4][55][54],[55]]. The importance of TIR (including ASTER's TIR subsystem) in the discrimination of minerals and rocks was revised by Ninomiya and Fu [[55]]. These authors highlight several studies in which the TIR region was fundamental for mineral discrimination, namely where silicate minerals occur, and reviewed the spectral indices proposed for lithological mapping using ASTER-TIR data. Nonetheless, the advent of hyperspectral remote sensing allowed the direct identification and quantification of specific minerals which represented a key contribution to mineral exploration [3][53]. Cudahy [[4]] in a review on mineral mapping projects for exploration led by Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia, pointed out that hyperspectral remote sensing can be less popular among exploration companies because of limited spatial coverage, the relatively high-cost of quality datasets, and the inherent complexity of hyperspectral data.

2. Influence and application

Despite the successful application of different types of remote sensing data to distinct mineral deposits, the current growing economic and technological advances, which rely on other mineral commodities, highlights the need to use and adapt remote sensing data and image processing techniques on new deposit types. Nowadays, green technologies, like electric vehicles, represent an important sector of the economy [[56]] and lithium (Li) has become a critical metal to the green-power industry [[57][58]]. However, Li exploration with the resource of remote sensing data and techniques represents an emergent field, with several difficulties and unknown possibilities. Taking this into account, this review aims at (i) providing information about what can be accomplished in Li exploration using remote sensing methods; (ii) identifying the main difficulties associated with this kind of deposits; and (iii) providing insights on how to overcome these difficulties as well as future research perspectives. This paper presents the first summary of the developments made in the field of remote sensing applied to Li exploration and we consider it to be timely and appropriate due to the high global demand of this metal to the production of Li-ion batteries [58]. Additionally, this review can help to promote new applications and to solve new exploration problems.

In general, past application studies relied on four distinct approaches: (i) geobotanical mapping; (ii) lithological mapping; (iii) mineral alteration mapping; and (iv) Li minerals/Li pegmatite discrimination. Different types of satellite products with distinct characteristics were employed as well as diverse image processing algorithms ranging from simple logical or mathematical operations (band ratios) to more evolved and complex algorithms like machine learning algorithms.

Despite the early attempt to target Li mineralizations with the launch of the Landsat missions, there is an unequivocal exponential growth on the publication numbers in the last decades. Nonetheless, since it still is an emergent field, the studies are limited to a small number of research groups, mainly based in Europe. However, considering the market demand for this raw material, we expect that many other studies will flourish in the near future all around the globe.

References

1. Stefan Saradeth; Thomas Weißmann; AQUIFER – Remote Sensing as Support for the Management of Internationally Shared Transboundary Aquifers in Africa. *The Future of Drylands* **2008**, , 217-228, 10.1007/978-1-4020-6970-3_26.
2. Meer, V.D. Bakker validated surface mineralogy from high-spectral resolution remote sensing: A review and a novel approach applied to gold exploration using AVIRIS data. Terra Nova 1998, 10, 112–119.
3. H.M. Rajesh; Application of remote sensing and GIS in mineral resource mapping-An overview. *Journal of Mineralogical and Petrological Sciences* **2004**, *99*, 83-103, 10.2465/jmps.99.83.
4. Tom Cudahy; Mineral Mapping for Exploration: An Australian Journey of Evolving Spectral Sensing Technologies and Industry Collaboration. *Geosciences* **2016**, *6*, 52, 10.3390/geosciences6040052.
5. Rejith Rajan Girija; Sundararajan Mayappan; Mapping of mineral resources and lithological units: a review of remote sensing techniques. *International Journal of Image and Data Fusion* **2019**, *10*, 79-106, 10.1080/19479832.2019.1589585.
6. Floyd F Sabins; Remote sensing for mineral exploration. *Ore Geology Reviews* **1999**, *14*, 157-183, 10.1016/s0169-1368(99)00007-4.
7. Maliheh Abbaszadeh; Ardeshir Hezarkhani; Enhancement of hydrothermal alteration zones using the spectral feature fitting method in Rabor area, Kerman, Iran. *Arabian Journal of Geosciences* **2011**, *6*, 1957-1964, 10.1007/s12517-011-0495-0.
8. Charlotte A. Bishop; Jian Guo Liu; Philippa Mason; Hyperspectral remote sensing for mineral exploration in Pulang, Yunnan Province, China. *International Journal of Remote Sensing* **2011**, *32*, 2409-2426, 10.1080/01431161003698336.
9. Inés Di Tommaso; Nora Rubinstein; Hydrothermal alteration mapping using ASTER data in the Infiernillo porphyry deposit, Argentina. *Ore Geology Reviews* **2007**, *32*, 275-290, 10.1016/j.oregeorev.2006.05.004.
10. Ehsan Farahbakhsh; Hodjat Shirmard; Abbas Bahroudi; Taymor Eslamkish; Fusing ASTER and QuickBird-2 Satellite Data for Detailed Investigation of Porphyry Copper Deposits Using PCA; Case Study of Naysian Deposit, Iran. *Journal of the Indian Society of Remote Sensing* **2016**, *44*, 525-537, 10.1007/s12524-015-0516-7.
11. Mahdieh Hosseinjanizadeh; Majid H. Tangestani; Mapping alteration minerals using sub-pixel unmixing of ASTER data in the Sarduiyeh area, SE Kerman, Iran. *International Journal of Digital Earth* **2011**, *4*, 487-504, 10.1080/17538947.2010.550937.

12. Mahdieh Hosseinjanizadeh; Mehdi Honarmand; A remote sensing-based discrimination of high- and low-potential mineralization for porphyry copper deposits; a case study from Dehaj–Sarduiyeh copper belt, SE Iran. *European Journal of Remote Sensing* **2017**, *50*, 332-342, 10.1080/22797254.2017.1328646.
13. Mahdieh Hosseinjanizadeh; Majid H. Tangestani; Francisco Velasco Roldán; Iñaki Yusta; Sub-pixel mineral mapping of a porphyry copper belt using EO-1 Hyperion data. *Advances in Space Research* **2014**, *53*, 440-451, 10.1016/j.asr.2013.11.029.
14. Amin Beiranvnd Pour; M. Hashim; Identification of hydrothermal alteration minerals for exploring of porphyry copper deposit using ASTER data, SE Iran. *Journal of Asian Earth Sciences* **2011**, *42*, 1309-1323, 10.1016/j.jseaes.2011.07.017.
15. Amin Beiranvand Pour; M. Hashim; Hydrothermal alteration mapping from Landsat-8 data, Sar Cheshmeh copper mining district, south-eastern Islamic Republic of Iran. *Journal of Taibah University for Science* **2015**, *9*, 155-166, 10.1016/j.jtusci.2014.11.008.
16. Morteza Safari; Abbas Maghsoudi; Amin Beiranvand Pour; Application of Landsat-8 and ASTER satellite remote sensing data for porphyry copper exploration: a case study from Shahr-e-Babak, Kerman, south of Iran. *Geocarto International* **2017**, *33*, 1186-1201, 10.1080/10106049.2017.1334834.
17. Nannan Zhang; Kefa Zhou; Identification of hydrothermal alteration zones of the Baogutu porphyry copper deposits in northwest China using ASTER data. *Journal of Applied Remote Sensing* **2017**, *11*, 15016, 10.1117/1.jrs.11.015016.
18. Reda Amer; Timothy Kusky; Ahmed El Mezayen; Remote sensing detection of gold related alteration zones in Um Rus area, Central Eastern Desert of Egypt. *Advances in Space Research* **2012**, *49*, 121-134, 10.1016/j.asr.2011.09.024.
19. Andrea Ciampalini; Francesca Garfagnoli; Benedetta Antonielli; Sandro Moretti; Gaia Righini; Remote sensing techniques using Landsat ETM+ applied to the detection of iron ore deposits in Western Africa. *Arabian Journal of Geosciences* **2012**, *6*, 4529-4546, 10.1007/s12517-012-0725-0.
20. Islam Abou El-Magd; Hassan Mohy; Fawzy Basta; Application of remote sensing for gold exploration in the Fawakhir area, Central Eastern Desert of Egypt. *Arabian Journal of Geosciences* **2014**, *8*, 3523-3536, 10.1007/s12517-014-1429-4.
21. Safwat Gabr; Abduwasit Ghulam; Timothy M. Kusky; Detecting areas of high-potential gold mineralization using ASTER data. *Ore Geology Reviews* **2010**, *38*, 59-69, 10.1016/j.oregeorev.2010.05.007.
22. Safwat Gabr; Safaa M. Hassan; Mohamed F. Sadek; Prospecting for new gold-bearing alteration zones at El-Hoteib area, South Eastern Desert, Egypt, using remote sensing data analysis. *Ore Geology Reviews* **2015**, *71*, 1-13, 10.1016/j.oregeorev.2015.04.021.
23. Safaa M. Hassan; T. M. Ramadan; Mapping of the late Neoproterozoic Basement rocks and detection of the gold-bearing alteration zones at Abu Marawat-Semna area, Eastern Desert, Egypt using remote sensing data. *Arabian Journal of Geosciences* **2014**, *8*, 4641-4656, 10.1007/s12517-014-1562-0.
24. Lei Liu; Jun Zhou; Ling Han; Xinliang Xu; Mineral mapping and ore prospecting using Landsat TM and Hyperion data, Wushitala, Xinjiang, northwestern China. *Ore Geology Reviews* **2017**, *81*, 280-295, 10.1016/j.oregeorev.2016.10.007.
25. Masoud Moradi; Sedigheh Basiri; Ali Kananian; Keivan Kabiri; Fuzzy logic modeling for hydrothermal gold mineralization mapping using geochemical, geological, ASTER imageries and other geo-data, a case study in Central Alborz, Iran. *Earth Science Informatics* **2014**, *8*, 197-205, 10.1007/s12145-014-0151-9.
26. Zhang, X.; Pazner, M.; Duke, N. Lithologic and mineral information extraction for gold exploration using ASTER data in the south Chocolate Mountains (California). ISPRS J. Photogramm. Remote Sens. 2007, 62, 271–282.
27. Basem Zoheir; Controls on lode gold mineralization, Romite deposit, South Eastern Desert, Egypt. *Geoscience Frontiers* **2012**, *3*, 571-585, 10.1016/j.gsf.2012.03.003.
28. Alvaro Crosta; Carlos Roberto Souza Filho; F. Azevedo; C. Brodie; Targeting key alteration minerals in epithermal deposits in Patagonia, Argentina, using ASTER imagery and principal component analysis. *International Journal of Remote Sensing* **2003**, *24*, 4233-4240, 10.1080/0143116031000152291.
29. Mohand Bersi; Hakim Saibi; Moulley Charaf Chabou; Aerogravity and remote sensing observations of an iron deposit in Gara Djebilet, southwestern Algeria. *Journal of African Earth Sciences* **2016**, *116*, 134-150, 10.1016/j.jafrearsci.2016.01.004.
30. Diego Fernando Ducart; Adalene Silva; Catarina Labouré Bemfica Toledo; Luciano Mozer De Assis; Mapping iron oxides with Landsat-8/OLI and EO-1/Hyperion imagery from the Serra Norte iron deposits in the Carajás Mineral Province, Brazil. *Brazilian Journal of Geology* **2016**, *46*, 331-349, 10.1590/2317-4889201620160023.
31. P. Duuring; S. G. Hagemann; Y. Novikova; T. Cudahy; Carsten Laukamp; Targeting Iron Ore in Banded Iron Formations Using ASTER Data: Weld Range Greenstone Belt, Yilgarn Craton, Western Australia. *Economic Geology* **2012**, *107*,

585-597, 10.2113/econgeo.107.4.585.

32. Sankaran Rajendran; A. Thirunavukkarasu; G. Balamurugan; K. Shankar; Discrimination of iron ore deposits of granulite terrain of Southern Peninsular India using ASTER data. *Journal of Asian Earth Sciences* **2011**, *41*, 99-106, 10.1016/j.jseaes.2011.01.004.
33. Byron R. Berger; Trude V. V. King; Laurie C. Morath; Jeffrey Phillips; Utility of High-Altitude Infrared Spectral Data in Mineral Exploration: Application to Northern Patagonia Mountains, Arizona. *Economic Geology* **2003**, *98*, 1003-1018, 10.2113/gsecongeo.98.5.1003.
34. F. Van Der Meer; M. Vazquez-Torres; P. M. Van Dijk; Spectral characterization of ophiolite lithologies in the Troodos Ophiolite complex of Cyprus and its potential in prospecting for massive sulphide deposits. *International Journal of Remote Sensing* **1997**, *18*, 1245-1257, 10.1080/014311697218395.
35. Gongwen Wang; Wenhui Du; E. J. M. Carranza; Remote sensing and GIS prospectivity mapping for magmatic-hydrothermal base- and precious-metal deposits in the Honghai district, China. *Journal of African Earth Sciences* **2017**, *128*, 97-115, 10.1016/j.jafrearsci.2016.06.020.
36. Lawrence C Rowan; John C Mars; Lithologic mapping in the Mountain Pass, California area using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data. *Remote Sensing of Environment* **2003**, *84*, 350-366, 10.1016/s0034-4257(02)00127-x.
37. Nazi Mazhari; Azadeh Malekzadeh Shafaroudi; Majid Ghaderi; Detecting and mapping different types of iron mineralization in Sangan mining region, NE Iran, using satellite image and airborne geophysical data. *Geosciences Journal* **2017**, *21*, 137-148, 10.1007/s12303-016-0018-9.
38. Yuanjin Xu; Jianguo Chen; Pengyan Meng; Detection of alteration zones using hyperspectral remote sensing data from Dapingliang skarn copper deposit and its surrounding area, Shanshan County, Xinjiang Uygur autonomous region, China. *Journal of Visual Communication and Image Representation* **2019**, *58*, 67-78, 10.1016/j.jvcir.2018.11.032.
39. Rodrigo Salles; Carlos Roberto Souza Filho; Tom Cudahy; Luiz E. Vicente; Lena Virgínia Soares Monteiro; Hyperspectral remote sensing applied to uranium exploration: A case study at the Mary Kathleen metamorphic-hydrothermal U-REE deposit, NW, Queensland, Australia. *Journal of Geochemical Exploration* **2017**, *179*, 36-50, 10.1016/j.gexplo.2016.07.002.
40. Othman, A.; Gloaguen, R. Improving Lithological Mapping by SVM classification of spectral and morphological features: The Discovery of a new chromite body in the mawat ophiolite complex (Kurdistan, NE Iraq). Remote Sens. 2014, 6, 6867–6896.
41. Alireza Eslami; Majid Ghaderi; Sankaran Rajendran; Amin Beiranvand Pour; M. Hashim; Integration of ASTER and landsat TM remote sensing data for chromite prospecting and lithological mapping in Neyriz ophiolite zone, south Iran. *Resource Geology* **2015**, *65*, 375-388, 10.1111/rge.12076.
42. Mohsen Pournamdari; M. Hashim; Detection of chromite bearing mineralized zones in Abdasht ophiolite complex using ASTER and ETM+ remote sensing data. *Arabian Journal of Geosciences* **2013**, *7*, 1973-1983, 10.1007/s12517-013-0927-0.
43. Sankaran Rajendran; Salah Al-Khirbash; Bernhard Pracejus; Sobhi Nasir; Amani Humaid Al-Abri; Timothy Kusky; Abduwasit Ghulam; ASTER detection of chromite bearing mineralized zones in Semail Ophiolite Massifs of the northern Oman Mountains: Exploration strategy. *Ore Geology Reviews* **2012**, *44*, 121-135, 10.1016/j.oregeorev.2011.09.010.
44. Khaled S. Gemail; Naglaa Adb Elrahman; B. M. Ghiath; R. N. Aziz; Integration of ASTER and airborne geophysical data for mineral exploration and environmental mapping: a case study, Gabal Dara, North Eastern Desert, Egypt. *Environmental Earth Sciences* **2016**, *75*, ., 10.1007/s12665-016-5368-0.
45. Robert Zimmermann; Melanie Brandmeier; Louis Andreani; Kombada Mhopjeni; Richard Gloaguen; Remote Sensing Exploration of Nb-Ta-LREE-Enriched Carbonatite (Epembe/Namibia). *Remote Sensing* **2016**, *8*, 620, 10.3390/rs8080620.
46. Sabins, F.F.; Miller, R.M. Resource assessment—Salar Uyuni and vicinity. In Proceedings of the Tenth Thematic Conference on Geologic Remote Sensing (Ann Arbor, MI, Environmental Research Institute of Michigan), San Antonio, TX, USA, 9–12 May 1994; pp. 9–12.
47. N. Serkan Öztan; Mehmet Lütfi Süzen; Mapping evaporate minerals by ASTER. *International Journal of Remote Sensing* **2011**, *32*, 1651-1673, 10.1080/01431160903586799.
48. Enton Bedini; Mineral mapping in the Kap Simpson complex, central East Greenland, using HyMap and ASTER remote sensing data. *Advances in Space Research* **2011**, *47*, 60-73, 10.1016/j.asr.2010.08.021.

49. Lei Liu; Jun Zhou; Fang Yin; Min Feng; Bing Zhang; The reconnaissance of mineral resources through aster data-based image processing, interpreting and ground inspection in the Jiafushaersu area, West Junggar, China. *Journal of Earth Science* **2014**, *25*, 397-406, 10.1007/s12583-014-0423-9.
50. Amin Beiranvand Pour; Tae-Yoon S. Park; Yongcheol Park; Jong Kuk Hong; Basem Zoheir; Biswajeet Pradhan; Iman Ayoobi; M. Hashim; Application of Multi-Sensor Satellite Data for Exploration of Zn–Pb Sulfide Mineralization in the Franklinian Basin, North Greenland. *Remote Sensing* **2018**, *10*, 1186, 10.3390/rs10081186.
51. Kruse, F.A.; Boardman, J.W. Characterization and mapping of kimberlites and related diatremes using hyperspectral remote sensing. In Proceedings of the 2000 IEEE Aerospace Conference. Proceedings (Cat. No.00TH8484), Big Sky, MT, USA, 25 March 2000; Volume 3, pp. 299–304.
52. P. Sheik Mujabar; S. Dajkumar; Mapping of bauxite mineral deposits in the northern region of Saudi Arabia by using Advanced Spaceborne Thermal Emission and Reflection Radiometer satellite data. *Geo-spatial Information Science* **2018**, *22*, 35-44, 10.1080/10095020.2018.1530857.
53. Freek D. Van Der Meer; Harald Van Der Werff; Frank J.A. Van Ruitenbeek; Christoph Hecker; Wim H. Bakker; Marleen Noomen; Mark Van Der Meijde; E. J. M. Carranza; J. Boudewijn De Smeth; Tsehaie Woldai; et al. Multi- and hyperspectral geologic remote sensing: A review. *International Journal of Applied Earth Observation and Geoinformation* **2012**, *14*, 112-128, 10.1016/j.jag.2011.08.002.
54. Michael Abrams; Y. Yamaguchi; Twenty Years of ASTER Contributions to Lithologic Mapping and Mineral Exploration. *Remote Sensing* **2019**, *11*, 1394, 10.3390/rs11111394.
55. Ninomiya, Y.; Fu, B.; Thermal infrared multispectral remote sensing of lithology and mineralogy based on spectral properties of materials. *Ore Geol. Rev.* **2019**, *108*, 54–72, .
56. Christmann, P.; Gloaguen, E.; Labbé, J.-F.; Melleton, J.; Piantone, P. Chapter 1—Global lithium resources and sustainability issues. In Lithium Process Chemistry; Chagnes, A., Światowska, J., Eds.; Elsevier: Amsterdam, The Netherlands, 2015; pp. 1–40.
57. Camille Grosjean; Pamela Herrera Miranda; Marion Perrin; Philippe Poggi; Assessment of world lithium resources and consequences of their geographic distribution on the expected development of the electric vehicle industry. *Renewable and Sustainable Energy Reviews* **2012**, *16*, 1735-1744, 10.1016/j.rser.2011.11.023.
58. Arrobas, D.L.P.; Hund, K.L.; Mccormick, M.S.; Ningthoujam, J.; Drexhage, J.R. The Growing Role of Minerals and Metals for a Low Carbon Future; The World Bank: Washington, DC, USA, 2017. [Google Scholar]