GEEA
Thematic set article: Analysis of Exploration Geochemical Data
Geochemistry: Exploration, Environment, Analysis
Published online June 20, 2017
https://doi.org/10.1144/geochem2017-901 | Vol. 17 | 2017 | pp. 183–185

Introduction to the thematic issue: analysis of exploration geochemical data for mapping of anomalies

Emmanuel John M. Carranza[1,2]* & Renguang Zuo[3]

[1] Economic Geology Research Centre (EGRU), James Cook University, Townsville, QLD, Australia
[2] Institute of Geosciences, State University of Campinas (Unicamp), Campinas, São Paulo, Brazil
[3] State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan 430074, China
* Correspondence: ejmcarranza@gmail.com

The journal Geochemistry: Exploration, Environment, Analysis (GEEA) 'focuses on mineral exploration using geochemistry…' (http://www.geolsoc.org.uk/geea). GEEA is well-known for geo-analysis, which involves development of techniques and methods for systematic measurements of the chemical properties of a variety of Earth materials (e.g. rocks, soils, sediments, waters, vegetation, etc.). The most common chemical property measured from every geochemical sample is the concentration of one or more elements. The task of analysing geochemical concentration data (or geochemical data in short) from mineral exploration programmes aims basically to identify and separate samples with anomalous chemical concentrations from samples with background chemical concentrations. GEEA has published at least 50 papers on exploration geochemical data analysis (Appendix 1), which represent roughly 10% of all papers published in GEEA since its first issue in 2001. To contribute to the achievement of GEEA's aim, this thematic issue contains eight papers on the development of methods and techniques for exploration geochemical data analysis.

Traditionally, methods and techniques for analysis of geochemical data for mapping of anomalies to support mineral exploration broadly fall into two categories of statistical analysis (Levinson 1974; Rose *et al.* 1979; Howarth 1983): (1) univariate analysis; and (2) multivariate analysis. In recent years, not only statistical but also spatial analysis is involved in mapping of geochemical anomalies to support mineral exploration (Zuo *et al.* 2016) (see Appendix 1). Moreover, with advancements in geographic information systems, most exploration data are integrated with geochemical data for more effective mapping of significant geochemical anomalies (Bonham-Carter 1994; Pan and Harris 2000; Carranza 2008). The eight papers contained in this thematic issue demonstrate the utility and added value of integrated analysis.

In the first paper, **Ghane & Asghari (2017)** used minimum/maximum autocorrelation factor analysis, which is a multivariate geostatistical method, and sequential indicator simulation methods on drill core geochemical data to model the Sury Gunay epithermal gold deposit, NW Iran. The results of their study indicate that high values of mineralization factors correlate with volcanogenic breccia and dacite porphyry, which are the known hosts of the deposit, and that high probabilities of silicification correlate with high concentrations of ore elements.

In the second paper, **Shahrestani & Mokhtari (2017)** incorporated drainage density of catchment areas in correcting stream sediment geochemical residuals for the effect of dilution on element concentrations to recognize significant geochemical anomalies. Using known occurrences of Au mineralization to validate their results, their study showed that drainage density does indeed enhance significant stream sediment geochemical anomalies.

In the third paper, **Cracknell & de Caritat (2017)** applied self-organizing maps to integrate and analyse catchment-based National Geochemical Survey of Australia (NGSA) geochemical data together with geophysical and geological data across northern Australia to identify areas prospective for gold. The results of their study, validated against known Au mines and mineral occurrences, indicate that catchment-based geochemical data and summaries of geophysical and geological data can be combined to highlight areas that potentially host previously unrecognized Au mineralization.

In the fourth paper, **K. Wang *et al.* (2017)** demonstrate the application of partial least squares regression (PLSR) to the analysis of multivariate geochemical anomalies. They applied PLSR separately to major oxides and trace elements to extract geochemical anomalies. The results of their analysis, which were validated by known occurrences of mineral deposits, show multivariate anomalies of major oxides and trace elements coinciding with known ore-bearing strata and ore-controlling faults. The associations of major oxides and trace elements extracted by PLSR are similar to those extracted using the traditional cluster method; however, PLSR allows mapping spatial variations that cluster analysis does not. Therefore, PLSR is now a proven technique for mapping of multivariate geochemical anomalies to support mineral exploration.

In the fifth paper, **Chen & Wu (2017)** applied the one-class support vector machine (OCSVM) to identify multivariate geochemical anomalies from stream sediment survey data of the Lalingzaohuo district, China. They compared the performance of the OCSVM model with that of the previously proposed continuous restricted Boltzmann machine (CRBM). The results show that anomalies identified by the OCSVM model occupy 19% of the study area and contain 82% of the known mineral deposits whereas anomalies identified by the CRBM model occupy 35% of the study area and contain 88% of the known mineral deposits, indicating the advantage of the OCSVM model over the CRBM model.

In the sixth paper, **Zhao *et al.* (2017)** applied staged factor analysis (SFA) and fractal/multifractal techniques to process lithogeochemical data from the Laochang district, Yunnan province, SE China, to identify geochemical signatures related to the deposit-type sought. The results of their study clearly demonstrate that SFA greatly assisted interpretation of geochemical zonation patterns genetically related to intrusions as well as multi-element associations of the mineral deposit-type sought as validated by known mineral occurrences. The results of their fractal/multifractal analyses further illustrate that element distributions are greatly influenced by fault density and that integrated methods are useful for identifying significant multi-element anomalous signatures and generating reliable target areas for further prospecting.

In the seventh paper, Li *et al.* (2017) applied local singularity analysis (LSA) to geochemical data from fracture fills to identify and extract geochemical anomalies associated with the Shaxi porphyry Cu-Au mineralization. The results of their study indicate that combining LSA with fracture fill geochemical analysis can effectively delineate geochemical anomalies associated with deep-seated or concealed porphyry-type mineralization as validated by known mineralized areas.

In the eighth paper, **W. Wang *et al.* (2017)** applied principal components analysis and the fractal/multifractal analytical techniques to stream sediment geochemical data to reflect the geology, metallogenesis and mineral potential in the Duolong mineral district, Tibet, China, which is an underdeveloped area that has received attention in recent years due to its Cu-Au resources. The results of their study, validated by the few known mineral deposits in the area, show that geochemical anomalies are spatially coincident with structures, suggesting the presence of mineralization but also a genetic relationship between mineralization and regional fault structures. The results of their study further indicate that the spectrum-area multifractal model is more effective for characterizing spatial patterns caused by specific geological processes, and the singularity theory can reveal the geochemical behaviour of elements or element associations from various geological processes.

Acknowledgement We thank Editor-in-Chief Kurt Kyser for agreeing to publish this special collection of papers in a thematic issue of GEEA. We are grateful to all the authors for the contributions, even to those who withdrew their papers after considering the reviewers' comments and those whose manuscript were not acceptable to the reviewers. We deeply appreciate the support of the following individuals for the invaluable time they have given to review the submitted manuscripts, many of who graciously reviewed more than one manuscript indicated by numbers in parenthesis: Peyman Afzal (2), Monica Arias, Guoxiong Chen, Shishi Chen, David Cohen, Yuan Feng (2), Mario Gonçalves (2), Eric Grunsky, Ardeshir Hezarkhani, Karel Hron (2), Yue Liu (2), Jennifer McKinley, Ahmad Reza Mokhtari (2), Charles Moon (2), Martiya Sadeghi, Ricardo Valls, Qingfei Wang, Wenlei Wang (2), Fan Xiao (2), Shuyun Xie, Douglas Yager, and Mahyar Yousefi (3). We also thank Jessica Pollitt, staff editor of GEEA, for assisting the authors, reviewers and ourselves regarding the use of the online manuscript submission and review system.

References

Bonham-Carter, G.F. 1994. *Geographic Information Systems for Geoscientists: Modelling with GIS*. Pergamon, Ontario.

Carranza, E.J.M. 2008. *Geochemical Anomaly and Mineral Prospectivity Mapping in GIS. Handbook of Exploration and Environmental Geochemistry*, **11**. Elsevier, Amsterdam.

Chen, Y. & Wu, W. 2017. Application of one-class support vector machine to quickly identify multivariate anomalies from geochemical exploration data. *Geochemistry: Exploration, Environment, Analysis*, first published May 9, 2017, https://doi.org/10.1144/geochem2016-024

Cracknell, M.J. & de Caritat, P. 2017. Catchment-based gold prospectivity analysis combining geochemical, geophysical and geological data across northern Australia. *Geochemistry: Exploration, Environment, Analysis*, first published Month XX, 2017, https://doi.org/10.1144/geochem2016-012

Ghane, B. & Asghari, O. 2017. Modeling of mineralization using minimum/maximum autocorrelation factor: case study Sury Gunay gold deposit NW of Iran. *Geochemistry: Exploration, Environment, Analysis*, first published May 16, 2017, https://doi.org/10.1144/geochem2016-453

Howarth, R.J. (ed.) 1983. *Statistics and Data Analysis in Geochemical Prospecting, Handbook of Exploration Geochemistry*, **2**. Elsevier, Amsterdam.

Li, X., Yuan, F. *et al*. 2017. Singularity mapping of fracture fills and its relationship to deep concealed orebodies – a case study of the Shaxi porphyry Cu-Au deposit, China. *Geochemistry: Exploration, Environment, Analysis*, first published May 16, 2017, https://doi.org/10.1144/geochem2016-444

Levinson, A.A. 1974. *Introduction to Exploration Geochemistry*. Applied Publishing Ltd., Calgary.

Pan, G.C. & Harris, D.P. 2000. *Information Synthesis for Mineral Exploration*. Oxford University Press, Inc., New York.

Rose, A.W., Hawkes, H.E. & Webb, J.S. 1979. *Geochemistry in Mineral Exploration*. 2nd edn. Academic Press, London.

Shahrestani, S. & Mokhtari, A.R. 2017. Improved detection of anomalous catchment basins by incorporating drainage density in dilution correction of geochemical residuals. *Geochemistry: Exploration, Environment, Analysis*, first published May 9, 2017, https://doi.org/10.1144/geochem2016-015

Wang, K., Keyan, X., Nan, L., Yuan, C. & Shengmiao, L. 2017. Application of Partial Least Squares Regression for Identifying Multivariate Geochemical Anomalies in Stream Sediment Data from Northwestern Hunan, China. *Geochemistry: Exploration, Environment, Analysis*, first published June 13, 2017, https://doi.org/10.1144/geochem2016-455

Wang, W., Cheng, Q. *et al*. 2017. Fractal/multifractal analysis in support of mineral exploration in the Duolong mineral district, Tibet, China. *Geochemistry: Exploration, Environment, Analysis*, first published May 16, 2017, https://doi.org/10.1144/geochem2016-449

Zhao, J., Chen, S. & Zuo, R. 2017. Identification and mapping of lithogeochemical signatures using staged factor analysis and fractal/multifractal models. *Geochemistry: Exploration, Environment, Analysis*, first published May 16, 2017, https://doi.org/10.1144/geochem2016-013

Zuo, R., Carranza, E.J.M. & Wang, J. 2016. Spatial analysis and visualization of exploration geochemical data. *Earth-Science Reviews*, **158**, 9–18.

Appendix 1

GEEA articles on analysis of exploration geochemical data for mapping of anomalies published since the first issue in 2001 until the present thematic issue.

Clare, A.P. & Cohen, D.R. 2001. A comparison of unsupervised neural networks and k-means clustering in the analysis of multi-element stream sediment data. *GEEA*, **1(2)**, 119–134.

Garrett, R.G. & Grunsky, E.C. 2001. Weighted sums – knowledge based empirical indices for use in exploration geochemistry. *GEEA*, **1(2)**, 135–141.

Xu, Y. & Cheng, Q. 2001. A fractal filtering technique for processing regional geochemical maps for mineral exploration. *GEEA*, **1(2)**, 147–156.

Klassen, R.A. 2001. The interpretation of background variation in regional geochemical surveys – an example from Nunavut, Canada. *GEEA*, **1(2)**, 163–175.

Batista, A.C., Ferreira da Silva, E.A., Azevedo, M.C.C., Sousa, A.J. & Cardoso Fonseca, E. 2002. Soil data analysis from central Portugal by Principal Component Analysis and geostatistical techniques. *GEEA*, **2(1)**, 15–25.

Zhang, L. & Bai, G. 2002. Application of the artificial neural network to multivariate anomaly recognition in geochemical exploration for hydrocarbons. *GEEA*, **2(1)**, 75–81.

Stanley, C.R. 2003. Statistical evaluation of anomaly recognition performance. *GEEA*, **3(1)**, 3–12.

Panahi, A., Cheng, Q. & Bonham-Carter, G.F. 2004. Modelling lake sediment geochemical distribution using principal component, indicator kriging and multifractal power-spectrum analysis: a case study from Gowganda, Ontario. *GEEA*, **4(1)**, 59–70.

Carranza, E.J.M. 2004. Usefulness of stream order to detect stream sediment geochemical anomalies. *GEEA*, **4(4)**, 341–352.

Garrett, R.G. & Lalor, G.C. 2005. The Fe/Na ratio, a framework for modelling trace element distributions in Jamaican soils. *GEEA*, **5(2)**, 147–157.

Reimann, C. 2005. Geochemical mapping: technique or art? *GEEA*, **5(4)**, 359–370.

Stanley, C.R. 2006*a*. Numerical transformation of geochemical data: 1. Maximizing geochemical contrast to facilitate information extraction and improve data presentation. *GEEA*, **6(1)**, 69–78.

Stanley, C.R. 2006*b*. Numerical transformation of geochemical data: 2. Stabilizing measurement error to facilitate data interpretation. *GEEA*, **6(1)**, 79–96.

Ali, K., Cheng, Q., Li, W. & Chen, Y. 2006. Multi-element association analysis of stream sediment geochemistry data for predicting gold deposits in south-central Yunnan Province, China. *GEEA*, **6(4)**, 341–348.

Kelepertsis, A., Argyraki, A. & Alexakis, D. 2006. Multivariate statistics and spatial interpretation of geochemical data for assessing soil contamination by potentially toxic elements in the mining area of Stratoni, north Greece. *GEEA*, **6(4)**, 349–355.

Ali, K., Cheng, Q. & Chen, Z. 2007. Multifractal power spectrum and singularity analysis for modelling stream sediment geochemical distribution patterns to identify anomalies related to gold mineralization in Yunnan Province, South China. *GEEA*, **7(4)**, 293–301.

Grünfeld, K. 2007. The separation of multi-element spatial patterns in till geochemistry of southeastern Sweden combining GIS, principal component analysis and high-dimensional visualization. *GEEA*, **7(4)**, 303–318.

Stanley, C.R. & Noble, R.R.P. 2007. Optimizing geochemical threshold selection while evaluating exploration techniques using a minimum hypergeometric probability method. *GEEA*, **7(4)**, 341–351.

Stanley, C.R. & Noble, R.R.P. 2008. Quantitative assessment of the success of geochemical exploration techniques using minimum probability methods. *GEEA*, **8(2)**, 115–127.

Stanley, C.R. 2008. Missed hits or near misses: determining how many samples are necessary to confidently detect nugget-borne mineralization. *GEEA*, **8(2)**, 129–138.

Garrett, R.G., Lalor, G.C., Preston, J. & Vutchkov, M.K. 2008. Variation in geochemical background levels for Jamaican soils. *GEEA*, **8(2)**, 149–156.

Garrett, R.G., Reimann, C., Smith, D.B. & Xie, X. 2008. From geochemical prospecting to international geochemical mapping: a historical overview. *GEEA*, **8(3–4)**, 205–217.

Smith, D.B. & Reimman, C. 2008. Low-density geochemical mapping and the robustness of geochemical patterns. *GEEA*, **8(3–4)**, 219–227.

Zhang, C., Fay, D., McGrath, D., Grennan, E. & Carton, O.T. 2008. Use of trans-Gaussian kriging for national soil geochemical mapping in Ireland. *GEEA*, **8(3–4)**, 255–265.

Benavides, J., Kyser, T.K., Clark, A.H., Stanley, C. & Oates, C. 2008*a*. Exploration guidelines for copper-rich iron oxide–copper–gold deposits in the Mantoverde area, northern Chile: the integration of host-rock molar element ratios and oxygen isotope compositions. *GEEA*, **8(3–4)**, 343–367.

Benavides, J., Kyser, T.K., Clark, A.H., Stanley, C. & Oates, C. 2008*b*. Application of molar element ratio analysis of lag talus composite samples to the exploration for iron oxide–copper–gold mineralization: Mantoverde area, northern Chile. *GEEA*, **8(3–4)**, 369–380.

Urqueta, E., Kyser, T.K., Clark, A.H., Stanley, C.R. & Oates, C.J. 2009. Lithogeochemistry of the Collahuasi porphyry Cu–Mo and epithermal Cu–Ag (–Au) cluster, northern Chile: Pearce element ratio vectors to ore. *GEEA*, **9(1)**, 9–17.

Noble, R.R.P. & Stanley, C.R. 2009. Traditional and novel geochemical extractions applied to a Cu–Zn soil anomaly: a quantitative comparison of exploration accuracy and precision. *GEEA*, **9(2)**, 159–172.

Reis, A.P., Silva, E.F., Sousa, A.J., Patinha, C., Martins, E., Guimarães, C., Azevedo, M.R. & Nogueira, P. 2009. Geochemical associations and their spatial patterns of variation in soil data from the Marrancos gold–tungsten deposit: a pilot analysis. *GEEA*, **9(4)**, 319–340.

Grunsky, E.C. 2010. The interpretation of geochemical survey data. *GEEA*, **10(1)**, 27–74.

Jackson, R.G. 2010. Application of 3D geochemistry to mineral exploration. *GEEA*, **10(1)**, 143–156.

Carranza, E.J.M. 2010. Mapping of anomalies in continuous and discrete fields of stream sediment geochemical landscapes. *GEEA*, **10(2)**, 171–187.

Howarth, R.J. & Garrett, R.G. 2010. Statistical analysis and data display at the Geochemical Prospecting Research Centre and Applied Geochemistry Research Group, Imperial College, London. *GEEA*, **10(3)**, 289–315.

Carranza, E.J.M. 2010. Catchment basin modelling of stream sediment anomalies revisited: incorporation of EDA and fractal analysis. *GEEA*, **10 (4)**, 365–381.

De Kemp, E.A., Monecke, T. *et al.* 2011. 3D GIS as a support for mineral discovery. *GEEA*, **11(2)**, 117–128.

Montreuil, J.F., Corriveau, L. & Grunsky, E.C. 2013. Compositional data analysis of hydrothermal alteration in IOCG systems, Great Bear magmatic zone, Canada: to each alteration type its own geochemical signature. *GEEA*, **13(4)**, 229–247.

Grunsky, E.C., Drew, L.J., Woodruff, L.G., Friske, P.W.B. & Sutphin, D.M. 2013. Statistical variability of the geochemistry and mineralogy of soils in the Maritime Provinces of Canada and part of the Northeast United States. *GEEA*, **13(4)**, 249–266.

Grunsky, E.C. 2013. Predicting Archaean volcanogenic massive sulphide deposit potential from lithogeochemistry: application to the Abitibi Greenstone Belt. *GEEA*, **13(4)**, 317–336.

Adcock, S.W., Spirito, W.A. & Garrett, R.G. 2013. Geochemical data management – issues and solutions. *GEEA*, **13(4)**, 337–348.

Garrett, R.G. 2013*a*. Assessment of local spatial and analytical variability in regional geochemical surveys with a simple sampling scheme. *GEEA*, **13 (4)**, 349–354.

Garrett, R.G. 2013*b*. The ‘rgr’ package for the R Open Source statistical computing and graphics environment - a tool to support geochemical data interpretation. *GEEA*, **13(4)**, 355–378.

Yousefi, M., Kamkar-Rouhani, A. & Carranza, E.J.M. 2014. Application of staged factor analysis and logistic function to create a fuzzy stream sediment geochemical evidence layer for mineral prospectivity mapping. *GEEA*, **14(1)**, 45–58.

Liu, Y., Cheng, Q., Xia, Q. & Wang, X. 2014. Multivariate analysis of stream sediment data from Nanling metallogenic belt, South China. *GEEA*, **14(4)**, 331–340.

Luz, F., Mateus, A., Matos, J.X. & Gonçalves, M.A. 2014. Copper, Zn and Pb soil geochemistry data from the NE domain of the Iberian Pyrite Belt in Portugal: implications for mineral exploration. *GEEA*, **14(4)**, 341–358.

Lin, X., Zhang, B. & Wang, X. 2014. Application of factor analysis and concentration-volume fractal modeling to delineation of 3D geochemical patterns: a case study of the Jinwozi gold field, NW China. *GEEA*, **14(4)**, 359–367.

Huang, J. & Zhao, P. 2015. Application of a multi-fractal model for identification of Cu, Au and Zn anomalies in Western Yunnan, Southwestern China. *GEEA*, **15(1)**, 54–61.

Payne, C.E. & Peters, K.J. 2015. Geochemistry in prospectivity modelling: investigating gold mineralization in the Taupo Volcanic Zone, New Zealand. *GEEA*, **15(2–3)**, 193–204.

De Caritat, P. & Cooper, M. 2016. A continental-scale geochemical atlas for resource exploration and environmental management: the National Geochemical Survey of Australia. *GEEA*, **16(1)**, 3–13.

Reimann, Ladenberger, A., Birke, M. & de Caritat, P. 2016. Low density geochemical mapping and mineral exploration: application of the mineral system concept. *GEEA*, **16(1)**, 48–61.

Mathieu, L. 2016. Quantifying hydrothermal alteration with normative minerals and other chemical tools at the Beattie Syenite, Abitibi greenstone belt, Canada. *GEEA*, **16(3–4)**, 233–244.

Chen, X., Zheng, Y. *et al.* 2016. Application of classical statistics and multifractals to delineate Au mineralization-related geochemical anomalies from stream sediment data: a case study in Xinghai-Zeku, Qinghai, China. *GEEA*, **16(3–4)**, 253–264.