New and game-changing developments in geochemical exploration

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If you are a gold digger you want to find more gold. Therefore, you collect and analyse a maximum amount of, in particular, geological data and information as that would give you the best clues for finding new occurrences. Geological maps are the main communication tools for geologists. Such maps may be quite complex for non-geologists but even for fellow geoscientists as these often cramp a multitude of subsurface information into a 2D frame. Geochemical information ranks high on the list of most wanted information for exploration geologists. Such information normally comes from geochemical analyses of rock or soil samples. For regional inventories often geochemical data sets from stream sediments are used. Nation- or even continent-wide geochemical data sets have now become available for many regions on this planet.

To identify geologically relevant patterns and correlations in such maps various techniques are being used, including geostatistical ones. The current problem is that relevant geochemical anomalies such as prospective gold occurrences or heavily polluted spots may not be entirely visible on such maps as these tend to smooth or be much suppressed by normal geostatistical correlation techniques which are often performed to identify larger, regional trends. Recently, mathematical geologists developed new techniques that may spot such anomalies much better and that separate these from regional background values. These techniques proved to work so well that they should receive more attention by the geological community and in particular by geoscientists who are involved in geochemical exploration or in environmental protection.

These new techniques are based on our strongly improved understanding of geological processes and on new developments in mathematical geology. Many, if not most natural processes are quite complex and have a non-linear nature. That means that these processes do not develop linearly in time and space and that their products or results are not distributed regularly on maps or in cross sections. Their products occur in relatively narrow space and/or time intervals. Earthquakes are good examples of such non-linear processes but also cloud formation and hydrothermal mineralisation. These last processes may result in quite irregular ore bodies which nevertheless bear properties of self-similarity (the shape, or the spatial distribution, “looks” the same at different scales). The sizes of ore bodies, clouds, coastlines etc. depend on the scale at which they are measured and the outcome is not scale-independent. That was first recognized and described by Mandelbrot in 1975 when he named these objects as fractals or fractal geometries. Subsequent advancements have extended the concept of fractal geometry to multifractal fields such as fractal density defined on fractal geometry. If fractals emphasise on more or less self-similar geometrical properties of products of non-linear processes, multifractals were further developed for quantify complex fields or densities defined on geometries, which can be fractals. Therefore, fractals and multifractals do not obey Euclidean measuring laws and their dimensions depend on the applied measures.

The lengths of coast lines, which are the products of a wide variety of non-linear processes, depend on the lengths of the measuring rods that are used. The shorter the measuring rod, the longer the coast line is. This length is thus related to the scale by a (fractional) power. For fractal modelling Mandelbrot developed a special set of mathematical formulas.

Among the first Bölviken et al., in 1992 recognised fractal geometry theory as relevant for geochemical exploration and Cheng et al., in 1994, introduced multifractals theory and translated this into mathematical terms through a fractal model which calculates ore element Concentrations in mineral district viz their Areas. Through this (C-A) fractal model, concentration anomalies can be distinguished rather easily from their background values via a threshold point in a log-log diagram. Several associated, refined fractal calculation models developed from the C-A method since (the Spectrum-Area, the Concentration-Distance and the Concentration-Volume fractal models). The significance of the innovation of C-A model is that it makes multifractals capable of dealing with locations rather than early global statistical frequency models that have no locational “predictability”. C-A model can be used to delineate areas based on spatial distribution of concentration with special self-similarity and fractal dimensions. This work makes fractal and multifractals theory capable of identifying or predicting locations favourable for mineral deposits.

Another major breakthrough was made in 1997, again by Cheng, who developed a method to map mineralisation as a singularity process, i.e. a non-linear process that displays for example peak results (high concentrations of minerals) in time and/or space. Local Singularity Analysis (LSA) focuses on accentuating very high or very low concentration anomalies in areas with geochemical data through their spatial relation to geological phenomena, e.g. the proximity to faults.

In Local Singularity Analysis mapping, a set of geochemical data of an area is processed twice. First, contour maps are made while applying standard geostatistical mapping and interpolation techniques (kriging, moving average, etc). Next, a local singularity mapping exercise is conducted for the same dataset. The local singularity index is estimated from the C-A fractal calculations at the samples in relation to local geological conditions (fault patterns etc.). The optimally estimated local singularity is then applied to upgrade the firstly produced maps by multiplying the contour values with a special factor. The local singularity is expressed as a power in this factor which is less than 2 in case of local enrichment and greater than 2 in places of local depletion. Comparison between LSA maps and traditionally prepared contour maps demonstrates that LSA maps display a much larger diversity in concentration values that predict occurrences of (even hidden) anomalies much better. Significant progress has been made for correlation of vertical anomalies as well. In several recent papers, Zuo et al. (2015) and Chen et al. (2016)

show convincing examples of detecting such anomalies through fractal models.

These fractal models have been tested by field evidence and proved to give reliable results for many different geological situations, both in 2D and 3D representations. Multifractal models are essentially filtering techniques and these fractal anomaly separation models, including LSA, have been integrated with geostatistical interpolation methods by Cheng in 2015 which interpolate values with variability retained. This integration improved geostatistical methods or deterministic algorithms such as inverse distance weighting for more and more accurate and convincing results.

In conclusion, geochemical exploration has been greatly facilitated by recent progress in mathematical geology, particularly by applying fractal models that separate anomalies from background concentrations. In a first stage, that was successfully done by applying such fractal models to point concentrations. Convincing attempts to translate such point data into maps were conducted in the last two decades, in particular by coupling C-A fractal anomaly separation models with geological phenomena and geostatistics without stationary assumption. The next and last challenge to properly map (even deeply seated) geochemical anomalies is to integrate fractal models and data fusion and information synthesization. As many mathematical geoscientists are working on this matter by today we may well expect a final and game-changing breakthrough soon.

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