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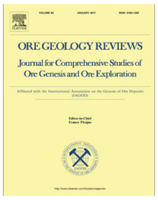

The true sample catchment basin approach in the analysis of stream sediment geochemical data

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ABSTRACT

The Sample Catchment Basin Approach (SCBA) is one of the techniques widely employed in the analysis of stream sediment geochemical data and delineation of anomalous catchments. However, this method fails to take into account the real catchment basin boundaries of each sample by incorporating only the incremental area between two adjacent samples. In other words, the SCBA incorrectly assumes that the geochemistry of every sample catchment within a drainage is independent from upstream sample catchment(s) feeding into this drainage. The chemical composition of sediment at the basin outlet originates from the whole basin upstream and not the incremental area as postulated in the SCBA. Consequently, the calculated background values for various lithologies and the background value for the element of interest at the basin outlet might be far from reality.

This study used a True Sample Catchment Basin Approach (TSCBA), that reflects the true catchment boundary of every stream sediment sample, and in which all calculations are carried out on the premise that this boundary and the true area affect the composition of each sample. The results obtained from the application of both the SCBA and TSCBA to a gold endowed study area in western Iran clearly illustrated the superiority of the TSCBA over the SCBA. In addition, this study demonstrated the advantage of using the modified dilution correction equation of Mokhtari and Garousi Nezhad (2015), as compared to the existing Hawkes's equation commonly used for dilution correction of residual values.

1. Introduction

The goal of sampling and analyzing stream sediments is to distinguish anomalous basins from those that are not as indicated by the mainly relative changes in element concentrations across catchment basins (Rose et al., 1970; Carranza, 1994; Moon, 1999; Cohen et al., 1999; Rantitsch, 2000). However, a significant proportion of variations in elemental concentration is due to upstream lithology (Bonham-Carter et al., 1987; Carranza and Hale, 1997; Carranza, 2009) and this may create false positive or false negative geochemical anomalous basins. Therefore, it is required to remove the effect of background from concentrations measured at the basin outlet.

One of the widely accepted and implemented techniques in the analysis of geochemical datasets acquired from stream sediment surveys is the Sample Catchment Basin Approach (SCBA) (Bonham-Carter and Goodfellow 1984, 1986; Bonham-Carter et al., 1987; Carranza and Hale, 1997; Spadoni, 2006; Carranza, 2010; Abdolmaleki et al., 2014). This method tries to estimate the background concentration of elements in different lithological units as well as the background value for every sample catchment basin by employing catchment basins with incremental geometry. The following study has revisited this approach and tried to modify it by considering the true boundary of the catchment basin that affects the chemistry of the stream sediment sample. The new approach is called the True Sample Catchment Basin Approach (TSCBA). In order to clarify the problem associated with the SCBA, it is necessary to revisit a fundamental definition: the definition of catchment basin or watershed. For this purpose, we have used the definition from USGS: "A watershed is an area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel. The word watershed is sometimes used interchangeably with drainage basin or catchment. Ridges and hills that separate two watersheds are called the drainage divide. The watershed consists of surface water-lakes, streams, reservoirs, and wetlands- and all the underlying ground water. Larger watersheds contain many smaller watersheds. It all depends on the outflow point; all of the land that drains water to the outflow point is the watershed for that outflow location." (U.S. Geological Survey, 2015). Fig. 1 depicts a diagram showing a large catchment basin restricted by

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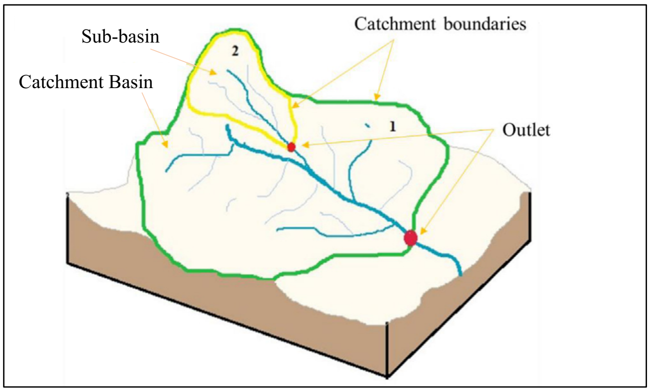

Fig. 1. A block diagram showing a catchment basin, sub-basin, catchment boundary and the outlet.

higher elevations or ridges that includes a smaller catchment highlighted as sub-basin. Waters falling on the inside brim of the catchment will flow to the outlet or outflow point that is the lowest point along the boundary of a catchment where water flows out of basin (Fig. 1). Delineating the catchment is carried out by identifying the point of interest (outlet), drawing a line perpendicular to the contours, picking the high points on a topographic map, and continuing until returning back to the point of interest (Petts and Amoros, 1996; DeBarry, 2004; U.S. Geological Survey, 2015).

By considering the above definition for catchment basin, it is expected that the sediment delivered at the basin outlet would be originated from the whole basin and parent lithological units located at the upstream. In other words, stream sediment and elemental concentration at each sampling point are representatives of the whole materials at the upstream from which they are derived.

1.1. Sample catchment basin approach

As a significant proportion of variations in elemental concentration in stream sediments is due to upstream lithology, the SCBA first tries to estimate the background concentration of uni-element in every lithological unit and then calculate the background (or the expected) value for the concentration of the element in the stream sediment sample at the basin outlet. Stream sediments associated with a catchment basin containing exposed mineralization would have higher concentrations of elements, as compared to stream sediments associated with non-mineralized basins. In this technique, the geometry and boundary of every sample catchment basin are delimited by the next sample upstream; so the basin area is known as the incremental area (Fig. 2) (Bonham-Carter et al., 1987; Carranza and Hale, 1997; Carranza, 2009). In other words, the catchment basin area of every sample in this approach is not extended to its natural boundaries upstream, except for the uppermost sample for which there is no sample above (catchment No. 3 in Fig. 2).

Eq. (1) represents the weighted mean formulation by which background concentration for each element (M_j) in every lithology can be estimated (Bonham-Carter and Goodfellow 1984, 1986; Bonham-Carter et al., 1987; Carranza and Hale, 1997):

$$M_j = \sum_{i=1}^{n} Y_i X_{ij} / \sum_{i=1}^{n} X_{ij} \qquad (1)$$

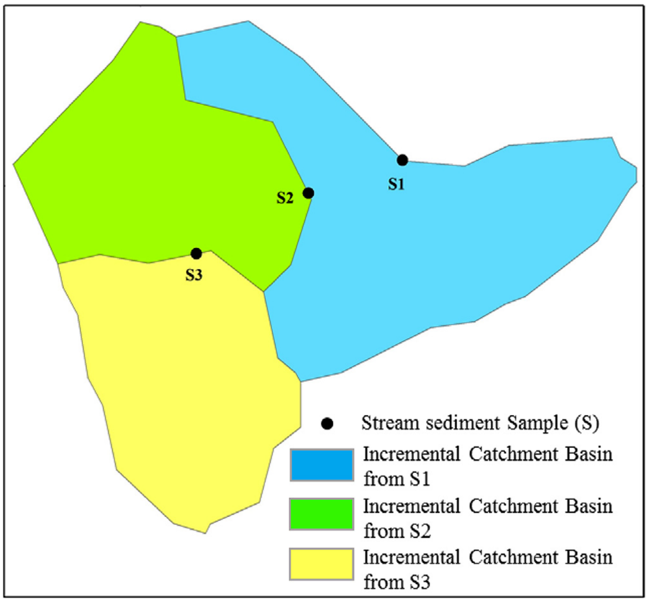

Fig. 2. An example of the incremental catchment basins geometry used in the SCBA.

where Y_i represents uni-element concentrations in the stream sediment sample i (=1,2,...,n), and X_{ij} is the area of each of the j (=1,2,...,m) lithology units in the sample catchment basin i. Then, the local background uni-element concentrations ($\acute{Y}_i$) due to j lithology units in each sample catchment basin can be estimated through Eq. (2):

$$\acute{Y}_i = \sum_{j=1}^{m} M_j X_{ij} / \sum_{j=1}^{m} X_{ij} \qquad (2)$$

It should be emphasized that in the above equations, the area size for catchment basins refers to the incremental sizes limited between two samples as shown in Fig. 2. In addition, the area sizes of different lithological units used in the above equations are also the lithological area constrained in these incremental catchment basins.

2. Problem definition

The target domains for Eqs. (1) and (2), as explained above, are incremental catchment basin areas and areas of different lithologies inside these basins. But taking into account the definition of catchment basin, the whole area of a catchment basin defined by its natural boundaries (true catchment basin) contributes to the chemical composition of the sample at the basin outlet and not merely the incremental catchment basin area. In other words, in the existing equations, samples are considered independent from each other and it is assumed that every sample is influenced only from its own basin area, something which does not match the real-world scenario. Consequently, the resulting values obtained from these equations may be far from the reality. This problem was noticed by Moon (1999) and Carranza (2004).

Moon (1999), by a study in NW Scotland, used productivity to remove dilution effect and highlighted the anomalous catchment basins. To calculate the productivity, he multiplied the concentration values by the true area size of catchment basins and not the incremental area between the samples. However, Moon (1999) realized that for large catchment basins, the productivity became very high for all elements and could create outlier values. To deal with this unresolved problem, he suggested the catchments that were statistically outliers in terms of size had to be eliminated before plotting productivity maps. Moreover, Carranza (2004) pointed to the true area size of catchment basin and used the whole basin area size above every sampling point, in Aroroy gold district in the Philippines, to remove the dilution from the residual