Short note: on the use of radioelement ratios to enhance gamma-ray spectrometric data

Brian Minty

Geoscience Australia, GPO Box 378, Canberra, ACT 2601, Australia. Email: Brian.Minty@ga.gov.au

Abstract. Radioelement ratios are useful for mapping subtle variations in radiometric signatures in map data. But the conventional method for calculating radioelement ratios has the significant limitation that if just one of the radioelements comprising the ratio has a small spread of concentration estimates relative to its mean, then it will not contribute significantly to the ratio map. However, if both the numerator and denominator are first normalised to approximately the same mean and spread prior to ratioing, then they will contribute equally to the enhancement of the differences between them across the map area.

Introduction

The ratios of radioelement concentration estimates derived from airborne gamma-ray spectrometric surveys have been used for many years for mineral exploration. Darnley (1972), for example, noted that the most important parameters in uranium exploration by airborne gamma-ray spectrometry are the uranium (U) to thorium (Th) and U to potassium (K) ratios. Almost all economic U deposits have a preferential concentration of U relative to both Th and K. However, experimental surveys over several types of Canadian U deposits at that time demonstrated that the U to Th ratio was generally more specific for potentially economic U mineralisation than the U to K ratio (Darnley, 1972).

The gamma-ray method has also been used for the detection of mineralisation other than U. These applications grew from the realisation that non-radioactive elements could be detected by their association with radioactive elements; that relative variations in radioelement concentrations could be more important than their absolute values; and that the ratios between the radioelements, in particular, could indicate environments suitable for mineralisation (Dodd et al., 1969; Shives et al., 1997). Shives et al. (1997) noted that the elements Nb and Mo can be indirectly detected through their association with U and Th, and radioelement ratios can be used for the detection of mineralisation associated with alteration (Moxham et al., 1965). Shives et al. (1997) demonstrated the use of both airborne and ground gamma-ray spectrometry to map K alteration associated with several styles of mineralisation. These include volcanic-hosted massive sulphide base metal and gold deposits, and shear-hosted gold deposits. Since Th enrichment does not accompany K during hydrothermal alteration, the ratio of Th to K is well suited to detect such alteration.

Radioelement ratios are also useful for mapping subtle variations in radiometric signatures in map data, with application to geological and environmental mapping. There is often a strong correlation between K, U and Th in the natural environment. U and Th, in particular, share a similar geochemistry and correlate highly. Ratios of the radioelements can be used to subdue or remove the gross variations in map data due to lithological variations and thus enable the detection of more subtle radioelement signatures. Ratioing also tends to remove environmental artefacts in the data due to soil moisture, vegetation, or the effect of non-radioactive overburden. This is because the attenuation coefficients for the gamma rays used to detect K, U and Th are similar for the range of earth materials and air encountered during surveying. Attenuation effects are thus minimised in ratio images of radioelement data.

This paper briefly reviews the conventional method for calculating radioelement ratios. It is then demonstrated that, in some areas, the use of these ratios can be enhanced through suitable normalisation of the radioelement data before the calculation of ratios.

Standard radioelement ratios

The conventional ratios used in gamma-ray spectrometry are U/Th, U/K and Th/K (IAEA, 1991). The International Atomic Energy Agency (IAEA, 1991) noted that, because of the noise in gamma-ray spectrometry data that derives from the random nature of radioactive decay, care needs to be taken in the calculation of these ratios. The IAEA (1991) described a common method of calculating ratios as follows.

Neglect (mask) those data points where the estimated K concentration is less than 0.25% as these are most probably over water. Using the element with the greatest estimated error (usually U for U/Th and U/K, and Th for Th/K) progressively sum elemental concentrations from adjacent observation points in the vicinity until the accumulated concentration exceeds a threshold value. The ratio is then calculated using the accumulated sums.

This scheme ensures that ratios are calculated with both numerator and denominator above a pre-defined noise limit. For gridded data, the ratios can be calculated directly as the gridding process introduces a degree of smoothing into the concentration grids. Grant (1998), however, recommended the use of this scheme for both line and grid data.

Normalised radioelement ratios

The advantage of using standard radioelement ratios is that, with time, interpreters can build an understanding of the significance of the ratio values. For example, Yeates et al. (1982) note that in some parts of the Lachlan Fold Belt, New South Wales, Australia, tungsten deposits are closely associated with granites that have U/Th ratios greater than 1.0. However, for the qualitative interpretation of map data, using the standard ratios does not always produce the most diagnostic representation of how a pair of radioelement concentration estimates differ across a survey area.
As an example, consider an area where the mean K value is 1, and the spread of the K values ranges from 0.9 to 1.1 (i.e. a very narrow range). If, however, the Th values in this area have a large spread relative to their mean, then the Th/K ratio over the area will closely reflect the Th values (they are essentially being divided by 1). If the K values had a small spread relative to a mean other than 1, then the Th/K ratio over the area will closely reflect a scaling of the Th data by the reciprocal of the mean K value. So in this example the Th/K ratio is not enhancing those areas of the map where Th and K differ.

In general, if just one of the radioelements comprising the ratio (either the numerator or denominator) has a small spread of concentration estimates across the map area relative to its mean, then it will not contribute significantly to the ratio map, and the ratio will be dominated by the variation in the other radioelement across the map area. One solution is to normalise both the numerator and denominator radioelement estimates to approximately the same mean and spread before ratioing. If the numerator and denominator are first normalised in this way then both radioelements should contribute equally to the enhancement of the differences between them across the map area.

The method used here for calculating the ratios of gridded radiometric data incorporates both normalisation to zero mean and unit standard deviation, and a preferential scaling of one of the normalised grids to adjust the relative contribution of the two grids to the ratio. An arbitrary value (10) is also added to both the numerator and denominator to avoid divide-by-zero errors in the computations. For example, the Th/K ratio ($R$) is calculated as follows:

$$R = \frac{10 + s \times \text{Th}_{\text{norm}}}{10 + \text{K}_{\text{norm}}}$$

where $\text{Th}_{\text{norm}}$ and $\text{K}_{\text{norm}}$ are the normalised grids, and $s$ is the scaling factor. For $s > 1$, Th is preferentially weighted relative to K, and for $s < 1$, K is preferentially weighted relative to Th. The scaling factor, $s$, is chosen by trial and error such that the ratio image best enhances features of interest in the data. Where necessary, a series of images derived using different values of $s$ can be used to enhance a range of different features.

The effect of normalising radioelement concentrations before calculating ratios is demonstrated in the following examples.

Figure 1 shows pseudocolour images of radiometric data from the Petermann Ranges area, Northern Territory, covering an area of ~150 km EW by 80 km NS. In the left panel, Figure 1a–c show thorium, potassium and the conventional Th/K ratio, respectively. In the right panel, Figure 1d–f show normalised Th/K ratios for

![Images](https://via.placeholder.com/150)

Fig. 1. Pseudocolour images of radiometric data from the Petermann Ranges area (top-left 129.5E–24.8S, bottom-right 131.0E–25.6S, 150 km EW by 80 km NS), Northern Territory: (a) thorium; (b) potassium; (c) conventional Th/K ratio; (d) normalised Th/K ratio ($s = 0.5$); (e) normalised Th/K ratio ($s = 1.0$); and (f) normalised Th/K ratio ($s = 2.0$), where $s$ is a scaling factor that controls the relative contribution of Th and K to the Th/K ratio (see text).
three different values of $s$. Figure 1d ($s = 0.5$) shows the effect of enhancing $K$ (specifically, the inverse of $K$) relative to $Th$. Figure 1e ($s = 1.0$) shows the effect of approximately equal contributions from $Th$ and $K$ to the ratio. Furthermore, Figure 1f ($s = 2.0$) shows the effect of enhancing $Th$ relative to $K$ in the ratio. Figure 2 shows the same radioelements and ratios for the Pilbara region, Western Australia, covering an area of $\sim 150$ km EW by 100 km NS.

Note that in both these examples, the conventional $Th/K$ ratio is biased towards $Th$ – i.e. Figure 1c and f are similar, as are Figure 2c and f. This is quite common in many $Th/K$ ratio images and is because the fractional standard deviation (standard deviation divided by the mean) of $Th$ over the study areas is significantly larger than for $K$. So in these cases most of the variation in the conventional ratio images is due to the variations in $Th$ across the map areas, and only the larger-amplitude $K$ anomalies have a significant influence on the final ratio images. However, by an appropriate normalisation and scaling of the data we can enhance the contribution of $K$ to the ratio. The normalisation results in the enhancement of smaller-amplitude $K$ features in the $Th/K$ ratio images.

Figure 3 shows histograms of the Pilbara $K$ and $Th$ data before normalisation (Figure 3a and b) and after normalisation (Figure 3c and d). After normalisation $K$ and $Th$ have a similar spread about the same mean. This ensures that they contribute equally to the ratio and thus best enhance the differences between them across the survey area. The examples shown here are for the $Th/K$ ratio, but $U/Th$ and $U/K$ ratios can be similarly enhanced.

Fig. 2. Pseudocolour images of radiometric data from the Pilbara area (top-left 118.5E–20.75S, bottom-right 120.0E–21.75S, 150 km EW by 100 km NS), Western Australia: (a) thorium; (b) potassium; (c) conventional $Th/K$ ratio; (d) normalised $Th/K$ ratio ($s = 0.5$); (e) normalised $Th/K$ ratio ($s = 1.0$); and (f) normalised $Th/K$ ratio ($s = 2.0$), where $s$ is a scaling factor that controls the relative contribution of $Th$ and $K$ to the $Th/K$ ratio (see text).
Conclusion

In many circumstances the conventional radioelement ratio method is sufficient for the enhancement of the differences between radioelement concentrations across map areas. However, there are areas where the range of radioelement concentration values are such that the ratio image is dominated by one or other of the radioelements. In these cases it is advantageous to normalise the radioelement concentration values to a similar range of values before ratioing and imaging.

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References


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短報：ガンマ線分光分析データの品質向上のための放射性元素比率の使用

Brian Minty

1 ジオサイエンス・オーストラリア

要旨：放射性元素比率は放射線源構成の微妙な変化の空間分布データをマッピングするのに役立つ。しかし、放射性元素比率を計算するための従来の手法には、もし放射性元素のうちの1つが推定濃度値の分布範囲がその平均値に対して小さい場合、その元素は放射性元素比率マップにあまり寄与しないという大きな制約がある。

しかしながら、放射性元素比率を求める前に、分子分母の平均値と値の分布範囲の両方を揃えるような規格化を行えば、濃度値の分布範囲が小さな放射性元素も、マッピング領域全域に渡って均等に放射性元素比率の改良に寄与するようになる。

単報：ガマ昇スクレートロミター星の影を限界化するための放射性原料比の使用

Brian Minty

1 デジトパラメータ

要約：放射性原料比は、放射性特有の微少な変化を地質マップの技術で導くことができる。しかし、放射性原料比率を計算するための従来の手法には、もし放射性元素のうちの1つが推定濃度値の分布範囲がその平均値に対して小さい場合、その元素は放射性元素比率マップにあまり寄与しないという大きな制約がある。

しかししながら、放射性元素比率を求める前に、分子分母の平均値と値の分布範囲の両方を揃えるような規格化を行えば、濃度値の分布範囲が小さな放射性元素も、マッピング領域全域に渡って均等に放射性元素比率の改良に寄与するようになる。