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Automated pattern recognition to support geological mapping and exploration target generation – A case study from southern Namibia

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ABSTRACT

This paper demonstrates a methodology for the automatic joint interpretation of high resolution airborne geophysical and space-borne remote sensing data to support geological mapping in a largely automated, fast and objective manner. At the request of the Geological Survey of Namibia (GSN), part of the Gordonia Subprovince of the Namaqua Metamorphic Belt situated in southern Namibia was selected for this study.

All data – covering an area of 120 km by 100 km in size – were gridded, with a spacing of adjacent data points of only 200 m. The data points were coincident for all data sets. Published criteria were used to characterize the airborne magnetic data and to establish a set of attributes suitable for the recognition of linear features and their pattern within the study area. This multi-attribute analysis of the airborne magnetic data provided the magnetic lineament pattern of the study area.

To obtain a (pseudo-) lithology map of the area, the high resolution airborne gamma-ray data were integrated with selected Landsat band data using unsupervised fuzzy partitioning clustering. The outcome of this unsupervised clustering is a classified (zonal) map which in terms of the power of spatial resolution is superior to any regional geological mapping. The classified zones are then assigned geological/geophysical parameters and attributes known from the study area, e.g. lithology, physical rock properties, age, chemical composition, geophysical field characteristics, etc. This information is obtained from the examination of archived geological reports, borehole logs, any kind of existing geological/geophysical data and maps as well as ground truth controls where deemed necessary.

To obtain a confidence measure validating the unsupervised fuzzy clustering results and receive a quality criterion of the classified zones, stepwise linear discriminant analysis was chosen. Only a small percentage (8%) of the samples was misclassified by discriminant analysis when compared to the result obtained from unsupervised fuzzy clustering. Furthermore, a comparison of the aposterior probability of class assignment with the trustworthiness values provided by fuzzy clustering also indicates only slight differences. These observed differences can be explained by the exponential class probability term which tends to deliver either fairly high or low probability values.

The methodology and results presented here demonstrate that automated objective pattern recognition can essentially contribute to geological mapping of large study areas and mineral exploration target generation. This methodology is considered well suited to a number of African countries whose large territories have recently been covered by high resolution airborne geophysical data, but where existing geological mapping is poor, incomplete or outdated.

1. Introduction

The Geological Survey of Namibia (GSN), a directorate within the Ministry of Mines and Energy, embarked on a high resolution airborne geophysical campaign two decades ago with the aim of

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achieving complete national coverage of both magnetic and gamma-ray (radiometric) data. To date, apart from very small gaps, the country is completely covered by a number of high density airborne geophysical data suites. In addition, nearly complete coverage of Landsat 7 satellite imagery is existent.

The main objective of acquiring such data has been to support geological mapping and stimulate mineral exploration in the country, add value by updating existing geological maps and to highlight areas with increased mineral potential. Conventional geological mapping using aerial photo and satellite image interpretation coupled with field visits is often handicapped by several factors, such as (a) dense vegetation or extensive sand cover, (b) extensive size of the study area; (c) time and budget constraints; (d) mapper's skills. A number of African countries with large surface areas, such as Mauretania, Nigeria or Namibia, have acquired high resolution airborne geophysical data sets in the past through national and international funding for support of geological mapping and mineral target area generation. Despite being in possession of complete airborne geophysical data sets, hardly any of these countries have complete geological map coverage. This paper suggests a methodology to support geological mapping of extensive areas using high resolution airborne geophysical data, integrated with satellite imagery or any other related data complete from the same area.

Our paper will show how automated linear feature detection and objective classification methods can accelerate the process of extracting information and evaluating the airborne geophysical and remote sensing data suites to provide new geological insight. It is also apparent that in view of the size of the country coupled with the huge amount of existing airborne geophysical and remote sensing data that a novel approach is required. Furthermore, high quality geophysical and remote sensing data can be recorded and processed rapidly using various moving platforms, while the process of interpreting and evaluating such data is by far not as fast as data acquisition. To overcome the ever increasing gap between data acquisition and the interpretation of these data, our paper demonstrates a recent methodology (Paasche and Eberle, 2009, 2011) to extract structural and lithology information in a largely automated and objective manner. At the end of this process, an interpretation map is obtained revealing various sets of linear trends as well as a number of (pseudo-) lithology units characterized by their varied physical and chemical properties.

The method uses fuzzy clustering methods (e.g. Hoeppner et al., 1999) and allows integrating high resolution airborne geophysical data with any other data sets, e.g. remote sensing, regional geochemistry or hyper-spectral imaging. Prior to clustering, all data sets need to be gridded uniformly so that a multivariate sample vector can be created at each grid point. Unsupervised fuzzy cluster analysis classifies every sample into a number of classes (groups) with no prior training and concomitantly assigns every sample a fuzzy class membership for all classes. In contrast, crisp cluster analysis does not provide a numerical measure of the degree of cluster membership, but rather in a binary sense, i.e. a sample is a member of a specific cluster (1), or a sample is not a member of this cluster (0). Once a sample is assigned to a specific cluster, it will always belong to this cluster. Moreover, linear stepwise discriminant analysis is used to validate the performance and trustworthiness of unsupervised fuzzy clustering achieved at every grid point (Paasche and Eberle, 2011). This new approach facilitates high resolution/high quality map compilation of extensive areas with downsized input of time and effort.

Multivariate statistical classification methods have been used in geophysical data interpretation for a few decades. First suggestions to use decision theoretical and multivariate statistical techniques for the integrated interpretation of magnetic and gravity data were published as early as 1972 by Harff (1972). Since the advent of powerful computing capabilities, case studies of crisp clustering have successfully been carried out over small areas selected for mineral exploration, hydrogeological or engineering geology (e.g. Eberle, 1993; Schetselaar, 2002; Tronicke et al., 2004; Martelet et al.; 2006; Teixeira et al., 2006; Eberle et al., 2010). More recently, fuzzy cluster analyses have become increasingly popular, since they offer a fuzzy, but quantitative, numerical assessment of the classification trustworthiness (e.g. Paasche et al., 2006; Paasche and Eberle, 2009, 2011). In this paper, we will discuss the maps resulting from both automated recognition of linear features using a combination of published ridge detection algorithms on high resolution airborne magnetic data and consecutive fuzzy clustering of high resolution airborne gamma-ray data and satellite imagery from part of the Karas Region situated in southern Namibia. All grid data were co-located with a grid spacing of 200 m which easily enabled the creation of a multivariate sample vector at each grid point. In order to prevent constraints of the computing capacity of a standard laptop computer, we did not use the original grid data, which were 50 m spaced, but rather created a new grid with 200 m spacing.

2. Study area

The study area extends between latitudes S26°30′ and S28°30′ and longitudes E17°00′ and E19°20′ in south-central Namibia, approximately rectangular in shape with a width of 100 km and approximate length of 200 km in the SW–NE direction (Fig. 1). The village of Grünau is situated approximately in the centre of the study area, and the Karasburg – Grünau – Seeheim road separates the area into a northeastern and southwestern part, which coincidentally are different in terms of their morphology. To the northeast of this road, the morphology is characterized by graben and horst features with partially steep escarpments, while around and southwest of Grünau the landscape is fairly flat and monotonous becoming more and more arid closer to the South Africa – Namibia border which runs along the banks of the Orange river (Fig. 1).

Geologically, the study area extends across the SE–NW trending Gordonia Subprovince of the Namaqua–Natal Metamorphic Belt between its Southern Front Zone in the southwest and the Namaqua Front in the northeast (Cornell et al., 2006; Miller, 2008a). The Gordonia Subprovince is a high-metamorphic grade, deeply exhumed, intensely foliated terrane with a granulite and charnockite core and lower grade marginal zones. Pretectonic rocks within this subprovince have apparent ages of about 2000 Ma (Miller, 2008a). High grade metamorphism is strongest in the Klein-Karas and Grünau areas, which gradually weakens when approaching the Pofadder-Marshall Rocks lineament and shear zone in the southwest and Excelsior–Lord Hill lineament and shear zone in the northeast (cf. Fig. 1; Becker et al., 2006). The Namaqua tectogenesis took place in the time interval from 1300 to 1100 Ma.

Large parts of the study area are, however, overlain by younger rock of the pan-African Nama Group and the Jurassic-Tertiary Karoo Supergroup (Geological Survey SWA/Namibia, 1977). These are mostly sandstone, shale and quartzite of the Nama Group and tillite, silt-, mud-, limestone of the Karoo Supergroup as well as extensive post-Karoo dolerite sills (Schneider, 2008).

The tectonic stress pattern within the study area is primarily reflected by three sets of dykes with different age and composition. The late Proterozoic, pre-Nama Gannakouriep dyke swarm trends SW–NE to SSW–NNE and is strongly reflected by the magnetic data (Fig. 2a). According to geological mapping (Geological Survey SWA/Namibia, 1977), the occurrence of Gannakouriep dykes is most frequent in the vicinity of the Klein-Karas and Grünau settlements. The Gannakouriep Suite represents a mafic dyke