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Introduction to Vertical Geology thematic issue

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Abstract
This paper is an introduction to the special issue of the first Vertical Geology Conference - VGC-14 which was held at the University of Lausanne in February 2014. The context of the meeting and its goal is presented and a definition and short introduction to the theme of Vertical Geology is given. Finally, the paper introduces all articles contained within this special issue.
Keywords: Lidar, photogrammetry, hyperspectral, virtual outcrops, 3D geology, natural hazards, geosciences.

Introduction
The first Vertical Geology Conference - VGC-14 - took place at the University of Lausanne on 6th and 7th February 2014. During these two days around 70 scientists participated in the meeting. In accordance with the multidisciplinary theme of the conference, these scientists came together from a diverse range of research fields, such as structural geology, geology, pattern recognition, geomatics, sedimentology, natural hazards, infrastructure and others. This made the VGC-14 conference a unique forum for interdisciplinary research, and a means of initiating transdisciplinary research that can emerge when linking different viewpoints. The variety of research presented made it difficult to identify a single journal that would accept to cope with such a broad range of topics. However, the European Journal of Remote Sensing accepted to host this special issue containing some of the contributions that were presented originally as extended abstracts within the proceedings of the conference [Humair et al., 2014].

Introduction to the concept of Vertical Geology
Why vertical geology? Vertical Geology emerged as a theme of research linking classical geology and recent geomatics technologies for 3D outcrop analysis and representation. Geology has always included the third dimension, but it has mostly used and produced

2D horizontal projection, i.e., geological maps. Since, the mid-20th century the dream of linking the earth sciences and computers [Krumbein, 1962] began to be tangible because of two major advances: (1) the constant improvement of computer capabilities and their wide distribution; (2) the arrival of new techniques of remote sensing [Scaioni et al., 2014], providing new types of data, such as LiDAR [Haugerud et al., 2003], photogrammetry, hyperspectral imaging, positioning based on global navigation satellite systems (GNSS), etc. The first advance led to complex and computational 3D geological modelling [Caumon et al., 2009; Zanchi et al., 2009]. The second has given us access to accurate and high resolution ground surface topography [Shan and Toth, 2008] and real 3D data for obtaining geological information [McCaffrey et al., 2005], leading to true 3D input for models [De Kemp and Sprague, 2003; Eide et al., 2015].

Complementary to 3D surface information from LiDAR or photogrammetry are other remote sensing methods, including LiDAR intensity data [Franceschi et al., 2009] and hyperspectral imaging [Kurz et al., 2011], which are natural additions to virtual outcrop geology. This subject is a topic of intensive research that involves the building of real 3D surface geological maps [Bellian et al., 2005; Buckley et al., 2010; Hodgetts et al., 2013], using image understanding and pattern recognition techniques [e.g., Viseur et al., 2007]. Until now, its main application is the 3D modelling of reservoir analogues [Buckley et al., 2010] (Fig. 1), mapping and analysis of sedimentary architecture [Eide et al., 2015], and structural characterisation in order to generate discrete fracture networks (DFN) for reservoir modelling [Wilson et al., 2011].

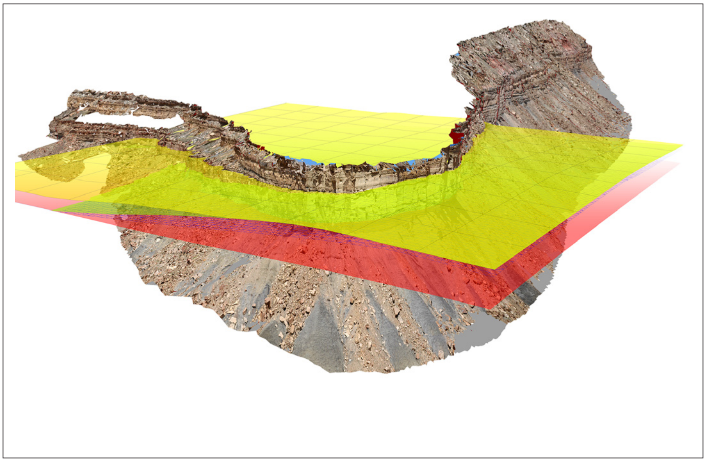

Figure 1 - Laser scanning data interpretation for reservoir modelling (data from Enge et al. [2010]).

In natural hazards, the use of 3D data such as high resolution 3D point clouds has been also developed for landslide investigation purposes [Jaboyedoff et al., 2012]. The main input for geology is the structural characterisation of rock mass [Jaboyedoff et al., 2007; Lato et al., 2009; Sturzenegger and Stead, 2009; Assali et al., 2014] and automation of the discontinuity set recognition [Lato and Vöge, 2012; Riquelme et al., 2014], as well as input

for DFN models [Sturzenegger and Stead, 2009].
Recently, the evolution of photogrammetry, in particular methods coming from the computer vision field, such as structure from motion (SfM - [Snavely et al., 2008]), which permits 3D point clouds to be created from numerous highly overlapping and convergent camera images taken from different positions. SfM is currently having a high impact in earth science research [James and Robson, 2012; Westoby et al., 2012, Fonstad et al., 2013], in tandem with the developments and popularisation of Unmanned Aerial Vehicles (UAV's), which can provide data from usually inaccessible points of view [Colomina and Molina, 2014]. Based on these advances, the possibility to achieve 3D point clouds coupled with true colour images, at relatively low cost and with high automation, is adding a new dimension in accessibility to geoscientists across the various disciplines.
All these recent evolutions open the door to many new techniques and applications, and permit new research topics to be pursued. This allows us to investigate new problems as well as revisit old questions, such as dolomitization [Jacquemyn et al., 2015], with fresh input tools.

Conference objectives

The ideas that initiated the VGC-14 conference were (1) to present and discuss the most recent scientific results and techniques for mapping near-vertical cliff sections by remote sensing as input for 3D geo-modelling; (2) to identify related critical issues and promising developments; and (3) to provide a forum for information and knowledge exchange between academic, government and practising geoscientists about 3D digital geology.
The presentations focused on remote sensing of the terrain surface and digital processing to support 3D geological modelling and interpretation in various fields of geosciences such as (non-exhaustive list):

- Digital geological mapping: vertical rock walls, remote lithological mapping, examination of sedimentary structures, mineralogical/geochemical mapping;
- Structural geology: characterization of ductile and brittle deformation structures in outcrops, fracturing pattern recognition and tectonic structures;
- Reservoir analogues: characterization and virtual outcrop building;
- Natural hazards: rock falls, landslides and rock mass quality assessment, characterization of release areas and deposits;
- Tunnelling and mining: underground imaging, 3D excavation modelling;
- Numerical modelling: representation of complex 3D geological bodies, simulation based on remote sensing data; and
- Innovations: new sensors, techniques, tools and data, automatic 3D geological features recognition.

Contributions

This special issue includes nine articles that cover a number of aspects of Vertical Geology.
The first two papers cover hyperspectral imaging. Paper one, *Mapping of iron and steelwork by-products using close range hyperspectral imaging: A case study in Thuringia, Germany,* presented by Denk et al. [2015] is dedicated to geological 3D mapping using hyperspectral imaging methods.
The second paper by Murphy et al. [2015], entitled *Mapping clay minerals in an open-*

pit mine using hyperspectral and LiDAR data, presents a state-of-the-art approach of the coupling between terrestrial hyperspectral (shortwave infrared) and laser scanning data. The authors demonstrate the potential of this technique to map various types of clay minerals (kaolinite, illite-smectite, Fe-smectite, nontronite, talc, and chlorite) in an open-pit iron-ore mine in Western Australia.

The second topic, illustrated by four papers, is related to geological mapping using LiDAR and photogrammetry. Franceschi et al. [2015], in *Integration of 3D modeling, aerial LiDAR and photogrammetry to study a synsedimentary structure in the Early Jurassic Calcari Grigi (Southern Alps, Italy)*, investigate the extensional structure of Monte Cornello. With the use LiDAR and photogrammetric data, the authors reconstruct 3D faults and stratigraphic surfaces, showing the synsedimentary character of this structure.

Humair et al. [2015] propose a contribution, *Geological layers detection and characterisation using high resolution 3D point clouds: example of a box-fold in the Swiss Jura Mountains*. In this paper, the authors compare photogrammetric and LiDAR methods for structural mapping, and assess the radiometric characteristics of each data set (LiDAR intensity and image grey values) to assist the automation of lithological mapping.

Similarly, Matasci et al. [2015] in *Geological mapping and fold modeling using Terrestrial Laser Scanning point clouds: application to the Dents-du-Midi limestone massif (Switzerland)* analyse the contribution of the backscattered LiDAR energy to map the main lithology in difficult-to-access sections in the Swiss Alps.

DEM extraction using photogrammetry on two different study sites based on oblique stereo-images is the theme of Sørensen et al. [2015] in *Point clouds from oblique stereo-imagery: Two outcrop case studies across scales and accessibility*. The first example comes from a quarry in Denmark, where the distance of acquisition is a few tens to a hundred meters, and where a terrestrial laser scanning (TLS) survey was completed for the purpose of change detection. The second example compares the DEM extracted from oblique imagery acquired on large terrain surfaces in Greenland at distances ranging from 2-5 km, this result is compared to the DEM obtained using standard panchromatic aerial photographs. In both case the results are accurate enough for most of the geological applications depending on the scale of work.

The third topic is related to remote sensing for geotechnical studies. Matano et al. [2015] in their paper *Laser scanning application for geostructural analysis of tuffaceous coastal cliffs: the case of Punta Epitaffio, Pozzuoli Bay, Italy* propose an original workflow to treat and analyse TLS data using Open Plot software and ArcScene. The main discontinuity sets are extracted using best fit planar surfaces, and each of them are represented in a 3D model. The reported results show that the main failure mechanisms could be identified, allowing kinematic tests of the different sections of a tuffacious coastal cliffs to be performed.

Spreafico et al. [2015] in *Terrestrial Remote Sensing techniques to complement conventional geomechanical surveys for the assessment of landslide hazard: The San Leo case study (Italy)* again compare LiDAR and photogrammetric methods, this time for assessing the structural stability of settlements built on top of rock plateaux in the northern Apennines. As managing the evolution of the instability is important to ensure human safety, as well as the cultural heritage, mapping and analysis of the 3D discontinuity network was carried out to aid geological and numerical modelling.

The final paper, *Common problems encountered in 3D mapping of geological contacts using high-resolution terrain and image data* [Guerin et al., 2015] is a Technical Note relating to the accuracy of manual digital geological mapping using an integrated set of remotely sensed data (DEM's, high-resolution aerial and ground-based imagery).

Conclusion and looking forward to 2016

As VGC-14 proved to be a successful forum for connecting researchers from geomatics and different geoscience disciplines, we hope that the conference theme can evolve into an established series. The use of digital mapping techniques in geology and geoscience is rapidly proliferating, and new technology, sensor integration, software, visualisation and graphics methods are all converging to push the boundaries of current geoscience research. Recognising this, the conference is being organised again in 2016. It is hoped that the many researchers working with spatial measurement methods in geoscience will contribute with their latest developments and novel applications, again making a successful forum for multidisciplinary research. VGC-16 will take place in Bergen, Norway, 22-23 September 2016 (http://virtualoutcrop.com/vgc2016).

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