GEOVISION ’99 “Guest Editorial”

This special issue of Computers and Geosciences contains a selection of papers from a total of seventy abstracts presented during the first Geovision congress, held in the Belgian city of Liege from May 6th –7th 1999. The congress aimed to bring together imaging specialists from different earth science disciplines, including remote sensing, geophysics and microscopy. To our knowledge, it was the first of its kind and it made a significant contribution in breaking down artificial barriers between these disciplines. By reporting on the outcome of the congress via this special issue of a journal with a large audience in the earth science community, we hope to promote the importance of digital imaging as an innovative tool to help scientists understand the Earth and its environment.

Imaging and the Geosciences

Visual information has always played a central role in the geosciences. For centuries, it was the only evidence that geologists could rely upon in the construction of their theories about the Earth. Drawings and sketches made in the field or traced from an optical projection of a microscope slide were some of the key tools used to convince colleagues of the validity of a particular model. In time, however, other techniques were developed and new types of sensors helped to extend geologists’ perception far beyond the limitations of human vision. New disciplines were created that specialised around the acquisition, processing and analysis of data from selected regions of the electromagnetic spectrum (for example, radar, acoustic waves, or infrared light) or selected physical properties (for example, magnetism, X-ray diffraction, or mechanical strength). The science of imaging was born.

If one thinks about images in terms of visible information alone, then the use of digital imaging may appear to be restricted to field geologists. But if one extends the notion of image to a broader definition, such as “a dense matrix of measurements of any property for a geological object”, then every geologist should become interested. Under this definition, the problems that can be addressed using image processing and analysis techniques are increasing all the time. Among the most obvious applications are remote sensing, geophysics and microscopy. All three share the attribute that the geological objects they study are difficult to characterise using conventional techniques. They are either too large, buried below the ground surface or too small to be easily addressed by the normal human visual system without assistance. This was probably the main reason why these three disciplines led the way in the development of quantitative imaging techniques, capable not only of visualising but also of analysing the data. But these days other disciplines like geochemistry, which might appear to be a non-imaging technique due to the sparse nature of the data, are adapting the imaging techniques developed elsewhere to great advantage. This imaging-based view of our science is also supported by the shared lineage of geostatistics and mathematical morphology, both originating from Matheron’s original thinking.

Computers and Images

Nowadays it appears obvious that numerical images can be manipulated using a personal computer, or even sent across the Internet. But we should remember that this was still an exceptional application as recently as the 1980s. It could not be done without the aid of a specialised array processor or a powerful and expensive workstation. Despite this, the first attempts at quantifying visual information were pioneered during the second half of the 19th Century and the basics of image processing were defined during the 1950s. The main contribution of the 1990s has in fact been the exponential increase in computing power and the development of the sophisticated processing algorithms that this power has made possible. In this regard, there remains a long way to go. The next steps will be the integration of processing algorithms into the data acquisition phase, producing sensors and instruments that provide information, rather than data, and leaving scientists free to concentrate on the scientific analysis at the end of the workflow.

Whatever the imaging application, the following steps have to be performed:

- *Image acquisition*
- *Calibration and filtering (or pre-processing)*
- *Enhancement, classification and segmentation (or image processing)*
- *Analysis (or image interpretation)*

Although this progression is quite logical, it is evident that not all disciplines in the geosciences have paid the same attention to each step. For example, geophysicists are very much concerned with problems of inversion that relate primarily to data acquisition and filtering. Having spent considerable time and resources getting their image they still rely in large part on visual interpretation. In contrast, remote sensing specialists have little opportunity to intervene in the acquisition process, which is often predetermined by satellite design and orbit. They have minimal control on the lighting and atmospheric conditions, so they focus on the enhancement and classification of the image to extract spectral signatures related to particular geological materials. Finally, microscopists typically use a cheap CCD camera designed for broadcast applications to acquire their images, but they expend considerable effort putting numbers to their visual data such as grain sizes and shapes, deformation structures and mineral co-occurrences.

In future geologists should take a pioneering role in the development of imaging techniques. Geoimaging will not find full maturity unless specific sensors and algorithms are designed that are tailored to geoscientific problems. Home video cameras, desktop scanners and generic image processing software may help but they will never solve the problems in a rigorous scientific fashion. It is very instructive to note that almost every reference book in the field of quantitative image analysis refers to a founding publication by Delesse in the Annales des Mines of 1848. As a geologist faced with petrographic descriptions, he was one of the very first to try to formalise the problem of phase ratio estimation. Subsequently, renowned mathematicians developed his ideas into the general framework of stereology, but would this have happened at all if he had not put his geologically derived ideas forward in the first place?

The same remains true for many other problems in the geosciences. Geologists must be able to discuss their needs with electronic engineers and physicists, computer scientists and mathematicians. This is not a question of large scientific budgets, but merely a need for education and dialogue. The Society for Mathematical Geology is one ideal forum for stimulating new ideas and developments in geoimaging, and we believe that Geovision was also a success in this regard.

Geovision '99

And so to the papers presented at the meeting. Among the most fascinating imaging techniques, resistivity imaging certainly occupies an important place. Rapidly evolving from 1-D to 2-D and even 3-D imaging, resistivity mapping derived from the multiple coupling of electrodes is generating a lot of interest. The range of applications in the paper by ***Dahlin*** *demonstrates this. Also in the field of geophysics, seismic and electrical tomography may still have a poor resolution compared with video images but they can be used to gain significant structural information about the subsurface.* ***Demanet et al.*** *show how image segmentation techniques such as the watershed transform are a good starting point for locating faults in palaeo-seismological applications.*

X-ray based tomography is a very popular method for imaging soft tissues and medical applications certainly stimulated the development of such imaging techniques. But here, again, the specific needs of geologists and material scientists have led to different options in addressing the imaging problem. ***Van Geet et al****. describe early attempts at the 3-D imaging of rocks with microscopic resolution. 3-D imaging is becoming standard in microscopy and will stimulate the need for more sophisticated analysis and processing algorithms. Among the imaging techniques with 3-D capability, confocal microscopy is probably the most mature. Once again, biological applications are the most common and geological applications remain confidential or unreported. In this issue,* ***Menendez et al.*** *present a very successful application to the study of the evolution of a porous network during the mechanical cracking of granite and the cementation of a sandstone. The three dimensional reconstruction of the porous structure is the only possible method for gaining an insight into the interconnectivity of the voids.*

*Confocal imaging is of course only possible in favourable circumstances and it remains constrained by the necessary transparency of the medium. Undoubtedly, two dimensional imaging from thin sections is still an efficient method for the description of rock textures; for example, with respect to modelling groundwater flow (****Pina et al., Sardini et al.****). Pores occupy a major proportion of many rocks and are of particular interest because they host either water or petroleum resources, but the mineral constituents themselves are of paramount importance in many other fields such as ore reserve evaluation, geomechanics and petrography.* ***Rogen et al.*** *indicate how the quantitative image analysis of back-scattered electron micrographs may help to establish not only pore size distributions in chalk, but also the grain size distribution of the calcite matrix.*

<u>Thompson et al.'s</u> *work is based on a clever video image acquisition technique using a proprietary rotating polariser. The identification of the mineralogy of each pixel within the image relies on an artificial neural network technique that aims to mimic the human perception of mineral species. This is a brilliant combination of two high-level techniques that are all too often underestimated by earth scientists.*

Radargrammetry and radar interferometry have already demonstrated promising capabilities for the automatic modelling of topography in remote regions. ***<u>Kervyn's</u>*** *applications to active fault zones and the monitoring of volcanic domes demonstrate the advantages and disadvantages of each method. Although some specific problems have to be overcome in geological remote sensing, such as the atmosphere and vegetation, it is striking how close these techniques are to interferometric microscopy and stereoscopic electron microscopy, which are used to model the topography of materials and rock samples.*

Finally, ***<u>Bonifazi et al.</u>*** *present their work on the automated monitoring of flotation froth. It is a good illustration of the importance of imaging not only as a quantitative aid to the field geologist or mineralogist, but also as a potential replacement for human operators undertaking dangerous or repetitive visual tasks in the minerals industry. Geologists and mining engineers must work together to help transfer these techniques from the research laboratory to the industrial workplace.*

This special issue presents examples of the application of imaging techniques throughout the geosciences. But it must be noted that quantitative imaging with sensors and high-powered computers should never be regarded as a possible tool with which to replace skilled geologists. Rather, geoimaging techniques should be considered as an invaluable aid in the decision-making process and an important step forward in enhancing and making objective our subject's observations.

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