Topics

Virtual geological outcrops – fieldwork and analysis made less exhaustive?

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For geologists studying outcrops in the field, there is an ever-increasing need for the acquisition of accurate and comprehensive data, whatever their purpose. Fortunately, this need is mirrored by an expanding range of digital data capturing technologies that provide the possibility of examining geological outcrops in minute detail from the desktop. Although difficult technologically, there is also a need to combine differing datasets into a single, accurate, digital model that will allow field geologists to place their data in a wider context. This paper examines the techniques available, and highlights new Light Detection and Ranging (LIDAR) technology which should prove to be a unifying technique, being able to combine images and local coordinates on-site.

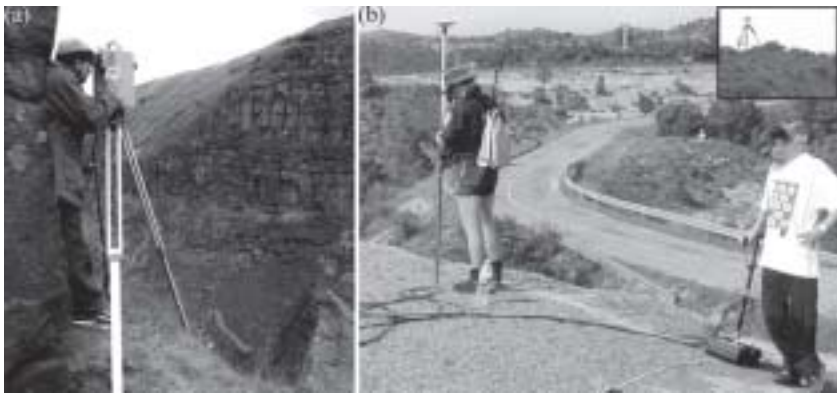


Fig. 1. a. Acquiring co-ordinate points using a reflectorless Total Station surveying instrument. The equipment measures distance, vertical and horizontal angle, which convert into *x, y, z* co-ordinate points. **b.** Differential Global Positioning System (GPS) equipment, a mobile GPR receiver (left figure) checking position against a base station (inset) and +6 satellites. The right figure is collecting Ground Penetrating Radar (GPR) subsurface data.

Traditional outcrop studies

Geologists study well-exposed rock outcrops for a range of purposes. For example, whilst the regional geologist seeks to place each outcrop in a wider context, the engineering geologist may have designs on the outcrop and the rock mass immediately behind it. In another case, the petroleum geologist may need an abstract link between outcrop data and a reservoir with similar geology, providing generic links between, for example, tectonic setting and depositional environment. Every motive for outcrop studies emphasizes particular parameters. The engineering geologist may need to measure fracture geometry and friction angles, to calculate, for example, factors of safety for rock slope stability. A single joint set can greatly affect the result. Regional geologists may need stratigraphical information, while the reservoir geologist has an additional interest in the geometry and distribution of sedimentary architectures such as deep-sea channels and fluvial point bars.

Scale also varies within the discipline. For example, regional geologists use large-scale, remote sensing techniques, such as aerial photography and satellite imagery. Whilst for them a single set of representative measurements, such as dip and strike, may suffice for each outcrop, engineering and reservoir geologists usually need many measurements, along with their relative positions. As geologists' needs and purposes differ, so too have the expanding topographical survey methods to provide a digital framework. Below we briefly detail a range of techniques that can be used to amass and combine accurate positional information and image data for geological use.

Conventional (Total station) surveying

As the modern equivalent of the Abney Level, Laser Total Stations (Fig. 1a) can provide co-ordinate points (x, y, z) with or without a travelling target reflector. The 'reflectorless' mode allows steep, remote cliff faces to be surveyed. Measurement accuracy is typically 20 mm in ideal conditions, but errors increase towards the maximum range of 2 km.

From this, and given enough points, one can create a locally accurate, digital, model of the surface studied. Using a total station, a professional surveyor can acquire and annotate about 100 points per hour, and in May 2000 our two-man team acquired 1700 co-ordinate points over a 4-day period at a study site in Ireland (Fig. 2a). Our target was a Carboniferous, deep-water sandstone channel-fill, with sub-surface data being provided by Ground Penetrating Radar (GPR) profiles. The Total Station survey points provided a reference datum for these profiles, and from the co-ordinate points a digital surface model was built (Fig. 2b). These data, however, needed consider-

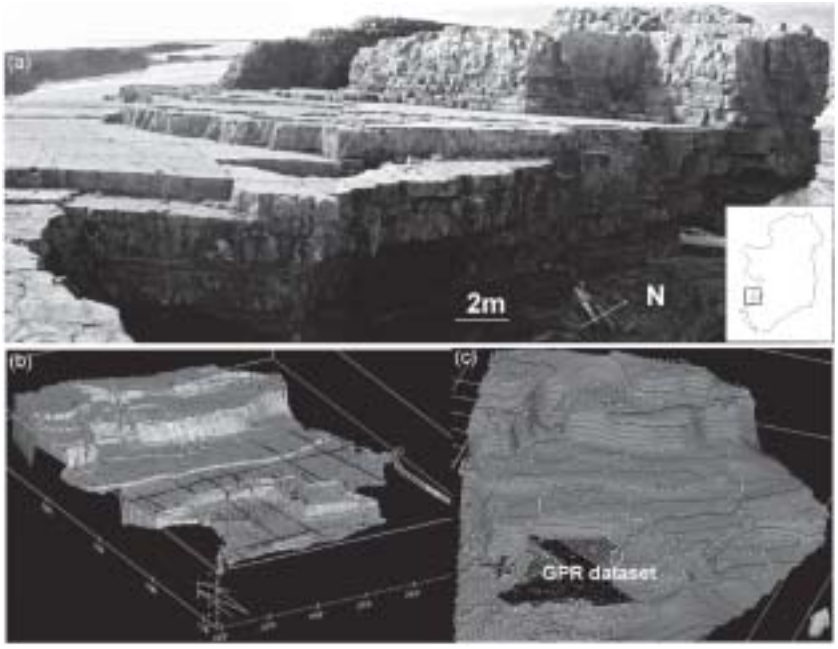


Fig. 2. a. Photograph, with location map (inset), of the Bridges of Ross study site, County Clare, Western Ireland. **b.** Digital surface model, created using conventionally surveyed data points (dots). Sedimentary logs (columns) and 2D GPR profiles (black lines) are shown. **c.** Digital surface model created using differential GPS data points (dots). Contour lines are 0.5 m. A 3D GPR dataset was added.

able post-fieldwork data processing. Accuracy varied with range across the model and interpolation between measured points caused some gross errors.

Differential GPS surveying

A GPS (Global Positioning System) station records its real-world position by tracking a minimum of six satellites at once. In the differential GPS method, a mobile receiver GPS checks its position against the satellites and a second, static or base station GPS receiver (Fig. 2b). In ideal conditions, the differential positioning system provides an accuracy of 10 mm (x, y) and 20 mm (z). The user may choose between recording automatically at set intervals or at individually designated sample points.

In July 2002, on the same Irish outcrop, we acquired around 13 000 differential GPS data points using a Leica 500 system over a 7-day period. GPS measurements require less post-processing than Total Station data, with software converting real-world co-ordinates into local (x, y, z) co-ordinates. The resulting digital surface model (Fig. 3c) is much more detailed than the original model acquired using the Total Station.

GPS data acquisition accompanied a second phase of three-dimensional Ground Penetrating Radar (GPR) data acquisition. The combination of a more detailed surface survey and a continuous sub-surface survey allowed previously unknown geological features to be recognized and mapped as three-dimensional surfaces within the undisturbed outcrop.

Control point (polynomial) rectification

Once a digital surface model has been created from the survey data described above, outcrop photographs or photomosaics can be draped on to this surface by matching points on the photograph with the same points identified on the digital model. The photograph is least distorted where the outcrop faces are relatively planar and there are sufficient control data points.

In 1999, at a Scottish Borders study site (Fig. 3a), our two-man team acquired 62 co-ordinate points by conventional surveying in 2 hours. The result was a regularly spaced, data point grid (Fig 3b), over which the outcrop photograph could be draped to create a digital model of the surface (Fig 3c). A later comparison with measured outcrop distances showed that the model was an accurate representation of the surface, to around 20 cm, with the largest distortions occurring in irregular areas.

Digital photogrammetry

Photography is a very efficient way of capturing large amounts of outcrop information, and can be used to gain accurate measurements through photogrammetry. Although most images are two-dimensional, stereoscopic photograph pairs have provided the possibility of three-dimensional views for over 150 years. Stereo-glasses of various types allow viewers to appreciate depth semi-quantitatively, which is of value in determining the characteristics of the land surface.

Over the last 15 years, digital photogrammetry software has automated regional topographic mapping. This involves the use of a digital elevation model (DEM), with a draped ortho-rectified image (ORI), both derived from a digitized stereo-pair of aerial photographs. Ground control is not required, but is needed for accurate scaling and correction for lens distortion effects. The resulting 3D draped model is viewable interactively, of great importance in the study of inaccessible and/or dangerous sites, which are thus measurable from the relative safety of an office.

Technological advances now provide automatic acquisition of satellite photography, but the remotely sensed data are usually too coarsely sampled (low resolution) for geological outcrop study purposes. De-

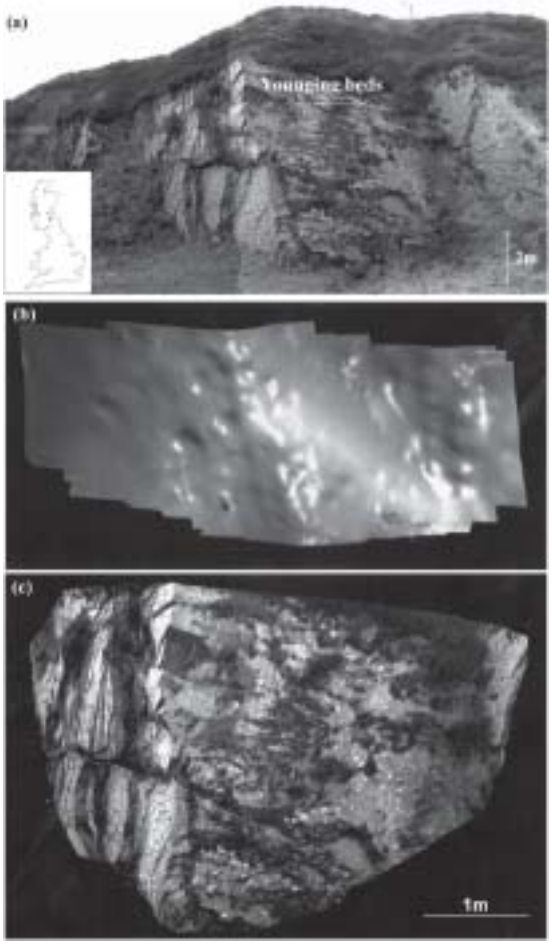


Fig. 3. a. Outcrop photomosaic, with location map (inset), of Cow Peel Bridge, Scottish Borders, UK. Ordovician deep-water sediments have undergone multiple faulting and 90° tectonic rotation. **b.** Surveyed data points have been interpolated to create a regularly spaced grid (DEM). **c.** Outcrop photomosaic (a), has been rectified and draped over (b) to form a digital surface model.

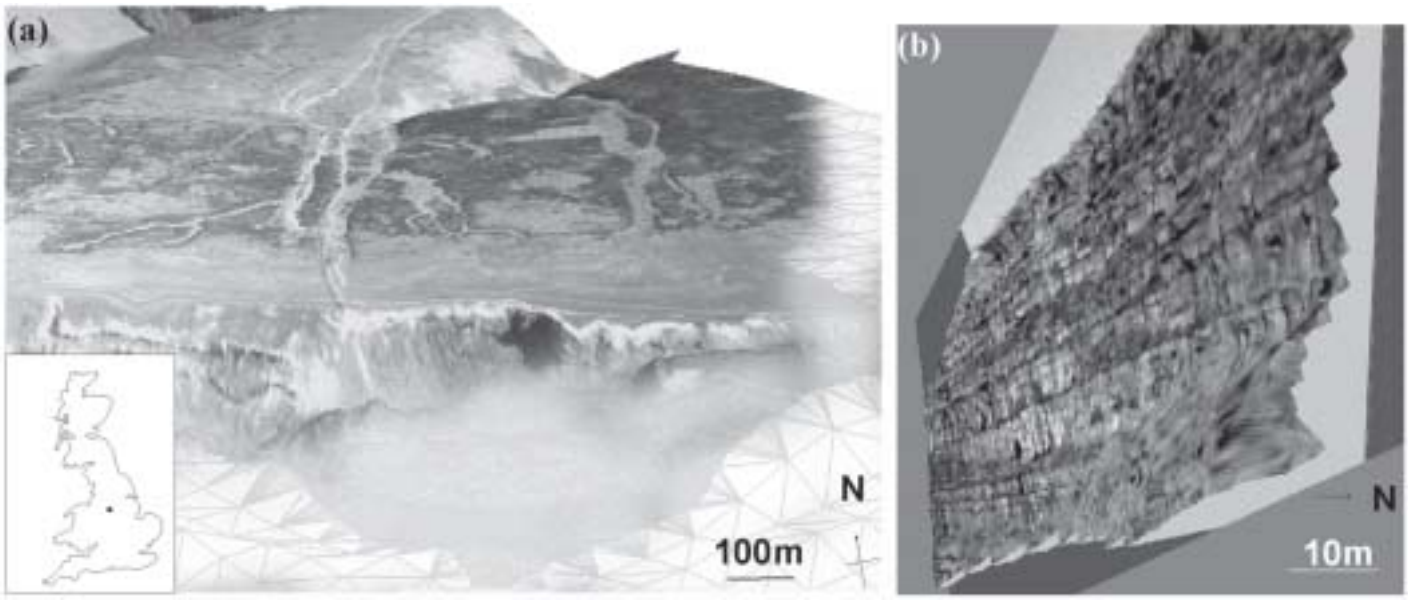
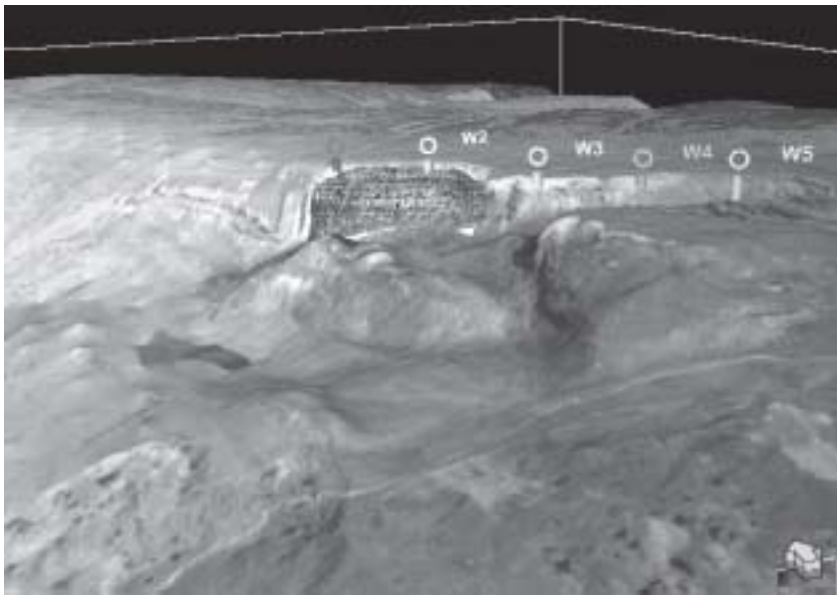


Fig. 4. a. Digital model of Alport Castles, Peak District, UK, with location map (inset). An aerial photograph stereo-pair were combined with ground control to produce a 3D draped model. **b.** Digital cliff-face model created from close-range photographs and conventionally surveyed data points. The DEM was at 10 cm spacing. Survey points are marked by crosses.

tailed geological features exposed on near-vertical cliff faces are difficult to image from overhead. The issue is resolved by applying digital photogrammetry techniques to ground level cliff-face photographs. Photogrammetric output from these studies can be combined, the resulting digital data model providing high-resolution detail where needed in a lower resolution context.

At a Derbyshire study site, a digital model was created from two aerial photographs with some ground control (Fig. 4a). The DEM spacing was around 25 m over horizontal areas and about 4 m over the cliff face. The aerial photographs did not show cliff exposures of the Carboniferous sandstones required by the study, so a close-range, cliff-face stereo-photograph pair was acquired in 2001. The two photographic parallel lines of sight, needed for accurate photogrammetry, proved difficult to achieve. Conventionally surveyed cliff-face data points were used as a control. The resulting 3D draped view (Fig. 4b) was appropriate for sedimentary studies, having about a 10 cm resolution. Common points on both datasets were also identified, the cliff model being rotated, translated and 'docked' on to the large-scale aerial digital model. The combined Digital Outcrop Model (Fig. 5) not only provided a large-scale site model, but could also be analyzed in detail at cliff-face scale.



LIght Detection And Ranging (LIDAR) surveying

LIDAR is the latest ground survey method, although related airborne LIDAR has been available for some time. LIDAR is a development of Total Station technology, with a rotating mirror moving a laser beam over an outcrop, in a similar way to an electron beam painting a television screen. The rapid, automatic acquisition of data points creates a highly detailed point cloud. LIDAR typically acquires 18 000 points per second, with a current measurement accuracy of around 12 mm. Like their Total Station parents, the first LIDAR instruments had a measurement accuracy of around 25 mm.

LIDAR acquisition equipment typically scans 360°

Fig. 5. Digital Outcrop Model of the Alport Castles study site. Digital aerial and terrestrial photogrammetric output were imported and draped. Abseiled sedimentary logs (W1-5) were also imported, providing additional control for analysis.

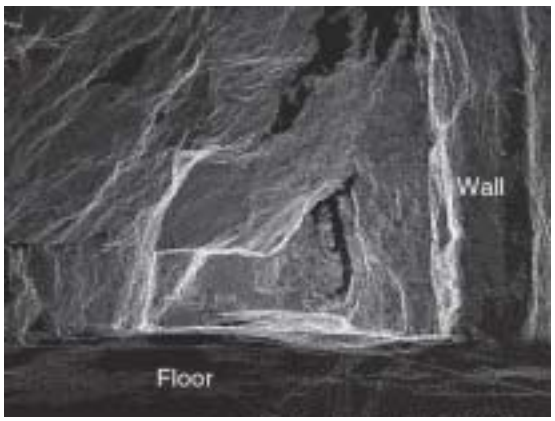


Fig. 6. Looking West in a point cloud of Gaping Gill Main Chamber, Derbyshire, UK, acquired by a Z3210 LIDAR surveying instrument. The survey is composed of ~15 million co-ordinate points.

and across a 90° swath. A fully 3D digital model results from combining scans, post-acquisition data processing software automatically recognizing reflector patches placed in overlap zones. LIDAR technology is developing rapidly: both image quality and scan rate is ever improving. However, the equipment is relatively expensive and is in short supply at the time of writing.

In September 2003, 15 million data points were acquired using Z210 LIDAR equipment in 4 hours by our two-man team. Survey conditions were far from ideal, 100 m below ground at Gaping Gill Main Chamber, a limestone cavern in North Yorkshire, UK. Three LIDAR scans were combined to form the best possible digital data set of the cavern.

During post-survey data processing, a surface fit is performed, allowing current computers to quickly render the image for interactive visualization. The resulting 30 Mb model had 750 000 triangular apices (Fig. 6), with an average measurement error of 25 mm. This allowed an identification of the main geological features controlling development of the visible chamber; namely faults, joints, bedding planes and overhangs.

Exposed geological surfaces typically had tens of thousands of points recorded, but the intersections typically had a smaller number of recorded points, but over a larger length scale. In each case the strike and dip calculated was far more accurate than those normally measured on-site by traditional compass and clinometer. Furthermore, higher order surface properties can be accurately calculated. Examples are roughness, important to engineering geologists, and corrugation, important to structural geologists.

The latest LIDAR instruments now carry a digital camera. Photographs are automatically ortho-rectified and combined with the (x, y, z) point data. As noted in the introduction, LIDAR technology will now be able to offer field geologists both image data and positional accuracy, on-site and in a digital format that allows interpretation, classification and parameterization.

Overview

There are many techniques that can be used to create digital models of study sites, depending on different balances of photographic and survey data (Fig. 7). Indeed, there are more than mentioned in this article, for example, algorithmic processes that convert video passes of objects to digital models without any need for control points.

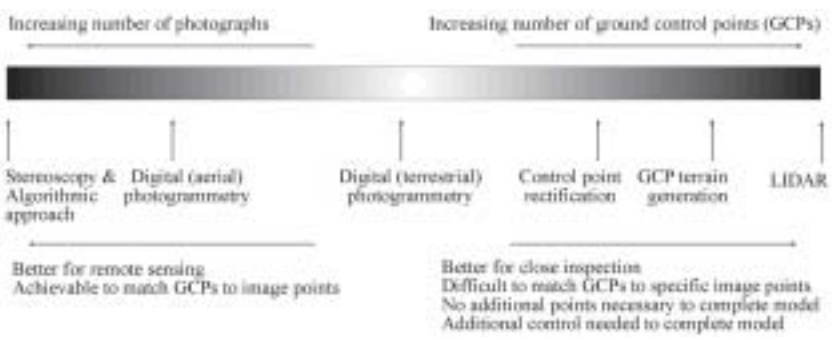
A digital model can be rapidly generated from survey points, with no photographs required. However, not only is significant post-fieldwork data processing involved in creating a digital model, but field observations are difficult to identify on specific model areas. There were also model surface distortions, where the control points were widely spaced.

The polynomial rectification method requires relatively few photographs, but plenty of ground control, and they do not have to be taken at a precise angle and range, which is the case in digital photogrammetry. However, any errors in matching the grid produced from co-ordinate points and the photograph will distort the final model, which may not be initially obvious.

Digital photogrammetric methods are semi-automated, and the resulting models allow whole field areas to be visualized and analyzed in 3D for large-scale stratigraphy. However, small-scale geological features are not usually resolved, especially on near-vertical cliff faces. Photogrammetric techniques can be adapted to use terrestrial photographs and ground control, to create a high-resolution digital model. Although technically difficult to create, digital datasets can be integrated to form a Digital Outcrop Model, which can be used for virtual fieldtrips or a data source for future studies.

LIDAR technology provides solutions for almost all of the problems described above, Figure 7 illustrating the range between control points and image data. The two key survey data types appear as end members of a data spectrum. The latest LIDAR equipment is able to reconcile the two end members automatically. We believe that this will have tremendous impact on field geology.

Fig. 7. Summary diagram comparing different techniques to create digital surface models of study sites. Techniques depend on site specifics and the type of field data acquired.



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