The Use of Geographical Information Systems (GIS) in Rock Characterisation

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Περίληψη

Ένα κυλινδρικό δοκίμιο του ψαμμίτη Penrith εξετάστηκε γεωφυσικά και οπτικά. Τα γεωφυσικά αποκαλύπτουν ότι ο ψαμμίτης περιέχει δύο επίπεδα όπου η διαφορά των κυμάτων p, αν και μικρή, παρουσιάζει μέγιστο. Πετρολογικές λεπτές τομές κόπηκαν κατά μήκος αυτών των δύο επιπέδων και από αυτές τις λεπτές τομές φωτογραφίες ελήφθησαν μέσω ενός μικροσκοπίου υπό μεγέθυνση 8x. Οι πόροι που αναγνωρίσθηκαν στις φωτογραφίες εισήχθησαν στο IDRISI 4.1, ένα raster Γεωγραφικό Σύστημα Πληροφοριών. Αυτή η μελέτη δείχνει πως τα Γεωγραφικά Συστήματα Πληροφοριών μπορούν να παρέχουν μετρήσεις επιφανειών πόρων, περιμέτρου πόρων και «πορώδους» όπως επίσης και να προσδιορίσουν διαφορές σε αυτά τα χαρακτηριστικά πετρωμάτων οι οποίες μπορουν να εξηγήσουν μερικές από τις διαφορές που προσδιορίστηκαν από τα γεωφυσικά.

Abstract

A cylindrical laboratory specimen of Penrith sandstone has been examined geophysically and optically. Geophysics reveals that the sandstone contains two planes where the difference in p-wave velocity, although small, is at a maximum. Petrological thin sections have been cut along these two planes and photographs have been taken of them with a microscope under 8x magnification. The pores which have been recognised from the pictures taken have individually been inserted into IDRISI 4.1, a raster-based Geographical Information System. This paper shows how Geographical Information Systems can provide measurements of pore area, pore perimeter, and "porosity", and detect differences in these rock characteristics which may account for some of the difference in the geophysical measurements detected.

Introduction

Microscopic characteristics have been used widely to describe the texture of rock, especially in sandstones where extensive studies have provided systematic descriptions of sandstone grains. These descriptions have been both qualitative (Pettijohn et al., 1972; Dusseult et al., 1979) and quantitative (Khan, 1956; Dobereiner et al., 1986). Quantitative descriptions, e.g. of grain contact and packing density, can correlate well with other aspects of rock behaviour, such as mechanical strength and deformability (Dobereiner et al., 1986). One factor upon which the mechanical behaviour of rock will depend is anisotropy, as this will make the mechanical properties of the rock vary with direction. Anisotropy in rock can be quantified by studying its directional velocity using compressional (p) and shear (s) wave seismic data (Winterstein, 1990; Crampin, 1989), and from these, determining the coefficient of anisotropy, ie. the ratio of the velocities of elastic waves in different directions; such anisotropy is usually different for different rock types (Lama et al., 1978).

In this study the differences in p-wave measurements made on a cylindrical sample of Penrith sandstone are correlated with microscopic characteristics of its pores, especially their geometry. This required the use of a precise image analysis tool. For this, IDRISI (Eastman, 1993), a raster-based Geographical Information System (GIS) was utilised to provide precise and reliable measurements of pore area, as well as pore/solid area ratios, and perimeter, from the optical measurements made. The sandstone comes from the Lower Permian of N.W. England, a coarse grained well sorted, red orthoquarzitic deposit with a high degree of mineralogical and textural maturity (Waugh, 1970).

Background

P-wave velocities have been measured on a cylindrical sample of Penrith sandstone of 38 mm diameter and 77 mm height, which had been cored so that its vertical axis was oriented 90° to the layers of bedding in the sandstone (Passas et al., 1995). Twelve measurements have been taken on a horizontal plane, parallel to the layers of bedding along the diameter of the sample, at intervals of 15° rotation around the circumference of the cylinder, and one unique measurement normal to the bedding (2260 m/sec) along the axis of the cylinder: the experimental method used is as described by King (1970). The p-wave velocities measured along the bedding were in a range of 2326 m/sec to 2515 m/sec (Fig. 1A). These

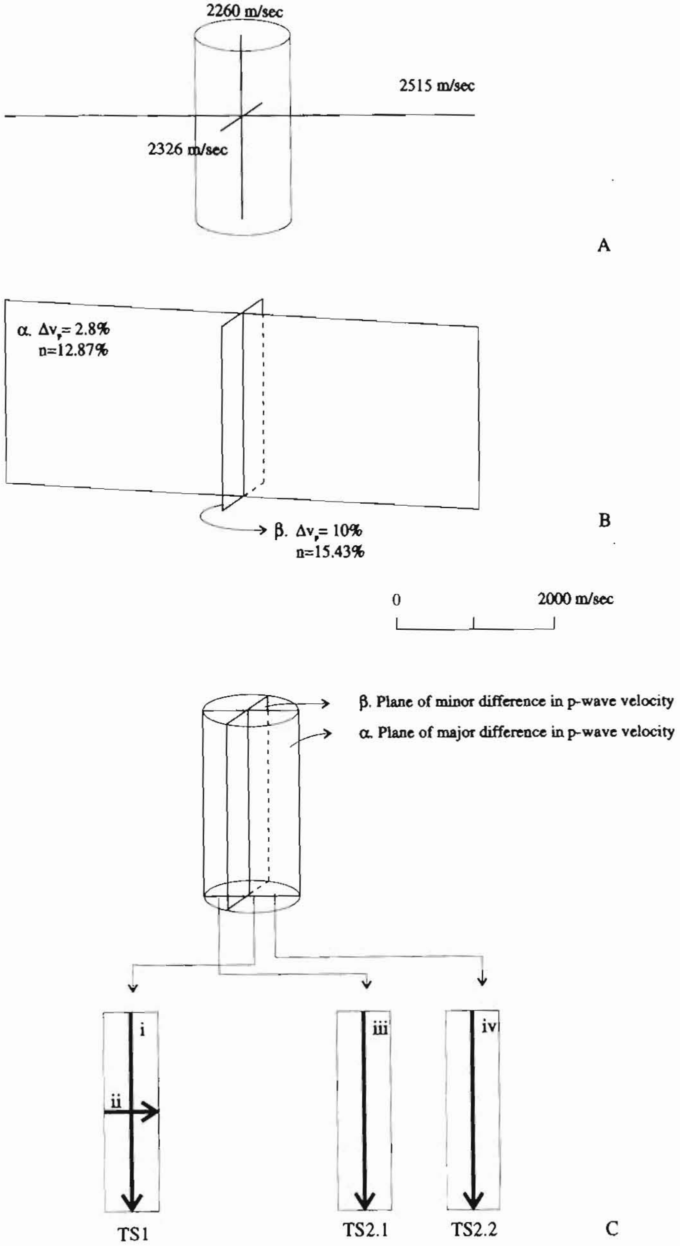

Fig. 1. **(A)**. Graphical representation of the extreme values of p-wave velocities measured in the cylindrical sample of Penrith sandstone, **(B)**. Planes of major (a) and minor (b) difference in p-wave velocities (Dvp); n: "porosity" in these planes, **(C)**. Thin section cutting strategy followed and directions for taking pictures from the thin sections (after Passas et al., 1995).

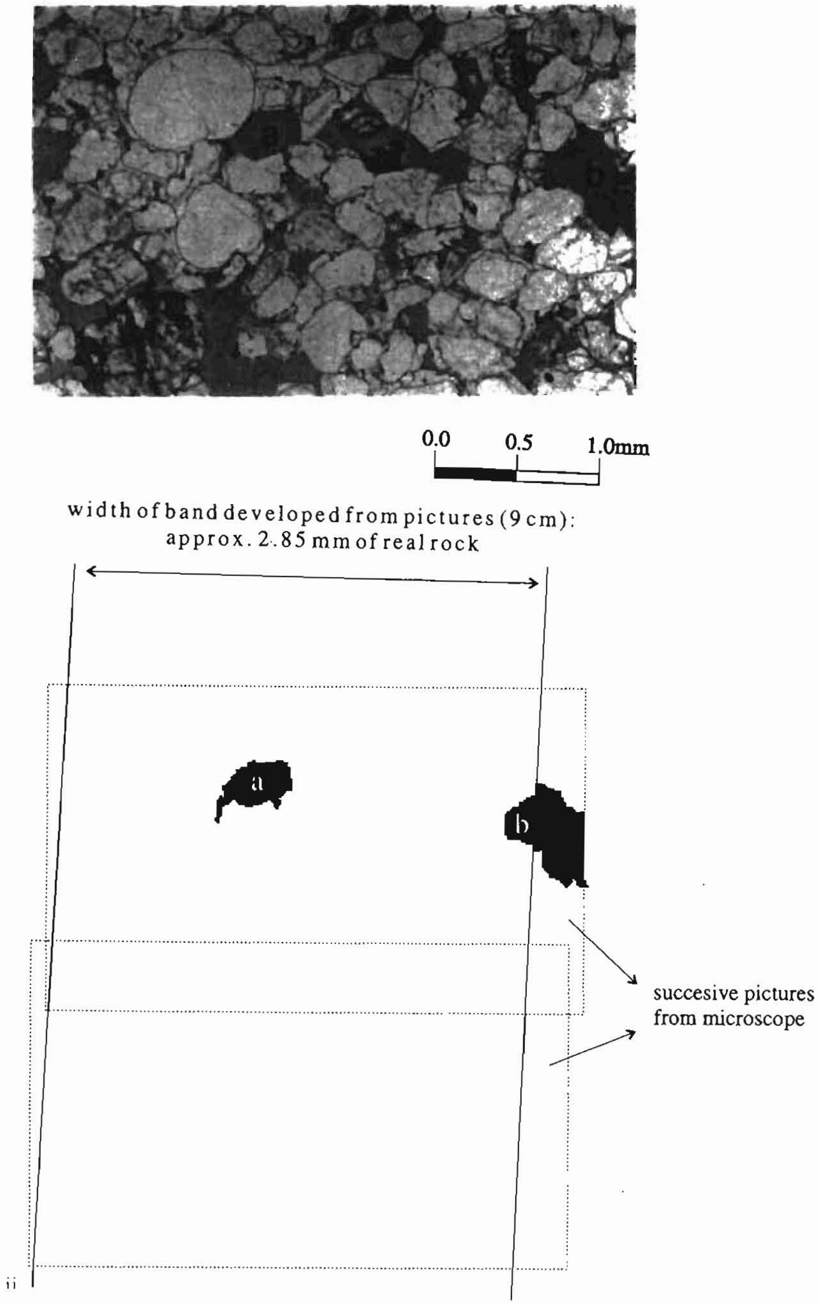

Fig. 2. (i). Picture taken with photographic microscope where pores, e.g. a and b, are indicated with a specific colour; (ii). These pores may appear in their full extent (a), and are involved in area/perimeter measurements, or may partially appear (b) and are included in the "porosity" determination.

two end values, occurring in planes 90° to each other, together with the unique value normal to the bedding, form the planes α and β of Fig. 1B; they correspond to the planes of major (10%) and minor (2.8%) difference in p-wave velocities respectively. Petrological thin sections have been cut along these two planes and photographs taken with a microscope under 8x magnification along the directions i, ii, iii and iv as shown in Fig. 1C. The rock has a uniform mineralogy dominated by the mineralogy of its grains and their cement, both of which are quartz. The crystallographic orientation of the quartz does not exhibit a preferred orientation within the rock and thus the pores which have been recognised from the pictures (Fig. 2i) are considered to be the rock characteristic most likely to account for the difference found on planes a and b based on the geophysical measurements made.

The use of GIS in pore area and perimeter measurement

The pores recognised from the above procedure have been inserted into IDRISI 4.1 (Eastman, 1993) one by one, using a digitizer: vector files were created of 588 rows and 416 columns each, and with this procedure it was possible to give an individual value to each pore. The vector files were imported as images into IDRISI. Within the GIS, a different label was assigned to each pore.

The above procedure enabled the study of 2130 and 1580 pores, recognised on planes α and β respectively, to be made. Area and perimeter measurements were made of the pores for these two pore populations and these measurements were given to IDRISI in cells and cell side units respectively. The resulting values file was imported into an Excel-compatible spreadsheet. Within the spreadsheet the measurements obtained were converted into unit values of cm^2 and cm for pore area and perimeter respectively. It was then possible to statistically analyze the data and to plot histograms for the area (Fig. 3) and perimeter (Fig. 4) of the pores involved in this investigation. By calculating the cumulative frequency of pore areas pore size distribution curves were also possible to be drawn (Fig. 3) for planes α and β.

Calibration of the Computer-Aided System Used

The methodology described above establishes a computer-aided system for measuring pore size, pore size distribution and pore perimeter,

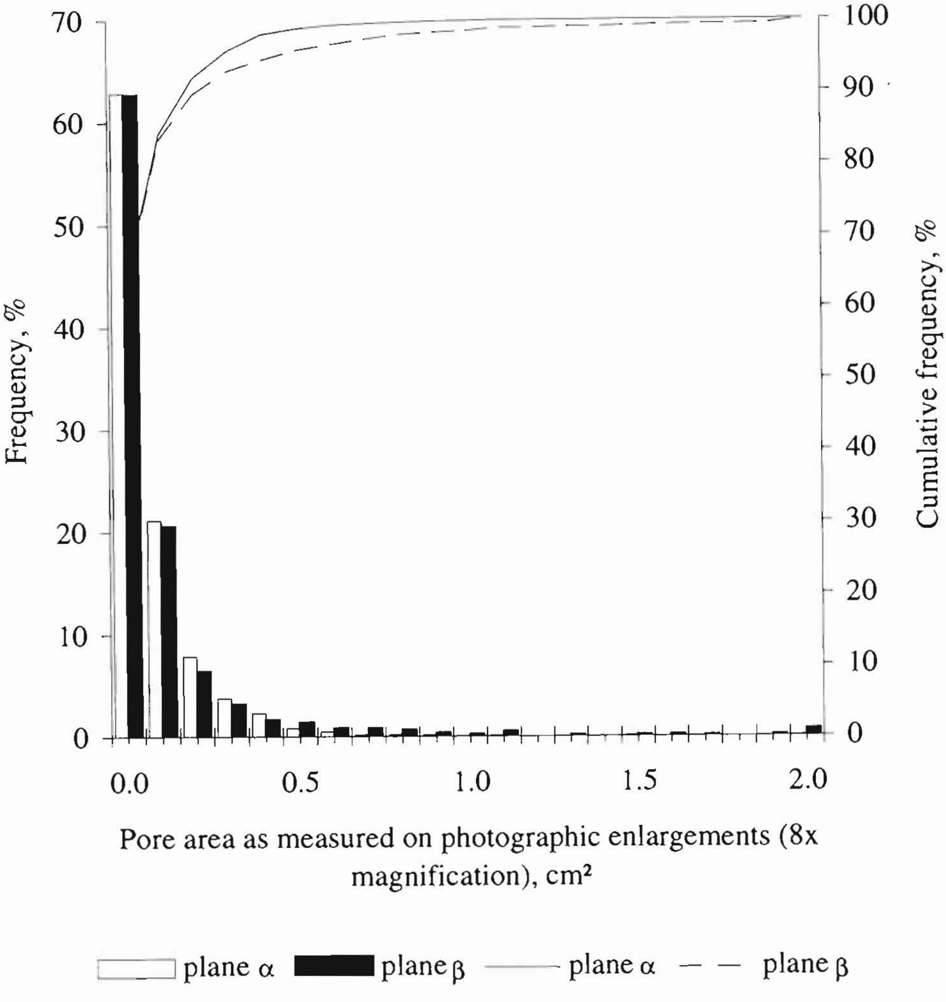

Fig. 3. Histograms of the pore area measurements and pore size distribution curves.

but it is necessary to calibrate such a system to confirm the extent to which the geometry of any shape determines the accuracy of the stored value for its area and its perimeter.

To calibrate the system three shapes were considered, viz. rectangular, circle, triangle. These shapes were of known dimensions, and therefore of known area and perimeter. The area was kept the same for the three single shapes. Based on this principle, three images were produced each one containing the above three shapes with the shape area kept constant in anyone of the three images but varying between the different images. The input of the images into IDRISI followed the

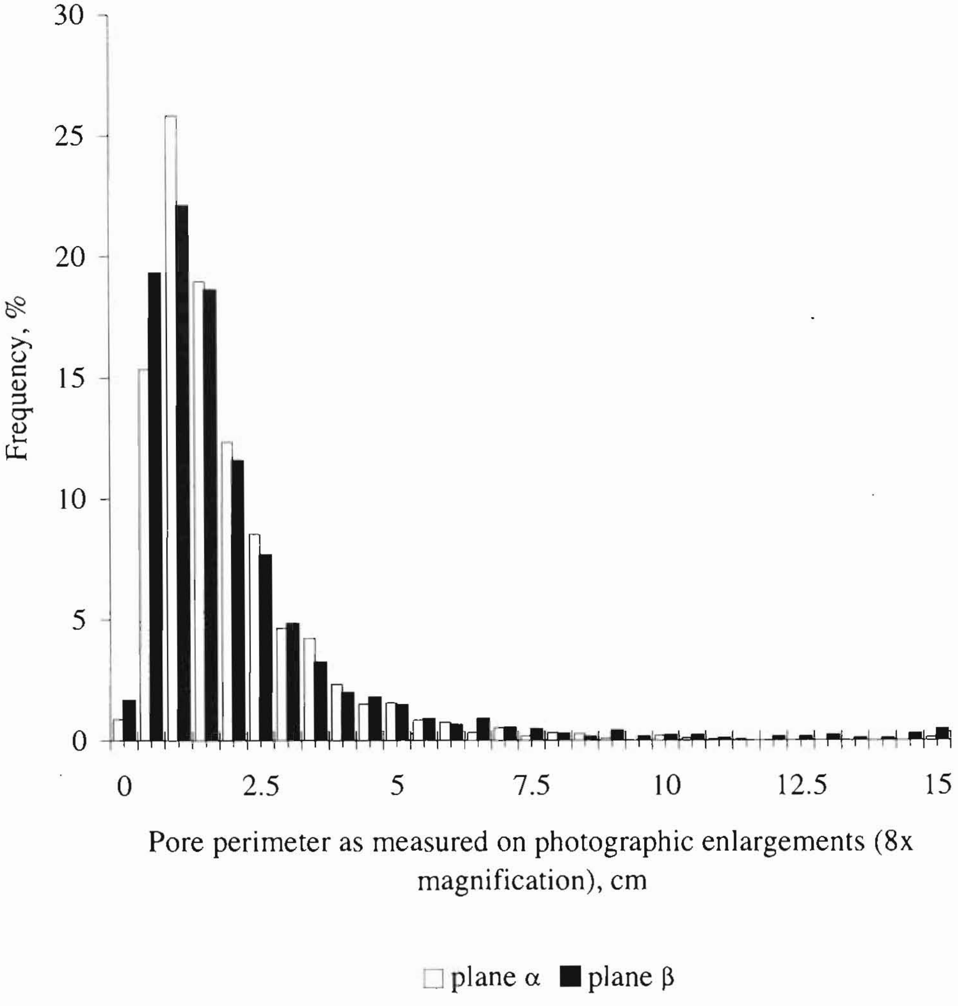

Fig. 4. Histograms of the pore perimeter measurements.

same procedure as used for the pores in this study, viz. by digitization.

The results calculated on the known areas and perimeters and those acquired from IDRISI are given in Table 1 where the values for area and perimeter are expressed as a percentage of the real values.

The areas measured by IDRISI are consistently lower than the real ones. This difference seems to be in the range of 0.01% to 1.01%; it is small. This can be appreciated from Fig. 5, where the real shape areas have been plotted against the areas found with IDRISI; all the points fall either on or very close to the line which is 45° to the axes. The

Shape	Real dimensios		Measurements within IDRISI 4.1				Variation	
	Shape area cm² A	Shape perim cm B	Shape area cells	Shape perim. cell sides	Shape area cm² C	Shape perim. cm D	Variation in measuring area, % E [(A – C)/A]*100	Variation in measuring perim., % F [(B – D)/B]*100
1. rectangular (b = 3 cm, h = 2 cm)	6.001	0.00	2360	198	5.98	9.96	0.38	0.36
2. circle (d = 2.8 cm)	6.16	8.80	2432	222	6.161	1.17	0.01	– 26.96
3. triangle (b = 3 cm, h = 4 cm)	6.00	13.00	2340	274	5.93	13.79	1.23	– 6.07
4. rectangular (b = 5 cm, h = 3 cm)	15.00	16.00	5909	318	14.97	16.00	0.23	– 0.02
5. circle (d = 4.4 cm)	15.21	13.82	5945	348	15.06	17.51	1.01	– 26.72
6. triangle (b = 6 cm, h = 5 cm)	15.00	18.81	5899	438	14.94	22.04	0.40	– 17.18
7. rectangular (b = 10 cm, h = 4 cm)	40.00	28.00	15786	558	39.98	28.08	0.05	– 0.29
8. circle (d = 7 cm)	39.59	21.99	15604	568	39.52	28.58	0.18	– 29.99
9. triangle (b = 10 cm, h = 8 cm)	40.00	30.80	15654	714	39.65	35.93	0.89	– 16.66

Note: b: base of rectangular or triangle; h: height of rectangular or triangle; d: diameter of circle, 1 cell = 0.0025326 cm²; 1 cell side = 0.05032494 cm, when the per cent variation in measuring area/perimeter is positive, then the real area/perimeter is greater than the meas ured one; the opposite is valid for negative variations.

TABLE 1. Measurements and calculations on the accuracy of using IDRISI in measuring area and perimeter of shapes of known area.

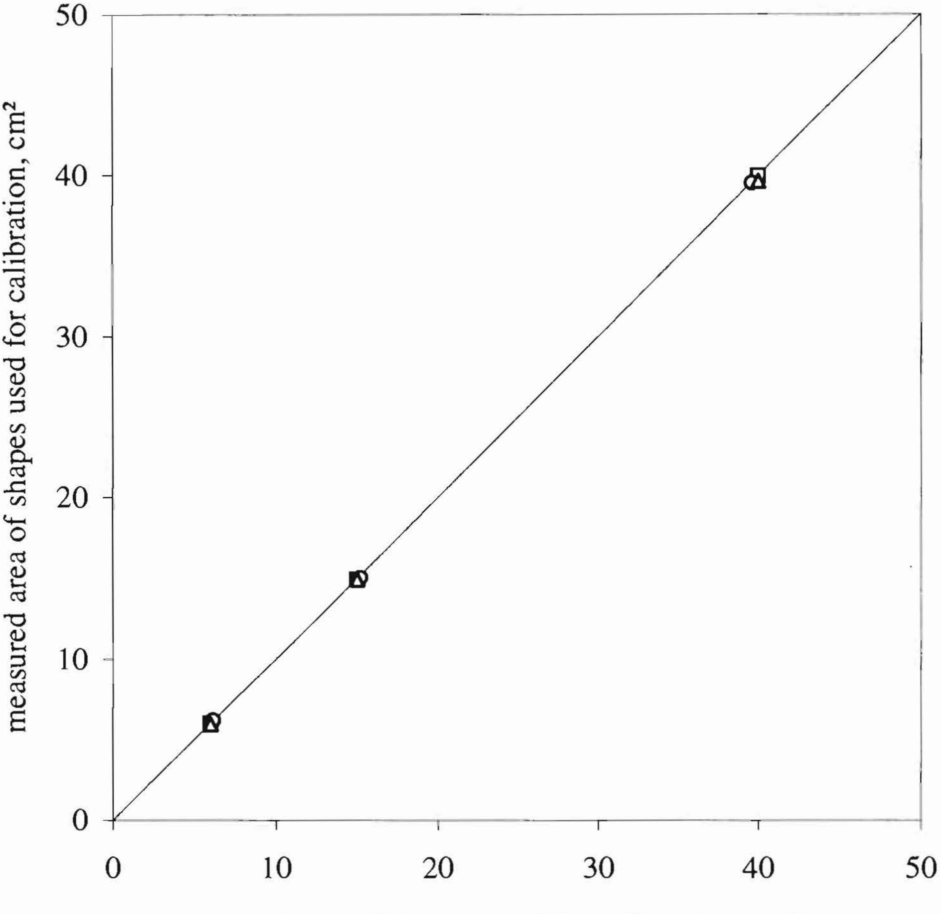

Fig. 5. Calibration of the system for measuring area. Plot of real areas vs areas measured within IDRISI. Explanation in the text.

perimeter measurements are less accurate since for most of the non-rectangular shapes; IDRISI seems to give values higher than the real ones, particularly for the circular shapes (Table 1, Fig. 6), the error is 28%. By far, the greater majority of the pore perimeter values obtained from the enlarged photographs used in this study were much less than 2.5 cm (Fig. 4) where, the error in perimeter length would be less than 0.7 cm.

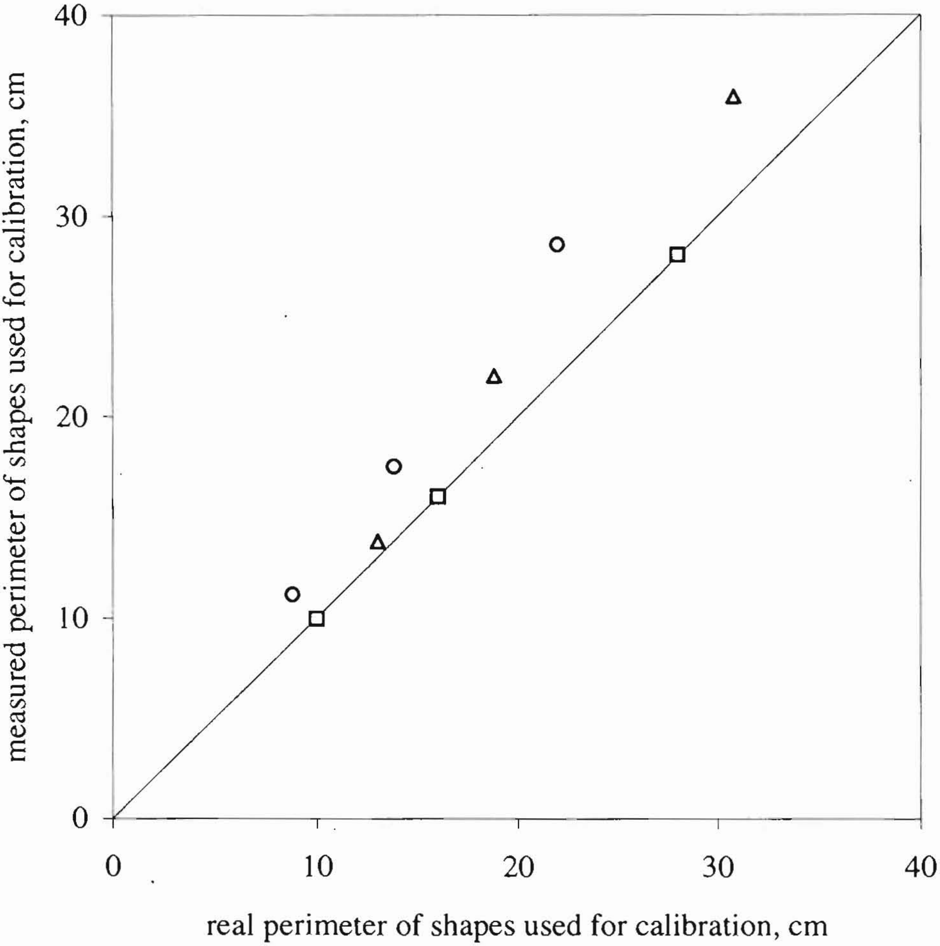

Fig. 6. Calibration of the system for measuring perimeter. Plot of real perimeters vs perimeters measured within IDRISI. Explanation in the text.

"Porosity" measurements acquired from the thin sections

The pores recognised from the thin sections involved in this study have been inserted in IDRISI (Eastman, 1993), by scanning the traced pores using Scangal (Scangal, 1988) at 240 dpi (dots per inch) resolution: the scanned Tagged Image File Format (TIFF) images were imported into IDRISI and with this procedure the GIS attributed one value to the pores and an other one to the solid part of the initial pictures.

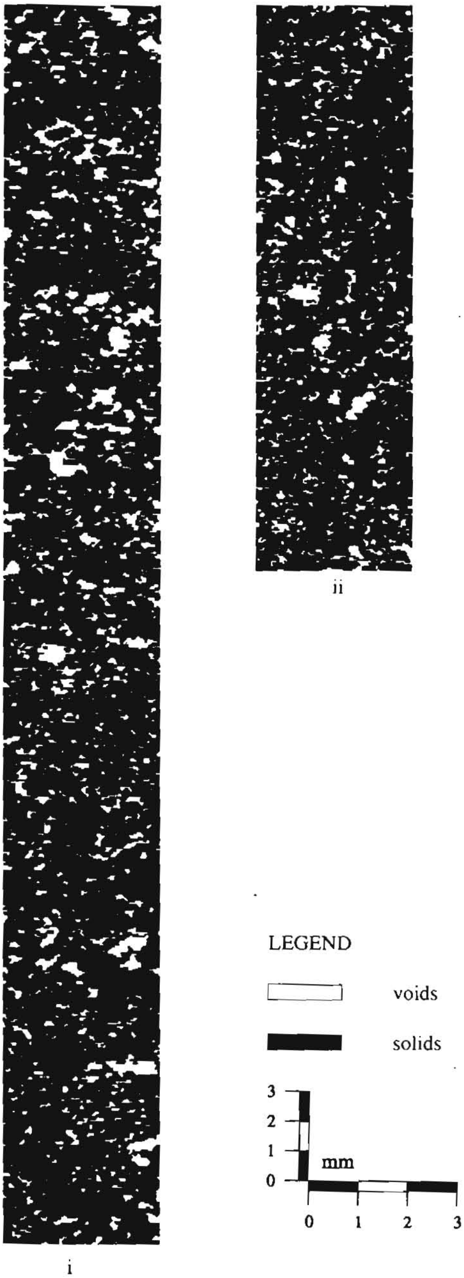

Fig. 7. Bands i and ii as produced by IDRISI.

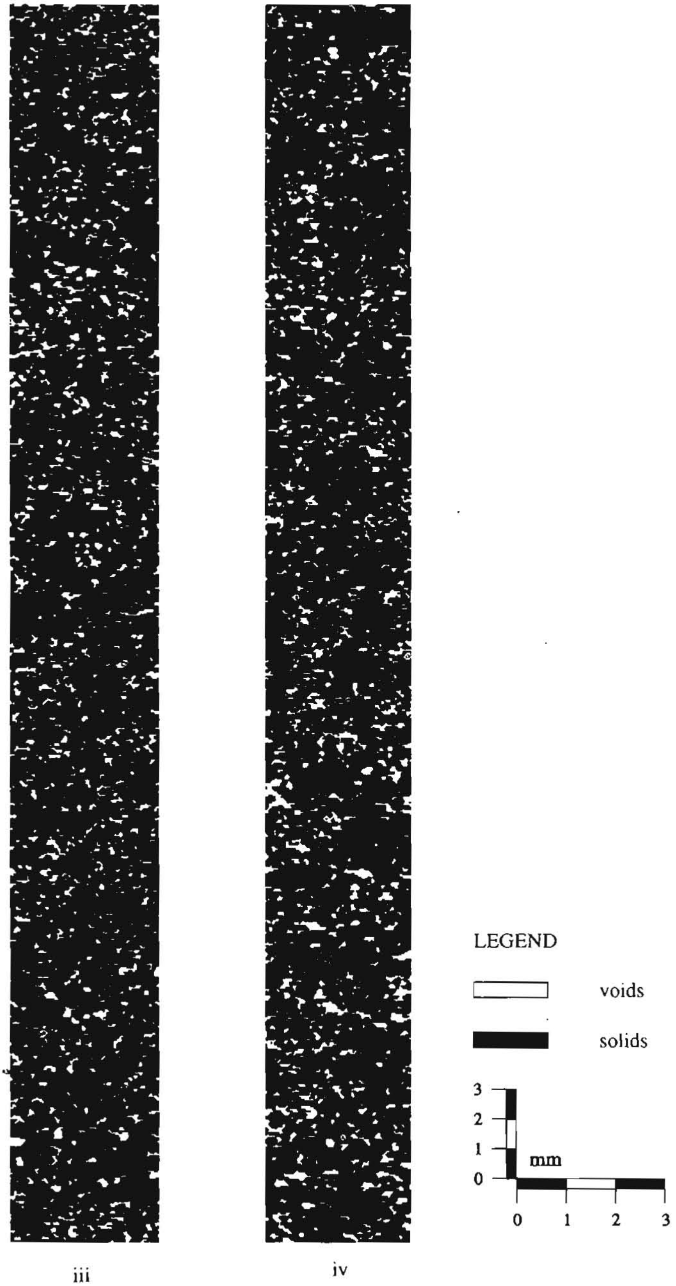

Fig. 8. Bands iii and iv as produced by IDRISI.

The above procedure enabled the visualisation, within IDRISI, of the bands of the thin sections along which pictures were taken, and area measurements of those parts of the thin sections covered by voids and solids, separately. The bands appear in Fig. 7 and 8 for both the planes a and b respectively. From these measurements, which were in cell units, the area ratio between the void and the total rock area can be calculated, which can be considered as a "porosity" measurement for the rock in the given direction of the focusing plane (Passas, 1996; Passas et al., submitted). These measurements show that the "porosity" is 16.11%, 14.75%, 13.42% and 12.32% for the bands i, ii, iii and iv respectively (Fig. 1B).

The accuracy of the area ratio measurements within IDRISI, based on the shapes of known areas used for calibration proved that IDRISI gives higher area ratios than exist in reality in the range of 1.14 to 5.13% (Passas, 1996; Passas et al., submitted).

Discussion

The two methodologies followed in this investigation, viz. that for measuring pore area and perimeter, and that for measuring "porosity", involved different pore populations. Area/perimeter measurements were possible only for pores which existed as their full extent on the pictures taken, while the "porosity" measurements covered the full area of the bands photographed included the pores of the previous operation plus pores that partially appeared on the pictures taken (Fig. 2ii). Direct comparisons between pore area, perimeter and porosity are therefore not possible, however, a total of 3710 pores were included in the study of area and perimeter, and are considered to reflect the nature of porosity overall.

From the results obtained it can be inferred that the pore area and the pore size distribution are similar (Fig. 3) for the planes α and β. On the other hand, there appears to be a difference as far as the perimeter of the small pores is concerned (Fig. 4). Descriptive statistics of the pore perimeter measurements for the two populations involved (Table 2) reflected this observation; the value for the mode was found 1.41 for plane α and considerably lower for plane β at 0.91. Similar descriptive statistics for the area measurements did not show any difference at all (Table 2), a fact reflected in the similarity of the histograms and pore size distributions observed. Additionally, the "porosity" measurements reveal that the plane where the major difference in p-wave velocities occurred (plane α) is less porous than the plane of minor difference in p-wave velocities (plane β). The measurements indicate that porosity alone, as measured in two dimensions, may not be sufficient to explain the differences revealed in p-wave velocity and that other differences should also be considered, such as grain area and perimeter, nature of contacts between grains etc.

	Area measurements		**Perimeter measurements**	
	plane a	**plane b**	**plane a**	**plane b**
Mean	0.12	0.15	2.11	2.26
Stand. Err.	0.00	0.01	0.03	0.06
Median	0.07	0.07	1.61	1.61
Mode	0.03	0.02	1.41	0.91
Stand. Dev.	0.14	0.29	1.61	2.31
Variance	0.02	0.08	2.59	5.34
Range	2.78	3.72	23.75	28.58
Min	0.001	0.010	0.20	0.20
Max	2.780	3.730	23.95	28.78

TABLE 2. Descriptive statistics on the pore area and perimeter values obtained from IDRISI.

The measurements which were feasible with IDRISI in the context of pore geometry as they appear on petrological thin sections, viz. pore area, pore perimeter and "porosity", and the correlations acquired, are comparable with the same measurements and correlations found by using an image analyser (Passas et al., 1995), namely, SigmaScan Image (Jandel, 1993) using scanned Tagged Image File Format (TIFF) images of the same pores with 75 dpi (dots per inch), a resolution equivalent to the resolution used while digitizing these pores for this study. IDRISI can be a useful and reliable image analysis tool in observing and quantifying certain spatial problems on a micro scale.

Conclusions

The differences observed in the maximum and minimum p-wave velocities in known directions through a laboratory sample of Penrith sandstone have been compared with differences in the geometric characteristics of the pores observed on two planes in those directions. A raster-based GIS has been proved to be a precise and sensitive image analysis tool for providing a quantitative analysis of the pore area and for describing the rock in terms of its "porosity" on these two planes.

Comparative studies on pore area, perimeter, and "porosity" on the two planes of major and minor difference in p-wave velocities showed that the pores on the plane of major difference may have a higher perimeter and do have a higher "porosity" than those on the other plane while their area does not seem to vary at all. These results indicate that from the pore characteristics considered here only the pore perimeter and "porosity" show some distinct difference which could account for the difference in p-wave velocities observed. Use of the technique has also showed that other microscopic characteristics of rock must be used to reveal further information.

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