Magnetic susceptibility measurements on ancient and modern potsherds using a fast, cheap and portable probe

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Paul W.J. Glover

Département de géologie et de génie géologique, Université Laval, Québec, Canada

INTRODUCTION

It has been estimated that there exist over 100 million ancient potsherds in various collections worldwide, many of which have never been studied and for which the provenance is ambiguous or unknown. Indeed, many collections are extremely badly catalogued or completely mixed-up. We have been using a novel portable probe to measure the magnetic susceptibility and electrical conductivity of potsherds in the hope that this fast, cheap and portable measurement can provide data that will help to sort similar looking potsherds into sets in a manner which may help to define their provenance. The probe, which resembles a firearm, uses the Hall effect to make a non-destructive measurement on the potsherd. The probe is attached to an Dell Axim X51 PDA, which runs software that allows the measurement to be carried out and logged. Each measurement, which is made by pressing a button on the gun, takes only a few seconds. We have made measurements on three suites of ancient potsherds as well as a suite of modern potsherds that were created by using a garden centre and a hammer! In each case a set of 5 stacked measurements were taken on the inside and outside faces of the potsherd in two perpendicular directions. Potsherds which were either (i) so flat that the inside and outside could not be distinguished, (ii) so curved (radius of curvature less than 5 cm) that the probe tip could not approach the surface sufficiently closely, or (iii) smaller than the probe tip, were excluded from the suite of measurements. Each suite contained over 50 measureable potsherds. All measurements were completed within one day. In this pilot study we found that (1) each suite was represented by a normal distribution of magnetic susceptibility values, (2) the four different suites could be distinguished statistically on the basis of their magnetic susceptibilty measurements, but (3) the distinction was not sufficiently powerful to separate all potsherds (i.e., there was a significant overlap of the susceptibility distributions). This seems to confirm that the method may be used to give additional information that can be used to help to provenance a potsherd, but the susceptibility measurement is not sufficient on its own. In addition, we found that (4) the electrical conductivity measurements depended upon the local conditions (mainly humidity) and was of no use in distinguishing between suites of potsherds. However, most interestingly, we found that (5) there is a statistically significant difference between the magnetic susceptibility measured on the inside face and that measured on the outside face for all three ancient suites of potsherd, but not for the modern potsherds. The reason for this is not currently known. One hypothesis is that the difference is due to the manufacturing style. Further studies are being planned to extend our database.

Methodology and Samples

Measurements were made on 4 suites of potsherds from various localities and representing different types of temper. One of the suites was modern, being obtained by breaking common garden pots. In each case potsherds at least 70 mm by 60 mm with an area of 50 mm by 40 mm with low curvature were chosen at random from a larger population. The area of low curvature allows the probe to approach closely the surface. All potsherds showed characteristics that enabled the orientation of the potsherd to be known (e.g., part of the lip or base).

Location	Temper	Number of Samples	Age (approx.)
Macedonian (Archaic-Classical)	Quartz	55	2500 BC
Syrian (Upper Mesopotamia)	Basalt	156	2700 BC
Late Woodland (Mississippian II)	Shell	138	1100 AD
Modern (broken garden pots)	?	69	2007 AD

Five measurements were taken for each sample, direction and face. We have used the arithmetic mean of these five measurements.

Hence, we have, for each sample, a measurement of the magnetic susceptibility in the vertical and horizontal direction for the inside and outside faces of the original pot.

These four datasets have been analysed statistically.

The mean of the two directions for each face was calculated and is labelled 'directionless'. Additionally, the mean of these directionless datasets was also calculated and is called the 'total' measurement. Statistical analysis has also been carried out on these values.

APPARATUS

The Multi-Parameter Probe allows the instant measurement of the magnetic susceptibility (10^{-3} SI) as well as the relative and absolute conductivity (S/m) values of small and large objects such as drilling cores, field samples, floats, showings, and potsherds.

The operator can record data one reading at a time or in a continuous scanning mode (10 times/second) to make a profile. The recorded data from the Dell Axim readout unit or PC are stored in ASCII file: sample identification, recorded values, date, time, etc. can be recorded. Afterwards, the ASCII format data can be imported to third-party software (Excel, Microstation, Autocad, etc).

The Multi-Parameter Probe is used here to measure split cores. The probe was designed initially to find concentrations of sulphide ores in mineral exploration.
The probe is connected to a logging unit by cable (as used by us) or by Bluetooth. Measurements are made by pressing a button on the probe. A measurement takes less than 2 seconds to make. A set of 5 measurements with two reference zero measurements takes less than 30 seconds. Pressing another button on the probe allows the next sample to be measured.

The unit measures magnetic susceptibility and electrical conductivity. We found that there was no significant difference in the electrical conductivity measurements between samples and sample sets, and hence have not analysed these data further.

STATISTICAL ANALYSIS

Macedonian

Face	Direction	Mean	SD	Std. Error	Range	Max	Min	Median	Skewness	Kurtosis	KS value	KS critical	Normal
Internal	Vertical	0.841	0.399	0.0537	1.618	1.662	0.0435	0.852	0.158	-0.753	0.102	0.163	Yes
Internal	Horizontal	0.833	0.399	0.0537	1.612	1.654	0.0416	0.824	0.131	-0.888	0.0965	0.222	Yes
Internal	Directionless	0.837	0.398	0.0536	1.615	1.658	0.0425	0.826	0.137	-0.830	0.0849	0.396	Yes
External	Vertical	2.481	1.299	0.175	5.614	5.701	0.0870	2.451	0.302	-0.523	0.0996	0.186	Yes
External	Horizontal	2.316	0.810	0.109	3.233	3.968	0.735	2.306	0.0754	-0.857	0.0949	0.243	Yes
External	Directionless	2.399	1.029	0.139	4.150	4.561	0.411	2.414	0.138	-0.779	0.0773	0.530	Yes
Mean	Directionless	1.618	0.708	0.0955	2.760	2.987	0.227	1.643	0.111	-0.839	0.0942	0.253	Yes

Test of normality carried out with a Kolmogorov-Smirnoff test with Lilliefor`s correction.

Syrian

Face	Direction	Mean	SD	Std. Error	Range	Max	Min	Median	Skewness	Kurtosis	KS value	KS critical	Normal
Internal	Vertical	89.991	38.431	3.077	228.410	240.120	11.710	92.245	0.230	0.693	0.0504	0.413	Yes
Internal	Horizontal	89.879	38.729	3.101	212.040	223.720	11.680	92.130	0.186	0.0942	0.0425	0.649	Yes
Internal	Directionless	89.935	38.395	3.074	220.225	231.920	11.695	91.545	0.193	0.382	0.0452	0.568	Yes
External	Vertical	154.497	97.642	7.818	482.410	483.800	1.390	142.120	0.832	0.478	0.0727	0.043	Yes
External	Horizontal	152.819	100.090	8.014	531.600	533.130	1.530	134.525	0.990	1.080	0.0963	0.001	No
External	Directionless	153.658	98.288	7.869	507.005	508.465	1.460	140.098	0.893	0.735	0.0769	0.025	No
Mean	Directionless	121.797	63.526	5.086	337.240	346.930	9.690	114.373	0.680	0.566	0.0661	0.092	Yes

Test of normality carried out with a Kolmogorov-Smirnoff test with Lilliefor`s correction.

Late Woodland

Face	Direction	Mean	SD	Std. Error	Range	Max	Min	Median	Skewness	Kurtosis	KS value	KS critical	Normal
Internal	Vertical	23.928	5.920	0.504	29.265	39.652	10.387	23.663	0.252	0.0929	0.0638	0.179	Yes
Internal	Horizontal	24.259	6.607	0.562	34.496	45.083	10.587	23.636	0.629	0.512	0.0682	0.116	Yes
Internal	Directionless	24.093	6.129	0.522	31.880	42.368	10.487	24.076	0.415	0.334	0.0501	0.507	Yes
External	Vertical	54.373	19.715	1.678	99.051	116.022	16.971	52.389	0.722	0.503	0.0940	0.005	No
External	Horizontal	54.087	24.038	2.046	118.599	127.490	8.891	49.398	0.889	0.776	0.0895	0.009	No
External	Directionless	54.230	21.013	1.789	103.001	115.932	12.931	52.049	0.772	0.566	0.0771	0.043	No
Mean	Directionless	39.161	12.493	1.063	59.692	73.788	14.097	37.398	0.618	0.147	0.0718	0.078	Yes

Test of normality carried out with a Kolmogorov-Smirnoff test with Lilliefor`s correction.

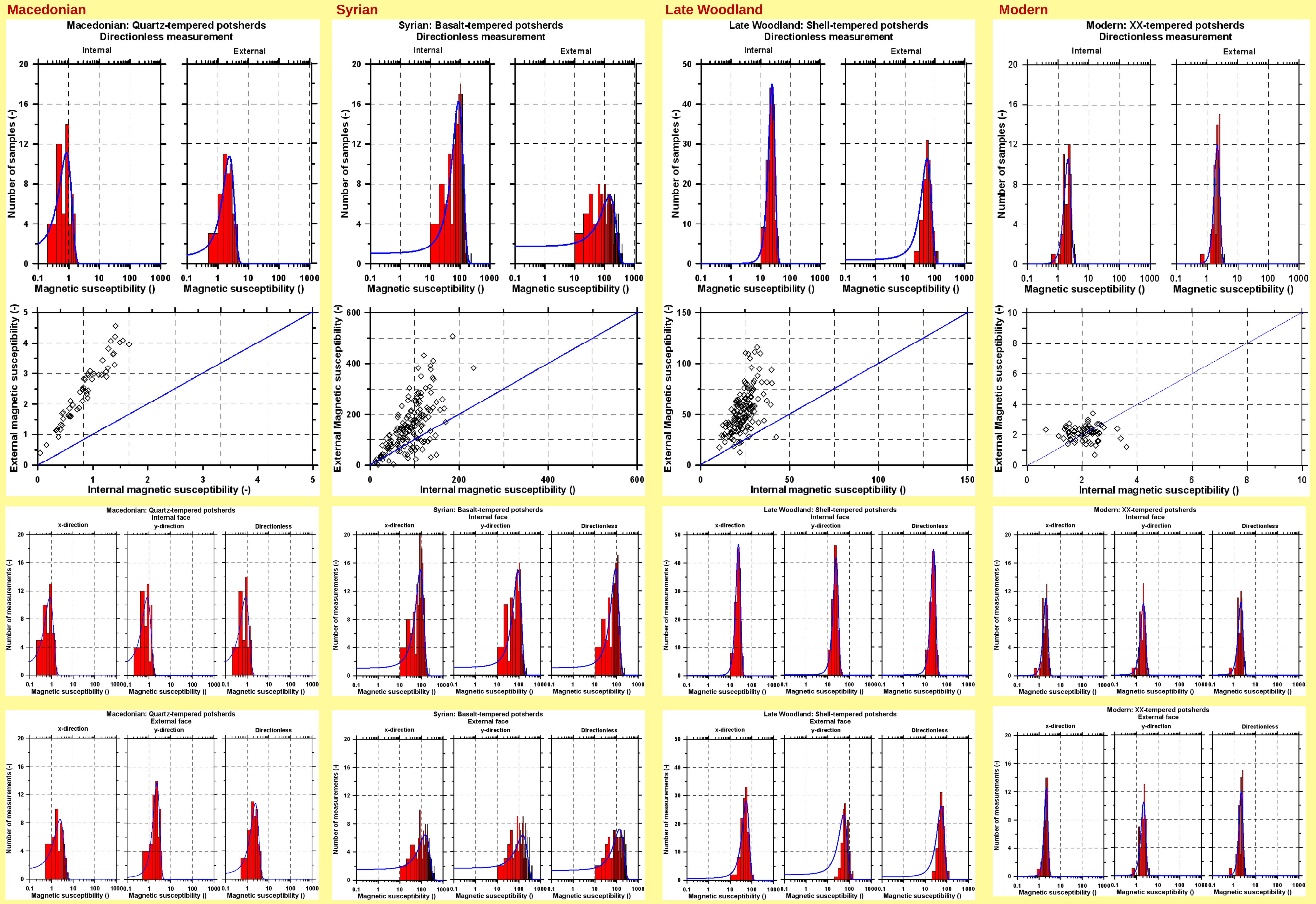
Modern

Face	Direction	Mean	SD	Std. Error	Range	Max	Min	Median	Skewness	Kurtosis	KS value	KS critical	Normal
Internal	Vertical	2.078	0.507	0.0610	2.785	3.450	0.665	2.122	0.0921	0.619	0.0699	0.518	Yes
Internal	Horizontal	2.078	0.545	0.0656	3.063	3.743	0.680	2.081	0.398	0.894	0.0551	0.793	Yes
Internal	Directionless	2.078	0.523	0.0629	2.924	3.596	0.672	2.100	0.249	0.776	0.0616	0.683	Yes
External	Vertical	2.160	0.441	0.0531	2.318	3.133	0.815	2.198	-0.494	0.455	0.0807	0.311	Yes
External	Horizontal	2.123	0.531	0.0639	3.216	3.860	0.644	2.130	0.218	1.354	0.0678	0.561	Yes
External	Directionless	2.142	0.464	0.0559	2.702	3.432	0.730	2.199	-0.290	0.713	0.0949	0.124	Yes
Mean	Directionless	2.110	0.344	0.0414	1.454	2.902	1.447	2.099	0.161	-0.574	0.0705	0.504	Yes

Test of normality carried out with a Kolmogorov-Smirnoff test with Lilliefor`s correction.

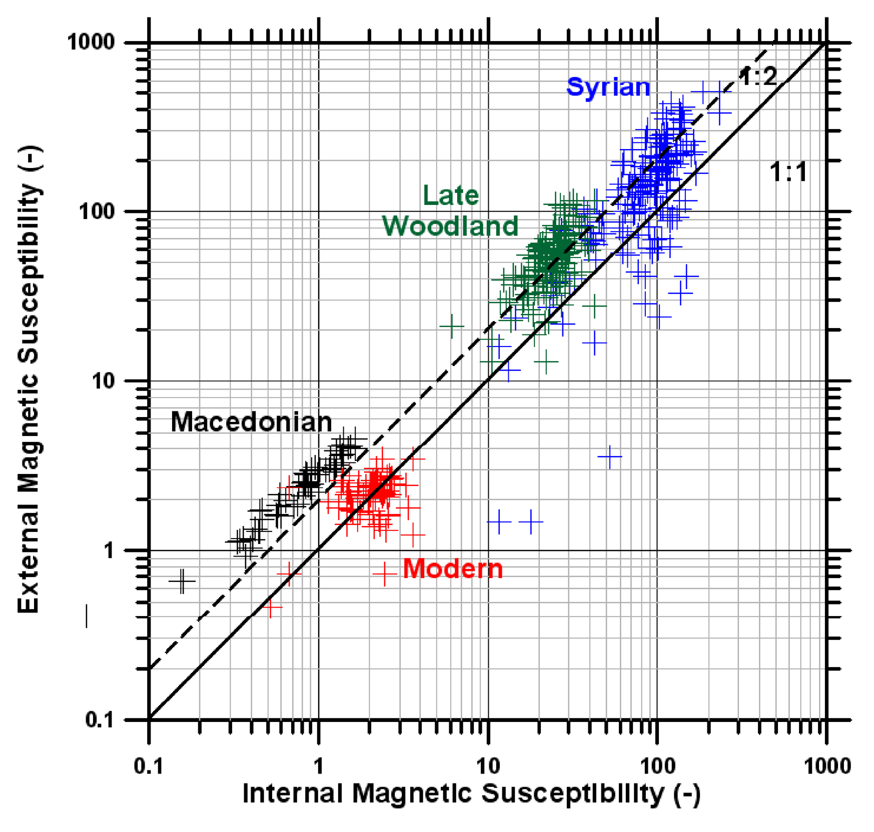
Please see attached full statistical analysis for ANOVA, paired and unpaired t-tests, and non-parametric analyses.

DATA



INTERNAL & EXTERNAL

Magnetic susceptibility for each of the 4 datasets: a cross-plot between internal and external measurements showing that the external measurements of the archaic samples are about twice that of the internal measurements. There is no difference for the modern samples.



CONCLUSIONS

1. The MPP probe from GDD provides a cheap, fast and effective method for measuring the magnetic susceptibility of potsherd samples that are greater than about 70 mm by 60 mm and are not too curved.
2. For the three groups of archaic potsherds (Macedonian, Syrian and Mississippian II) and the modern potsherds, there was no difference between measurements made vertically or horizontally. Hence the operator need not have prior knowledge of the orientation of the potsherd to the original pot in order to make an effective measurement.
3. For the three groups of archaic potsherds (Macedonian, Syrian and Mississippian II), there was a clear statistical difference ($P<0.001$) between the measurements made on the internal and external faces, irrespective of temper, origin and age of the sample. The external measurements are approximately twice that of those made on the internal faces. We know of no mechanism for this difference.
4. By contrast, for the modern potsherds, there was clearly no statistical difference ($P>0.327$) between the measurements made on the internal and external faces.
5. Inter-group comparisons between the one modern and three archaic sets of potsherds shows that all of the datasets can be distinguished statistically using any of the measurements (vertical, horizontal, directionless on either face or the mean of all) except the Macedonian and Modern datasets which can only be distinguished statistically using some of these measurements (all internal measurements and the mean of all).
6. It is proposed that the magnetic susceptibility measurements made using the MPP probe can be used to sort potsherds between two or more calibrated datasets for the purposes of helping understand their provenance.

For additional information, please contact:
Département de géologie et de génie géologique, Faculté des sciences et de génie, Université Laval, Sainte-Foy, Québec, CANADA, G1K 7P4
Dr. Paul W.J. Glover (paglover@ggl.ulaval.ca; téléphone : +1 (418) 656-5180, Homepage: http://www.ggl.ulaval.ca/personnel/paglover/Home.htm)