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THE STATISTICAL MODELLING OF THE TEXTURAL PROPERTIES OF CAVE SEDIMENTS USING LOG SKEW LAPLACE DISTRIBUTIONS : ROBIN HOOD'S CAVE, CRESWELL CRAGS, U.K.

by

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(4 figures)

ABSTRACT.- This paper demonstrates that log skew Laplace distributions can be used successfully to model particle size data from the cave sediments of Robin Hood's Cave, Creswell Crags, U.K. This new approach has led to the development of a more detailed geomorphic history of the cave than had been achieved previously with the use of standard procedures involving the estimation of low order sample moments for the same grain size data.

RESUME.- Modélisation statistique des propriétés texturales des sédiments de grotte en fonction des distributions log skew de Laplace. Cet article démontre l'utilité des distributions log skew de Laplace dans la modélisation des données granulométriques des sédiments de la grotte de Robin Hood, à Creswell Crags, U.K. Cette nouvelle approche a permis une reconstitution morphogénétique plus raffinée que les précédentes, tirées des méthodes habituelles.

I.- INTRODUCTION

Information on the particle size distributions of cave-infill sediments are routinely collected as an aid to lithostratigraphic correlation or palaeoenvironmental studies in caves (see for example Campbell, 1977 ; Colcutt, 1979 ; Farrand, 1975a,b ; Hughes, 1983 ; Jenkinson & Gilbertson, 1984 ; Laville *et al.*, 1980). These particle size studies usually take the form of mass-size data which may be analysed in a wide variety of ways. Without doubt the most widely used of methods has been the estimation of sample moments (e.g. mean, mode, sorting, skewness), or the so-called «Folk and Ward» estimates (Folk & Ward, 1957 ; Friedman, 1979a,b ; Inman, 1952). There are numerous examples where the estimation of these properties have proved sufficient to identify the origins of the sediments laid down in caves (e.g. Shackley, 1972 ; Tankard & Schweitzer, 1975).

In other studies, the results of the statistical analysis of grain size data from caves have not been as clear. One example is provided by the results of grain size studies presented by Griffin (1985) from her

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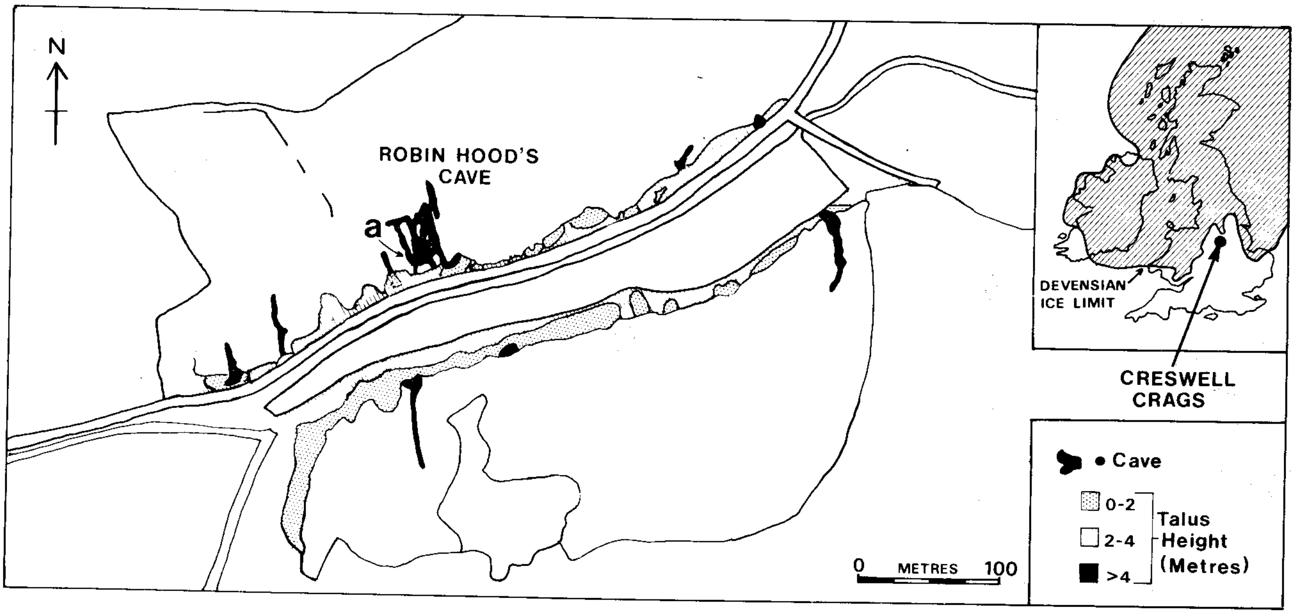

Fig. 1.- The location of section A, Robin Hood's cave, Creswell Crags, U.K.

analyses of sediments of Mid- to Late-Devensian (Weichselian) age exposed at «Section A» in Robin Hood's Cave, Creswell Crags, England (fig. 1). Figure 2 shows the plots through the sequence of low order sample moments obtained using the standard statistical approach to particle distribution studies. Similarly standard laboratory procedures were used — dry sieving, with sieves at 0.5 phi intervals, combined with the results of hydrometer analysis of the silt-clay fraction (Kaddah, 1977). These plots «hint» that the size properties of the sediments in this exposure do alter upwards through the sequence.

However, the magnitude of the variations displayed are suprisingly restricted, given the extent to which the parallel studies of the palaeontological and archaeological data obtained for this exposure have suggested that the effects of notable climatic changes are represented in the exposure. Specifically these other studies (Briggs *et al.*, 1985 ; Jenkinson *et al.*, 1986, 1987) suggest that sedimentation in the lower part of this sequence occurred in a number of milder interstadials towards the end of the period of time known as the Upton Warren Interstadial in Britain (see Lowe & Walker, 1984), whilst the upper part of the sequence accumulated in a period of increasingly severe cold and geomorphological instability, which was associated with the approach of the late Devensian icesheets to within 25 kms of the site, approximately 16-20 000 years ago.

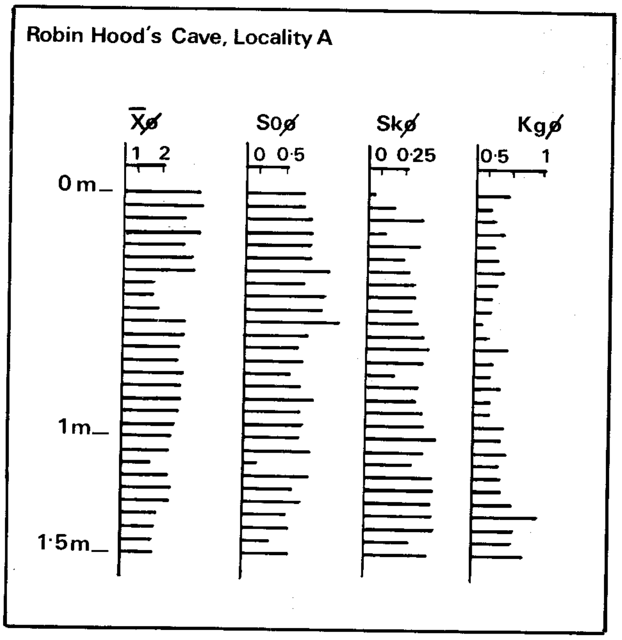

Fig. 2.- Variations in mean, sorting, skewness and kurtosis of the cave sediments exposed at section A, Robin Hood's Cave, Creswell Crags, U.K. Redrawn with permission from Griffin (1985).

Similar observations of the apparent inability of this «traditional» approach to particle size data to discriminate satisfactorily between sedimentary environments in other contexts has caused some commentators to call for its discontinuation (e.g. Ehrlich, 1981). In addition, significant doubts as to the statistical validity of some of the methods used have been expressed (Bagnold, 1979 ; Bagnold & Barndorff-Nielsen, 1980 ; Christiansen *et al.*, 1984 ; Fieller *et al.*, 1984 ; Fieller & Flenley, 1987 ; Flenley *et al.*, 1987).

II.- LOG SKEW LAPLACE MODELS

This paper describes an alternative method for the statistical analysis of the particle size data which may yield a more accurate and hence more sensitive picture of the patterns of climatic change which have influenced sediment generation and deposition in caves. This alternative approach is based upon the application to grain size data of statistical models which derive from the log skew Laplace family of statistical distributions. In other geoarchaeological contexts, the application of log skew Laplace models to such data have been able to yield information of greater palaeoenvironmental precision and accuracy than those based upon of the estimation and plotting of sample moments (for example, see Fieller *et al.*, 1984a,b ; Flenley *et al.*, 1987 ; Fieller & Flenley, 1987).

The development and application of log skew Laplace models to grain size data are described in Fieller *et al.* (1984a,b), Fieller & Gilbertson (1985), Fieller & Flenley (1987), Flenley *et al.* (1987), Olbricht (1983). The approach is essentially a simplification of that described by Bagnold & Barndorff-Nielsen (1980), Barndorff-Nielsen *et al.* (1980), Christiansen *et al.* (1984) which involved «fitting» log-hyperbola to grain size data.

An example of a log skew Laplace distribution fitted to particle size data from Creswell Crags is shown in figure 3. The X axis displays the logarithm of the size of the particles in millimetres. The Y axis displays the logarithm of the relative proportion by mass of the various particles present. Examination of this figure indicates that the mass-size frequency data plot as an inverted «V» when plotted on these scales. This feature was first noted by Bagnold (1937) in his pioneering work on windblown sediments. This property has been shown subsequently to be present in sediments deposited in many other, but not all, sedimentary contexts (Bagnold & Barndorff-Nielsen, 1980 ; Fieller *et al.*, 1984a).

When present, this feature is the basis for the use of the log skew Laplace distribution for the statistical

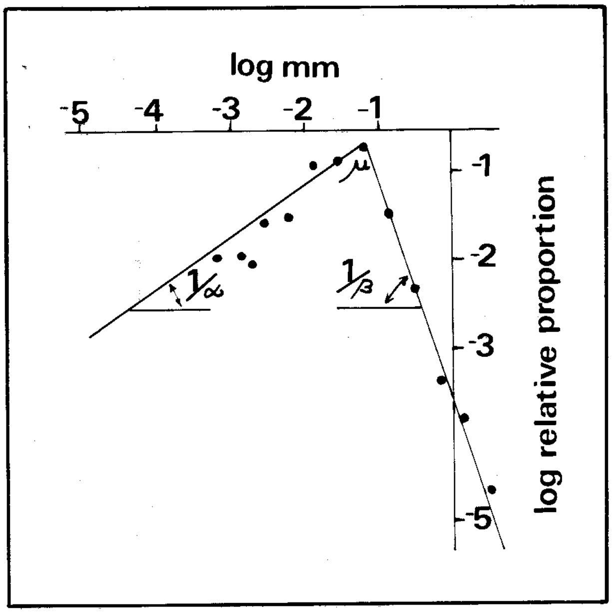

Fig. 3.- A truncated log skew Laplace distribution fitted to typical particle size distribution data from the cave sediments at section A. Robin Hood's Cave. Creswell Crags. U.K. The parameters *alpha* and *beta* are. respectively. the reciprocals of the tangents of the acute angles made by the two lines with the horizontal axis. and *mu* is the abscissa of their point of intersection.

modelling of the particle size distribution under study. On this logarithmic scaling the log skew Laplace distribution is therefore represented by a pair of straight lines, one «fitted» to the log of the relative abundance of the finer size particles, the other to the relative abundance of the coarser particles.

The «fitting» is performed by the method of maximum likelihood using specially written computer programs. The distribution is specified by three parameters which are defined on figure 3. It is important to note that these parameters reflect distinct properties of the samples and so are essentially independent of each other. Flenley *et al.* (1987) have demonstrated that it is possible to model multi-modal grain size distributions using «mixed» log skew Laplace distributions, and to use this statistical modelling technique to integrate mass size frequency data obtained through sieving with that obtained by pipette or hydrometer analyses (Fieller & Flenley, 1987).

III.- AN OUTLINE OF THE SEDIMENTOLOGICAL HISTORY OF SECTION A, ROBIN HOOD'S CAVE

Examination of the plots of the grain size data used for all the samples from Section A in Robin Hood's

Cave at Creswell Crags, when plotted on log-log axes, showed that they all had distributions appropriate to the fitting of unimodal log skew Laplace distributions. This raised the opportunity for a more precise description and analysis of the original grain size data obtained from this exposure which had been analysed in a conventional manner as shown in figure 2. The results of analysing these same data using log skew Laplace distributions are summarized in figure 4. This new analysis indicates a more complex sedimentological history than that suggested by the traditional approach (fig. 2).

input suggested by the increasing values of mu in this material, suggest the periodic introduction and sorting of finer sediment by water movement in the cave. A marked change occurs at about the depth of 1.16 m. Above this level the parameter plots shown in figure 4 are characterized by a series of marked oscillations which become progressively stronger with distance upward through the sequence. These oscillations suggest increasing by strong pulses of very fine sediment, possibly loessic in origin. These more variable geomorphic conditions imply the onset of the relatively bleak, open and cold conditions that

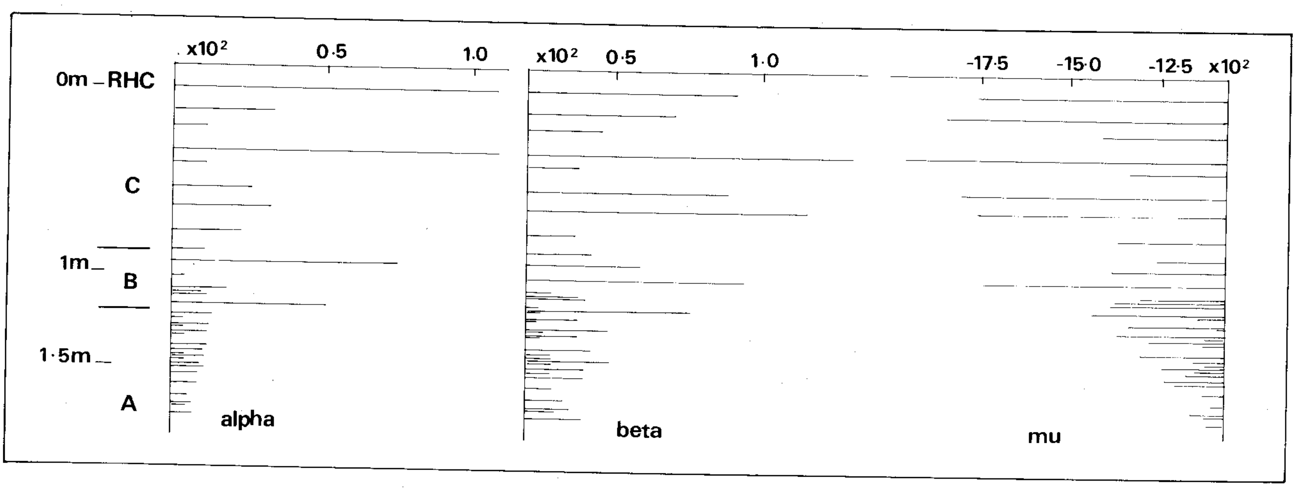

Fig. 4.- Variations in the parameters *alpha, beta* and *mu* estimated for the particle size data of the cave sediment samples from Robin Hood's Cave, Creswell Crags, shown after conventional statistical analysis in figure 2.

Several features of interest are apparent. The plots of alpha and beta throughout the profile show sympathetic patterns of variation, even though the values calculated for these parameters are quite independent of each other. This feature suggests that the values displayed are reflecting «real» variations in the properties of the sediments.

Below 1.5 m the evidence indicates a relatively uniform layer of sediment, possibly accumulating as the result of the steady accretion of fine grained debris falling from the granular Magnesian Limestone of the bedrock walls of the cave. Between 1.5 and 1.20 m in depth, there is a body of sediment which is characterized by a series of small scale oscillations. The modal grain size has decreased compared to that of the deposits below. The fluctuating values of the parameters and the higher energy

were eventually to culminate in the extreme cold of the Late Devensian maximum c. 16-20 000 years ago.

In general, this outline interpretation, which was suggested by the statistical modelling of the grain size data using log skew Laplace models, is also seen to correspond to that identified previously by the archaeological and palaeontological data. The sedimentary history of this site is less clearly evidenced in the plots of low order sample moments of the same grain size data shown in figure 2.

IV.- CONCLUSIONS

Particle size distribution data from Robin Hood's Cave, Creswell Crags, England can be modelled successfully using log skew Laplace distributions. The analysis has suggested that this means of handling grain size data has reflected more clearly important properties of cave sediments, and in consequence has facilitated the development of a more detailed and reliable sedimentological history of an important cave site than had been achieved before using standard methods of analysing particle size data.

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BIBLIOGRAPHY

BAGNOLD, R.A., 1937.- The size-grading of sand by wind. *Proceedings of the Royal Society of London*, A163 : 250-264.

BAGNOLD, R.A., 1979.- Acceptance of the Sorby Medal of the International Association of Sedimentologists. *Sedimentology*, 26 : 159-160.

BAGNOLD, R.A. & BARNDORFF-NIELSEN, O., 1980.- The pattern of natural size distributions. *Sedimentology*, 27 : 199-207.

BARNDORFF-NIELSEN, O., DALSGAARD, K., HALGREEN. C.. KULHMAN, H., MOLLER, J.T. & SCHOU, G., 1980.- Variation in particle size over a small dune. *University of Aarhus, Department of Theoretical Statistics. Research Reports* n° 51.

BRIGGS, D.J., GILBERTSON, D.D. & JENKINSON. R.D.S. (eds). 1985.- *The Peak District and Northern Dukeries : A Field Guide and Handbook.* Cambridge, Quaternary Research Association. 221 p.

CAMPBELL, J.B., 1977.- *The Upper Paleolithic in Britain.* Oxford. Clarendon Press, 2 vols.

CHRISTIANSEN, C., BLAESILD. P. & DALSGAARD. K.. 1984.- Reinterpreting «segmented» grain-size curves. *Geological Magazine.* 121 : 47-51.

EHRLICH, R., 1981.- «Size analysis wears no clothes or Have moments come and gone ?» *Journal of Sedimentary Petrology.* 53 : 1.

FARRAND, W.R., 1975a.- Analysis of the Abri Pataud sediments. *In* Movius. H.L. (ed.), Excavation of the Abri Pataud. Les Eyzies (Dordogne). *Bulletin of the Peabody Museum*, 10 : 27-68.

FARRAND, W.A.. 1975b.- Sediment analysis of a prehistoric rock shelter : the Abri Pataud. *Quaternary Research*, 5 : 1-26.

FIELLER, N.R.J. & FLENLEY. E.C.. 1987.- Statistical analysis of particle sizes and sediments. *University of Sheffield Department of Probability and Statistics, Research Report* 288/87. 19 p.

FIELLER, N.R.J.. GILBERTSON. D.D. & OLBRICHT. W.. 1984a.- A new method for the environmental analysis of particle size data from shoreline environments. *Nature*, 311 : 648-651.

FIELLER, N.R.J.. GILBERTSON. D.D. & OLBRICHT. W.. 1984b.- Skew log Laplace distributions to interpret particle size distribution data. *Manchester-Sheffield School of Probability and Statistics. Research Report* n° 235 : 17 p.

FIELLER, N.R.J. & GILBERTSON, D.D., 1985.- Skew log Laplace distributions and environmental discrimination from particle size data at the Dawlish Warren spit-dune complex. *Proceedings of the Ussher Society*, 6 (2) : 270-271.

FLENLEY, E.C., FIELLER, N.R.J. & GILBERTSON. D.D.. 1987 (in press).- The statistical analysis of «mixed» grain size distributions from aeolian sands in the Libyan Pre-desert using log skew Laplace models. *In* Frostick. L.E. and Reid, I. (eds.), *«Desert Sediments : ancient and modern»*. Special publication of the Geological Society of London.

FOLK, R.L. & WARD, W.C., 1957.- Brazos River Bar : a study in the significance of grain size parameters. *Journal of Sedimentary Petrology*, 31 : 514-529.

FRIEDMAN, G.M., 1979a.- Address of the Retiring President of the International Association of Sedimentologists : Differences in size distributions of populations of particles among sands of various origins. *Sedimentology*, 26 : 3-32.

FRIEDMAN, G.M., 1979b.- Differences in size distributions of populations among sands of various origins : addendum to IAS Presidential address. *Sedimentology*, 26 : 859-862.

GRIFFIN. C.M., 1985.- An examination of the zonal model of sedimentation in caves. *In* Fieller. N.R.J.. Gilbertson. D.D. and Ralph. N.G.A. (eds.). Palaeoenvironmental Techniques : Research Design. Methods and Data Analysis. Oxford. *British Archaeological Reports International Series.* 258 : 21-28.

HUGHES. P.J.. 1983.- Geoarchaeology in Australia. *In* Connah. G. (ed.). *Australian Field Archaeology : A Guide to Techniques.* Canberra. Australian Institute of Aboriginal Studies. 109-117.

INMAN. D.L.. 1952.- Measures for describing the size distribution of sediments. *Journal of Sedimentary Petrology.* 22 : 125-145.

JENKINSON. R.D.S. & GILBERTSON. D.D.. 1984.- *In the Shadow of Extinction : The Quaternary Geology and Palaeoecology of the Lake. Fissures and Smaller Caves at Creswell Crags.* Sheffield. University of Sheffield Monographs in Prehistory and Archaeology.

JENKINSON. R.D.S.. GILBERTSON. D.D.. GRIFFIN. C.M.. HUNT. C.O.. ROWE. P.J. & COLES. G.M.. 1986.- New Upper Palaeolithic Human Remains from Robin Hood's Cave. Creswell Crags S.S.S.I.. U.K. *In* Roe. D.A. (ed.). Studies in the Upper Palaeolithic of Britain and Northwest Europe. Oxford. *British Archaeological Reports International Series.* 296 : 89-97.

JENKINSON. R.D.S.. GILBERTSON. D.D.. COLES. G.M.. HUNT. C.O. & ROWE. P.J. (in press). A Holocene human burial in late Pleistocene deposits in Robin Hood's Cave. Creswell Crags. U.K. *Derbyshire Archaeological Society.*

KADDAH. M.T.. 1974.- The hydrometer method for detailed particle-size analysis : 1. Graphical interpretation of hydrometer readings and test of the method. *Soil Science.* 118 : 102-108.

LAVILLE. H.. RIGAUD. J.P. & SACKETT. J.. 1980.- *Rock Shelters of the Perigord : Geological stratigraphy and Archaeological Succession.* New York. Academic Press.

LOWE. J.J. & WALKER. M.J.. 1985.- *Reconstructing Quaternary Environments.* London. Longmans.

MISKOVSKY. J.C.. 1972.- Etude sédimentologique du remplissage. *In* de Lumley. H. (éd.) *La grotte moustérienne de l'Hortus.* Marseille. C.N.R.S.. 101-153.

OLBRICHT. W.. 1982.- *Modern Statistical Analysis of Ancient Sediments.* Unpublished M.Sc. Dissertation. University of Sheffield. Department of Probability and Statistics.

SHACKLEY. M.L.. 1972.- The use of textural properties in the analysis of cave sediments. *Archaeometry.* 14 (1) : 133-145.

TANKARD. A.J. & SCHWEITZER. F.R.. 1976.- Textural analysis of cave sediments : Die Kelders cave. Cape Province. South Africa. *In* Davidson. D.A. & Shackley. M.L. (eds.). *Geoarchaeology : Earth Science and the Past.* London. Duckworth. 289-316.