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

by

Nicholas R.J. FIELLER¹, David D. GILBERTSON², David J. BRIGGS³, Chris M. GRIFFIN² & Rogan D.S. JENKINSON⁴

(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.


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

¹ Department of Probability and Statistics, University of Sheffield, Sheffield S10 2TN, U.K.
² Department of Archaeology and Prehistory, University of Sheffield, Sheffield S10 2TN, U.K.
³ Department of Geography, University of Sheffield, Sheffield S10 2TN, U.K.
⁴ Creswell Crags Visitor Centre, Crags Road, Wetbeck, Worksop, Nottinghamshire S80 3LH, 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 surprisingly 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).

Fig. 1.- The location of section A, Robin Hood's cave, Creswell Crags, U.K.
cal validity of some of the methods used have been expressed (Bagnold, 1979; Bagnold & Barndorf-Nielsen, 1980; Christiansen et al., 1984; Fieller et al., 1984; Fieller & Flennley, 1987; Flennley 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 the estimation and plotting of sample moments (for example, see Fieller et al., 1984a,b; Flennley et al., 1987; Fieller & Flennley, 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 & Flennley (1987), Flennley et al. (1987), Olbricht (1983). The approach is essentially a simplification of that described by Bagnold & Barndorf-Nielsen (1980), Barndorf-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 & Barndorf-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 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. Flennley 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 & Flennley, 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).

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 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 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.

**AKNOWLEDGEMENTS**

Christine Griffin acknowledges the award of an SERC/CASE Research Studentship sponsored by Derbyshire and Nottinghamshire County Councils.

**BIBLIOGRAPHY**


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.


