Preliminary Report on Some Earth Resistance Measurements made near Tyning's Farm on the Mendip Hills, Somerset.

By L. S. Palmer, D.Sc., Ph.D.

I. INTRODUCTION

The electrical resistance measurements described below were made with a Geophysical Megger Earth Tester provided in 1938 by the Royal Society. The alternating and rectifying mechanisms associated with the generator unit had been re-designed as a result of experience gained when investigating Lamb Leer Cavern in 1938 and 1939. The ohm-meter unit had been renewed by Messrs. Evershed and Vignoles because the insulation of the current coil of the original instrument broke down when being used on the boulder-clays and chalk of the Holderness Plain during the Spring of 1947. As a result of this the instrument needed re-calibration before the absolute readings in ohms could be relied upon. This does not affect the deductions made below, which depend on relative resistance values. The electrodes had been re-designed with a view to reduction in weight and increase in strength, and the electrical contacts were made more secure by replacing the previously used springs with grub screws. The apparatus as now modified worked reliably and satisfactorily throughout a ten-day camp in July, 1947, during which time the measurements recorded below were carried out by members of the University of Bristol Spelæological Society together with others interested.

It is assumed in the following sections that the usual methods of making earth resistivity measurements with a Megger Earth Tester are understood.*

II. OBJECTIVES

The general purpose of the investigation was to detect unknown caves in the limestone rocks of the Mendip Hills. From theoretical considerations† it would not be expected that a cavern in limestone would be detected unless it was of considerable dimensions, not too far below the surface, and not covered with any stratum of highly conducting material. Such a cavern would be indicated by an abnormal high-resistance region

* See references 3 and 4 and a brief note by Brigadier E. A. Glennie in *Cave Research Group News Letter*, 1947, No. 7.

† To be discussed in a subsequent paper on the G.B. Cave.

superimposed on a normal (σ_s, b) graph of the one, two, three, or more layer type, where σ_s is the apparent specific resistance of the rock and b is half the distance between the current electrodes. Unless the normal graph is known, an ' S ' bend, for example, might be interpreted either as a low-resistance water- or clay-filled cavity at a given level, or as a high-resistance boulder or air-filled cave at a slightly lower level and vice versa for a reversed ' S ' bend. If the normal curve intersected the ' S ' bend through its centre, it might be inferred that an otherwise open cave had a clay-filled upper portion or a clay-filled lower portion if the ' vertical anomaly ' was a reversed ' S ' bend.

For these reasons the first objectives were to select sites, if possible, which would give the normal vertical rectilinear graph for a homogeneous limestone half-space, the normal curve for a layer of soil on limestone and a typical three-layer curve for (say) soil upon limestone upon sandstone or some similar combination of three strata.

Secondly, it was proposed to investigate a site near Tyning's Farm on the Mendip Hills where a rift was being worked, in order to determine, if possible, whether or not the rift entrance was likely to open out into a cave. As the entrance was only about 20 ft. below the surface this objective seemed a feasible one.

A third but minor objective was to take two or more sets of measurements at a given site, one using the electrode spacings appropriate to the formula,

$$\sigma_s = K.R. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where K is a constant (say 100 or 2000 or some other simple factor) and the other where K is equal to some integral number of times the distance (2b) between the current electrodes, and to compare the forms of the resulting graphs. In the above equation σ_s is the apparent specific resistance at a given depth, K has the value $\pi(b^2-a^2)/2a$ (a and b being half the spacing between the potential and current electrodes respectively when symmetrically placed above the point under investigation), and R is the ohm-meter reading.

III. SELECTION OF SITES

In view of the objectives stated in the foregoing section, a site was sought which would yield a straight vertical (σ_s, b) graph for homogeneous isotropic limestone, but nowhere on the Mendip Hills is there limestone uncovered even if it is uniform throughout its depth. Although exposed limestone areas occur in West Yorkshire, it is highly improbable that they would be uniform and without bedding planes for any considerable depth. Consequently, the idea of getting a standard graph of this simple type was abandoned.

For the two-layer type of graph a site was selected on a large field situated 51° 18′ 0″ N. and 2° 46′ 5″ W. (Reference O.S. Somerset 6 in. Sheet XVIII S.W.). A Transverse running N.–S. was laid out as indicated at Site I in *Fig.* 1. The resulting graphs are given in *Fig.* 3 and discussed in the following section.

Site II (*Figs.* 1, 2, 7) was located at 51° 18′ 20″ N. and 2° 45′ 50″ W. near the entrance to a small rift A which is situated at the junction of the Limestone Shales (K beds) and the Mountain Limestone on the

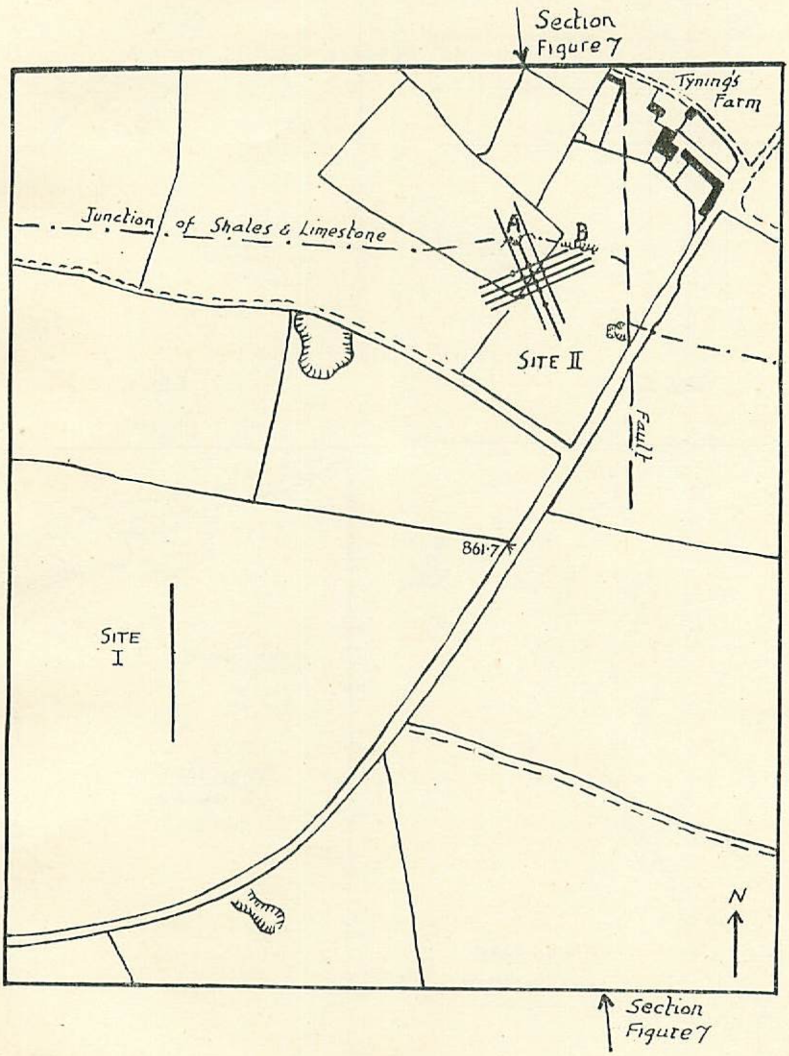

Fig. 1.

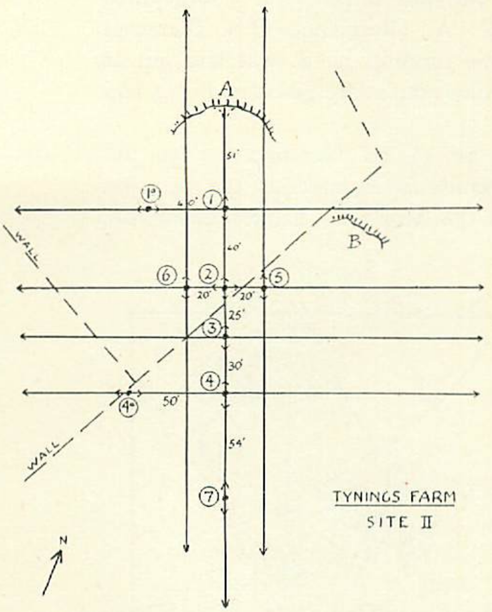

Fig. 2.

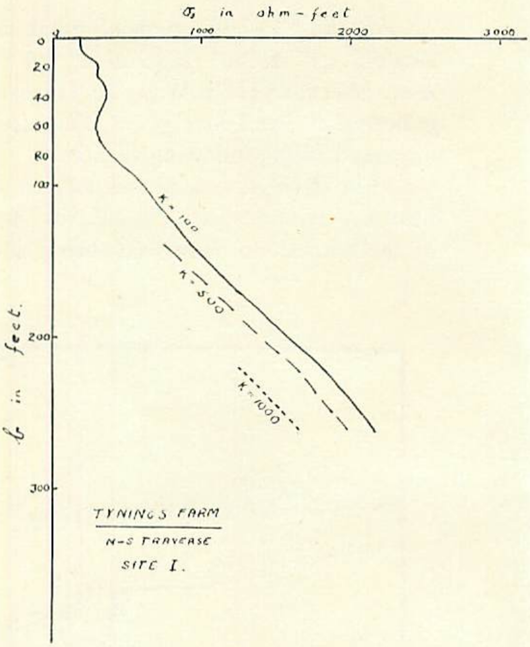

Fig. 3.

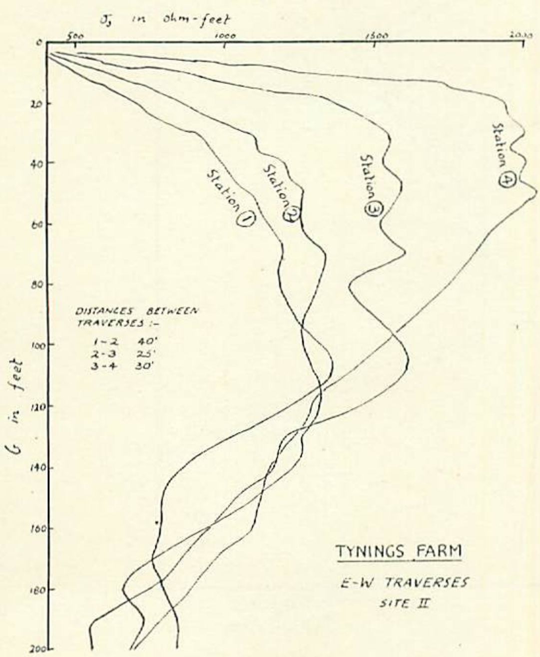

Fig. 4.

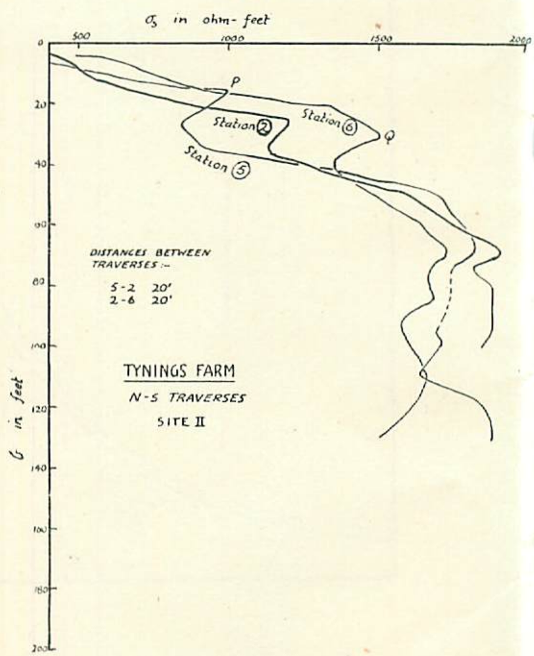

Fig. 5.

800 ft. contour near Tyning's Farm. Stations (1) to (7) with traverses running approximately N.–S. or E.–W. as shown in *Figs.* 1 and 2 were set up, and the resulting graphs are given in *Figs.* 4, 5, and 6 and are discussed below.

Site I and Station (1) on Site II were used to test the minor third objective referred to above, and the results are shown in *Figs.* 3 and 8.

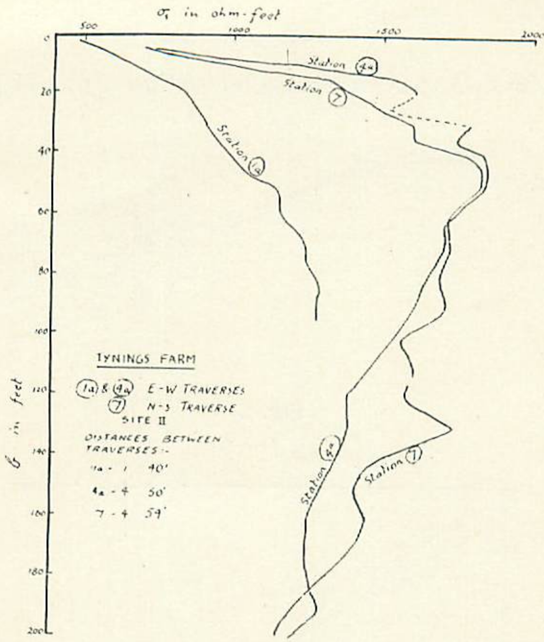

Fig. 6.

IV. SOME THEORETICAL CONSIDERATIONS

Hitherto it has been almost the universal practice to space the current and potential electrodes equal distances apart and symmetrically disposed along a line passing through the site to be investigated. Most theoretical formulæ also accord with this practice, which is usually associated with the name of Wenner.* With the Wenner technique, K in equation (1) is equal to $\frac{4}{3}\pi b$, b being half the separation of the current electrodes and 1·5 times the separation of the potential electrodes. Consequently for measuring to small depths (i.e., using small values of b) in a high-resistive medium such as limestone, an ohm-meter reading to at least 100 ohms would be required. To use the particular megger available which reads to 30 ohms,

* F. Wenner: (*a*) *Bull. Bureau of Stds.*, 1916, Vol. 12, p. 469; (*b*) *U.S. Bureau Stds., Sci. Paper*, 1917, No. 258.

the Wenner method was not suitable and the general formula for a homogeneous isotropic medium :—

$$\sigma_s = \frac{\pi\,(b^2 - a^2)}{2a}\,R = K.R. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

was therefore adopted. To simplify computations in the field, the value of K can be kept constant by suitably disposing the electrodes in accordance with the solutions of the equations :—

$$\frac{\pi(b^2 - a^2)}{2a} = 100,\ 500,\ 1000,\ \text{etc.}$$

the variable a for each value of b being read off previously prepared graphs

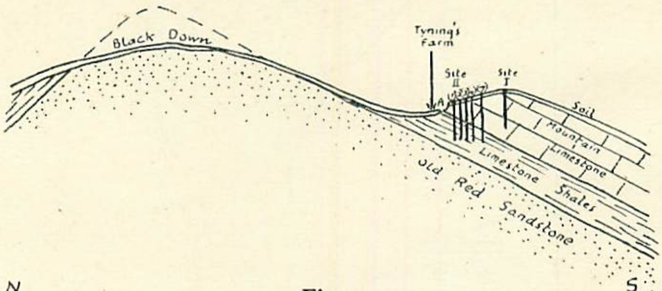

Fig. 7.

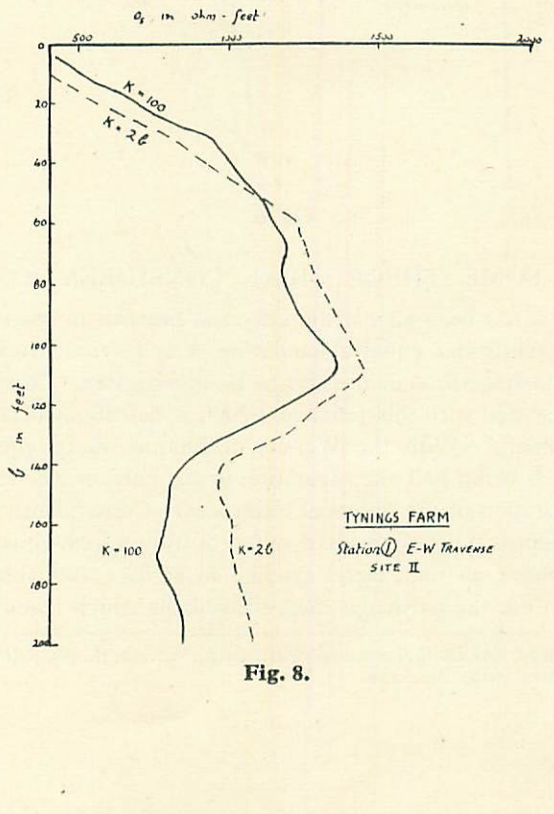

Fig. 8.

for each constant value of K. Alternatively, K could be made equal to Cb where C is some convenient integer.

For media which are not homogeneous and isotropic (e.g., a series of parallel strata, a cave in limestone, a fault, etc.), deviations from the normal (σ_s, b) graph will occur. These will need to be interpreted from a knowledge of the normal curves for the given values of K in use, and from a knowledge of the theoretical curves to be expected from such geological peculiarities as those cited above in parenthesis. These theoretical curves for the Wenner technique have been obtained by several authorities.* The particular shapes of the graphs for the present values of K have been determined, and it is hoped will be discussed in a subsequent publication.

For two horizontal layers, the upper of depth h and specific resistance σ_1, and the lower of infinite depth and specific resistance σ_2, we have :—

$$\sigma_s = \frac{\pi (b^2-a^2)}{2a} R =$$

$$\sigma_1 \left\{ 1 + \frac{(b^2-a^2)}{a} \sum_{n=1}^{n=\infty} \left(\frac{\sigma_2 - \sigma_1}{\sigma_2 + \sigma_1} \right)^n \left[\frac{1}{\sqrt{(b-a)^2 + (2nh)^2}} - \frac{1}{\sqrt{(b+a)^2 + (2nh)^2}} \right] \right\} \quad ..(3)$$

where n is an integer varying from 1 to infinity.

It may be mentioned that, on the theoretical graphs, points of inflection resulting from a boundary layer between two strata at a depth h occur approximately at current electrode spacings (2b) equal to about four times that depth (or $h = 0{\cdot}5b$), whilst a vertical anomaly caused by a cave at a depth h appears at a current electrode spacing equal to $2\sqrt{2}\,h$, (or $h = 0{\cdot}7b$). These theoretical considerations will be discussed more fully elsewhere, but the former may be deduced from equation (3).

These preliminary remarks on the theoretical aspect of the problem will assist in appreciating the interpretations of the practical (σ_s, b) graphs which are given below.

V. MEASUREMENTS AND RESULTS

Fig. 3 shows the results obtained on Site I. The electrode spacings were such that K (equation (2)) was equal to 100 for the full-line graph, 500 for the dashed graph and 1000 for the dotted graph. These graphs

* In particular : (i) L. V. King—(*a*) *Proc. Roy. Soc.*, 1933, A. 139, pp. 237–77 ; (*b*) *Phil. Trans. Roy. Soc.*, 1934, A. 233, pp. 327–52. (ii) J. N. Hummel—(*a*) *Zeits. f. Geophysik.*, 1928, Vol. 4, pp. 22, 67, 178 ; (*b*) *Amer. Inst. Min. and Met. Engs., Tech. Pub.*, 1931, No. 418. (iii) F. Tölke—*Naturwissenschaften*, 1938, Vol. 50, p. 809.

are discussed further when referring to *Fig.* 8 below. Except for a slight vertical anomaly at b = 20 ft. to 60 ft., the graphs conform to the types obtained from equation (3) by making the appropriate substitutions from equation (2). They commence at the surface (b = 0) where σ_1 = about 200 ohm-ft.—that for the top soil—and would eventually ($b \to \infty$ in equation (3)) become asymtotic to the vertical line $\sigma_s = \sigma_2$, σ_2 being the apparent specific resistance for dry limestone (over 5000 ohm-ft.). These graphs form a useful standard of comparison for shallow soil on limestone (*see* Site I, *Fig.* 7). It is not possible (owing to the unexpected deviation of the graph at b = 20 ft. to 60 ft.) to determine the value of b for the point of inflection, about a half of which would have given the approximate thickness of the subsoil (probably <4 ft.).

Turning to Site II, the four graphs in *Fig.* 4 refer respectively to the four E.–W. traverses through stations (1) to (4), which lie on the N.–S. line running through the rift opening at A (*Figs.* 2, 7). These curves are typical of the three-layer problem in which the middle layer has the highest resistance and the top layer has the lowest resistance. This is in accordance with the section shown in *Fig.* 7 (Site II), which is based on Welch's paper entitled "The Geological Structure of the Blackdown Pericline".* It is significant that the maximum resistance value gets progressively higher as the limestone layer gets thicker, and the topsoil becomes thinner, that is, as successive stations get further from the junction of the limestone shales and mountain limestone (point A in *Figs.* 1, 2, 7). It is not possible to discuss absolute values with any certainty, but it is apparent from *Fig.* 4 that whereas the graphs start (b = 0) at approximately the σ value (<400 ohm-ft.) for soil (as in *Fig.* 3), they terminate ($b \to \infty$) at some value ($\doteqdot 700$ ohm-ft.) intermediate between that of soil and that of mountain limestone (>5000 ohm-ft.). Tölke† gives for loam, clay, shales, and limestone values of σ up to 150, 1200, 2400, and 10,500 ohm-ft. respectively. The present work gives values of σ well within these limits.

The three curves in *Fig.* 5 are for N.–S. traverses through Stations (2), (5), and (6), and could not be taken to the same depth as the E.–W. traverses of *Fig.* 4.

Curves (1a), (4a), and (7) in *Fig.* 6 were obtained as confirmatory or additional evidence from stations outside the area covered by the stations (1) to (6). Traverses through (1a) and (4a) were E.–W. and that through (7) was a N.–S. traverse (*Fig.* 2).

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* *Proc. Bristol Nat. Soc.*, 1932, 4S., Vol. VII, Pt. V, pp. 388–96.
† Loc. cit.

VI. INTERPRETATIONS

So far we have only considered the graphs as examples of normal two- or three-layer cases, but there are evident abnormalities on Site II which will now be discussed. The nature of the abnormalities will naturally be a matter of some speculation, because any interpretation depends on a knowledge of the normal curves appropriate to the particular stations. On the whole it appears that at b = 30 over the area covered by Stations (2), (3), (4), (5), (6), and (7) (*see Fig.* 2) there is a reversed 'S' bend which is particularly noticeable on the N.–S. traverses at Stations (5), (2), and (6) (*Fig.* 5). This suggests either an open bedding plane horizontal along the N.–S. line at a depth of about 15 ft. but tilting downwards in the direction (5) to (6), or westwards at an angle of about 15 ft. in 40 ft. or 21° (*see* points P and Q in *Fig.* 5). Welch marks the dip of the strata here as 22° but in a more southerly direction. The bedding plane is not very apparent at Stations (1) and (1a) (*Figs.* 4, 6) and may, therefore, be limited to the area covered by Stations (2) to (7). The vertical height of the bedding plane, if such be the correct interpretation, may be 5 to 10 ft.

There are indications of a similar effect at b = 70 ft. ($h \doteqdot 35$ ft.) (except at Stations (4) and (7)) and possibly at b = 110 ft. ($h \doteqdot 55$ ft.). The slight 'bulges' at b = 50 ft. on the E.–W. traverses only, could be caused by a rift or passage running roughly N.–S. along the line of the Stations (1) to (4) and at a depth of approximately 25 ft. This may be the continuation of the rift running in from the cliff face at A.

From these conclusions it is suggested that any future excavation should be designed either to force the rift entrance at A (*Figs.* 1, 2) or quarrying should be commenced at the rock face marked B and continued downwards at about 20° or so in a S.–W. direction practically parallel to the nearby wall and hedgerow. This second alternative would check the conclusions* deduced from abnormalities P and Q in *Fig.* 5.

The final objective of this investigation was to note the difference in the normal forms of curve resulting from electrode spacings appropriate to different values of the factor K in equations (1) and (2). These differences at Site I may be seen by comparing the graphs of *Fig.* 3, and at Site

* These conclusions can only be taken as approximate because the interpretation is complicated by the fact that the junction between the limestone and the shales is not parallel to the surface. This matter is now being investigated theoretically.

II Station (1) by comparing the graphs in *Fig*. 8. It will be noted that in *Fig*. 8 the curves cross at $K = 100 = 2b$ approximately. These different, yet normal, curves serve to emphasize the necessity for comparing abnormalities or vertical anomalies in measured curves not only with the theoretical curve appropriate to the types and dispositions of the geological media involved, but also with the theoretical curve appropriate to the particular technique employed.

The author, with those members of the Spelæological Society who took part in this work, are pleased to record their gratitude to Brigadier E. A. Glennie and to two students from Hull University College who assisted in the field work at Tyning's Farm.