COMPASS & TAPE

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COMPASS & TAPE

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Cover: Pen and ink of an instrument reader emerging from a low, wet area.
One that I would have fun mapping myself. - Joanna Florio-Jefferys

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THE ACCURACY OF A CAVE SURVEY
by Denis Warburton

With a number of cave surveys being published in 1962, every major Mendip cave and many of the smaller ones have now been surveyed, most of them to a fairly high standard of accuracy. The main purpose of this article is to discuss, rather comprehensively, a number of points regarding the accuracy of surveys, with particular emphasis on Mendip caves. I should like to stress the word "discuss"; this is not an attempt to set out a rigid procedure, or for that matter any procedure at all, but rather to put forward some ideas of my own. These ideas have emerged from more than a decade of surveying underground.

I should also like to emphasise that my surveying colleagues in the W.C.C. do not necessarily agree with some of my conclusions, and I hope that any disagreements will be freely and fully ventilated in the pages of this Journal. This long, and in places rather controversial, article may seem to many readers to be somewhat too technical, but if they will bear with me for a few pages it will be seen that it is not as difficult as all that. Should some of the older members have trouble with the calculations, their "eleven-plus" children will certainly come to their help.

The system for indicating the accuracy of a cave survey is now based almost exclusively on the recommendations of the Cave Research Group. Their publication "Cave Survey" has become the cave surveyor's Bible since it was first published in 1950, and almost all the Mendip surveys have been given a C.R.G. grading. The only major exception ia the survey of G.B. Cave and the (valid) reasons for not giving this a grading are detailed in the accompanying publication.

It will be helpful at this point if the grades are detailed.

GRADE 1 Rough diagram from memory - not to scale.

GRADE 2 Sketch plans, roughly to scale, no instruments used; distances and directions estimated.

GRADE 3 Rough survey. Small pocket compass graduated to 10 degrees; lengths by marked cord or by stick of known length.

GRADE 4 Prismatic compass graduated in single degrees (compass error not known), measuring tape or marked cord.

GRADE 5 Calibrated prismatic compass, clinometer, metallic or steel tape, bearings to nearest degree.

GRADE 6 Calibrated prismatic compass or Miner's Dial mounted on tripods; clinometer with tripod; distances by chain or steel tape, or tacheometry.

GRADE 7 Theodolites for bearings and slopes; distances by steel tape, chain or by tacheometry. Or by any more accurate method which may be devised in the future.

Grades 1 and 2 do not concern us here; they are of considerable value in writing up Club Logs and discussing the latest discoveries (n very useful Grade 1 may be drawn on a polished bar using only the right forefinger and a splash of bitter), but the present article is to consider only surveys with measurements. Grade 2, it is worth noting, may give quite a reliable sketch survey in many Mendip caves. Although the direction is only estimated, the steeply dipping limestone over much of the area enables the bearing to be arrived at with considerable precision - for instance, over much of Eastwater the passage direction can be determined to within 20 degrees or better, merely by looking at the dip of the roof.

With Grade 3 we come to the first of the measured grades. No fixed positions are normally used in this survey, and as well as marked cord a "body's length" is often used as a measure of distance, especially in constricted passages. Many people consider this grade as quite useless for a survey -later on we shall test the validity of this idea.

The next grade has for its bearing "prismatic compass graduated in single degrees" and it is stated that the compass error is not known. Marked cord may still be used for the distance, and most important of all, there is no means of measuring the vertical component. The writer feels that this grade is not a logical bridge between Grades 3 and 5, in that the accuracy of direction has been improved by a factor of about 10 over Grade 3, while the distance and the vertical component are not affected. On many occasions in the last few years there have been surveys produced which are considered by the surveyor to be only of Grade 4, even though a clinometer has been used. The fact that so many Mendip caves have steeply descending passages makes some form of inclination measurement almost essential, even if it is only a simple protractor and a plumb line.

The accuracy of the bearing also seems to be greater than the other measurements warrant, and it would seem that a compass(not necessarily prismatic) reading to the nearest 2-3 degrees would best fit the case. With this in mind, I have modified the requirements for Grade 4 in the present article, to read (with apologies to the C.R.G.):-

<u>GRADE 4</u> Hand compass reading to 2-3 degrees, simple clinometer (or angles of dip estimated - this only comes with considerable practice) measuring tape or marked cord.

With reference to "marked cord" it should be noted that a non-compensatory error can be introduced here. Cords, and to a lesser extent cloth tape, are liable to alter considerably in length when wet or when subject to an excessive pull, and this error is not apparent on a closure. If either of these articles is used it should be checked for length at the time the survey is made, preferably against a steel tape or similar standard. This is seldom convenient, and tends to destroy the idea of Grade 3 as a rapid preliminary survey, so that any errors from this source must generally be accepted. The alternative is to use a steel tape for the survey, this ia only slightly less convenient than a cord.

With Grade 5 we come to the first of the 'precision' gradings, in which all the three readings are as accurate as the instruments permit. The Grade states "bearings to the nearest degree," but with most if not all prismatic compasses the limit of rending the dial is 0.5 degree. The reading angle of the clinometer is not stated; with a number of the popular types used for cave survey the reading limit is at least as good as 0.5 degree and in some types may be considerably better.

Some little discussion is warranted here on the 'calibration' of a compass. There are three possible causes of error in a compass bearing. The first is that the engravings of the card or dial may not be exact, and that some of the scale intervals will be less and some more than a degree. In theory this could lead to an accumulated error in certain bearings. This is quite a difficult thing to check without very precise equipment not normally available to amateurs, and it can be accepted that it does not normally occur in any good compass to the extent that would noticeably affect a care survey. Most compasses that are used for this work are obtained on the 'ex-Government' market and these instruments are made to a very much higher standard than necessary. We can neglect this error.

Another error, and one that is more likely to be found, is caused by the magnet (or set of magnets) not being correctly oriented with respect to the card. This can be shown by taking the instrument to a point from which several bearings can be taken and related to the O.S. map. One must, of course, ensure that there is no possibility of any magnetic material nearby affecting the result; one or two trials at different points will soon enable this error to be ascertained. As a matter Or interest it may be mentioned that the writer has never encountered this error in any of the compasses used by the Survey Group - even in one rescued from a pile of brass scrap! It can occur, however, and it can be very serious on a Grade 4 survey, as this grade does not call for a calibrated compass.

An excellent example of an error probably due to this cause can be seen if the surveys of August Hole by Stride (1948, accuracy not specified) and Rennie (1962, Grade 6) are compared. When allowance has been made for scale and passage detail, it will be seen that the two plans are very close indeed in distance and in the relation of the various extensions and twists of the passage. The linear distance from the entrance to the commencement of the final rift is almost identical on the two surveys, but the bearings differ by 40 degrees! As the compass used on the Grade 6 survey must have been calibrated to claim Grade 6, then the compass used by Stride must have had a constant error of 40 degrees. This, of course, is another of the non-compensatory errors that does not show up in a closure. Even for a low grade survey it is worth doing a rough check on the calibration, preferably not in a limestone region, as there is often a different magnetic field over limestone to that found elsewhere.

The correction that springs to mind most readily when the 'calibration' of a compass is mentioned is the correction for the local magnetic anomaly. Although it is very easy to find the local magnetic field "from a point near the cave entrance", this is one of the traps into which it is very easy to fall. The snag is that if we do just that, we are relating the whole of our survey to one single position line which may well be affected by an extraneous field quite apart from the one we are trying to correct. To give an extreme example: near our cave entrance is a wall junction marked on the 6" map, and a mile or so away is a church spire which is also marked. We take our readings before each survey trip, and arrive at a local field of 2.5 degrees (a quite common figure). On the fourth trip we get a reading of 1 degree, a very low figure. Searching for the reason we eventually find that the iron gate at the corner of the field is open, whereas on the previous occasion it was shut. Experiment proves that we can get any field we like between 1 and 5 degrees by swinging on the gate! The solution is not always so obvious, but the results may well be as inaccurate as in this example.

If we are to correct for the local magnetic anomaly in a logical way we must check it at several points in the area covered by the cave - say half a dozen points. If the first three readings give the same figure we may be reasonably certain that there is no need to check further. In extreme cases it may even be necessary to prepare a magnetic map of the area of the cave, with the further headache that one is never certain that the deviations penetrate to the depth of the cave. It is not always easy to find a number of well marked position lines in some areas, but unless we do it we are liable to introduce an error of comparable magnitude to the one we are correcting.

Let us assume for a moment that we are not correcting it, and that we are plotting our survey using the figure for magnetic deviation given on the O.S. map. In the limestone area of Mendip generally we shall be in error by 1-3 degrees. If we have only one entrance, or two linked by our own survey on the surface, there will be no way of telling that our survey is not correct -it will merely have been swung bodily round by 1-3 degrees from our O.S. datum point at the entrance. In short, it will not matter, except to a purist. If we are hoping to prove the existence of an alternative entrance, then we must survey above ground to that entrance using our underground survey instruments, rather than plotting off the O.S. map.

The only time that the magnetic anomaly can affect us is when we use a mixture of magnetic bearings and O.S. position lines without relating the two. This is quite rare in cave surveys - the only instance that springs readily to mind on Mendip is the location of the Priddy Green dig in relation to Swildons Hole (I may be wrong here, but I imagine that the location of the P.G. dig has been taken off the O.S. map rather than by a laborious traverse from the Swildons entrance). If we want to do the type of survey that calls for accurate surface to underground linkages we must determine the local magnetic anomaly properly -if not, we should not determine it at all.

The clinometer may need calibrating as well as the compass. Once more the error of engraving the scale may be neglected, but the zero should be checked, as this may be found to be as much as two degrees out. This has a relatively large effect in a level passage such as those in Stoke Lane I, and even more so if all the measurements are taken in the one direction. This error is reduced considerably by the use of the 'leap-frog' technique mentioned later, and eliminated completely if back bearings are taken.

The distance measurement of Grade 5 is given by steel tape, and this does not call for much comment. In several tapes used by the writer (they have a relatively short life in some caves) a considerable magnetic disturbance could be caused when the tape was extended near the compass, but none when it was coiled. If this is found to be the case it is important to make a rule that the compass shall only be read when the tape is rolled. A tape that has been placed on the market only recently is made of a material called Fibron, and this may prove to be the ideal measure for cave surveying (at least if the maker's claims can be upheld). It is claimed not to stretch or shrink, to be unaffected by mud and water, and to be uncreaseable. It is also cheaper than conventional tapes.

Grade 6 differs from Grade 5 only in the fact that the instruments are tripod mounted instead of being hand-held. This, of course, increases the reading accuracy somewhat, but the most noticeable effect of using tripods is the considerable reduction of position error. A point to bear in mind is that if a mirror clinometer is used, then from its very nature it cannot be mounted directly on a tripod, but it will be found that the use of this instrument in the hand does not introduce any appreciable error if the tripod platform is used as a rear sight. The essential point of this grade is that the instruments are read from a stable platform, and this need not necessarily be a tripod. It can be a rock ledge, a cairn built up for the purpose, or even the box in which the instruments are carried.

Grade 7 is a somewhat controversial one. The original wording is quite unambiguous, "theodolite for bearing and slopes". No doubt the intention of the author was to ensure instrumentation that would give the most accurate possible measurements, and a professional theodolite would, of course, give results far superior to magnetic instruments <u>in suitable passages</u>. However, on some cave surveys in recent years there has been a tendency to lash up a hybrid instrument from an ex W.D. astro-compass, and refer to this with supreme optimism, as a theodolite.

Now a theodolite traverse differs radically from a magnetic one in its general properties. In the latter, each single bearing is related to a fixed position line (the earth's magnetic field) and an error in one leg does not affect the rest of the survey by more than the amount of that error. In other words, if our first leg is inaccurate by, say, 5 feet, then the rest of the survey points will be affected by that error to the extent of 5 feet only. A theodolite traverse, on the other hand, has the property that each bearing is related, not to a fixed position line, but to the direction of the previous bearing. It can easily be shown that the possible errors with this method of surveying can soon become very great unless the bearings are taken with great precision. This cannot be done with homemade theodolites, and n non-closed traverse can soon become quite useless. An even bigger snag with a theodolite traverse lies in the fact that gross errors can have a disastrous effect. To give an example, a reading mistake of 20 degrees in the first angle of a Grade 7 survey (not at all impossible under difficult conditions) will reduce the whole survey to the equivalent accuracy of a Grade 3, <u>even if no other mistakes at all are made</u>. The Survey Group are at the moment working on a Grade 7 survey using a professional theodolite, but there will be many additional precautions taken that are only possible under ideal conditions.

There are two ways of avoiding the difficulties. The first is to use the instrument in the same way that a theodolite is used in O.S. work - for triangulation instead of traverse. The separate triangles can be summed on the spot and any gross errors corrected immediately. Even in this case a further problem remains; that of relating the triangulation network to a position line outside the cave. Unless one is very lucky with fixed positions this can all too easily lead to a Grade 7 survey being linked to surface detail with a much less accurate position line. Given a suitable type of cave an astro-compass is reliable enough for triangulation, and a very good example of its use is in the survey of G.B. Cave. The other way of avoiding the difficulties is simply to do a proper Grade 7 - using a theodolite! Ideally this should be the type that is used for mine surveys; it should be capable of reading to about 1 minute of arc or better and it should be easy to read. A suitable instrument for the purpose would be the Wild T1A and ancillary equipment, at a price of L380!

Of course, a low accuracy survey can be made with a converted astro-compass even on a traverse, but surely the whole point of a Grade 7 survey is that it should be more accurate than a Grade 6? The anomaly here may be seen when the survey of St.Cuthbert's Swallet is considered. A "Grade 7" survey with an astro-compass failed to close by "several feet and eleven degrees" in 141 feet, a figure one would expect to better on a Grade 5 survey.

If there are disturbing magnetic effects in a passage, due to ironwork or local magnetic bodies, then such a survey may have to be used to get & line through at all, but it should not be called Grade 7. For the calculations made later in this article the writer has taken advantage of the last part of the definition of Grade 7, "or by any more accurate method which may be devised..." This method simply consists of the general instrumentation of Grade 6, modified in such a way as to reduce the error to & minimum, by the use of special tripods to reduce position error, by 'leap-frogging', and by reading all the instruments to the closest possible limits. A further refinement in this "Grade 7" is the obtaining of closures in each passage by the simple method of surveying it twice! In actual cave survey practice this would probably be given a grading of 6 - it is included here to give an idea of the limits of accuracy of a magnetic traverse. It should be emphasised that this is only a makeshift Grade 7; if a good theodolite is used with the proper precautions, a true Grade 7 will be more accurate than a Grade 6 by a factor approaching 10 rather than 2. However, as the calculation of error for a theodolite traverse is entirely different from a magnetic traverse we shall not consider it here.

An important thing to notice is that the gradings do not indicate the absolute accuracy of the survey, but merely detail the instruments used. This was probably considered to be unavoidable owing to the fact that both caves and cave surveyors vary enormously and the only actual figure given in "Cave Survey" ia the statement that the accuracy of a Grade 4 survey cannot be expected to be better than 5%. The grades obviously increase in accuracy from 1 to 7, but it is not at all clear how, for instance, a Grade 4 survey would compare with a Grade 6 survey of the same passage.

In talking to various members recently, I have found some confusion as to the definition of the accuracy of a survey, and also on the relative merits of different techniques of surveying. From time to time in various publications there have been criticisms of the C.R.G. gradings, and there have been several modifications proposed. In some surveys the grading has been given as 4-5, or 3.5, and these modifications, without any way of backing them up with actual figures, cannot give a very helpful picture. One suggested method of approach was given by Ellis in "Belfry Bulletin" No.169, which gave gradings to individual instruments; these gradings being then added to arrive at the overall figure. This approach is very practical and gives a much more flexible system than the original scheme, but it still does not answer some important questions, namely - how accurate is (say) a Grade 5 survey likely to be, and how much more accurate would it be if we surveyed the same cave to Grade 6? How far out would that stream passage be if we only surveyed it to Grade 4? We need an answer in feet, or degrees, or percentages, not in vague generalities.

Unfortunately, we must here start to delve into the methods and formulae of statistics, but we shall not delve too deeply, and the reader whose mathematics has long since dissolved in a cloud of rust need not worry. The next few paragraphs can be (and probably will be) skipped over, and the conclusions alone considered. Experienced statisticians will notice that certain somewhat loosely worded statements are made - this is done deliberately to avoid turning the article into a mathematical exposition. The writer has neither the wish nor the ability to be considered an authority on statistics.

It has become accepted practice to talk about an accuracy of so many percent, and this practice will be adopted in the discussion that follows. It should also be made clear that when we talk about accuracy in the majority of cave surveys we really mean precision, as we can only state the accuracy when a special type of closed circuit occurs; this is an academic point that we can afford to ignore from now on.

When we say that a survey of a passage 500 feet long has an accuracy of 2%, we mean that a point at the end of the passage has a "probable error" of 2% of 500 feet; that is, it may be 10 feet from where our plan shows it to be. The point about using percentages instead of quoting the "probable error" in feet, is that surveys of widely varying length may be directly compared. A "probable error" of 10 feet does not mean that the point will always be within 10 feet of its true position, but rather that it will lie within the 10 feet a certain proportion of the time, say 95%. This means that one can say that the point will be within the 2% limit 19 times out of 20, but that there will be occasions, namely 1 in 20, when the error of the survey will exceed the expected 2%.

There is a measure in statistics known as the "standard deviation". This can be derived from sets of actual measurements and in certain cases it may be calculated theoretically. Its exact meaning and the way of calculating it need not concern us here - what matters is that we can use it to come to certain conclusions about our measurements, either singly or in sets which make up a survey. In the case just quoted, the error was said to lie within 2% on 19 occasions out of 20. From this the standard deviation can be calculated directly - it happens to be almost exactly 1%. And now we are in a position to say this about our measurements:-

They are in error by more than 1% once in 3 times
" " " " " " " 2% " " 20 "
" " " " " " " 3% " " 400 "
" " " " " " " 4% " " 16,000 "
and so on.

In general, although it is possible that our error will reach a very large value - say 10% in this case - it is extremely unlikely.

In the previous paragraph we have deduced the standard deviation from the stated fact that the error was expected to lie within 2% 19 times out of 20. In an actual cave survey, of course, the reverse applies; we find the standard deviation first, from the measurements (if we have sufficient of the right type), from past experience or from theory. Having the standard deviation we can then make predictions about the accuracy of the parts of the survey that do not lie on closed circuits.

All the predictions based on this standard deviation assume that the errors concerned are random ones, or errors of the compensatory type as they are sometimes called. To put it rather simply we can say that we are accounting for errors and not mistakes! Errors of the non-compensatory type are not included in this analysis, for the simple reason that in small sets of measurements such as we deal with in cave surveys they are not amenable to analysis. This type of error also includes mistakes such as reading 216 degrees for a bearing of 261 degrees, or booking a length as 25 feet instead of 35 feet.

The question of random errors compared with constant bias is an important one. In the calculations that follow it may be thought that too much emphasis has been placed on random errors and not enough on systematic bias. This has been done deliberately - the writer feels that as far as practical work is concerned systematic errors are not as important as sometimes thought. Without going into too much detail, if there is a systematic bias in the measurement of distance there will be an alteration of scale and if there is a systematic bias in the measurement of direction there will be an alteration of orientation. In neither case will the shape of the survey be affected. Also the systematic errors are well known and can be easily eliminated; not so the random ones.

We can now come to cave measurements! If we stand at a known point in a cave, Point A, and we want to know the location of another point, B, which we can see, we need to make three measurements:

1) The magnetic bearing from A to B; i.e. relating the bearing to a known position line on the surface (the earth's magnetic field).
2) The angle of inclination from A to B; i.e. relating the direction in a vertical plane to a known position line (the vertical one due to gravity).
3) The distance from A to B.

These three measurements are necessary and sufficient to obtain the correct location of point B. It is, of course, possible to cover (2) by standard levelling techniques, but this is not common. Caves are not as well planned as mines!

There are now four sources of error which must be considered:

a) Compass error. Even when the compass is set and calibrated, there remain residual errors due to sighting difficulties, reading uncertainties and minor local magnetic deviations.
b) Clinometer error. This is mainly due to sighting difficulties and reading uncertainties.
c) Tape error. This is mainly due to incorrect tension on the tape and faulty judgement of interpolated distances. The fact that the end of the tape may not be exactly on the survey point or the target is not included in tape error, but in position error. The tape error should be the smallest and most predictable of the errors.
d) Position error. This is probably the most important and least recognised source of error. The most usual way of surveying a passage is to set up the instruments at A, take the readings from A to B, then move to B and sight forwards again to the next point, C, and so on. The position error arises from the fact that the instruments will not be stationed exactly on the same point as the target lamp for the previous sighting. With lower grades of survey and with difficult caving conditions this error might be expected to assume major proportions, and its reduction offers one of the simplest ways of increasing the accuracy of the survey.

The compass and clinometer errors are independent of the length of the survey leg (remember we are considering percentages and not absolute values); for small errors they amount to about 1.75% per degree, and for larger amounts are easily looked up in a table of sines. The tape error is inversely proportional to the distance; that is, it is of greater importance on short legs than on long (an error of 3 inches in a leg of 5 feet is 5%, but in a leg of 50 feet ia only 0.5%). Similarly, the position error is more important on short legs than on long.

We now require to assess the cumulative effect of all these errors, and to do this without considering each survey separately we must simplify the problem slightly. Purists may object to this, but our simplifications do not affect the arguments to any great extent. First we shall assume that our cave survey has all its legs of the same length, and secondly that we may sum our errors vectorially.

The figures in Table 1 show the "reading limits" adopted for the five grades of survey, and Table 2 the standard deviations taken from these, expressed as percentages. It will be noted that for the top three grades the standard deviation is taken as three times the "reading limit", but for the lower grades only 1.5-2 times. This is because in the lower grades one is not working to the limits set by the optical and mechanical parts of the instruments, but rather to the limits of one's own care and patience.

TABLE 1

"Reading Limits" for various Grades

	3	4	5	6	"7"	
Compass	10	2	0.5	0.2	0.2	degrees
Clinometer	-	2	0.2	0.2	0.2	degrees
Tape	24-36	3	1	0.5	0.25	inches
Position	12	8	4	0.5	0.25	inches

TABLE 2

Standard deviations of measurements expressed as percentages

		3	4	5	6	"7"
Compass		25.8	8.7	2.62	2.62	1.05
Clinometer	-	7.0	2.62	1.05	1.05	
Tape	10 ft.	40.0	5.0	2.50	1.25	0.63
	20 ft.	20.0	2.5	1.25	0.63	0.32
	50 ft.	8.0	1.0	0.50	0.25	0.13
	100 ft.	4.0	0.5	0.25	0.13	0.06
Position	10 ft.	20.0	10.0	5.00	1.25	0.63
	20 ft.	10.0	5.0	2.50	0.63	0.32
	50 ft.	4.0	2.0	1.00	0.25	0.13
	100 ft.	2.0	1.0	0.50	0.13	0.06

It is an extremely difficult thing to read a high-precision compass to 0.2 degrees, even under the best conditions, whereas a compass with 10 degree intervals as required for Grade 3 can often be read much more accurately with little effort. The figures in Tables 1 and 2 have been derived from a mixture of theory, experiment and experience on actual cave surveys. They are open to criticism as to their exact values.

Table 2 also gives the standard deviations of the tape and position errors expressed as a percentage of different lengths of leg. 10 and 20 feet as average legs are fairly typical of many Mendip caves, 50 feet might be reached in some of the larger ones, while 100 feet is included as an extreme value to facilitate plotting the graphs. We now calculate the overall error for each grade, expressed as a percentage error for different lengths of leg. Notice also here that the overall error is the three-dimensional one - the plan error will be rather less. These figures, in graph form, comprise Fig.1.

Now a cave passage of, say, 500 feet in length would have 50 legs of 10 feet, but only 5 legs of 100 feet, and the error is calculated by multiplying the error per leg by the square root of the number of legs. Figs. 2-6 show the result of this operation - again as a percentage, this time of the full traverse. The percentage error per leg is least for a long leg owing to the reduced effect of tape and position errors, but this is more than offset by the compensatory effect due to a large number of legs. Many would consider that in an actual survey this point should not be pressed too far. It is possible that a passage which gave an average leg of 10 feet would be far more difficult to survey than one which gave an average leg of 100 feet, and this would tend to narrow the gap. We shall return to this point later.

We can derive intermediate values from these graphs simply by plotting other graphs of certain of the quantities. For instance, suppose we have a Grade 5 survey of a 350 feet long passage, the average leg being 16 feet. From the appropriate graph, Fig.4, we can read off the accuracies for the four lengths of traverse. Then plotting the four figures obtained against the total lengths (Fig.7) we can find the accuracy figure for a 350 feet traverse, which turns out to be 1.02%. In this way we can check the expected accuracy of all parts of our survey.

FIG 1

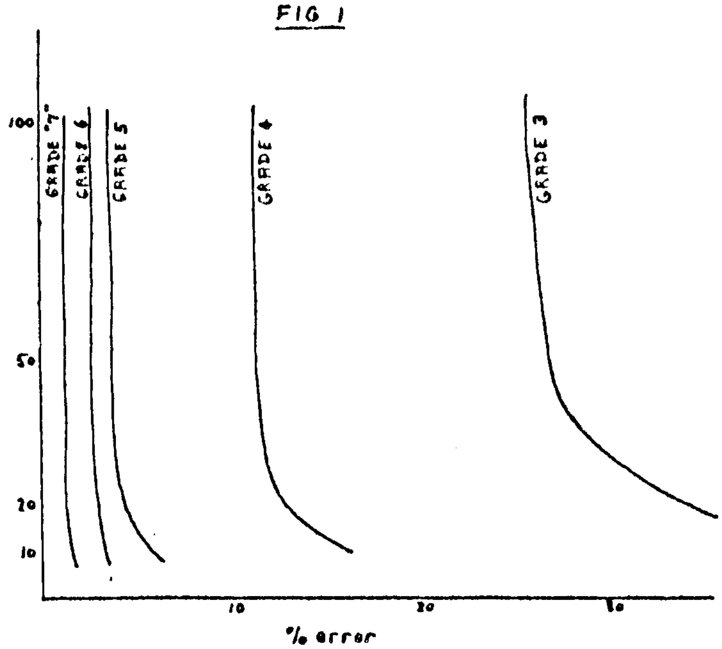
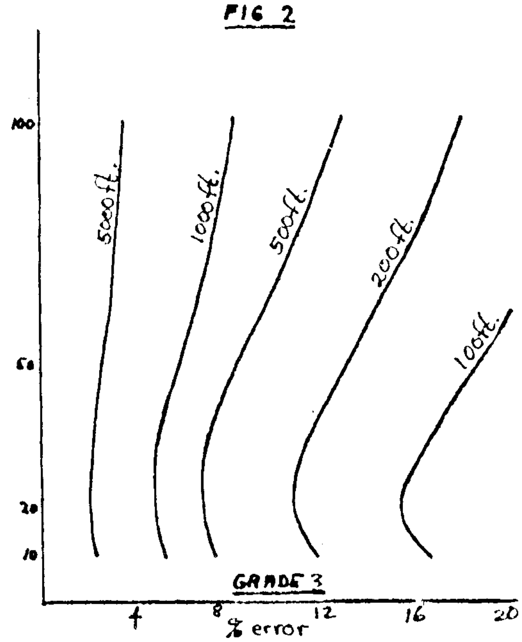


FIG 2



FIC 3

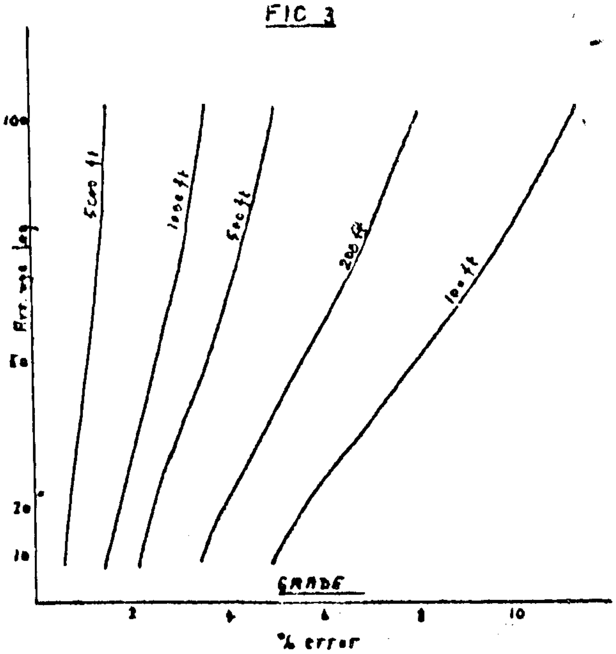


FIG 4

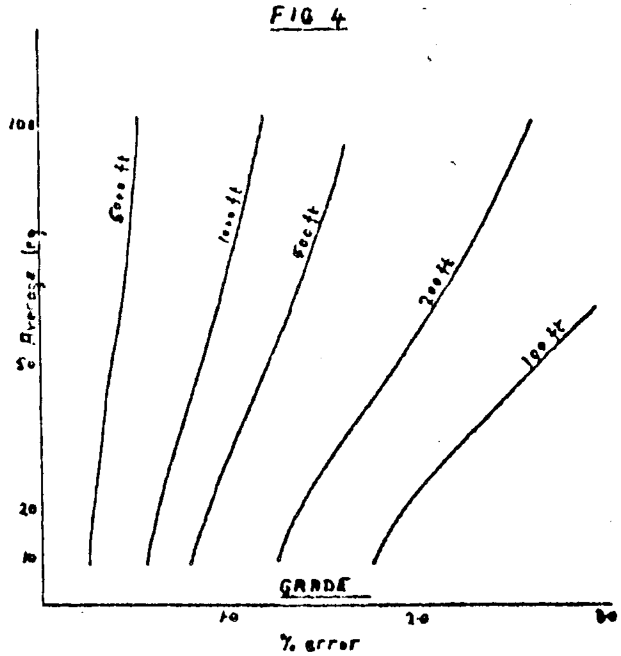


FIG 5

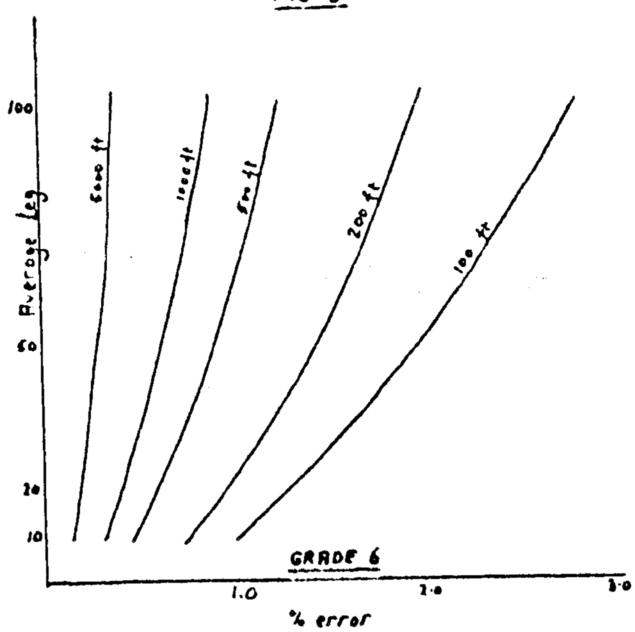


FIG 6

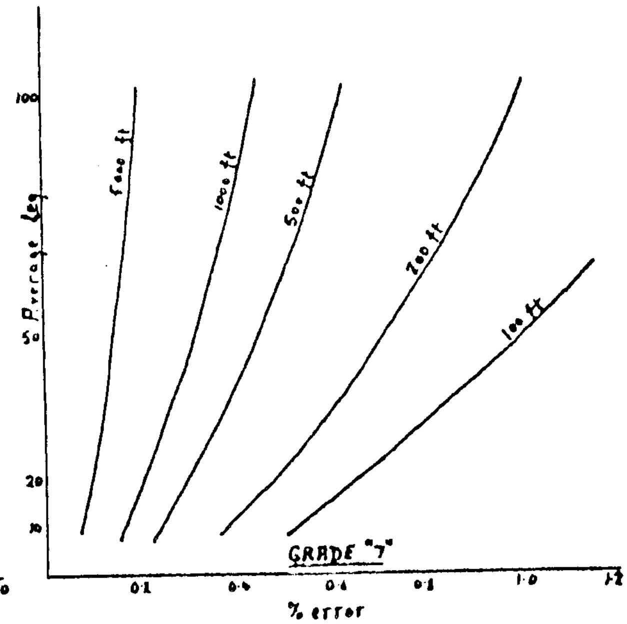
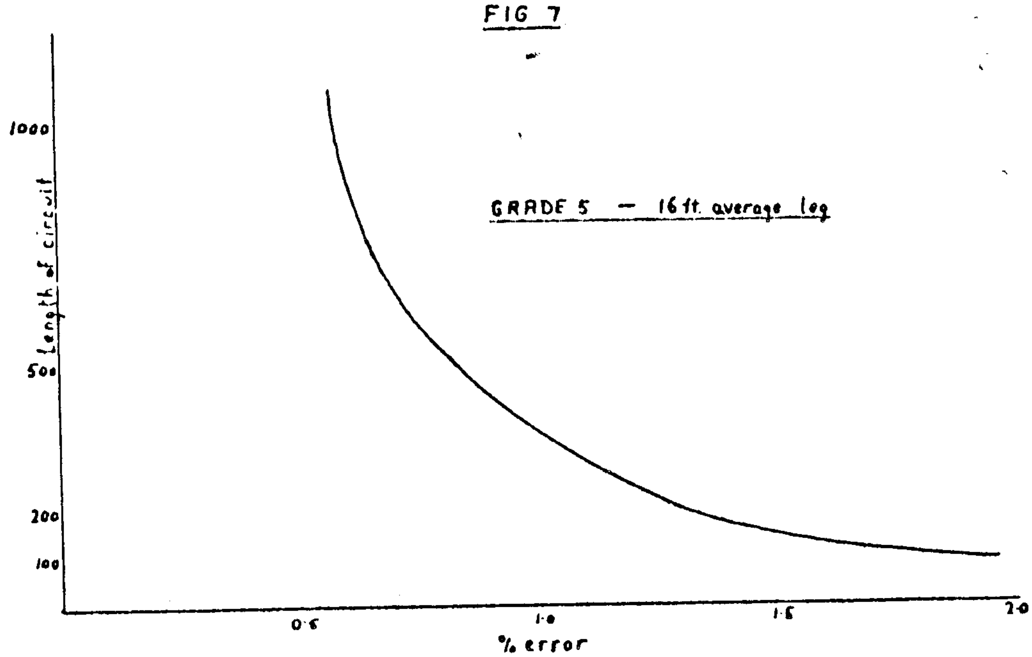


FIG 7



The preceding pages may seem to many practical cavers to be an example of theory run wild, and when the writer first began to consider the problem some years ago it seemed that such a mass of theoretical considerations could have little or no real value. However, detailed records had been kept of surveys over many years and each closure was subjected to the mathematical treatment. This process has now been followed with nearly thirty closures. This is the acid test. A theory has been derived from reasoning and experimental work - it can now be seen if its predictions have any real validity by testing them against actual field work.

The results are shown in Table 3. This shows the actual percentage error obtained from closures in the caves given, together with a 'theory' column which is the calculated figure of 2 S.D.'s modified by a factor which allows the use of the more generally quoted plan error instead of the 3-dimensional error of the theory.

It can be seen that in general our theory gives quite acceptable results. True, there are five misclosures greater than the theoretical instead of the one or two that one would expect, but three of those five are only just over the limit, only Nos. 5 and 27 being much out. Many interesting things can be shown by further work on these figures, but for now we shall only refer to one or two. Surveys of Grade 6 conform most closely to our theory, Grade 5 is rather less accurate than we would predict and Grade 3 is very much more accurate.

The last column in the table is the ratio of the actual error to the theoretical error. Those readers who have a leaning towards statistics and who have followed the argument this far are invited to plot the distribution of the results using these figures.

It might be considered that the actual grading could best be given by a percentage error (weighted for circuit and length of leg), but this is not practicable. To do it in any reliable manner would involve obtaining at least half a dozen closures (natural or constructed) and even then there would be a doubt. The most useful way of indicating the accuracy is to specify the instruments used with any pertinent details, and also the full closure figures. Anyone sufficiently interested can derive the information he wants from these figures.

Another point brought out to a certain extent by these figures is at first sight a rather startling one. <u>The accuracy is independent of the difficulty of the passage from the caving point of view</u>. This at first sight is ridiculous - "obviously" the survey of the Primrose Path will be less accurate than the survey of the Beehive Passage. But if we are doing a Grade 5 survey we are reading our compass and clinometer to the nearest 0.5 degree and our tape to the nearest inch - the difficulty does not come into it. Our measurements will be slower and probably more painful, but they will not be less accurate.

Also, we find surprisingly little difference between different surveyors. One of us is rather more accurate than all the others, but only by a small amount. Only in the case of a very careless surveyor would individual accuracy come into the picture, and so far in the Survey Group we have had no careless people wanting to become surveyors.

TABLE 3

No.	Cave	Length ft.	Avge. leg ft.	Grade	% Mis-closure	Theory	Ratio
Surveys of W.C.C. Survey Group							
1	Eastwater	542	13	6	.03	.76	.08
2	"	288	15	6	.41	1.10	.74
3	"	259	11	6	.42	1.07	.78
4	"	110	12	5	2.96	2.96	2.00
5	"	675	18	5	1.49	1.24	2.40
6	"	680	18	5	.92	1.24	1.48
7	"	285	11	4	2.58	5.13	1.00
8	"	118	17	4	3.11	8.66	.72
9	Hilliers	302	13	5	1.78	1.82	1.96
10	Stoke Lane	340	15	5	1.30	1.76	1.48
11	Fernhill	58	10	5	3.44	3.81	1.80
12	Pate Hole	348	29	5.5	1.79	1.79	2.00
13	" "	504	34	5.5	.57	1.47	.78
14	Balch Cave	154	22	6	1.79	1.76	2.04
15	" "	127	21	6	.41	1.94	.42
16	" "	207	23	6	.47	1.50	.62
Other Surveys from Cave Literature							
17	Ease Gill	8335	22	4	.78	.91	1.72
18	" "	1492	17	3	1.62	6.08	.54
19	" "	1270	18	4	.87	2.77	.62
20	" "	748	16	4	3.34	3.29	2.02
21	" "	820	32	3.5	1.22	5.76	.42
22	St. Cuthberts	1308	16	4.5	1.80	1.82	1.98
23	Ogof F.D.	515	18	6 -4	.40	.88	.90
24	" "	1265	17.5	6 -4	.24	.58	.82
25	" "	909	19	4 ?	3.30	3.03	2.18
26	" "	392	24.5	6	.77	1.20	1.28
27	" "	1903	27	6	.89	.54	3.30
28	Nidd Head	257	29	3.5	2.88	10.88	.52

This brings us to the question of downgrading of surveys, a subject on which the writer feels quite strongly. Some surveyors produce a survey using the instrumentation of a certain grade, and then claim a grade lower on their published survey. This is just as misleading as claiming a grade higher, and no surveyor would be likely to do that. The writer has perpetrated this offence, Grade 5 being claimed instead of Grade 6 for much of Eastwater Swallet. So has Ford in St.Cuthberts and Stanton in Swildons. Probably in each case (certainly in my own) this was done in view of a statement in "Cave Survey" - "if the conditions are very adverse, a grade of survey should be claimed lower than ....normal". We have just seen that this "escape clause" is not valid, as the conditions have very little effect on the accuracy. Survey grades should be given according to the list given at the beginning of this article, otherwise the whole point of the C.R.G. grading scheme is lost.

Returning to our mass of figures with the assurance that our theory is a reasonable one, let us now take out certain values from the graphs as being fairly typical of Mendip conditions; say a 200 feet passage of 20 legs representing a rather "difficult" passage, and a 500 feet passage representing a somewhat larger one. The first would be typified by Browne's Passage in Stoke Lane I, and the second by the passage running Eastwards from the Beehive in Lamb Leer.

	3	4	5	6	7
200 ft.	11.5	3.53	1.24	0.74	0.38
500 ft.	6.7	2.50	0.85	0.59	0.30

These figures are the overall standard deviations of the measurements and we may make the predictions mentioned earlier. For example, in a Grade 5 survey of 500 feet of passage in 25 legs, the percentage error will exceed 1.70% only once in twenty times, exceed 2.55% only once in 400 times, etc.

But the most interesting thing about this table is not the actual figures, which are based on a large number of variables, but in the relation between the various grades, and even more striking, the results when an actual survey is plotted on to paper.

Let us take the first passage 25 an actual survey. It is a 200 ft. passage, so in the pages of the Journal one would plot it to a scale of 40 feet to one inch, giving a plan 5 inches long with a fair amount of detail. Taking an error figure of two standard deviations, and taking 0.80 as a multiplying factor to arrive at the plan error (our original figures are for the three-dimensional error), we have:-

	3	4	5	6	7
%	18.4	5.65	1.98	1.18	0.61
inches	0.90	0.28	0.10	0.06	0.03

A drawing of passages with the above errors incorporated is shown in Fig.8 For reasons of space this has been kept to a fairly simple passage with no branches; the detail is sketched in treating all grades as alike. Remember that the error figure of two standard deviations represents a figure that will be exceeded only once in twenty times; more than two-thirds of the time the error will be only half as great, so that we have here drawn a survey rather worse than we would normally get.

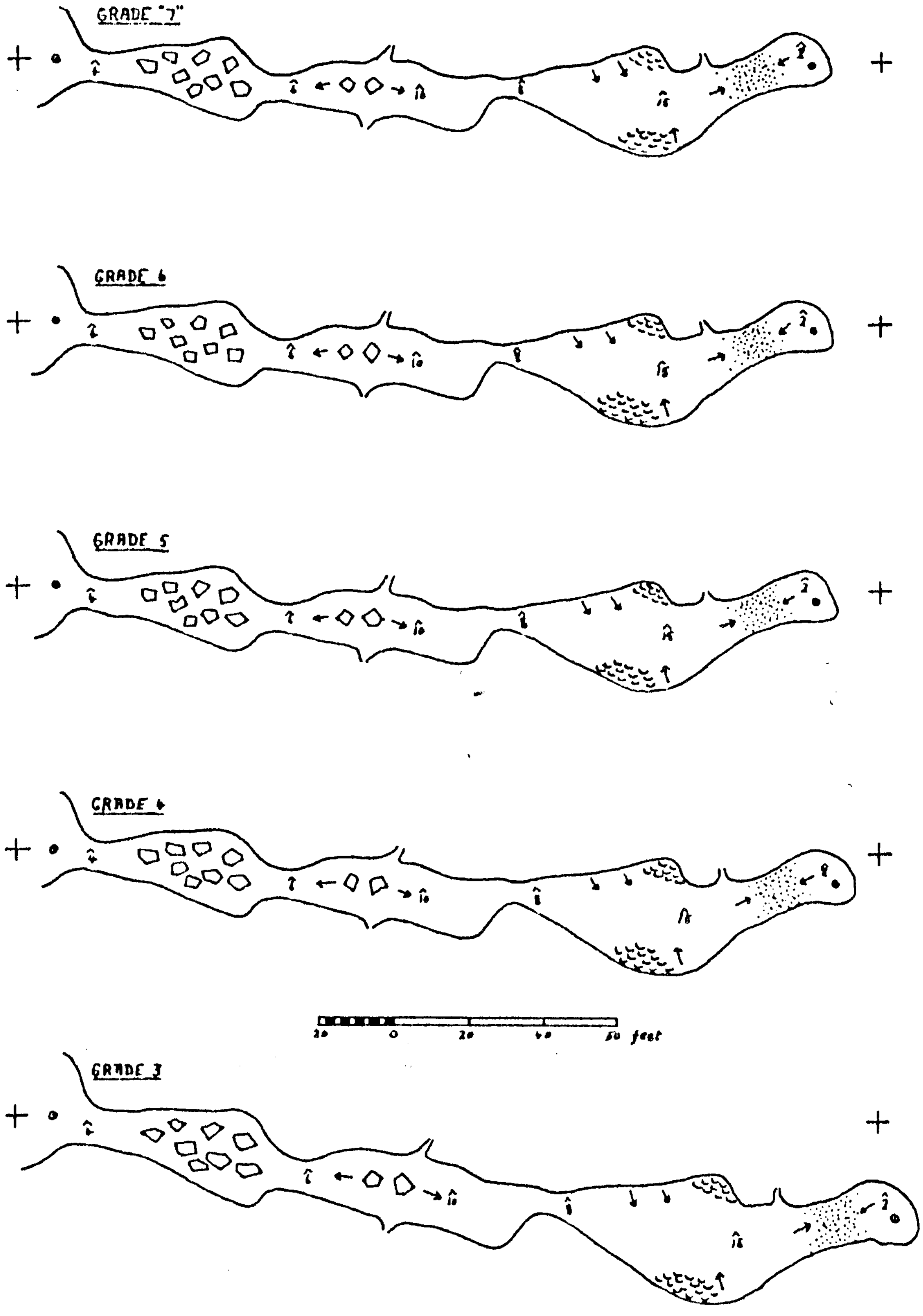
To enable comparisons to be made I have included the intersections of a grid without plotting the lines. From a normal inspection of this plan it will be seen that only Grade 3 shows any appreciable departure from the most accurate plan. Even this is sufficiently close to be quite acceptable for most normal work such as exploring the cave and predicting places to dig. Only if we take a pair of dividers and start measuring carefully do we find the discrepancies, and very few cavers do this.

The second of our passages is 500 feet long, and to get into a page of the Journal would be reproduced at a scale of 80 feet to an inch. The plans have not been drawn here, but it can be seen that similar considerations apply, and in an even more marked degree. This leads us to the rather startling conclusion that as far as the surveys in the Journal are concerned, then a Grade 4 is as good as a Grade 7, and even a Grade 3 is only slightly inferior.

If we consider the same plans drawn out as much larger surveys, as in the case of the full size sheets produced by the Survey Group, a similar situation is found. The plan of the 200 foot passage would probably be drawn to a scale of 20 feet to an inch, or even to 10 feet to an inch if we have collected a lot of detail. Taking the latter case as the most unfavourable one, we have a passage 20 inches long on the plan, with the following errors:-

	3	4	5	6	7
inches	3.6	1.1	0.40	0.24	0.12

FIG 8



In fact, our plans in Fig.8 are scaled up by 4:1. The error on a Grade 4 survey is now more noticeable, but for normal use it is perfectly acceptable. The conclusion here is that for large surveys a Grade 5 is as good as a Grade 7, and a Grade 4 only slightly inferior. A Grade 3 would not normally be produced to this size except in the case of isolated passages in a more accurate survey, and if the scale is anything like 10 feet to an inch even this is not likely.

Another major factor which should be remembered in considering the accuracy of a given grade is the fact that at the extremes there are other factors operating. In the lower grades of 3 &nd 4 we are not working to the limits of our equipment, and many of our measurements will be more accurate than required for the grade. At the other end of the scale the reverse applies. It is relatively easy for a Grade 6 or 7 survey to be lowered in accuracy by one or two doubtful legs. This means that the already small difference between the various grades will be reduced even more.

<u>The main difference between surveys of the same cave to different grades is in the passage detail</u>. We include here things like the exact outline of passages and the shapes of the chambers. This is the argument we have been leading up to in the preceding pages. While an accurate framework is the first thing to consider in a survey, we have seen that we do not need to go to extremes in our quest for line accuracy. Much of the time spent in making measurements to minute fractions of a degree or an inch would often be better spent in increasing the amount of detail and improving the offsets.

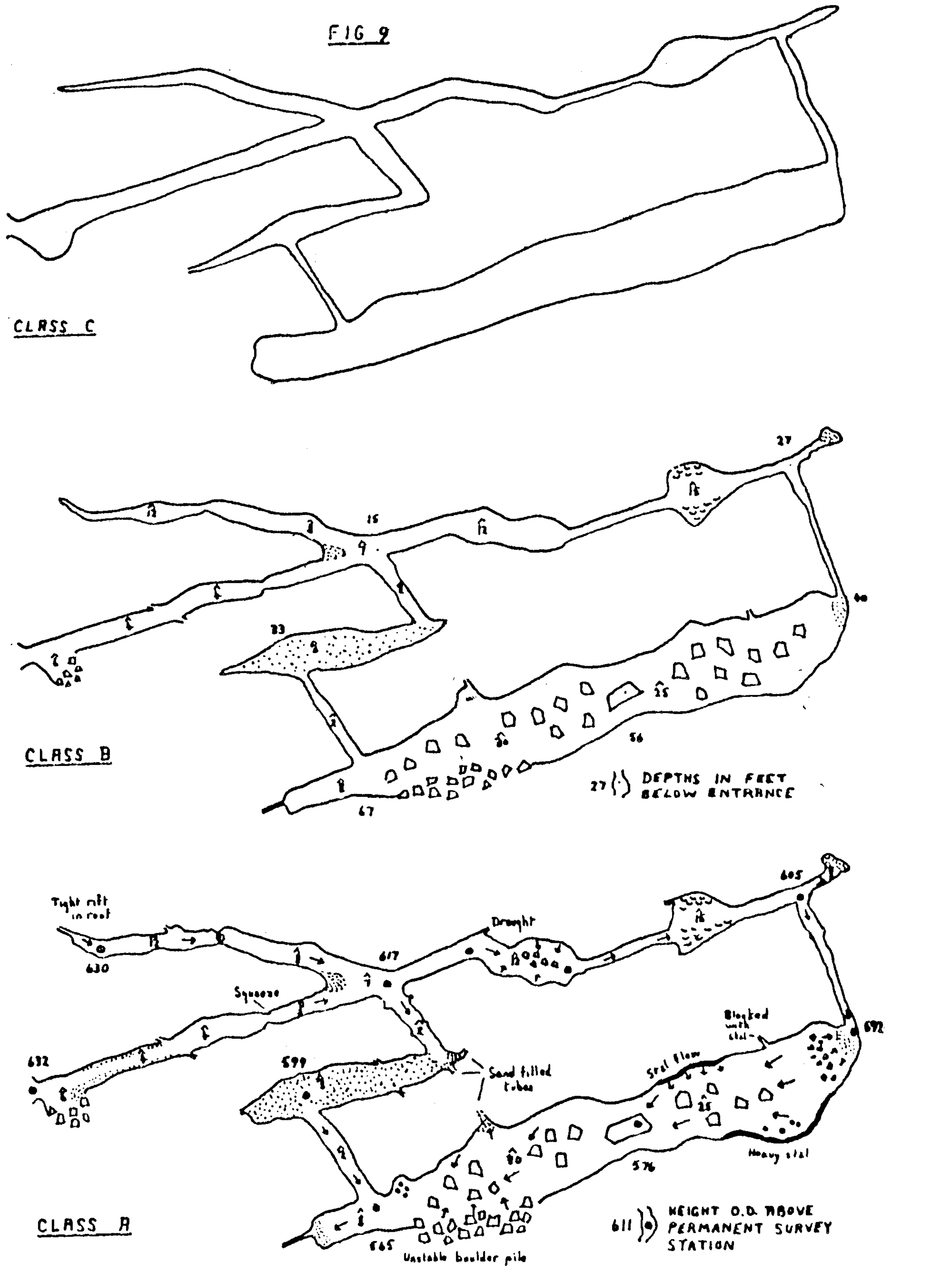
It might seem from the last paragraph that the writer is advocating less accurate surveys, but this is not the case. To fully record the detail of a single section of passage will take far longer than the time needed to read the instruments, and advantage should be taken of this to make the measurements as accurate as possible. But if one is not intending to record any detail, then there is no point in spending the time necessary to make accurate measurements. <u>A simple line survey of Grade 6 or 7 has no more value than a Grade 4 survey</u>.

The Cave Research Group recommend three separate types of plan. Class C, for exploration and organising further work, is based on Grades 1-3; Class B, intended for such work as "the correlation of surface and underground features, study of water levels...." is based on Grades 4 and 5, and Class A, for "research in geology, physics...." based on Grades 6 and 7. Class A demands "the highest possible standards of accuracy and detail".

Let us now consider the surveys that have been made on Mendip since serious exploration began at the turn of the century. Even in the very early days there were sketch surveys of caves such as Eastwater and Wookey Hole, which although diagrammatic, nevertheless fulfilled their purpose. These would now be considered as Class C surveys, as would be nearly all the plans produced before the war. In some cases, notably in the surveys made by Jack Duck, the degree of accuracy and detail was high enough to bring the plans into Class B, but these were the exceptions.

With the upsurge in caving since the war, and following the general recommendations of the C.R.G., virtually all the Mendip Caves have now been surveyed to produce a Class B plan, including a number of resurveys of caves such as Lamb Leer and Eastwater. It would seem that the possibilities of further work in this field are now very limited, but this is not the case. Mendip has very few caves and very many cavers. <u>We should like to see many or all of the larger caves re-surveyed with the intention of producing a Class A plan</u>!

FIG 9


CLASS C
CLASS B
27 (·) DEPTHS IN FEET BELOW ENTRANCE
CLASS A
Tight rift in roof
Draught
Squeeze
Sand filled tubes
Blocked with stal
Stal flow
Heavy stal
Unstable boulder pile
611 (●) HEIGHT O.D. ABOVE PERMANENT SURVEY STATION

This, of course, is not a thing to undertake lightly. A Class B survey of a major cave may take from half a dozen trips for a Lamb Leer to 25 or 30 for an Eastwater. For a Class A survey one could probably double this to arrive at a reasonable estimate. The thought of doing a Grade 6 Class A survey of St.Cuthberts would cause most individual surveyors to seek an excuse to go fishing at Weston, but surveyors nowadays come as teams rather than as individuals. A survey that would be utterly impossible for the lone hand with a motley collection of stooges becomes possible with a good survey team, and becomes practicable with a number of teams working together.

In Fig.9 I have tried to show the basic differences between Class C, B and A surveys. It must be remembered that a Class A survey would always be produced in large sheet form and not in the pages of the Journal. It is impossible to put all the detail one can gather on a full scale sheet with a scale of 10 feet to an inch, let alone on a duplicated quarto sheet. If the recommendations of the C.R.G. are strictly adhered to there should be a certain amount of detail drawn even on the Class C plan, but this is not often done.

An essential point here is the requirements of a Class A survey for detail. It is to be used for "research into geology, physics, etc." The geologists and physicists must tell us what details they want recorded and how accurately. Do they need water temperatures in degrees or tenths of a degree? Do they want the position of joints recorded to within 5 feet, or 1 foot or one inch? Do they want, as additional to the main survey, outline plans marked with easily located fixed survey stations for other workers to add details to their own requirements? Would it be useful to have multiple layer plans printed on tracing paper, in various colours?

This type of question and the answers must be fully discussed to obtain the maximum benefit from what will be a considerable task. We hope to have made the tentative first steps to this aim with the survey of Balch Cave (published October 1962) and we hope for suggestions, advice and constructive criticism from all who are interested in cave surveys. As we have stated earlier, Mendip has a very limited number of caves compared with its caving 'population', and if sufficient enthusiasm could be harnessed to such a project we could well pioneer a new field of cave science.

COMMENTARY ON WARBURTON ARTICLE
by Bob Thrun

Denis Warburton's article deserves to be brought to the attention of American cave surveyors. It is not well-known to cavers in the United States because the Wessex Cave Club Journal does not get much circulation here. It seems to be about as well known in Britain as any club publication could be. I first heard of Denis Warbuton's article in the discussion of survey grades in British caving publications. S. J. Collins [1] relied heavily upon Warburton's paper. Collins said that Warburton's work showed that survey grades were not very useful. Irwin and Stenner, in a paper on survey errors [2], praised Warburton's work and based parts of their own paper on it. Bryan Ellis [3] said "This system [Cave Research Group survey grading] has been shown by Warburton (1963) to be valid in practice and it has been accepted by practically all cave surveyors." It appeared that Warburton's work must be most remarkable. People on opposite sides of an argument regarded his work as authoritative and used it to support their positions. I obtained a copy, saw that it was an excellent article, and later got permission from the Wessex Cave Club to reprint it [4].

Warburton was not the first to discuss survey errors in the caving literature, nor did he provide the definitive paper on statistics. He admits that his treatment is not mathematically rigorous and that he uses terminology loosely. However, the changes that would be made by more rigorous mathematics would not significantly alter his conclusions. He was the first to make a comparison of excpected errors with the closure errors that were gotten in actual cave surveys. His paper is all the more remarkable for having been done in the pre-computer era.

References

1. Collins, S. J., "Grading Must Go", Cave Research Group of Great Britain Newsletter, No. 131, September 1972, pages 27 to 31, reprinted from Belfry Bulletin, No. 297, July 1972

2. Irwin, D. J. and R. D. Stenner, "Accuracy and Closure of Traverses in Cave Surveying", Transactions of the Brithsh Cave Research Asscoiation, Vol. 2, No. 4, pages 151 to 165, December 1975

3. Ellis, Bryan, Cave Surveying, 1976, page 3

4. personal communication, Jim Moon, Chairman, Wessex Cave Club, November 1988

AN EVALUATION OF THE SMARTLEVEL AS A SURVEY INCLINOMETER

by Roger V. Bartholomew NSS 9349

The Smartlevel module is a digital inclinometer designed to be inserted in a slot in a specially made carpenter's level (figure 1). Both the module and level are distributed by Wedge Innovations, 532 Mercury Drive, Sunnyvale, CA 94086, Cost $89.95 + $6.50 post/pack.

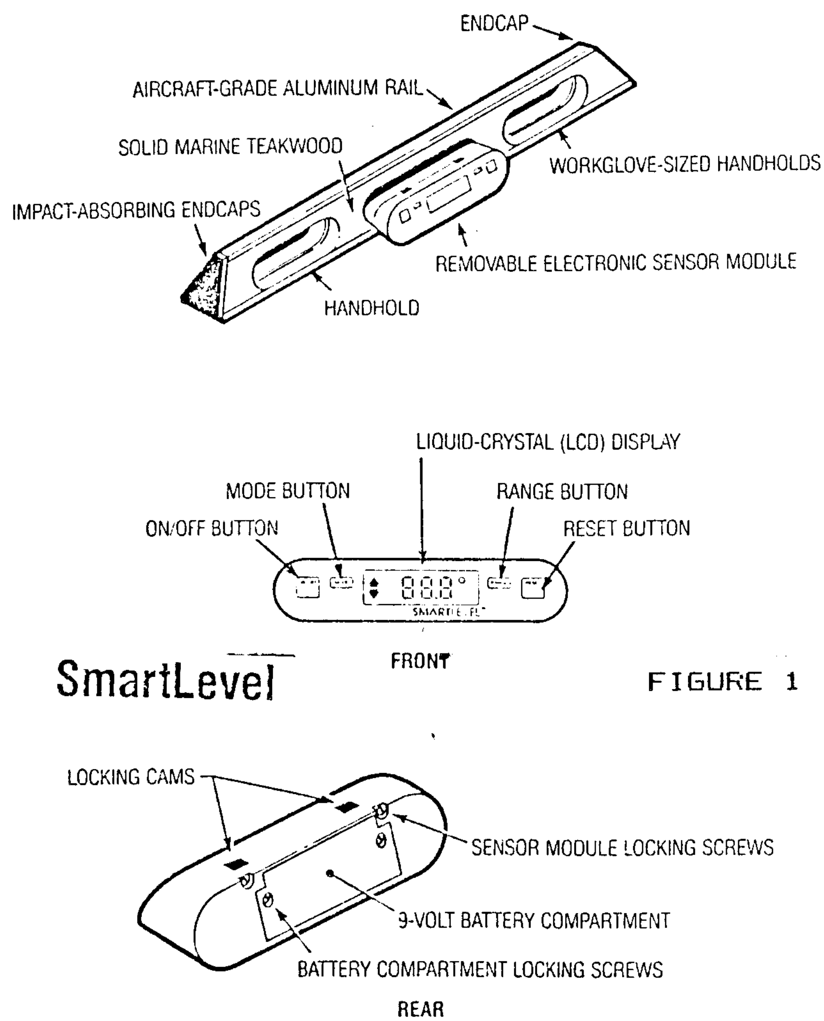


FIGURE 1

The Smartlevel module measures inclination angles from -90.0 to +90.0 degrees to the nearest 0.1 degree. This is the most important feature favorable for its use as a tripod mounted cave survey inclinometer. A large liquid crystal display (LCD) presents readings from 0.0 to 90.0 degrees and up or down arrows on the display indicate whether the angle is positive or negative. The inclination angels can be displayed to the nearest 0.2 or 0.5 degree. This feature is favorable for its use as a hand held cave survey inclinometer. Three other modes allow the inclination to be displayed as: rise over run, percent of slope, or simulated bubble. The rugged solid state sensor and the LCD are sealed inside a weather resistant (not weather proof) polycarbonate module. A 9 volt battery resides in a poorly gasketed compartment in the module. When the module is turned upside down it still measures inclination angles and the LCD automatically flips upside down so the angle can be read right side up!

There are two types of periodic calibration required. "Superset" must be done every 6 months and "Reset" must be done each day. "Reset" is done easily by placing the module on a flat surface which does not have to be level, pressing a button, turning the level around 180 degrees and pressing the button again. If the module is dropped, the "Reset" calibration must be done, and this means that a flat piece of aluminum or plastic must be carried along. The "Reset" calibration can also be done by not turning the module 180 degrees. This will make the slope at which it is inclined read zero degrees. This would be valuable for calibrating a particular sighting device where the sighting line is not parallel to the base of the sensor and where the sighting line can be set level for the calibration.

An investigation was made into the sensitivity of the angle reading to rolling of the module about the survey station to survey station axis. The module was mounted in a device so that it could be held at a fixed inclination angle and then could be rolled about the station to station axis (figure 2). Viewing from the instrument station through the Smartlevel module to the target station a positive (+) roll angle was defined as counterclockwise displayed angles were recorded for roll angles from -15 to +15 degrees for inclination angles of 0.5, 10.1, 57.1, and 85.0 degrees. The graphed data (figure 3, page 23) showed that the angle reading remained constant for roll angles of -5 and +5 degrees. This is very favorable for its use as a hand held or tripod mounted cave survey inclinometer.

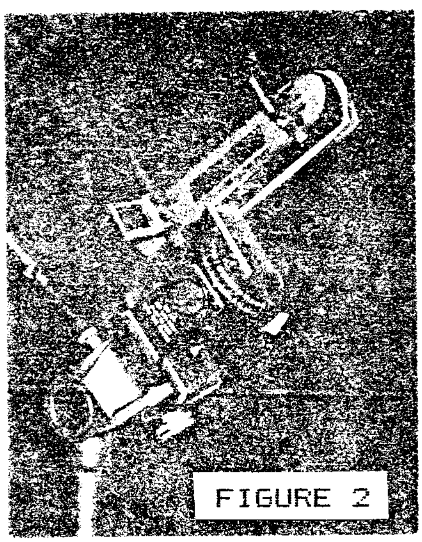


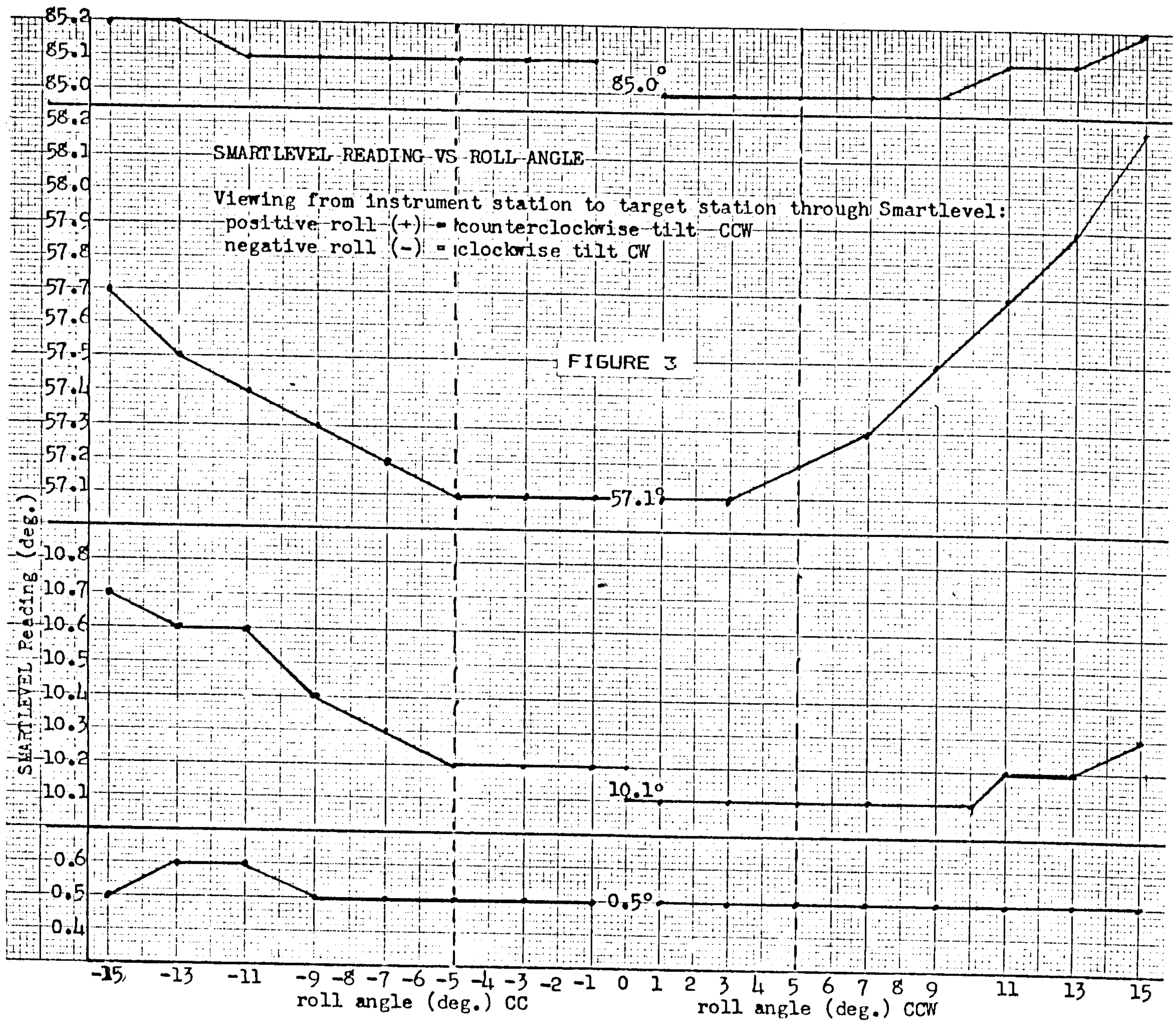
FIGURE 2

The Smartlevel module has no sighting device. Since the display has to be viewed from the side, 90 degrees from the station to station axis, a brunton type sighting device having a hinged mirror with a center line on one end and a hinged slotted pointer on the other end would be the best. With this type of sighting arrangement and because the sensor functions when inverted, this inclinometer can be placed flat against either side of the cave passage wall. There are some ferromagnetic materials inside the module which will effect a Suunto compass when the module is brought closer than six inches to the compass.

There is no sample and hold button so it must be sighted and read at the same time. A manufacturer's representative said in the summer of 1990 that a sample and hold button was under consideration. Another improvement would be to use a light emitted diode (LED) display since the LCD needs to be illuminated by a light.

Tests need to be made of the Smartlevel's sensitivity to cave temperature and humidity. Attaching a sighting device to the module package: oval in one plane and trapezoidal in another in another. Perhaps the sensor and electronics can be removed and mounted together with a sighting device in a cave adapted sealed package. Perhaps a cave adapted box with sighting device can be made into which the whole module can be mounted.

The Smartlevel module has the potential to be a precise and easy to use clinometer for cave surveying.


SMARTLEVEL READING VS ROLL ANGLE
Viewing from instrument station to target station through Smartlevel:
positive roll (+) = counterclockwise tilt CCW
negative roll (-) = clockwise tilt CW
FIGURE 3
85.0°
57.1°
10.1°
0.5°
SMARTLEVEL Reading (deg.)
roll angle (deg.) CC
roll angle (deg.) CCW

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