Cave Technology Symposium 2012

*The BCRA Cave Technology Symposium was held in Priddy, Mendip in June. **Mike Bedford** looks back on the weekend's activities.*

The BCRA's Cave Technology Symposium was launched as a complementary event to the long-standing and highly popular Cave Science Symposium and, to date, has been organised around a similar pattern. This year though, given the essentially practical nature of technology projects, the format was changed to allow for practical sessions. Accordingly, day one gave opportunity for underground demonstrations while the second day followed the previous format of more formal presentations.

The Symposium was held in the village of Priddy in the Mendip are of Somerset over the weekend of 9th/10th June 2012. Here we provide an overview of the weekend's activities and provide summaries of each of the talks. Information on next year's event is also provided.

The Demonstrations

Saturday's activities started with a short walk across the fields from Upper Pitts, the home of the Wessex Cave Club. Our destination was Swildon's Hole where demonstrations of the Nicola 3 cave radio and high-brightness LED lamps for cave photography and video were planned.

Nicola 3

Graham Naylor brought a prototype of the new Nicola 3 cave radio which is currently being evaluated for use by rescue teams both in the UK and elsewhere and which he described in his first talk the following day. The radio was set up on the surface using the innovative capacitively-coupled wire antenna, as described in Graham's second talk on the Sunday. For those who saw the Nicola 3 for the first time, its small dimensions, compared to previous cave radios, left a lasting impression.

Underground, a HeyPhone was used because the second complete Nicola 3 prototype was undergoing trials in France, although a partially-complete (receive-only) Nicola 3 was available in the cave. This arrangement allowed interoperability with the previous generation of rescue radio to be verified while also demonstrating some of the Nicola's new features.

Although the venue didn't permit the new radio to be used at anything approaching its potential range, good communication was achieved between cave and surface. More significantly, given that these aspects are markedly different from those of the HeyPhone, the surface party was able to try out the user interface, comprising a keypad and alphanumeric LCD display.

Underground, a Bluetooth earpiece was used successfully as an alternative to the more familiar hand microphone. Although the current prototype doesn't feature all the planned functionality and further software development is ongoing, the demonstration was more than adequate to allow its potential to be demonstrated. No doubt forthcoming demonstrations of a more complete System Nicola 3 will be eagerly anticipated.

LED Lights

In anticipation of his talk the following day, Footleg took several of the LED lamps that he'd designed for cave photography and video into Swildon's Hole. After providing a quick demonstration of the lamps, to illustrate the fact that they featured narrow, medium or wide-angle LEDs which could be used separately or in combination, those of us who had taken cameras underground were given the opportunity to try them out.

It was immediately apparent that the lights were seriously bright and this impression was confirmed when we started to take photographs. Although a tripod would have been beneficial for photographing large chambers or for competition-grade work, for general purpose use, close-up, the shutter speed was sufficiently short to allow the camera to be hand-held so long as a reasonably high ISO speed (i.e. 400) was selected. On later scrutiny, while a few of the photographs exhibited a degree of blurring due to camera shake, in the main the shots were perfectly sharp. The underground photos accompanying this article were all taken using these lights.

Despite the longer exposures, compared to the use of flash, several benefits of this form of lamp were evident. First, setting up and fine-tuning the lighting was very much easier because the effect is evident before actually taking a photograph. Second, although not demonstrated in Swildon's, the beneficial motion blurring effect exhibited on flowing water was discussed. Indeed, this is a reason that cave photographers have often continued to use old, long-burning flash bulbs in preference to electronic flash. Finally, as demonstrated by Footleg, in addition to still photography, these lamps are also suitable for video use.

The experience of using Footleg's lamps was sufficient to prove their value; indeed I'm now considering building some myself. It's pertinent to point out that the two underground photographs that appear in this article were taken using the LED lamps in preference to flash. Hopefully the results speak for themselves.

Templeton Dig

Following the demonstrations in Swildon's, Jon Riley gave us a conducted tour of the Templeton Dig, another short walk from Upper Pitts. To say that we were impressed would be an understatement; indeed I heard the comment that the weekend would have been worthwhile on the basis of this trip alone.

For those who are unfamiliar with it, the project involves removing the infill from a natural surface shaft. The dig demonstrated the use of technology – primarily but not exclusively mechanical engineering – on a grand scale. Earth is brought to the surface in a tub, guided on rails and hauled by hydraulic-power. An interesting feature is the way in which the tub translates from a vertical to a sloping and ultimately to a horizontal orientation as it emerges from the pitch. CCTV cameras at the bottom of the rail assembly allow the surface operator to control the device safely. Beyond the depth at which it was considered impractical to extend the rails further, an electric winch is used to remove material from the lower part of the dig. Access to the lower parts of the dig is provided by an impressive arrangement of fixed steel ladders and steel grill platforms.

The statistics are impressive. The dig has currently reached a depth of 220 feet (67m) which makes it the deepest surface pitch in the Mendip caving area. The surface depression is about 30m across; reducing to somewhat more modest proportions once the rock is reached.

The Talks

Talks on the Sunday took place in the function room of the Hunter's Lodge Inn. A very full programme of talks demonstrated something of the diversity of work currently being carried out under the tile of 'cave technology'.

Cave Exploration with a Laser Scanner – from GG to Mulu
Kevin Dixon

Kevin started by showing the large amount of kit, typically, that's needed to make a 3D scan of a cave. He then gave a recap on scanner basics before considering the types of scanner on the market, with prices ranging from £15,000 to over £100,000. The general procedure for scanning a large cave chamber was then described, referring to some of his earlier scans for illustration. Generally it's necessary to scan from several stations to obtain partial scans from a range of viewpoints, these individual scans subsequently being stitched together using software.

In looking at his first large-scale scan, that of Gaping Gill main chamber, Kevin described how it had been necessary to scan from 20 stations, over the course of four weekends, generating no less than 12 million points. He also explained how it had been necessary to scan the entrance pitch while suspended by the winch, during which time he had to remain perfectly motionless. This exercise had, for the first time, provided accurate dimensions for the chamber and confirmed that it was, indeed, of equivalent proportions to York Minster, as has often been claimed.

Kevin then moved on to describe his largest scanning exercise to date, of Deer Cave and Sarawak Chamber in the Mulu National Park, Malaysia. Sarawak Chamber, currently the largest known cave chamber at 700m × 400m × 100m high at its tallest, proved particularly challenging, and not only because of the need to transport the equipment through the flooded surface rivers and entrance on a home-made raft. Scanning took three whole days, with the party camping in the cave over the entire period. Subsequently, around 45 days were expended in processing the 13 million points of data. Of the various statistics that came to light as a result of Kevin's scanning exercise, one would have been particularly awe-inspiring the UK-based cavers. It transpires that Sarawak Chamber is 224 times larger than Gaping Gill in terms of volume.

To finish, Kevin gave an update on a couple of other projects. First up was his development of a 'cave endoscope' that he'd developed to check out rifts and cracks. And second was the DistoX all-in-one Digital Compass, Clino and Laser, that had been designed by Beat Heeb. Kevin had built and sold out 100 of the circuit boards necessary to convert a Leica Disto A3 to the DistoX and expected to have another batch of 81 ready very soon.

Introduction to System Nicola Mk. 3
Graham Naylor

Graham spoke about the System Nicola Mk 3 – a fully digital platform for implementing cave radio systems. Following a bottom up re-design of the hardware using a commercially off the shelf (COTS) FPGA board, the radio is now approaching readiness for production. It has been validated in field tests in Yorkshire and the Mendips.

The initial programming has been to implement an SSB transceiver at the Nicola II and the HeyPhone frequencies, though it can easily be adapted to any frequency in the LF-VLF range as well as to adopt any desired modulation scheme.

The FPGA incorporates four embedded soft processors (picoblaze) which are programmed in assembler. These perform independent tasks; house-keeping and wired serial comms, audio rate digital signal processing, Bluetooth handling (pairing etc.) and user interface via touchpad and LCD screen (for text messaging).

The output stage uses a class DE amplifier using MOSFETS in an H-bridge arrangement allowing high efficiency to be achieved enabling high antenna currents while maintaining good battery lifetime.

The received signal from the antenna is sampled with a 14bit ADC running at 512kHz. The audio signal is sent to the speaker in the handset using PWM at high frequency from the FPGA and so providing efficient class D operation of the audio output. Audio can be picked up using a handset (speaker and mic) or via the Bluetooth link to a headset (providing best audio integrity). This link can equally be directed to a mobile phone allowing relaying of the call to a distant party. The FPGA board incorporates a flash memory allowing the storage of audio messages and repeating to extend the range within a cave.

Two more prototype units should be completed this summer and if the final bugs have been ironed out a larger batch will be produced towards the end of the year.

A New Approach to Wire Antennas
Graham Naylor

Graham presented some results of antenna coupling, building on David Gibson's conclusion from the previous year that the transmitted signal is proportional to the antenna current. The System Nicola Mk 3 uses capacitive coupling to direct the current into the ground. By cancelling the capacitive component with a series inductor, the antenna impedance can be minimised (leaving the ground resistance) and so maximising the antenna current.

He showed some plots of how the antenna capacitance and impedance at resonance varied with wire length and height of the wire above the ground. Generally, the higher the antenna capacitance, the lower the achievable antenna impedance and the higher the antenna current. In this way antenna currents can be achieved which are typically about twice those of a conventionally earthed antenna arrangement (as used by the HeyPhone and Nicola Mk II).

The further advantage of this scheme is that good ground coupling can be achieved even on scree slopes on the surface or boulder filled or dry passage underground. Capacitive coupling can be achieved either with two wires insulated from the ground or one wire insulated from the ground and the other connected to ground conventionally using electric fence tape or a ground stake. The resonant load impedance of this antenna allows the square wave voltage output from the H-bridge to be transformed into a clean sinusoidal current in the ground, thus reducing dramatically the emission on harmonics.

Developments in Rope Testing
Bob Mehew

Bob started by describing the rope test rig and then presented some force time outputs from the load cell instrument which he and his co-workers had been developing. He presented an interpretation of the features in these outputs back up by some high speed camera work and some theoretical work. Their hypothesis is that the knot slips when the force being applied by the active end of the rope reaches a certain value equivalent to the friction between rope strands within the knot and then sticks until the new frictional value is exceeded.

Bob then went onto describe their calculations to compute the energy time behaviour of the rope. Since some results indicated the system created energy, a theoretical investigation was conducted using a simple model. Various features predicted by the model were confirmed by observations and lead to the need to develop a system for measuring rope extension. The results from two developed systems had shown that reasonably accurate distances can be calculated when compared to measured values and hence sensible energy data.

Bob noted that the aim of the work was to model the destructive drop test so as to identify potential parameters which could then be measured using a non destructive test. Whilst they had been developing the instrumentation they had looked at a few parameters including different types of knots. The result from albeit a single set of samples using figure of nine, figure of eight and overhand knots to create the end loops indicated that the overhand knot was less strong than the other knots.

They had also looked at the effect of extending the overall length of the rope sample and found that whilst a sample of only 0.41m length survived ten drops, a 1.0m sample only survived two drops and a 1.5m sample only survived one drop. Bob noted that the standard required a new rope sample of 2.0m length to survive 5 drops. He made the point that it is energy which is important in this work and that the fall factor concept at short lengths of rope is misleading. Lastly they had looked at a more complex model but had found poor agreement between prediction and experimental work.

Bob concluded his talk by noting there was a wide range of areas to investigate including the influence of the knot, other models and different knots, ropes and anchor systems.

Finally Bob acknowledged the support of the Bradford Pothole Club in allowing free access to the rig and the support of his co-workers, Roy Rodgers, Steve Richards and Alan Latchford.

Higher Frequency Cave Radio – What and Why
Rob Gill

Rob's talk, presented by Mike Bedford as Rob was abroad, considered the use of frequencies higher than customarily used for cave radio. It is recognised that higher frequencies are more severely attenuated as they pass through rock, hence the use of low frequencies such as 87kHz for cave radios such as the HeyPhone.

The talk centred on some recent experiments at KMC Valley Entrance in the Yorkshire Dales to explore the practicality and techniques of using much higher frequencies. This was very much a 'suck it and see' exercise to determine whether it was worth pursuing this line of experimentation and whether some promising results reported from the US over a number of years could be reproduced under UK caving conditions.

As these were preliminary tests, conventional amateur radio equipment was used as this was able to operate across the HF and VHF bands.

However this equipment was neither sufficiently cave proof or cheap enough to risk on a regular basis. It was acknowledged that if initial results were encouraging, then dedicated, rugged – and potentially sacrificial – equipment would be built to support further experiments.

Rob described a number of antenna ideas that were tried, with dipole antennas resting on the surface or suspended on short canes about a metre above the surface. An electrically short dipole with earthed ends (similar to the HeyPhone antenna) was also tried though results were not convincing. The antenna options underground were limited, particularly at HF where even a short whip antenna was difficult to use without it scraping on the passage wall.

Overall, results were encouraging. Two-way SSB speech transmission was possible at 3.5MHz and 7MHz over a distance of nearly 200m and frequencies as high as 50MHz and 145MHz at over 100m. Of course, this doesn't mean the use of low frequencies was redundant and the reasons for using them for cave radio systems remained unchallenged. Rob explained that the HF bands were crowded and the only readily available frequency allocations for speech transmission required an amateur radio licence – there was also the ever-present possibility of distant radio amateurs causing interference or hearing the surface station and trying to establish contact! However, there were some potential applications where higher frequencies would be an advantage, such as through-the-rock GPS-style navigation systems and wide bandwidth data transmission. In any event, it was good to simply understand what was practically possible, even if no immediate application was obvious. Experiments will continue.

LED Lights for Cave Photography and Video
Footleg

As a follow-on to the presentation made at the 2010 Cave Technology Symposium, Footleg's talk concerned his latest developments in the field of LED lamps for video and photography. To allow for comparisons to be made, Footleg started by providing a reminder of his earlier design based on the SSC P7 and showed examples of photographs taken using this lamp. Before progressing to the look at his new design, the pros and cons of LED lighting compared to flash were summarised. On the positive side, it's possible to preview the lighting effect before taking a photograph, autofocus can operate, and wide angle illumination is achievable. The fact that a longer exposure is required was a mixed blessing. While it may require that a tripod is used and that subjects remain still, the blur of moving water can be beneficial and it also provides a means of 'light painting' a scene.

Footleg then proceeded to describe his two new designs, one of which uses a pair of Cree XM-Ls and the other six Cree XP-Gs. The XM-L lamp features wide-angle optics while the XP-G lamp employs wide-angle optics for two of the LEDs, intermediate-angle optics for another two and narrow-angle optics for the third pair. Switches allow the three angles of illumination to be used independently or in any combination. For each lamp Footleg discussed the constant current driver, heatsink and battery choices (NiMH for the X-ML and Li-ion for the XP-G).

Attention then turned to several quite detailed comparisons. Footleg provided efficiency comparisons of the P7, XM-L and XP-G LEDs in isolation, of various drivers / battery combinations, and of the complete lamps. Of perhaps more importance to the photographer, Footleg concluded by presenting comparisons for the complete lamps, of relative brightness, the exposure times required at a given ISO speed and aperture and of the ISO speed required to achieve a specified exposure time and aperture. A particularly impressive figure is that the XP-G lamp with all six LEDs running was 65 times brighter than the earlier P7-based lamp.

A Review of Current Cave Surveying Software
Footleg

Footleg gave a talk on the current state of software for processing cave survey data, and drawing up cave surveys. Starting with the data processing, Footleg demonstrated how survey data is entered and processed using the Survex software package. Starting with a simple file and expanding on this to show how data for larger cave systems is handled, we saw how a 3D model of the cave system could be produced. Footleg demonstrated how the software distributed errors due to loop closures throughout the cave network, and reported statistics on the level of error, length of survey data and depth of cave. Features covered included compensating for magnetic declination changes over time, data from diving surveys and fixing entrances to position multiple caves on the same grid coordinates so that they all appear in the correct positions relative to each other in the 3D model.

Next we were given an overview of two software applications for producing final survey drawings suitable for publication. Tunnel, developed by UK caver Julian Todd presents a drawing interface where you build up your entire survey in one large drawing. Therion, developed by a pair of Slovakian cavers uses a different approach where drawings are built from smaller scraps representing parts of the cave. You have to compile a Therion project to pull all the scraps together and see how the complete survey will look. Both these applications share one key feature which differentiates them from standard vector drawing programs. They can adjust drawings automatically when the cave survey data changes due to a new loop closure or correction of an error. This saves countless hours of redrawing when a cave centreline changes position as often happens when new loops are made, or new entrances linked into to existing passages.

The drawing interface of Tunnel is more visual than Therion, with different line types and symbols appearing in the sketching interface looking similar to how they will appear in the final rendered drawing. The cave centreline is imported into Tunnel from the Survex format data files, and you sketch around this centreline, attaching the walls to the survey stations in the drawing. Therion has a much cruder drawing interface where all line types appear the same until you render the final survey, and all symbols and other points appearing as identical blue dots. But because you are working on small scraps one at a time this is not too unmanageable. The learning curve is a bit steeper for Therion than for Tunnel, but the program supports more features. Therion allows the creation of plans, extended elevations and sections. Multiple different maps can be put together from different scraps, allowing one set of drawings to be used to generate a main survey with enlarged detail sub surveys of key parts of the system. Tunnel currently only supports creating plan sketches. Elevation support is not yet implemented. The final output from both programs is of equally high quality.

Using Tunnel, when you need to distort the sketch onto a new centreline then this operation is done by importing the old drawing into a new drawing based on the new centreline. In Therion the survey stations are marked in the drawing scraps, and adjustments to distort the sketches in these scraps are done when you compile the project to produce the final rendered survey. For smaller projects or when data is not being updated constantly then the Tunnel approach of allowing you to work on the entire drawing at once and having to regenerate the drawing onto new data as a specific step works well. But if new survey data is regularly being added to a project then having to regularly perform this regeneration of the drawing onto a new centreline becomes a hassle. If a cave becomes very complex then making sense of the entire drawing with many overlaying passages can be difficult when drawing. Therion handles both these scenarios much better because you are only ever adding new scraps to the main project as new survey data is added. Scraps cannot contain overlapping passages so it is always clear what you are drawing in the drawing interface even for very complex caves. So for large on-going projects Therion works very well. But it takes more effort to learn the basics than Tunnel, and can appear very complicated for larger caves.

Finally Therion comes with its own 3D model viewer (called Loch), which can display both Survex generated and Therion generated models. The Therion models can include 3D landscape overlays of the surface overlying the cave, and have surface maps or photographs overlaid on the semi-transparent surface. You cannot measure distances directly from the Therion model viewer, but Therion can output Survex model files for viewing in the Aven viewer which comes with Survex. This viewer allows you to highlight named series in the cave, and measure distances between stations. To get the best of everything you can use all these tools in conjunction with one another, and as all three are available free of charge as open source software there is no reason not to take a look at all three of them.

Taking Cave Rescue Telephones Forward
Stuart France

Stuart France gave an update on this project which began in 2009. There are orders for a mix of 40 handsets and base stations from various cave rescue teams. All the parts have bought including some now obsolete chips (MAX761EPA+). This leaves 10 blank PCBs available if anyone else is interested in building some. There has been a delay and the need to change the hardware and the software due to CROs requesting external 12 volt power for the base stations rather than internal 'D' cells which would have provided a shelf life of 5 years and an operational life of 2 weeks – more than enough for any cave rescue scenario. Stuart showed the final circuit boards populated and wired up, ready to go except for the boxes and the new base station software. Brian Jopling (SMWCRT) has kindly volunteered to machine all 40 diecast boxes, but the soldering of the remaining PCBs will need to be contracted out because Stuart lacks the time to make so many himself.

A short demonstration of the prototypes was given in the field outside the Hunters in the rain, and observers commented favourably on the clarity of the sound using telephones compared to cave radios, which is a feature that CROs liked too.

Making and Using Caver Counters
Stuart France

Stuart France showed various methods for detecting cavers; cap lamp lights, break beams, body heat, buried pressure pads. Of these, the light detector is his usual method. Directional body heat detection had proved hard to achieve well in damp, cold environments.

Photos of a micro-power break beam sensor with the optics drilled into stone blocks at the sides of a cave passage were shown - this is at the prototype stage but encouraging as it holds promise for counting individuals accurately rather than the 'group counter' approach using light detection and a 20-second retriggerable timer front-ending the data logger to provide some signal conditioning. Buried pads have not been tried as they would need a particular type of floor (sandy or sediment layers) and fitting them would obviously mean disturbing those sediments.

Stuart went on to show his data analysis tools which provide new views on the underlying hourly total data. For example, it is easy to create time of day or day of week profiles over long periods of time for the purpose of revealing the relative use of caves by weekend sport cavers versus professionally led groups that tend to come mid-week during office hours.

Some actual results were then presented comparing usage at Eglwys Faen and Ogof Clogwyn spanning many years past, and Ogof Draenen in recent years.

Why Earth Resistivity Surveying Doesn't Work
Mike Bedford

Mike's presentation concerned the geophysical technique of earth resistivity surveying which has been used by cavers in an attempt to find new caves non-invasively (i.e. without digging). He introduced the subject by showing positive results of earth resistivity surveys over a couple of known caves. This seemed at odds with his title which he proceeded to explain by suggesting that the technique is good at confirming the existence of known caves but not at finding new caves. Furthermore, he defined finding a new cave in a way that required the discovery to be confirmed by cavers gaining access. Correspondence with Bill Buxton and Neil Weymouth – two cavers with significant experience of the technique – was presented. Both confirmed that they had 'found' existing caves but not any significant new passage. Mike said that he hadn't found any evidence of cavers using earth resistivity to find new caves. While the title of the presentation sounds particularly negative, Mike said that his aim was positive. The talk discussed several reasons for the failure of Earth resistivity surveying and suggested methods of improvement. By addressing these issues, it was hoped that a higher level of success could be achieved in the future.

This summary didn't discuss each point in detail because an article on this topic was published in the previous issue of the CREG Journal (Bedford, 2012). Briefly, though, Mike presented a statistical analysis suggesting how improbable it is to find new caves without some prior knowledge. More positively he suggested that modelling software should be used extensively, before starting a surveying exercise, to check whether a cave of the expected dimensions and of the probable depth, would be detectable given the conductivity of the local limestone and the thickness and conductivity of any overburden. He also emphasised the importance of correctly estimating or measuring errors. Without this information, the software process of inversion could over-fit the data with the result that non-physical artefacts could be shown, some of which could have the appearance of sub-surface cavities. He also discussed that fact that not all high resistivity features are caves and the fact that finding a void isn't the same as finding a way into that void.

Mike concluded by presenting a tantalising example of a cave that had, apparently, been discovered by earth resistivity surveying. However, rather than disproving his earlier assertion, this example wasn't quite all it first appeared.

Thanks

Thanks are due to Rob Gill and Allan Richardson who were involved with me in the organisation, and to Les Williams who provided technical support. Thanks also to Roger Dors, licensee of the Hunter's Lodge Inn, who made a room freely available for Sunday's talks. Most importantly, I'd like to thanks those who made demonstrations and gave talks, and to those who made the Symposium a success by their attendance.

Next Year

The BCRA 2013 Cave Technology Symposium will be held over the weekend of 20th/21st April in South Wales. Talks will be held on the Saturday at Tretower Village Hall, Tretower, Powys, NP8 1RF. Registration will start at 09:00 and talks will run from 09:30 to 17:00 with a break for lunch. Practical sessions will take place on the Sunday from Whitewalls, NP8 1LG. Please be changed and read to leave on foot at 10:00. Entry is free to BCRA members and speakers, otherwise there's a charge of £5 which include tea and coffee on the Saturday.

Accommodation, which must be pre-booked, has been reserved at Whitewalls (Chelsea Speleological Society) for the Friday and Saturday night. Contact Stuart France on 01495 321569 (daytime), 01874 730527 (evenings) or 07740 871845.

Talks, posters and demonstrations are sought on any area of cave technology including, but not limited to, surveying, data logging, communication, digging, cave detection, photography, lighting and explosives. To offer a talk or for any other enquiries contact **tech-sym@bcra.org.uk**.

References

Bedford, Mike (2012) *Why Earth Resistivity Surveying Doesn't Work*, CREGJ **78**, June 2012, pp. 6-9.

Continued on page 24 with a photo-gallery of Saturday's demonstrations

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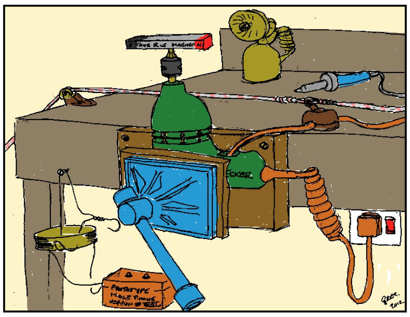
Clockwise from top-left: 1. and 2. Templeton Dig, 3. Footleg's LED-based lamp for photography and video, 4. and 5. Nicola Mk 3 on the surface, 6. HeyPhone in Swildon's Hole communicating with the Nicola radio.

THE ADVENTURES OF GREG

Illustration: Adrian Higgins
Words: Mike Bedford

1. Greg was sure he'd read something about a rotating bar magnet generating an induction field. Initial tests suggested he might be onto a winner. His prototype cave radio was small, light and rugged and hadn't involved any of that tiresome electronic design.

Arithmetic wasn't one of Greg's strengths. But after poring over his calculations all afternoon, Greg saw the error of his ways. For compatibility with the HeyPhone the magnet would need to spin substantially faster but what's a decimal position or three between friends? And on a positive note, that 87Hz signal would have some serious ground-penetrating potential.



2. The other miscalculation in this sorry episode concerned the size of the magnet. Just let's say that Greg's receivers are rarely the most sensitive known to man, and that's putting it mildly. This wasn't the first time that Greg had to fine tune a design, though, and it most certainly wouldn't be the last.

But why, he wondered, were his mates so reluctant to come anywhere close to his new and improved cave radio? Never had Greg seen a party descent a pitch so quickly.