can.

We have above identified two principal distortions in rock art photography: that which occurs in the production of a photographic record, and that which occurs subsequently, during the archival storage of the record. Most of the many processes involved would affect each colour or dye uniformly, including that in the image of a colour scale on the photograph. The principle of colour calibration and re-constitution involves the following basic steps:

a. Translate the photographic record (print, negative, slide, film, video) into digital information. This record must include an image of the calibration reference device (i.e. the colour scale) which has been photographed together with the rock art subject.
b. Instruct the computer to recall the true digital colour information contained in the reference device and compare it with that found on the photographed colour chips as they appear now. The computer determines overall distortion irrespective of source.
c. The computer then compensates for the distortion measured in each primary colour, re-constituting colours as required to re-create the known true colours in the photographed colour scale.
d. By extending the same corrections to the rest of the image and assuming that distortion was uniform over the entire image surface, the original subject colours are re-constituted by the same process.
e. The corrected image is then out-put to the required format (separations, colour printer, electronic storage).

At the time of writing we have conducted twelve case studies of colour re-constitution of rock art imagery, and we emphasise that this project is far from complete. The main purpose of this paper, apart from explaining the rationale of the work and presenting preliminary results, is to ensure the earliest possible dissemination of detailed recording recommendations guaranteeing the best-possible conditions for future colour re-constitution. Many thousands of IFRAO Standard Scales have now been distributed world-wide, one year after the first edition of the Scale was printed, and have hopefully been received by up to 6000 rock art researchers. However, in order to use the Scale most effectively it was necessary and urgent to conduct a pilot program that could determine optimum conditions of the Scale's use in the field. We have succeeded in digital colour re-constitution since December 1994, and we are working on perfecting the procedures with the intention of creating customised software. At the present time, all calibration is still done manually, but a considerable simplification of the process is possible through programming its repetitive aspects so that the operator merely has to supervise the procedure after downloading the raw data. Once the appropriate software has been written, the calibration process itself can largely be computer generated, with the operator only having to select sites for reference device spot checks for white, black, red, green and yellow. After calibration, the photographic image of the blue chip is checked to confirm accuracy, and if there is a minor discrepancy, it can be compensated for manually or automatically. This envisaged procedure is simple and efficient, which will be necessary in future calibration of large numbers of images held in archives. To render the proposed technology fully effective, massive numbers of images will need to be processed, and it would not be realistic to expect operators to spend a great deal of time manipulating imagery by review and manual adjustment — nor would such a manual process be remotely as precise as the purely digital (mathematical) manipulation of the colour properties (because it would rely on various subjective factors). Hence it is the ultimate aim of this project to create software that takes care of the repetitive calibration. But at the same time it should also be compatible to other programs the rock art specialist of future decades is likely to use. For instance, the calibrated and digitised image would be ideally suited for colour enhancement treatment (Rip 1989), which would assist research enormously in securing information about rock art that cannot be obtained by other means. This type of procedural extension is a quite modest development in terms of software requirements and should be envisaged to become available comparatively soon. Other possibilities of further applications exist also, and it is obviously important that future developments in the area of rock art imagery manipulation take into account all possibilities of this kind. For instance, integrated programs about rock art could include a comprehensive bibliography organised as per the keyword system being introduced by the Centro Studi e Museo d'Arte Preistorica in Pinerolo, Italy (Seglie 1991).

We emphasise that there is no a priori reason why the IFRAO Standard Scale should have to be used as the preferred device profile in a rock art colour management system. Any agreed colour standard could be used, provided it includes suitably sized and spaced (i.e. spaced within the colour solid) spot colour chips. Some popular colour charts, however, are not well suited. For example the Munsell Soil Color Charts bear only a small range of colours on each page, representing only one hue designation, so to use it effectively one would have to include two or three charts on the photograph. Also, there are numerous colour chips per page, so they are individually small relative to page size. As we will see below, the area of the calibration chips available on the photograph is an important consideration in colour accuracy. Finally, the Munsell charts are very expensive, and the prospect of supplying many thousands of them to researchers in developing countries would be financially daunting. Other expensive colour standards have also been used by rock art students, notably the Kodak Color Separation Guide and the Letraset Pantone colour charts.

Universal availability was one of the many motivating considerations in producing the IFRAO Standard Scale, which is being supplied free to all specialists of the world. Another is that the digitised systems being produced now and in the future should not be expected to have to convert calibration values for any number of standards, simply because we have not been able to agree on a uniform standard. The digital calibration procedure is entirely based on the colour values of the IFRAO Standard Scale. These are given in Table 2. The monochrome scale chips are of the following reflection densities: 0.0 (white), 0.70, 1.60 and 2.0 (black). Their values were chosen to comply with the Kodak Three-Aim Point Control methods for reproducing colour reflection copy with traditional masking and colour separation procedures. The first three represent average highlight, middle tone and shadow values in colour or black-and-white reflection copy.

Colour	YCC (CMY)	RGB	CMYK	HSB	L*a*b*
Red	0, 10, 10	214, 0, 39	0, 100, 100, 0	349°, 100, 84	47, 75, 49
Yellow	0, 0, 10	255, 215, 0	0, 0, 100, 0	51°, 100, 100	94, -14, 100
Green	10, 0, 10	0, 134, 73	100, 0, 100, 0	153°, 100, 53	55, -79, 36
Blue	8.8, 10, 0.2	50, 0, 90	89, 100, 2, 0	274°, 100, 35	22, 49, -45

***Table 2.** The digital colour values of the IFRAO Standard Scale in YCC colour space, and for RGB, CMYK, HSB and CIE L*a*b* spaces.*

Colour re-constitution of rock art imagery was first attempted in December 1994, in the well-equipped computer centre of the Indira Gandhi National Museum of Man in Bhopal, India. In the first trials, four photographs of cupules and rock paintings of the Bhimbetka rock art complex were used (Figure 3). These attempts succeeded at once and we conducted numerous experiments subsequently (Bednarik 1994b) in an effort to determine optimum conditions for the field use of the Scale. During these trials we considered also the question of calibrating photographs taken before the introduction of the Scale and we found that limited re-constitution is possible if there is only a black-and-white scale present. In good-quality slides in which no direct light from a flash or strobe is reflected by such a scale, colour calibration of 70 - 80 per cent may be possible. This is because pure white areas, which should be of 0.0 - 0.05 reflection density, may bear discolouration. Similarly, the black chips are usually not quite black in the image, and we know that their reflection density should be 1.95 - 2.0. By compensating for both these known distortions the image can be considerably improved. Naturally this applies only to scales with pure white and black markings, not to wooden rulers and other assorted devices, the true colour of which is not readily available.

We have found that, in some circumstances, even photographs lacking any scale may be improved by our procedures. They may bear natural white, black or coloured patches of known values, especially areas of shadows in the case of pictures taken with artificial lighting. Deep shadows provide an excellent reference point for black. Alternatively, common objects of known colours may appear on a photograph, and may assist the operator in securing limited calibration. Such reference points may include white accretionary deposits, charcoal, chalk marks, site management signs, freshly damaged or broken rock, one's own hand, a note book or some other object fortuitously appearing in the picture. They may even be provided by field recordings of Munsell colour designations of pigment or of rock varnish or other patination where these are available and can be relocated on a photograph. The result of such limited calibration would be of debatable absolute colour fidelity, but it is certainly a considerable relative improvement.

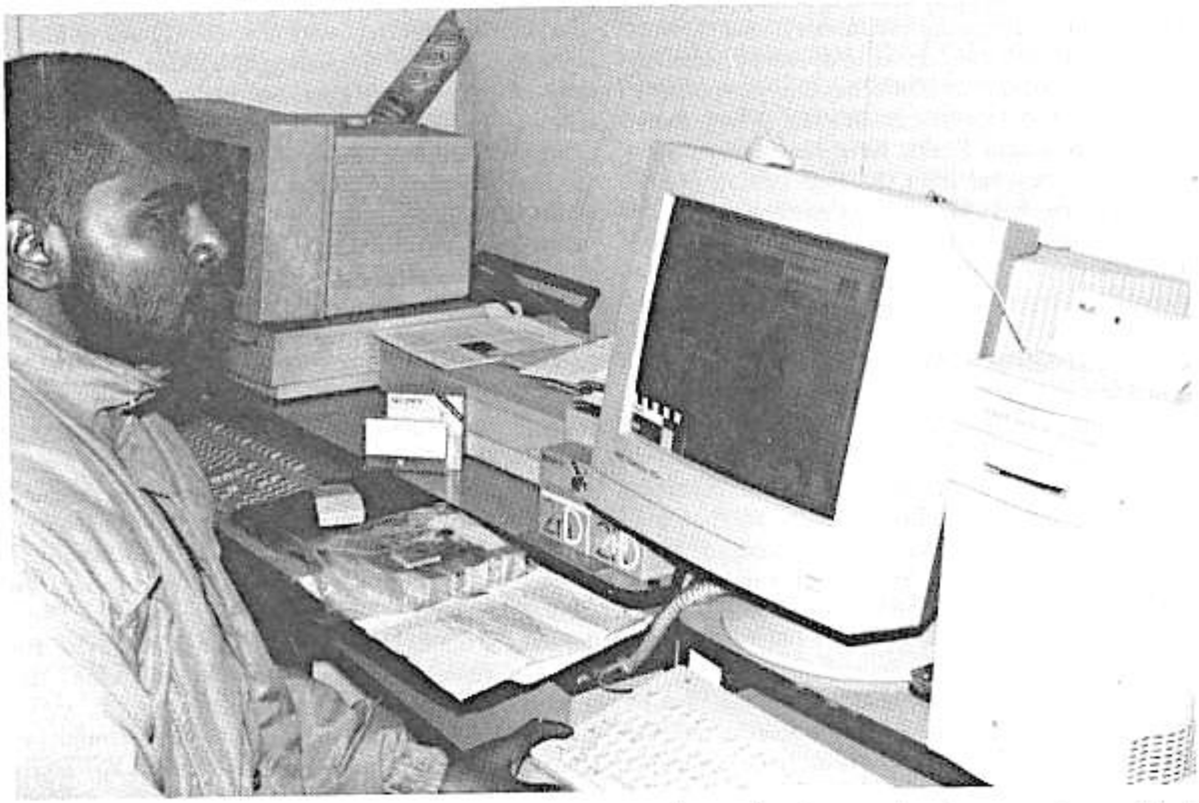

***Figure 3.** K. Seshadri engaged in the first attempt to re-constitute colour in a rock art image, using a slide of a Palaeolithic cupule in Auditorium Cave, Bhimbetka; 8 December 1994, computer centre of the National Museum of Man in India.*

Nevertheless, such alternative applications of this methodology are of only limited value, and they involve an inordinate amount of operator effort. They can justifiably be used for photographic recordings of rock art that has since vanished, but it would not be reasonable to apply them to post-1994 photographs in which the inclusion of scales was neglected. In effect one may say that, in rock art colour re-constitution and in the establishment of permanent archives, 1994 was the year zero. As from now it is inappropriate to create archival rock art records without using a colour calibration device profile that is backed by proven computer applications. In fact it is now imprudent, and inconsiderate to future researchers, to take any photographs of rock art without a colour scale, irrespective of the purpose of the photograph as perceived at the time it is taken.

Optimum recording conditions

The principal objective of the present paper is to provide clear recommendations for the use of the IFRAO Standard Scale. The guidelines initially issued with the Scale were limited to aspects of rock art conservation and to prolonging the life span of the Scale itself: to avoid placing the Scale near the rock art, and to store it in a dark, dry and cool place (Bednarik 1994a). However, it was also recommended that the Scale be so positioned that it would appear near a margin of the photograph, and that *it must receive the same photographic exposure as the rock art motif.* It would have been premature to provide further guidelines for field use at the time, but it was clear that they should be made available before extensive use of the Scale began. The optimum conditions for the use of this new research tool of colour re-constitution have now been determined and they are summarised below.

1. *Recording medium:* The colour calibration input should preferably be as **slides** (transparencies) or colour **negatives**. This is because the scanning process presently required for paper prints is inferior to the digitisation directly from film, and colour transmission from photographs to CRT does not produce precise results.
2. *Lighting:* **Natural lighting** is clearly superior to artificial light, which means that increased exposure times are preferable to the use of flash or other artificial lighting. Where necessary and possible, use a sunlight reflector. Avoid direct lighting in dark locations, and when using artificial lighting, use white light, not yellow halogen light.
3. *Direction:* Where artificial light is necessary, and especially for three-dimensional subjects (petroglyphs, cupules), the light source should be from the **upper left**, and the Scale should also be on the left upper corner of the frame.
4. *Area:* Full 100 per cent calibration, which would result in a colour re-constitution adequate for rigorous technical and scientific purposes, requires that at least **5-10 per cent** of the photograph's area should be occupied by the Scale. With standard lenses this might correspond to a distance of about 0.5 to 0.8 metre. There is a gradual but initially negligible loss in reliability as the image area occupied by the Scale decreases with distance.
5. *Distance:* One Scale suffices for distances of up to 1.5 metres. If uneven lighting is unavoidable, place the Scale in the better lit section. For distances between 1.5 and 4.5 metres, two scales must be used for optimal results: place one of them anywhere suitable, but the second one always vertically and in the upper left corner of the frame. Beyond a distance of 4.5 metres, the Scale is too small to permit a calibration level approaching 100 per cent, because at that distance the colour chips become too small to obtain precise digital readings from (i.e. using lenses of standard focal length).
6. *Alignment:* Care must be taken to position the Scale so that it is **parallel** to the predominant plane of the rock art motif, and about the same distance from the camera lens. Misalignment will reduce the reliability of colour calibration.
7. *Reflection:* The Scale has been printed on matt stock, but this does not eliminate reflection entirely. If a camera-mounted flash is used, the scale must not be at right angle to the camera's focal axis, and if the subject is side-lit, the Scale should be perpendicular to the focal axis (Figure 4).

Special attention should be given to the last two points which refer to the factors most likely to result in unsuitable photographs. It will be obvious from them that the use of camera-mounted flash or floodlight is not to be recommended, because to comply with recommendations 6 and 7, the rock panel would have to be photographed at an angle (Figure 4b). This is not desirable for several reasons (uneven lighting and focusing, foreshortening), hence it is to be preferred that the lighting device be positioned independent of the camera location.

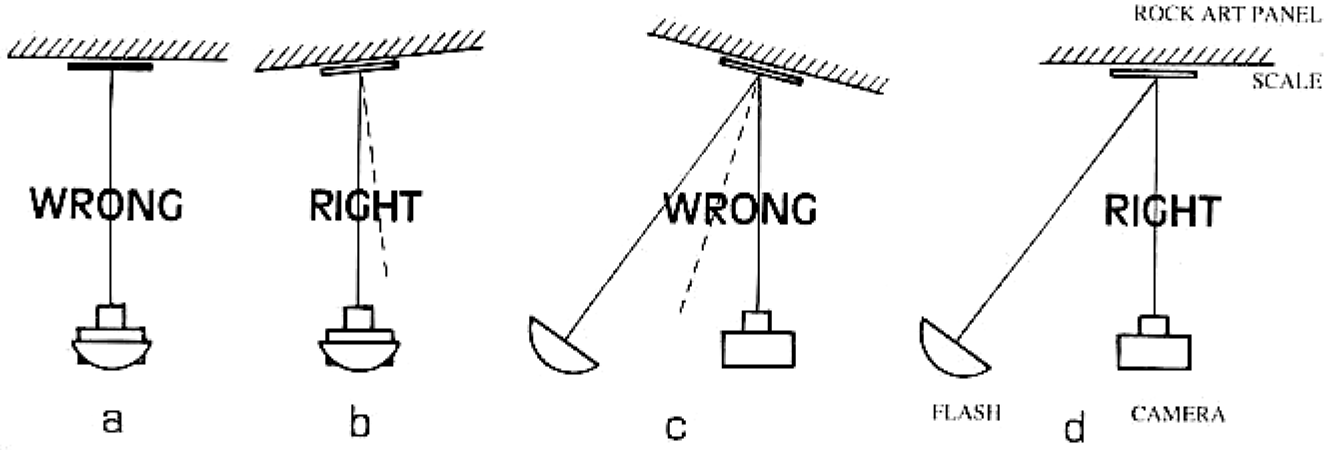

Figure 4. The relative positioning of camera, flash/strobe, scale and rock art: light and camera in the same position (a and b), and in two different positions (c and d).

This is the preferred procedure in any case because camera-mounted lighting always results in poor image depth. In placing the lighting separately it must be made certain that the Scale is not angled mid-way between camera focal axis and lighting axis (Figure 4c). Ideally, both the art panel and the Scale should be perpendicular to the focal axis, and the lighting should be from the left (Figure 4d), at an angle of reflection suitable for the relief of the rock panel: a low angle (20 - 50° to the focal axis) for an uneven panel, a higher angle (50 - 80°) for a very flat panel.

Conclusion

The present paper does not satisfactorily deal with colour printing, being concerned primarily with scientific and archival applications of the method described. This is in part also because current technology in the area of transposing digital colour information to the printing press remains inadequate. Printing presses can reliably reproduce only a fraction of the more than 16 million colours of a 24-bit colour monitor.

It is obvious that most rock art imagery is of a very restricted colour spectrum, roughly between yellow, red and black, with many shades of brown and ochre. One of the most promising ways of developing specialised rock art colour programs for scientific applications would therefore be to create a customised colour library for our discipline which printers would use for achieving best results. Such a standardised library could then be attached to the software programs that specialists in our field will inevitably use world-wide. As we have noted above, there are possibilities of connecting the program being developed with various other digital functions, thus creating a major support structure for the discipline.

On the basis of existing technology, the discipline really does not have a choice in how to render our photographic records permanent. Perhaps an alternative technology of electronic (or other) storage will become available in some future century, but in the meanwhile rock art is being lost at an ever-accelerating rate, and it would be irresponsible of us to hesitate any longer in striving for a universal recording system. We have been considering the use of computers now for some time in this field, and we have procrastinated because of a lack of direction and disciplinary standards. Standards are at last becoming available, and the direction to be taken is fairly self-evident. The system we have described here promises to deal satisfactorily with the demands of future technologies.

Many technologies or standards introduced during the history of humanity proved to be cul-de-sacs, often because at the time they were conceived, no thought was given to how they would be affected by future developments. An example is the historical reluctance of some countries to adopt the metric system, which results in the ultimate need to convert to it at an astronomical cost. The lesson from this is that one should not introduce measures that may, at some future time, become incompatible and, in the case of the computerisation of rock art records, substantially defeat their purpose. It is therefore advisable that, before we embark on an ambitious program of standardising the records of world rock art, we take into consideration the foreseeable long-term developments in this field, to the best of our abilities.

If rock art research is to be a viable discipline it cannot rely on the long-term survival of rock art, it has to create an archival data bank on a global scale. Colour standardisation and calibration are absolutely essential for this to be meaningful. While this is obvious, it is much harder to predict the shape technological innovations will take in future centuries. We may begin by extrapolating from our present position: to 'save' rock art for posterity, we shall have to create massive permanent records of it. Anati's (1984) early quantitative estimate of global rock art resources was probably quite conservative. We know that it excluded several large concentrations (e.g. in China, with upwards of 10 000 sites) and underestimated others. With an expected true number well in excess of 100 million motifs it is obvious that, at the present rate of progress, it may take centuries to record this global corpus *satisfactorily*. By that time, a good portion would have fallen victim to relentless deterioration, so we need to find less time-consuming ways, not only more effective ways of recording. For instance, the use of a video camera has the benefit of preparing the data in a format facilitating subsequent digital colour re-constitution. Digital cameras are already in use for recording rock art. It does not seem unrealistic to predict that, sometime in the next century, rock art recorders would take a computer-supported video (or similar) system or digital camera into the field that would calibrate colour at the site, while the actual art can be viewed to check the recording for veracity. Upon return to the base institution, the fully corrected, permanent digital records would simply be downloaded onto the archive memory. Vast numbers of art panels could be recorded for all future in this fashion as the questions of digital storage capacity are solved, and they need to be recorded only once. But irrespective of the technology's sophistication, a calibration standard would still have to be used, therefore we suggest that the future of the IFRAO Standard Scale seems assured.

With the present developments, rock art photography has become a method of temporarily storing optical information about rock art until a permanent form of storage becomes available. It is no longer a means to its own end, but a *provisional* form of recording rock art. To unlock coded optical information from photographic records it is not sufficient to produce good photographic imagery: it must be colour calibrated also.

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Résumé. *Le but principal de la récente introduction de l'échelle internationale IFRAO pour le calibrage des couleurs était de faciliter l'instrumentation de la reconstitution chromatique. Cet article rapporte le premier essai positif à réaliser ce but. On explique la subjectivité de l'enregistrement photographique; on élucide le caractère éphémère de tel enregistrement et on considère les principes fondamentaux de perception chromatique et du traitement digitalisé de l'information chromatique. On explique aussi le rôle de la digitalisation de l'image et des systèmes de la mise en réserve des données d'art rupestre. Finalement, l'article donne des lignes détaillées pour utiliser l'Échelle Standard IFRAO et réaliser les meilleurs conditions possibles pour la manipulation digitalisée des données photographiques d'art rupestre.*

Zusammenfassung. *Der Hauptzweck des kürzlich vorgelegten IFRAO internationalen Farbkalibrierungs-Standards war es, die Einführung von Farb-Rekonstitution zu ermöglichen. Dieser Artikel berichtet die erste erfolgreiche Verwirklichung des Systems. Die Subjektivität photographischer Unterlagen wird erklärt, die Kurzlebigkeit solcher Unterlagen besprochen, und die Grundlagen von Farbwahrnehmung und der elektronischen Verarbeitung von Farbdaten werden erörtert. Die Rolle von elektronischen Bildumwandlungs- und Aufbewahrungs-Systemen in Felskunst wird ebenso erklärt. Abschliessend enthält der Artikel auch detaillierte Anweisungen für die Verwendung der IFRAO Standard Skala um die bestmöglichen Bedingungen für zukünftige elektronische Manipulation photographischer Felskunstinventare zu bewirken.*

Resumen. *El principal propósito del recientemente presentado modelo internacional de graduación de colores de IFRAO fue de facilitar la implementación de la re-constitución de colores. Este artículo informa acerca del primer intento exitoso para lograrlo. Se explica acerca de la subjetividad de la documentación fotográfica, lo pasajero de tales documentos es elucidado y los principios básicos de la percepción de colores y el procesamiento digitalizado de la información de los colores es considerado. El rol de la digitalización de imágenes y sistemas de almacenamiento en la documentación del arte rupestre es también explicado. Finalmente, el artículo provee pautas detalladas para el uso de la Escala Standard de IFRAO a fin de obtener las mejores condiciones posibles para el futuro manejo de codificación de la documentación fotográfica del arte rupestre.*

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