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AUTOMATION IN THE SORTING AND SIZING OF ROUGH GEM DIAMONDS

By P. G. READ, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A., F.I.S.T.C.,
Technical Manager of the Diamond Trading Company

(being the substance of a talk given to the Gemmological Association of Great Britain at Goldsmiths' Hall on 11th October, 1976)

APPROXIMATELY 80% of the world's production of rough gem diamonds are marketed by the De Beers Central Selling Organisation. Before these diamonds can be valued and offered for sale, they must be separated into categories of shape, quality, colour and size, and it is the Diamond Trading Company, a principal member of the C.S.O., which performs this task. Until about ten years ago, the entire operation was done by hand. Today, partly because of the shortage of skilled labour, and partly because of the increase in the production and sales of rough diamonds, several of the simpler tasks have been successfully automated by D.T.C.'s Research and Development department. This department, which was formed seven years ago, consists of a team of electronic and mechanical development engineers who have all had previous experience of similar work in industry.

The word automation often conjures up visions of machines ousting the human operator from his skilled work, and, at best, relegating him to the task of machine minder. In the diamond business, however, both the economics of sorting and the practical limitations of what can be achieved with electronics and mechanics combine to make the use of automation and automatic sorting aids particularly applicable to the less skilled and more monotonous tasks. This leaves the Sorter free to concentrate on the more interesting aspects of his work.

D.T.C.'s Research and Development department first becomes involved with a new project when the need for a specific sorting aid has been determined by the development co-ordinator, who acts as an information link between the department and the diamond floors. Once an outline specification for such an aid has been agreed with the appropriate diamond department, and authorization for the new project has been obtained from the Executive Committee, a search is made of all commercial equipments to see if there exists a product which either directly, or after modification, fits the specification. This is because it is much more expensive to design and build a new machine than to purchase and adapt an existing one. The new project will then pass through the stages of drawing office design, feasibility tests on a "mock-up", prototype assembly and test, and finally, when all engineering drawings are completed, manufacture of the production version. The time taken to progress from the initial request to the finished product is normally between one and two years, depending on the complexity of the project.

The four main operations in which automatic or semi-automatic equipment is currently being used are:

Sieving Shape Sorting Colour Sorting Sizing (weighing)

To these can be added an extra operation which occurs at intervals during the sorting sequences, that of counting. In Figure 1, the sequence in which these operations occur during the five-week work cycle that precedes a "sight" is indicated in a generalized flow chart. This flow chart shows in simplified form one sequence for goods under 1·2 carats in size.

The automatic machines which will now be described have been chosen to illustrate both modified commercial equipments, and those equipments designed entirely within D.T.C.'s R. and D. department.

First of all on the flow chart we have sieving, which is initially used to divide the incoming "run-of-mine" shipments of diamonds into two groups called smalls (diamonds smaller than 1·2 ct) and sizes (diamonds greater than 1·2 ct). The sizes are then again divided by sieving into a further series of weight groups. Although sieving is not a precise method of separating diamonds into weight categories, it is used at this initial stage for reasons of speed. The

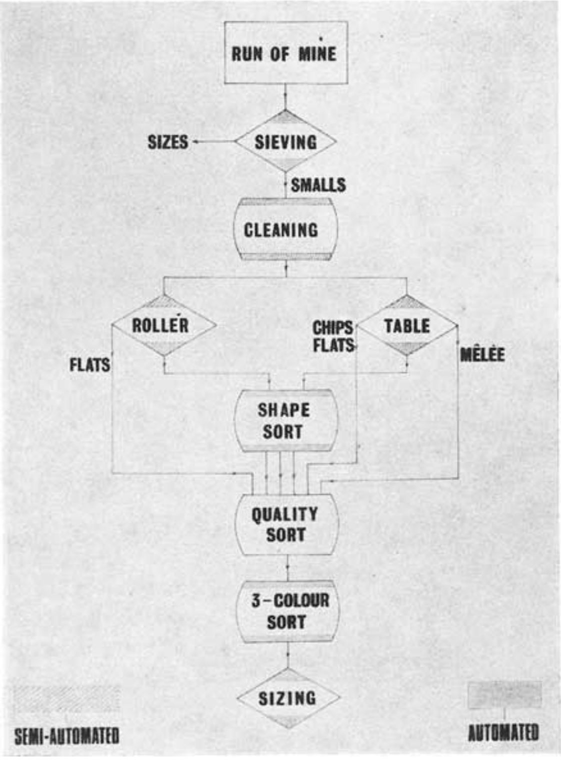

Fig. 1. Generalized flow chart showing a simplified sequence of operations for "Smalls" (diamonds less than 1·2 carats).

accurate weighing of the diamonds into precise weight categories finally takes place at the end of the various sorting operations. Hand sieving used to be one of the least attractive jobs for a sorter, and as the quantity of diamonds increased over the years it also became a very arduous task.

Some years ago, motorized cam-driven sieving machines were introduced which roughly copied the type of motion used when hand-sieving. More recently these have been replaced by the simpler and more robust version which is shown in Figure 2. The new machine is a good example of a commercial equipment which has been modified to make it more suitable for use with diamonds. It consists of a sieving frame to which can be clamped a range of sieves. The frame is mounted resiliently onto a baseplate by means

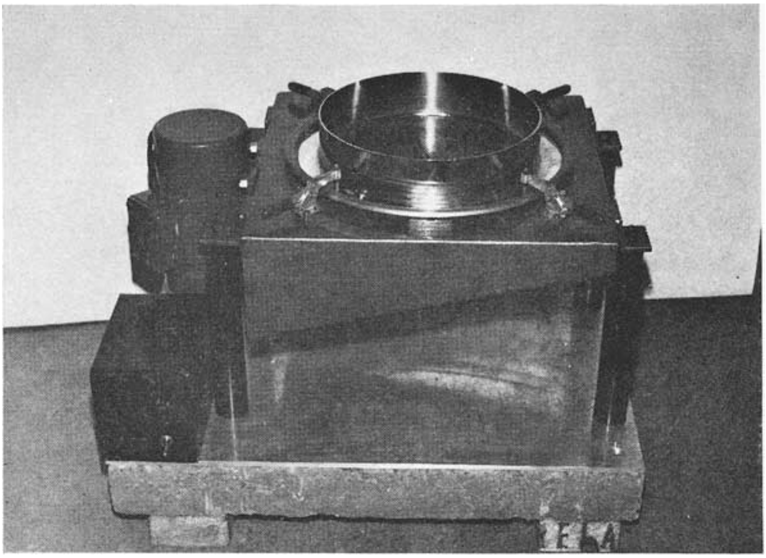

FIG. 2. Motorized sieving machine. Interchangeable ten-inch sieve plates are clamped under a hopper assembly.

of rubber blocks. Bolted to the sieving frame is an electric motor. On the top and bottom shafts of the motor are adjustable eccentric weights. When the motor is running, these weights cause the motor, and hence the sieving frame, to vibrate. Adjustment of the position of these weights allows the vibration to be set for correct sieving operation. In order to encourage a flow of diamonds across the sieve plate, the motor is switched off and on every ten seconds. This makes the motor speed pass through resonances in the frame assembly to give a stirring motion to the diamonds.

The sieving machine is basically a very simple design, and, as it has no complicated mechanical linkages between the source of the vibration and the sieve plate, it requires the minimum of maintenance. The sieve plates are our design. They are approximately ten inches in diameter, and are manufactured from stainless steel. The holes in the plate are punched out on a numerically controlled machine tool to very high dimensional tolerances. The holes are made two thousandths of an inch larger in diameter than required, and a final plating process reduces these holes to correct size and also puts a hard protective surface on the plate. The plating of the sieve plates is necessary not only to reduce wear on the plates, but also to prevent the diamonds from becoming dirty during sieving. If it does become necessary to clean the diamonds between the various sorting operations, this is done by the use of ultrasonic baths and centrifuge driers.

In complete contrast to sieving, we have automatic shape sorting. This is a project still under development, but experimental results indicate that it is feasible to sort diamonds automatically into their basic shape categories of Stones, Shapes, Cleavages, and Flats. So far, the prototype shape sorter (Figure 3) consists of a modified commercial particle analyser, comprising a high-definition television camera with associated shape determining computers, and a D.T.C.-designed and built diamond feeder and sorter.

The diamonds to be sorted are contained in a hopper which is shaped like a hollow inverted pyramid. At the bottom of the hopper are four holes, and through these holes pass four pickup rods with small recessed cups on their ends. Both the cups and the rods are hollow and have vacuum applied to them. As the rods are driven up through the diamonds in the hopper, they pick up one diamond in each cup. A transfer plate above the hopper receives the four diamonds from the rods and holds them by vacuum. Vacuum is

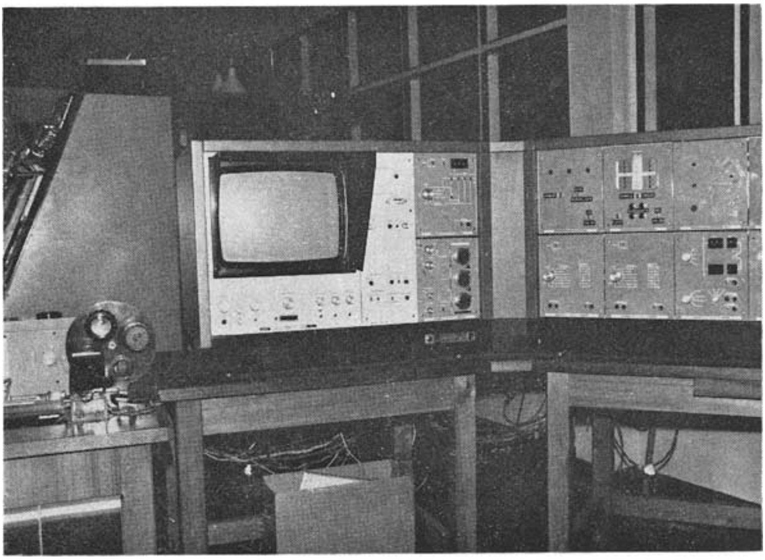

Fig. 3. Shape-sorting using an Imanco particle analyser to identify the basic shapes of diamonds which are fed automatically to a high-definition television camera (extreme left).

then switched off the rods and they are retracted into the hopper ready to pick up four more diamonds for the next feed cycle.

The vacuum transfer plate then moves horizontally to the television camera position, and deposits the four diamonds in a precise pattern on the flat surface formed by the two side-illuminated prisms. When the television camera has passed its video information on the diamonds to the shape determining computers and they have identified the shape of each of the four diamonds, the two prisms are pivoted to allow the diamonds to drop into four sorting channels, one for each diamond. In these channels are gates which are set by the computers to sort the diamonds by shape into the appropriate output boxes.

The mechanism of shape determination is as follows. The computers are fed with the video output of the television camera in digital form. From this they measure both the perimeter of each diamond image and its total area. They then divide the area by the perimeter squared (A/p^2) to produce a dimensionless shape factor (i.e. a factor which is independent of the size of the diamond). This shape factor can be, typically, 3×10^{-2} for a triangular shape, 7×10^{-2} for an octahedron, or 9×10^{-2} for a spheroid. By setting acceptance limits for the shape factor it is possible to make a simple sort between triangular flats and octahedra. By using more sophisticated shape factor formulae and greater computing power, it is hoped that the shape recognition capability of this machine can be extended to cover all shape categories.

While machines of the complexity of the television shape sorter are very exciting engineering concepts, there also exist much simpler machines which are capable of doing a limited degree of shape sorting. One of these, the roller sorter (Figure 4a), is very useful for extracting flats and maccles from a batch of mixed diamonds. It consists of two contra-rotating steel rolls, the gap between the rolls being adjusted so that it is small at one end and large at the other. The rolls are inclined so that the end with the wide gap is the lowest. Diamonds are fed, in single line, to the top end of the rolls, and as they pass down the rolls under gravity they fall through into containers at the point where their minimum dimension is just less than the gap between the rolls.

Another simple shape sorter is the vibratory table (Figure 4b). This can make a progressive sort between the rounder shapes and the flatter ones. The table works on the principle that those diam-

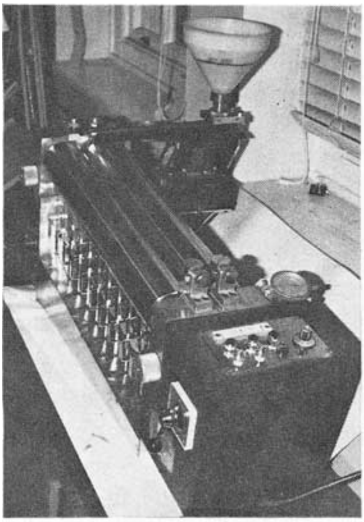

FIG. 4a. Roller Sorter separates flats from stones and shapes by sensing smallest dimension.

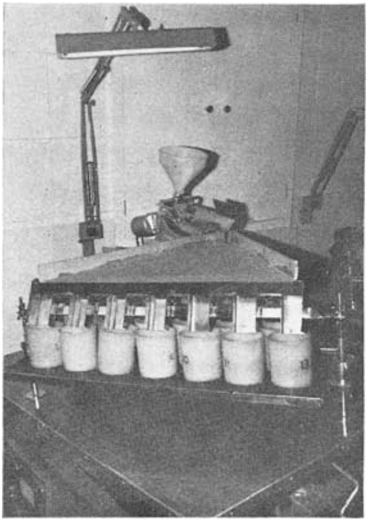

FIG. 4b. Vibratory table used for simple shape-sorting uses difference in surface contact.

onds having flatter surfaces, and therefore more contact area, will travel further across an inclined vibratory surface than diamonds with a more rounded shape, which will tend to roll off. The coefficient of friction of the table surface is important, and various surfaces are used for specific sorting requirements.

Sorting diamonds for colour is one of the more exacting and interesting tasks, but even this can lose its attraction when it is necessary to sort tens of thousands of diamonds in sizes ranging from 1 ct down to twenty or forty to the carat. This is another area where automation is the only sensible way to sort enormous quantities of diamonds within the allocated time.

Some years ago, long before the Diamond Trading Company had a Research and Development department, a member of the staff saw a press release which described a colour sorter designed by Gunson's Sortex Ltd to separate discoloured peas from green ones. He contacted the Company and put our problem to them. The result was a machine which was able to sort diamonds into two broad colour categories. Although this still meant that for a three-colour smalls sort a considerable amount of hand sorting had to be done, the work load was considerably reduced.

The latest colour sorter (Figure 5) is the result of further liaison

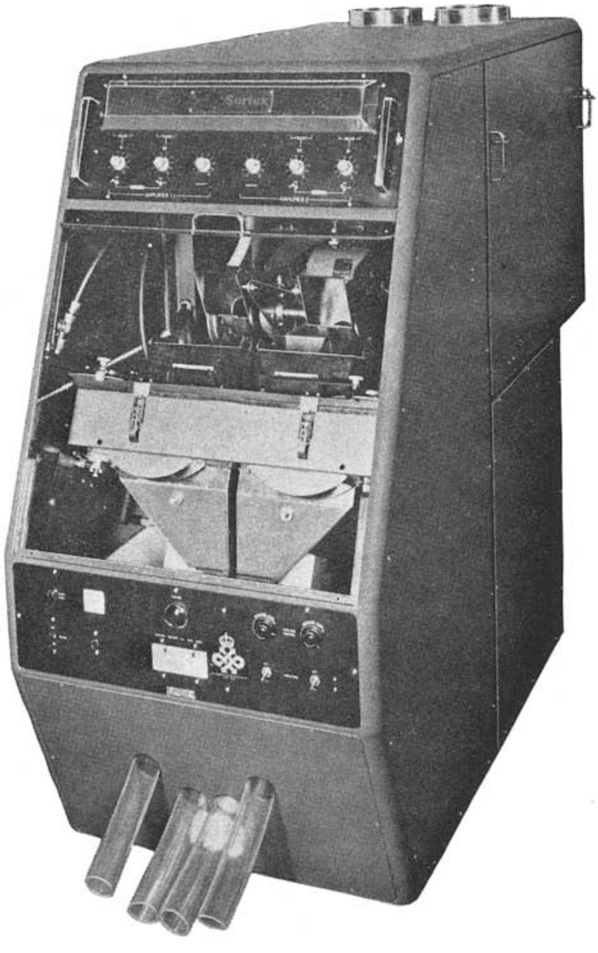

FIG. 5. Gunson's Sortex twin-channel colour-sorter for diamonds.

between my department and this Company, and represents a considerable advance on those first early machines. As with the majority of automatic sorters, the diamonds start off in a hopper, from which they are extracted by a linear vibratory feeder. The feeder drops the diamonds into a "V"-belt feeder which accelerates and separates them before allowing them to fall through an optical "box". This box contains quartz halogen lamps and photomultipliers, which measure the degree of colour in the diamond. If the diamond's colour is above a certain pre-set limit a tiny jet of air is released to deflect the diamond into a separate sorting channel.

Before dealing with the fourth area of operation, that of sizing, I will describe a diamond counter which was designed in my department. Although in this instance there were commercial equipments available, none of these had a specification which met our needs. In particular, we required a very high accuracy of count, giving a maximum error of plus or minus one in 100,000 at a count rate of 600/minute. In addition we needed to be able to count diamonds over a large range of sizes, from 0·5 ct to 10 ct.

The counter (Figure 6) consists basically of a vibratory bowl feeder, and a detector. The bowl feeder acts as both a hopper and as

FIG. 6. Counter and batcher for rough diamonds uses a twin infrared light-curtain as detector.

a means of delivering the diamonds one at a time to the detector. The diamonds are constrained into a single line by the output chute of the bowl, and are velocity separated as they fall from the chute. To prevent overloading the output chute, a section of the final part of the feed track can be adjusted in width to pass only a single line of diamonds.

The detector consists of a light-curtain formed by "bouncing" an infrared beam between two parallel mirrors. The angle between the mirrors and the infrared source is adjusted to increase the number of reflections between the mirrors to a point where there is just enough infrared energy left in the final beam to be detected by a photocell. Two such curtains are placed one beneath the other in the detector. The first one is used to count the diamonds as they break the beam, and the other is used to check this count. This enables any malfunction in the feeding or in the photo-optics to be detected. Provision is also made for counting out pre-set numbers of diamonds by means of a batching switch.

Finally, we come to the need for weighing individual diamonds so that they can be accurately separated by weight. Rough gem diamonds are sized into a series of weight categories. From 1·81 carats upwards these categories span one carat intervals, that is 1·81 to 2·80, from 2·81 to 3·80 and so on. Below 1·81 carats, there are smaller subdivisions.

Outside the confines of each one carat weight category, the price of the diamonds is not linearly related to weight, but tends to follow a square law. For example, a two carat diamond is approximately four times the price of a one carat diamond of similar colour and quality. For this reason, each of the individual weight categories into which the diamonds are sorted has its own price per carat. As there may be large differences in the price per carat between adjacent weight categories, it is essential that each diamond is weighed accurately. This need for accuracy is not only a requirement for the individual weighings, but, as I will explain later, is also important when considering the cumulative error in totalling the individual weighings of a batch of several thousand diamonds.

D.T.C.'s experience of automatic weighing started eight years ago when we commissioned a system consisting of twenty balances and a D.E.C. PDP8I computer. The balances were designed to work either independently, when they used a built-in program, or under the control of a computer, which collected the weighing data from each machine and directly controlled the sizing. The computer used the weighing data it collected to produce a print-out of the weighings for each machine. This print-out gave the number of stones, total weight and average weight for each weight category, and after they were checked by the operator, the data was stored on magnetic tape ready for further processing by the Company's main computer. As it was probably the first computer controlled weighing system of this complexity that had ever been built, we inevitably discovered many problems when it was put into operation. Over the following years we made a variety of modifications to both the balance and the computer program. Despite the difficulties in operating and maintaining this first system, it became an indispensable part of the Company's operation.

Finally, with over five years experience of operating an automatic weighing system behind us, we obtained authorization to start work on the design of our own automatic weigher, to act as a replacement for the original machines. The new design project was started two years ago and the resulting production machine can be seen in Figure 7a. The original operating specification was adhered to

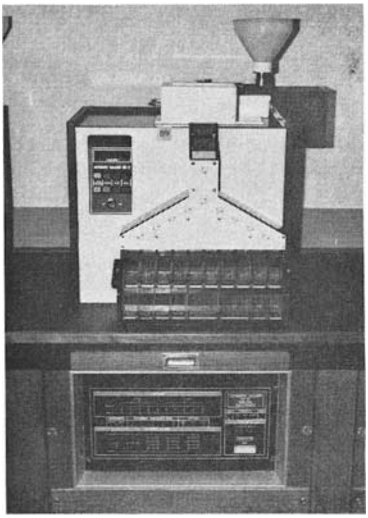

FIG. 7a. Automatic diamond weigher. The top unit contains the weigh head, feeder and sorting mechanisms. The bottom drawer unit contains the control electronics.

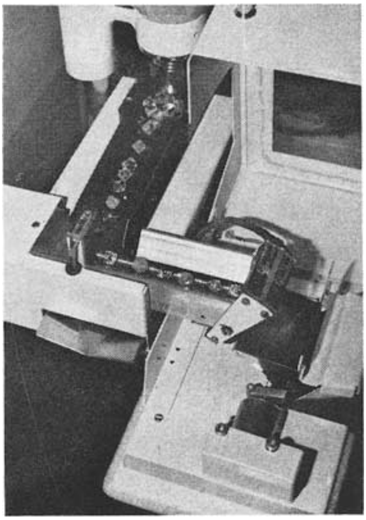

FIG. 7b. Two-stage feeder of auto-weigher. Diamonds are extracted from the conical hopper by the black vibratory track and fed to the screw feeder.

in that the new balance can weigh on-line, or off-line, to the computer, but we have uprated the specification with regard to accuracy and speed of operation, and have given priority to operating simplicity, reliability and ease of maintenance.

As with our television shape sorter, the mechanical handling part of the design was the most difficult. By mechanical handling, I mean the delivery of one diamond at a time from a bulk hopper to a weigh pan, followed by its placement in the appropriate sortbox. This problem is made more acute by the fact that a typical batch of diamonds may contain sizes ranging from one carat up to fifteen carats.

The central part of the problem, that of removing the diamond from the weigh pan, was solved by the decision to purchase a Mettler tablet balance to form the heart of our machine, as this balance has its own pan unload mechanism. The last part of the mechanical handling problem, that of placing the diamond, following its ejection from the weigh pan, into the correct sortbox was the simplest as this had already been done successfully in the previous design. We simply saved space by arranging our sortboxes in two stacked tiers.

The delivery of one diamond at a time from the hopper to the weigh pan was, as we knew from experience, to be the biggest problem. Our solution is part mechanical and part electronic. We use a hybrid two-stage feeder in conjunction with some sophisticated photo-electric logic circuitry (Figure. 7b).

The first stage of the feeder is a linear vibrator, which moves the diamonds out from the bottom of the hopper, and feeds them along a track which constrains them into a single line. The angles of the tracks are carefully chosen to achieve the desired single-line separation without jamming or flooding.

At the output end of the track, the diamonds are dropped one-at-a-time onto the start of a screw-feeder, which consists of a pair of contra-rotating rolls. These rolls have a screw-thread cut into them whose pitch has been carefully chosen to provide a means of both driving the diamonds forward and keeping them separated. A stepping motor is used to drive the screw-feeder rolls to ensure that they stop precisely, with the minimum of overrun, when controlled by the photo logic. Separation of the diamonds is achieved by means of two sets of photo-electric detectors, one at the start of the screw feeder and one at its end.

The operation of the Mettler pan eject mechanism is initiated by the weight signals from the weigh head. When no diamonds are fed to the weighpan, the eject mechanism does not operate. An electronic zero circuit is operated automatically by the machine once every fifteen weighings to take care of any drift in the balance zero, and to relieve the operator of this task. Error circuits are built in to give warning of the failure of the photo-electric circuits, or to warn if any of the lower sortboxes (which are not completely visible to the operator) become full.

When used on-line to the computer, the weight information is fed out by digitally coded electric signals to the computer. The information is processed by the computer, which then sends back digitally coded sortgate signals to operate the appropriate sortgate. Two PDP8E computers are used in the new installation to service thirty auto-weighers. When using the system on-line, the operator types in the information on the diamonds she is about to weigh together with the code number of the machine she is going to use. She then loads the diamonds into the hopper of that machine and presses the feeder start button. When all of the diamonds have been fed and weighed, the operator then returns to the teletype and requests from the computer a tabulated print-out of the weighings. The known total weight of the batch of diamonds is fed to the computer before weighing commences; the difference between this and the sum of individual weighings represents the cumulative error. In a batch of 1,000 diamonds, the maximum permitted error would be ±1 carat, representing a worst case of 1,000 weighings multiplied by ±0·001 carat. Normally, however, this error would not exceed 0·2 carat.

The front panel of the electronics drawer unit (Figure 7a) carries 51 engineering lamps, which enable the correct functioning of the machine to be checked and act as an aid to fault diagnosis. Also contained on the panel are the photo-electric pre-sets, and a switch which enables weighings to be simulated so that the sortgate functions and limits can be checked.

Like all completed systems, the equipments I have described in this article are already technically dated. The scope of what can be achieved is constantly being enlarged by new techniques and components, a recent example being the solid state microprocessor. This device, which packs the heart of a computer into a single integrated circuit, now makes it possible to build powerful computing capabilities directly into an equipment, this bringing the era of the intelligent machine one step closer.

Like the American space program, it would seem that almost any technical feat can be accomplished, given sufficient funds. In the commercial world however, the cost of automating a process must be balanced against the expected advantages. Using this criterion, the automation of diamond shape sorting and sizing, as described in this article, can be justified. However, the cost of automating an operation such as the sorting of rough diamonds for quality would be prohibitive and could not be justified. This is because of the number of variables involved (i.e. size and position of inclusions, naats, internal and external fissures, etc.), and also the need for assessing the optimum yield from a diamond. The solution here would probably be to develop improved handling and inspection aids. These could take the form of automatic feeding of diamonds to an inspection position, provision for holding and turning the diamond for all-round viewing, and a means of placing the diamond after assessment into the appropriate sortbox. Such an approach would use to full advantage that most versatile and adaptive of all information processors, the skilled diamond sorter.

OBSERVATIONS ON SOME RHODESIAN EMERALD OCCURRENCES

By N. A. METSON, B.Sc., and A. M. TAYLOR, Ph.D., F.G.A.

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DURING the summer of 1974 one of the authors (A.M.T.) was fortunate to inspect the emerald occurrences near Fort Victoria, Rhodesia. This was made possible through the assistance of Dr J. W. Wiles, the Director of the Geological Survey, Salisbury. Dr Wiles and Mrs S. Anderson, of the Geological Survey, kindly reviewed this article. Considerable thanks are due to Mr Cyril Gurr of the Mines Department, Fort Victoria, for his valuable assistance as guide to the area and for providing additional emerald samples for analysis.

The object of the investigation was to try and further our understanding of emerald formation in Nature by studying in particular the trace element geochemistry of emerald and associated country-rock. A summary of certain aspects of this investigation that may be of gemmological interest are given, and other data or details may be referred to in the report by Metson (1975). An account of the visit to the area is related in the U.S. *Lapidary Journal* (Taylor, 1976).

The emerald occurrences visited were the Novello Prospect and the abandoned Twin Star Mine, both of which are located about 17 km NW. of Fort Victoria. Some samples of Chikwanda emerald were kindly provided by Mr Cyril Gurr. This claim was not visited, but is located some 6 km north of the famous Bikita lithium mine about 80 km east of Fort Victoria. Details of the local geology, together with spectrographic analyses of the emeralds and enclosing country rock, are admirably recorded by Martin (1962). The trace element geochemistry that particularly interested us was the following:

(1) What elements are responsible for the colour of emerald? Besides Cr and Fe, very few emerald analyses report whether or not other transition metals were analysed for, in particular, V, Ni, Mn, all of which can give various green shades to synthetic beryls when grown by the hydrothermal method (Emel'yanova *et al.*, 1965).

(2) Similarly, one needs to know whether these potential colouring elements are present in the host rock.

(3) The alkali content of the emeralds is of interest for two important reasons. Because of their comparatively large size (Li excepted) they locate themselves within the channel sites of the emerald structure, together with varying amounts of water molecules, and so directly increase the density of the crystal as the unit cell size is not significantly increased by these substitutions; also increase in density goes hand in hand with increase in refractive index. The R.I. and S.G. of gem quality emeralds have long been used as a pointer to their place of origin and, combined with information on the nature of the inclusions present, it is very often that one can make such a pronouncement with a degree of certainty. Thus it would be reasonable to conclude that all gem-quality emeralds from a particular deposit would have closely similar amounts of

alkali and water substitution.

Secondly, the type of alkali present in emerald may be an indication of the chemical nature of the hydrothermal fluid responsible for the crystallization. This is particularly the case if the alkali concentration in the emerald represents an increase over what is present in the host rock. Ideally, to obtain this information one should analyse the fluid inclusions present in emerald, but this is a rather difficult task to perform satisfactorily even with present-day technology.

(4) The relationship and/or distinction between beryl-producing pegmatites and emerald-producing pegmatites is of special interest and will be speculated upon later.

GEOLOGICAL SETTING

According to Martin (1962) the geological setting of the three emerald occurrences (viz. Novello, Twin Star, Chikwanda) is very similar. There is an older basement complex consisting of greenstones, banded ironstones and ultramafics which has been intruded by granite or granodiorite. At the Novello and Chikwanda areas the serpentine is thought to be of Shamvaian age (2,650 m. years). The Twin Star mine is only 6 or 7 km distant from the Novello Prospect and within the same serpentine belt. The Chikwanda claims, however, are located about 90 km eastward, near the Bikita pegmatite mine.

Novello Prospect: The discovery of emerald and alexandrite in this area was made by Mrs C. Girdlestone in 1960. The occurrences lie in a narrow belt of serpentine that traverses the Girdlestone ranch. Considerable lateral shearing has taken place and some transverse faulting. Large lens-shaped bodies of quartz and pegmatite extend along the shear zones over a distance of about 5 km through the pegged area. The pegmatites contain spasmodic minor amounts of beryl and the lithium minerals, petalite and lepidolite. There are two emerald occurrences, both associated with pegmatites, which are located close to either side of the Chipopoteke River, the course of which follows a transverse fault across the serpentine belt. The abandoned workings consist of a number of prospect pits, some 2 to 4 metres deep and 4 to 10 metres across (Figure 1b). The workings are in an area of mica-rock intruded by numerous pegmatite stringers. Useful samples for study were recovered from the dumps. Thin sections of the country-rock showed it to consist essentially of

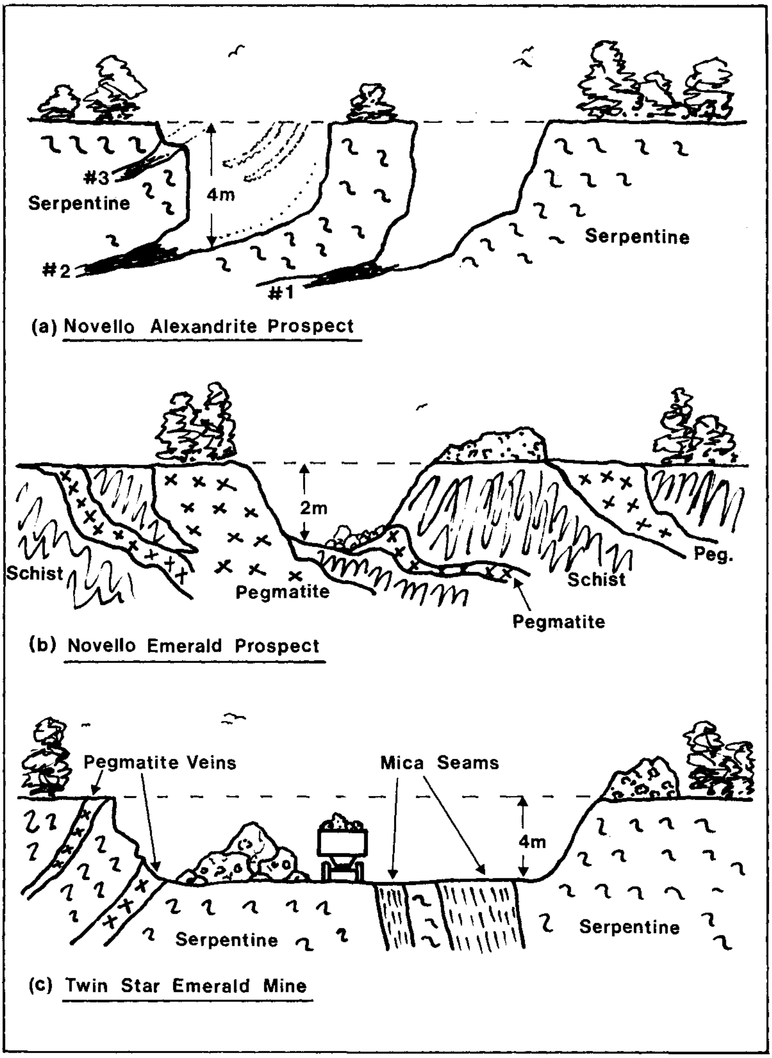

FIG. 1. Idealized cross-sections of the mine-workings investigated.

phlogopite mica, but graduations exist from phlogopite to chloritized phlogopite to chlorite rock. The groundmass consisted of minor sericitized plagioclase feldspar, muscovite, quartz and opaque minerals. Samples of mica-rock were found containing pegmatite stringers 2 to 3 cm wide carrying quartz, mica and euhedral beryl as grey-coloured hexagonal prisms of 1 to 5 mm diameter. Opaque and fractured emerald crystals of similar size were found in the mica-rock, but confined to within 20 cm of a beryl-containing pegmatite stringer. They were especially abundant in very contorted mica-rock and tended to concentrate along minor fold axes. The non-contorted mica-rock appeared barren of emeralds. Emerald crystals were recovered only from material found on the dumps, hence their true distribution would be best evaluated by the original prospectors.

The Novello alexandrite-chrysoberyl prospect is located a little over 1 km distant NE., but still within the same serpentine belt. No pegmatites are apparent in the immediate vicinity. Two pits about 4 m deep had been excavated in the serpentine in order to follow three gently dipping phlogopite mica seams of 10 to 100 cm thickness. The prospecting operation was being conducted by four African workmen and the mine manager. Two smaller mica seams that did not extend to any depth had already been worked out, but excavation was continuing on three well-defined seams (Figure 1a).

Twin Star Mine: The excavations here are considerably more extensive than what had been done at Novello. A derelict treatment-plant stands nearly surrounded by huge piles of tailings. The main workings are developed in serpentine and consist of a shallow elongated pit, some 4 to 5 m deep and extending approximately 200 m long and up to 50 m wide, with various offshoots. Several steeply dipping quartz-pegmatite veins 10 to 30 cm wide are exposed in the walls of the excavation (Figure 1c). The mine was operational over the period 1965-69 when it was recorded that rough and cut stones to the value of £2650 were produced.

Active mining of emeralds had been undertaken from seams of mica rock enclosed in the serpentine. A few samples taken from the stock piles at the old treatment-plant showed glassy quartz studded with radiating clusters of slender beryls and pale emerald prisms, 1 to 2 mm diameter and 1 to 2 cm long. Clusters of darker, extensively flawed emerald prisms, 1 to 2 cm size, in parallel growth, partially coated with mica, were obtained for chemical analysis. At the time of the visit (1974) a new lease had been taken out over the property by a Salisbury-based gem dealer and some prospecting work was being done on a mica seam at the far end of the old open-cut.

PHYSICAL PROPERTIES OF THE EMERALDS

Samples of emerald crystal were selected from each locality (viz., Novello, Twin Star, Chikwanda) and cleared of any adhering mica. The specific gravity range for samples from each locality was determined by a heavy-liquid dilution method. The refractive indices were determined by using a Rayner spinel-type refractometer after a flat surface was ground and polished on each crystal. The data obtained are presented in Table 1.

TABLE 1

PHYSICAL PROPERTIES OF EMERALDS AND BERYL

Type	*Specific Gravity Range*	*Refractive Index*		*Double Refraction*
		ω	ε	ω-ε
Novello beryl*	2·66-2·67	1·576	1·570	0·006
Novello emerald	2·68-2·74	1·581	1·576	0·005
Twin Star emerald	2·67-2·71	1·586	1·580	0·006
Chikwanda emerald	2·72-2·74	1·590	1·583	0·007
Chatham, synthetic	2·65	1·563	1·560	0·003
Chivor, Columbia	2·68-2·69	1·577	1·572	0·005
Sandawana	2·74-2·76	1·593	1·586	0·007

*An off-white beryl taken from an adjacent pegmatite vein.

The somewhat higher and variable values of S.G. and R.I. of natural emeralds compared to those recorded for Chatham synthetic emeralds are due to more extensive ionic and molecular substitutions existing in the former. Chatham synthetic emerald can be taken as a convenient standard "pure emerald", essentially lacking in iron, alkali and water substitution. Thus the higher the S.G. or R.I. found for emerald, the more of these substitutions can be expected, particularly of the larger alkali ions and of water molecules, both of which go to take up channel lattice sites in the structure. For example, the Miku emerald reported by Hickman (1972) has an S.G. of ~ 2·75 and is analysed as having 5·8 wt % potential channel ion components (viz. Na_2O+K_2O+CaO, which includes cations of ~ 1Å radius or greater) and a high water content of 2·6%. Of the Rhodesian emerald samples examined, that from Chikwanda had the highest S.G., averaging 2·73, and the alkalis (Na_2O+K_2O) totalled 4·7 wt %; water was present but the amount not determined. The physical properties obtained for the Chikwanda emerald agree closely with those determined by Martin

(1962), but somewhat higher values, compared to Martin's, were found for the refractive indices of the Novello emerald.

CHEMICAL COMPOSITION

Host rock and representative emerald samples were analysed by atomic absorption for the following elements: Na, K, Mg, Ca, Fe, Mn, Li, Ni, Cr and V. The glass fusion technique was used to get the samples into solution, except for Li (as the fusion mixture consisted of lithium tetraborate 60 parts, lithium carbonate 10 parts, rubidium iodide 1 part). Samples for Li analysis were prepared by the $HF/HNO_3/H_3BO_3$ method. Analyses for the host rocks at Novello and Twin Star are shown in Table 2, which includes, for comparative purposes, two analyses by Martin (1962). The emerald analyses are shown in Table 3, as weight % oxides and as atom weight %.

TABLE 2

EMERALD HOST-ROCK ANALYSES

wt%		1		2		3	4
Cr_2O_3	(Cr)	0·39	(0·27)	0·13	(0·09)	(0·2)	(0·1)
FeO	(Fe)	9·97	(7·8)	5·96	(4·6)	M	M
NiO	(Ni)	0·10	(0·08)	0·12	(0·09)	(0·1)	(tr)
MnO	(Mn)	0·08	(0·06)	0·04	(0·03)	(0·1)	(0·1)
MgO	(Mg)	M	(M)	M	(M)	(M)	(M)
CaO	(Ca)	tr	(tr)	vst	(vst)	(0·5)	(–)
Li_2O	(Li)	0·5	(0·2)	0·31	(0·15)	(–)	(0·5)
Na_2O	(Na)	0·16	(0·1)	0·87	(0·6)	(–)	(0·5)
K_2O	(K)	8·98	(7·4)	7·88	(6·5)	(–)	(–)

M = Major; tr = trace, < 0·03%; vst = very slight trace, < 0·001%

(1) Phlogopite rock, Novello
(2) Phlogopite rock, Twin Star
(3) Serpentine, Novello (Martin, 1962)
(4) Biotite rock, Chikwanda (Martin, 1962)

SPECTROSCOPIC ANALYSIS

Thin polished plates of emerald were examined with a recording-type spectrophotometer over the wavelength range 300-700 nm. All the emeralds gave the characteristic chromium spectrum having two broad bands centred near 430 and 600 nm and sharp (but weak

TABLE 3

EMERALD ANALYSES

wt%	1		2		3		4		5	
Cr_2O_3 (Cr)	0·59	(0·41)	0·08	(0·05)	0·28	(0·19)	0·05	(0·04)	0·55	(0·38)
FeO (Fe)	0·79	(0·61)	0·39	(0·30)	0·33	(0·25)	0·15	(0·12)	0·51	(0·40)
NiO (Ni)	0·02	(tr)	tr	(tr)	tr	(tr)	tr	(tr)	0·01	(tr)
MnO (Mn)	tr	(tr)	tr	(vst)	tr	(vst)	tr	(vst)	tr	(tr)
MgO (Mg)	0·80	(0·48)	0·17	(0·10)	0·25	(0·15)	0·05	(0·03)	0·28	(0·17)
CaO (Ca)	vst	(–)	–	(–)	–	(–)	vst	(–)	–	(–)
Li_2O (Li)	tr	(tr)	0·01	(vst)	0·01	(vst)	tr	(tr)	0·02	(tr)
Na_2O (Na)	4·04	(3·0)	1·45	(1·08)	1·97	(1·46)	1·14	(0·84)	2·24	(1·66)
K_2O (K)	0·65	(0·54)	0·01	(tr)	0·06	(0·05)	0·19	(0·16)	0·28	(0·24)

tr = trace, $<0{\cdot}03\%$; vst = very small trace, $<0{\cdot}001\%$

1. Dark green emerald, Chikwanda
2. Pale green emerald, Twin Star
3. Dark green emerald, Twin Star
4. Pale green emerald, Novello
5. Dark green emerald, Novello.

intensity) peaks at 470 nm in the blue and at 680 and 683 nm in the red. There was no evidence of any absorption that could be attributed to vanadium and subsequent chemical analysis did not reveal the presence of this element.

Infrared spectra obtained on powder samples showed that water molecules were present in the emeralds from the three localities. Analysis of the data indicated that they were of the type II variety described by Wood and Nassau (1968); that is, the water molecules are located in channel sites adjacent to an alkali ion which influences their orientation.

INCLUSIONS

The inclusions present in a crystal may provide some information as to the environment in which it grew. Emeralds are of particular interest in this respect, as both natural and man-made stones always contain inclusions which are often definitive of their origin—whether that be due to perhaps a contact metasomatic event or a carefully attended growth in a crucible.

Examination of the emerald samples available did not reveal anything in the way of inclusions that was unexpected. The most abundant inclusions present in samples from all three localities were flakes of the host-rock material, i.e. brown phlogopite-biotite mica. The flakes averaged in size about 0·2 mm across and showed some tendency to be orientated more or less parallel to the prism faces. In some cases the mica flakes followed fracture lines and often they were broken or resorbed. Martin (1962) noted the presence of considerable muscovite "veining" and fine muscovite aggregates in Chikwanda emerald. In the present study, fine mica aggregates were also observed, but the type of mica could not be identified with certainty. Some of the coarser mica flakes showed occasional pleochroic haloes.

Next in abundance to the mica inclusions, but seen only in the Twin Star and Chikwanda emeralds, were "negative crystal" inclusions. These appeared to consist of both liquid only and liquid-vapour (two phase) inclusions. Such inclusions have been reported in emeralds from other world localities, such as India (Anderson, 1971) and Tanzania (Thurm, 1972). The "negative crystals" generally occurred in clusters and were always orientated parallel to the c-axis of the crystal. They were often very elongate or tubular and divided into sections.

Black opaque material, possibly chromite, was observed in several of the Novello samples. An attempt to isolate this material by magnetic methods proved unsuccessful. Fissuring occurred in all samples, it being more prevalent in the Novello emeralds and least so in the Chikwanda stones. Feathers were uncommon.

In summary, the major inclusions in the Novello, Twin Star and Chikwanda emeralds clearly reflect the nature of the host-rock material. The absence of any noticeable liquid or liquid-vapour inclusions in the Novello samples make them somewhat distinctive from those of Chikwanda and Twin Star.* The presence of fine mica aggregate in the Chikwanda stones allows them to be distinguished from those of Twin Star. The Chikwanda and Twin Star emeralds, with their abundance of mica and "negative crystal" inclusions are reasonably distinctive on the world scene.

DISCUSSION

The rather intriguing geochemical coincidences associated with the formation of emeralds in Nature were first revealed by the famous Norwegian geochemist V. M. Goldschmidt, around about the year 1920. A readily available summary of this work can be consulted in his textbook entitled "Geochemistry" (Clarendon Press, 1954). The formation of these Rhodesian emerald deposits conforms with the predicted state of affairs. The associated pegmatites carry a little beryl and the host rocks consist of chrome-bearing mica-rock or "schist", if this term may be used without necessarily implying a sedimentary origin.

In Table 3 it can be seen that the chrome content of the emerald samples ranges from 0·04% (pale-green) up to 0·59% (dark-green), and in all but one of the five analyses the iron content is slightly greater (i.e. FeO range 0·15 to 0·79 wt%). The pale emeralds having low chrome also tend to have low iron values. Of other possible chromophores, we see that both nickel and manganese were detectable, but in trace amounts (i.e. NiO 0·00X to 0·02%; MnO 0·00X%); however at this concentration level they would have no effect on the overall colour of the stone. Vanadium was analysed for but not detected.

Turning attention now to the host-rock analyses, we see that the phlogopite rock at Twin Star contained 0·39 wt% Cr_2O_3, and at

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*A recent communication from Mrs S. Anderson, Geological Survey Department, Salisbury, states that certain samples of emerald-beryl from Novello do possess prominent negative crystals and two-phase inclusions.

Novello 0·13%, which are chrome values of similar magnitude as for the emeralds found in them. Thus no appreciable concentration of chromium would be required locally for emeralds to form, assuming ideally, that what chromium is present is readily available for the growing beryl crystal; that is, it can all be at least temporarily mobilized from its initial state and transferred to its final state in the emerald. Unfortunately we were not able to produce any concrete evidence as to the initial state of the chromium. Perhaps the two most likely possibilities are:

(*a*) finely disseminated chromite and

(*b*) ionic substitution within the phlogopite mica.

Whether or not any appreciable ionic substitution actually occurs while a natural emerald crystal is growing depends on the local availability of the element in question, as well as whether it can be mobilized, at least temporarily, while emerald growth is under way. Another factor of importance is the acceptability to the beryl crystal lattice of the ion (or combination of ions) on crystal chemical grounds. Some insight into the latter problem may be had by examining the data gathered by Feklichev (1963) who lists the maximum concentrations reported for various elements in beryl analyses. (See Table 4.).

TABLE 4

SELECTED MAXIMUM OXIDE CONCENTRATIONS REPORTED IN BERYL ANALYSES (Feklichev 1963)

Cr_2O_3	2·00 wt%	MgO	3·37 wt%
V_2O_3	0·90	CaO	3·98
Fe_2O_3	2·83	Li_2O	1·39
FeO	1·2	Na_2O	4·22
NiO	0·10	K_2O	2·25
MnO	0·74	H_2O+	3·00

If one uses the data simply as a guide to the acceptability of chromophoric ions by the beryl lattice, then it would seem that chromium and iron are almost equally acceptable and nickel the least so. Of the four chromophoric elements detected in the Rhodesian emeralds (viz. Cr, Fe, Ni, Mn) it likewise seems that chromium is the one most readily accepted. It was a little disappointing that no data on vanadium was forthcoming from this investigation. Campbell (1975) has reported emeralds or pale-green beryl of ambiguous colour from the Filabusi area, Rhodesia, but we have not examined any samples.

The alkali substitution in these emeralds is of interest. In all cases the order of abundance is $Na > K > Li$, whereas for the host rock, it is $K \gg Li \simeq Na$. The Na_2O levels for the emeralds are quite high, ranging from 1·14 to 4·04 wt%, the latter value being for a Chikwanda stone and close to the maximum value reported for any beryl (see Table 4). Alkali substitutions in beryl are necessarily coupled substitutions involving other ions in order to maintain charge balance. This is most likely achieved by concurrent substitution of a divalent ion for Al^{3+}, or by the leaving out of an occasional beryllium ion to form a vacant lattice site, e.g.,

(*a*) $Be_3.Al_{2-x}(MgFe^{2+})_x.Si_6O_{18}.(Na_x,nH_2O)$

or (*b*) $Be_{3-\frac{x}{2}}.Al_2.Si_6O_{18}(Na_x,nH_2O)$

Since the emerald analyses given are only partial analyses, with no data on beryllium content or iron valence, it would be hazardous to suggest which type of substitution might be predominant. Both would cause an increase in specific gravity compared to ideal emerald, with the former type more so.

The origin of emerald and the differences from that of beryl have been discussed by Martin (1962), from observations made on the same Rhodesian occurrences. Of particular importance is the small size and irregular nature of the pegmatites and the ability of the beryllium to diffuse out into the country rock. In the case of the Twin Star emerald locality and the Novello alexandrite occurrence, this migration of beryllium-containing fluid has been over considerable distances and has resulted in crystallization of beryllium minerals within seams of phlogopite rock, enclosed within the serpentine. Martin has suggested that the ultramafic host-rock (i.e. serpentine or dunite) has a natural "tightness" and plasticity which results in intrusion of only small and irregular-shaped pegmatitic bodies, which are in contrast to the large, linear pegmatites found in the more fractured rocks, such as greenstone and granite, from which the bulk of industrial beryl is mined. Certainly the smaller or thinner the pegmatitic vein, the more chance there might have been for beryllium to diffuse into the country-rock. However, there are in other parts of the world instances of narrow pegmatite veins carrying beryl, which show no evidence of adjacent emerald or beryl crystallization in the country rock. A suitable example would be the Mica Creek Pegmatite near Mt Isa, Australia. Here, a near-vertical pegmatite outcrops in schistose rocks over several hundred metres and ranges from 0·5 to 3 metres wide and in places contains beryl crystals up to 20 cm in size together with quartz, feldspar and muscovite. In order to try and explain these field observations perhaps a little speculation may be permissible.

During the pegmatitic stage of crystallization, which is defined as when crystals coexist with a silicate magma and an aqueous-rich fluid, any beryllium present may itself be immobile and confined to the pegmatite vein, i.e. beryl crystallizes within the pegmatite. On the other hand, in the hydrothermal stage of crystallization, which is defined as when crystals coexist only with an aqueous fluid (or aqueous liquid and vapour), i.e the silicate magma has been exhausted or crystallized, any beryllium remaining is now much more mobile and may be transported via a hydrothermal fluid along shear zones in the country-rock. It is suggested that emerald crystallization tends to be associated with that very hazy "in between" period of mineralization whereby pegmatites grade in hydrothermal veins. This may explain why the Rhodesian emeralds are associated with very small pegmatites and quartz veins.

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EPIPHANIUS ON GEMSTONES

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EPIPHANIUS, Bishop of Salamis in Cyprus, was born in Palestine at the beginning of the 4th century A.D. His reputation for both erudition and piety grew and impressed deeply all who knew him, including Jerome who called him "five-tongued" in allusion to his command of Greek, Syriac, Hebrew, Coptic, and Latin. But although his learning and reputation for honesty protected him to some extent from persecution by the Arian Emperor Valens, they were not sufficient to prevent his becoming embroiled in a quarrel over Origen's orthodoxy, which involved not only himself but also Theophilus of Alexandria and John Chrysostom. In fact, a strain of naïveté runs through his work. A myriad facts and ficta have been acquired but not assimilated, and Photius had no hesitation in criticizing his style as "low and careless".

The pamphlet on the twelve stones of Aaron's breastplate has come down to us in different versions, the Greek *Peri Lithōn* (ΠΕΡΙ ΛΙΘΩΝ) being an abbreviation of a much longer work. It is a description of and commentary on the Septuagint version of *Exodus* 28.17-20, (3rd century B.C.). We have Jerome's assurance that Epiphanius himself had given him a copy of the work and indeed he quotes from it in his commentary on Isaiah.[1] This original version, however, has been lost, and what we have are two parallel epitomes of the section which described the stones. There are also versions in Latin, Georgian, Syriac, Coptic and Armenian.[2] The Greek text is to be found in Migne: P.G. 43.294-302, and what follows is a translation (printed in italic) of and brief commentary (printed in roman) on the Greek epitomes.

De Gemmis[3]

1. The first stone is called a Babylonian sard. It is flame coloured and blood red, like a pickled sardion fish which derives its name from the colour. It is translucent and doctors use its therapeutic power to heal swellings and wounds inflicted with iron. There is another stone called sardonyx, also

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[1] *In Isaiam* 15.54—Migne: P.L.24.525.

[2] For a full account see H. de Vis: *Epiphanius de Gemmis,* (London, 1934).

[3] Written just before 394 A.D.

known as molochite, which can soften sebaceous tumours. Both these stones are greenish. The sard is very influential, especially during the first days of Spring when these illnesses begin.

Sard is a brownish form of chalcedony, but Epiphanius's stone sounds more like cornelian. Theophrastus (*De Lapidibus* 30) says that the translucent, redder kind of sard was the "female" of the species. Both it and the darker "male" variety were extensively used for seals, especially in the Aegean area, as Pliny tells us [*Historia Naturalis* 37.31 (106)]. Exactly what was the sardion fish I do not know. Sarda became a very general name not only for pickled Tunny and Pelamyd but for a great variety of other potted fish, as D'Arcy Thompson says.[4] Molochite simply means "fibrous" and probably refers to the laminate structure of sardonyx. "Greenish" is a puzzle, unless Epiphanius is referring to another type of chalcedony which is grey or greyish-blue, fibrous to crypto-crystalline, found in fissures and cavities in basaltic rocks.[5]

2. The topaz is bright red, even more than an anthrax. *It is found in Topaz, a city of India. Some masons once were quarrying stones there when it appeared in the middle of another stone they were cutting. They saw how brilliant it was, told certain [Theban] buyers it was alabaster,[6] and sold it to them for a small sum of money. The Thebans then approached the Queen who was ruling [Egypt] at that time. She took the stone and placed it in her crown, right in the middle of her forehead. The gem has the following property when tested. When it is rubbed on a doctor's whetstone the liquid it exudes is not bright red like itself but milky, and fills as many drinking bowls as the grinder wishes. Moreover, it remains the same weight as when he started. The juice from it is used to anoint diseased eyes, and drinking it is good against dropsy and for those dying from [eating] "sea-grape".[7]*

The topaz described by Pliny was green, almost certainly the modern peridot, though in medieval authors the word is used for a yellow stone. It is true that nowadays a red topaz is known, but this is because the name topaz has been restricted to aluminium fluosilicate. Natural red stones from Brazil have been found occasionally and it is possible to produce a rose-pink shade in some of the brownish-yellow Brazilian stones by the application of heat. But it

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[4] *A Glossary of Greek Fishes*, (London, 1947), 229.

[5] Pliny, however, describes molochite (malachite?) as a green stone, [37.36 (114)], as does Isidore: *Etymologiarum Libri* 16.7.11.

[6] The Greek here is corrupt. Presumably "Thebes" refers to the city in Egypt.

[7] Probably a kind of fish. See Pliny: 32.49 (138).

seems fairly clear that Epiphanius's topaz is not the same as our stone. Perhaps his reference to the *anthrax* is not fortuitous and indicates that his topaz is actually a kind of almandine. The name almandine is a corruption of albandine from Alabanda in Asia Minor—hence the curious reference to alabaster, which otherwise does not make sense. Almandine is very brittle and therefore would grind easily to a powder.[8] Epiphanius's account, however, may be a remarkably garbled version of a passage from Juba [apud Pliny: 37.32 (108)] which recounts a tale about the peridot (topaz). "Juba states that Topazos is the name of an island situated in the Red Sea . . . Juba records that the stone was first brought from here as a gift for Queen Berenice, the mother of Ptolemy II . . . The stone is found also near Alabastrum, a town in the Thebaid". Here we have "Topazum" and "in rubro mari" close together, as well as references to an Egyptian Queen, and Alabastrum, a Thebaid city. Confused tradition may well have turned the topaz into a piece of red alabaster sold in Egypt by Thebans—hence Epiphanius's version.

3. The smaragdus, *also called* prasinus [*leek-green*].[9] *It also*[10] *is green and there are various kinds. Some are called Neronian or Domitian. The Neronian is sharp in colour,*[11] *very green, transparent and brilliant. They say it is called a Neronian (or Domitian) for the following reason. Nero (or Domitian) poured oil into the appropriate vessels and after a while the oil turned green on account of the verdigris. A rock which was liberally soaked with this oil turned yellowish-brown. Some people say that Nero discovered an ancient worker in mother-of-pearl, or a gem-cutter, or the most effective way to deal with* smaragdus, *and therefore it was called Neronian. Others* [*prefer to use the term*] *Domitian. But there are other types of* smaragdus. *One, which is found in Judaea, is very like the Neronian. Another is found in Aethiopia by the River Phison.*[12] *The Greeks call this river the Indus; the natives call it the Ganges. The* anthrax *can also be found in the*

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[8] The *New English Bible* translates topazion as chrysolite, but it is obviously not Epiphanius's stone. It is unfortunate that the NEB translators have chosen "chrysolite" because the name has been used at different times for different stones, and should really be used these days only to refer to olivine. Besides, both the Septuagint and the Vulgate, as well as Epiphanius, have chrysolite as a tenth stone, so it is unnecessarily confusing to use it as a name for the second.

[9] Cf. Theophrastus: *De Lapidibus* 37. Pliny: 37.34 (113).

[10] The Greek implies that the preceding item was green too, as the topaz of Pliny almost certainly was.

[11] I.e. an acid green. The text, however, is doubtful. Another reading could be "small in size."

[12] Aethiopia often referred vaguely either to North Africa or to India. Phison is referred to in *Genesis* 2.11.

same river. "There are found the anthrax *and* prasinus".[13] *They say that this gem* [*obviously the* smaragdus] *has the ability to reflect one's face as in a mirror. Novelists maintain it gives one power to foretell the future.*

Smaragdus is a word which covers various types of beryl, including aquamarine and emerald. *Prasinus* refers to prase, a dark leek-green chalcedony or, possibly, to quartz coloured by actinolite fibres inside it. The name Neronian almost certainly arises from Pliny's story that Nero looked at a green stone to relieve his eyes from the glare of the arena.[14] Pliny also says (*ibid.*) that certain *smaragdi* have the power to reflect objects just as mirrors do. "Aethiopian" *smaragdi*, according to Juba, were bright green but usually had flaws and were not uniformly tinted.[15] These stones actually came from Egypt. Theophrastus (23) says that the *smaragdus* turns water green and he may be right, since if the stone is placed in an opaque white vessel and illuminated obliquely from above the water may well take on a greenish cast.

4. The anthrax *is a bright, sharp red and is found in Libyan Carthage in Africa. Some people, however, say that the gem is to be found like this. It cannot be seen during the day, but at night it shines from afar like a lamp or sparking ember and so gives light from a great distance. Those who look for the stone know this and so it is easily discovered. Anyone who wishes to steal it cannot walk off with it unnoticed, because if he conceals it inside his clothes, the glow shines out through the folds. This is why it is called a carbuncle. For a while the heliotrope, which is called "wine-faced", was supposed to be similar. There is a chalcedony quite like it which is found in the same place.*

Epiphanius's evidence is contradictory here. If the stone is bright red it cannot be like a darker, more violet-coloured stone (the heliotrope). The word *anthrax*, however, was used to cover a

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[13] *Genesis* 2.12. Epiphanius gives the Septuagint version. The Hebrew refers to bdellium and onyx (*bedholah* and *shoham*), a version followed by Jerome (*bdellium et lapis onychius*), as well as later translators. The discrepancy simply means that there were different Greek versions available in ancient times and that Epiphanius used one rather than another. Even the Hebrew can vary. See E. Wurthwein's comments on Jeremiah in *The Text of the Old Testament*, trans. P. R. Ackroyd, (Oxford, 1957), 37.

[14] 37.16 (64). He did *not* use the stone as an eye-glass. This suggestion was made by C. W. King in *The Natural History . . . of Precious Stones*, etc., (London, 1865), 322-3, based upon an inferior MS. reading. In his Loeb edition of Pliny's *Historia Naturalis* (1962), D. E. Eichholz suggests that Nero looked at the stone to relieve his eyes from the glare of the arena. Cf. Pliny: 37.16 (62-3). J. W. Meadows noted that "the green mineral found in copper deposits [is] good for the eyes," and ground malachite was certainly used as a cosmetic. "Thus the beneficial properties of malachite would be attributed to all the stones that were called by the same name," and so *smaragdus* which had begun by referring to crystals of green malachite was later restricted to the finest varieties of green stone and so to the emerald. the best of all. Thus the emerald inherited not only the name but also the properties of *smaragdus*; "Pliny on the Smaragdus," *Classical Review* 59 (1945), 50-51.

[15] Quoted by Pliny: 37.18 (69).

wide variety of crimson-red stones and here it may refer to *pyrope* which is blood-red but can deepen to purplish if its constitution approaches that of almandine. Theophrastus (18) also describes the *anthrax* and correctly implies that Carthage was simply a port of export and not the locality where the stone was to be found. Archelaus observed that Carthaginian stones were rather dark, appearing dark red or violet indoors and flame red in the open air.[16] Perhaps this accounts for their being likened to heliotrope.[17]

5. The sapphire is a deep crimson, like the colour of dark purple [porphyry].[18] *Many varieties of this can be found. One is "basiliscus", stippled with gold. This stone is not admired quite as much as that which is completely crimson. Apparently "basiliscus" is found in India and Aethiopia. It is said that in India there is a temple of Dionysus which has 365 steps made of sapphire leading up to it, though most people do not believe it. It is a marvellous stone, very beautiful and elegant,*[19] *and is often made up into anklets and small necklaces, especially for Kings. It can ward off pain. Ground up with milk, it heals the scabs from pimples and tumours when smoothed on the sore places. It is written in the Law that when Moses beheld his vision on the mountain and was given the Ten Commandments, he stood upon sapphire stone.*[20]

This is an extraordinary passage because "sapphire" in the ancient world referred to lapis lazuli—almost certainly the stone in *Exodus*[21]—and the gemstone is, of course, blue. *Porphyrizōn*, Epiphanius's adjective, is a tricky word to translate because its meaning is much disputed, but there can be little doubt that some shade of deep red is always meant by the term.[22] Imperial porphyry from Egypt, so Pliny tells us, was red, mottled with white dots, [36.11 (57)]. In the same place he describes the properties of two other stones, *ophite*, a light green marble, and *mephis*,[23] which leads me to

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[16] Quoted by Pliny: 37.25 (95).

[17] A stone which must have been violet or purple in colour. The *heliotrope* described by Pliny [37.60 (165)] was a green stone extensively streaked with red, not in the least wine-faced or carbuncular.

[18] This word may have slipped into the text from a marginal note.

[19] Or, "very finely coloured and very beautiful".

[20] *Exodus* 24.10.

[21] The NEB translates *Exodus* 28.18 by "lapis lazuli".

[22] There is a very full discussion by H. Gipper: "Purpur," *Glotta*, 42 (1964), 39-69. He supplies a colour example of "purple" which is a shade of crimson. One may compare with this the frontispiece to L. M. Wilson: *The Clothing of the Ancient Romans*, (Baltimore, 1938), which shows seven different shades of "purple" obtained from recipes in the *Papyrus Graecus Holmiensis*. Only one has the slightest blue tinge to it. All are obviously variations upon red. Cf. F. E. Wallace: "Colour in Homer and in Ancient Art," [Smith College Classical Studies, 9 (1927), frontispiece], which shows the reddish shade for "purple."

[23] Possibly Dolomite.

wonder if Epiphanius (or his epitomizer) has not vaguely remembered this passage and attributed the qualities of very different stones to lapis lazuli. How the discussion became attached to sapphire is a mystery.[24]

6. The iaspis *is similar in colour to the* smaragdus. *It is found near the banks of the River Thermodon and round Amathus, a city in Cyprus. There are many varieties of "Amathusian" stone. Its colour is greenish, like that of* smaragdus, *but duller and more cloudy. Inside it glows green like copper rust, with four rows of veins. I have heard (and novelists also say this) that it disperses hallucinations. Another kind is bluer than the sea,*[25] *deeper than flower or dye.*[26] *Another is found in the caves of Mount Ida in Phrygia, similar in shade to shell-fish blood, but brighter (like wine), or deeper*[27] *than amethyst. You see,* iaspis *has more than one colour or potency. A fourth is more porous, lighter in colour, does not shine at all, yet is not altogether devoid of [power]. A fifth is like frozen water; novelists say it is a cure for hallucinations.*[28] *It is found in Iberia and among Hyrcanian shepherds who live in Caspia. There is another* iaspis *called "antique" which is like snow or sea-foam. Novelists say it frightens off wild beasts from one's land, and ghosts.*

It is fairly clear that Epiphanius is not describing what we mean by *jasper*. The term obviously covered what are now regarded as a number of separate gem materials. including many varieties of quartz, (prase, blue chalcedony, cornelian, rose quartz, rock crystal, etc.) and quite possibly malachite, azurite, and even jade, although this is not likely to have been common in the Mediterranean area. Pliny refers to Orientals preferring green *iaspis* which they wore as an amulet, [37.37 (118)] and this seems to indicate jade. Galen says that the most powerful *iaspis*, a pale yellowish-green colour, came from Aethiopia and that the light-green variety was a good charm against ailments of the stomach.[29] This green variety could be

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[24] The word I have translated as " crimson" (*porphyrizōn*) is given as "purple" or "purplish" in the Lexicons, but this is very misleading, as it conjures up an impression of dark reddish blue which is not the shade intended by ancient usage. Pliny says that lapis lazuli (*sappiri*) is also light blue and only rarely tinged with crimson (*purpura*), [37.39 (120)]. This is repeated, in garbled fashion, by Isidore, who omits the word "rarely", [*Etymologiarum Libri* 16.9.2.]

[25] *Glaukos* always refers to blue-grey.

[26] The alchemist pseudo-Democritus tells us that *anthos thalassion* was a dye made from sea-weed. *Glaukos* dye was also made from woad, and therefore blue.

[27] The text is confused. It actually reads, '"more yellowish-brown", but this is nonsense when referred to amethyst, though it would describe a form of agate. "Deeper" is an alternative MS. reading.

[28] Perhaps for DT's, since amethysts—with which the *iaspis* is compared—were worn to counteract the effects of drunkenness.

[29] Quoted by Aetius of Amida: *Libri Medicinales* 2.18. Cf. *Ibid.* 2.36.

malachite or jadeite, which agrees with Pliny's description of its having white lines running through it, and Epiphanius's mention of "veins".[30] The blue was probably common blue chalcedony or azurite; the white, milky quartz; the colourless, rock crystal. I suspect that the red-violet variety may well have been amethyst itself.[31] "Sea-foam" *iaspis* could, perhaps, be meerschaum or pumice. Theophrastus's *malōdēs* suggests *mēlōdēs*, as Caley-Richards point out, ("Theophrastus on Stones", Ohio, 1956, page 49, note 19), whose colour would be pale yellow, like the *hypochloros* of Galen's Aethiopian *iaspis*. Could the pumice "from the foam of the sea" have been incorporated into the general term *iaspis*, too?[32]

7. The ligyrion. *I cannot discover at all where this stone is to be found, though I have consulted both natural scientists and ancient authorities who keep the history of such things. There is a stone "lankurion" which is called "lagurion" in a particular dialect, and I am convinced that this is* ligyrion *since the Scriptures transpose names—for example,* smaragdus *for* prasinus. *Among the names of gemstones they do not mention "hyacinthus", and yet it is an outstanding and valuable stone. Thus we have come to believe that there is no stone called* ligyrion *in Holy Scripture. Well now,* hyacinthus *has several forms. The more deeply coloured the variety, the more valuable it is regarded as being. It is similar in colour to wool which has been dyed crimson*[33] *a number of times. Holy Scripture says that the High Priest's vestments were dyed with hyacinth and crimson,* (porphyra)[34]. *One variety is called "sea-shade"; a second, "rose"; a third, "natural";*[35] *a fourth, "sea-perch";*[36] *a fifth, "part-white". They are found in the wild interior of Scythia, are highly prized, and have the following magical properties. If you throw them into a fire, they are not spoiled but put the embers out. Not only that, if anyone carries the stone wrapped in linen and puts it on to the hot coals, the linen wrapping does not catch fire either, but remains undamaged. The stone is said to be good for women in labour who want an easy birth. It also drives away ghosts.*

According to modern authorities, *ligyrion* was probably

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[30] 37.37 (118). The NEB also translates *iaspis* as "jade", *Exodus* 28.18.

[31] See Pliny: 37.40 (121).

[32] Theophrastus: 22.

[33] The awkward word *hypoporphyrizōn*, again.

[34] *Exodus* 28.5.

[35] Literally, "native", presumably meaning it was the natural colour of the hyacinth.

[36] *Channiaeus*. The derivation is uncertain. "Spongy" could be an alternative.

amber.[37] Epiphanius obviously thinks that the stone is more likely to have been a form of hyacinth (or jacinth), which may, indeed, be yellow, but it is unlikely that the varieties of hyacinth refer to types of zircon, as the *Encyclopaedia Britannica* (11th edn) [14, 25] suggests, because zircons come mainly from south-east Asia, and as far as I know, no ancient examples have been found. The tale that it could be thrown into fire without being damaged suggests remarkable hardness.[38] Pliny's hyacinth is probably blue corundum [37.41 (125)], a stone he compares with amethyst and finds wanting. Sapphire could well be what Epiphanius means by "sea-shade". "Sea-perch" could be yellowish-grey or silvery-blue.[39] Pink ("rose") and colourless ("part-white") stones are rare, but can be found. The main puzzle, however, is his reference to the hyacinth's being the colour of crimson wool. "Blue-john", the finest material, was violet or purple in colour, but came from Derbyshire in England. Trade with the Middle East might well have taken specimens as far as Cyprus or Palestine, but I do not know of any examples being found.[40] Theophrastus (16 and 29) mentions that amber was dug up in Liguria. It is possible that *ligyrion* originally denoted Ligurian amber, a more plausible etymology than "lynx-urine" which Theophrastus assumes (28).[41]

8. Agate.[42] *This is supposed to be the gem called "white-edged" which I mentioned in my discussion of the hyacinth.*[43] *It is an amazing stone, a rather dark blue, with a white circle round the outside, like marble or ivory. It is found round about Scythia. There is a type of agate which is the colour of a lion. When ground up with water and smeared on bites or stings it drives away the poison of a scorpion, or of vipers and such-like creatures.*

Pliny's description of agate [37.52 (139-143)] mentions a large number of stones which might or might not be classified nowadays as agates. Both the blue and the "lion-coloured" varieties described by Epiphanius are almost certainly true agates. Pliny, too,

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[37] E.g. D. E. Eichholz: *Theophrastus de lapidibus*, (Oxford 1965), 108-9.

[38] Hyacinth or jacinth are terms now used only for red-brown zircon or hessonite garnet.

[39] See D'Arcy Thompson: *A Glossary of Greek Fishes*, 284.

[40] NEB translates *ligyrion* as "turquoise" which is unlikely to be right.

[41] The Old Georgian version of Epiphanius describes an animal called *lygyron*, "which is of the colour of the wild cow, like a red heifer, and on the tip of its tail it has a bunch of hair which gives off a greenish reflection. It is called *lyngos ouros*, i.e. "lyngos-tail", (de Vis.).

[42] *Achatēs*. See E. Sarofim, "Origin of the name Agate," *J. Gemm.* 1969, XI, 6: 203. Over the centuries the spelling of the word has varied. It appears first in English in the *Ancren Riwle* (c.1230).

[43] He called it "part-white" before, but the text could be faulty.

mentions the agate's supernatural power (*sacra*) over the bites of spiders and scorpions (*loc. cit.* 139).

9. Amethyst. This has a deep flame-coloured band around it. It is rather pale[44] *in the middle and emits a "wine-like" colour. It also has various forms and probably comes from the mountains of Libya.*[45] *One variety is rather like a pure hyacinth; another is similar to the murex-fish. It can be found on the sea-banks of Libya.*

Pliny's description is well-known. "The reason for its name is said to be that it approaches the colour of wine but shades off into violet before it reaches this colour," [37.40 (121)]. He also mentions a variety in which the purple fades into white (*ibid.* 123) and that is probably the impression Epiphanius wishes to convey about his first stone which reminds one of the reddish-violet colour of "Siberian amethyst". The "hyacinthine" is the ordinary purple variety; the "murex", a purplish or deep crimson stone. The *New English Bible* translates "amethyst" as "jasper"[46] and this may well be correct for Epiphanius's gem, since his word *amphicochlos* describes the shell of the murex-fish and hints at bands in the colour.

10. Chrysolith. Some people call this stone chrysophyllon. *It has a fairly golden colour and is found in the two faces of rock on the reservoir near the walls of Persian Babylon. Both Babylon and the reservoir are called Persian (Achaemenid) because that was the name of Cyrus the Great's father. There is also* chrysopastus *which doctors grind up and give their patients to drink to cure ailments of the stomach and bowels.*

The chrysolith is probably yellow corundum, for example, yellow sapphire,[47] a fairly pale variety. "Chrysopastus" simply means "shot through with gold". The *New English Bible* translates chrysolith as "topaz", and it may be that citrine, which for many years was not distinguished from topaz, is the stone described by both Pliny and Epiphanius.

11. The beryl is bluish,[48] *the colour of the sea or of a rather watery hyacinth-stone. It is found round the base of Mt Taurus. If you hold up the stone to the sun and peer through it, it appears to shine like glass, with brilliant millet-grains within. Another beryl is like the pupils of a dragon's eyes, and another like wax. This one is found about the mouth of the Euphrates.*

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[44] Various other translations are possible, paler, whitish, rather white, whiter.

[45] Horace mentions the African purple industry: *Odes* 2.16^{36} and so does Propertius: 4.3^{51}.

[46] *Exodus* 28.19.

[47] Cf. Pliny: 37.42 (126).

[48] *Glaukizōn*. See above, note 25. Pliny calls this type green, 37.20 (76).

There is no difficulty in identifying both the blue and greyish-white stones, as both are indeed common varieties of beryl.[49] Beryls were then probably not free from impurities, and I presume it is these Epiphanius means by "millet-grains".[50]

12. The onychion *is very yellow-brown.*[51] *They say that girls who wed royalty or money particularly like this stone because they can have it made into drinking-cups. Other stones, ambiguously called* onychia, *are like the colour of a honey-comb, and some people say that they have been created out of disordered water.*[52] *They also say that* onychitae *are named from their natural colour since onyx is blood-red, like the marble used by the Smart Set.*[53] *Others, without investigation, inaccurately call the marble "onychite" in view of its being pure white colour.*

Various types of stone are mentioned here. *Onychion* is perhaps some form of banded chalcedony, though I suspect that since it can be worked into cups it is more likely to be another type of *onychia*—stalagmitic calcite, which is sometimes commercially still called "oriental alabaster" and "onyx marble". This was extensively quarried in ancient Egypt and much used for vases, statues, and the ornamentation of buildings. Pliny calls it *alabastrites.*[54] He warmly recommends honey-coloured onyx but does not at all approve the gleaming white or "glassy" look. It is the latter which Epiphanius probably means by his frozen stone. Red marble may be red granite from Egypt and the stone which is like it, sardonyx.

I am very grateful to Mr J. R. H. Chisholm for reading and commenting upon an earlier draft of this article.

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[49] NEB translates "cornelian".

[50] Modern aquamarines are almost certainly free of impurities, but that is because they come mainly from sources, such as Brazil and Madagascar, which are unlikely to have been available in ancient times. Pliny says that all beryls have flaws or inclusions and that those without them are pale and lifeless, 37.20 (77).

[51] See also Theophrastus: 31 and Pliny: 37.24 (90-91).

[52] This does not make sense and the text needs emendation. The verb can mean "to freeze" and it looks as though Epiphanius means that the marble has the appearance of frozen or petrified liquid. Rock crystal was believed to be frozen water, frozen so hard that it would not melt again, and it looks as though Epiphanius is recording a similar belief about some onychia. Could the idea refer to frozen Nile water? This would be yellow because of the river's alluvial content.

[53] Literally, "elegant, charming, witty men."

[54] 36.12 (61) and 37.54 (143).

A GEOLOGICAL CURIOSITY*

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ACCORDING to the saying, "history never repeats itself". One could say the same of the problems met by the jeweller-gemmologist. Their variety is illustrated by a problem on the border of gemmology, which at the same time is a geological enigma whose subject was revealed to the Lucerne Geological Congress in 1968 by Dr U. P. Büchi.

We are sometimes indebted to the daily press for a great many surprises: a news item written hurriedly and with a lack of knowledge of the subjects tackled and in emphatic stop-press style often envelopes the various facts in a cloak of mystery which makes them attractive in the readers' eyes. This has happened with the fact described below. A number of newspaper articles published towards 1965 in Switzerland and Germany have announced the discovery of "fossil black pearls" of great beauty and great value. Their quality has been compared to that of the most beautiful oriental pearls. The man who made the discovery is an amateur of geological curiosities who seems to have quite a flair for the discovery of rarities: Mr E. Glanzmann lives near Langenthal: he is a farmer, and long contact with nature has developed his inborn gifts of observation. Whilst studying the geological make-up of his land he observed, in a quarry of building-stone, some strange opaque black spherular objects embedded in the rock. By digging, he freed them from their matrix. They are illustrated in Figure 1.

If you would believe the journalist, you would become excited over "the precious formations of inestimable value showing the same quality as oriental pearls". If, however, these little black balls are held in the hollow of your hand, their blackish colour, their lack-lustre surface and their unassuming appearance leave you with a much poorer impression. It seems, however, to be truly a new discovery. Such ball-like formations seem to be a unique case. What is their origin? To find out, I suggest a journey to Switzerland.

The place where they were found is on the Swiss Plateau about 30 km north-west of Berne. It was at Oschwand (known as having

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been the residence of the painter, Cuno Amiet), in an isolated and peaceful part of the Bernese countryside, that in rural calm and quiet I met Mr E. Glanzmann, who did me the honours of his lands and showed me the place of the discovery, which can be seen in Figures 2 and 3. After having found the black balls he had an identification problem to solve. The unusual nature of the case made it a

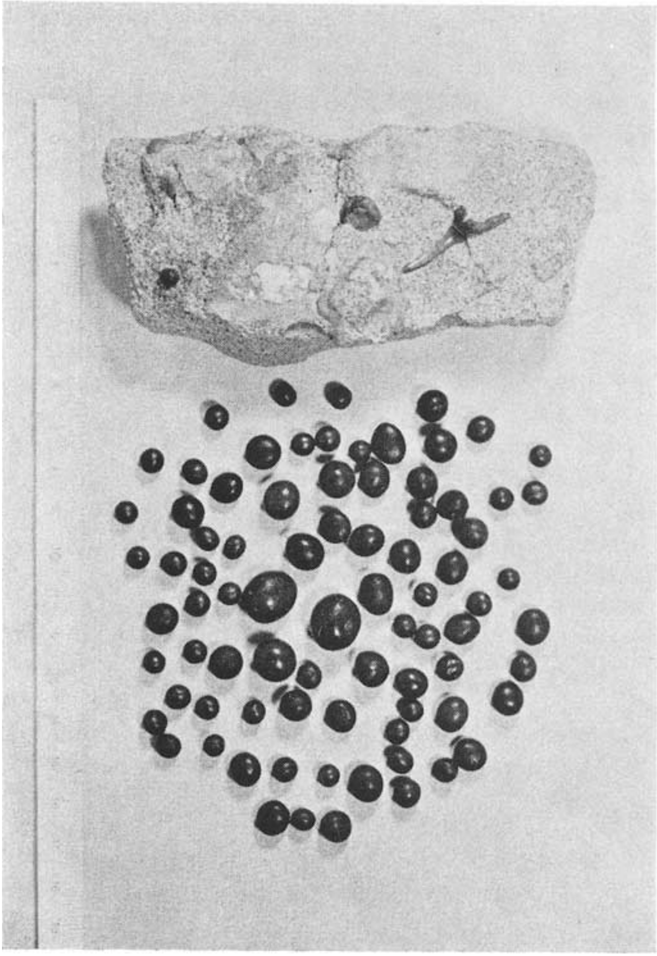

FIG. 1. Piece of grey-brown sandstone, with two spheres *in situ*, as well as a fossil, at right, and a *scutella* (convex part slightly darker grey than the colour of the sandstone). Below, a number of balls taken out of their matrix and cleaned.

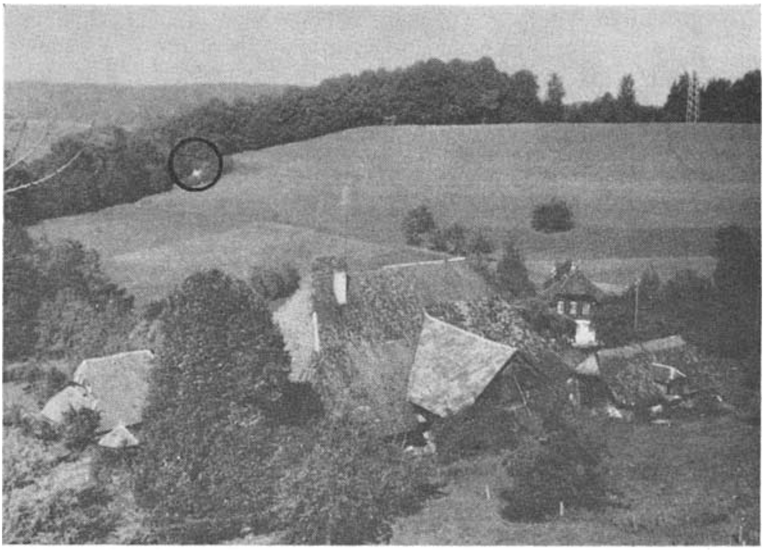

FIG. 2. General view of Oschwand: the quarry is high on the left, at the edge of the trees. The spot is marked by a circle.

FIG. 3. Oschwand: the building-stone quarry.

problem for a geologist, and Mr Glanzmann sought the explanation among several geologists. But, as there were no precedents, they have not so far been able to pronounce a final judgment on the origins of these objects. Towards 1965, however, contrary to the journalists' imagination, Professor F. Rutsch, of Berne University, declared that there was no question of their being fossil pearls, without propounding any other hypothesis for their provenance. Some of the savants with whom Mr Glanzmann had made contact have taken an interest in the question and tackled it systematically. The results of their research have been embodied in a paper by Messrs U. P. Büchi and G. Wiener.* Before reporting the main features of this study, let us first consider the more modest results of a routine gemmological examination.

Colour: black, sometimes a little greenish, opaque.

Shape: generally spherical, sometimes ovoid or slightly flattened. Some specimens have a slight surface depression.

Dimensions: diameter varies from 3 to 10 mm: a single ovoid specimen is 18 mm long.

Specific gravity: rather variable: 8 specimens, measured by hydrostatic weighing, using dibromoethane, gave results of 2·01 to 2·59, which probably indicate their irregular compositions. There was no obvious porosity.

Refractive index: the irregular surface does not allow a precise reading to be obtained on the refractometer, even by the distant-vision method: a vague shadow-edge may be seen at about 1·55.

Fluorescence: under x-rays, inert: under long-wave ultraviolet, inert: under short-wave ultraviolet, inert.

Microscopic examination: the surface is granular in texture: small colourless crystals are sometimes visible at the surface: the outer layer of the spheres is harder than the interior.

Radiography: radiographs of 5 specimens showed more or less great permeability, evidenced by a spotted appearance of the film, but with no regular structure recognizable.

The limitations of gemmological methods did not permit a definite conclusion to be reached on the identity of these spherules and from now on we have recourse to other disciplines. The following account is based on the work of Messrs Büchi and Wiener, which it summarizes.

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*Bull. Ver. Schweiz. Petrol. Geol. Ing., 1967, 34, 85, 17-28.

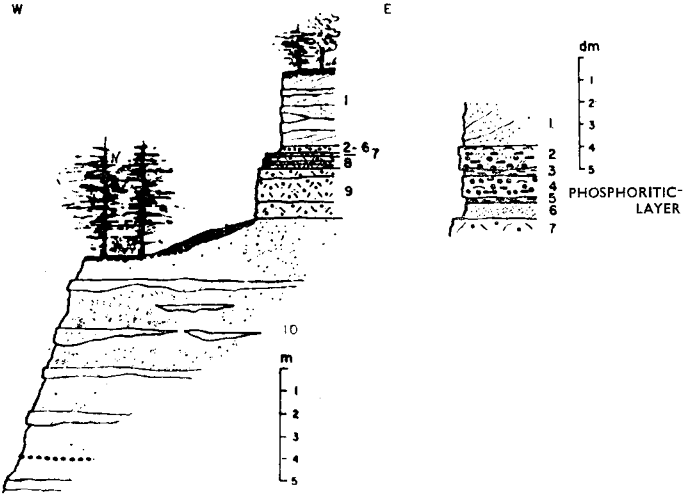

Fig. 4. Geological profile of the Oschwand quarry.

1. Medium to coarse calcareous sandstone, carbonized remains of plants and drift-wood: minimum thickness 3·00 m.
2. Medium calcareous sandstone with rolled pebbles and numerous marly pebbles, fossils, shells and *scutellae:* thickness 0·08-0·12m.
3. Brown and beige marl: thickness 0·01-0·03m.
4. Phosphoritic layer in which the black spherules were found: medium and grey-beige calcareous sandstone, numerous alpine pebbles, marly vesicles: various fossils, in particular *scutellae*, to whose presence the black balls are related: thickness 0·01-0·12m.
5. Light beige marl: thickness 0·02-0·03m.
6. Calcareous sandstone, medium, grey-blue, small alpine pebbles: thickness 0·07-0·15m.
7. Shelly calcareous sandstone, grey-blue, hard, alpine pebbles: thickness 0·22m.
8. Shelly sandstone, calcareous, grey-blue, hard, pebbles: thickness 0·70m.
9. Shelly sandstone, calcareous, grey-blue, pebbles in banks of 0·30-1·00m., thickness 2·00m.
10. Coarse to medium sandstone, grey, with strong calcareous deposits: at about 11m under the base of the sandstone, a band of pebbles: gradient of the bed about 8° towards SE.: thickness 13·00- + Xm.

Geology of the Region

The two places where black spheres were found (Oschwand and Stouffenbach) are situated in the shelly sandstone of the upper marine molasse. The profile of the building-stone quarry at Oschwand is illustrated by Figure 4. The most interesting part of this sectioned view is the phosphoritic bed No. 4, rich in alpine shingle and locally in fossils, in particular large *scutellae* up to 80 mm in diameter. This is the bed in which the black spheres were found. They lie sparsely in the sandstone, with some local concentrations.

Petrographical Examination

In thin section under the microscope the spheres have a fine structure, which is irregular and without any sign of concentric growth-zones. The chemical composition is largely phosphatic (fine skeleton of colophony slowly soluble in HCl but not in organic acids). This calcium phosphate is practically amorphous and impregnated with microcrystalline calcite. The components of the host-rock (sandstone) are not present, or only in minimal quantity. On the surface, the balls are partly impregnated with glauconite. The sand grains have penetrated the material, from which it follows that the spheres were relatively soft at the time of their deposition in the sand. This latter has a different composition: in the compacted parts, about 35% carbonates and about 5% dolomite, with glauconite quite frequent.

Examination in the light of sedimentary petrography shows that there is no question of their being fossil pearls: the chemical composition excludes this possibility and, moreover, the concentric structure of a pearl is lacking. The phosphate content and the other peculiarities show that we must rather consider whether they may be coprolites.

MICROPALAEONTOLOGICAL FINDINGS

In thin sections the black spheres are characterized by the presence of fossilized micro-organisms, some of which Professor Reichel, of Basle, has been able to identify (Figures 5, 6 and 7). By way of comparison, Fig. 8 is a photograph of a thin section across a clayey nodule from the surrounding phosphoritic bed showing numerous remains of micro-fossils. The difficulties in identifying the micro-fossils found and their small number did not permit of the black spherules' age being determined by palaeontological methods.

ORIGIN OF THE PHOSPHATED BALLS

In principle, the objects may be of either organic or inorganic origin. J. Schadler (1932, 1934, 1944) has described larger objects, of irregular shapes, found in the Austrian oligocene and miocene, which are partly of inorganic origin. It seems, however, that some organisms have contributed to the phosphatic enrichment.

The products of the Oschwand and Stouffenbach localities, however, are very different from the Austrian objects, in respect both of shape (spherical) and of size (maximum diameter about 10 mm). The Austrian finds have been partly designated as being coprolites of terrestrial mammals.

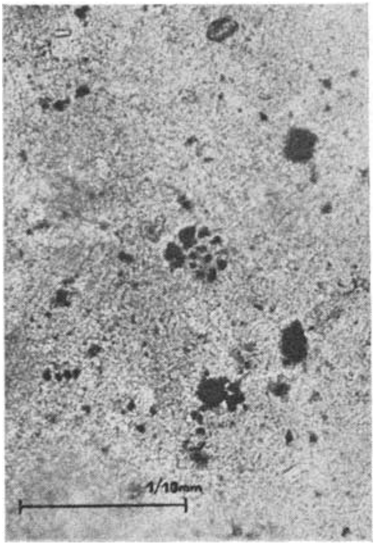

FIG. 5.

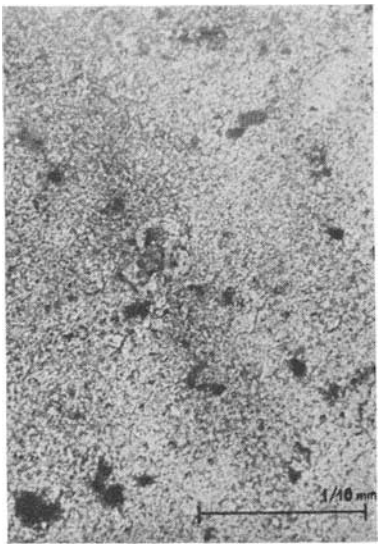

FIG. 6.

FIG. 7.

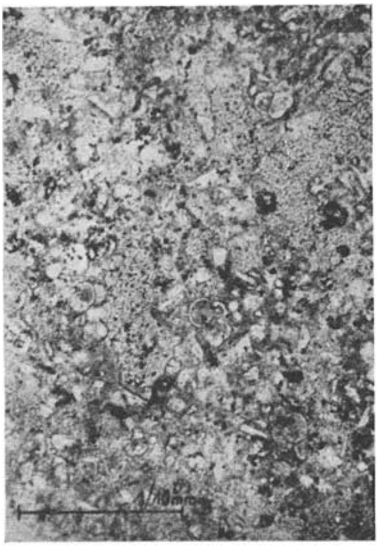

FIG. 8.

FIGS. 5, 6, 7. Thin sections across the phosphatic balls. Note the fine grain and the remains of microfossils, particularly in Fig. 7.

FIG. 8. Thin section across a marly nodule from the phosphoritic bed.

For those of the Bernese shelly sandstone it seems that the origin could equally be animal, because near to the black spheres have been found echinids in important quantities and the presence of excrementary balls of these latter is known. The fossil remains of small organisms found in the phosphoritic layer do not correspond with the age when the *scutellae* existed: they could, however, be part of the food which these latter failed to digest. This group of animals, algae-eaters, also swallow sand and mud, but retain only the digestible parts. The *scutellae* are in such a good state of preservation that important geographical displacements cannot have taken place: so the formation of the black spheres could be due to the coprolitic waste-matter of the *scutellae*. As these residues have not been transported, it seems that it is a matter of a primary bed, for the balls have only been found in the phosphoritic horizon of the shelly sandstone. Other horizons, also containing the same rounded pebbles of alpine origin, do not contain the phosphatic balls. Moreover, the black balls are marked by the imprint of sand-grains, which show that they have not been rolled and must originally have been soft. The spherules seem to have been permeated by the calcium phosphate during or after their deposition. The necessary conditions for the formation and concentration of phosphate are likewise fulfilled in this region (marine basin, proximity of glauconitic formations, phosphate-producing fauna and fishes). The discovery has been made in two places only, for systematic search has not so far been undertaken. It seems that other kinds could be expected in the same stratigraphic surroundings, according to the regional distribution of the *scutellae* in the shelly sandstones of neighbouring districts.

Conclusion

The resulting solution of the problem of the nature and origin of the black spherules is both unexpected and rather unromantic! Nature's oddities and curiosities are numberless, and the contrast between the real nature of these geological finds and the eulogistic descriptions quoted at the beginning of this article will no doubt raise a smile on the lips of more than one reader. The mistake arises from the erroneous idea that rarity alone raises an object to the rank of an article of finery or adornment. But other factors hallowed by tradition are of just as great importance as rarity: more than rarity, it is beauty—in shape, orient, lustre—and also fashion, which have given to the pearls used in jewellery the privileged position they occupy nowadays among articles of adornment.

ACKNOWLEDGMENTS

The author here records his thanks to Mr E. Glanzmann for the information kindly provided and for having made available the photographs reproduced as Figures 2 and 3, as well as his lively gratitude to Dr U. P. Büchi, who kindly made Figures 4, 5, 6, 7 and 8 (originally published in *Bulletin des Ver. Schweiz. Petrol. Geol. Ing.*,) available and permitted their reproduction: of these, the excellent thin-section photographs (Figures 5, 6, 7, 8) were taken by Miss L. Eymann.

Gemmological Abstracts

ACCORD (J. P.). *Tourmaline.* Lapidary Journal, 1977, 31, 1, 216-229.

An account of the rediscovery of gem-quality tourmaline in Maine. M.O'D.

ACCORD (J. P.). *Tourmaline.* Lapidary Journal, 1977, 31, 2, 512-525.

Continues the article begun in vol. 31, no. 1 (v. sup.). Outlines further discoveries in Maine and reviews the use of tourmaline in jewellery. M.O'D.

ALEXANDER (A. E.) and ZARA (L.). *Garnets, legend, lore and facts.* Mineral Digest, 1977, 8, 6-16.

A general review, superbly illustrated in colour, of the gem members of the garnet family of minerals. M.O'D.

ALTHAUS (E.). *Farbe aus Fehlern.* (Colour from defects.) Lapis, 1977, 2, 5, 8-9.

Describes the operation of colour centres in fluorite. M.O'D.

BLAIR (G.). *Pyrite-collectors' delight.* Lapidary Journal, 1977, 31, 1, 46-50.

An illustrated account of the formation and occurrence of pyrite. M.O'D.

BOWER (C. E.). *Digging for black opals at the Royal Peacock opal mines, Virgin Valley, Nevada.* Lapidary Journal, 1977, 31, 2, 526-533.

Opal from this region has been stabilized by a process not described; on mining, the stones are immediately placed in mineral oil to preserve the water content. After the stabilization has been carried out the stones may be fashioned without fear of crazing. The water content of stabilized opal is stated to be less than 1%. M.O'D.

BRIDGE (P. J.), DANIELS (J. L.) and PRYCE (M. W.). *The dravite crystal bonanza of Yinnietharra, Western Australia.* Mineralogical Record, 1977, 8, 2, 109-110.

Dravite is found enclosed in a phlogopite-plagioclase schist, the plagioclase being a calcic oligoclase. The crystals of dravite are almost equant and resemble garnets, with which they are frequently confused. The colour is a golden brown (Ridgway colour blister 15″m). M.O'D.

BÜRGER (H.). *Was ist Azurlapis?* (What is "azurlapis"?) Lapis, 1977, 2, 4, 22-23.

This mixture contains about 60% quartz and 40% azurite/malachite. The concretions, either dark blue or green, are found in the U.S.A. and have a specific gravity of 2·88-2·99 with a yellowish-blue or yellowish-green streak. M.O'D.

COURTER (W. E.). *Michigan's favorite gemstone.* Lapidary Journal, 1977, 31, 1, 150-158.

A description of Petoskey stone with references to datolite and agates. M.O'D.

DANIELS (A.) and BALL (R. A.). *Opal in South West Queensland.* Australian Gemmologist, 1976, 12, 12, 359-363. 5 figs.

Gives a short summary of historical background (opal discovered 1872-3) and geology of the area (deposits are in early tertiary and cretaceous beds of freshwater and marine origin; common opal widespread, gem opal very localized). The paper then deals with Yowah nuts which are siliceous almond-shaped nodules of ironstone occurring in the Cunnamulla Mining District, some of which contain precious opal. They are up to 2 cm in diameter. Considerable details of locality, opal occurrence and structure are given but the paper is beset by the printers' errors which so often plague this journal. R.K.M.

DOUGLAS (I. N.) and RUNCIMAN (W. A.). *Application of magnetic circular dichroism spectroscopy to the optical spectra of natural and irradiated diamonds.* Physics and Chemistry of Minerals, 1977, 1, 129-136.

MCD spectra of natural Type Ia and electron-irradiated Type Ia and Type IIa diamonds show that there are at least four different defect centres occurring in diamonds. M.O'D.

DUNN (P. J.). *Apatite: a guide to species nomenclature.* Mineralogical Record, 1977, 8, 2, 78-82.

The general formula for the apatite group of minerals can be expressed as $Ca_5(XO_4)_3(F,Cl,OH)$. The (XO_4) position is most commonly filled by the phosphate radical (PO_4) and there is some substitution by the carbonate radical (CO_3) in some varieties. The most common apatites are fluorapatite, $Ca_5(PO_4)_3F$. hydroxylapatite, $Ca_5(PO_4)_3(OH)$ and chlorapatite, $Ca_5(PO_4)_3Cl$. M.O'D.

DUNN (P. J.), APPLEMAN (D. E.), NELEN (J.) and NORBERG (J.). *Uvite, a new (old) common member of the tourmaline group and its implications for collectors.* Mineralogical Record, 1977, 8, 2, 100-108.

The general formula of the tourmaline group may be written $Na(R)_3 Al_6B_3Si_6O_{27}(OH,F)_4$. Where the R position is occupied by lithium/aluminium the variety is elbaite, where R is ferrous iron the variety is schorl, ferric iron is buergerite and where magnesium, dravite. Many tourmalines are mixtures of two or more species since there is extensive substitution in the group. The variety in which calcium replaces sodium may be described as $CaMg_3(MgAl_5)B_3Si_6O_{27}(OH)_4$ and specimens have been found in Sri Lanka, DeKalb (New York) and Gouverneur (in the same State). They have been given the name uvite after the province of Uva (Sri Lanka) and the name has been confirmed by the IMA Commission on New Minerals and New Mineral Names. The crystals show no outward difference from other varieties of tourmaline; the specific gravity ranges from 2·96-3·06, the hardness is about 7½, comparable with dravite. Most specimens are brown though some from DeKalb are colourless and some from Franklin, New Jersey, are light green. The refractive indices are the same as those of dravite and provide no means of distinguishing the species. Examination with the electron microprobe at the National Museum of Natural History (Smithsonian Institution) proved the identity of uvite and dravite in 80 specimens. Generally speaking dravite is the magnesium tourmaline with sodium greater than calcium and uvite is the magnesium tourmaline with calcium greater than sodium. Most brown tourmaline associated with calcium minerals is uvite and most brown tourmaline associated with schist and non-pegmatite micas is dravite. M.O'D.

Edgar (A.) and Vance (E. R.). *Electron paramagnetic resonance, optical absorption and magnetic circular dichroism studies of the CO_3^- molecular ion in irradiated natural beryl.* Physics and Chemistry of Minerals, 1977, 1, 165-178.

X-irradiation of some natural beryls at room temperature showed some new absorption lines in the EPR spectrum, some known optical absorption lines in the 500-700nm range and a shift of the absorption edge to lower energies. Two of the paramagnetic centres responsible for the new lines have been identified as atomic hydrogen and methyl, CH_3. The third is thought to be the CO_3 molecular ion located in the widest part of the structural channel. The "Maxixe" centre is attributed to this ion. M.O'D.

Ferguson (R. W.). *California's cuttable serpentines.* Lapidary Journal, 1977, 31, 1, 174-180.

Serpentines found in the State include antigorite, soapstone, chrysotile and various locally-named varieties. M.O'D.

Fujisaki (Y.). *Inclusions in emerald from Muzo, Colombia.* J. Gemm. Soc. Japan, 1976, 3, 4, 147-156.

Inclusions in an emerald from Muzo were studied by means of microscopic and electron microprobe analysis. Solid inclusions were found to be pyrite, pyrrhotite, pentlandite and rutile. Characteristic 3-phase inclusions were smaller than those commonly encountered in Colombian material. M.O'D.

Gübelin (E. J.) and Weibel (M.). *Grüner Vanadium-Grossular, Kenya.* (Green vanadium-grossular, Kenya.). Lapis, 1977, 2, 4, 17-21.

Vanadium-bearing green grossular has been found in the Lalatemi Hills and, as an accessory mineral with blue zoisite, at Miralani, south of Moshi, Tanzania. It has now been found in Kenya in the Taita district and the mine at which it is found is known as the Lualenyi mine. About 3% V_2O_3 causes the green colour. Among the minerals included are byssolite (probably) and lines composed of minute liquid droplets are also found. M.O'D.

Gübelin (E.). *Einschlüsse im Fluorit.* (Inclusions in fluorite.) Lapis, 1977, 2, 5, 16-19.

Typical inclusions are illustrated in colour, including green crystals of chlorite, secondary liquid inclusions, 3-phase inclusions and euhedral pyrite crystals. M.O'D.

Hopkins (R. H.), Steinbrugge (K. B.) and Stewart (A. M.). *Laser damage-initiating inclusions in $CaLa_4(SiO_4)_3O:Nd$ crystals.* Journal of Crystal Growth, 1977, 38, 255-261.

Laser damage in rods of this material arises from iridium particles trapped in the material during growth. They appear to enter during fluctuations in growth rate but can be minimized by using a slightly oxidizing growth atmosphere with automatic control of crystal diameter, together with control of the thermal geometry of the growth station. M.O'D.

Van de Walle (P.). *Les bulles gazeuses.* (Gas bubbles.) Bulletin, Société Belge de Gemmologie, 1976, 4, 2-6.

Includes black-and-white photographs of some common gem inclusions. M.O'D.

WATANABE (K.) and SUMIYOSHI (Y.). *Synthesis of corundum single cyrstals by the flux method.* J. Gemm. Soc. Japan, 1976, 13, 4, 147-156.

Corundum crystals were grown by various methods including seeding, top-seeding and temperature rotation. The flux was cryolite (Na_3AlF_6) and a number of dopants were tried including Cr^{3+}, Fe^{3+}, Ti^{4+}, La^{3+}, Nd^{3+}, Dy^{3+}, Yb^{3+}. Good crystals were obtained and alteration of habit according to dopant was observed. M.O'D.

WEIBEL (M.). *Rosafluorit.* (Rose fluorite.). Lapis, 1977, 2, 5, 6-7. Illus. in colour.

The finest pink fluorite is found in Switzerland and occurs as octahedra often in association with quartz, calcite and chlorite; apatite and hematite are also occasionally found as neighbours. The colour is thought to be due to the operation of a colour centre. The Gotthard area produces the best pink fluorite. M.O'D.

WEINER (K. L.). *Thermolumineszenz.* (Thermoluminescence.) Lapis, 1977, 2, 5, 20-21. Illus. in colour.

Two types of fluorite displaying thermoluminescence are illustrated in colour. M.O'D.

WILD (K. E.). *Das Schatzkästchen von Idar-Oberstein.* (The jewel-box of Idar-Oberstein.) Lapis, 1977, 2, 6, 11-13.

Gives an account of the Heimatmuseum in Idar-Oberstein and a brief history of gemmological activity in the area. M.O'D.

WILSON (M. M.). *Sapphire blue.* Lapidary Journal, 1977, 31, 1, 32-44. Illus. in colour.

An account of the various locations of corundum in the United States. M.O'D.

WILSON (W. R.). *Famous mineral localities: the Pulsifer quarry.* Mineralogical Record, 1977, 8, 2, 72-77.

The Pulsifier quarry is situated in Androscoggin County, Maine, and is especially celebrated for purple apatite which owes its colour to Mn^{2+}. The mineral is found in pockets in the pegmatite which runs through the district, and tourmaline is also found. An especially fine specimen of the purple variety of apatite, now in the Smithsonian Institution, forms the cover photograph for the issue. M.O'D.

WRIGHT (C.). *Arkansas, land of quartz.* Lapidary Journal, 1977, 31, 1, 188-196.

The article describes and illustrates the variety of quartz crystal types found in the State. M.O'D.

ZAPATERO (L.). *Estudio de inclusiones por el método de los tres granos.* (Study of inclusions by the three grain method.) Boletin del Instituto Gemológico Español, 1977, 16, 21-25. Illus. in colour.

Inclusions are pin-pointed and examined under drops of Canada balsam; they can be permanently mounted, presumably in thin section. M.O'D.

ZEITNER (J. C.). *Our American gems.* Lapidary Journal, 1977, 31, 2, 468-478.

A general survey of gem materials found in the United States and hints on visiting gem-producing areas. M.O'D.

Gem mining in Sri Lanka. Facets, 1977, 1, 4, 2/5. 2 illus.

A description of the methods used for recovery of gemstones from the "illam", of which there may be more than one layer in some pits. J.R.H.C.

Mohs, Brewster, Carlyle and the table of hardness. Mineral Digest, 1977, 8, 82-86.

An account of the life of Friedrich Mohs and the table of hardness bearing his name. M.O'D.

Turquoise. Mineral Digest, 1977, 8, 64-68.

A general review showing artefacts made with turquoise. M.O'D.

Why the CSO is a diamond's best friend. Gem World, 1977, 4, 1, 16-22.

Reviews the work of the Central Selling Organization and its effects on world diamond prices. M.O'D.

NOTE.—*Facets* is a new periodical published by the State Gem Corporation of Sri Lanka (24, York Street, Colombo, Sri Lanka); though called a "Quarterly Newsletter" it has so far been published at irregular intervals – Vol. 1, No. 1 in July 1975, No. 2 in December 1975, No. 3 in July 1976, No. 4 in February 1977.

BOOK REVIEWS

O'DONOGHUE (Michael), ed. *The Encyclopedia of Minerals and Gemstones.* Orbis Publishing Co., London, 1976. pp. 304. Numerous illustrations in colour and many diagrams. £7·95.

The importance and value of this handsomely produced book are hard to assess. It consists of a series of chapters by different authors, entitled The Chemistry of Minerals (Robert Thompson); The Crystalline State (John Bradley); Geology for the Collector (Alan Woolley); Minerals Valuable to Man (Robert Symes); Identifying Minerals (Michael O'Donoghue); The Fashioning of Stones (Colin Winter); Conserving and Displaying Minerals (Michael O'Donoghue); ending with the most important and by far the longest section of the book – The Mineral Kingdom, by Michael O'Donoghue, who also edited the whole work. The concluding pages contain a lot of useful information: identification tables, a full bibliography, a list of useful addresses, and an excellent index.

The book is superbly illustrated throughout, with clear and instructive diagrams in the earlier chapters and a wealth of photographs in colour of mineral specimens, which make the book a delight to browse through and should assist the collector considerably in the identification of unknown specimens. It is interesting to note that the one plate representing faceted gemstones is probably the least successful in the book, indicating the intrinsic vulgarity of over-large cut stones compared with crystals which maintain their dignity and impressiveness under any enlargement. Some of the "blown up" pictures of minerals in their natural state to be found in this book are indeed quite awe-inspiring. We have in recent years admittedly become somewhat blasé when faced with photographs of this sort of quality, so many are the "picture-books" dealing with gem materials which have been published. But here the illustrations both large and small are skilfully used to enhance and assist the text, which without their aid might make rather dry reading, at least for the layman.

As the book is weighted rather more on the natural minerals than on the limited number which can legitimately be used for human ornament, we are pleasingly reminded that these islands of ours, so weak in true gem materials, have produced many mineral specimens of the finest quality. The attractive display made by typically radiating crystals of wavellite which have emanated from a quarry near Barnstaple, for instance, are honoured by being reproduced in three places in the book.

Only the last – descriptive – half of the book corresponds at all closely to the usual conception of an encyclopaedia: but the editor of the whole assemblage, and its chief contributor, would probably claim that its all-embracing scope, which aims to inform the budding mineralogist, amateur lapidary and gemmologist, warrants such a title. Certainly it would be difficult to think of another.

The late Sir James Walton was the first to conceive the idea, in his "Physical Gemmology", that the subject should be taught by beginning with the atom, continue with the grouping of atoms or ions into crystals, and so on, in logical sequence. Much the same basic approach has been adopted in this "Encyclopedia", and quite difficult concepts have been made plain by the skilful use of diagrams. These early chapters certainly make more attractive reading for the beginner than the traditional form of textbook, and the average collector and amateur lapidary does not need more than can be conveyed by this "easy" treatment.

The chapter on fashioning stones covers a lot of ground in its forty-odd pages, starting with details of the increasingly popular pastime of tumble-polishing, which requires the minimum of skill but a good deal of care and know-how for really good results. Practical details, with clear diagrams to assist the reader, are given to enable the keen do-it-yourself man to construct his own tumbling machine or even a vertical or horizontally running lapidary bench for sawing, grinding and polishing gems. The same chapter includes quite a useful description of minerals suitable for cutting, arranged in alphabetical order. There has been an extraordinary outburst of enthusiasm in this country for collecting, polishing and even mounting ornamental stones, with two specialist magazines, numerous clubs, and commercial suppliers. The pity of it is that "gem collecting" in the field so far as Britain is concerned is limited almost entirely to various ornamental forms of chalcedony.

In writing the chapter on identifying minerals, the editor (M. O'Donoghue) has allowed himself far too small a space (only seven pages) to do more than write a pleasing essay on this complex subject. This is more suited to an article for a large general encyclopaedia than in a specialized one. It may gratify "rockhounds" by making the subject seem easy, but will disappoint the budding gemmologist, who will have expected something more specific from one who has become well-known for his energetic study and reporting of the subject.

As against this, the meatiest part of the book and by far the longest is the section entitled "The Mineral Kingdom" for which O'Donoghue is also responsible. Here, the most essential data are given for some 1,000 minerals, which comprise all those likely to be met by the amateur in the field or from popular suppliers, and many more besides. The information is necessarily given in a condensed form. Following the name of the mineral, the composition, crystal system, physical properties, appearance, type of occurrence and appearance are listed, as well as the more important occurrences. The order followed is a chemical one, as in the Chemical Index of Minerals compiled by Dr M. H. Hey and issued by the Mineral Department of the British Museum (Natural History). The non-specialist will find it difficult with such an arrangement to find a mineral of which he knows only the name, but he will be aided in this by reference to the index. The appearance of a large number of the minerals is made clear by provision of coloured photographs of typical specimens. An unusual feature of these brief descriptions is that in many cases a directive is given for the cleaning of specimens of the mineral concerned. Water, and not just water but *distilled* water, is often recommended as the safest cleaning agent. This seems unnecessarily fussy, and becomes really amusing when suggested for so chemically tough a mineral as painite, which, despite its extreme rarity, has found its way into the text as it has, for some curious reason, into several other recent books on gemstones. Only two crystals of painite are as yet in captivity, and it may interest readers to know that a recent analysis has led to the revised formula for the mineral – $CaZrB(Al_9O_{18})$ – and to the establishment of its crystal structure (hexagonal) being related to another rare mineral recently claimed as a gemstone by American workers – jeremejevite.

A tremendous amount of work and thought has gone into the making of this book and it is undoubtedly full of good things as well as being very reasonably priced. Its weakness lies perhaps in its attempt to be of universal appeal to anyone attracted to the mineral kingdom for one reason or another. The earlier chapters if expanded and filled in with more detail (especially the one on identification) would have formed a very pleasant text for the instruction of the collector of minerals and amateur lapidary. And the last, descriptive part, if given more expanded treatment in the case of the hundred or so really important minerals would have provided a very acceptable reference book. Though admittedly some of the impressive illustrations of fine mineral specimens would lose a little of their grandeur by being diminished in size, the volume would have been made far easier to handle, hold, and house by being reduced somewhat from its 12 x 9 inch dimensions. It could be given more pages, slightly smaller type, and then not require a lectern to read from in comfort.

A reviewer is expected to point out misprints or more serious errors when a book such as this is under notice, if only to show that he has studied the text with the requisite thoroughness. There are admittedly and inevitably some mistakes to be found in this "Encyclopedia", such as the occasional misplacing of captions in the coloured photographs, the description of Clerici solution, and so on, but these small points are of more interest to the editor of the work than to the reader. One's main feeling should be one of gratitude for a book which is not only full of fine pictures but also full of useful information. B.W.A.

SÖHNGE (G.). *Tsumeb, a historical sketch.* 2nd edn. Committee of the S.W.A. Scientific Society, Windhoek, 1976. pp. 92. (Scientific Research in South West Africa, 5th series.) Price on application.

The Tsumeb area, long celebrated among mineralogists, produces copper, lead, zinc, cadmium, silver and germanium. Mining began in the 1870's but the main construction of pit gear and larger exploitation did not begin until the early 1900's. To the mineralogist the minerals resulting from oxidation of the primary ore deposits are of the greatest interest. Exploitation still continues and further deposits should be found. M.O'D.

ASSOCIATION NOTICES

MR B. W. ANDERSON

Mr B. W. Anderson, B.Sc., F.G.A., Vice-President of the Association, is to be congratulated on having been elected a Fellow of King's College, London.

FELLOWS' ACTIVITIES

On the 8th June, 1977, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a demonstration of some of the recently produced synthetic crystalline materials to the Swiss Gemmological Association at Villars-sur-Ollon, Vaud, Switzerland: many specimens were available for individual microscopic examination.

The Rev. S. B. Nikon Cooper, B.D., F.G.A., and Mrs Nikon Cooper had the honour of being presented to H.M. the Queen Mother at the Buckingham Palace Garden Party on Tuesday, 26th July, 1977, when they enjoyed some minutes' conversation with Her Majesty.

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful to the following for their gifts:

Mr B. D. Fernando, Colombo, Sri Lanka, for First Day Cover stamps – Special Issue – 7th April, 1977, handicrafts of Sri Lanka – with gemmological interest, one with a jewellery box and the other with a caparisoned elephant in ivory.

Mr Michael van Moppes, of Wessex Impex Ltd, for one fine specimen of "potato stone" from Dulcote, Somerset, together with four other good specimens of the material being mined.

MEMBERS' MEETINGS

North-West Branch

On the 26th June, 1977, a visit was made to Castleton, Derbyshire, the interesting old mining area where specimens of calcite, fluorite and barytes may be found.

South Yorkshire Branch

A joint field trip with the Sheffield Amateur Geological and Lapidary Society was held on the 3rd July, 1977, to Dirtlow Rake and Pindale. Pink banded barytes, fluor, galena and calcite may be found at Dirtlow Rake, and fluor crystals, calcite crystals, hydrocarbons and various fossils at Pindale.

OBITUARY

Mrs Alix Stewart (D. 1956), Scotland, died on the 24th June, 1977.

EXAMINATIONS 1978

The dates for the 1978 Gemmological Examinations are as follows:

Preliminary: Theory, Tuesday, 27th June

Diploma: Theory, Wednesday, 28th June

Practical, Tuesday, 27th June, Thursday, 29th June or Friday, 30th June (London). Other centres as arranged.

Gem Diamond Examination: Monday, 12th June.

The *final* date for entry is the 1st March.

Entry forms available from the Association.

DIALDEX REFRACTOMETER

We are pleased to announce that the Dialdex Refractometer is now available from stock.

ANNUAL GENERAL MEETING

The 47th Annual General Meeting of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2. on the 23rd May, 1977.

The Chairman, Mr Norman Harper, welcomed members and expressed particular thanks for the work that the Examiners undertook, especially with the large increase of entrants and the fact that it had to be done during the summer period. He also mentioned that because of the large number of failures in the Diploma Examination it seemed essential to raise the standard required for a pass in the Preliminary Examination and stated that the Council had decided to raise the pass standard in the Preliminary Examination to the same as that required in the Diploma. The Chairman also thanked members of Council, Branch Representatives and Instructors for the time that they gave up for the Association.

The Chairman then proposed the adoption of the Annual Report and Accounts which was seconded by Mr John Roach and duly carried.

Sir Frank Claringbull was re-elected President, Mr N. A. Harper re-elected Chairman, Mr D. King re-elected Vice-Chairman and Mr F. E. Lawson Clarke re-elected Treasurer.

Mrs S. Hiscox and Messrs E. M. Bruton, D. J. Ewing, and M. J. O'Donoghue were re-elected to the Council.

The Chairman announced that Messrs Hard Dowdy, Watson Collin & Co., Chartered Accountants, had signified their willingness to continue as Auditors.

Finally the Chairman expressed the Association's thanks to the Goldsmiths' Company for the ready willingness of the Wardens to place various rooms at the Hall at its disposal for meetings whenever convenient, saying "we are greatly indebted to them."

COUNCIL MEETING

At a meeting of the Council held on Monday, 23rd May, 1977, at Saint Dunstan's House, the following were elected to membership:

Fellowship

Douglas, David N., Market Drayton. D. 1966
Heyerdahl, Sten S., Oslo, Norway. D. 1969
Jucker, Ronald W., Urdorf, Switzerland. D. 1975
Penn, Leslie, Birmingham. D. 1949

Ordinary Membership

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LETTERS TO THE EDITOR

From Mr C. A. Schiffmann, F.G.A., G.G.

With reference to "The 'Black Pearls' of Guyana" by Mr Gosling in the *Journal of Gemmology,* 1976, XV, 4, 209, the mode of formation of these items seems to be not known with certainty. May I suggest a possible hypothesis?

Considering the size, the shapes of the items illustrated, and the local conditions under which they have been found, in my opinion there is a striking analogy with similar items described by U. Büchi, Zürich, 1968, at the International Geological Congress in Lucerne. I had myself the opportunity of getting quite a number of these pieces on their spot of occurrence in the Canton of Berne, Switzerland, from the man who discovered them, and I reported on them at the XIIth International Gemmological Conference in Stockholm, 1968. Similar objects have been mentioned already in 1932, 1934 and 1944. From the former studies, it seems quite evident that these are coprolites from long extinct animal species.

As I expect this is not generally known, I enclose a reprint of the corresponding paper I wrote for the *Schweizer Goldschmied* (August 1969) – a journal little known outside Switzerland and, since then, merged into the *Schweizer Uhrmacher- und Goldschmiede-Zeitung*. If you would deem it interesting for your readers to have this paper published in an English version, I should gladly agree to it.*

From the irregular shapes in Fig. 2 of Mr Gosling's article, the items appear somewhat flattened. Consequently it is probable that they were soft originally and have hardened in the course of time, together with partial replacement which might make for the limonite (goethite) stated. My suggestion would be to investigate them for remains of fossilized micro-organisms and for the presence of phosphate. The measurements mentioned (2 to 20 mm) are partly larger than the ones of the items found in Switzerland (3 to 10 mm) and might be accounted for by a larger species producing them. As these cases demonstrate, all items contemplated for jewellery purposes do not necessarily have a very noble origin!

I hope to have contributed something to clear up the question posed by Mr Gosling's article.

Yours sincerely,
C. A. Schiffmann

11th January 1977. Gübelin Gemmological Laboratory, Lucerne.

From Mr E. A. Jobbins, B.Sc., F.G.A. and Dr M. T. Styles, B.Sc., Ph.D.

Dear Sir,

"Black Pearls" and Coprolites

You have very kindly drawn our attention to the letter from Mr C. A. Schiffmann concerning the origin of the "Black Pearls from Guyana" described by Gosling (Gosling 1976).

We have now re-examined the Guyanese "black pearl" specimens presented by Mr Gosling to the IGS collections (MI 35396) and a spherical black coprolite from Switzerland supplied by Mr Schiffmann, using the energy-dispersive x-ray analyser on the Geoscan electron microprobe. Approximate concentrations of major elements have been calculated from raw data by direct comparison of measured intensities with known standards. Relative errors could be significant but the results are nonetheless useful for the purposes of this investigation.

The outer surface of the coprolite "pearl" from Switzerland was analysed and consists of major Ca, P and Si, minor Al, Fe and K and traces of Mg, Na, Ti, Cl and S. The approximate composition is 32% CaO, 25% P_2O_5 and 10% SiO_2 with the minor and trace elements possibly accounting for 10% by weight; the remainder is probably accounted for by OH, organic and other constituents with

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*A slightly shortened version, translated into English, appears on pp. 445-453 *supra*. – Ed.

atomic numbers below 11 which are not detectable using this analyser. The concentrations of Si and the minor elements varied within the outer surface of the specimen. The concentrations of Ca and P are consistent with the specimen being largely composed of apatite, which accords with a coprolitic origin as suggested by Mr Schiffmann.

Three "black pearls" from Guyana were sectioned. Two had the concentric structure illustrated in Gosling's paper, whilst a third consisted of quartz grains cemented by a brown ferruginous (limonitic) material with a very dark brown continuous outer surface coating. The specimen illustrated by Gosling was semi-quantitatively analysed by the electron microprobe and an area scan gave major Fe, Al, minor Si, Ti and trace (less than 1% by weight) Mg, P, S, Cl, K and Ca. This gives an approximate composition of 65% Fe_2O_3, 8% Al_2O_3, 4% SiO_2 by weight. The outer 'skin' is richer in Fe (approx 75%) and in Al (approx 12%) and lower in Si (approx 1%) with a trace of Cr. Near the centre and elsewhere are distinct quartz grains. The dark layers which accentuate the concentric structure are slightly richer in Si, Al, K and S which possibly indicates the presence of fine-grained clay minerals and pyrite.

The "pearls" from Guyana are thus essentially composed of an iron mineral – limonite (goethite). Much of the Al is probably present as bauxitic mineral(s) such as gibbsite, some Si as quartz grains, and some Si with Al as clay minerals in clayey layers. Neither phosphorus nor calcium was detected in concentrations greater than 1% – both elements are commonly found in coprolitic material. Taking into account the concentric growth structure and the chemical composition it appears most unlikely that the "black pearls of Guyana" are coprolitic in origin.

Gosling describes the occurrence of the 'black pearls' in light yellowish clay with some subangular quartz pebbles and comments that they are more abundant on the gently sloping banks of creeks and are concentrated at the heads of similar creeks; Bleackley (1964) notes that bauxites in Guyana are frequently underlain by kaolinitic clays. Pisoliths comparable with the "pearls" are a common constituent of many laterites which have been formed as surface or sub-surface deposits in tropical areas with oscillating water tables (see MacFarlane 1976, p. 70) and it seems probable that the "black pearls" formed as pisoliths in laterite deposits which are now being eroded by river action.

Yours sincerely,
E. A. JOBBINS
M. T. STYLES

7th July 1977. Institute of Geological Sciences, London, SW1 2DE.

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Bleackley, D. 1964. *Bauxites and Laterites of British Guiana.* Bull. Geol. Surv. Br. Guiana, No. 34, 156 pp.
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MacFarlane, M. J. 1976. *Laterite and Landscape.* Academic Press, London. 151 pp.

CORRIGENDA

In the printing of each of the penultimate and antepenultimate lines of Table 4 on p. 247 *supra* the tilde was unfortunately omitted over the ν, and the last three lines of the Table should read as follows:

5. Energy $E = \tilde{\nu} \times 1{\cdot}99 \text{ x } 10^{-16}$ ergs,
$= \tilde{\nu} \times 1{\cdot}24 \text{ x } 10^{-4}$ eV,
$= \tilde{\nu} \times 2{\cdot}86$ cals/mole.

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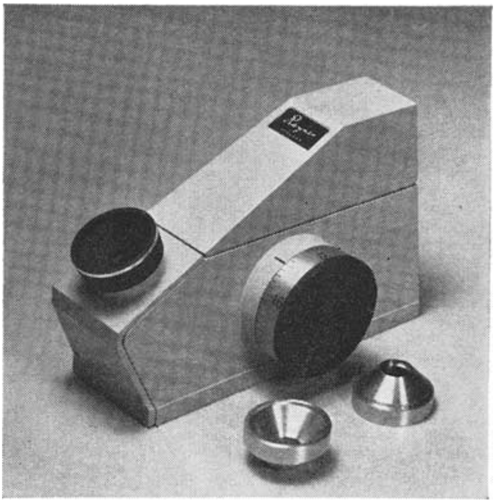
Names of authors are printed in small capitals, pages of abstracts and book reviews in italics.



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