Internal Radiohalos in a Diamond

MARK ARMITAGE

ABSTRACT

The discovery of possible short half-life radioisotope-produced radiohalos and other unusual inclusions in a small type la diamond raises questions about the current theory of diamond formation within the earth. Such radiohalos are often found in biotites in pegmatites and granites, where it appears they could not have survived heat over extended time periods, either during pegmatite and granite formation or subsequent cooling, thus remaining an enigma potentially challenging uniformitarian explanations of granite/pegmatite formation. The mention of diamonds in the Bible in the context of the Garden of Eden may suggest that diamonds as part of the original creation are created gemstones.

INTRODUCTION

Current cosmological theories regarding the origin of the earth revolve around a scenario which includes gravitational compaction of stellar gases and matter, hot magmatic processes operating at the surface in crustal formation, and radiogenic heating of the earth from deep within its core and mantle. These processes, it is said, had to take their course over millions, perhaps billions, of years to arrive at a point where life could have a platform upon which it could emerge and develop.

The amount of heat generated by the compaction of stellar matter and gravitational attraction, plus the heat given off by the supposed radioactive processes operating in the core and mantle, could not have been dissipated in a short period of time, and certainly would not have disappeared instantly if this scenario for the earth's origin is correct. Similarly, rocks such as granites, that are usually believed to have crystallized from hot magmas, must thus have taken many thousands of years to cool. It is readily apparent, therefore, that the time-scales for these processes, as they are understood to have occurred according to the uniformitarian interpretation of earth history, are incompatible with the biblical creationist understanding of the earth's age and origin.

If the earth was created, then a relevant consideration is whether there are still some of the originally created materials, be they rocks or minerals, at the earth's surface today. But how would we recognize such created materials? In any case, it is always likely that those created materials that have survived until today at the earth's surface are not necessarily in their pristine form, having suffered from the ravages of subsequent events, not the least being the Flood with all the catastrophic geological processes associated with it. Furthermore, because of the consequent recycling, any created materials may be difficult to identify today because they would thus bear in them features that today we would recognize as having been formed by natural processes. Thus granite bodies that display an intrusive relationship to fossil-bearing, Flood-deposited strata have proven difficult to explain as part of a postulated original, created crystalline-crust/basement. Similarly, diamonds appear to have originated deep inside the earth, yet have been brought to the surface through Flood strata by volcanic activity. However, new evidence from a chance discovery in a diamond may yet give clues to help solve some of these perplexing questions.

DIAMONDS AND THEIR FORMATION

Diamonds are probably the most intensely sought after of all the mineral gems known to man, as more than US$9 billion is spent annually to unearth, process, cut, polish and market them internationally. On average, about 250 tons of kimberlite 'ore' must be mined to yield a one carat diamond.[1] In 1980 alone, DeBeers, the huge international diamond mining enterprise, spent over US$50 million on diamond advertising, a figure which represented only 2% of its US$2.7 billion in sales of rough diamonds for that year.[2] In 1991, DeBeers spent over US$ 140 million on advertising, mostly in the United States and Japan.

It is said that diamonds 'are forever' because of their unique hardness and resistance to physical weathering, that they are 'a girl's best friend' because of their fiery brilliance and value, but what do we really know about their origin? Have they really formed over long periods of geologic time under the kinds of harsh conditions frequently described by gemmologists?

Diamonds are classified into two major categories — Type I which contain nitrogen, and Type II which do not.[3] There are four generally recognized sub-categories based on the form and placement of the nitrogen, and the presence or absence of boron. Type la diamonds, for example, which may comprise over 98% of the world's natural diamonds, contain from 200 ppm up to a maximum of 5,500 ppm nitrogen atoms distributed in small clusters or aggregates throughout the diamonds.[4] Diamonds in this category are normally colourless, light yellow or brown. Type lb diamonds, which comprise around 1% of natural diamonds, are yellow and contain lesser amounts (150–600 ppm) of nitrogen atoms in individual carbon substitutional sites. Normal colours of this type range from light to bright yellow or even amber. Type Ila diamonds comprise less than 1% of all diamonds and contain very small concentrations of nitrogen at amounts in the range of 4 to 40 ppm (undetectable or barely detectable by IR spectroscopy). These diamonds are generally colourless or brown. Some of the world's very large diamonds are in this category. Type IIb diamonds, the rarest and purest type, contain up to around 20 ppm boron and even less nitrogen. These are usually blue or grey in colour, and are electrically conductive.

The origin and formation of diamonds has yet to be firmly agreed upon, let alone completely understood by geologists and gemmologists, but it is generally accepted by most that diamonds crystallize from a liquid melt in the earth's upper mantle at depths between 150 and 300 km.[5] It is thought that they must form at these depths because it is there that the high temperatures (ranging from 1,100–2,900°C) and high pressures (ranging from 725,000 to 1,000,000 pounds per square inch or 5,000 to 6,900 MPa) are found. Some researchers have suggested that diamonds may even form at depths of 450 km below the earth's surface, because of the great temperatures and pressures required for certain mineral inclusions in them to form.[6] It has also been reported[7] that diamond-like material may be present in dense stellar clouds. If so, then it is not clear what types of pressures and temperatures would have produced such 'diamonds'.

Efforts to produce gem-grade synthetic diamonds, though intensive, have produced only meager results. Researchers at General Electric Company in New York in 1955[8] successfully formed tiny industrial grade diamonds under extreme laboratory temperatures and pressures (1,400°C and 60,000 psi or 410 MPa) and over several week intervals. Synthetic gemstones are, however, another story. Although General Electric has produced and polished some gem quality stones (up to 5 carats over many weeks) the cost of production remains prohibitively high.

For natural diamonds discovered to date, their crystallization is thought to have occurred between 1 and 3 billion years ago in molten magma containing relatively high concentrations of magnesium and iron.[9] The diamonds, according to some, must have resided for from several million up to 2 billion years in the upper mantle beneath cratons, the oldest parts (in a relative sense) of the present day continents, which are said to have formed over 2.5 billion years ago. The diamond phase of carbon remained stable there, because the pressure was high and the temperature relatively cool (800 to 1400°C), so that once crystallized no further melting took place. It is believed that subsequently a low melting point rock, rich with $C0_2$ and H_20 (either kimberlite or lamproite), came up from below these diamond mantle sources and transported the diamonds to the earth's surface fairly rapidly (10–30 km per hour) via propagating cracks in the mantle and crust. The molten magma cooled, and therefore hardened, as it approached the earth's surface, with some of the solidified magma explosively blowing out of the resulting 'cold volcanoes'. It is thought the diamonds then remained in the concealed rocks within the conduits (in what are called pipes), or were removed by erosion to other surface environments such as river systems during the next 25 million to 1.6 billion years.

Whatever the scenario for diamond formation is, unfortunately much remains speculative. We can only infer what has happened, and is happening, in the crust and mantle below based on laboratory experiments and conditions such as those described above, and on the physical presence of diamonds (plus inclusions) and their host rocks (with contained xenoliths) at the earth's surface today. Certainly no diamonds have been excavated from depths greater than 1500 metres, and it is always possible that there may have been other sources for diamonds. The fact that fully-formed, optically visible internal radiohalos have now been found in diamonds[10] may well cast a different light on current theories of diamond genesis.

RADIOHALOS

Pleiochroic halos, or radiohalos, are tiny (10–40 microns in diameter) concentric spheres of discolouration that have been observed under the microscope in some biotite (one of the mica minerals found in granites and pegmatites) since the late 1800's.[11] At first their presence was not clearly understood, however in 1907 Joly and Mugge[12,13] independently suggested that radioactivity was responsible for their existence. These rings of discolouration are formed during the radioactive decay of uranium-238 (^{238}U) and other unstable isotopes contained in small grains included within some biotite flakes. High energy alpha particles emitted during the decay process travel radially outward from the inclusions into the surrounding mineral, leaving it discoloured because of the damage done to the mineral's crystalline structure. A typical ^{238}U halo found in biotite from a granite is seen in Figure 1.

The amount of energy associated with the specific alpha particle emitted is characteristic of that particle and will determine how far that particle will travel in the host mineral to form the ring. Therefore, the diameter of each of the rings may be accurately measured to determine which specific radioactive isotope was in the inclusion and therefore

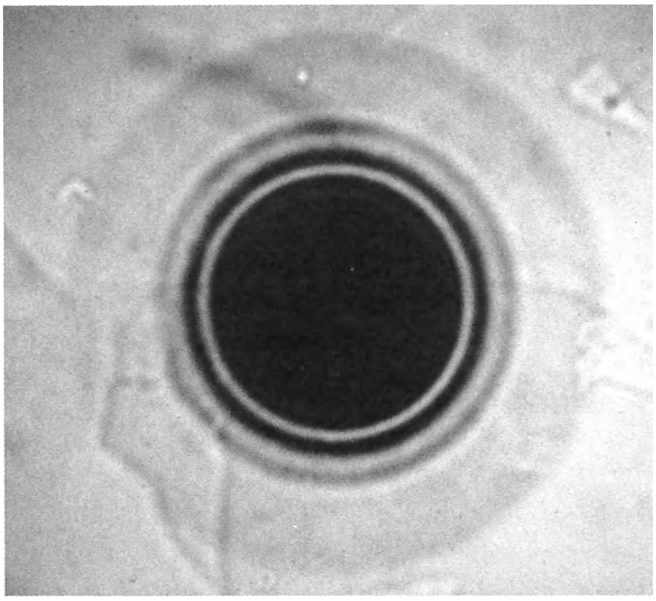

Figure 1. *Photomicrograph of a typical* ^{238}*U radiohalo in biotite, Murray Bay, Quebec, Canada (300X magnification).*

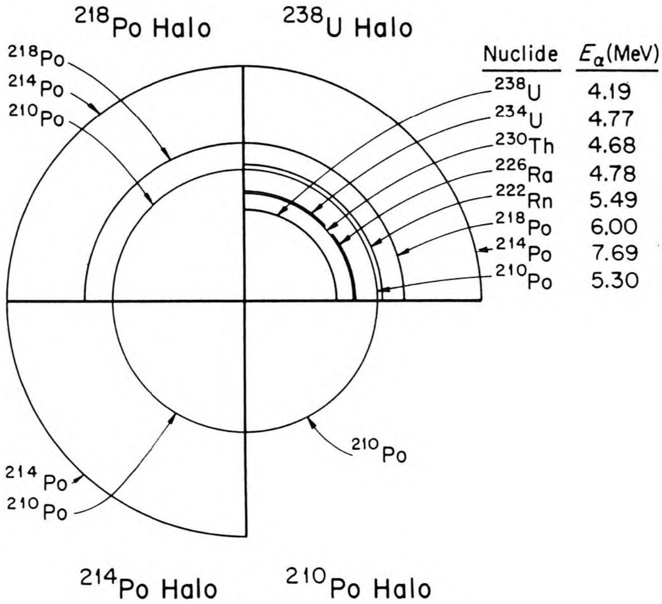

Figure 2. *Diagram of the pleiochroic rings that are found in the most important halos and the radioisotopes responsible for them.*

responsible for the halo. In the case of diamond that diameter would be reduced somewhat due to the higher density of its carbon matrix, although by what percentage this reduction is has unfortunately not been quantified. Mendelssohn *et al.*[14] suggested a conversion factor of 0.70 which they said could be theoretically justified and was experimentally determined, but gave no elaboration upon these claims. The parent radioactive atom, via alpha particle emission, will form a daughter atom which may or may not be radioactive. In the case of ^{238}U, eight successive alpha decay daughters will form five distinct halo rings (see Figure 2). Three of the alpha particles emitted in the ^{238}U decay chain are so close together in energy that their rings are not distinguishable.

Polonium is a daughter element found in the last three alpha emission steps of the decay chain of ^{238}U (see Figure 3). Although beta particles are emitted from ^{214}Pb, ^{214}Bi, ^{210}Pb and ^{210}Bi, polonium-210's immediate precursors, the beta particles do not have sufficient energy to discolour the mineral. Polonium appears three times in the decay process: as ^{218}Po, ^{214}Po and ^{210}Po. Each polonium isotope has its own characteristic halo (see Figure 2 again).

Some ^{210}Po halos found in granite are not associated with evidence of a parent and thus appear to be parentless, that is, there is no ring structure evident of the previous alpha particle emitting parent in the decay chain. These single ring halos appear to have formed as a result of the decay of ^{210}Po into ^{206}Pb, which is stable radiogenic lead. For example, the halo shown in Figure 4 appears to be located in an undisturbed location without cracks or fissures (at this magnification/level of observation at least). Gentry *et al.*[15] have already shown that there appears to have been no gross transport of alpha radioactivity to the polonium halo inclusions (radiocentres) by way of laminar flow of solutions through thin clefts, or by diffusion of radon-222 to such sites.

The half-life of ^{210}Po is only 138 days, a significant difference from the half-life of ^{238}U. ^{210}Po halos have been reported in great numbers, even more than 20,000 per cubic centimetre in one Norwegian biotite alone.[16]

An example of a ^{214}Po halo can be seen in Figure 5. These are designated as ^{214}Po halos because they exhibit a dual ring structure, and

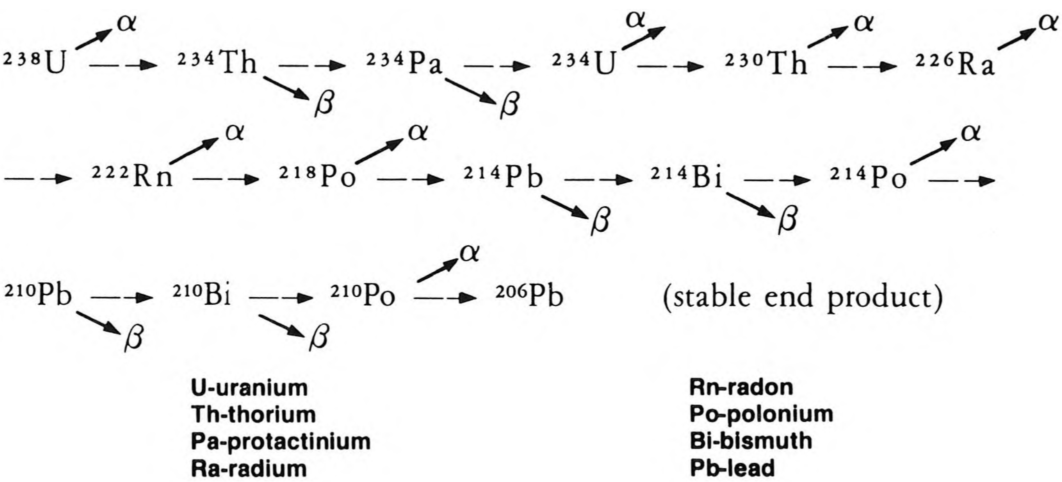

Figure 3. *Diagram of the decay chain of* ^{238}*U, showing which particles are emitted at each radioactive decay step.*

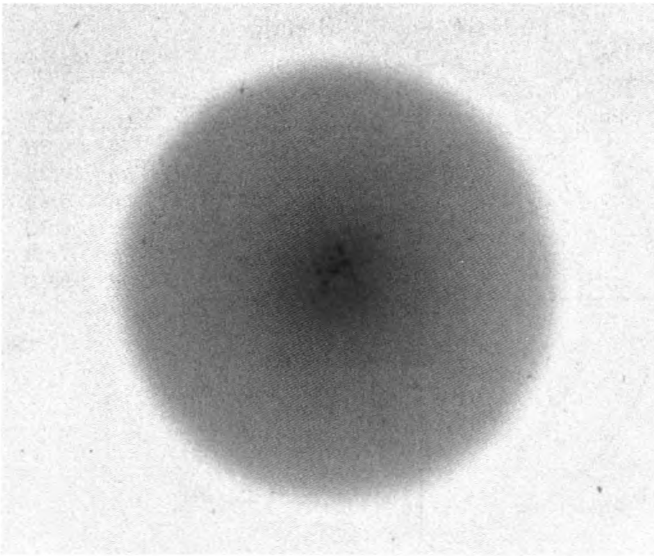

Figure 4. *Photomicrograph of a typical ^{210}Po radiohalo in biotite, Bancroft, Ontario, Canada (250X magnification).*

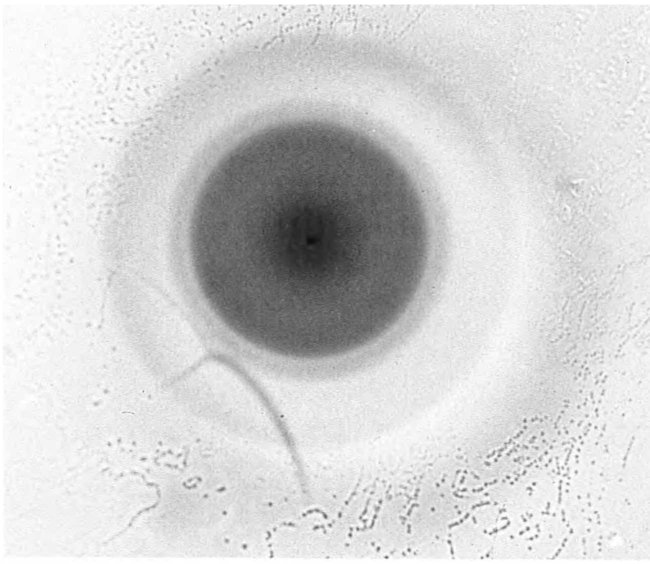

Figure 6. *Photomicrograph of a typical ^{218}Po radiohalo in biotite, Ii Mori, Japan (250X magnification).*

because ^{214}Po appears to be the initiating isotope of the decay process. ^{214}Po decays to the next alpha emitter, ^{210}Po, which in turn decays to ^{206}Pb (see Figure 3 again) — hence the dual ring structure characteristic of ^{214}Po halos. The astounding aspect of these halos is that the half-life of ^{214}Po is 164 microseconds! Furthermore, as with ^{210}Po, the ^{214}Po that produced the halos appears to be parentless, meaning that only ^{214}Po was probably present at the start of halo formation.

Finally, ^{218}Po halos (see Figure 6) exhibit a three ring structure, which indicates that halo formation was initiated by ^{218}Po alone. The half-life of ^{218}Po is three minutes. ^{218}Po halos are found widely in Precambrian granites, for example, and have been estimated at a total count of ten to one hundred thousand trillion halos.[17]

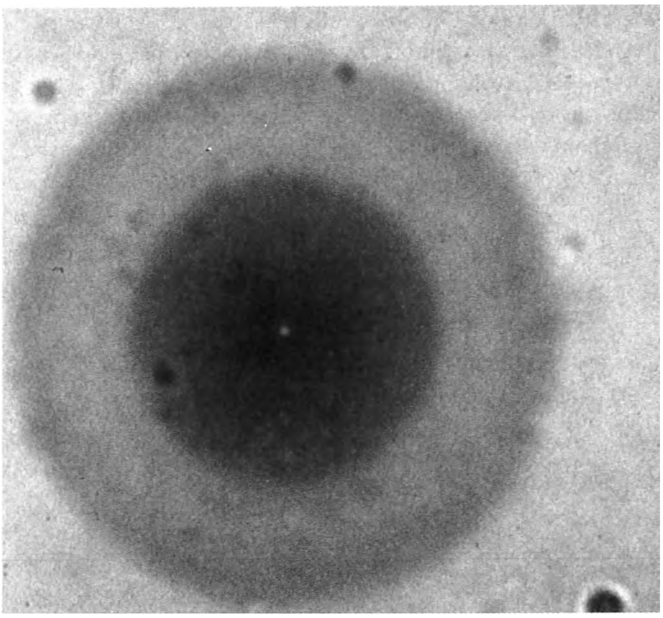

Figure 5. *Photomicrograph of a typical ^{214}Po radiohalo in biotite, Murray Bay, Quebec, Canada (250X magnification).*

RADIOHALOS IN A DIAMOND

Figure 7. *Photomicrograph of the .06 carat type IaAB diamond (25X magnification).*

The small diamond (0.06 carats or 0.012 grams) examined in this study (see Figure 7) is thought to be unique, even one of a kind, being transparent with over 75 internal radiohalos visible at 125X–250X under a bright-field optical microscope (see Figures 8 and 9). Unfortunately, no information as to the source of this diamond is available, except its unusual inclusions were first examined by Anthony de Goutière of de Goutière Jewellers Ltd in Victoria, British Columbia (Canada). Mr de Goutière later donated the diamond to the Gemological Institute of America’s Bryon C. Butler Inclusions Collection for further study.[18]

Other diamonds reported to have radiohalos in them are opaque,[19] and the radiohalos can be seen only by sectioning the diamond, then etching and observing the halos under cathodoluminescence. There may exist, however, many other gem diamonds with internal halos, since very few gemmologists examine diamonds under greater than 10X–

Figure 8. *Photomicrograph of the radiohalos in the diamond (50X magnification).*

50X magnification. Unless inclusions are readily apparent to the naked eye or to a 10X loupe, they go undetected. On the other hand, although geologists studying diamonds and the inclusions in them regularly use the high magnifications under which radiohalos are visible, any radiohalos in diamonds that they may have observed would probably have gone unreported, due to little significance being attached to them. So just how rare radiohalos in diamonds are is not clear. Nevertheless, there remain many thousands of tons of diamond-bearing kimberlite yet to be excavated which may yield diamonds with internal halos if properly inspected.

These particular halos in the diamond examined (see Figure 10) can be clearly seen in the transparent host diamond material, and have up to four visibly formed rings. They approximate 25 microns in diameter, which would correspond to the ^{238}U decay series rather than the larger 30 micron ^{232}Th decay series, although exact size matching is difficult due to the greater density of the diamond's carbon matrix having reduced the penetration of the alpha particles that produced the halo rings. It has been shown[20] that in the ^{238}U decay chain five of the eight alpha emitting daughters will form distinct rings, including the innermost ^{238}U ring (see Figure 2 again). That ring is clearly absent in these halos, and not bleached out. The visible rings present would thus appear to have been produced by ^{214}Po and ^{218}Po (accounting for the two outermost rings) and ^{210}Po and ^{222}Ra (almost touching as the next inside ring), all with extremely short half-lives on the order of days or minutes. The innermost visible ring could be ^{234}U, ^{230}Th or ^{226}Ra, since these rings often overlap, and therefore any of these three could be the initiating radioisotope. True identification of the halo-initiating radioisotope would require sectioning of the diamond and destructively testing the halo centres with an ion microprobe mass spectrometer.

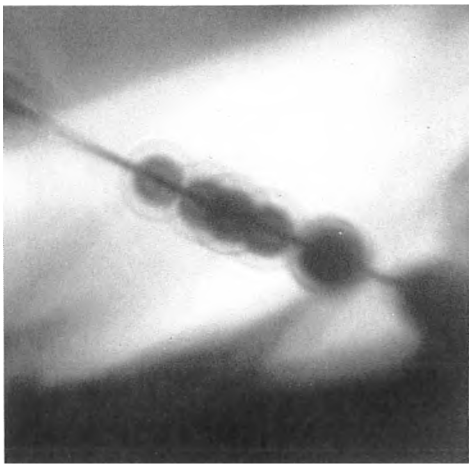

Figure 9. *Photomicrograph of the radiohalos in the diamond (100x magnification).*

However, whichever radioisotope was responsible for initiating the formation of the halos in this diamond, if ^{238}U was not involved then it is clear that the half-life of the initiating radioisotope is on the order of thousands rather than billions of years (^{234}U 248,000 yr half-life, ^{230}Th 75,200 yrs and ^{226}Ra 1622 yrs). Some of the halos are clearly not the product of ^{234}U decay, showing only three rings (Figure 11) which may represent parental radium or polonium. These observations only serve to compound the question of diamond formation. How could these short-lived halos become imprinted if the supposed formative cooling processes involved required such lengthy intervals? It has already been demonstrated that even brief periods of elevated temperatures will anneal (remove) halos,[21] so if these radiocentres were in the diamonds from the time of the latter's formation, then the subsequent claimed temperatures over extended eons would have eradicated any halos.

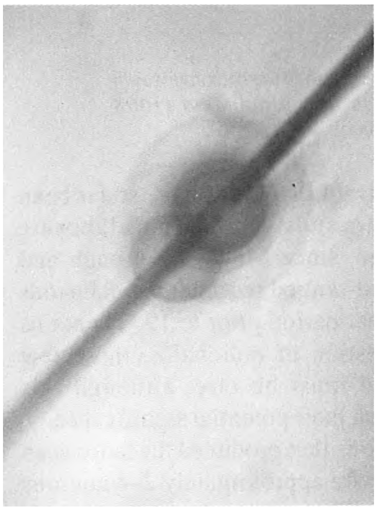

Figure 10. *Photomicrograph of the radiohalos with four rings in the diamond (200X magnification).*

THE INCLUSIONS

Twenty to thirty different minerals, such as garnet, sulphides, olivine and even diamond itself, have been described as inclusions inside diamonds,[22] along with 58 different types of impurities, including uranium and thorium. Generally speaking, diamonds with inclusions are small, at 0.25 carats or less, but this is because most inclusions are seen and then excised from the diamonds during processing

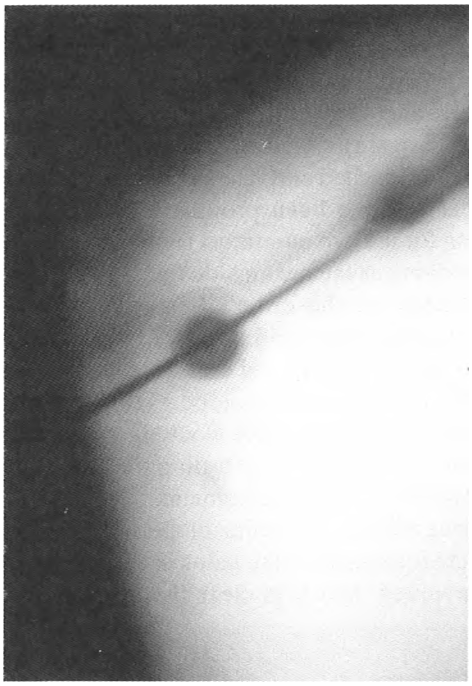

Figure 11. *Photomicrograph of the radiohalos with three rings in the diamond (100X magnification).*

(cutting). It may be significant that halos have so far been encountered only in diamonds exhibiting elaborate stratigraphy.[23] Furthermore, since Meyer's thorough and detailed summary[24] of broad-ranged research on inclusions in diamonds over the 25-year period prior to 1987 contains no mention or even suggestion of radiohalos, those few radiohalos so far reported must be rare, although this conclusion does not diminish their potential significance.

The radioactive inclusions that produced the halos seen in the diamond in this study are approximately 2–4 microns in diameter (see Figure 12). To have produced these halos these tiny inclusion centres must therefore have had fairly high concentrations of the relevant radioisotopes. What is potentially difficult to understand is that many of the mineral inclusions and elemental impurities in isolation have much lower melting and boiling points than the diamonds they are found in. For example, in the case of the ^{234}U, which may have produced the halos observed here, the melting point of elemental uranium is 1132°C, less than one third the melting point of carbon (3730°C), while the melting points of uranium oxide minerals vary between 1300°C and 2180°C. Similarly, even if the ^{234}U were in the crystal lattices of tiny zircon inclusions, temperatures of less than 2000°C would have resulted in ^{234}U loss from the zircon and its diffusion into the diamond. It is often envisaged that the diamonds simply grew around the inclusions, but one wonders how could such concentrated inclusion centres have failed to disperse, and/or their impurities diffuse, under the greater than ^{234}U boiling point conditions in the magmatic fluid during diamond crystallization.

One further enigma with respect to this particular diamond has to do with the presence of unusual hollow tubes with brown radiation stains within the diamond (Figure 13). At first, these tubes were thought to be laser drilled holes,[25] but were dismissed as such when a few of the tubes were found to extend to the surface of the diamond, and those that did lacked the conical appearance associated with laser drilling. No remnants of inclusions can be seen at the sharp corners of the geometric patterns made by these long tubes. Some of the tubes clearly terminate with radiohalos, while others do not (see Figures 13 and 14). Though most certainly of natural origin, what these tubes are, or represent, remains a puzzle, but they cannot be fission tracks either. Fission tracks do not twist around at right angles and spiral as these long tubes do, but are generally short, straight, thin tubes that are randomly oriented and scattered relative to one another.

Radioactivity measurements were performed on the diamond with both a 40% HPGe shielded detector and a four inch through-hole NaI shielded detector. Neither detector registered any radioactivity, any still present in the diamond being below the minimum detectable activity. Thus the radioisotopes that produced the halos are no longer detectable, having decayed.

GRANITES, BIOTITES AND HALOS

Biotite is the crystalline mineral in which halos most often appear, and biotites with halos are most commonly

Figure 12. *Photomicrograph of inclusion centres in two radiohalos (100X magnification).*

found in pegmatites. Pegmatites, in turn, are found scattered throughout the crystalline portions of the world's continental crust, often in mountainous areas, but particularly associated with granites. The most spectacular biotites are those in pegmatites that contain abnormally large crystals mixed with medium-sized and smaller crystals. Some single crystals up to many metres long have been reported.[26]

Granites, in which biotites containing halos are also found, are rocks consisting of coarse grains of quartz, potassium feldspar (orthoclase) and micas (muscovite and/or biotite), and are the most abundant plutonic rocks of the mountain belts and continental shield areas. They occur in great batholiths, or intrusive bodies, that may occupy thousands of square kilometres, and often form a significant part of the crystalline basement rocks of the continents. As a result of the bewildering variety of shapes, sizes, appearances and field relationships, many origins have been proposed for granites and their associations within the earth's crust.[27] Some granitic bodies show clear intrusive characteristics and therefore, it is thought, must be of igneous origin. After the emplacement of the main granitic body, and while it was cooling, it is proposed that a highly fluid residual granitic melt provided an environment for the concentration of certain chemical components and elements, and thus it is thought large biotite crystals were able to grow in what became pegmatite bodies. Other granites grade into the rocks that surround them and appear to show no intrusive characteristics. Most geologists believe that such bodies may represent material produced by melting during metamorphism at high temperatures and pressures.[28] Debate amongst geologists certainly has long centred on how the various bodies of granite form, but it is recognized that they are of both igneous and metamorphic origin, and it is generally agreed that they must have cooled from a hot melt over long periods of geologic time.[29]

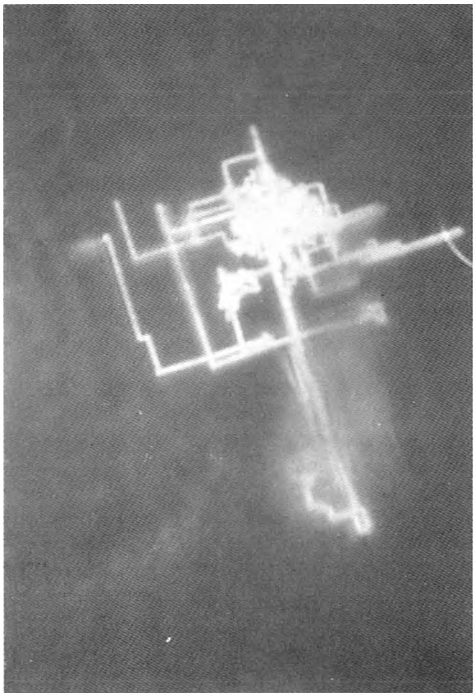

Figure 13. *Photomicrograph of the hollow tubes in the diamond (100X magnification).*

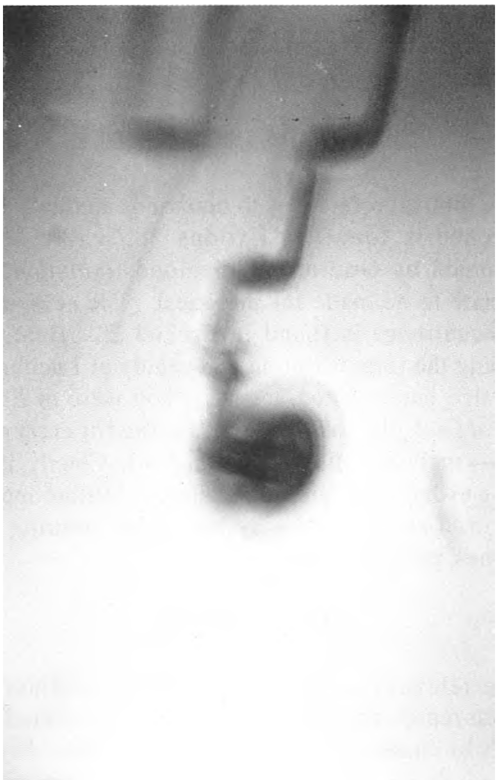

Figure 14. *Photomicrograph of the hollow tubes that terminate with halos (200X magnification).*

The biotite collected from the Bancroft, Ontario (Canada) area, for example, is claimed to be over 900 million years old and to have cooled over 10,000 to 20,000 years from a hot melt.[30] Since the half-life of ^{238}U is about 4.5 billion years, it is not surprising that fully-developed ^{238}U halos have been found in such biotite. The biotite with its tiny inclusions would have crystallized and cooled sufficiently to capture the uranium halos long before all the ^{238}U had decayed. However, it needs to be remembered that any extended heating/annealing event will erase the halos from the biotite.[31,32] This is also a major consideration with respect to ^{210}Po, ^{214}Po and ^{218}Po halos, which also occur in biotites in granites (and pegmatites). Since the granites are believed to have cooled over thousands of years, yet the polonium radioisotopes only have a fleeting existence and extended heating erases the halos, the existence of the polonium halos in granites is clearly a major enigma. One is forced to conclude that if the polonium was not introduced subsequent to granite formation (the evidence for which appears to be lacking), then the existence of these polonium halos in some granites could well indicate virtually instantaneous crystallization of those granites, which would then be designated created rocks. Such a conclusion is not without its own unresolved dilemmas, not the least of which is how do we then explain the intrusive relationships between granites containing polonium halos and fossil-bearing sedimentary strata if the former were created rocks and the latter Flood rocks or post-Flood rocks?

DIAMONDS IN THE BIBLE

The biblical references to diamonds are few. The first occurrence is found in Exodus 28, where Moses is commanded by God to use diamonds *(yahalom)* in the breastplate to be made for the priest. The next, and only other, occurrence is found in Ezekiel 28. Here, God is describing the former station and beauty of Lucifer, one of the created hand-picked angels. *'You were in Eden, the garden of God',* the passage says, *'adorned by every precious stone'* — including diamond *(yahalom)*. Clearly, if God is referring to diamond here, and Lucifer's glorified appearance before the Fall, then he may have been wearing created gemstones, particularly diamond.

DISCUSSION

The relevant question therefore is whether or not diamonds represent created gemstones or gemstones formed naturally by ongoing geologic processes? Unlike the granites described above, it is possible for small diamonds to be manufactured in the laboratory under carefully designed and controlled conditions. To date, these man-made diamonds come nowhere close to the kind of brilliance, clarity and size as seen, for example, in the Excelsior diamond (970 carats), or the Cullinan diamond (the largest ever found at 3,106 carats). If the spectacular diamonds excavated so far do represent created gemstones, then it is probably unlikely that man will ever come close to duplicating these within a laboratory. Further, it is difficult to conceive that God would have allowed natural processes to continue turning out such gemstones as diamonds throughout the years subsequent to the original creation events, though this is in part a theological rather than a scientific question.

If crustal diamond 'pipe' formation was associated with the global Flood and its aftermath (they most often travel vertically through fossil-bearing sedimentary layers), and if diamonds are created gemstones, then it is possible to assume that many diamonds may have existed sub-crustally prior to the Flood as a component of the foundations of the continents to later be carried to the surface by the eruption of kimberlite magmas.

CONCLUSIONS

Serious questions regarding the currently accepted diamond genesis scenario have been raised as a result of the presentation here of unusual and as yet unexplained inclusions and radiohalos in a diamond. It is unlikely that this diamond represents a one-of-a-kind anomaly, since the 25 micron halos are undetectable under less than 125X magnification. The unusual presence of possible short half-life radioisotope-produced halos, probable highly concentrated, comparatively low melting point inclusion centres, and hollow tubes twisting at right angles within the diamond matrix, point to possible formation under a completely unknown set of conditions, conditions that may only be explained in light of the events of creation week. Further investigation of these highly unusual features, including whether they are present in other diamonds, is required before firm conclusions can be drawn as to the origin and formation of diamonds within the biblical framework of earth history.

ACKNOWLEDGMENTS

I thank Dr Robert Gentry for supplying samples of biotite for photomicrography, and for help with illustrations. The text of this paper has greatly benefitted from the comments of reviewers and Dr Andrew Snelling.

REFERENCES

1. Kirkley, M. B., Gurney, J. J. and Levinson, A. A., 1991. Age, origin and emplacement of diamonds — scientific advances in the last decade. **Gems and Gemology, 27**(1):2–25.
2. Koskoff, David E., 1981. **The Diamond World**, Harper & Row, New York, New York.
3. Meyer, H. O. A., 1985. Genesis of diamond: a mantle saga. **American Mineralogist, 70**:344–355.
4. Evans, T., 1992. Aggregation of nitrogen in diamond. *In*: **The Properties of Natural and Synthetic Diamond**, J. E. Field (ed.), Academic Press, pp. 259–289.
5. Kirkley *et al.*, Ref. 1, pp. 2–25.
6. Meyer, H. O. A., 1987. Inclusions in diamond. *In*: **Mantle Xenoliths**, P. H. Nixon (ed.), John Wiley and Sons, pp. 501–524.
7. Allamandola, L. J., Sanford, S. A., Tielens, A. G. G. M. and Herbst, T. M., 1993. Diamonds in dense molecular clouds: a challenge to the standard interstellar medium paradigm. **Science, 260**:5104.
8. Koskoff, Ref. 2.
9. Meyer, Ref. 3.
10. Mendelssohn, M. J., Milledge, H. J., Vance, E. R., Nave, E. and Woods, P. A., 1979. Internal radioactive haloes in diamonds. **Diamond Research**, 17:2–7.
11. Talbot, S. L., 1977. Mystery of the Radiohalos. **Research Communications Network**, Newsletter No. 2.
12. Gentry, R. V., 1968. Fossil alpha-recoil analysis of variant radioactive halos. **Science, 160**:1228.
13. Mugge, O., 1907. **Zentr. Mineral**:397.
14. Mendelssohn *et al.*, Ref. 10, pp. 2–3.
15. Gentry, Ref. 12.
16. Gentry, Ref. 12.
17. Gentry R. V. *et al.*, 1974. 'Spectacle' array of ^{210}Po halo radiocentres in biotite: a nuclear geophysical enigma. **Nature, 252**:564.
18. Koivula, J. I. and Kammerling, R. C. (eds), 1988. Gem News: Remarkable diamond. **Gems and Gemology, 24**(4):248–249.
19. Mendelssohn *et al.*, Ref. 10.
20. Gentry, R. V., 1973. Radioactive halos. **Annual Review of Nuclear Science, 23**:347–362.
21. Armitage, M. H. and Back, E., 1994. The thermal erasure of radiohalos in biotite. **CEN Tech. J., 8**(2):212–222.
22. Meyer, Ref. 6.
23. Mendelssohn *et al.*, Ref. 10, p. 7.
24. Meyer, Ref. 6.
25. Koivula and Kammerling, Ref. 18.
26. Thorpe, R. and Brown, G., 1985. **Field Description of Igneous Rocks**.
27. Marmo, V., 1971. **Granite Petrology and the Granite Problem**, Elsevier.

28. Marmo, Ref. 27.
29. Marmo, Ref. 27.
30. Guy, R., vice-president, Geoscience Resources, Burlington, N.C., letter of 20/5/1992.
31. Gentry, R. V., personal communications, May 1992.
32. Armitage and Back, Ref. 21.

Mark Armitage studied biology and plant pathology at the University of Florida, has a B.S. in Bible and is currently a graduate student in biology at the Institute for Creation Research. Active in creationist circles, Mark is currently Executive Director of the San Fernando Valley Chapter of the Bible Science Association.