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Radiohalos in the Shap Granite, Lake District, England: Evidence that Removes Objections to Flood Geology

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Abstract

The Shap Granite in the Lake District of northern England intruded the surrounding host rocks as a magma that released hydrothermal fluids as it crystallized and cooled. These hot fluids in turn produced an atypically wide contact metamorphic and metasomatic aureole around the intrusion. There is no evidence at the boundary for tectonic emplacement of a primordial cold granite body. This study documents an abundance of Po radiohalos in the Shap Granite. These Po radiohalos had to have been produced in the granite after the hydrothermal fluids released in the granite had assisted in the formation of the granite's distinctive orthoclase feldspar megacrysts, and after the crystallized granite had subsequently cooled below the 150°C annealing temperature of radiohalos. The abundance of Po radiohalos is consistent with the hydrothermal fluid transport model for Po radiohalo formation and with catastrophically rapid granite formation. These features imply that the Shap Granite formed in 6–10 days and its Po radiohalos within hours to days once the granite cooled below 150°C. Hydraulic fracturing of the host rocks overlying the pluton facilitated rapid unroofing of the granite. Continued rapid erosion then deposited granite pebbles in the basal conglomerate of the overlying limestone. It is, therefore, conceivable that the Shap Granite formed, was unroofed, and the basal conglomerate with granite pebbles was deposited, all within 2–3 weeks during the early-middle part of the Flood year. The Po radiohalos and other evidence associated with this granite thus remove objections to Flood geology and any need to place the Flood/post-Flood boundary in the lower Carboniferous.

Keywords

Shap Granite, Northern England, Contact metamorphic aureole, Hydrothermal fluids, Po radiohalos, Orthoclase feldspar megacrysts, Catastrophic granite formation, Hydraulic fracturing, Rapid unroofing, Overlying basal conglomerate, Flood/post Flood boundary

Introduction

An oft-repeated claim is that a timescale of a million years or more for the formation and cooling of molten granite bodies unequivocally disproves Flood geology and its biblical chronological framework (Young, 1977). But many lines of current research are dispelling this misguided thinking (Snelling, 2006b, 2008a; Snelling & Woodmorappe, 1998; Woodmorappe, 2001). Nevertheless, there exist granite bodies whose geological contexts place very tight time constraints on their formation and cooling histories, so much so, that some Flood geologists feel compelled for this and other reasons to place the end of the Flood well down in the geologic record, even as low as the so-called lower Carboniferous (or Mississippian) (for example, Robinson, 1996). An example of such a granite body is the middle Devonian Shap Granite of the Lake District, England. However, an investigation of radiohalos in this granite provides evidence that further dispels these objections to Flood geology and alleviates the need to place the end of the Flood so far down in the geologic record.

Geology of the Lake District, England

The Lake District in northwest England contains a small dome of Lower Paleozoic (Ordovician and Silurian) sedimentary and volcanic strata, an inlier protruding from beneath a cover of Carboniferous and Permo-Triassic sedimentary strata (Smith, 1992). Figure 1 is a generalized geological map of the area, while Figure 2 shows the generalized geological succession of strata (Moseley, 1990).

The oldest rocks in the district (the lowermost in the exposed strata sequence) are Skiddaw Group greywackes, siltstones, and mudstones (now slates in some cases), with sandstones. These appear to have been deposited almost entirely by turbidity currents in relatively deep water. Even though these sedimentary strata are more than 3,000 meters thick, their accumulation via turbidity currents need not have taken the oft-claimed millions of years. Instead, such a thick strata sequence could have accumulated very rapidly early in the Flood year as catastrophic global tectonic upheavals triggered an abundance of turbidity currents, at intervals as short as minutes.

Such a catastrophic depositional environment has been confirmed by recognition of large blocks hundreds of meters in diameter which slid downslope as the sediments accumulated (Webb & Cooper, 1986). The burial of such large blocks indicates that each cycle of these turbidite sediments had to be tens to hundreds of meters thick, so that the whole 3,000 meters thick sequence was deposited within days during the Flood. One source of this huge thickness of sediments would have been the sediments on the pre-Flood ocean floor (Austin, Baumgardner, Humphreys, Snelling, Vardiman, & Wise, 1994). The conventional Ordovician age assigned to these Skiddaw Group sediments is based mostly on graptolites, but acritarchs and other microfossils have lately been used.

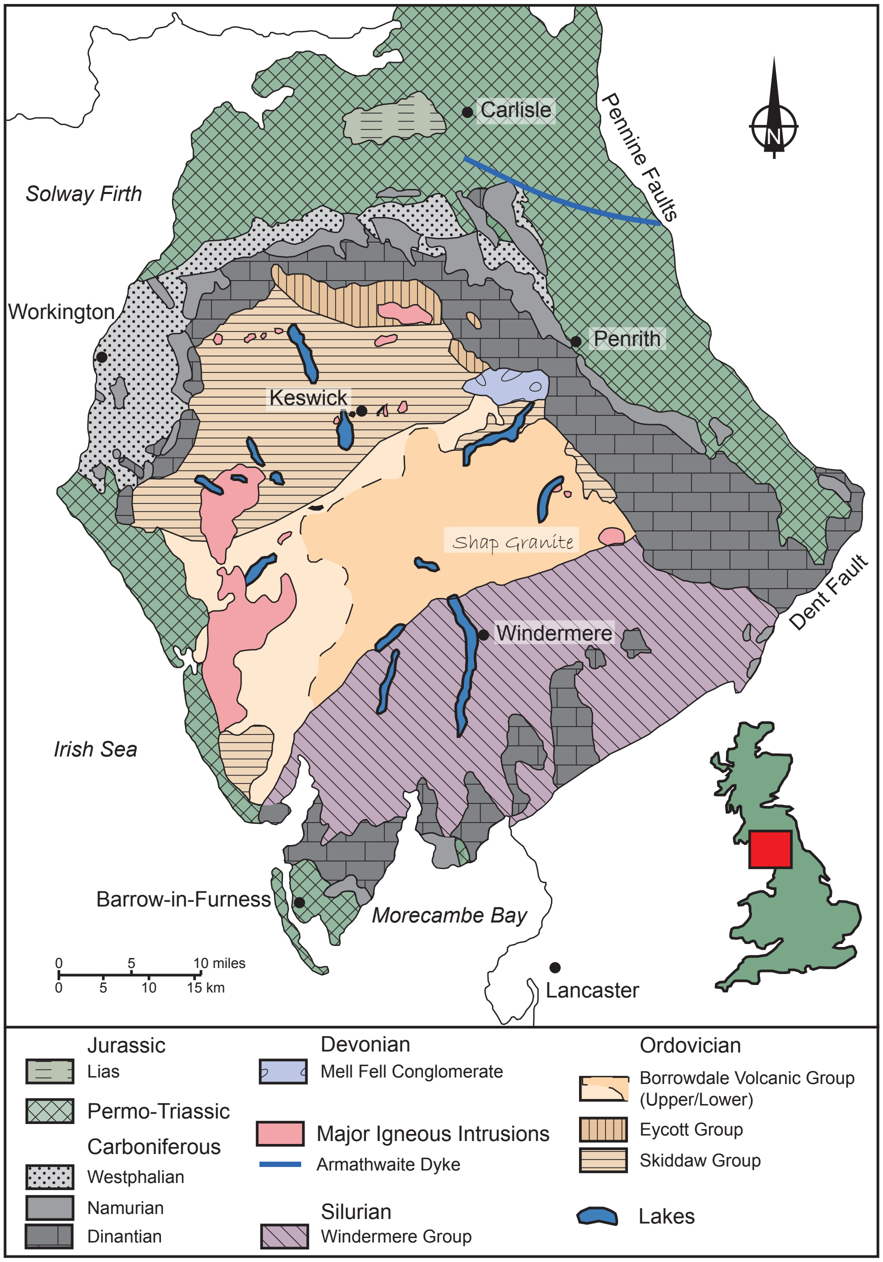

Figure 1. Geology of the Lake District, northern England, showing the location of the Shap Granite.

Overlying the Skiddaw Group sediments are the Eycott Group volcanic strata. These likely erupted partly in submarine conditions, as some of the last Skiddaw Group sediments are interbedded with them. They consist primarily of basalt and basaltic andesite lavas that preceded the main large-scale catastrophic explosive volcanism of the overlying Borrowdale Volcanic Group. Dominating the landscape over 800 km^2 of the Lake District, the Borrowdale Volcanic Group consists of about 6,000 meters of calc-alkaline basalt, basaltic andesite, and andesite lavas followed by the catastrophic explosive eruption of widespread and voluminous dacitic and rhyolitic pyroclastic deposits (tuffs and ignimbrites), and lavas, associated with volcano-tectonic faulting (Branney & Kokelaar, 1994). Garner (1992) has discussed the evidence for subaqueous, rather than the oft-claimed subaerial, eruption of these volcanics and has shown how the rapid, catastrophic accumulation of the entire volcanic succession during the Flood is consistent with all the field data and what is known about explosive volcanism. For example, in the AD186 Taupo, New Zealand, eruption hot ash-flows or ignimbrites traveled for 80 km in all directions with an initial speed of 250–300 m/sec, so that 30 km^3 of rhyolitic volcanic ash was erupted in less than 10 minutes (Wilson, 1985)!

Unconformably overlying both the Skiddaw Group and Borrowdale Volcanic Group strata are the predominantly sedimentary strata of the 3,000 meter thick Windermere Group. Deposition commenced in the latest Ordovician with the thin (60–150 m) Coniston Limestone, which contains reworked volcanic ash, and occasional brachiopods and trilobites. Sedimentation was then continuous throughout the so-called Silurian, with thick turbidite sequences of sandstones, flagstones (thin, hard sandstones), gritstones, mudstones, and dark shales deposited that are quite fossiliferous (trilobites,

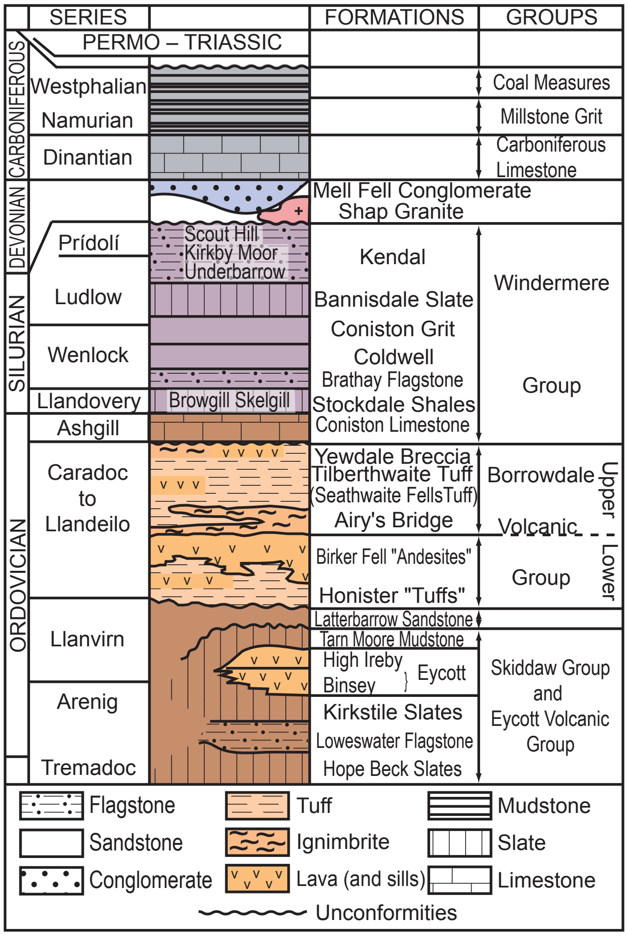

Figure 2. Time-stratigraphipc chart showing the strata sequence in the Lake District, northern England, including the relative time position of the Shap Granite.

graptolites, brachiopods, ostracods). Apart from uniformitarian assumptions about sedimentation rates, there is no evidence in these Windermere Group strata that would preclude their having been deposited rapidly, especially the thick turbidite sequences, as part of the catastrophic sedimentation during the early part of the Flood. Even the black shales in the Windermere Group, which conventionally would be interpreted as having been deposited in a quiescent, anaerobic, deep marine environment, could have been deposited catastrophically. For example, there are marine black shales in Scotland that must have been deposited as a result of a submarine earthquake induced tsunami, because the shales intertongue with large boulders (Bailey & Weir, 1932). Furthermore, recent experiments have demonstrated that muddy sediments do accumulate rapidly, at flow velocities that transport and deposit sand (Macquaker & Bohacs, 2007; Schieber, Southard & Thaisen, 2007).

In addition to the sediments and extruded volcanic rocks, there was also massive intrusive volcanism. Even as early as the Ordovician, the intrusion of the large Lake District Batholith (Bott, 1974; Firman & Lee, 1986) had begun, as represented by the now extensive outcrops of the Eskdale Granite. Intrusive activity apparently continued until the early Devonian, represented by the Skiddaw and Shap Granites. The dates for the granites are based on K-Ar, Rb-Sr, and U-Pb radioisotope whole-rock and mineral, model and isochron methods (Brown, Miller, & Soper, 1964; Pidgeon & Aftalion, 1978; Rundle, 1979, 1981; Wadge, 1978). It has thus been suggested that the batholith may be genetically related to the Borrowdale volcanicity (Soper, 1987; Soper, Webb, & Woodcock, 1987). There is evidence for continuation of a large volume of intrusive activity through the Silurian to the early Devonian (Firman & Lee, 1987; Webb, Millward, Johnson, & Cooper, 1987). The east-west belt of relatively low gravity anomalies suggests the area is underlain by the large granite batholith, for which gravity minima coincide with the outcropping Eskdale, Skiddaw and Shap Granite plutons. These plutons are parts of the roof of the batholith that was exposed by erosion. The heat from these granite intrusives produced wide contact metamorphic aureoles, while hydrothermal fluids from the cooling granites penetrated the overlying Skiddaw, Borrowdale and Windermere Group rocks, depositing copper, lead, tungsten, and iron ores in fracture veins (Firman, 1978b).

By the late Devonian all earlier formed strata were being severely eroded. As a result, the coarse-grained, poorly-sorted Mell Fell Conglomerate was deposited in what has been interpreted as a series of alluvial fans. At least 275 m thick (some estimates are as high as 1,500 m thick), this conglomerate consists of pebbles of mostly Silurian Windermere greywacke, but also some Skiddaw type and Borrowdale volcanic pebbles (Wadge, 1978). Possible cross-stratification in this conglomerate is added testimony to its rapid deposition.

This severe erosion had waned by the early Carboniferous or Dinantian (equivalent to the Mississippian in the USA), giving way to deposition of a sequence of predominantly limestones that has been interpreted as a series of cyclothems (Ramsbottom, 1977). However, the Basement Beds to these limestones consist of conglomerates and sandstones that appear to fill irregularities in the pre-Dinantian erosion surface, and are therefore extremely variable in thickness—over 200 meters in the southwest, about 10 m in the Shap area, and completely absent in places. It is in this lower Carboniferous basal conglomerate that pebbles of, and pink feldspar crystals from, the Shap Granite are found, just over a kilometer to the east of the outcropping Shap Granite. Then during the Namurian (mid-Carboniferous) these limestones were overlain by typical cyclothem sequences consisting of sandstones, shales, and gritstones followed by limestones. These in turn were overlain by the Westphalian (upper Carboniferous, or Pennsylvanian in the USA) Coal Measures, up to more than 600 meters of cyclothems consisting of shales, sandstones, and coals, followed by several hundred meters of red beds.

Finally, Permian-Triassic sedimentary strata outcrop along the southwestern, northern and northeastern margins of the Lake District. The lowest deposits (Permian) were breccias that are overlain by, and interbedded with, the Penrith Sandstone, followed by so-called evaporite deposits (mainly gypsum and anhydrite). These latter strata are usually interpreted as representing a desert environment, but can be equally well explained as precipitites, that is, they precipitated from water oversaturated in those salts due to catastrophic influxes of salt-laden hydrothermal fluids into cold ocean waters during the Flood (Hovland, Rueslätten, Johnsen, Kvanne, & Kuznetsova, 2006; Nutting, 1984; Sozansky, 1973).

The Shap Granite

The Shap Granite is one of the best-known and most distinctive rock types in northern England (Skipsey, 1992). With its coarse porphyritic texture and large, pink orthoclase feldspar megacrysts, it has been quarried as a building stone used in London and many other places. Although the Shap Granite only outcrops over a small area of 5.5 km^2 (Figure 3), geophysical studies and field evidence have revealed that it is a steep-sided stock-like intrusion with a subsurface extension to the northwest (Boulter & Soper, 1973). This granite pluton was intruded near and at the unconformity between the Ordovician Borrowdale Volcanic Group lavas and tuffs, and the overlying Silurian Windermere Group. The heat and hydrothermal fluids from the crystallizing granite magma as it cooled generated a broad (600+ meter wide) metamorphic and metasomatic aureole around its contact with its host rocks (Grantham, 1928; Harker & Marr, 1891; 1893).

The Shap Granite has a characteristic porphyritic texture dominated by pink orthoclase feldspar megacrysts often more than 3 cm in length with good rectangular shapes and twinning parallel to their long axes (Lee, Waldron, & Parsons, 1995). The matrix is coarse and consists of glassy grey quartz, cream plagioclase feldspar, and black biotite crystals. Hornblende is occasionally a minor constituent, while accessory minerals include zircon, apatite, allanite, sphene (titanite), and magnetite (O'Brien, Plant, Simpson, & Tarney, 1985).

Also present in the granite is a suite of mafic microgranular enclaves, essentially quartz microdiorite, often incorrectly called xenoliths, typically 10–20 cm in size (Cox, Dempster, Bell, & Rogers, 1996; Skipsey, 1992). They can be angular or rounded, and may have either sharp or fuzzy boundaries with the normal granite. Furthermore, they also usually contain the same pink orthoclase feldspar megacrysts as in the granite, but they are less frequent and more rounded than in the normal granite. These observations have fueled debate about the origin of these mafic enclaves.

The Shap Granite when first mapped was shown to be a composite intrusion, with three separate main stages, each containing different types of mafic enclaves, after an initial more primitive fraction of the magma represented by the early mafic enclaves (Grantham, 1928; Harker & Marr, 1891). These three granite stages show cross-cutting relationships, and show a progressive increase in both grain size and orthoclase feldspar megacryst content. The second stage represents 90% of the intrusion, and the third and last stage of the intrusion contains approximately 50% orthoclase feldspar megacrysts. Firman (1978a) demonstrated that the whole-rock geochemical data (Grantham, 1928) was consistent with a mixing hypothesis. However, textural observations (Grantham, 1928), mixing trends (Firman, 1978a), rare earth element patterns (O'Brien et al., 1985) and the crystallization path (Cox et al., 1996) all suggest

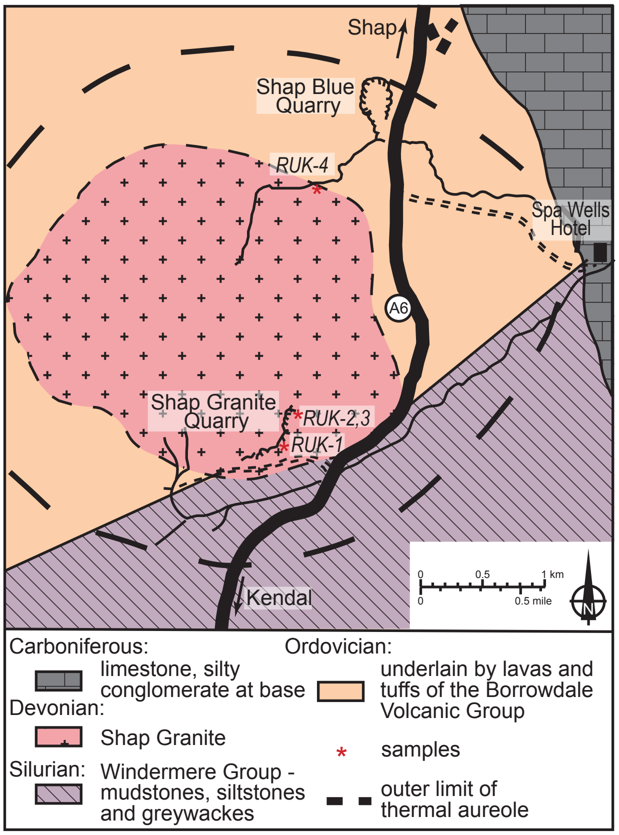

Figure 3. Geologic map of the Shap Granite, showing the atypically wide contact metamorphic and metasomatic aureole surrounding the boundary of the granite with its host rocks. Sample locations are marked. The nearby basal conglomerate to the Carboniferous limestone outcrops near the Spa Wells Hotel (right).

little open system fractionation has occurred. Changes in pressure and/or fluid content, together with partial hydridization, seem to have dominated the granite magma's chemical evolution as it was intruded, crystallized, and cooled. Indeed, the mafic (quartz microdiorite) enclaves are now regarded as the result of hydridization of the granite by co-intrusion of a mafic magma. Good evidence for this is provided by seismic reflection data for sills in the nearby related Eskdale Granite (Evans, Rowley, Chadwick, Kimbell, & Millward, 1994). There is also good observational evidence that magmatic hydrothermal fluids played a major role in the formation of the orthoclase feldspar megacrysts during granite crystallization and cooling at temperatures of 410°C and 370°C (Cox et al, 1996; Lee & Parsons, 1997; Lee, Waldron, & Parsons, 1995).

Brown et al (1964) have summarized all previous attempts to date the Shap Granite (Dodson, Miller, & York, 1961; Kulp et al., 1960; Lambert & Mills, 1961). Six Rb-Sr model ages determined on biotite from the granite ranged from 364±24Ma to 403±15Ma, while 15 K-Ar model ages, also determined on biotite, ranged from 381±12Ma to 410Ma. Subsequent U-Pb measurements on zircons from the granite yielded a discordia line with an upper intercept age of 390±6Ma (Pidgeon & Aftalion, 1978). Wadge, Gale, Beckinsdale, and Rundle (1978) made three further K-Ar model age determinations on biotites from the granite, which yielded ages of 394±12Ma, 394±12Ma and 403±12Ma, averaged to 397±7Ma. However, they also performed 22 Rb-Sr measurements on whole-rock granite samples, and biotite and orthoclase feldspar megacryst separates, which yielded a 21-point Rb-Sr isochron line corresponding to an age of 394±3Ma. Given this apparent agreement (concordance) between these ages for the Shap Granite obtained by three radioisotope dating methods (K-Ar, Rb-Sr, and U-Pb), it has been concluded that in conventional terms this granite is early Devonian (Emsian).

The Perceived Problem

The Shap Granite has been convincingly dated, in conventional terms, at 394±3Ma, or middle Devonian. Yet just over a kilometer to the east of the outcropping granite, near the Spa Wells Hotel (Figure 3), is an outcrop of the lower Carboniferous basal conglomerate to the overlying Carboniferous limestones, in which are found pebbles of, and pink orthoclase feldspar megacrysts from, the Shap Granite (Figure 4). So if this conglomerate dates to approximately 354Ma, there are only 40 million years, in conventional terms, for complete cooling of the granite, erosion of perhaps 1–3 kilometers of host metamorphosed sediments to unroof the granite, and then erosion of the granite to deposit these granite pebbles and feldspar megacrysts in the nearby conglomerate bed.

Placement of these processes during the Flood year requires 40 million years of conventional geologic time to be compressed to perhaps only 2–3 weeks! To alleviate this problem some have placed the Flood/post-Flood boundary within this interval, allowing more time in the immediate post-Flood period for the cooling and unroofing of this granite (Robinson, 1996; Robinson, Tyler, and Garton, personal communication, 2002). This view makes the upper Carboniferous coal measures, which overlie the limestones and their basal conglomerate, post-Flood. It also makes the Carboniferous-Recent fossils the result of the post-Flood recolonization of the earth. Since radiohalo studies have provided evidence that granites had to crystallize and cool rapidly (Snelling, 2005a; Snelling & Armitage, 2003), a radiohalos investigation of the Shap Granite was undertaken.

Field Work

A field trip to the Shap Granite was made in early October 2002. Several sections of the boundary of the granite with its host rocks were followed and inspected in outcrop. Four samples of the granite were collected. Three of these were from the sporadically used Shap Granite Quarry, and one from an outcrop of the granite at its host rock boundary, not far from the active Shap Blue Quarry (Figure 3). Figure 5 shows views of the granite and of the sampled outcrops.

Experimental Procedures

A standard petrographic thin section was obtained for each granite sample. In the laboratory, a scalpel and tweezers were used to remove flakes of biotite from the sample surfaces. Where necessary portions of the samples were crushed to liberate the constituent mineral grains. Biotite flakes were then hand-picked and placed on the adhesive surface of a piece of clear Scotch™ tape. Once numerous biotite flakes had been mounted on the adhesive surface of this tape, a fresh piece of clear Scotch™ tape was placed over them and firmly pressed along its length so as to ensure the two pieces of tape were stuck together with the biotite flakes firmly wedged between them. The upper piece of clear Scotch™ tape was then peeled back in order to pull apart the biotite flakes. This upper piece of clear Scotch™ tape with thin biotite sheets adhering to it was then placed over a standard glass microscope slide. This procedure was repeated with another piece of clear Scotch™ tape placed over the original Scotch™ tape with biotite flakes adhering to it. These adhering biotite flakes were progressively pulled apart and transferred to microscope slides. In this way tens of microscope slides were prepared for each granite sample, each slide with many (at least 20–30) thin biotite flakes mounted on it. This is

Figure 4. Outcrops of the conglomerate, containing the Shap Granite pebbles and pink K-feldspar crystals, at the base of the Carboniferous (Dinantian) limestone in the creek bank near the Spa Wells Hotel (Figure 3).
(a) The conglomerate can be seen at the bottom of the creek bank
(b) Closer view of the basal conglomerate layer with rounded pebbles clearly visible
(c) Even closer view of the conglomerate showing the clasts in a course matrix
(d) Another enlarged view of the conglomerate in which granite and K-feldspar clasts can be seen

similar to the method pioneered by Gentry (Gentry, personal communication). Fifty microscope slides were prepared for each sample to ensure good representative sampling statistics. Thus there was a minimum of 1,000 biotite flakes mounted on microscope slides for each sample.

Each slide for each granite sample was then carefully examined under a petrological microscope in plane polarized light, and all radiohalos present were identified, noting any relationships between the different radiohalo types, and any unusual features. The numbers of each type of radiohalo in each slide were counted by progressively moving the slide backwards and forwards across the field of view, and the numbers recorded for each slide were then tallied and tabulated for each sample. Because of the progressive peeling apart of many of the same biotite flakes during the preparation of the microscope slides, many of the radiohalos appeared on more than one microscope slide. Only radiohalos whose radiocenters were clearly visible were thus counted to ensure each radiohalo was only counted once.

Results

Figure 6 shows the typical mineralogy and textures of the Shap Granite under the microscope in the samples collected for this study. All radiohalos results are listed in Table 1. All four samples contained abundant ^{238}U, ^{232}Th, and Po radiohalos, some representative examples of which can be seen in Figure 7. As well as the absolute numbers of each of the radiohalo types counted, Table 1 also shows the average total numbers of radiohalos and of just Po radiohalos per slide, plus abundance ratios for pairs of radiohalo types.

The four samples average between 9 and 16 radiohalos per slide, and between 6 and 12 Po radiohalos per slide. This compares well to similar average numbers of radiohalos in other Paleozoic-Mesozoic granitic rocks, well above the numbers of radiohalos in Precambrian granitic rocks (see Tables 1 and 2, and Figures 5 and 6, Snelling, 2005a). ^{210}Po radiohalos outnumber ^{238}U radiohalos by between 2.3 to 1 and 8.7 to 1, and greatly outnumber ^{214}Po and ^{218}Po radiohalos, 35-227 to 1 and 48-571 to 1, respectively. This is also typical of other Paleozoic-Mesozoic granitic rocks.

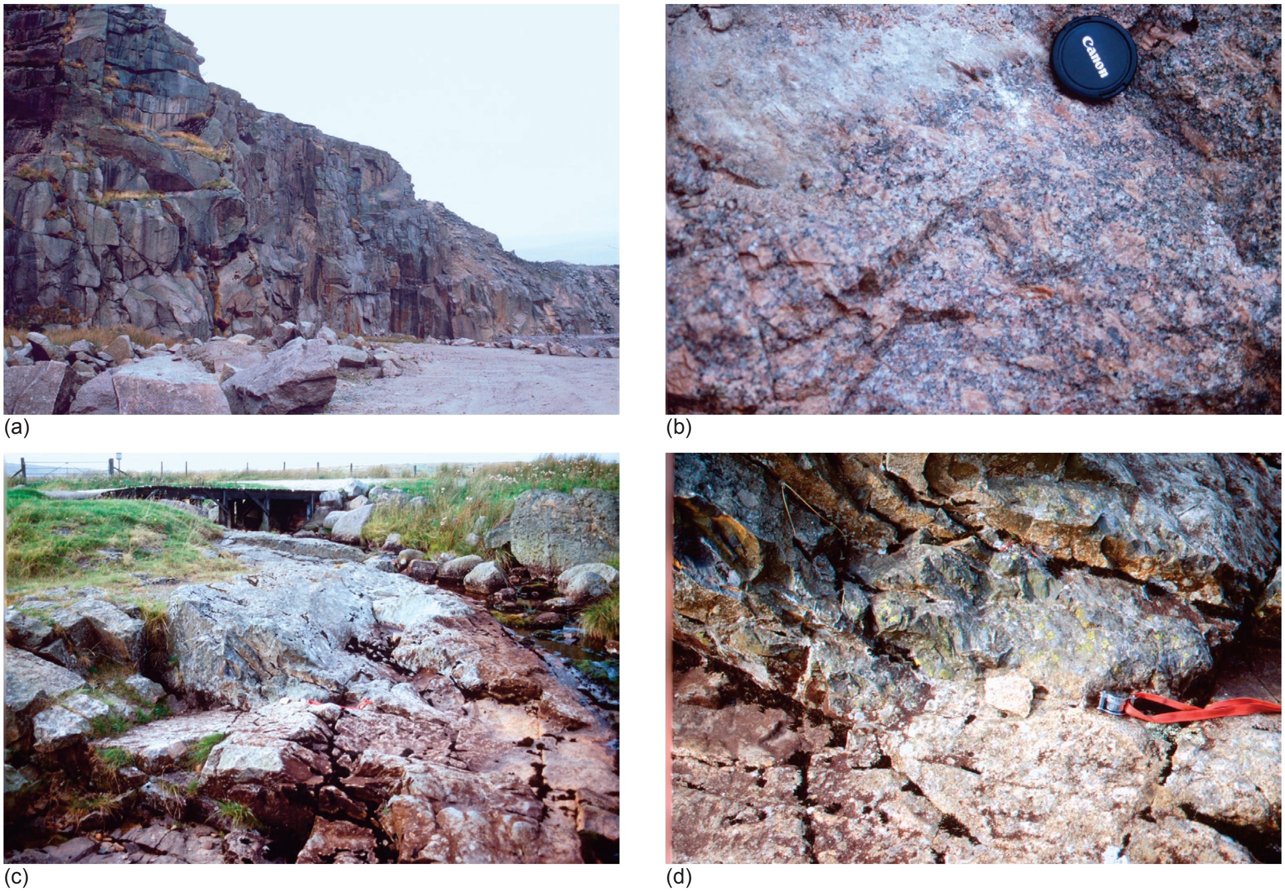

Figure 5. Outcrops of the Shap Granite sampled in this study (locations indicated in Figure 3).

(a) The northern end of the Shap Granite Quarry's east-facing wall in the vicinity of where samples RUK-2 and 3 were collected.

(b) Close view of the Shap Granite in the quarry showing the abundance of pink K-feldspar megacrysts in the granite

(c) The boundary of the pink granite (foreground) with the overlying grey contact hornfels at the site of sample RUK-4, taken from the "clean" area towards the creek. The red ribbon marks the granite/hornfels boundary, which is sharp.

(d) Closer view of the granite/hornfels boundary, marked by the hand lens and red ribbon. The boundary is sharp, with no evidence of any cold tectonic emplacement of the granite.

Discussion

The significance of so many observed Po radiohalos in these Shap Granite samples depends on how they are understood to have formed. In conventional thinking they are "a very tiny mystery" (G. Brent Dalrymple, as quoted by Gentry, 1988, p. 122) that can therefore be conveniently ignored because they have little apparent significance. However, if the formation of these Po radiohalos cannot be explained, then their significance cannot be fully comprehended. The reality is that the mystery of the Po radiohalos is ignored, because it constitutes a profound challenge to conventional wisdom.

Comprehensive reviews of what these Po radiohalos are and how they may have formed are provided by Gentry (1973, 1974, 1984, 1986) and Snelling (2000). It has been established that all the observed Po radiohalos are generated exclusively from the Po radioisotopes in the ^{238}U decay series, namely, ^{218}Po, ^{214}Po, and ^{210}Po, with contributions from none of the other species in the ^{238}U α-decay chain (Gentry, 1974). Furthermore, it has been estimated that, like the ^{238}U radiohalos, each visible Po radiohalo requires between 500 million and 1 billion α-decays to generate it (Gentry, 1988), which equates to a corresponding number of Po atoms having been in each radiocenter. Thus the crucial issue is how did so many Po atoms get concentrated into these radiocenters to generate the Po radiohalos, when their half-lives are only 3.1 minutes (^{218}Po), 164 microseconds (^{214}Po), and 138 days (^{210}Po)?

Gentry (1986, 1988, 1989) insists that the Po must be primordial, that is, created by God instantaneously in place in the radiocenters in the biotite flakes in the granites, and thus the granites are also created rocks. In other words, he argues that granites did not

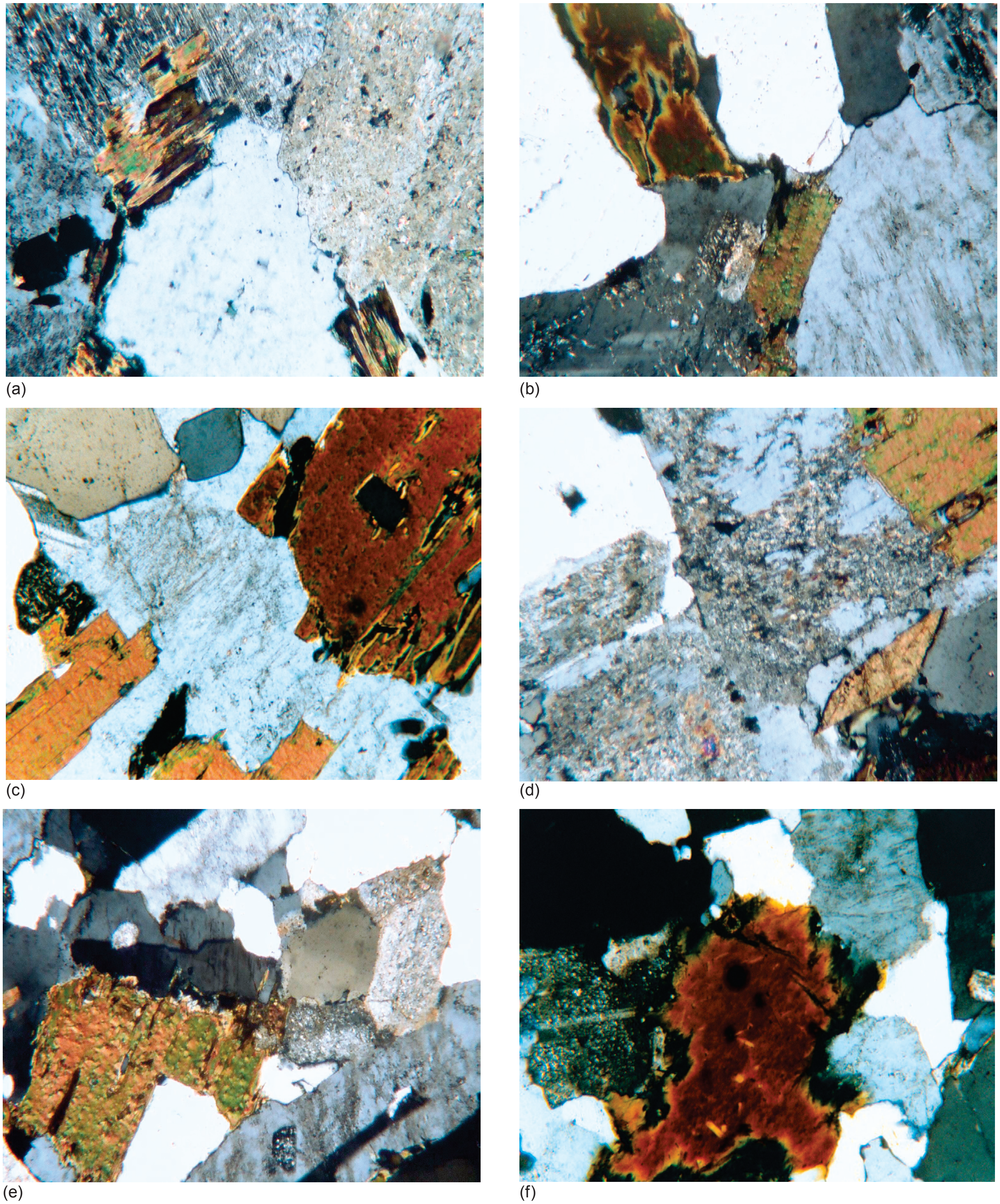

Figure 6. Representative photo-micrographs of the Shap Granite samples used in this study. All photo-micrographs are at the same scale (20× or 1 mm = 40µm) and the granite is as viewed under crossed polars.
(a) RUK-1: quartz, K-feldspar, plagioclase (with sericite), biotite, apatite
(b) RUK-2: quartz, K-feldspar, plagioclase, biotite
(c) RUK-2: quartz, K-feldspar, plagioclase, biotite (with halos)
(d) RUK-3: quartz, K-feldspar, plagioclase (with sericite), biotite, sphene (titanite)
(e) RUK-4: quartz, K-feldspar, plagioclase (with sericite), biotite
(f) RUK-4: quartz, K-feldspar, plagioclase (with sericite), biotite (with halos).

Table 1. Data table of radiohalos numbers counted in the collected Shap Granite samples.

Sample	Number of Slides	Radiohalos					Total Number of Radiohalos per Slide	Number of Po Radiohalos per Slide	Ratios				
		^{210}Po	^{214}Po	^{218}Po	^{238}U	^{232}Th			^{210}Po:^{238}U	^{210}Po:^{214}Po	^{210}Po:^{218}Po	^{214}Po:^{218}Po	^{238}U:^{232}Th
RUK-1	51	311	9	3	138	18	9.4	6.3	2.3:1	34.6:1	104:1	3:1	7.7:1
RUK-2	51	454	2	0	52	7	10.1	8.9	8.7:1	227:1	—	—	7.4:1
RUK-3	51	576	5	12	212	7	15.9	11.6	2.7:1	115:1	48:1	0.4:1	30:1
RUK-4	51	571	3	1	216	18	15.9	11.3	2.6:1	190:1	571:1	3:1	12:1

form from the crystallization and cooling of magmas, but rather are the earth's created foundation rocks. Moreover, where granites such as the Shap Granite have been intruded into fossiliferous Flood-deposited strata, Gentry (1989) insists that these granites also represent originally created rocks. He argues that during the Flood they were tectonically intruded as cold bodies, and that the contact metamorphic aureoles were produced by the heat and pressure generated during tectonic emplacement, augmented in some cases by hot fluids from depth.

Such an interpretation is inconsistent with the field and petrological evidence from the Shap Granite. The contact between the granite and the metamorphosed fossiliferous (Flood-deposited) host rocks it intruded is a sharp, knife-edge boundary, with no fracturing, brecciation or mylonization that should be evident in either the adjacent granite or host rocks if the granite had been intruded tectonically as a cold body (Figure 5c & d). Indeed, granite sample RUK-4 was collected right at the boundary, yet it displayed no petrographic signs of cold tectonic emplacement effects and looked no different from the other samples that were collected further away from the boundary. Furthermore, if the theorized accompanying hot fluids from depth had a temperature of >150°C, as likely they would, then they would have annealed all the radiohalos (Laney & Laughlin, 1981). In fact, hydrothermal fluids were responsible for forming the pink orthoclase feldspar megacrysts within the granite at 410°C and 370°C; so the presently-observed Po radiohalos in the granite could only have been generated subsequently, after the granite had cooled below 150°C. Thus the Po radiohalos were formed after the granite was intruded and after it and its contact metamorphic aureole in the host rocks had cooled. Indeed, the rock in the contact metamorphic aureole at sample site RUK-4 consists of andesite that has been extensively recrystallized to hornfels by the intense magmatic heat and hydrothermal fluids emanating from the intruding magma (Skipsey, 1992). Furthermore, tongues and veins of granite can be seen penetrating the metamorphosed host rock, proving that the granite intruded as a magma, and is therefore not primordial (that is, created).

The other competing model for the formation of the Po radiohalos is a hydrothermal fluid transport model (Snelling, 2005a; Snelling & Armitage, 2003). In this model it is postulated that the Po isotopes as well as the ^{222}Rn parent of ^{218}Po were produced from ^{238}U decay in the zircons that are the radiocenters of nearby ^{238}U radiohalos located in the same biotite flakes as the Po radiohalos. The hydrothermal fluids released by the crystallizing and cooling granite magma flowed along the biotite cleavage planes and transported the ^{222}Rn and Po isotopes from the zircon radiocenters. The Po isotopes, including the ^{218}Po produced by ^{222}Rn α-decay (half-life of 3.8 days), were then precipitated in lattice defects along the same biotite cleavage planes where S, Cl and other atoms chemically attractive to Po were located, within a millimeter or so of the zircon radiocenters. These Po precipitation sites became the radiocenters for the Po radiohalos. As the Po in the radiocenters α-decayed, new Po atoms were supplied from the hydrothermal fluids flowing through the biotite lattice. Thus, provided the supply of Po isotopes was sufficient and the hydrothermal fluid flows were sustained and rapid, the required Po concentrations would have been supplied to the radiocenters to produce the 500 million—1 billion Po α-decays to generate the Po radiohalos within hours or days, consistent with the fleeting half-lives of the Po isotopes.

Because hydrothermal fluid flows are crucial to this Po radiohalos formation model, it might be expected that the greater the volume and flow of hydrothermal fluids, the greater the probability that more Po radiohalos would be generated. This prediction has proven true in several situations. First, in granites where hydrothermal ore deposits have formed in veins due to large, sustained hydrothermal fluid flows, there are huge numbers of Po radiohalos, for example, in the Land's End Granite, Cornwall (Snelling, 2005a). Second, where hydrothermal fluids were produced by mineral reactions, at a specific pressure-temperature boundary during regional metamorphism, four to five times more Po radiohalos were generated, precisely at that specific metamorphic boundary (Snelling, 2005c; Snelling, 2008b). Third, where hydrothermal fluids flowing in narrow shear zones had rapidly metamorphosed the wall rocks, Po radiohalos were present in the resultant metamorphic rock, a type of metamorphic rock that otherwise does not host Po radiohalos (Snelling, 2006a). Fourth,

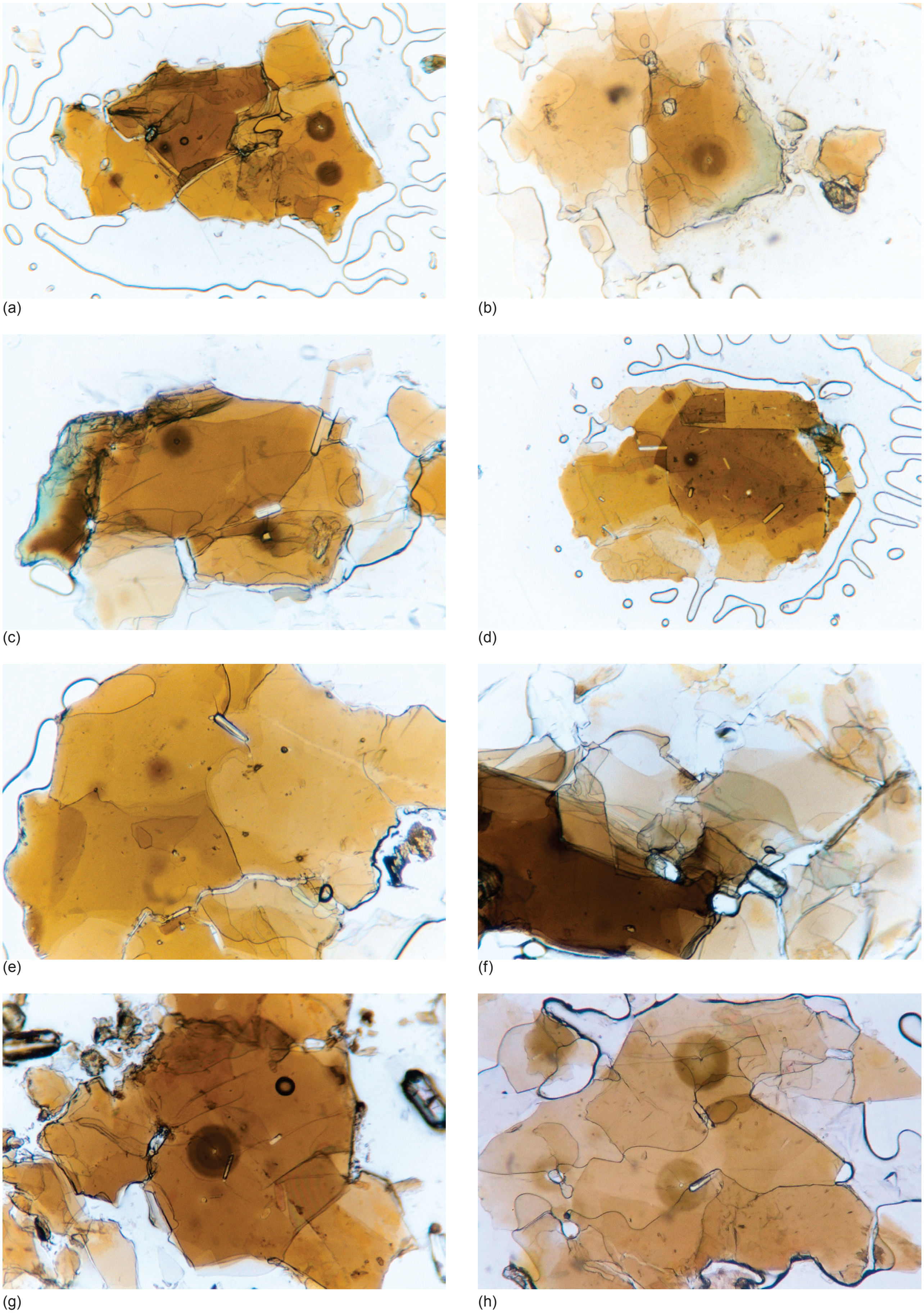
(a) (b) (c) (d) (e) (f) (g) (h)

Figure 7 (opposite). Some representative radiohalos found in biotite flakes separated from the Shap Granite in this study. All photo-micrographs are at the same scale (40× or 1 mm = 20μm) and the biotite flakes are as viewed in plane polarized light.
(a) RUK-1: two overexposed ^{238}U radiohalos and a ^{210}Po radiohalo with a zircon grain nearby
(b) RUK-1: an overexposed ^{238}U radiohalo with a tiny zircon grain in its center
(c) RUK-1: a ^{218}Po radiohalo with a faint outer ring, and an enlarged ^{210}Po radiohalo
(d) RUK-2: a ^{210}Po radiohalo, a possible ^{238}U radiohalo, and some fluid inclusions
(e) RUK-2: a ^{214}Po radiohalo, a ^{210}Po radiohalo, and a fluid inclusion
(f) RUK-4: a ^{210}Po radiohalo (left), and a large zircon grain
(g) RUK-4: an overexposed ^{238}U radiohalo and a fluid inclusion
(h) RUK-4: an overexposed ^{238}U radiohalo, and a reversed overexposed ^{238}U radiohalo

in a sequentially intruded suite of nested granite plutons where the hydrothermal fluid content of the granites correspondingly increased, so that the last intruded central pluton was connected to coeval explosive, steam-driven volcanism, the numbers of Po radiohalos generated increased inwards within the nested suite of granite plutons (Snelling & Gates, 2008). Such evidences provide confirmations that give confidence in this hydrothermal fluid trasnport model for forming Po radiohalos.

The hydrothermal fluids generated by the crystallization and cooling of the Shap Granite produced several effects that indicate substantial volumes of sustained fluid flow were involved. The hydrothermal fluids carried the heat released by the crystallizing granite and dispersed it by convection into the host rocks. These fluids generated the 600+ meter wide contact metamorphic and metasomatic aureole around the granite (Grantham, 1928; Harker & Marr, 1891, 1893). The enormous width of this aureole, nearly half the radius of the exposed Shap Granite stock itself, is most unusual compared with other granites. This large width is testimony to the large volumes of hydrothermal fluids that produced it. Additionally, the hydrothermal fluids penetrated along fractures in the host rocks well beyond the aureole to deposit ore veins of copper, lead, tungsten, and iron (Firman, 1978b). Then within the granite itself the magmatic hydrothermal fluids played a role in the formation of the orthoclase feldspar megacrysts, which are characteristic of this granite and dominate its porphyritic texture (Cox et al, 1996; Lee & Parsons, 1997; Lee, Waldron, & Parsons, 1995). Thus the large numbers of Po radiohalos in the Shap Granite are consistent with these other evidences of sustained hydrothermal fluid flows through it and out into the surrounding host rocks. The tiny zircon grains that are at the centers of the many ^{238}U radiohalos in the Shap Granite would have been the source of the Po isotopes transported by the hydrothermal fluids to generate the Po radiohalos.

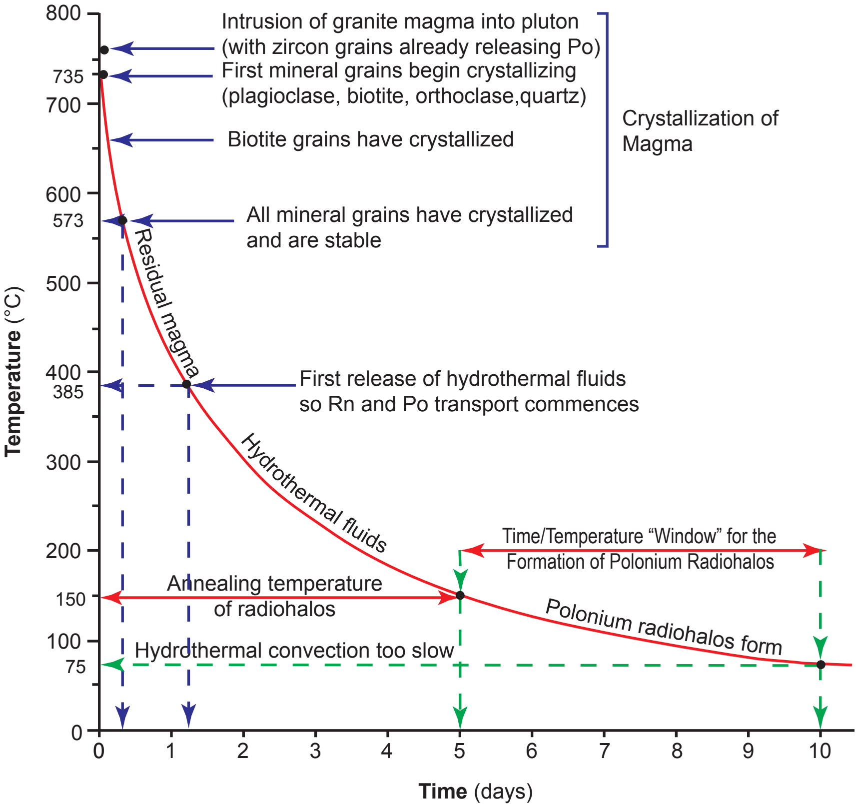

Figure 8. Schematic conceptual temperature versus time cooling curve diagram to show the timescale for granite crystallization and cooling, hydrothermal fluid transport, and the formation of polonium radiohalos (after Snelling, 2008a).

A constraining factor on the preservation of the Po radiohalos is that the damage left by the α-particles is retained in the biotite flakes only below 150°C. Above this α-particle annealing temperature (Laney & Laughlin, 1981) the damage either doesn't register or is obliterated. Thus all the radiohalos now observed in the Shap Granite had to form below 150°C, which is relatively late in the cooling history of the granite. Granite magmas when intruded are at temperatures of 650–750°C, and the hydrothermal fluids are released at temperatures of 370–410°C after most of the granite and its constituent minerals have crystallized. However, the accessory zircon grains with their contained ^{238}U crystallize very early at higher temperatures, and may have even been already formed in the magma when it was intruded. Thus the ^{238}U decay producing Po isotopes had already begun well before the granite had fully crystallized, before the hydrothermal fluids had begun flowing, and before the crystallized granite had cooled to 150°C. Furthermore, by the time the temperature of the granite and the hydrothermal fluids had cooled to 150°C, the heat energy driving the hydrothermal fluid convection would have begun to wane and the vigor of the hydrothermal flow would also have begun to diminish (Figure 8). The obvious conclusion has to be that if the processes of magma intrusion, crystallization, and cooling required 100,000–1 million years, then so much Po would have already decayed and thus been lost from the hydrothermal fluids by the time the granite and fluids had cooled to 150°C that there simply would not have been enough Po isotopes left to generate the Po radiohalos (Snelling, 2008a).

The data in Table 1 show that Po radiohalos greatly outnumber ^{238}U radiohalos in the Shap Granite. There are likely two reasons for this. First, many of the ^{238}U radiohalos are dark and overexposed with blurred inner rings (Figure 7), which indicates that there has been an enormous amount of ^{238}U decay, much more than the 500 million–1 billion atoms needed to produce a radiohalo with distinct inner rings. This implies that there likely would have been enough Po generated to form multiple Po radiohalos in the vicinity of each ^{238}U radiohalo. Second, as already noted above, much evidence suggests that the greater the volume and flow of hydrothermal fluids, the greater the number of Po radiohalos generated. Both the Shap Granite and its aureole indicate a large volume of hydrothermal fluids flowed within and outside of this granite. Thus there was a greater capacity for hydrothermal fluid transport of Po atoms to supply more radiocenters with the needed Po atoms to generate the observed Po radiohalos.

Even conventional thinking on the timescale for the granite intrusion, crystallization, and cooling processes is changing. Whereas formerly it was claimed that granites took a million years or more to form (Young, 1977), it is now recognized even in the conventional community that granite formation is a rapid, dynamic process operating on timescales as short as thousands of years (Clemens, 2005; Petford, Cruden, McCaffrey, & Vigneresse, 2000). Consequently, much evidence now favors the processes of magma generation, segregation, ascent, emplacement, crystallization, and cooling being catastrophic (Snelling, 2006b, 2008a; Snelling & Woodmorappe, 1998; Woodmorappe, 2001), consistent with the catastrophic plate tectonics model for the Genesis Flood event (Austin et al., 1994). Furthermore, the concept of accelerated radioisotope decay (Vardiman, Snelling, & Chaffin, 2005) allows nuclear decay processes at catastrophic rates during the Flood.

Both catastrophic granite formation and accelerated radioisotope decay are relevant to the hydrothermal fluid transport model for Po radiohalo formation. However, halo formation itself provides constraints on the rates of both those processes (Snelling, 2005a). If ^{238}U in the zircon radiocenters supplied the concentrations of Po isotopes required to generate the Po radiohalos, the ^{238}U and Po radiohalos must form over the same timescale of hours to days, as required by the Po isotopes' short half-lives. This requires ^{238}U production of Po to be grossly accelerated. The 500 million–1 billion α-decays to generate each ^{238}U radiohalo, equivalent to at least 100 million years' worth of ^{238}U decay at today's decay rates, had to have taken place in hours to days to supply the required concentration of Po for producing an adjacent Po radiohalo. However, because accelerated ^{238}U decay in the zircons would have been occurring as soon as the zircons crystallized in the magma at 650–750°C, unless the granite magma fully crystallized and cooled to below 150°C very rapidly, all the ^{238}U in the zircons would have rapidly decayed away, as would have also the daughter Po isotopes, before the biotite flakes were cool enough for the ^{238}U and Po radiohalos to form and survive without annealing. Furthermore, the hydrothermal fluid flows needed to transport the Po isotopes along the biotite cleavage planes from the zircons to the Po radiocenters are not long sustained, even in the conventional framework, but decrease rapidly due to cooling of the granite (Figure 8) (Snelling, 2008a). Thus Snelling (2005a) concluded from all these considerations that the granite intrusion, crystallization, and cooling processes occurred together over a timescale of only about 6–10 days.

One apparent difficulty with this model is its requirement for α-particle energy, as indicated by radiohalo radius, to be diagnostic and also independent of parent decay rate over many orders of magnitude. However, Chaffin (1994) has demonstrated that if the depth of the potential energy well for α-decay is increased, with a corresponding increase in the decay constant (and therefore the decay rate), then the decay energy of the α-particle may be held the same with only a slight increase in the nuclear radius, so that the radii of radiohalos also would remain the same while the α-decay rate increased. A second apparent and related difficulty is that if the ^{238}U decay rate was grossly accelerated by many orders of magnitude, then the decay of the Po isotopes might also be similarly accelerated, and thus there would not have been enough time for hydrothermal fluid transport to carry the Po atoms for even a millimeter within the biotite flakes. However, Austin (2005) and Snelling (2005b) have documented evidence that in an accelerated α-decay episode the parent isotopes which today have the slowest decay rates (and thus yield the oldest ages on the same rock samples) had their decay accelerated the most. The implication of this observation is that in an accelerated α-decay episode, those parent isotopes which decay at extremely high rates today should have experienced almost no acceleration of their decay. Thus the decay of the Po isotopes would have hardly been accelerated at all, in stark contrast to the huge acceleration of ^{238}U decay. This would, therefore, have allowed enough time for hydrothermal fluid transport of the Po atoms needed to generate the Po radiohalos.

However, someone might inquire what requires the hydrothermal fluid flow interval to be so brief? Surely, because the zircon radiocenters and their ^{238}U radiohalos are near to (typically within only 1 mm or so) the Po radiocenters in the same biotite flakes, could not the hydrothermal flow have indeed carried each Po atom from the ^{238}U radiocenters to the Po radiocenters within minutes, but the interval of hydrothermal fluid flow persist over many thousands of years during which the billion Po atoms needed for each Po radiohalo are transported that short distance? In this case the ^{238}U decay and the generation of Po atoms could be stretched over that longer interval. However, as already noted above, by the time a granite body and its hydrothermal fluids cool to below 150°C, most of the energy to drive the hydrothermal convection system and fluid flow has already dissipated (Snelling, 2008a). The hydrothermal fluids are expelled from the crystallizing granite and start flowing at between 410 and 370°C (Figure 8). So unless the granite cooled rapidly from 400°C to below 150°C, most of the Po transported by the hydrothermal fluids would have been flushed out of the granite by the vigorous hydrothermal convective flows as they diminished. Simultaneously, much of the energy to drive these fluid flows dissipates rapidly as the granite temperature drops. Thus, below 150°C (when the Po radiohalos start forming) the hydrothermal fluids have slowed down to such an extent that they cannot sustain protracted flow. Moreover, the capacity of the hydrothermal fluids to carry dissolved Po decreases dramatically as the temperature becomes low.

Thus sufficient Po had to be transported quickly to the Po radiocenters to form the Po radiohalos while there was still enough energy at and below 150°C to drive the hydrothermal fluid flows rapidly enough to get the Po isotopes to the deposition sites before they decayed. This is the time and temperature "window" depicted schematically in Figure 8. It would thus simply be impossible for the Po radiohalos to form slowly over many thousands of years at today's groundwater temperatures in cold granites. Hot hydrothermal fluids are needed to dissolve and carry the polonium atoms, and heat is needed to drive rapid hydrothermal convection to move Po transporting fluids fast enough to supply the Po radiocenters to generate the Po radiohalos. Furthermore, the required heat cannot be sustained for the 100 million years or more while sufficient ^{238}U decays at today's rates to produce the 500 million–1 billion Po atoms needed for each Po radiohalo. In summary, for there to be sufficient Po to produce a radiohalo after the granite has cooled to 150°C, the timescales of the decay process as well as the cooling both must be on same order as the lifetimes of the Po isotopes. Thus, the hydrothermal fluid flows had to be rapid, as the convection system was short-lived while the granite crystallized and cooled rapidly within 6–10 days, and as they transported sufficient Po atoms to generate the Po radiohalos within hours to a few days.

The Shap Granite does not appear to be unique, but rather is typical of other granites, in terms of its mineralogy, chemistry and texture, and the hydrothermal fluids it generated. Thus, this model for its rapid formation and cooling can be extended to other granite bodies, as has been done by Snelling (2005a, 2008a), Snelling and Armitage (2003), and Snelling and Gates (2008). Even the enormous metamorphic aureole is not unique to the Shap Granite. Many other granites are surrounded by aureoles, though often smaller. Almost all granites show evidence of the hydrothermal fluids they generated as they crystallized and cooled. The ubiquitous presence of Po radiohalos (Snelling, 2005a) is also testimony to these hydrothermal fluids. Even in those granites where fewer Po radiohalos would suggest less hydrothermal fluids were produced in them, the presence of Po radiohalos indicates there were still sufficient hydrothermal fluids to cool them rapidly. The volume of the Shap Granite is small compared with that of the large Lake District Batholith to which it belongs. Yet because this model of rapid formation and cooling has been applied successfully to so many other granite bodies, there are many reasons to conclude that each of the plutons making up the batholith likewise formed and cooled rapidly. Indeed, the volume of the nested granite plutons of the Tuolumne Intrusive Suite of Yosemite, California, is comparable to that of the Lake District Batholith, and Snelling and Gates (2008) have built a strong case that each of those voluminous plutons also formed and cooled rapidly.

The abundant ^{238}U and Po radiohalos in the Shap Granite are, therefore, compelling evidence that this granite formed in only about 6–10 days. This is consistent with its having intruded into the fossiliferous Flood-deposited Borrowdale and Windermere Group sediments and volcanics. The enormous scale of the contact metamorphic and metasomatic aureole surrounding the Shap Granite is also testimony to the rapid rate of granite cooling and thus rapid release of heat that drove the hydrothermal fluids forcefully out of the pluton and into the surrounding host rocks. Once in the host rocks, the hydrothermal fluids combined convectively with ground waters to disperse the granite's heat and together produce the aureole. The aureole's size also is consistent with the granite producing, and the host rocks containing, large volumes of hydrothermal fluids and ground waters, respectively. The ground water would be a consequence of rapid sediment deposition only days and weeks before granite intrusion during the Flood.

The force of the intruding granite magma inevitably weakened the surrounding host rocks, particularly above the resulting pluton because the buoyant magma had pushed its way upwards into them. Any induced fracturing of the overlying rocks would have been exploited by the ascending magma. Hydrothermal fluids released by the crystallizing and cooling magma would also tend to be forced upwards more easily than laterally. The high fluid pressures would result in acute hydraulic fracturing of the roof rocks overlying the granite pluton, and the hydrothermal fluids released upwards would produce intense hydrothermal alteration. This combination of intense hydraulic fracturing and hydrothermal alteration of the host rocks directly overlying the granite pluton (the roof) makes the roof more susceptible to subsequent weathering and erosion and thus to being stripped away rapidly to expose (or unroof) the top of the granite pluton (Tyler, 1990). In the case of the Shap Granite, the large size of the metamorphic/metasomatic aureole compared to the width of the pluton (Figure 3) likely implies that the hydraulic fracturing and hydrothermal alteration of the roof rocks was very intense, resulting in their increased susceptibility to subsequent rapid erosion and rapid unroofing of the pluton.

In regard to the relative timing of deposition of the strata sequence in the Lake District during the Flood (Figure 2), there appears to have been a depositional hiatus at the time the Shap Granite was intruded, with an unconformity at the top of the Silurian Windermere Group before later deposition of the Carboniferous limestone. This implies that when the Shap Granite intruded, its Windermere and Borrowdale Group host rocks were either being uplifted, perhaps by the ascending magma itself, or the Flood water level was dropping, or both. Thus it is entirely possible that within days of intrusion and cooling of the Shap Granite stock the overlying heavily fractured and altered roof rocks were exposed to rapidly falling water levels from their uplifted and arched-up surface, resulting in their rapid erosion to quickly expose the granite beneath. However, due to the tidal movement of the global Flood waters, repeated sediment-laden surges would have quickly eroded both the roof rocks and the granite, so that dislodged pebbles of granite and orthoclase feldspar megacrysts from the granite would soon be deposited nearby in a conglomerate. With rising water levels the subsequent sediment deposition quickly transitioned into limestone.

In conclusion, therefore, the presence of abundant Po radiohalos in the Shap Granite and in the sharp granite/host rock boundary, and the large comparative width of the surrounding contact metamorphic and metasomatic aureole, together provide evidence that the granite was intruded as magma and cooled within 6–10 days and was then unroofed within a few days later. Thus, a coherent solution for the perceived time problems associated with the formation of the Shap Granite and the adjacent overlying basal conglomerate containing granite pebbles and orthoclase feldspar megacrysts appears to be available, with no compelling reason to place the Flood/post-Flood boundary between the intrusion of the Devonian Shap Granite and the deposition of the basal conglomerate to the Carboniferous limestone. These observations now show that it is plausible for the Shap Granite to have been generated, intruded, cooled, and then unroofed and eroded, to be immediately followed by deposition of the conglomerate basal to the limestone, all within the early-middle part of the Flood year.

Conclusions

The Devonian Shap Granite in the Lake District, England, was intruded as molten magma into the older explosively-erupted Ordovician Borrowdale Group lavas and tuffs and the fossiliferous Flood-deposited Windermere Group sediments overlying them. There is no evidence of fracturing, brecciation and mylonization at the granite/host rocks boundary that should be present if the granite stock had been emplaced tectonically as a cold body. Instead, the heat and hydrothermal fluids from the crystallizing magma produced a 600+ meter wide contact metamorphic and metasomatic aureole. Therefore, the abundant Po radiohalos presently observed in samples of the granite could not have been generated by primordial Po, because the hydrothermal fluids also helped form orthoclase feldspar megacrysts in the granite at

370–410 °C. Any pre-existing Po radiohalos in the granite would have been annealed at those temperatures that are well above the 150 °C annealing temperature for radiohalos. Instead, the abundant presence of Po radiohalos is consistent with a large volume of hydrothermal fluids released by the cooling granite. These fluids are also responsible for the atypically wide contact metamorphic and metasomatic aureole. Thus, this evidence supports a hydrothermal transport model for Po radiohalos and catastrophically rapid granite formation. This evidence suggests the Shap Granite formed within 6–10 days and its Po radiohalos within hours to days once the granite cooled below 150 °C. Hydraulic fracturing and hydrothermal alteration of the host rocks above the granite intrusion would have facilitated rapid unroofing of the pluton also within days. Sediment-laden Flood waters then surging over the exposed granite would have eroded granite pebbles and orthoclase feldspar megacrysts from the granite to quickly deposit them in a conglomerate bed nearby, where sedimentation soon transitioned into a Carboniferous limestone. It is, therefore, entirely conceivable for this sequence of events from formation of the Devonian Shap Granite through to the deposition of the stratigraphically overlying Carboniferous limestone to have occurred within 2–3 weeks during the early-middle part of the Flood year. The Po radiohalos and the other evidence associated with this granite thus remove objections to Flood geology, including the timescale for granite formation, and the need to place the Flood/post-Flood boundary in the lower Carboniferous.

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