Long Meg and her Daughters

Geological Survey (Summer 2023)

Interim Report

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Contents

This document was written by Paul Frodsham, Paul Logan and Steve Rozario. References to it should be structured as follows:

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Cover image. *Volunteers at work on the geology and condition survey of Long Meg stone circle, May 2023.*

1. Introduction

The Long Meg stone circle is one of northern England's most spectacular and important ancient monuments. It forms part of Scheduled Monument number 1007866, and is recorded on the Cumbria HER as site number 6154. The site lies at NGR NY57113721, near the village of Little Salkeld some 9 km north-east of Penrith. The stone circle is the most visible element of an extensive complex, described in a recent paper (Frodsham 2021, available at www.friendsoflongmeg.com) which also interprets the results of recent survey and small-scale excavation undertaken in 2013 and 2015 by the North Pennines AONB's Altogether Archaeology project in collaboration with Archaeological Services Durham University (ASDU 2013, 2016).

The stone circle (Fig. 1.1) dates from about 3000BC and consists of Long Meg herself and 68 of her Daughters (there were almost certainly several more Daughters back in the Neolithic; some, but nobody knows how many, were removed in the 18th century). Long Meg, a large monolith of red sandstone (Fig. 1.2), stands outside the circle of her Daughters which are volcanic boulders of various types.

In the above-mentioned overview of Long Meg, Paul Frodsham states that the Daughters are 'nearly all of rhyolite'. This, he realised immediately after publication, is wrong! The statement was based on specialist geological advice, which may have been wrong or (more likely, as he himself suggests) misinterpreted. Either way, he has been keen for some time to undertake a proper geological survey of the site, and this became possible during 2023 thanks to the Fellfoot Forward Landscape Partnership Scheme, hosted by the North Pennines AONB (now the North Pennines National Landscape) and funded by the National Lottery Heritage Fund.

On 21st and 22nd May 2023, a team of volunteers (see Appendix B) undertook a geological and condition survey of the stone circle. The results of the condition survey are of great importance and are the subject of a separate report; this document covers only the geological survey. The results, as set out in this report, are of very great significance to our understanding of Long Meg, and illustrate the great value of collaborative ventures that combine the expertise of individuals who tend to spend most of their time in archaeological, geological or other specialist silos.

This document is labelled as an 'interim report', because although it covers all the work done during the volunteer survey, and subsequent investigations, it is planned to undertake further fieldwork during 2024, after which an updated 'final' report will be produced (though there will doubtless still be more work to do).

Fig. 1.1. Aerial view of Long Meg and her Daughters from the south. Long Meg herself (bottom left) is red sandstone and stands apart from the ring of her volcanic Daughters, in line with the setting sun at the winter solstice when viewed from the centre of the circle. (Photo: Richard Carlton).

Fig. 1.2. Long Meg, with the carvings on her east face well illuminated by raking sunlight. (Photo: Paul Frodsham).

2. Methodology

The survey was designed to record as much information as possible about Long Meg's Daughters in two days in the field. The primary aim was to investigate, describe and hopefully identify the lithology of each Daughter. At the same time, several additional things were also recorded, as explained below.

In advance of the fieldwork, a Recording Form was designed to ensure that information was recorded in a structured manner. This was done by Sylvia Woodhead and Paul Frodsham, with additional input from other geologists. An initial site visit to test the methodology was undertaken on 10th April 2023, followed by the two full survey days on the 27th and 28th May.

The survey was led in the field by Paul Frodsham, supported by Fiona Knox of the Fellfoot Forward project, and conducted by a team of 25 Fellfoot Forward volunteers and eight Cumbrian geologists (see Appendix A).

Volunteers were divided into small survey teams of three or four, plus two geologists. There were four such teams on 27th May, and two on 28th May. Each Daughter was inspected by one team, and the survey progressed clockwise around the circle. Working in this way meant that individual teams did not work on sequences of adjacent stones, but each moved on to the next available stone as each was completed. A separate Recording Form was completed for each Daughter, and general photographs were taken of each one, together with close-ups showing lithological detail. All completed Recording Forms and photographs are retained within the project archive.

It is important to note that there had been a previous attempt to classify the Daughters, back in the early 20th century, a two-page summary of which was published as an appendix to a little-known paper about the stone circles of Castlerigg and Long Meg (Woolacott 1910). Unfortunately, this was published without a plan, so it took some time to work out which actual Daughters the various stone numbers referred to. However, the numbering system was eventually decoded, and it became possible to relate Woolacott's classifications to most Daughters (he didn't classify all of them, and it was impossible to be sure about the numbers of a few). He had most of them as either 'volcanic series of Borrowdale' or 'quartz porphyries and allied rocks', and while our classifications differ from his, this was a useful starting point.

The geologists engaged in heated debate about what the rocks were, with other volunteers learning rapidly 'on the job' and contributing keenly to on-site discussion (Fig. 2). There were significant challenges. The Daughters have been in their present locations for about 5,000 years, and their surfaces are consequently much-weathered and covered in lichen. It was obviously not possible to hammer bits off them to expose fresh surfaces, nor to scrub them with a wire brush, nor to test them with acid. The only permitted intervention, following discussion with Historic England, was the gentle removal of lichen from small, inconspicuous areas, which generally meant areas close to the ground. Identifying rocks in the field is often difficult under normal circumstances, and these restrictions added to the challenge.

Gradually, some consensus emerged. The Daughters appeared to fall into three distinct groupings, all igneous rocks not local to the area (the underlying geology is St. Bees Sandstone, part of the Triassic Sherwood Sandstone Group). It was also agreed that all the Daughters appear to be glacial erratics.

In addition to lithological analysis, each Daughter was measured and had various characteristics (eg dimensions, whether they were standing or fallen, nature of internal faces, distances to adjacent stones) recorded. Also, the immediate environs of each Daughter were investigated for damage, in particular ground disturbance by rabbits, which might be damaging important archaeological deposits. A separate report has been produced on the results of this work (Frodsham 2023). The information on the Recording Forms was tabulated and the resulting summary table is included within this report as Appendix B.

In the months following the survey, several follow-up meetings of geologists were arranged, co-ordinated by Steve Rozario. These included checking the results recorded during the two survey days, refining the lithological classifications, and inspection of parts of the surrounding landscape. After each such meeting, the results table (Appendix B) was updated. Further such work is planned.

During the survey, work focused on the Daughters and little attention was paid to Long Meg herself. However, during the follow-up meetings a great deal of time was spent examining and discussing Long Meg. The results of this work are incorporated into this report.

Finally (for now) the results were summarised within this interim report, which will be made available on the Friends of Long Meg website (wwwfriendsoflongmeg.com). Further work is planned for early 2024, after which a final report will be produced to replace this interim. It is also intended that the results will eventually be written up for publication in an appropriate journal.

Fig. 2. Two views of survey work in progress. (Photos: Sylvia Woodhead).

3. Results - lithology

3.1 Lithology and source of Long Meg

Long Meg is a large prismatic slab of relatively hard red sandstone, presumed to be reasonably local in origin. Her east face has displays pecked curvilinear motifs, popularly termed 'rock art'. Moving anti-clockwise around Long Meg from the carved surface, and labelling them A-D (Fig. 3.1.1), the consensus view of the geologists who have looked at this is that:

- Surface A is an original bedding plane (top surface) when the rock was still attached to its original outcrop.
- Surface B is original outcrop face (front vertical surface, way up shown by blue arrow).
- Surface C is an original bedding plane (bottom surface).
- Surface D is an original 'in outcrop' face (i.e. facing into the rest of the rockface, way up shown by blue arrow).

Other features of note:

- Surface D has significant quartz veining, which would originally have appeared very white, and is possibly slickensided, indicating movement along a fault or fracture by which the slab could have come loose from outcrop.
- Edge A-D has wear marks which have been attributed to quarrying to extract the slab (Fig. 3.1.2)
- The carvings on face A (Fig. 1.2) are of Irish type, and almost always occur on vertical faces, usually within monuments but occasionally on river cliffs (see discussion below).
- The body of Long Meg has penetrative fine quartz-veining roughly perpendicular to the bedding plane (Fig. 3.1.3).
- Traces of lamination are evident in surface B and D. The lamination is bedding-plane parallel, i.e. there is no cross-bedding, and definitely no aeolian cross-bedding (Fig. 3.1.5).

It has long been suspected that Long Meg was quarried from an outcrop of red sandstone, quite possibly from the banks of the Eden close to Lacy's Caves, and dragged up to the stone circle site. Questions of why people should have done this are beyond the remit of this document, but a link between the Eden and the stone circle was probably fundamental to construction of the latter (Frodsham 2021). It has also been suggested, on sound archaeological grounds, that the carvings on Long Meg (which are

Irish in character, with many comparable designs known in Irish Passage Graves) may have been made on the river cliffs before Long Meg was quarried and transported away. The problem with this suggestion, which makes a great deal of sense archaeologically, is that such carvings are almost always made on vertical faces, and geological examination of Long Meg (discussed below) demonstrates that her decorated face must have been horizontal in its natural position; there has simply not been sufficient earth movement in this area for the bedding planes to have been twisted through ninety degrees. It therefore seemed very unlikely that the carvings could have existed on Long Meg prior to her being set upright. However, all may not be quite so straightforward.

A number of potential sources have been postulated for Long Meg. In addition to the environs of Lacy's Caves (Penrith Sandstone), geologists also considered the St Bees Sandstone (exposed nearby at Gamblesby and Hunsonby) and the Eden Shales (exposed between Long Meg and Lacy's Caves in the river).

Sylvia Woodhead has also provided this link https://www.youtube.com/watch?v=CweThuYblgM to a talk by Dr Stuart Jones of Durham on red sandstones for the Wallcap project, in which he states that Long Meg is Penrith Sandstone (rather than St Bees) on the basis of its brick-red colour. Later in the talk he discussed sediment maturity of Penrith vs St Bees, and Paul Logan's micro-photographs of Long Meg support a Penrith Sandstone identification on the basis of sedimentalogical character, the St Bees sandstone being finer-grained and a less mature sediment.

Most of these possible sources have been examined and discounted, for the following reasons.

Lacy's Caves (Fig. 3.1.4) were discounted by the geologists because:

- The rock is highly friable
- The density of quartz-veining is much higher than in Long Meg and at multiple angles
- Where visible, the bedding in Lacy's Caves appears to be aeolian cross-bedded.

St Bees Sandstone at Gamblesby and Hunsonby. These locations were examined and photomicrographs taken for comparison (Fig. 3.1.8). These have also been discounted as possible sources for Long Meg for the following reasons:

- The sediment maturity is not the same.
- The outcrop at Hunsonby is too friable to support a slab of the size of Long Meg.

Eden Shales. The outcrop in the river near Long Meg has not been examined yet and can't yet be discounted, the BGS mapper description is of shales with thickening upwards sandstone beds. We need to investigate to confirm whether the thickening up beds reach adequate thickness and have similar lithology.

The probable source of Long Meg

Lacy's Caves, whilst comprising Penrith Sandstone, is a poor match, but while exploring outcrops about 100m to the north, at grid reference NY 56399 38346, we found a most interesting exposure in the Penrith Sandstone which has very high potential as a source for Long Meg.

Here, at the base of an outcrop of cross-bedded aeolian sandstones, there is a thick laminar-bedded (bedding-plane parallel) sandstone unit (Fig. 3.1.6). This might be a sheet-flood, water-lain unit within the Penrith Sandstone (some water-lain units can be found within the predominantly aeolian Penrith Sandstone e.g. at Low House woods near Armathwaite). Alternatively, the laminations might have formed in the relatively flat 'toe' or 'apron' of a large sand-dune, the laminations caused by grading separation in the slip-face avalanches. In this case the direction of movement of the dune would have been perpendicular to the face shown in the photo. The thickness of this unit has yet to be measured, but it appears similar to the thickness of Long Meg. Photomicrographs indicate that the stone here is almost identical to Long Meg in terms of grainsize and sediment maturity, and very different from the St Bees Sandstone at Gamblesby (Fig. 3.1.8).

Notably, the unit was visibly capable of supporting large roughly rectangular slabs. Where the bed had been undercut by the river a number of large slabs had fallen into near-vertical positions by the river bank (Fig. 3.1.7). These slabs had a similar density of quartz-veining to Long Meg. We did not observe any slickensided fault fractures similar to face D on Long Meg, but otherwise these slabs seemed to be a very strong match. Access is quite difficult and the slabs are heavily overgrown with moss; it is intended that close examination of them will take place during early 2024.

We all felt there was a strong probability this, or very nearby, was the source location for Long Meg as it fitted with both the geology and the archaeology. From the archaeological point of view, the bedding planes of these slabs are vertical, so Irish-type carvings may have been placed on them, where they would be seen by people in boats on the river. If so, further carvings may survive still in situ on other slabs; a careful search for any such carvings is a key task. Of course, whether any such carvings are (or were) present is not fundamental to the recognition of the source of Long Meg, but if any be located then it would be very exciting and would certainly back up the suggestions that Long Meg's carvings were already in place before she was transported to the stone circle site.

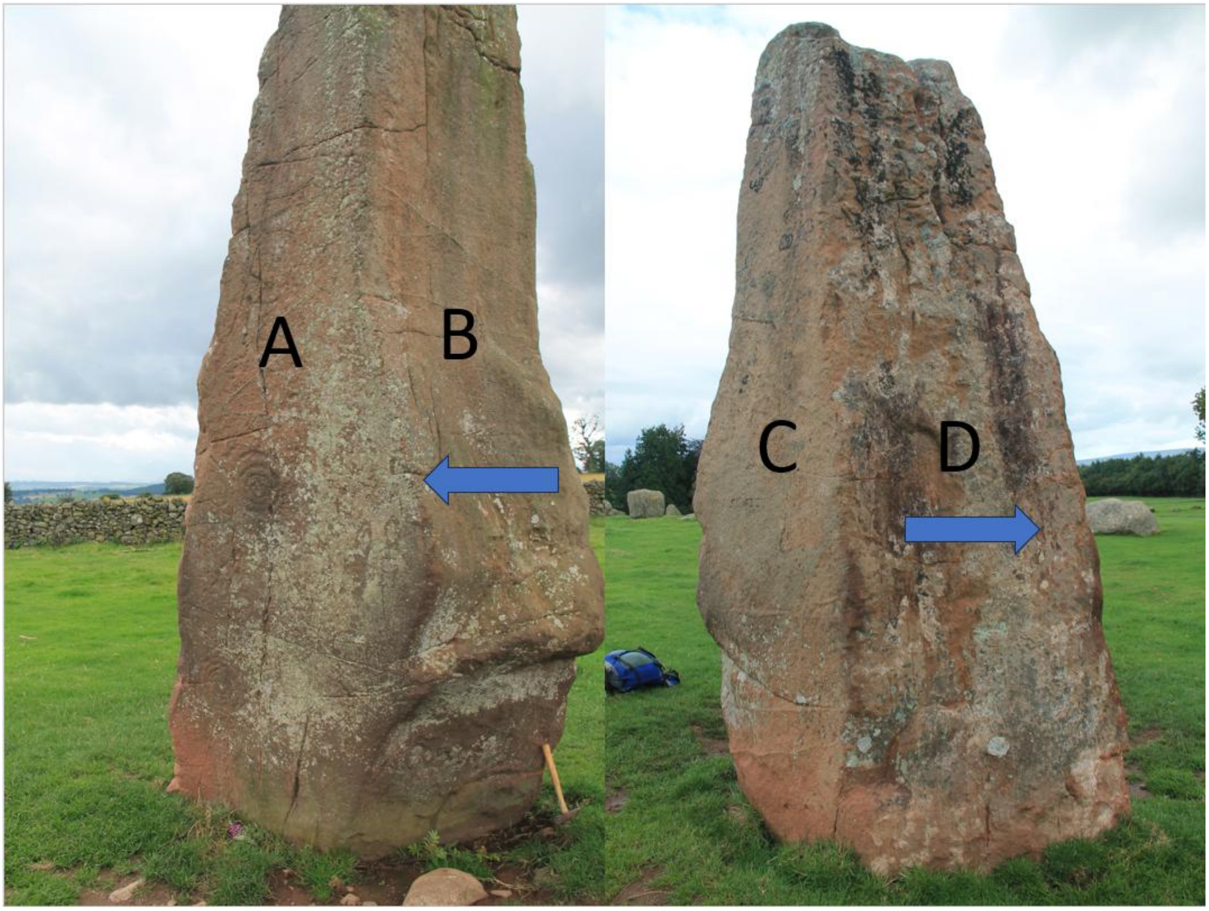

Fig. 3.1.1. The four faces of Long Meg (A = east, B = north, C = west, D = south). The blue arrows indicate the position of the slab in its natural state, with the arrow pointing towards the top (ie face A was at the top).

Fig. 3.1.2. Possible quarrying scars along edge A-D (see also Fig. 1.2, where the scars are highlighted by bright sunlight).

Fig. 3.1.3. Examples of penetrative fine quartz-veining in Long Meg.

Fig. 3.1.4. Two views of Penrith Sandstone at Lacy's Caves, not a good match for Long Meg.

Fig. 3.1.5. Bedding-plane parallel lamination visible in face B of Long Meg.

Fig. 3.1.6. Bedding-plane parallel laminations in sandstone unit north of Lacy's Caves.

Fig. 3.1.7. Two views of near-vertical slabs by river, originally part of the outcrop shown in Fig. 3.1.6.

Fig. 3.1.8. Photomicrographs (by Paul Logan) of:

Top: Long Meg

Middle: Penrith Sandstone outcrop at Lacy's Caves.

Bottom: St Bees Sandstone, Gamblesby

The field of view in each image is 3.5 mm wide.

3.2 Lithology of the Daughters

Lithological identification of the Daughters is complicated by:

- the growth of lichen on the surface which we are only allowed to remove by gentle sponging in inconspicuous locations,
- surface weathering affecting the appearance of the rocks,
- the constraint of not being able to chip or crack the stones to obtain fresh surfaces.

With these constraints it is often difficult to identify the true colour of the Daughters or identify minerals within them.

It was noticed during the survey that some Daughters are experiencing natural spalling or exfoliation and have flakes on the surface that are likely to naturally detach due to weathering etc. These flakes could be valuable for geological investigations if destructive testing methods were permitted on them.

Subject to the above constraints, the survey identified a number of probable groupings as follows (see also Appendix B):

a) **Type A** (quantity: 22): Medium to fine-grained, light-coloured, grey-green igneous rock. Contains slightly larger crystals of quartz and feldspar which can weather out of surface. Some samples contain linear xenoliths, of various sizes, of a dark-coloured foliated rock, thought to be Skiddaw Slate. Initially identified by the survey team as Ash, Volcanic Ash, Tuff, Tephra(ash), Lava, or Volcanic Fine-grained. Proposed subdivision into:

   - **Type A1 with visible xenoliths** (quantity: 10).
   - **Type A2 without visible xenoliths** (quantity: 12).

b) **Type B** (quantity: 42): Dark green igneous / volcaniclastic-sedimentary rocks. Some are obviously brecciated, with angular fragments, sometimes in 'jigsaw' patterns with harder material between fragments (fragment surfaces are etched in by weathering). Sometimes with apparent volcanic bombs. Initially identified by the survey team as Lava, Breccia, Explosion Breccia, Volcanic Breccia, Volcanic Ash, or Ash. Proposed subdivision into:

   - **Type B1 Lava** where definitive lava features can be seen (e.g. auto-brecciation, flow-banding) (quantity: 8).
   - **Type B2 Breccia** where definitive explosion / vent breccia features can be seen (quantity: 2).

- **Type B3 Tuff** where definitive ash fall features can be seen (quantity: 26).
- **Type B4 Lahar** where clearly a matrix-supported debris-flow with rounded clasts (quantity: 3).
- **Type B5 unclassified** where subdivision is uncertain (quantity: 3).

c) **Type C** (quantity: 4): Granites. Four of the daughters are coarse-grained, light-coloured igneous rocks, identified as granites by the survey team. There appear to be two different granites:

- **Type C 1** medium-grained black and white granite, no obvious phenocrysts, quartz, feldspar, biotite/muscovite visible (quantity: 3).
- **Type C 2** medium- to coarse-grained grey granite. Conspicuous large phenocrysts of a Carlsbad-twinned feldspar. Groundmass is predominantly quartz and feldspar with small quantities of darker minerals including biotite (quantity: 1).

The lichen populations of the two granite types are visibly different.

Probable identifications for these groups are as follows:

Type A: Threlkeld Microgranite

Type B: Borrowdale Volcanic Group

Type C: Granites, possibly Dalbeattie or Criffel (SW Scotland) or Skiddaw (Lake District).

Further photographs of these different rock types, together with more detailed discussion of specific Daughters, will be included in the final version of this report. A few notes and some sample photographs are presented below.

Type A: Threlkeld Microgranite

Threlkeld Microgranite is a felsic intrusive rock, a quartz-feldspar phyric microgranite, heavily altered with chlorite, sericite and calcite present. An analysis is available here https://iageo.com/g-94-threlkeld-microgranite/

We revisited Long Meg with some samples of Threlkeld Microgranite obtained by Helen James and a brief inspection showed significant similarity to several of the Daughters classed as Group A.

Threlkeld Microgranite can contain xenoliths of Skiddaw Slate. Helen James has taken photos in the quarry of some that do (see below), and these compare very closely with the appearance of Daughters of subgroup A1. Note that the two subgroups may be of no significance; it could be simply that some Group A Daughters display visible xenoliths, while others do not.

Exploration of a nearby roadside field clearance mound to the east of Long Meg found many reasonable sized boulders of Threlkeld Microgranite, so it's reasonable to assume these daughters were ice-transported to the general area and then collected by the builders of the stone circle.

Fig. 3.2.1. Skiddaw Slate xenoliths in Threlkeld Microgranite at quarry.

Fig. 3.2.2. Xenolith in Daughter no. 49 at Long Meg.

Fig. 3.3.3. Sample of Threlkeld Microgranite held against daughter number 49. Small pit-marks in daughter may be due to weathering-out of quartz/feldspar phenocrysts seen in fresh sample.

Fig. 3.2.4. Inspection of a modern roadside field-clearance mound (NGR NY586382) to the east of Long Meg found many boulders of Threlkeld Microgranite, presumably dug out of the boulder clay by ploughing (the mound is not visible in a Google Streetview image from 2009 so must be more recent than this). Although these boulders are smaller than those at Long Meg, they suggest that the Type A Daughters were ice-transported to the general area and then collected by the stone circle builders. Some of these boulders display xenoliths of the type recorded in the Type A1 Daughters.

Type B: Borrowdale Volcanic Group

A number of different lithologies are present, similar to known Borrowdale Volcanic types, such as the auto-brecciated andesite lavas and breccias illustrated here.

Fig. 3.2.5. Auto-brecciated andesite lavas are reasonably common in the BVG, e.g. this example from the English Lake District Geology website (https://englishlakedistrictgeology.org.uk/?Chapters:BORROWDALE_%26amp%3B_EYCOTT_VOLCANICS) described as 'Laminated sedimentary material was washed into the spaces between the blocks after the lava stopped flowing'. The author warns that these can be difficult to distinguish from peperites, intrusions into wet sediment which break up as they are intruded.

Compare this with some of the features on the Daughters shown in the following photos.

Fig. 3.2.6. Polished surface of a Daughter where it has been rubbed by cattle.

Fig. 3.2.7. Differential erosion of blocks and filling on surface of a Daughter.

Fig. 3.2.8. Etching out of angular fragments, leaving natural patterns reminiscent of axe shapes which surely must have been significant to Neolithic people (see discussion, below).

Fig.3.2.9. This Daughter incorporates a possible lava bomb incorporated into flow.

Fig. 3.2.10. Daughter no. 54 is classed as a volcanic breccia (Type B2), distinctly different in appearance from the auto-brecciated lavas. These volcanic breccias are typically formed in highly explosive eruptions.

Fig 3.2.11. A polished area of Daughter no. 53 (Type B3), clearly showing the green colour of the rock.

Type C: Granites

Previous investigators have suggested these are Scottish granites, but recently it has been suggested that one or both subtypes could be Skiddaw Granite. More detailed inspection of the four granite Daughters, and of their possible sources, is proposed. We have obtained some samples of Dalbeattie granite but have yet to compare these with the Daughters on-site.

Fig. 3.2.12. Daughter no. 16 is classed as Type C1 granite. Left: general view (lens cap is 75 mm across). Right: close-up of the crystals (hand lens is 35 mm long).

Fig. 3.2.13. Daughter no. 41 is the only example in the circle of Type C2 granite. Above: general view. Right: close-up of the crystals, showing a large Carlsbad-twinned phenocryst below the hand lens. (Hand lens is 35 mm long).

4. Results - other

In addition to examining and classifying the lithology of all the Daughters, a number of other things were also recorded during the survey. While not of specific relevance to the lithology of the stones, results are briefly noted here. Further details can be seen in Appendix B.

The results noted here, along with those noted in the previous section, demand further thought. There may be interesting patterns that have escaped previous notice. Further discussion will be included in the final version of this report.

4.1 How many Daughters are 'still standing'

Of the 68 Daughters surveyed, 24 are recorded as 'standing', while 44 are flat or fallen. The latter are usually described as 'fallen', but in several cases it is far from clear whether they were ever erect; they may have been placed within the circle without having been set upright. Probably most of the 44 have fallen, notably along the northern arc where the stones appear to have been set within the backfilled ditch of the great enclosure to the north, resulting in weak foundations and consequent subsidence. The 2015 excavations demonstrated that the form of fallen and largely buried Daughters cannot be accurately calculated from what can be seen on the surface; some fallen stones may be much larger than surface traces might suggest. This should be borne in mind when considering the locations and possible implications of particularly prominent stones within the circle.

4.2 The size of the daughters

All the Daughters were measured, with recorded dimensions varying according to whether they were standing or not. Dimensions of fallen or flat Daughters are actually quite meaningless, other than in giving a crude indication of size for those that are still largely above ground, because the 2015 excavations demonstrated that some which now hardly break the surface are actually massive below ground. Nevertheless, the measurements, combined, give a reasonably accurate indication of what can be seen on the site today. All measurements were made using tape measures, which were awkward to use when trying to measure the heights of the highest Daughters, so they should be regarded as no more than reasonably accurate.

Though much statistical analysis of the results could be done, with potentially interesting results, no more than a few general observations are presented here.

In terms of circumference, two daughters are particularly massive: 40 at 740cm and 63 at 850cm. The two smallest are 48 at 295cm and 48 at 300cm. Other than these four, all the other twenty (ie 83%) fall within the range 330 – 580cm. It is not unreasonable to suggest that a similar proportion of the fallen/flat stones could fall within the same range. This suggests that stones within this range were being favoured by the circle builders. Clearly they were capable of moving larger ones, as illustrated by 40 and 63, and obviously they could have moved smaller ones, but this seems to have been the size range that they were interested in.

In terms of height above the current ground surface (and bearing in mind that an unknown amount of each, perhaps as much as 25 or 33%, extends below ground), the 24 standing Daughters range from 98 to 260cm. Leaving out the two smallest (42 at 98cm; 60 at 100cm), and the five largest (11 at 260cm; 69 at 240cm; 40 at 225cm; 47 at 210cm; 63 at 210cm), the remaining 17 (70%) fall within the range 112 to 182cm, suggesting that the circle builders were particularly interested in stones of this size.

It might be interesting to combine circumference with height to give a crude indication of weight, and see how much variation there is, but this must wait until later. It would also be fascinating to consider the mechanisms by which stones of different sizes could be effectively moved, and how many people (or beasts) would be required to drag them across flat ground and up inclines.

All these figures are relatively meaningless in isolation, and there is a need to consider them within the wider context of the site, as suggested in Section 6, below. There is also a need to consider the general shape of the Daughters, to see whether any trends can be recognised.

4.3 The size of the gaps between the Daughters

We naturally tend to concentrate on the actual stones when considering the architecture of the stone circle, but we shouldn't lose sight of the fact that the gaps between them, which vary greatly in size, may also have been significant. A glance at a survey plan or aerial photograph makes this immediately apparent, and while the general pattern can be appreciated (and gaps measured) from such imagery, it is useful to have actual measurements, made in the field, to work with. Detailed consideration of the gaps has yet to be done, but questions such as whether the size of the gaps relates to adjacent stones, and whether some of the gaps result from the removal of Daughters (either in antiquity or more recently), may lead to some interesting speculation. There are very wide gaps in the north-west and east arcs of the circle, while in the north and to the south and south-east (with the exception of the wide gap between stones 60 and 61) the gaps are very small. Within a couple of the wider gaps, slight dips in the ground suggest that Daughters may have been removed; further fieldwork is needed to investigate these areas. If the sites of missing Daughters can be pinpointed, then excavation of their sockets (as with Daughter no. 17A during the 2015 excavations) becomes a possibility.

4.4 Are the Daughters set within a low circular bank?

This is a very important question. It has been noted in the past that many of the Daughters seem to be set within (or on) a low earthen bank, but expert opinion differed as to whether this was most likely to be an original feature of the site's architecture, or a result of ploughing (inside and outside the circle but not between the stones) in historic times. The survey teams were asked to examine the ground around each individual Daughter independently and assess whether it was set within a bank. The results are that 36 are definitely within a bank, 13 might be, and 19 seemingly are not. Of the 19 recorded as not lying on a bank,15 lie in the arc between stones 32 and 56, around the east side of the circle. However, within this arc, Daughters 47 to 51 are recorded as definitely on a bank. In some wide gaps, such as in the arc from Daughter no. 11 to 16, the bank appears to be present, and in at least one place to contain within it a slight hollow that could have resulted from the removal of a Daughter.

This issue requires further careful analysis in the field, and small-scale excavation may be necessary to resolve it. If it can be demonstrated that the bank was continuous, and all stones were set within or upon it, then it may well be that the footprint of the circle was originally laid out in the form of a continuous bank not unlike that of a henge, which is potentially of great significance in thinking about the origins of the circle and relationships with potentially contemporaneous sites elsewhere. It should be noted that there is no sign on the ground of a henge ditch, which is not surprising given the extent of historic ploughing, and also that no clear sign of one was noted during the 2013 geophysical survey.

4.5 The inner faces of standing Daughters

For all 24 Daughters classed as standing, their inner faces were recorded as either flat, curved or irregular. The results are: 17 (70%) flat*, 5 irregular, and 2 curved. This demonstrates that there was a deliberate policy on the part of the circle builders to place flat surface facing into the interior of the monument. The reasons for this are unknown, though some speculation will be attempted in the final version of this report. It would be interesting to compare the pattern with other stone circles in Cumbria and elsewhere. It is also interesting to note that Daughter no. 12 was carefully positioned so that the potentially very significant ‘axe-like’ markings are on her inner face, facing the centre of the circle.

* Of the 17 flat faces, two are on portal stones 68 and 69; their flat faces are turned through 90 degrees to face the axis of the portal (often termed the ’entrance’, though there is no proof that it ever functioned as such), and the lower surface of fallen portal stone 2, where it has been exposed by rabbit burrowing, also appears to be flat. This further demonstrates that the placing of these flat surfaces was a deliberate feature of the site’s architecture.

4.6 The potential significance of gypsum

One final thing worthy of note here, although no evidence has been found in support of it, is the possible use of gypsum at Long Meg.

Until recently, gypsum and anhydrite were extensively mined in the area between Long Meg and the Eden. We have no clear evidence that gypsum was used by Neolithic people at Long Meg, but on the other side of the Pennines, the Thornborough henges (near Ripon) lie above gypsum deposits, and archaeological evidence shows that Neolithic people probably plastered the banks of the henges with gypsum to make them white, possibly to mimic freshly dug ditches in chalk, as on the Yorkshire Wolds or Salisbury Plain (Harding 2013; Frodsham 2021). The gypsum was dug with antler picks from nearby pits, having possibly been originally discovered in swallow holes.

Given the many apparent similarities between the Long Meg circle and the Thornborough henges, and the fact that some people must surely have travelled across the Pennines and been familiar with both, it is reasonable to ask whether gypsum was also used in some way at Long Meg. While we have no proof, from the geological point of view it appears entirely feasible, for the following reasons:

- Although gypsum and anhydrite are both soluble in water and would dissolve quickly, landslips or erosion could reveal fresh gypsum exposures.
- Mine waste from the Long Meg mine is notably white and has not yet dissolved (though it is not clear exactly what this material consists of; it does not effervesce with dilute hydrochloric acid).
- The Long Meg gypsum was mined by a number of horizontal adits dug in from the hillside between the river and Long Meg, including adjacent to the stream between Lacy’s Caves and Long Meg.
- The exposure is recorded as almost 4 metres thick so, if found, could have been extensively worked by Neolithic people using antler picks.

5. Discussion

The results of the geological survey offer vast potential for endless fascinating speculation. Here, just a few key suggestions are presented; further analysis and speculation will be included within the final version of the report.

Although there is still more work to be done on the lithology of the Daughters, we can now be reasonably sure they all fall into the three groups discussed in Section 3, above. The distribution of these three groups is shown in the sketch shown here (Fig. 5.1). This is clearly not an entirely random distribution, but it is far from clear what the pattern actually represents. Although the Daughters present much variation in appearance, the four granite examples stand out as particularly different from all the others. These light-coloured boulders may well be placed at significant places around the circle; those at NNW and NNE are very close to the summer solstice sunset and sunrise. Perhaps the longest days of the year were celebrated at Long Meg in addition to the shortest, on which the main axis of the monument seems to be aligned. Further work is planned to investigate all such possible alignments, which may relate to the moon and other celestial bodies as well as to the sun. In addition to variations in lithology, variation in the size of the Daughters, and of the gaps between them, requires further thought. Why there should be particularly massive Daughters to east and west, and slightly west of south, but seemingly not to the north, requires explanation.

If we are correct in identifying almost all of the Daughters as either of the Borrowdale Volcanic Group (BVG) from the central Lake District, or Thelkeld Microgranite, from below Saddleback (Blencathra), then it may well be significant that both the central Lake District mountains and Saddleback are visible on the distant horizon from Long Meg. Neolithic people would have been very familiar with their environment and may well have been aware of the ultimate sources of these types of stone, and would no doubt have told splendid myths explaining how such boulders came to be located in the Eden valley.

We know that in some cases Neolithic people dragged (or floated) large stones great distances when constructing their monuments, and it may well be that the prestige associated with any particular monument related to the size of the stones within it and the effort involved in their acquisition and transport. However, we can now be fairly that Woolacott was correct in stating, back in the early twentieth century, that all the Daughters are glacial erratics, deposited by ice in the Eden Valley and not dragged all the way from the Lake District by people. It is possible that one or more concentrations of erratics could have been deposited within small areas, possibly at no great distance from Long Meg (Phil Davies pers. comm.), but it seems inconceivable that they could all have been dumped within the immediate vicinity of the site, and moving them, especially the larger ones, any distance would have been a huge undertaking, perhaps involving hundreds of people. It is possible that people went out looking for them, or they may have been found by chance when clearing woodland or ploughing; whatever the explanation, a decision was clearly taken that certain types of stone should be collected and transported to the circle.

The maps of erratics shown here as Fig 5.2 are fascinating, and demand much further thought. An obvious interpretation is that people were collecting BVG boulders from within several kilometres of Long Meg and transporting them to the circle, while leaving others untouched. It will be interesting to try and create a similar map for Threlkeld Microgranite erratics. It will also be interesting to survey other Neolithic monuments throughout the Eden valley and see how they fit into this pattern.

In addition to all the above fascinating conjecture, probably the single most profound result of the survey has been the recognition that most of the Daughters, beneath their weathered outer skins and coverings of lichen, are various shades of green. This has seemingly never been commented on before. Green axes, including those of jadetite from the Alps and of volcanic tuff from Langdale, were quarried from great heights ('up in the clouds') during the early Neolithic, and became widely dispersed. Elsewhere in world (eg amongst the Maori in New Zealand, the Aztecs in central America, and in ancient China) green stone was held in special regard. The reasons for this cannot be considered in any detail here, but may relate to green being widely regarded as the colour of life, while stone is often linked with death. The recognition that the circle builders at Long Meg seem to have been primarily interested in boulders that were green offers much potential for further thought and interpretation.

The link between green Daughters and green Langdale axes is further emphasised by the natural axe-like shapes on the inner face of Daughter no. 12 (Fig 5.3). Current evidence suggests that the Langdale axe factories were at their most active during the early Neolithic, a few centuries prior to the construction of the earliest stone circles, but such axes were still very much in use at the time the Long Meg circle was being built. It is also worth noting that several fragments of polished Landgale axes were found during the 2015 excavations at Long Meg, though these were probably associated not with the stone circle but with the great enclosure to its north.

The 2023 geological survey concentrated on the Daughters, but subsequent work, as reported above in Section 3.1, has also considered the nature and possible source of Long Meg herself. On the basis of lithological analysis, her probable source has been pinpointed, and further work is planned to investigate this area in early 2024. If this is indeed the source, and regardless of whether the carvings on her east face were added before she was quarried or subsequently, this supports Frodsham's (2021, 167-168) theory linking the red sandstone river cliffs with the stone circle, and further illustrates the key relationship between the Eden and the Long Meg complex, via the valley of the Long Meg Beck.

To conclude, the 2023 Fellfoot Forward geological survey of Long Meg and her Daughters has made a crucial contribution to our understanding of the geology and archaeology of one of northern England's most important prehistoric monuments, though there remains much potential for further work. It is important to note that Neolithic people almost certainly made no distinction between what we now call 'geology' and 'archaeology' – both, to them, would have been aspects of the complex but integrated natural and mythical world within which they lived their lives, rather than separate concepts. It is therefore immensely gratifying to see the results produced by this modern survey through the 'recombining' of two specialist fields that all too rarely interact. Ultimately, Long Meg in the Neolithic mind probably related to the way in which all things (people, nature, the heavens) were closely interrelated. It is therefore very appropriate that such profound results have resulted from the effective combination of what in the modern world have become two very different subjects. More such work, involving others in addition to geologists and archaeologists, may well encourage Long Meg to reveal more of her secrets.

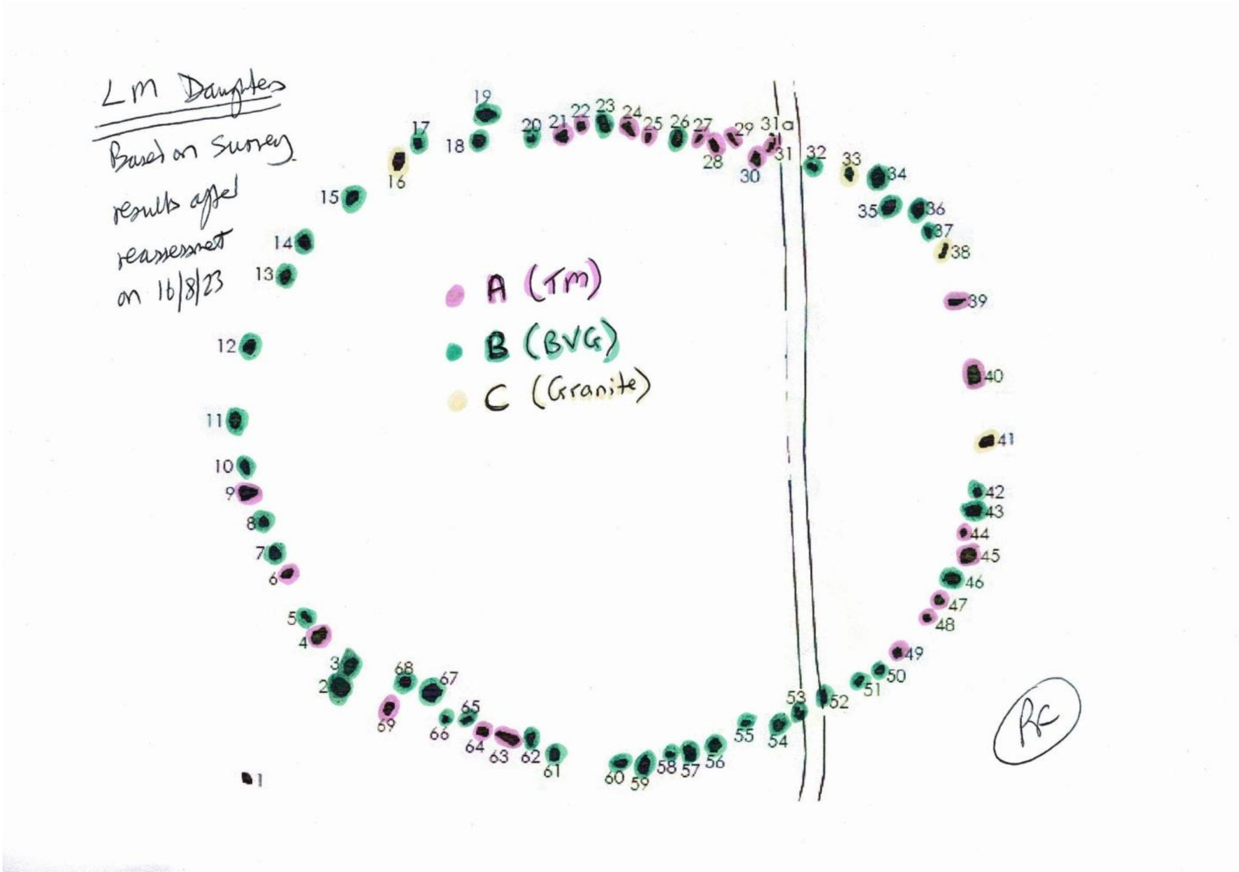

Fig. 5.1. Interim plan showing the distribution of the main three different lithologies of the Daughters, as identified by the 2023 geological survey. This is clearly not a random pattern, though what exactly it is trying to tell us in not immediately clear. Further analysis of the distribution, and an updated plan showing the different subdivisions of the BVG Daughters, will be included in the final version of this report.

A = TM = Threlkeld Microgranite (from below Saddleback/Blencathra, near Keswick).

B = BVG = Borrowdale Volcanic group (central Lake District).

C = Granite, possibly Dalbeattie or Criffel (SW Scotland) or Skiddaw (Lake District).

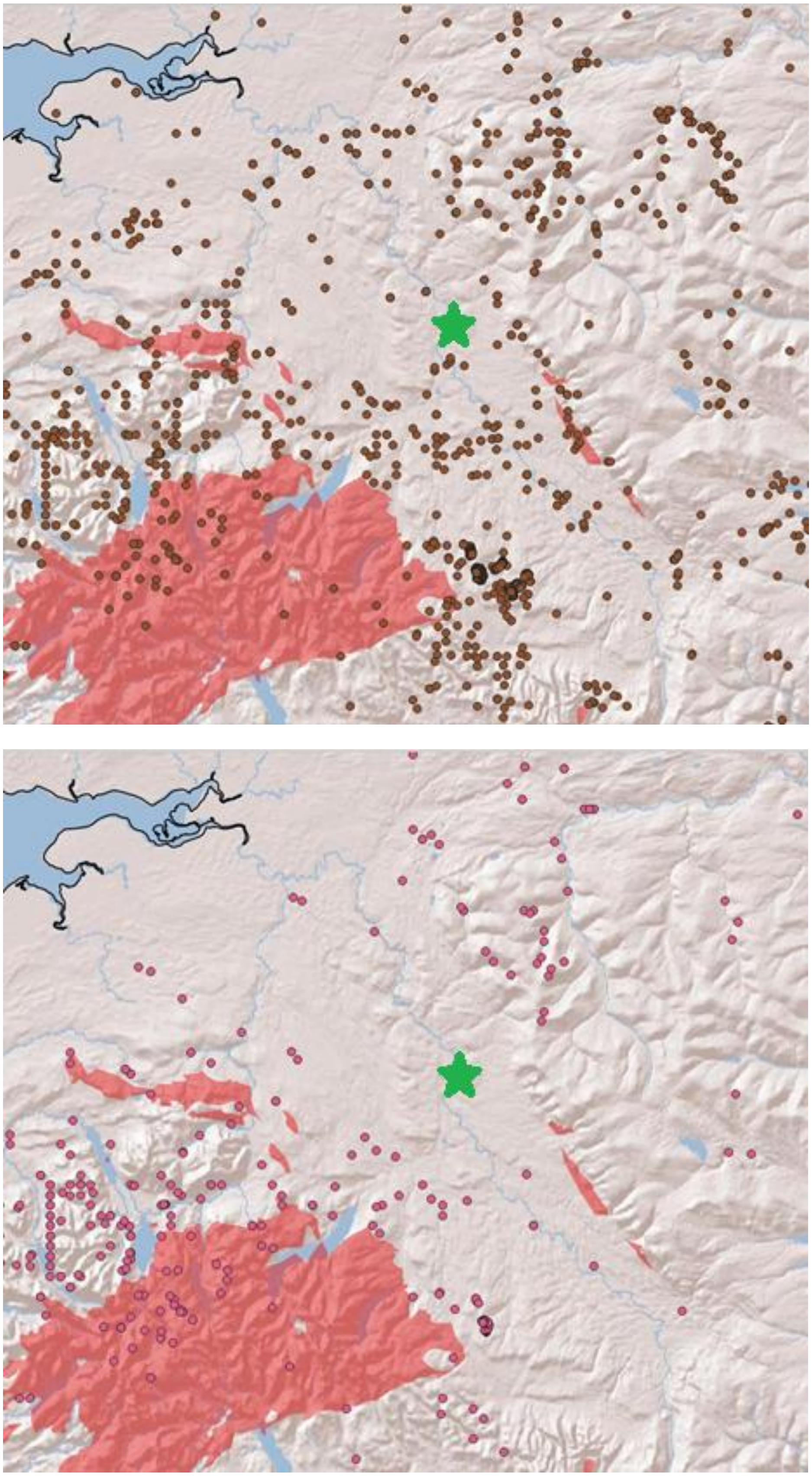

Fig. 5.2. Maps of recorded glacial erratic boulders in and around the Eden Valley. Long Meg is shown as a green star.

Above: all erratics.

Below: Borrowdale Volcanic Group (BVG) erratics.

(Thanks to Paul Carling for providing these maps, drawn by Les Knight.)

Fig. 5.3. Natural weathering on the inner face of Daughter no. 12 has produced shallow hollows shaped roughly like polished stone axeheads. These are entirely natural, but the similarity to axes (amongst the most important of Neolithic artefacts, being of symbolic as well as practical value) could surely not have escaped the attention of the circle builders. Shown below is a polished stone axe, from the Neolithic 'axe factories' at Langdale in the Lake District; axes from Langdale found their way all around Britain. Note the colour of the axe in comparison to the axe-shapes on Daughter 12. The green colour was almost certainly of huge significance to the people who made axes, and to those who built the stone circle.

5. Recommendations

The results of the geological survey are of very great significance to our understanding of Long Meg, but there is still much more work to be done! In a way, having established that all the Daughters are volcanic erratics, further research into their lithology might be regarded as of limited archaeological value, but, on the other hand, there could be patterns as yet unrecognised that could be revealed by more detailed analysis.

The following work, some of which is already in hand, is recommended. At some stage during 2024, an updated version of this report, covering completed further work, will be produced. Subsequently, a version of the report will be prepared for publication in an appropriate journal. Updates on work as it is completed will be provided on the Friends of Long Meg website (www.friendsoflongmeg.com).

- Measure the slab sizes and thickness at the potential source for Long Meg and compare the lithology in more detail. Investigate the field relations in the laminar bedded unit to confirm its origin. Search the potential source area for possible in-situ Neolithic carvings.

- Undertake further detailed study of the various subtypes of BVG Daughters, and prepare detailed discussion (with illustrations) for incorporation into the final report. Also, compare the distribution of subtypes with naturally occurring BVG erratics; does the sample contained within the stone circle correspond to the natural distribution, or are other factors potentially at play here?

- Update and refine the plan shown here as Fig. 5.1 to show the five subtypes of BVG amongst the Daughters.

- Consider the distribution of the different lithologies within the circle and seek to establish whether any potentially significant patterns can be identified, in general terms and with regard to possible solar/astronomical alignments (as suggested below).

- Obtain some samples of Skiddaw Granite in addition to the samples of Dalbeattie Granite. Compare these with the granitic daughters. A granite source in the Threlkeld area would be more geologically consistent with the prevalence of Threlkeld Microgranite and BVG here.

- Create high-resolution 3D photogrammetric models of a selection of Daughters, chosen to illustrate different stone types and geological features. Also a model of

Long Meg, and a lower-resolution one of the entire circle. And incorporate all these models into a single interactive model of the site. This could then be used to seek patterns in the form and setting of the Daughters within the circle.

- Investigate possible astronomical alignments within the architecture of the circle, in addition to the known link with the winter solstice sunset. For example, seek to establish whether the two granite Daughters in the NNW and NNE (nos. 16 and 33) relate to summer solstice sunrise and sunset. It is hoped that a computer model to enable such work will be developed in 2024.

- Survey the fields and walls around Long Meg for distributions and relative abundances of erratics. Understanding the natural abundance ratios of erratics in the area will help answer questions like:
    - Why are there no Shap Granite erratics at Long Meg? Were none deposited in the area(s) from which the Daughters were gathered, or does this represent a conscious selection decision by the builders?
    - What are the relative proportions of Threlkeld Microgranite, Borrowdale Volcanics and Granite erratics? How does this compare with the ratios in the stone circle? Again, does this represent a conscious rock-type selection decision by the builders?

- Investigate the potential for accessible (during the Neolithic) local gypsum outcrops, for example in Cave Wood and along the valley of the stream from Long Meg (bearing in mind that these may have been mined out by the modern gypsum workings).

- Investigate the lithology of any exposed sandstone along the valley of the Long Meg stream.

- Investigate the potential transport route for Long Meg in Cave Wood.

- Undertake further photomicrography of the Daughters and consider the implications of the results.

- If we can get access to some non-destructive testing equipment, particularly a portable XRF analyser (together with someone who knows how to operate it) we may be able to obtain much stronger confirmation of probable sources, particularly with regard to the granites.

- Undertake rapid assessments of other stone circles in the Eden Valley to establish the extent to which their lithologies differ from those identified at Long Meg.

- Small-scale excavations could be undertaken to investigate particular issues, such as the nature of the apparent circular bank into which many of the Daughters appear to be set, and the possible presence of stone sockets of 'missing' Daughters. Such excavations are recommended in the other report produced by this survey – the Condition Survey (Frodsham 2023).

- Consider all results in detail and provide a detailed overview of their potential archaeological implications with regard to Long Meg, taking into account comparable work at other Neolithic monuments throughout Britain and Ireland.

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Appendix A
Acknowledgements and participants

The Long Meg geology and condition survey was undertaken by a team of volunteers from the Fellfoot Forward Landscape Partnership Scheme, together with a team of geologists assembled by Sylvia Woodhead. The writers of this report are grateful to all for their expertise and enthusiasm, and for giving their time on an entirely voluntary basis. Thanks also to Fiona Knox (North Pennines National Landscape) for commissioning the survey, and for practical support throughout.

The following individuals all contributed to the planning and/or delivery of the survey:

Rod Allwright, Daisy Bagshaw, Robert Beech, Bruce Bennison, Geoff Brambles, Lottie Brzozowski, Paul Carling, Joy Davies, Phil Davies, Constance Elphinstone, Pauline Goodridge, Karen Greenhill, Damon Hall, Caroline Hartley, Mark Hartley, Helen James, Claire Jeffery, John Lackie, Paul Logan, Dan Normandale, Sarah Orme, Noel Pearson, John Pickin, Matthew Pullan, Steve Rozario, Deborah Sisk, Martin Sisk, Caroline Steven, Heather Tipler, Maralyn Wade, Lucy Watson, Geoff Wilson, Peter Woodhead, Sylvia Woodhead.

Appendix B
Tabulated summary of survey results

The table was compiled from data recorded in the field on individual recording forms, one for each Daughter. These are retained in the project archive. In some cases, information recorded during the initial survey has been updated following subsequent field visits (this is especially the case with regard to 'rock type', as the basic types were not finalised until long after the initial survey).

Key to the column headings used in the table (all measurements in cms):

Stone no. Using the numbers allocated by the 2013 Durham University/Altogether Archaeology survey.

S/F/U. S = standing. F – fallen or flat. U = uncertain.

Height. Maximum height from the ground surface.

Width 1. Widest width (measured parallel to the ground for 'S' stones).

Width 2. For 'F' stones only, the width at approximately 90 degrees to Width 1.

Circum. For 'S' stones only, the widest circumference, measured parallel to the ground surface

Bank. Is the stone set within an earthen bank? Y = yes. Y? = probably. N = no. N? = probably not. ? = uncertain.

Inner face. For Daughters classed as 'S', is the inner face (ie that facing towards the centre of the circle) flat (F), curved (C), or irregular (I).

Gap anti-c/w. Distance to the next Daughter, anti-clockwise.

Gap c/w. Distance to the next Daughter, clockwise.

W no. The number allocated to this stone by Woolacott (1910).

W type. The stone type (where stated) according to Woolacott (1910). B = 'Volcanic Series of Borrowdale'; Q = 'quartz porphyries and allied rocks'; G = granite; M = mica schist; U = unclassified.

Damage. A simple assessment of rabbit damage around/beneath the stone; see separate Condition Assessment report (Frodsham 2023) for details and discussion.

Rock type. As discussed in Section 3 of this report.

Notes. Anything about this Daughter deemed worthy of particular note.

Survey group. An identifier of which of the six groups within the survey team surveyed this particular Daughter.

Stone no.	S/F/U	Height	Width 1	Width 2	Circum	Bank	Inner face	Gap anti-c/w	Gap c/w	W no.	W type	Damage	Rock type	Notes	Survey group
2	F	120	290	260		Y	?F*	*590	n/a	?47	?Q	XXX	B3	OUTER PORTAL. Strongly laminated tuff. Very bad rabbit damage, exposing buried ?inner face (seemingly originally facing axis of 'entrance portal' rather than into circle) looks to be very flat, mirroring 69 at opposite side of 'entrance'. Quartz nodule (post-diagenetic) on what was presumably top surface when erect. Gap anti-c/w relates to 69.	6
3	F	100	260	170		?		*690	480	?48	?U		B3	INNER PORTAL. Strongly laminated tuff. Gap anti-c/w relates to 68.	6
4	F	50	265	170		Y		480	195	49	U		A1	Several xenoliths (some weathered out).	3
5	S	138	175		420	Y	F	195	550	50	B		B3	Very green cattle-rubbed smooth area on S end; also other green patches.	2
6	F	30	205	140		Y		555	215	51	Q	XX	A1	At least a couple of weathered-out xenoliths,	1
7	S	139	200		570	Y	I	220	320	52	B	XX	B1	Appears more grey than green.	4
8	S	112	157		440	Y	I	320	330	53	Q		B3		4
9	F	45	249	208		Y		330	210	54	Q	X	A2		2
10	S	180	240		540	Y	F	210	500	55	Q	XX	B3		3
11	S	260	260		580	Y	C	500	920	56	B	XX	B1	Clear flowbanding to S side.	1
12	S	178	205		584	Y	I	920	965	57	U	X	B1	Auto-brecciation, with quite large bomb. Polished green patches due to cattle-rubbing. Several 'axe-shaped' hollows on inner face, due to natural weathering (almost certainly pre-dating transport within ice, so already present when stone was installed on site).	4
13	F	100	160	101		Y		965	385	58	B	X	B5	BVG, but not allocated to a subgroup.	1
14	F	100	210	200		Y		400	755	59	B	XX	B3	Fine-grained ash, with large ejectar grains. Lots of lapilli, some weathered out, leaving small hollows.	3
15	S	178	240		572	Y	F	763	639	60	B	XXX	B3	Similar to 14, but with clearer lamination. Very bad rabbit damage.	2
16	F	85	265	87		Y		645	205	61	G	XX	C1	Granite (?Dalbeattie/Criffel). Same as 33 & 38. Black (biotite) and white (muscovite) mica. Some pink feldspar. Vein of rose-tinted quartz runs N-S right through it	4
17	S	150	150		360	Y	I	205	780	62	B	XX	B1	INNER PORTAL. Fine-grained light-coloured rhyolite lava, with lots of vesicles; large inclusions of lithified ash blocks.	1
18	F	130	183	123		N?		770	620	63	B	XXX	B3	INNER PORTAL. Ash with inclusions. Very bad rabbit damage - around and beneath.	4
19	F	120	310	175		N?		n/a	n/a	64	B	X	B4	OUTER PORTAL. Lahar: lots of varied inclusions within muddly debris flow. 240cm from 18.	4

20	S	170	112		330	Y	F	630	310	65	B	X	B3	Laminated ash. Green patches where rubbed by cattle.	3
21	F	63	190	170		Y		310	160	66	Q		A1	Unusually pink. Several linear xenoliths up to c7x1cm.	1
22	F	55	154	115		N?		155	206	67	U		A2		2
23	F	65	255	140		Y		205	200	68	B	X	B3	Lumpy surface; lots of lapilli (some still present, others weathered out leaving holes), also larger holes where bombs have weathered out. White quartz veins towards S end.	1
24	F	30	240	135		Y?		200	140	1	U	X	A2		3
25	F	20	160	100		Y		140	320	2	B		A2	Quite pink.	1
26	F	65	230	135		N?		325	200	3	B		B3	Laminated ash. Big fracture right through it.	2
27	F	10	180	70		?		200	125	4	U		A2		4
28	F	60	195	105		N?		125	205	5	Q		A2		2
29	F	20	215	75		Y		205	270	6	U		A2	Quite pink.	1
30	F	50	215	155		Y?		270	130	7	U		A2	Quite pink.	3
31	F	25	285	100		U		130	590	8	U		A2	Immediately adjacent stone (31A) is red sandstone, perhaps dumped here during road construction - BUT it is almost opposite Long Meg, so just might be significant (and might be bigger than implied by small extent of exposed surface).	3
32	S	182	130		370	N	F	582	430	9	B		B3	Very green where cattle-rubbed at NW and SE angles. Quartz vein at SW angle.	1
32A	F	5	50	50		N		n/a	n/a	?69			??	Extra stone, mostly buried, outside circle. Moved from line of road? Maybe Woolacott 69. Not checked during reinspection - recorded previously as 'tephra, fine-grained'.	1
33	F	54	195	135		N		425	265	10	G		C1	Granite (?Dalbeattie/Criffel). Same as 16 & 38.	4
34	F	184	285	195		U		270	250	11	B	XXX	B3	Apparently unique: very fine-grained and unusually mottled grey and brown colouring (no sign of green). Well laminated. Very bad rabbit damage.	2
35	F	65	250	170		Y		250	260	12	B		B3	Laminated ash with lapilli. Small exposed areas of green.	4
36	F	60	240	170		Y		270	180	13	B	X	B4	Lahar. Green interior exposed in several places.	3
37	F	90	185	85		N		170	240	14	B		B2	Probable vent breccia with angular bombs. Very green in places.	1
38	F	40	213	70		U		235	643	15	M	XXX	C1	Granite (?Dalbeattie/Criffel). Same as 16 & 33. Granular quartz/mica. Very bad rabbit damage - around and beneath.	2
39	F	53	246	85		N		637	940	16	Q	X	A2	More obviously glacially-smoothed than any others, with striations on S face.	4

40	S	225	240		740	N	F	940	820	17	Q	X	A1	HUGE eastern stone. Lithology (including phenocrysts) visually identical to sample from Threlkeld Quarry. Much exfoliation weathering to inner (W) face; surprising musical tone obtained from tapping 'loose' surface in places (not noted when tapping other stones with similar weathering, which tend to make a dull hollow sound). Very big gaps to either side.	1
41	F	80	240	150		N		820	620	18	G		C2	Granite (?Dalbeattie/Criffel). Different from other granites (16, 33, 38); coarser-grained, with large feldspar phenocrysts, and hardly any biotite. Some crystals observed to have ?Carlsbad twinning.	3
42	S	98	140		400	N	I	620	130	19	B	X	B4	Lahar with varied inclusions and very irregular surface. Quite green in places.	4
43	F	75	250	160		N		120	215	20	B		B1	Clear auto-brecciation.	1
44	S	160	110		300	N	C	220	210	21	Q	XX	A1	Several small xenoliths.	2
45	F	85	245	210		Y		200	190	22	Q		A1	Huge xenolith to SW angle. Smaller one, weathered out, on upper surface.	4
46	F	50	245	175		N		190	220	23	B		B3	Small area on S face, exposed due to cracking of surface, is very green and fine-grained.	1
47	S	210	105		430	Y	F	225	190	24	Q	X	A2	Quite green, with pinkish patches.	3
48	S	120	100		295	Y	F	190	560	25	Q		A1	One medium-sized xenolith on W side, part weathered out and part in situ. Big oval indentation on W face caused by exfoliation.	1
49	S	180	120		390	Y	F	560	220	26	Q	X	A1	Medium-sized xenolith on SW face.	?
50	S	125	170		425	Y	F	235	190	27	B	XX	B3	Ash with bombs, many weathered out leaving holes.	3
51	S	130	145		395	Y	F	190	500	28	Q	XX	B1	Flow-banded (?rhyolite) lava.	6
52	F	40	205	75		N		500	320	29	B		B5	BVG, but not allocated to a subgroup. Fine-grained. Very green on W face where polished by vehicle tyres.	5
53	F	75	170	90		N		330	183	30	B		B3	Ash with bombs, some weathered out leaving holes. White quartz coating (up to 50cm diam) on joint surface at NW angle. Very green on E face where polished by vehicle tyres.	6
54	S	160	165		500	N	F	190	345	31	B	XX	B2	Large bomb, 75cm diam, exposed in S face.	5
55	F	50	150	85		N		350	410	32	U		B3		6
56	F	35?	210	190		N		410	240	33	B		B3	Layered ash.	5
57	F	60	250	175		Y		240	150	34	B		B3	Layered ash.	6
58	F	30	140	60		Y		160	300	35	Q		B3	Layered ash.	5
59	F	75	275	140		U		300	200	36	B	XX	B1	Auto brecciated lava; varied inclusions within lava matrix.	6
60	S	100	190		420	Y	F	210	820	37	Q	X	B3	Clear lamination.	5
61	F	70	200	130		N		820	280	38	Q	X	B3		6
62	F	45	190	120		Y		280	170	39	Q	X	B3		5

63	S	210	355		850	Y	F	160	150	40	Q	X	A2	HUGE stone, just W of S. Extensive exfoliation on inner (N) face. Freshly exposed area at SW angle is very green.	6
64	S	140	170		465	Y	F	150	155	41	Q		A1	Several small to medium xenoliths.	5
65	F	30	175	85		U		160	200	42	Q	X	B5	BVG, but not allocated to a subgroup.	6
66	F	10	140	130		Y		180	240	43	B		B3	Almost completely buried. Upper surface, parallel to turf, is fractured presumably due to cattle/people trampling; exposed interior is very green.	5
67	F	130	280	280		Y		240	210	44	Q		B1	Seems to incorporate evidence of two separate lava flows, one above the other.	6
68	S	180	165		480	N	F*	220	*690	?45	?Q	XX	B3	INNER PORTAL. Layering demonstrates cross-stratification - aeolian or fluvial influences. 'Inner face' faces axis of 'entrance portal' rather than into circle. Gap c/w relates to 3.	5
69	S	240	200		520	N	F*	n/a	*590	?46	?Q	XX	A1	OUTER PORTAL. Quite pink. Several xenoliths. Suggestion of layering could be more to do with weathering than lithology. 'Inner face' faces axis of 'entrance portal' rather than into circle. Gap c/w relates to 2.	5

* see notes