Rapporter och meddelanden 109

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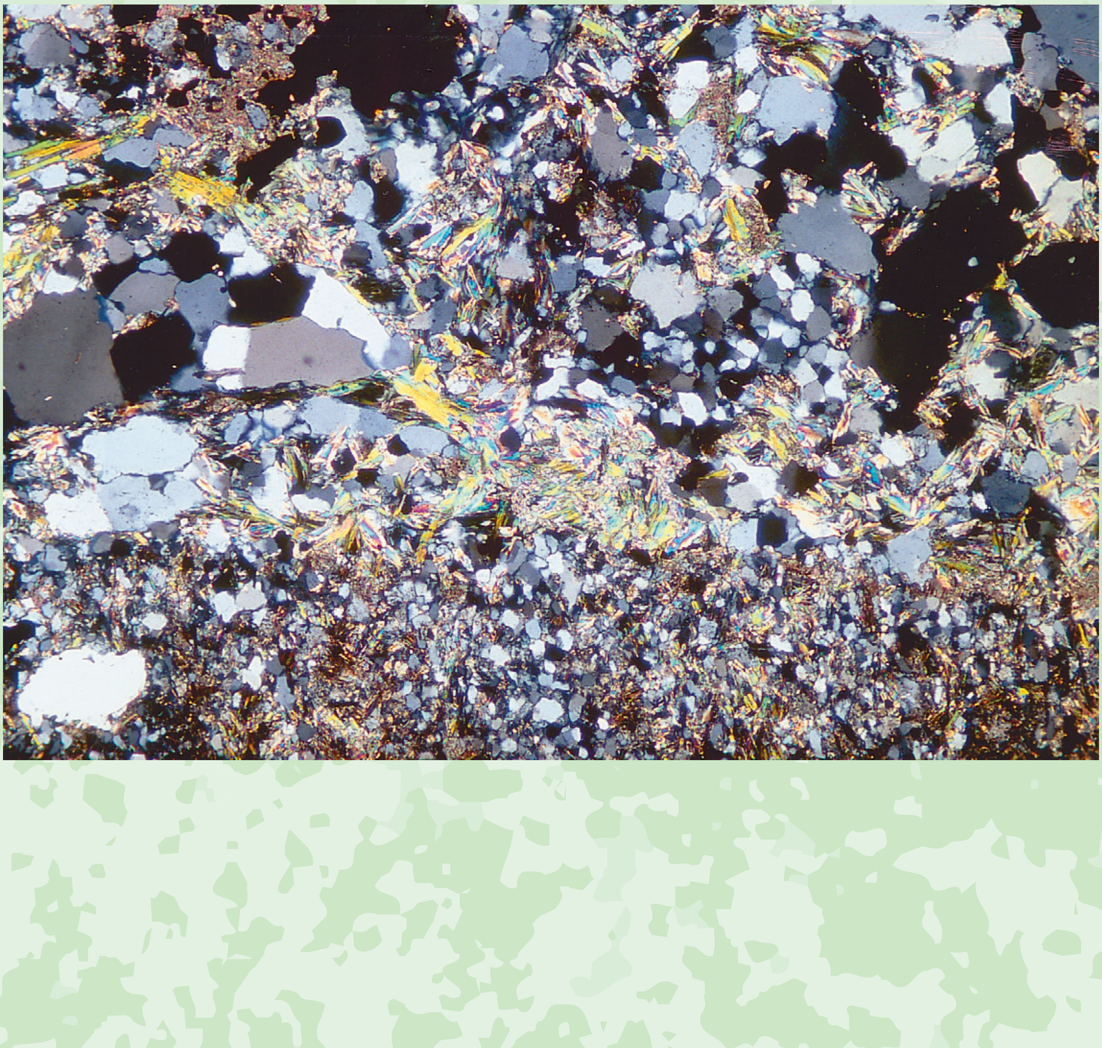

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Cover: Microphotograph. Sheaves of poorly oriented muscovite. Detail of fig. 8c. Long side of photo c. 4 mm.

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ABSTRACT

Two separate occurrences of post-tectonic, extremely matrix-poor breccias are described. The clasts are interpreted to be of a lower metamorphic grade than the country rock and to be flow-banded. As the clasts also had different rheological properties after breccia emplacement, an interpretation in terms of autoclastic flow breccias is suggested. Both breccias are intruded by porphyry dykes. At the Pellesberget breccia, the Gustafs porphyry clearly autobrecciated itself and intruded simultaneously with breccia emplacement. The evidence from Pellesberget implies post-Svecokarelian breccia emplacement as well as volcanism at 1474±4 Ma. The Bjursås breccia is also post-tectonic, but it was most probably emplaced before c. 1.79 Ga.

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INTRODUCTION

The bedrock of Bergslagen is dominated by c. 1.9 Ga metavolcanic, metasedimentary, and metagranitoid rocks (Stephens et al. 2000). They were deformed and metamorphosed during the Svecokarelian orogeny 1.80–1.85 Ga ago. Syn- to post-orogenic granites intruded large areas c. 1.8 Ga ago. Anorogenic rocks are rare, but a 1469±10 Ma alkali granitic to syenitic intrusion occurs at Noran (Claesson & Kresten 1997) and a Gustafs porphyry from a cross-cutting dyke has recently been dated at 1474±4 Ma by Lundström et al. (2002).

At Bjursås and at Pellesberget (Fig. 1), breccias that are post-tectonic in relation to the Svecokarelian fabrics also occur. They both have a number of confusing characteristics. The main purpose of this paper is to describe these features and to present a tentative interpretation of them.

Coordinate figures are according to the Swedish National Grid.

DESCRIPTION

Common features

The Bjursås and Pellesberget breccia occurrences share the following macroscopic traits:

1) The clasts are angular and one centimetre to some metres in size. The sizes of the clasts vary from place to place, but the size distribution is almost unimodal in each particular place.

2) The clasts have an extraordinarily good jigsaw fit (Figs. 2, 3, 6, 11). The breccias thus look virtually devoid of matrix.

3) Almost all clasts are foliated. The foliations even of adjacent clasts have different orientations (Figs. 2, 3).

4) The breccias are not overprinted by any later, penetrative fabric.

5) Macroscopically, the clasts look very similar to the country rocks, but for the most part a country rock provenance is doubtful. See below.

6) Porphyry dykes cross-cut the breccias.

The Bjursås occurrence

The Bjursås breccia has only a few outcrops, spread over an area of c. 400 square metres south of Lake Rappsmälingen, c. 12 km north-west of Falun (Figs. 1, 4).

The country rock

The country rock of the Bjursås breccia is a quartz-feldspar-biotite schist with a grano- to lepidoblastic texture and a grain size of c. 0.2 mm in which relict phenocrysts of quartz and feldspar occur. The biotites are commonly arranged in two intersecting s-planes (Fig. 5), which in turn define a well developed intersection lineation.

The breccia

For the most part, the clasts of the Bjursås breccia fit together extremely well, without any traces of a matrix (Figs. 2, 6). At first glance, they look macroscopically very similar to the country rock, but on closer inspection most clasts are found to differ significantly from it. For example, the clast foliation is mostly not defined by planar biotite fabrics as in the country rock, but by winding fine bands of sheaves of poorly oriented muscovite, chlorite and some biotite (compare Fig. 5 with Figs. 6a, b and cover picture). Clasts with this fine and gently winding banding (Fig. 7a) are so common that country rock clasts with the typical tectonic foliation (Fig. 7b) are easily recognized macroscopically.

Although this banding is prominent among clasts, it also occurs together with a muscovite foliation parallel to the contacts of clearly intrusive veins (Figs. 8a, b, c, d). These foliations are thus similar to flow foliations and their appearance in clasts suggests that the clasts are in fact cognate inclusions that became flow-foliated during an earlier intrusive pulse.

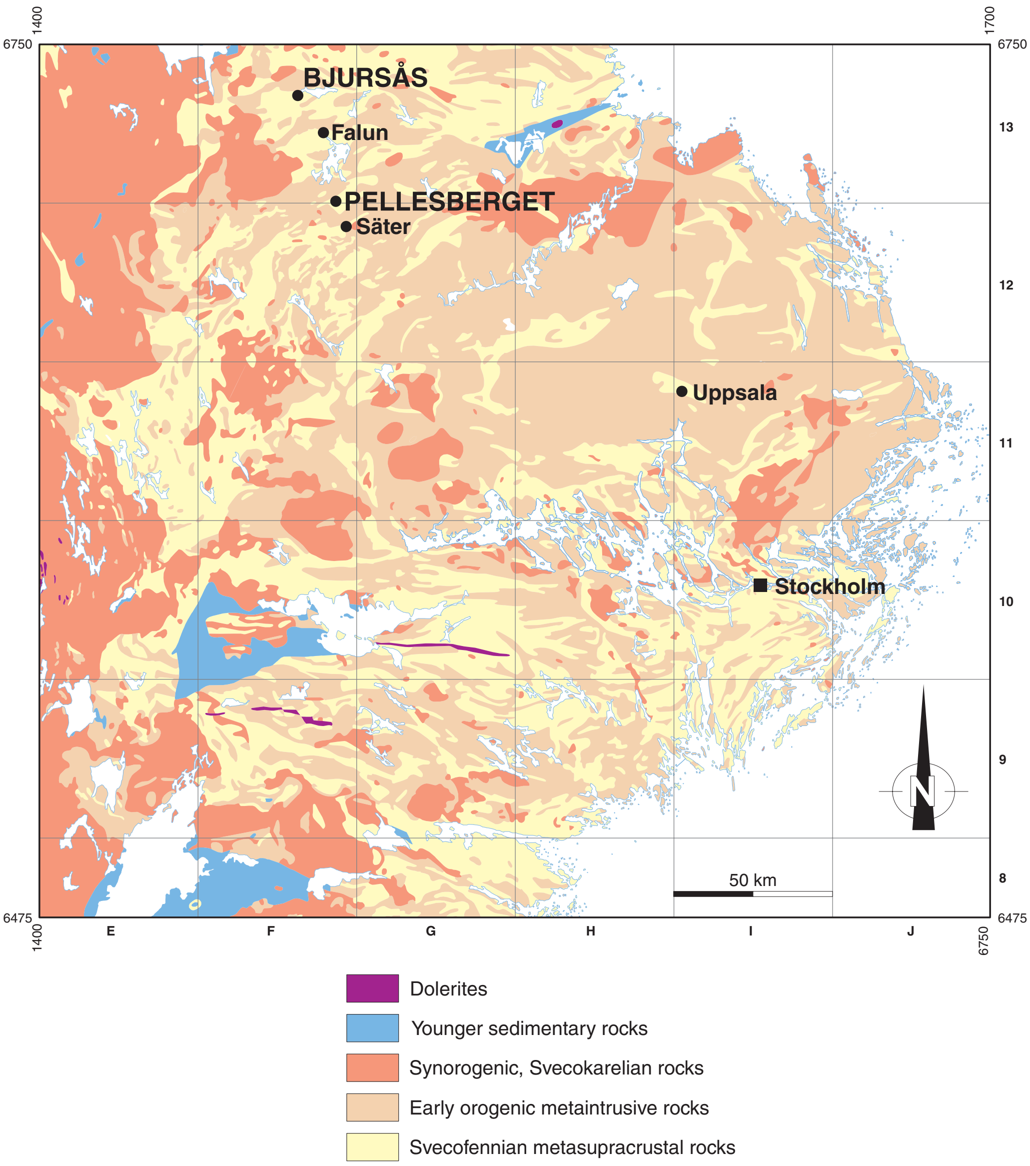

Fig. 1. Schematic geologic map of the Bergslagen province. Modified after Lundqvist et al. (1994).

Felsic intrusions

The Bjursås breccia is intruded by a subhorizontal, straight, roughly one metre thick dyke of a fine-grained, isotropic plagioclase porphyry (Fig. 4). The contacts of the dyke to the breccia are very sharp and consequently the age of the porphyry must also be the minimum emplacement age of the breccia. The porphyry is described in greater detail by Lundström et al. (2002).

The breccia also appears to be intruded by a quartz-porphyritic rock, which is more similar to the intrusive phases of the breccia, described in the previous section. Due to poor exposures, the field relationships between the quartz porphyry, the plagioclase porphyry, and the breccia remain unknown.

The Pellesberget occurrence

The Pellesberget breccia covers about half a square kilometre of a fairly well exposed area, c. 10 km north-west of Säter (Figs. 1 & 9).

The country rocks

A variety of distinctly foliated metamorphic rocks occur around the Pellesberget breccia. They are mostly granoblastic to lepidoblastic, fine-grained, even-grained botite- or hornblende-rich schists with porphyroblasts of garnet, cordierite, or andalusite (Fig. 10). Some are almost mylonitic, with fine-grained compositional banding. Obviously, the country rocks have undergone medium- to high-grade metamorphism and are entirely characterized by metamorphic textures.

Fig. 2. The Bjursås breccia. Local boulder in road-cut south of Lake Rappsmälingen, 2 km south-east of Bjursås (6732996/1481982).

Fig. 3. The Pellesberget breccia. Boulder 200 m north-east of the crest of Pellesberget (6699970/1493360).

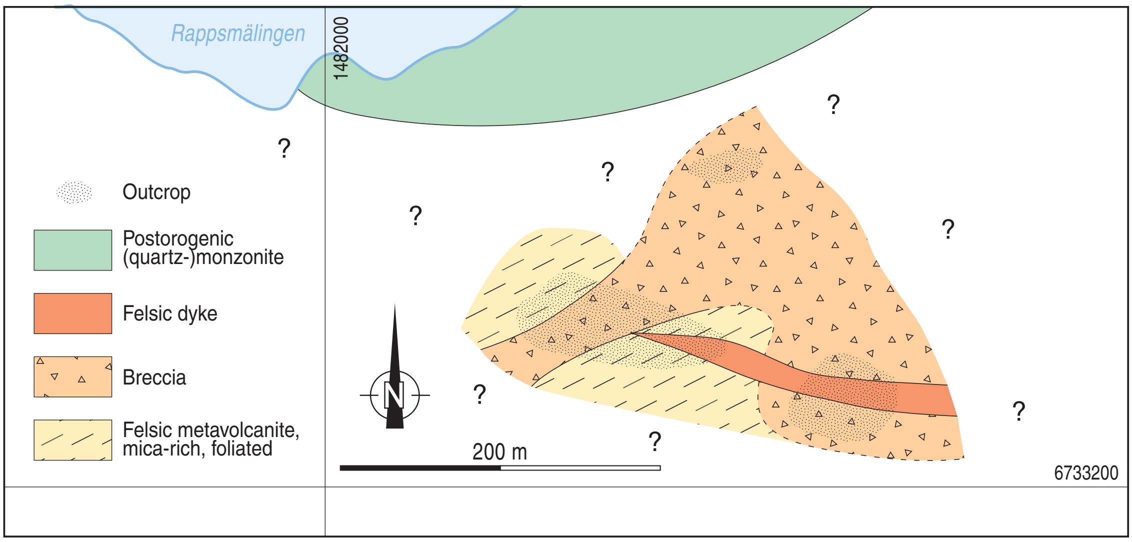

Fig. 4. Map of the Bjursås breccia. Compiled in November 1998.

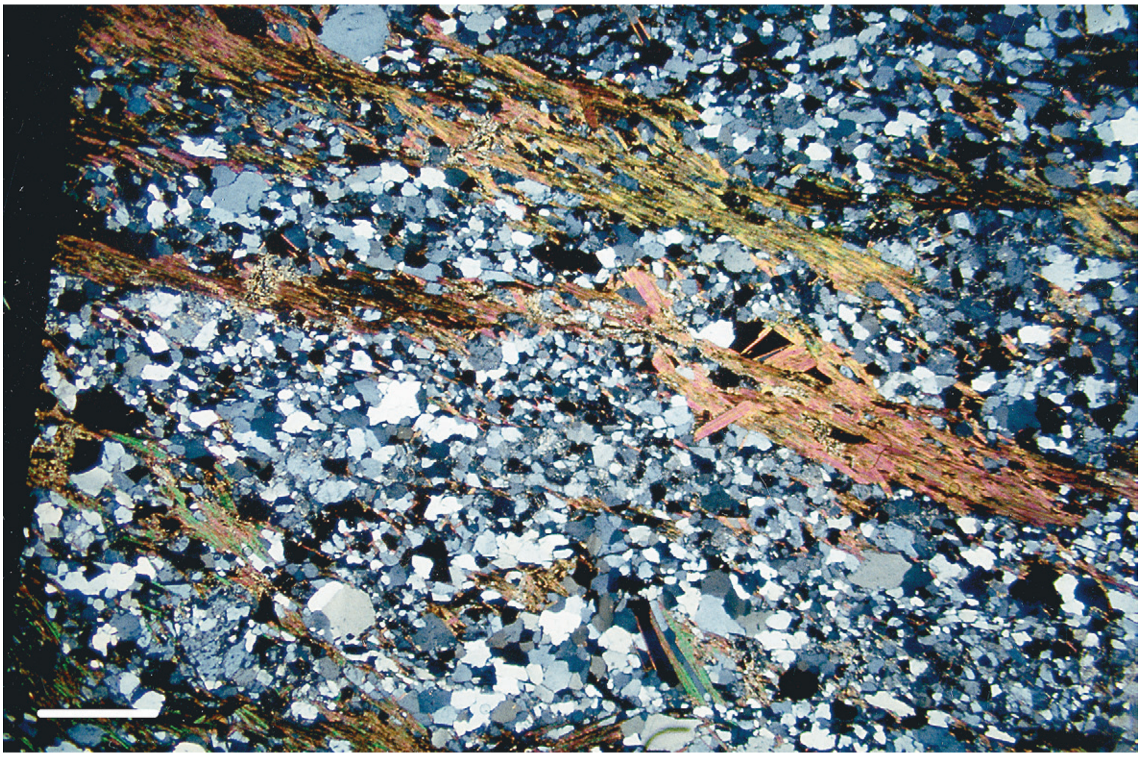

Fig. 5. Country rock of the Bjursås breccia. Metavolcanic, biotite-foliated quartz-feldspar-biotite rock. Microphotograph, crossed nicols. Outcrop south of Lake Rappsmälingen (6733055/1482127). Scale bar = 1 mm.

The breccia

Also the clasts of the Pellesberget breccia fit together very well, leaving no space between the clasts for a normal matrix (Figs. 3, 11). Some clasts consist for example of garnet porphyroblastic biotite schists (Fig. 12), very similar to the high-grade country rocks. Rare clasts of marble, evidently derived from adjacent country rocks, have also been found. These clasts are clearly different from the majority of the clasts, which apparently have not undergone the same high-grade alteration as the country rocks. Figure 13 is an attempt to illustrate this feature. Hence, a clast of a garnet-porphyroblastic biotite schist (Fig. 13b) adjoins an area of a texturally and modally much better preserved rock (Fig. 13c). Not only is the latter rock less

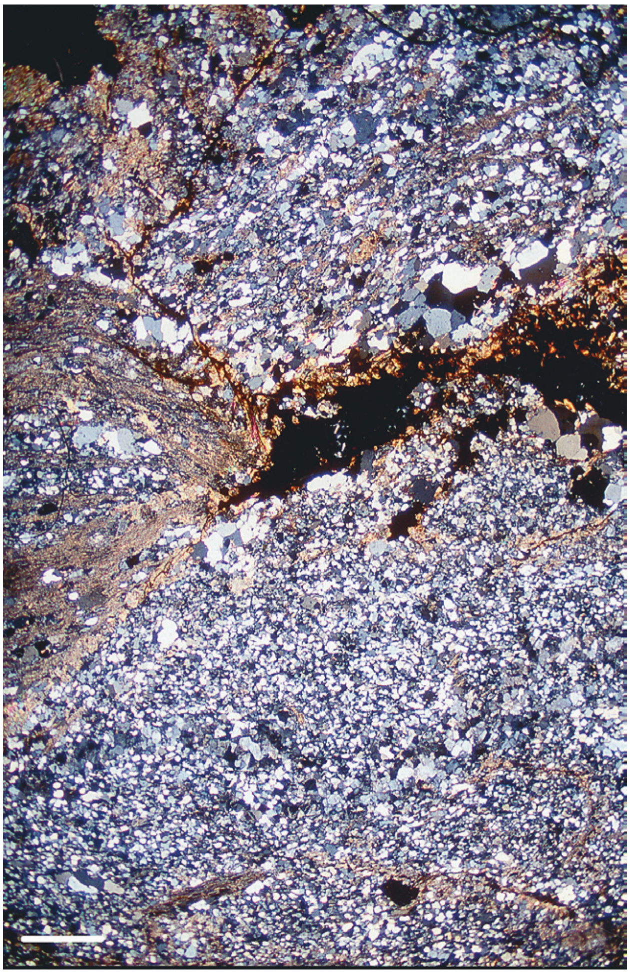

Fig. 6. Clasts in Bjursås breccia. Notice absence of matrix and almost microcrystalline, isotropic texture of bands. Microphotographs, crossed nicols. Local boulder south of Lake Rappsmälingen (6733226/1482267). Scale bar = 1 mm.
a) Overview

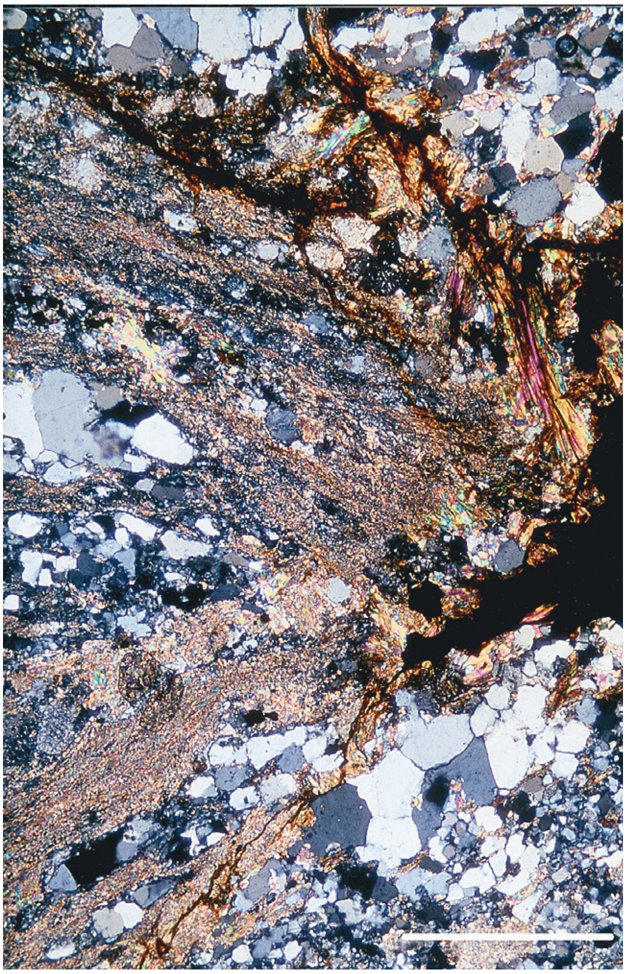

Fig. 6b. Detail of the area in Fig. 6a. Scale bar = 1 mm.

altered, containing chlorite instead of garnet and biotite, but it also features a relict porphyritic texture (Fig. 13d), which is not seen in the country rock. Furthermore, the better preserved rock was apparently able to adapt plastically to the outlines of the country rock clast (Figs. 13a, c), suggesting that the two rock types possessed different competencies after coming together in the breccia.

The Gustafs porphyry

The breccia is intruded by several dykes of the rhyolitic, quartz-feldspar porphyritic Gustafs porphyry, which is dated and described in greater detail by Lundström et al. (2002). Dykes of so-called Tuna dolerite, which are held to have intruded coevally (Hjelmqvist & Lundqvist 1953), also occur. The porphyry forms a somewhat irregular system of dykes and stocks (see Fig. 9) and, in the vicinity of the dykes, it intrudes and fills the voids between the breccia clasts (Fig. 14). In such instances, the porphyry clearly makes up an intrusive matrix in the breccia. Surprisingly, the Gustafs porphyry also forms clasts in the breccia (Figs. 15, 13a, c), in which case the foliation of the adjacent clasts locally adapts to the outlines of the Gustafs porphyry clast (see Fig. 15). Furthermore, fine-grained, almost cryptocrystalline, flow-banded varieties of the Gustafs porphyry locally form both clasts and matrix (Fig. 16), i.e. the porphyry has formed an autobreccia.

DISCUSSION

The many strange properties of the Bjursås and Pellesberget breccias suggest that they are the results of some unusual and poorly known process or processes. A number of interpretations in terms of such processes are discussed below.

Since the general view is that "strange breccias and unusual 'volcanic' rocks may be rewarding ground in which to search for unrecognized impact structures" (French 1998, p. 98), the Pellesberget and Bjursås breccias should

Fig. 7. Clast types in the Bjursås breccia.
a) Clasts with fine, gently winding bands. Local boulder south of Lake Rappsmälingen (6733996/1481982).

Fig. 7b) Clast of metagranitoid country rock. Local boulder south of Lake Rappsmälingen (6733226/1482267).

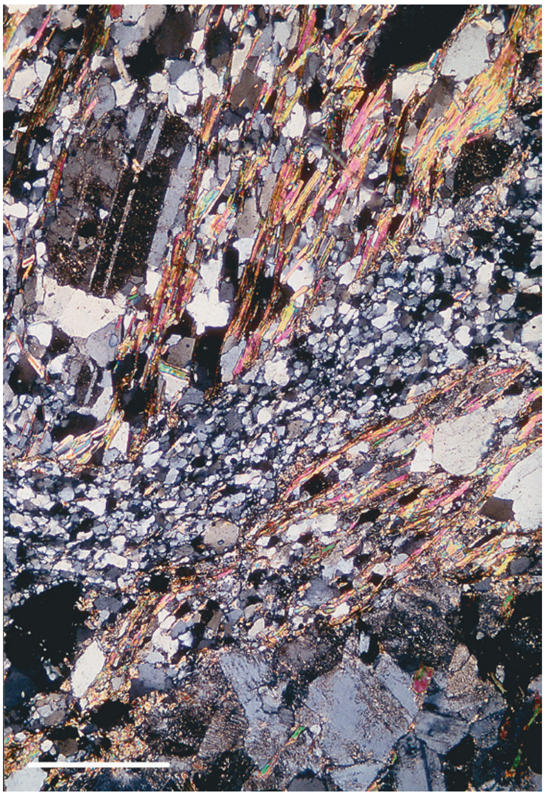

Fig. 8. The Bjursås breccia.
a. Intrusive veinlet with foliation parallel to contact, cross-cutting foliation of adjacent clast. Microphotograph, crossed nicols. Small prospect south of Lake Rappsmälingen (6733238/1482316). Scale bar = 1 mm.

Fig. 8b. Intrusion breccia with foliation parallel to contacts which cross-cut clast foliation. Scale in cm. Small prospect south of Lake Rappsmälingen (6733238/1482316).

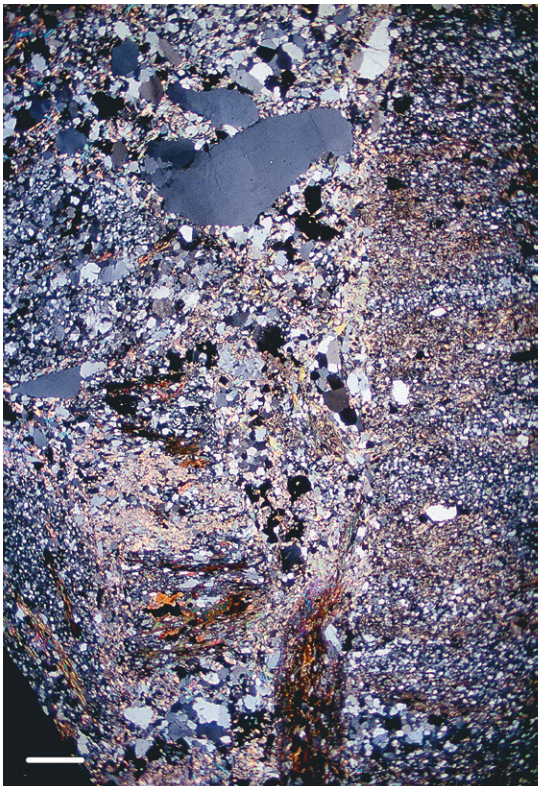

Fig. 8c. Intrusive veinlet with contact parallel foliation at right angles to the foliations of adjacent clasts. Microphotograph, crossed nicols. Drill core south of Lake Rappsmälingen (6733226/1482267). Scale bar = 1 mm.

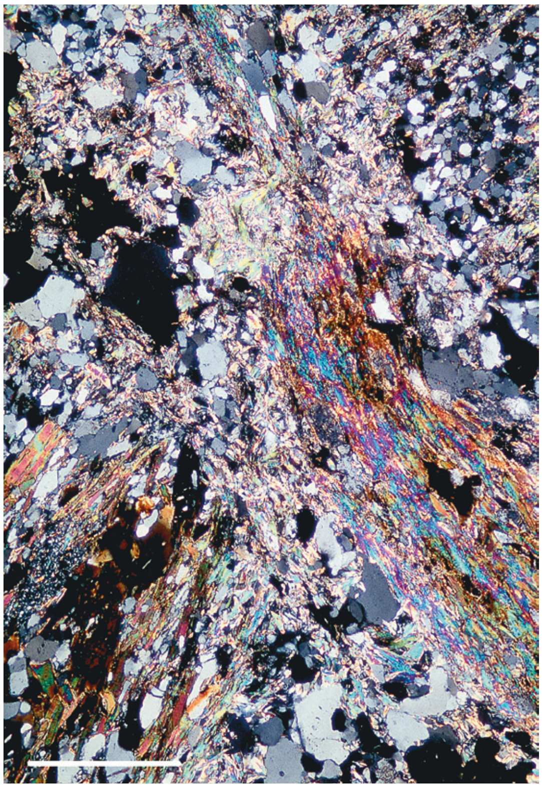

Fig. 8d. Detail of Fig. 8c. Scale bar = 1 mm.

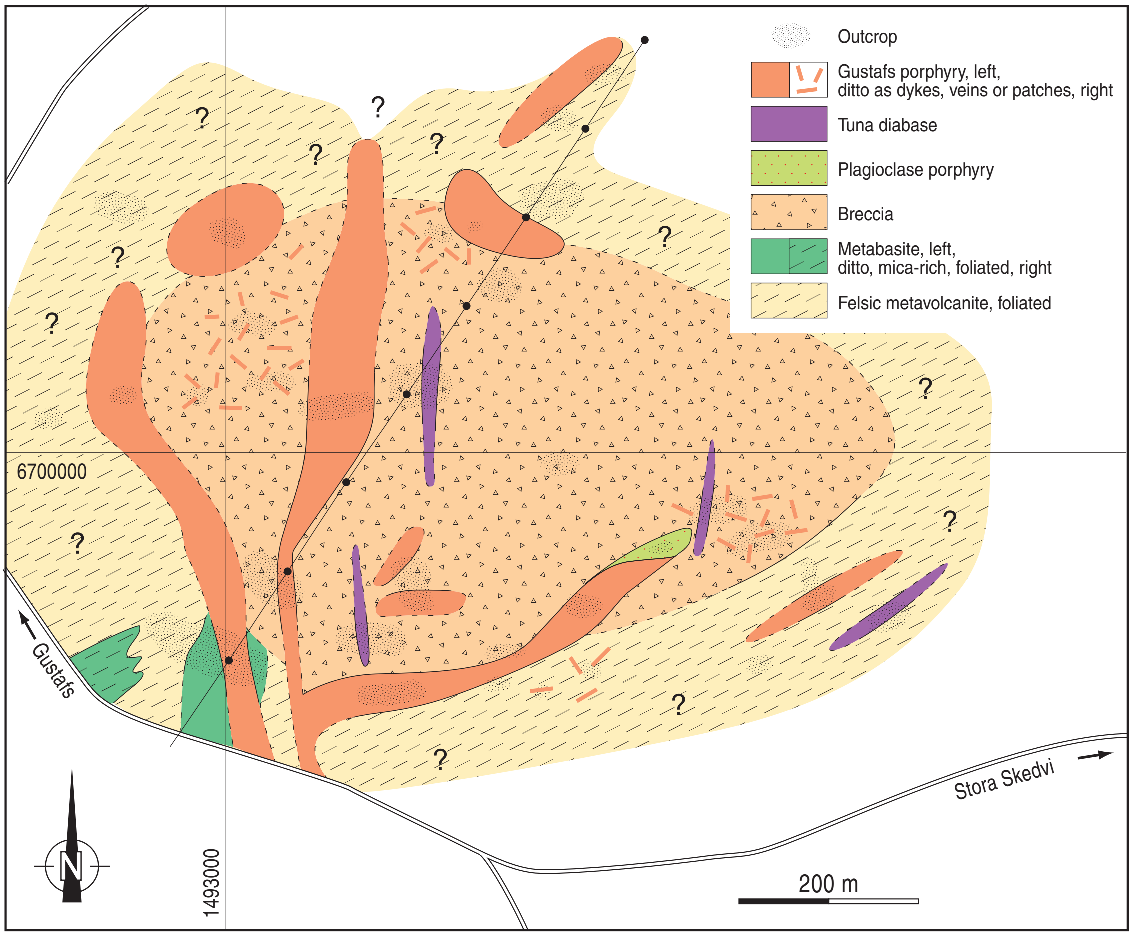

Fig. 9. Map of the Pellesberget breccia.

be good candidates for an impact interpretation. Especially as the most commonly used positive evidence for impacts, such as shock lamellae, diaplectic glasses or shatter cones, is so rare or so easily destroyed that its absence from the localities investigated should not in itself be discouraging. However, impact breccias mostly seem to have a matrix (French 1998) or at least to have highly variable grain sizes, in which "small fragments greatly outnumber large ones" (Melosh 1989). Furthermore, the clasts should consist of country rocks which may or may not show shock effects. Clearly, neither of these requirements is met at Pellesberget or Bjursås. Moreover, the field relationships between the Pellesberget breccia and the Gustafs porphyry suggest that the breccia emplacement was so slow that the porphyry could form both clasts and intrusive bodies within it. The emplacement was thus not as instantaneous as is typical of impact breccias. In the absence of positive evidence therefore, the impact alternative is discarded.

Crackle breccias and collapse breccias (e.g. Norman & Sawkins 1985, Laznicka 1988, Baker & Andrew 1991) form through the foundering of bedrock into voids created, for instance, by magma escape, hydrothermal dissolution etc. As they are mostly reported to be poor in matrix, they appear somewhat similar to the occurrences studied here. However, they rarely seem to be as completely devoid of matrix as the Pellesberget and Bjursås breccias. Furthermore, in many places they are mineralized or hydrothermally altered, which has not been commonly observed in the Swedish occurrences. As the clasts of crackle and collapse breccias are exclusively derived from the local country rock, they differ fundamentally from the breccias studied here, which only very rarely contain clasts of country rock.

All interpretations presuming that the clasts were derived from the country rocks will actually share one fundamental difficulty, i.e. that, since country rock-derived clasts must have been essentially rigid when emplaced, it is extremely difficult to imagine how they could be fitted together into the three-dimensional jigsaw puzzle that constitutes the breccias without any infilling of matrix. The recorded lithologic differences between clasts and country rocks mentioned above may therefore offer a solution.

Volcanic autobreccias – formed by autoclastic fragmentation of lava flows, domes, or intrusions through dif-

Fig. 10. Country rock of the Pellesberget breccia. Garnet porphyroblastic, biotite-foliated, granoblastic schist. Microphotograph, single nicol. Southern hillside of Pellesberget (6699764/1493265). Scale bar = 1 mm.

Fig. 11 The Pellesberget breccia.
a) Outcrop along power line, 200 m north-east of the road (6699889/1493058).

Fig. 11b. Outcrop along power line, 600 m north-east of the road (6700188/1493276).

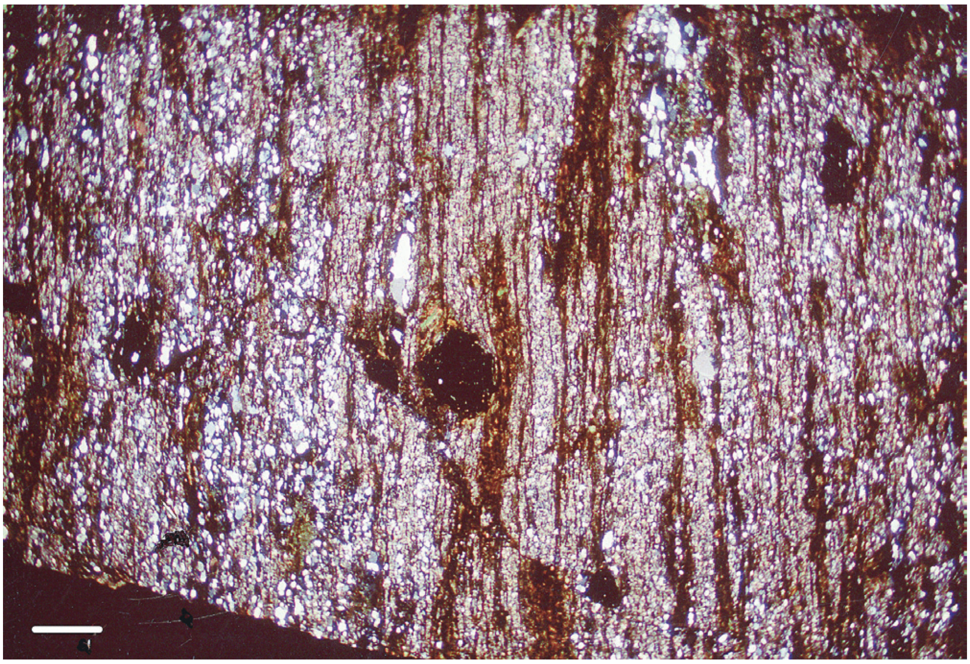

Fig. 12 Clast in the Pellesberget breccia consisting of garnet porphyroblastic biotite schist, probably derived from country rock. Microphotograph, double nicols. Outcrop along power line, 190 m north-east of the road (6699860/1493059). Scale bar = 1 mm.

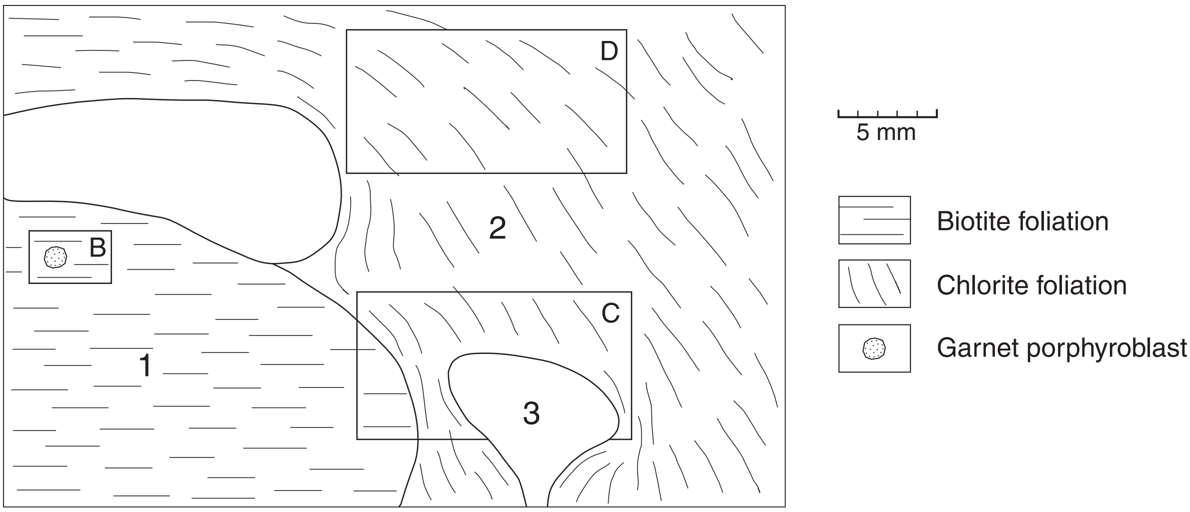

Fig. 13 The Pellesberget breccia. Differences in metamorphic alteration and post-emplacement competence between different clasts. Thin section from sample from local boulder, 200 m north of the crest of Pellesberget (6699970/1493360).

a) Overview of the thin section.

Area 1: Penetratively biotite-foliated, garnet porphyroblastic country rock clast, shown in Fig. 13b.

Area 2: Plastically deformed clast or intrusive matrix consisting of a chlorite-foliated, granoblastic rock with relictic quartz and plagioclase phenocrysts. Shown in Figs. 13c and d.

Area 3: Clast of isotropic Gustafs porphyry, visible in Fig. 13c.

B, C and D shows location of Figs. 13b, c, and d, respectively.

Fig. 13b. Detail of presumed country rock clast in area 1. Single nicol. Scale bar = 1 mm.

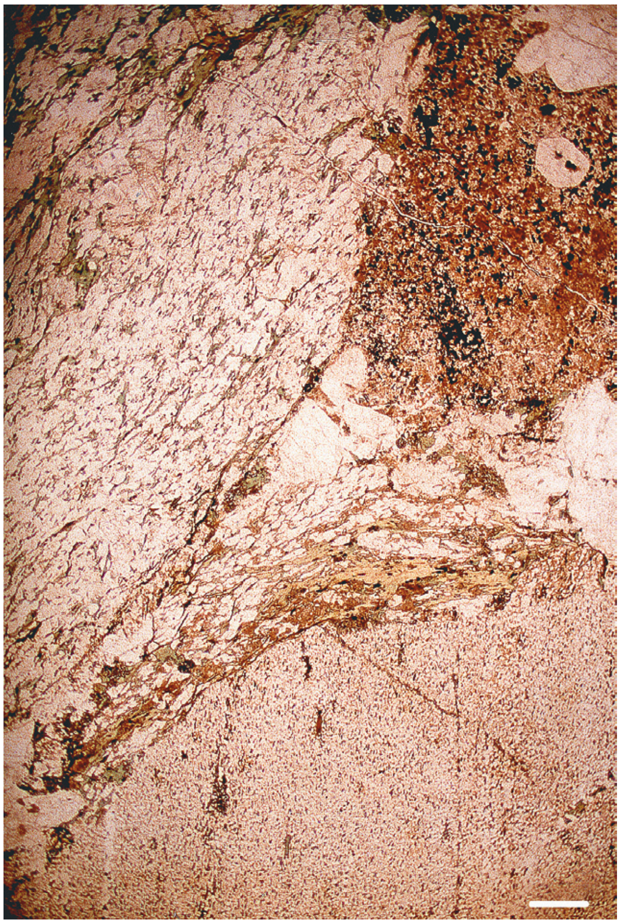

Fig. 13c. Detail of area 2 showing how the chlorite foliation moulds itself along the borders of the country rock clast. The brownish area is the Gustafs porphyry clast of area 3. Single nicol. Scale bar = 1 mm.

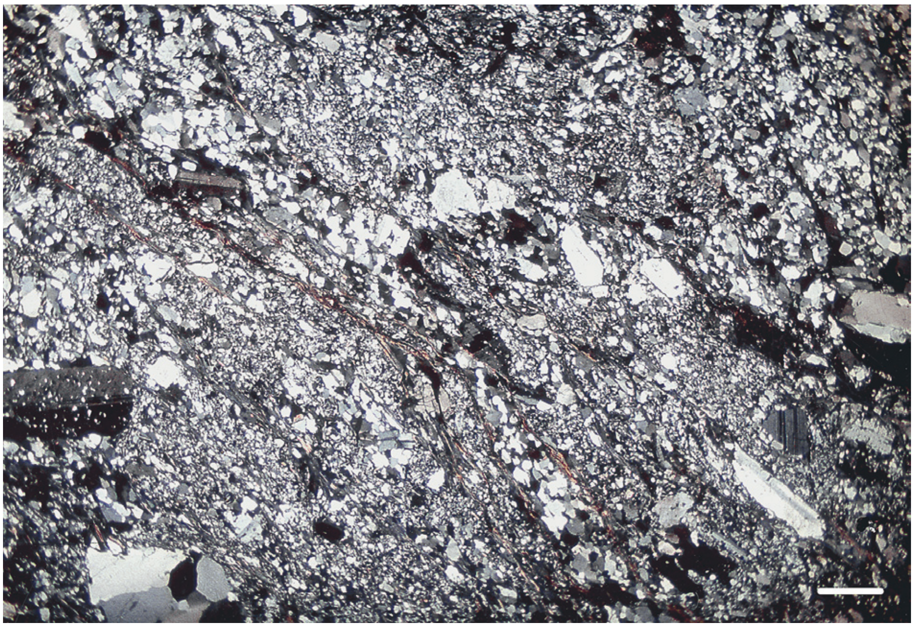

Fig. 13d. Detail of area 2. Notice relict phenocrysts of quartz and plagioclase. Scale bar = 1 mm.

Fig. 14. Pellesberget breccia intruded by Gustafs porphyry (red), which forms a local, void-filling matrix engulfing pre-existing, grey, presumably flow-foliated clasts. Scale in cm. 100 m west of the power line, 450 m north-east of the road (6700193/1493166).

Fig. 15. Clast of Gustafs porphyry in Pellesberget breccia. Notice tendency of adjoining clasts to adapt their foliations to the outlines of the porphyry clast. Outcrop under the power line, 200 m north-east of the road (6699887/1493017).

ferential movements of their more or less viscous parts – must by definition derive their clasts from the lava or intrusion itself. Lithologic differences between clasts and country rocks should therefore be normal for such rocks. Furthermore, they show many of the features described above. McPhie et al. (1993) describe volcanic autobreccias as "monomict, clast supported, matrix-poor, poorly sorted", and the similarity between their photographs (plate 10), Laznicka's (1988, Figs. 11–27) photographs, and the Bjurså and Pellesberget breccias is striking. Moreover, both the suggested flow foliation in the breccias studied here and the obvious competence differences of clasts even after emplacement in the breccias are easily reconciled with an autobreccia origin. The lack of a distinct metamorphic overprint on the clasts shows that their fabric formed after the orogenic culmination, which suggests some late, possibly magmatic event. As the Gustafs porphyry both intruded into the Pellesberget breccia and formed clasts within it, this breccia must have been emplaced approximately when the Gustafs porphyry intruded. It therefore seems likely that the suggested magmatic event occurred at about the same time.

Naturally, the Gustafs porphyry and the Bjurså plagioclase porphyry are the most likely candidates for the intrusive/coherent phases that created the autobreccias. Such a relationship is in fact demonstrated for the Gustafs porphyry in relation to the clasts thereof in the Pellesberget breccia (Fig. 16). However, for other clasts, no such affinity with the porphyries can be demonstrated, either lithologically (see above) or chemically (Table 1). With the exception of the rare Gustafs porphyry clasts, the porphyries were apparently not the coherent phases responsible for the autobrecciation. The autobreccia interpretation therefore still lacks an indication of a related coherent phase before it can be considered complete.

Fig. 16 Gustafs porphyry autobreccia.
a) Clasts of flow-banded Gustafs porphyry (below 50 öre coin) engulfed in matrix of the same material (below 10 p. coin). Local boulder under the power line, 190 m north-east of the road (6699884/1493006).

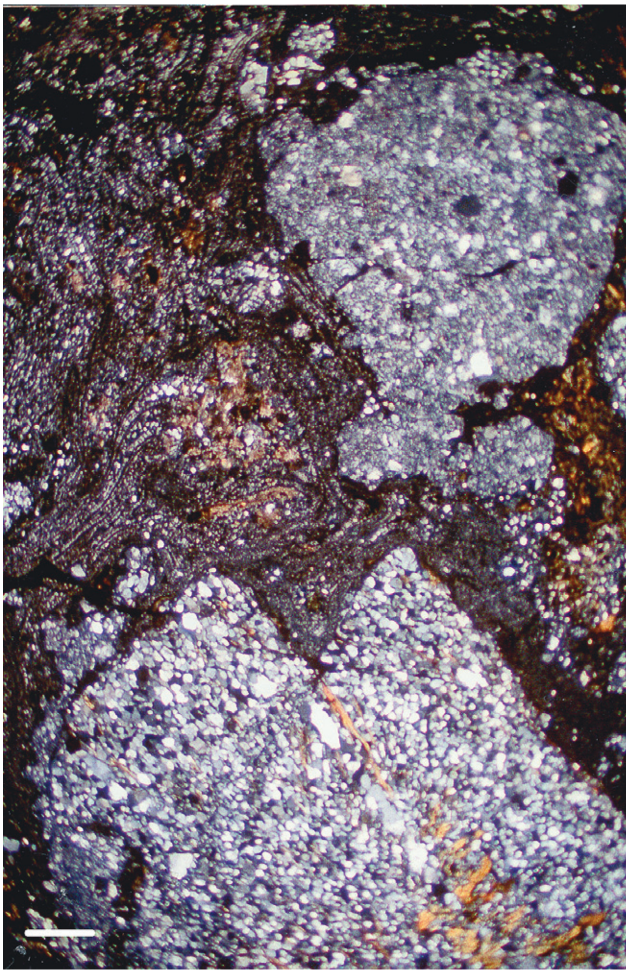

Fig. 16b. Clasts of Gustafs porphyry in flow-banded matrix according to Fig. 16a. Microphotograph, double nicols. Outcrop under the power line, 190 m north-east of the road (6699886/1493007). Scale bar = 1 mm.

CONCLUSIONS

As the Gustafs porphyry was able to both intrude and form clasts in the Pellesberget breccia, this breccia must have been emplaced coevally with the porphyry, i.e. at 1474±4 Ma (Lundström et al. 2001). Furthermore, the clasts of Gustafs porphyry and its associated autobreccia show that the porphyry must have been extrusive. For the Bjursås breccia, the situation is less clear, partly because the field relationships of the plagioclase porphyry are poorly known and partly because its dating produced ambiguous results. A poorly defined age of c. 1.79 Ga (Lundström et al. 2002) indicates that the Bjursås breccia may have been emplaced earlier, i.e. that it is significantly older than the Pellesberget breccia.

As the clasts of the Pellesberget breccia were apparently still ductile after deposition, it is suggested that they were formed and fragmented immediately before emplacement into the breccia.

Although the autobreccia hypothesis is incomplete, it is still favoured because it is the interpretation that is most compatible with the features observed.

The autobreccia interpretation suggested here implies a volcanic episode post-dating the Svecokarelian orogeny.

ACKNOWLEDGEMENTS

This study was financed by the Geological Survey of Sweden, whose support is gratefully acknowledged. Thanks are due to Dr Gregg Morrison for instructive e-mail discussions about the Kidston and other breccias, and to Dr D. Rogers, Canada, for information about the Tribag breccias. The authors are also much indebted to Tommy Pedersen for introducing us to the exposures at Bjursås.

TABLE 1. Chemical analyses of intrusions and breccia clasts.

Coord. N–S	6733238	6733226	6699836	6699970
Coord. E–W	1482316	1482267	1493060	1493360
Rock spec.	Plagioclase porphyry	Clast in breccia	Gustafs porphyry	Clast in breccia
Place	Bjursås	Bjursås	Pellesberget	Pellesberget
Sample	OIL 980094D	OIL 980093A	PB2C	PB17
SiO_2 wt-%	61.5	76.3	76.5	69.3
TiO_2	0.416	0.15	0.117	0.436
Al_2O_3	17.8	11.9	11.2	14.1
Fe_2O_3	5.17	2.49	2.41	4.81
MnO	0.107712	0.0223584	0.0376176	0.180336
MgO	1.73	1.53	0.157	2.62
CaO	1.21	0.142	0.134	0.707
Na_2O	3.65	1.71	3.36	6.07
K_2O	4.29	4.32	4.62	0.142
P_2O_5	0.331	0.0379	0.0270	0.126
Sum:	96.2	98.6	98.6	98.5
LOI	3.2	1.6	0.7	1.4
Ba ppm	950	1280	72.5	18.2
Be	1.03	0.783	4.99	<0.604
Co	<5.73	<6.08	66.7	13
Cr	16.7	13.6	<11.9	25.5
Cu	<5.73	8.65	37.8	7.91
Ga	40.1	30.2	31.5	22.7
Hf	6.88	5.51	46.2	6.81
Mo	<2.29	3.14	<2.38	3.29
Nb	11.8	11.9	112	13.2
Ni	<11.5	<12.2	<11.9	13.6
Rb	125	101	312	9.42
Sc	6.97	5.9	2.04	12.5
Sn	6.91	8.99	38.0	7.83
Sr	475	55.1	8.92	70.1
Ta	1.52	2.29	11.4	1.94
Th	12.8	9.62	47.7	10
U	6.54	4.18	24.6	4.24
V	50	<2.43	<2.38	33.8
W	2.37	5.46	598	4.87
Y	20.2	18.7	139	18.5
Zn	89.6	34.9	134	150
Zr	176	154	1210	190
La	32.5	20.7	53.9	13.7
Ce	58.3	31.7	132	24.3
Pr	10.4	6.78	14.0	6.12
Nd	39	20.5	60.7	17.2
Sm	8.41	4.75	15.9	5.81
Eu	1.98	1.32	0.363	1.58
Gd	7.31	3.98	18.4	5.19
Tb	1.01	0.754	3.46	0.857
Dy	5.83	3.93	26.5	5
Ho	1.19	1.11	5.91	1.13
Er	3.75	3	15.3	3.92
Tm	0.791	1.01	2.65	0.853
Yb	4.49	4.21	15.8	4.98
Lu	0.722	0.698	2.21	0.793

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