A late- to post-Caledonian hydrothermal pebble breccia from the basal gneiss region of Nord-Trøndelag, Central Norway

DAVID ROBERTS

Roberts, D.: A late- to post-Caledonian hydrothermal pebble breccia from the basal gneiss region of Nord-Trøndelag, Central Norway. *Norsk Geologisk Tidsskrift*, Vol. 66, pp. 235–241. Oslo 1986. ISSN 0029-196X.

A composite, near-vertical, hydrothermal breccia body penetrating Precambrian granitic gneiss near Skrøyvstad, Nord-Trøndelag, consists of 1.5–2 m wide outer zones of fractured and negligibly disrupted, stilbite-veined country rock, and a 0.5 m-thick central zone of subrounded to rounded, abraded fragments or 'pebbles' encrusted with radiate stilbite. The two zones are representative of shatter breccia and pebble breccia, respectively. The central pebbly zone is cemented by stilbite and also by later, low-density aphanitic quartz, possibly a type of chalcedony or in part devitrified opal. The in situ shattering of the gneiss is thought to be due to hydraulic fracturing and rupture following the build-up of pressure from ascending, trapped hydrothermal solutions. The resulting failure and accompanying decompression led to propagation of the main fissure and the violent ingress of ascending hydrothermal fluids. In this highly mobile, fluidised conduit system the rock fragments were abraded and milled, and subsequently coated with zeolite nucleating from the cooling solutions. Comparable composite breccia bodies described from many parts of the American cordilleras and from SW England occur above the apical portions of hydrous granitoid plutons and some carry rich mineralisations. Although the age of the Skrøyvstad breccia is unknown, arguments are presented for a Devonian or younger emplacement. There are no upper constraints on the age and it may even be as late as Tertiary if comparisons with breccia dykes occurring in SE Greenland are taken into account. The breccia is believed to overlie a hidden granite body. Indications of the presence of such a subsurface pluton just south of Skrøyvstad are found in gravimetric data.

D. Roberts, Norges geologiske undersøkelse, Postboks 3006, N-7001 Trondheim, Norway.

The term 'breccia' is a particularly wide-ranging and versatile rock name, applied as it is to products of sedimentary, volcanic and plutonic processes as well as those of the brittle regime of faulting. The present contribution serves to describe the occurrence of an unusual hydrothermal 'pebble' breccia from the Caledonides of Central Norway. This is a type of breccia which, to the writer's knowledge, has hitherto not been reported from Scandinavia, although irregular breccia masses showing some of the features described below are known from the Oslo Region (Olerud & Sandstad 1983, Olerud et al. 1984) and from the island of Frøya west of Trondheimsfjord (Torske 1983).

Location and geological setting

The breccia in question is exposed in a road-cut along a comparatively new unsurfaced road linking the communities of Høylandet and Salsbruket in the county of Nord-Trøndelag. It is located (Fig. 1) in the southeastern part of the 1:50,000 topographical map-sheet Foldereid near the northeastern end of the lake Skrøyvstadvatnet, 600 m south of Skrøyvstad, at grid-reference 596 857 UTM zone 32; the road is not marked on the topographic map.

Based on an air-photo study and reconnaissance mapping in 1982, it is clear that this part of the Central Norwegian basal gneiss region consists mainly of polydeformed heterogeneous 'basement' gneisses with an allochthonous 'cover' sequence of amphibolite-facies schists, gneisses and amphibolites, locally with marbles (cf. Birkeland 1958). This is interrupted by domal structures of granitoid orthogneisses, and megaboudins of metagranites, metagabbros and sporadic ultramafic rocks. The domes and boudins occur on all scales and only the larger units are marked on the 1:1 million scale geological map (Sigmond et al. 1984). The breccia at Skrøyvstad occurs in the central part of one of the larger domal struc-

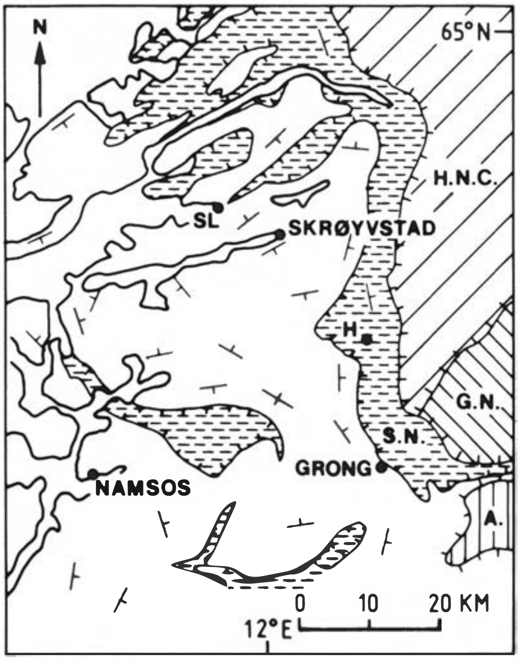

Fig. 1. Simplified map showing the principal tectonostratigraphic units in the region (thrust boundaries shown by ticked lines), and the location of Skrøyvstad. H – Høylandet: SL – Salsbruket: H. N. C. – Helgeland Nappe Complex: G. N. – Gjersvik Nappe: S. N. – Skjøtingen Nappe equivalent (=Seve Nappe): A. – Autochthonous Precambrian basement. The unornamented area is that of the parautochtonous/allochthonous Precambrian 'basement gneisses'.

tures in the region, in a Caledonian-foliated gneissic granite, the age of which is unknown. Although the area has not yet been mapped in any detail, a preliminary regional study encompassing the district shown in Fig. 1 has been carried out by Birkeland (1958).

The breccia

The country rock hosting the breccia is a pink, medium- to coarse-grained, homogeneous granitic gneiss with a foliation striking at c. 070° and dipping c. 30° to the south-southeast. The breccia is well exposed in the c. 3 m high road-cut, the central 'pebble zone' trending c. N-S with a dip of 80–85° to the west.

A feature of this undeformed breccia body is its composite nature (Fig. 2). An *outer zone* 1.5–2 m wide on either side of the central 'open' fissure consists of ruptured or shattered gneissic granite, the angular fragments separated by 1–3 mm thick, criss-crossing zeolite-filled cracks. It is significant that the individual fragments are not displaced or rotated in relation to each other, at least not in the outermost parts where there is a gradual transition into undisturbed country rock. Moving inwards within the 'outer zone', zeolite-filled cracks or zeolite veins thicken and increase in number; the fragments of gneiss are consequently smaller and at the same time show some evidence of progressive displacement or rotation closer to the central zone of the breccia.

The *central zone* of the breccia body, in general, has comparatively well-defined boundaries with the fractured and fragmental outer zone, although in places the boundary appears to be somewhat diffuse. The characteristic feature of this porous, 45–60 cm wide central zone is its pebbly appearance (Fig. 3). The fragments, mostly in the size range 1–10 cm but in one case up to 20 cm across, are subangular to subrounded and in some instances fairly well rounded, the

Fig. 2. The near-vertical hydrothermal breccia in the north-facing road-cut near Skrøyvstad. The central pebbly zone is clearly seen, outside of which is the fractured, zeolite-veined shatter breccia. The white patch near the centre of the photograph consists of aphanitic quartz.

Fig. 3. Close-up of part of the central pebble breccia showing the degree of rounding of the clasts, and the apparent clast-supported nature of the body.

smaller fragments generally showing a greater degree of rounding (Fig. 4). Another important feature is that the 'pebbles', without exception, are coated with buff to reddish-buff zeolite. Sliced and polished fragments, and thin-sections

Fig. 4. Hand-specimen taken from part of the central pebbly zone of the breccia, showing the rounded nature of the abraded fragments and their zeolite crust. Scale in mm and cm.

Fig. 5. Photograph of a sliced 'pebble' of abraded granite gneiss showing the radiate stilbite encrustation. The very outermost 0.5–1 mm rind is composed of a creamy white aggregate of microcrystalline quartz and some stilbite. Bar = 1 cm.

of the fragments, show the crust of zeolite to be 4–5 mm thick and the mineral growth to be disposed radially, i.e. normal to the rounded surface of the clast (Fig. 5). Both optical and X-ray investigations have shown that the mineral is stilbite.

With regard to the composition of the fragments in this central zone, a good 90% of those that have been observed in a broken state in outcrop or in sliced hand-specimen are of the same type of granitic gneiss as the country rock. However, a few of the smaller, stilbite-coated clasts show a variety of rock compositions: granodioritic gneiss, microgranite-porphyry, biotite schist and amphibolite. These rock-types do not crop out in the vicinity of the breccia and must therefore have been transported from some unknown depth to their present position in the breccia conduit.

The central pebbly zone of the breccia appears on first sight to be clast-supported. There is comparatively little in the way of finely comminuted rock material, and the zeolite mineralisation in-

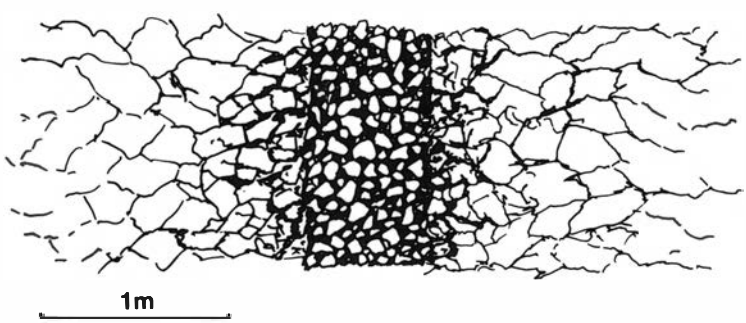

Fig. 6. Diagrammatic sketch section through the Skrøyvstad breccia showing the central pebble zone and the shatter zones on either side, with fracturing diminishing gradually outwards.

deed seems to have been ubiquitous, pervading the abundant open space between the abraded fragments of gneiss. There is a possibility, however, that the breccia may have been matrix-supported, and the finer material elutriated before precipitation of zeolite. In places within the central zone, the breccia has also been cemented by irregular patches and segregations of a white, amorphous, compact material (Fig. 2) with a barely perceptible spherulitic texture on the 1–3 mm scale. This is clearly later than the zeolitisation, as it also occurs as a 0.5–1 mm rind around the zeolite-encrusted clasts. Although an X-ray powder pattern on this white mass corresponded to that of quartz, the average density from 3 samples is 2.48; and the wt% H_2O from two samples 0.835. While a more detailed mineralogical study on this material is necessary, it is not unreasonable to conclude that it consists of microcrystalline quartz, perhaps chalcedony; the low S.G. may, however, denote that part of the material could be devitrified opal (J. Hysingjord, pers. comm. 1983).

Mode of formation of the breccia body

From the field relationships in the restricted area of outcrop it is clear that the breccia body as a whole, from initial fragmentation to ultimate cementation, developed in at least three main stages or pulses during what was in all probability one largely continuous brecciation event. Any mechanism postulated to explain the formation and emplacement of the breccia has to take into account the transition from a central zone of mobilised pebble breccia through a zone of fractured and negligibly disrupted stilbite-veined wall-rock into the apparently undisturbed metagranite (Fig. 6) which forms the country rock.

The earliest stage of development is represented by the outer zone of shattering and veining, the features of which are characteristic of hydraulic fracturing (Phillips 1972, 1986). Here, it is assumed that a near-vertical fissure was already present or developing, within which ascending hydrothermal solutions accumulated. This fracture was not necessarily a fault – indeed there is no direct evidence of faulting here – but perhaps just a dilated joint. A gradual build-up of pressure exerted by the hydrothermal fluids would cause permeation into adjacent zones, eventually resulting in a sudden release of elastic strain energy and extension of the main fracture (Phillips 1972). The abrupt reversal of this pressure gradient, reducing the effective stress, would have led to a gentle bursting apart of the rock in the flanking zone and thus produced the shattering and rupture and allowed easy access for the mineralising fluids. Breccias or breccia bodies of this type are known under a variety of names, such as *crackle breccia, shatter breccia, shatter pipes* and *rupture breccia,* and are common in association with, and above, granitoid intrusions in the porphyry-type, ore-mineralised systems of western North and South America (McKinstry 1955, Bryner 1961, Kents 1964, Sillitoe 1985), as well as above the Variscan batholiths of Southwest England (Halls et al. 1977, Goode & Taylor 1980, Allman-Ward et al. 1982).

As a consequence of the sudden decompression and upward propagation of the main fracture, hydrothermal fluids would have entered the widening, central brecciated zone at a high velocity. During this stage of development, in a highly fluidised (Reynolds 1954) system, fragments would have been torn away from the walls of the main fracture and carried upwards in the 'pipe', tossed around continually and progressively abraded and rounded; and in time coated by the zeolite cement nucleating from the cooling Na-Ca-rich solutions, a deposit which also filled the inter-clast voids and effectively sealed the system. Breccia bodies of this type, which have a distinctly conglomeratic appearance and for a long time were misinterpreted as water-worn shoreline gravel infillings of fissures (e.g. Foster 1866, Crane 1925), have been ascribed a variety of descriptive names – *breccia pipes, breccia chimneys, milled breccia, rubble breccia, pebble breccia* and *pebble dykes*. Nowadays, there is general consensus that these pebble breccias are associated with the violent release of gaseous volatiles evolved from a crystallising granitoid pluton during the latest stages of consolidation, and which migrated at a velocity great enough to maintain the fluidised state along tectonically controlled or thermal-contraction fissures. Fluidisation (Reynolds 1954) is an effective process leading to the development of breccia bodies of this type (Norton & Cathles 1973), and also has experimental backing (McCallum 1985). An area of uncertainty relates to the precise mechanism which triggered the process of fluidisation, e.g. throttled escape of a hydrous fluid from a magma, or a channelled phreatomagmatic explosive event (e.g. Wolfe 1980). An overview of the mechanisms of brecciation and likely processes involved has recently been presented by Sillitoe (1985).

The final stage in the development and cementation of the Skrøyvstad breccia involved the entry of more siliceous fluids which led to the irregular precipitation of the white, spherulite-textured, aphanitic quartz or perhaps, in part, devitrified opal. This also occurs as a thin outer rind around the clasts. Such a sequence, from initially pervasive solutions to later more silica-rich fluids, is commonplace in pebble breccia dykes (Kents 1964). The white siliceous mass is similar in many respects to the 'quartz-aphanites' described from breccia dykes from the western Americas, a material which 'represents siliceous late magmatic liquor(sic) strained out from the slowly cooling batholith after the exhaustion of its supply of hydrothermal solutions' (Kents 1964, p. 1560).

Discussion

The principal features of the Skrøyvstad breccia are its composite nature, the roundness of the pebbly clasts in the central conduit, and the pervasive zeolite cement. The brecciation also occurred at a comparatively late stage in the geological history of the area.

Implicit in the foregoing account of the breccia and its likely genesis is the inference that the structure probably developed above a crystallising granitoid pluton. The extent of the fragment rounding in a highly mobile channelway, the abundance of zeolite and later siliceous mineralisations deriving from hydrothermal solutions, and the striking similarity of the body to pebble breccias described from other parts of the world, all appear to point to the same conclusion. Another possibility to be considered as an origin for the active fluids is that of channelled dewatering in the late stages of a regional metamorphic/tectonic event. Since such breccias have not been reported previously from the metamorphic Caledonides, then this mechanism is not really regarded as a viable alternative. Yet another possible association for the brecciation is with the Late Palaeozoic to Mesozoic rifting known from various parts of western Norway and expressed in the form of scattered alkaline-basic lamprophyric to peralkaline syenitic dykes (Råheim 1974, Færseth et al. 1976, Furnes et al. 1982). However, the source of the hydrothermal solutions at Skrøyvstad is considered as more likely to have been the apical zone of a crystallising stock at an advanced stage of consolidation from a hydrous acidic magma.

The plate-marginal setting of the American cordilleran pebble breccias does not appear to apply in the case of the Skrøyvstad breccia, yet the plutonic connection seems incontrovertible. An alternative setting considered here for the production of granitic magma is that of a continental crust thickened as a result of continent-collisional underthrusting and orogenic contraction (cf. Roberts 1980). This is a situation which obtained in the Norwegian Caledonides during the mid-Silurian to earliest Devonian Scandian orogenic phase, which resulted from collision between the continents Baltica and Laurentia (Roberts & Gee 1985). Although the age of the breccia is not known, it is undoubtedly a late structure; late- to post-Caledonian. Its maximum age is thus probably Early Devonian.

To the east of the Skrøyvstadvatnet area the basement gneisses are tectonically overlain by Skjøtingen Nappe (= Seve Nappe) equivalents and by the Helgeland Nappe Complex (HNC) (Roberts et al. 1983) (Fig. 1). In this region the HNC is dominated by granodioritic and granitic rocks of the Bindal Massif, some of which have been dated to the time of the Silurian-Devonian transition (Priem et al. 1975). The sole thrust to the HNC is characterised by a complex mylonite zone, assumed to be of earliest Devonian age (Roberts et al. 1983). As this thrust contact is traced northwards it is transected by the Heilhornet Pluton (Nordgulen 1984), as yet undated but undoubtedly a very late Caledonian, or younger, body. It may thus be speculated that a granitoid pluton comparable in age to that of the Heilhornet massif may well occur at some depth beneath the axial zone of the domal structure at Skrøyvstad. A Bouguer gravity anomaly map (NGO 1978, NGU 1985) does, in fact, depict a substantial negative anomaly centred some 5–8 km south of Skrøyvstadvatnet and ascribed to the presence of a granitoid mass at some undetermined depth beneath this area (O. Olesen, pers. comm. 1985).

An alternative, but less likely possibility for the age of this hidden granite body and the Skrøyvstad breccia relates to the fact that Mo-mineralised alkali granites and syenites, hydrothermal veining and even local breccia dykes occur in SE Greenland (Bearth 1959, Geyti & Thomassen 1984) in a position which was of comparable palaeolatitude to that of the Nord-Trøndelag region on accepted pre-drift (pre-North Atlantic opening) reconstructions. These granitoid plutons are of Early Tertiary age. A suggestion concerning a possible Tertiary age for the breccia on Frøya, and for associated regional zeolite veining, has been made by Torske (1983). Although it is interesting to speculate on a Tertiary age for the Skrøyvstad breccia, it should be noted that the SE Greenland granitoids occur in association with rifting, a situation which does not appear to apply in the case described here.

Until the Skrøyvstad district is mapped in some detail, the extent of hydrothermal activity related to the inferred subsurface granitoid body will not be known. The Skrøyvstad breccia itself has not been traced outside the proximity of the road outcrop because of poor exposure, and no linear feature directly related to the brecciation has been detected on aerial photographs. Its original lateral and vertical dimensions are thus unknown. Whether or not the breccia system vented to the contemporary surface is an open question. From areas in Mexico and Arizona, Perry (1961) has reported that most subsurface pebble breccia dykes there thin out upwards and terminate as quartz veins, many of which are richly ore-mineralised. Valuable information on potential hidden mineralisations may thus be gained from a study of the distribution and ore mineralogy of quartz veins in the district south of Skrøyvstadvatnet.

Conclusions

The Skrøyvstad breccia body is a near-vertical composite structure comprising an outer zone of haphazardly fractured granitic gneiss country rock with zeolite-filled fractures, and an inner central zone of subrounded to rounded pebbly clasts encrusted with zeolite. The breccia carries no evident sign of tectonic deformation. The two zones are characteristic of shatter breccias and pebble breccias, respectively, as described from many parts of the cordilleras of western North and South America, and from Cornwall, England. Such breccia bodies, which are commonly ore-mineralised, occur above granitoid plutons.

The shatter breccia represents the earliest stage of brecciation and is considered to be due to hydraulic fracturing and rupture following the build-up of pressure from ascending, trapped hydrothermal solutions. Decompression resulting from this in situ fracturing led to a propagation of the main fissure and rapid, violent ingress of the hydrothermal fluids. Fragments within this highly fluidised central conduit system were torn from the walls and carried upwards from variable, unknown depths, and were abraded and milled and eventually coated with a zeolite crust. Zeolite also filled the inter-clast voids. Incursion of highly siliceous solutions and deposition of aphanitic quartz represents the last stage of development and sealing of the body.

Although the age of the brecciation is not known, it is argued that a late- to post-Caledonian (i.e. post-Scandian) age is most likely. The granitoid pluton which is assumed to have provided the source for the ascending hydrothermal solutions may be of comparable age to the nearby Heilhornet pluton which cuts the mylonites at the base of the Helgeland Nappe Complex. Gravity data show a substantial negative anomaly centred just south of Skrøyvstadvatnet. Alternative possibilities considered for the age of the brecciation are Late Palaeozoic-Mesozoic and Early Tertiary. Granites of Tertiary age, with hydrothermal veining and local breccia dykes, are known from Southeast Greenland related to rifting of the North Atlantic. These areas are considered to have lain at approximately the same palaeolatitude as Nord-Trøndelag on pre-drift continent configurations. The Greenland granitoids, however, occur in a rifting situation, and there is no real evidence to date favouring such a palaeotectonic setting in the case of the Nord-Trøndelag region.

Acknowledgements. – The writer is grateful to Chris Halls, John Phillips and Frank Vokes for their helpful comments and criticism of the first draft of the manuscript. Arne Grønlie, Øystein Nordgulen and Odleiv Olesen are thanked for their discussions of parts of the manuscript, and Jens Hysingjord for assistance with X-ray and density investigations of minerals. The breccia was discovered during the course of reconnaissance excursions in July 1982 in the company of Fylkesgeolog Ole Sivert Hembre, whose help and logistic support are acknowledged with thanks.

Manuscript received May 1986.

References

Allman-Ward, P., Halls, C., Rankin, A. & Bristow, C. M. 1982: An intrusive hydrothermal breccia body at Wheal Remfry in the western part of the St. Austell granite pluton, Cornwall, England. *In* Evans, A. M. (ed.) *Metallization Associated with Acid Magmatism.* John Wiley & Sons, 1–28.

Bearth, P. 1959: On the alkali massif of the Werner Bjerge in East Greenland. *Meddr. Grønland 153,* 63 pp.

Birkeland, T. 1958: Geological and petrological investigations in northern Trøndelag. *Nor. Geol. Tidsskr. 38,* 327–420.

Bryner, L. 1961: Breccia and pebble columns associated with epigenetic ore deposits. *Econ. Geol. 56,* 488–508.

Crane, G. W. 1925: Notes on the geology of East Tintic. *Trans. Am. Inst. Min. Metall. Eng. Preprint 1491,* 6–7.

Foster, C. LeN. 1866: Notes on New Rosewarne mine. *Rep. Miners' Assoc. Cornwall and Devon 1,* 26–28.

Furnes, H., Mitchell, J. G., Robins, B., Ryan, P. D. & Skjerlie, F. J. 1982: Petrography and geochemistry of peralkaline, ultrapotassic syenite dykes of middle Permian age, Sunnfjord, West Norway. *Nor. Geol. Tidsskr. 62,* 147–159.

Færseth, R. B., Macintyre, R. M. & Naterstad, J. 1976: Mesozoic alkaline dykes in the Sunnhordland region, western Norway: ages, geochemistry and regional significance. *Lithos 9,* 331–345.

Geyti, A. & Thomassen, B. 1984: Molybdenum and precious metal mineralization at Flammefjeld, Southeast Greenland. *Econ. Geol. 79,* 1921–1929.

Goode, A. J. J. & Taylor, R. T. 1980: Intrusive and pneumatolytic breccias in south-west England. *Rep. Inst. Geol. Sci. 80/2,* 23 pp.

Halls, C., Rankin, A., Ferriday, I. L., Blain, C. F., Bristow, C. M. & Gronow, C. 1977: A tourmalinized hydrothermal intrusion breccia at Wheal Remfry in the western part of the St. Austell pluton, Cornwall. *Trans. Inst. Min. Metall. 86,* 163.

Kents, P. 1964: Special breccias associated with hydrothermal developments in the Andes. *Econ. Geol. 59,* 1551–1563.

McCallum, M. E. 1985: Experimental evidence for fluidization processes in breccia pipe formation. *Econ. Geol. 80,* 1523–1543.

McKinstry, H. E. 1955: Structure of hydrothermal ore deposits. *Econ. Geol. 50th. Anniv. vol.* 170–225.

Norges geografisk oppmåling 1978: Gravity anomaly map, Namsos, 1: 250,000 sheet.

Norges geologiske undersøkelse 1985: Bouguer gravity anomaly map, Namsos, 1: 250,000.

Nordgulen, Ø. 1984: *The geology and emplacement of the Kråkfjellet Pluton, Bindal, Central Norway.* Unpubl. Cand. Real. thesis, Univ. of Bergen, 438 pp.

Norton, D. L. & Cathles, L. M. 1973: Breccia pipes – products from exsolved vapor from magmas. *Econ. Geol. 68,* 540–546.

Olerud, S. & Sandstad, J. S. 1983: Geology of the Skrukkelia molybdenite deposit, northwestern margin of the Oslo Graben, Norway. *Nor. geol. unders. 387,* 1–20.

Olerud, S., Sandstad, J. S. & Ihlen, P. M. 1984: Molybdenite mineralization spatially associated with Permian granite porphyries and hydrothermal breccias in the Skrukkelia area, northwestern margin of the Oslo Graben, Norway. *Proc. VI IAGOD symp.* 403–407.

Perry, V. D. 1961: The significance of mineralized breccia pipes. *Min. Eng. 13,* 367–376.

Phillips, W. J. 1972: Hydraulic fracturing and mineralization. *J. Geol. Soc. Lond. 128,* 337–359.

Phillips, W. J. 1986: Hydraulic fracturing effects in the formation of mineral deposits. *Trans. Inst. Min. Metall. B95,* 17–24.

Priem, H. N. A., Boelrijk, N. A. I. M., Hebeda, E. H., Verdurmen, E. A. T. & Verschure, R. H. 1975: Isotopic dating of the Caledonian Bindal and Svenningsdal granite massifs, Norway. *Nor. geol. unders. 319,* 29–36.

Reynolds, D. L. 1954: Fluidisation as a geological process, and its bearing on the problem of intrusive granites. *Am. J. Sci. 252,* 577–614.

Roberts, D. 1980: Petrochemistry and palaeogeographic setting of the Ordovician volcanic rocks of Smøla, Central Norway. *Nor. geol. unders. 359,* 43–60.

Roberts, D. & Gee, D. G. 1985: An introduction to the structure of the Scandinavian Caledonides. *In* Gee, D. G. & Sturt, B. A. (eds.) *The Caledonide Orogen – Scandinavia and Related Areas.* John Wiley & Sons, 55–68.

Roberts, D., Nissen, A. L. & Reinsbakken, A. 1983: Progressive mylonitization along the western margin of the Bindal Massif: a preliminary note. *Nor. geol. unders. 389,* 27–36.

Råheim, A. 1974: A post-Caledonian syenite porphyry dyke in the western gneiss region, Tustna, Central Norway. *Nor. Geol. Tidsskr. 54,* 139–147.

Sigmond, E. M. O., Gustavson, M. & Roberts, D. 1984: Berggrunnskart over Norge – M 1:1 million. *Nor. geol. unders.*

Sillitoe, R. H. 1985: Ore-related breccias in volcanoplutonic arcs. *Econ. Geol. 80,* 1467–1514.

Torske, T. 1983: A fluidization breccia in granite at Skaget, Svellingen, Frøya. *Nor. geol. unders. 380,* 107–123.

Wolfe, J. A. 1980: Fluidization versus phreatomagmatic explosions in breccia pipes. *Econ. Geol. 75,* 1105–1111.