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Mantled feldspar from the Noring granite, Peninsular Malaysia: petrography, chemistry and petrogenesis

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Abstract: Mantle feldspar found in the Noring granite, have been investigated in terms of their petrography and geochemistry. Petrographically the mantle feldspar consists of whitish plagioclase rim which mantle the pinkish K-feldspar core. The K-feldspar core consists of a single crystal or several crystals usually showing simple twinning. Plagioclase rim is generally composed of numerous euhedral to subhedral plagioclases with size usually less than 1 mm. In places the plagioclase rim consists of a single crystal about 2 mm thick. Formation of the mantled feldspar can be explained in two stages, (1) magma mixing and (2) late stage replacement. The plagioclase rim probably precipitated from a different magma type to the Noring magma probably of andesitic composition. The K-feldspar that has crystallised in the Noring magma act as substrates for the growth of plagioclase, producing the mantled texture. The aggregates of individuals crystals that have floated together in the magma attached to the K-feldspar as in the synneusis model of Vance (1969). Once this nucleation takes place there is relatively the straight forward process of crystal growth yielding the mantled texture (Hibbard, 1981). Small irregular outline plagioclase inclusions occur in the K-feldspar core being most abundant near the contact with plagioclase rim suggesting that the K-feldspar core replacing and enclosing relicts of plagioclase rim at the very late stage.

INTRODUCTION

Since Sederholm's (1891) original description of rapakivi texture one century ago, much controversy has centered on the origin of mantled, or rapakivi feldspar. The texture (s.s) was originally introduced to the Proterozoic age worbogite of southern Finland (Sederholm 1891). Now the rapakivi texture has been used to described the mantling of K-feldspar by plagioclase in granitic rocks (Hibbard, 1981; Bussy, 1990; Nekvasil, 1991). The mantling of K-feldspar by plagioclase is rather unusual textures in granitic rocks because in most cases these feldspars occur side-by-side in non-mantling relationship.

The aim of this paper is to describe the petrographic features and chemistry of the mantled feldspars in the pink hornblende biotite granite from Pergau area, Kelantan. Possible outline of petrogenesis of the texture is discussed. Brief petrographic features of the mantle feldspar has been by given Azman (1998). In this paper the outer plagioclase will be referred to as plagioclase rim whereas the inner K-feldspar will be referred to as K-feldspar core. Plagioclase and K-feldspar that are not related to the mantle texture will be referred to as individual plagioclase and K-feldspar respectively.

The granite is part of the Noring pluton (Fig. 1) which has been mapped as the Belimbing facies (Cobbing and Mallick, 1987). The Noring pluton formed the Stong complex with other two granite plutons i.e. Kenerong microgranite and Berengkat tonalite. The complex has been dated as Cretaceous (Bignell and Snelling, 1977; Cobbing *et al.*, 1992; Singh *et al.*, 1984) and located close to the Central Belt (Fig. 1) of Peninsular Malaysia. It was emplaced into metasedimantary rocks that comprised sillimanite gneisses and calc silicate gneisses. Brief geology and petrology of the granites have been described by Cobbing *et al.* (1992) and Singh *et al.* (1984) and some of the engineering properties of the rocks by Raj and Ahmad Nazmi (1994).

GENERAL PETROGRAPHY AND GEOCHEMISTRY

General petrography

The rock is coarse grained with average grain size between 0.5 mm to 3 cm. It is made up of plagioclase, pinkish K-feldspar megacryst, quartz, hornblende, biotite, apatite, sphene, allanite, epidote and magnetite. Average modal composition plot in granodiorite field on a QAP diagram (Streckeisen, 1976). Summary of petrographic descriptions of the individual minerals is given in Table 1.

Plagioclase crystals are euhedral to subhedral and are generally 1 to 8 mm in size. It has a

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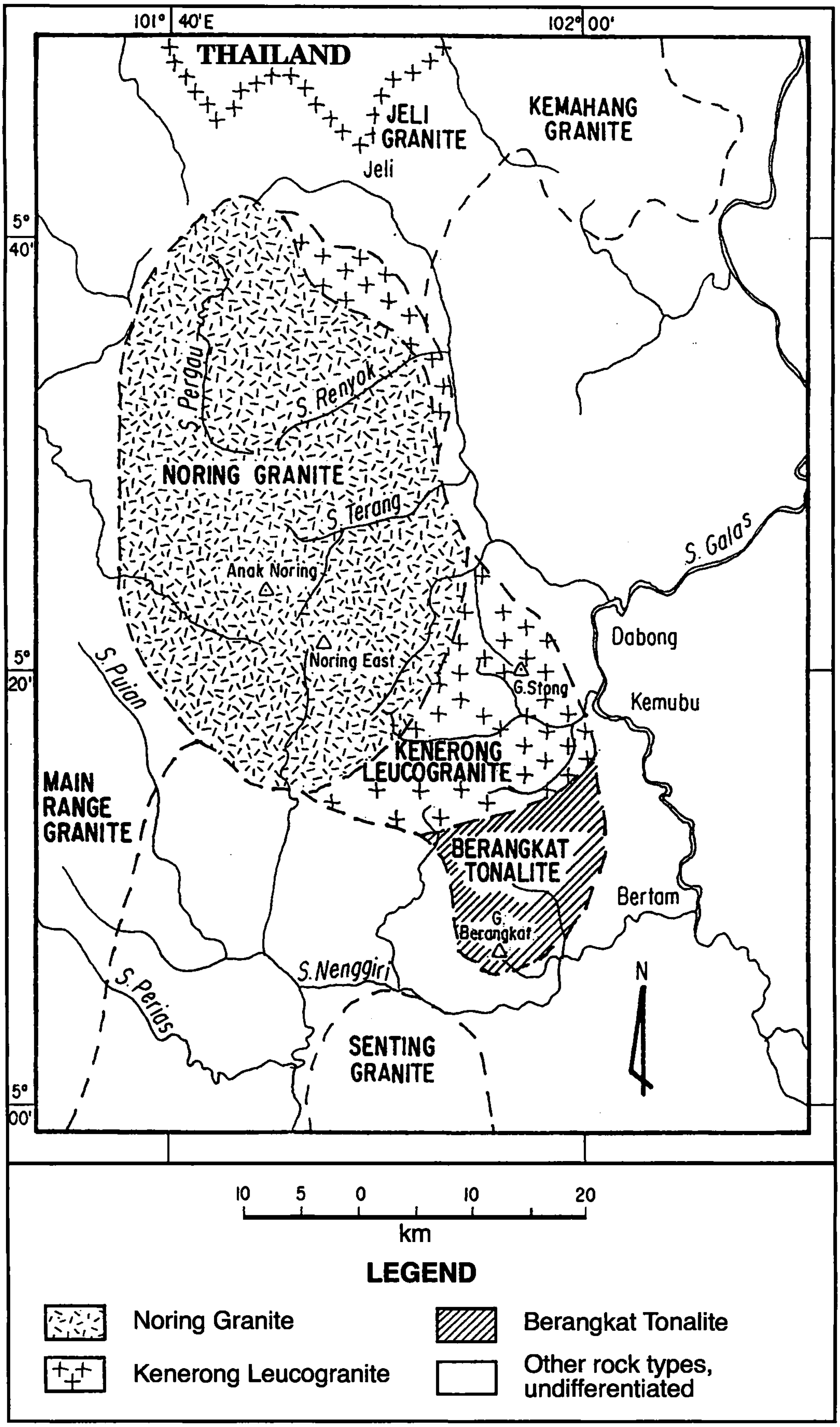

Figure 1. Map showing the location of Noring granite and Stong complexes.

Table 1. Summary of petrographic descriptions of the individual minerals in the Noring granite.

MINERAL	PETROGRAPHIC DESCRIPTIONS
Plagioclase	Euhedral to subhedral; 1 to 8 mm in size; compositional range between An_{28} to An_{50}; normal and oscillatory zoning; simple and polysynthetic twining.
K-feldspar	Up to 3 cm across often give the rock a distinctly porphyritic appearance; main types: perthitic orthoclase; mantled feldspar formed by mantling of plagioclase over orthoclase are common.
Quartz	Anhedral or occurs as subgrains; generally interstitial to all other minerals, especially plagioclase and orthoclase.
Hornblende	Euhedral to subhedral; 1 to 4 mm in size; simple twinning. Pleochroism is X = blue green, Y = brown green and Z = blue green; usually forms multi-granular aggregates with biotite, sphene, apatite and magnetite resulting in a clotted appearance.
Biotite	Anhedral plates up to 5 mm long; pleochroic scheme, X = dark brown and Y = brown; altered to chlorite at the margin; sometimes the crystals are weakly aligned resulting in a poor foliation in the rocks.
Accessory	Sphene — most abundant accessory mineral; euhedral to subhedral; found scattered or associated with the hornblende-biotite clots; faint pleochroism from brown to very pale brown; 0.5 to 1 mm in length. Apatite — small, colourless, subhedral to euhedral crystals with shapes varying from stumpy to elongated hexagonal prisms; inclusions in all other minerals, being most abundant as inclusion in biotite and hornblende. Zircon — is less common than apatite; found as subrounded crystals probably due to magmatic corrosion, usually as inclusion in biotite. Magnetite — main opaque phase.

compositional range between An_{28} to An_{50}. Inclusions of small biotite, sphene and quartz blebs are present. Regular zoning, both normal and oscillatory and simple and polysynthetic twinning are common. Large K-feldspars, up to 3 cm across often give the rock a distinctly porphyritic appearance. The main types are perthitic orthoclase and often shows euhedral outline in hand specimen but sometimes appears to be irregular in thin section. Simple twinning of the K-feldspar and the presence of small oriented euhedral inclusions usually plagioclase, oriented subparallel to the crystal faces of the host K-feldspar suggests that the minerals are magmatic. Mantling of plagioclase over orthoclase are common. Quartz is mostly anhedral and sometimes occurs as subgrains. It is generally interstitial to all other minerals, especially plagioclase and orthoclase. It also occurs as small round crystals at the margins of the plagioclase.

Hornblende is euhedral to subhedral with a grain size usually 1 to 4 mm across. It often shows simple twinning. Pleochroism is X = blue green, Y = brown green and Z = blue green. The mineral usually forms multi granular aggregates associated with the biotite, sphene, apatite and magnetite resulting in a clotted appearance. Biotite is the main constituent of mafic agreggates; its pleochroic scheme is X = dark brown and Y = brown. Sometimes the mineral is altered to chlorite at the margin. It occurs as anhedral plates up to 5 mm long and sometimes the crystals are weakly aligned resulting in a poor foliation in the rocks. Sphene is the most abundant accessory mineral of the Noring granite. Crystals are euhedral to subhedral in form and is either found scattered or associated with the hornblende-biotite clots. It shows a faint pleochroism from brown to very pale brown and is mostly from 0.5 to 2 mm in length. Apatite occurs as small, colourless, subhedral to euhedral crystals with shapes varying from stumpy to elongated hexagonal prisms. It occurs as inclusions in all other minerals, being most abundant in biotite and hornblende. Zircon is less common than apatite and is found as subrounded crystals usually in biotite probably due to magmatic corrosion. The main opaque phases in the Noring granite is magnetite.

Geochemistry

Geochemistry of this pluton shows that it is metaluminous (ACNK between 0.88 to 0.97) (Shand, 1943) with SiO_2 ranging from 62.51 to 70.46% (Cobbing *et al.*, 1992). The rocks have high alkali content, with Na_2O + K_2O ranging between 7.82–

8.71%. On a K_2O vs SiO_2 diagram (Peccerillo and Taylor, 1976), all samples plot in the high-K calc alkaline field. None of the five analysed samples have normative corundum (C = 0). On a Na_2O vs K_2O plot, all samples plot in the 'I' type field of White and Chappell (1983). The 'I' type nature of the granite is further supported by the occurrence of sphene and hornblende in the granite.

DESCRIPTION OF THE MANTLE FELDSPAR

The notable texture of this rock is the mantle feldspar in which whitish plagioclase (plagioclase rim) mantled the pinkish K-feldspar (K-feldspar core). The size of the texture ranges from several mm to 3 cm. The thickness of the plagioclase rim varies from 1 mm to 10 mm. The K-feldspar core also varies in size, from 2 mm to 2 cm across. Sketches some of the textures in hand specimen are given in Figure 2.

The K-feldspar core consists of a single crystal or several crystals usually showing simple twinning. Not infrequently it contains euhedral hornblende, magnetite and biotite inclusions. Small irregular outline plagioclase inclusions occur in the K-feldspar core being most abundant near the contact with plagioclase rim (Fig. 2b). The texture suggests that the K-feldspar core replacing and enclosing relicts of plagioclase rim (cf. Pitcher and Berger, 1972, p. 104). The rim is generally composed of numerous euhedral to subhedral plagioclases with size usually less than 1 mm (Fig. 2a). The crystals form a two dimensional touching network surrounding continuously the K-feldspar core. In places the plagioclase rim consists of a single crystal about 2 mm thick. Despite well developed euhedral growth zones, many crystals have irregular ahhedral margin indicating continued growth to a late stage. Common growth zones are normal and oscillatory types. Fine mymerkite intergrowth sometimes occurs along the K-feldspar core and plagioclase rim contacts indicating late stage intergrowth. Twinning according to albite, polysynthetic and Carlsbad-albite law are common. Hornblende, biotite and sphene can be seen associated with plagioclase at the margin of the texture.

CHEMISTRY

Compositions of plagioclase and K-feldspar (both from the mantle texture and individual feldspars) from the Noring granite have been determined by using electron microprobe analysis located at the University of Manchester. The instrument (modified Cambridge Instruments Geoscan) was running under the following condition: EDS analysis, 15 kV beam accelerating potential, 3 nA specimen current on cobalt metal with a count time of 40 liveseconds.

The results are presented in Table 2. The data have been divided into two i.e. plagioclase and K-feldspar from the mantle feldspar and those formed as individual crystals. Plot of the plagioclase data on an An-Ab-Or diagram is shown in Figure 3. It shows that the plagioclase from the mantle feldspar have restricted composition compared to the individual plagioclase. In terms of An %, the former ranges from An_{38} to An_{44} compared to An_{28} to An_{50} for the latter.

DISCUSSION

Comparison to other Rapakivi texture

The mantle feldspar in the present study has been compared to the rapakivi texture (mantling of ovoid K-feldspar megacrysts by plagioclase) found in the Proterozoic granites (e.g. Sederholm 1891; Dempster *et al.*, 1991,1994; Ramo and Haapala, 1995) (Table 3). There are several notable differences between those two textures, especially the age of the granites host and the plagioclase composition. The rapakivi texture is usually found in the granites with age ranging from 1.0 to 1.7 Ga (Proterozoic) whereas the Noring granite has been dated as Cretaceous (Singh *et al.*, 1984). Plagioclase rims in the present study have a rather restricted composition, An_{38-44} compared to plagioclase in the rapakivi texture, An_{10-40} (Ramo and Haapala, 1995). The rapakivi texture is typically composed of ovoid magacrysts of K-feldspar with a millimeter-thick shell of oligoclase whereas the mantle feldspar in the Noring granite consists of subhedral K-feldspar core mantled by numerous euhedral to subhedral plagioclase of andesine composition.

Conclusions from the petrographic and microprobe analyses

Theories involving the development of mantled feldspar fall into 2 categories, those dominated by magmatic processes and those invoking subsolidus processes. The present study shows strong evidence that the texture was formed by both processes. The features such as simple twinning and occurrence of hornblende inclusion in the K-feldspar core support the magmatic origin. Furthermore the plagioclase rim occurs as glomerocrysts which according to Vance (1969) can only be produced in a magmatic environment. Replacement texture at the margin of the K-feldspar core suggests that subsolidus process is also involved in the formation of the mantled feldspar. 'Islands' of anhedral plagioclase with irregular outline within the K-feldspar core

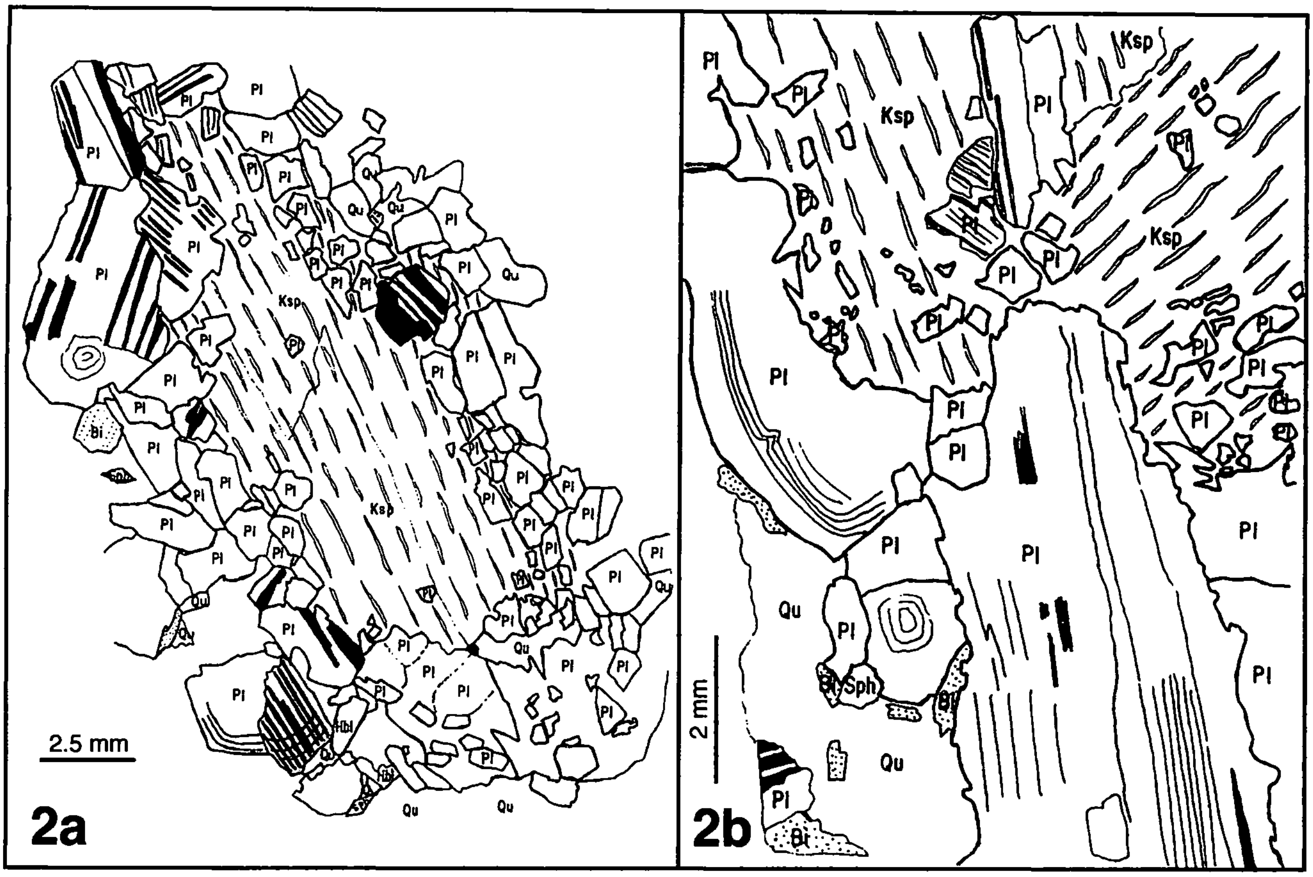

Figure 2. Microscopic sketches some of the mantle feldspar texture in the Noring granite. Note that plagioclase rim consists of numerous smaller plagioclase crystals (modified from Azman, 1998).

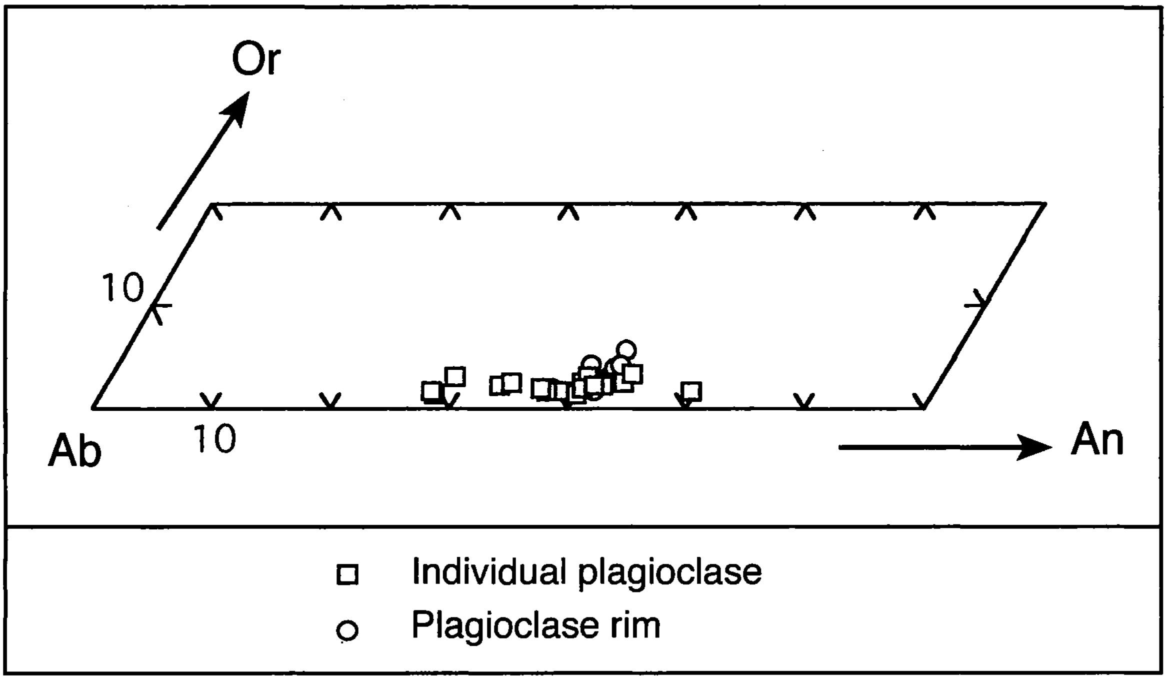

Figure 3. An-Ab-Or plot for the individual plagioclase and plagioclase rim of the Noring granite. Note that the plagioclase rim have more restricted An% compared to the individual plagioclase in the rock.

Table 2. Compositions of K-feldspar and plagioclase in the Noring granite. Note that the individual K-feldspar and plagioclase stands for those not related to the mantle texture.

Individual K-Feldspar						
Sample	PEG2 Core	PEG2 Rim	PEG2 Core	PEG2 Rim	PEG2 Rim	PEG2 Rim
SiO_2	65.06	66.88	66.13	65.25	65.77	64.88
Al_2O_3	18.55	18.11	18.22	17.84	17.97	17.98
FeO	0.07	0.04	0.11	0.06	0.01	0.07
Na_2O	0.719	2.46	2.07	0.57	0.77	0.76
K_2O	15.17	13.30	14.17	15.85	15.97	15.54
CaO	0.00	0.00	0.00	0.00	0.00	0.00
BaO	1.812	0.59	1.20	0.95	0.68	1.13
An %						
Ab %	4.50	15.60	12.70	3.47	4.60	4.60
Or %	95.50	84.40	87.30	96.53	95.40	95.40

K-Feldspar Core						
Sample	PER1 Rim	PER1 Rim	PER1 Core	PER1 Rim	PER1 Rim	PER1 Rim
SiO_2	65.47	64.79	64.91	65.12	65.03	65.81
Al_2O_3	18.09	17.75	17.85	17.87	17.64	17.95
FeO	0.08	0.00	0.21	0.18	0.00	0.04
Na_2O	1.47	0.90	0.69	0.96	1.29	0.44
K_2O	14.27	15.07	15.50	14.91	14.60	16.17
CaO	0.00	0.00	0.00	0.00	0.00	0.00
BaO	1.33	1.20	1.35	0.42	0.48	0.63
An %						
Ab %	9.30	5.70	4.30	6.00	8.10	2.60
Or %	90.70	94.30	95.70	94.00	91.90	97.40

Individual Plagioclase						
Sample	PE11 Core	PE11 Rim	PE11 Core	PEG2 Rim	PEG2 Core	PEG2 Rim
SiO_2	59.40	65.47	61.90	63.88	63.44	63.14
Al_2O_3	25.59	21.39	24.14	23.75	22.94	22.75
FeO	0.22	0.16	0.37	0.15	0.08	0.15
Na_2O	7.39	9.24	8.22	8.68	8.45	8.72
K_2O	0.28	0.20	0.38	0.27	0.26	0.31
CaO	7.58	3.65	5.70	5.62	5.45	5.23
BaO	0.00	0.00	0.03	0.04	0.00	0.01
An %	49.70	27.80	39.90	38.57	57.50	36.70
Ab %	48.45	70.59	57.50	59.60	37.40	61.19
Or %	1.85	1.61	2.60	1.83	5.10	2.10

Plagioclase Rim						
Sample	PER1 Rim	PER1 Core	PER1 Rim	PER1 Core	PER1 Rim	PER1 Core
SiO_2	62.43	61.87	60.99	61.51	62.61	62.01
Al_2O_3	23.75	22.97	23.71	23.47	23.99	23.94
FeO	0.22	0.26	0.19	0.42	0.39	0.20
Na_2O	8.60	8.19	7.92	7.93	8.20	8.21
K_2O	0.31	0.62	0.41	0.59	0.50	0.49
CaO	6.06	5.84	6.35	6.19	6.62	6.28
BaO	0.00	0.00	0.12	0.10	0.12	0.28
An %	40.50	39.80	43.20	42.00	43.20	41.90
Ab %	57.40	55.90	54.00	54.00	53.50	54.80
Or %	2.10	4.20	2.80	4.00	3.30	3.20

Table 3. Comparison of the mantled feldspar in the Noring granite and rapakivi texture (s.s) from worbogite from southern Finland.

CHARACTERISTICS	MANTLE FELDSPAR (Noring Granite)	RAPAKIVI TEXTURE FELDSPAR
Plagioclase composition	An_{38}–An_{44} (Andesine)	An_{10}–An_{40} (Oligoclase-Andesine)
Age of the granite	Cretaceous	Proterozoic era (1.0 to 1.7 Ga)
K-feldspar core	Unusually euhedral to subhedral but may consists of single or several K-feldspar crystals.	Usually ovoid, may consist of single crystal or more complex intergrowth of several crystals.
Plagioclase rim	Consists of numerous small plagioclase crystals in optically discontinuity.	Single crystal of oligoclase-andesine in optically continuity with the albite lamellae of perthite ovoid or several different oriented plagioclase grains.
Inclusion	Islands of small plagioclase are common in the K-feldspar core especially near the contacts with plagioclase rim.	Plagioclase inclusion common in the K-feldspar core.
K-feldspar composition	$Or_{89.6-97.4}Ab_{10.4-2.6}$	$Or_{50-80}Ab_{20-50}An_{0.5-4}$

indicates that the K-feldspar has replaced the plagioclase probably at a very late stage.

A variety of mechanisms have been proposed to account for the switch from K feldspar to plagioclase crystallisation. This includes (a) degasing of fluid saturated magma, (b) decompression and (c) magma mixing. Microprobe analyses show that the plagioclase rim has more restricted composition compared to the individual plagioclase. This may suggests that the plagioclase rim precipitated from a different magma type to the Noring magma possibly of andesitic in composition. Variations in melt composition as a consequence of magma mixing and/or mingling can produce the mantled feldspar (Hibbard, 1981,1991; Bussy, 1990). The K-feldspar that has crystallised in the Noring magma act as a substrate for the growth of plagioclase, producing the mantled texture (Hibbard, 1991). The aggregates of individuals crystals that have floated together in the magma attached to the K-feldspar as in the synneusis model of Vance (1969). Once this nucleation takes place there is the relatively straight forward process of crystal growth yielding the mantled texture (Hibbard, 1981). Other evidences that may support the magma mixing process are (i) occurrence of small rounded mafic inclusion (hornblende ± biotite) usually 1 to 2 mm in size and (ii) discontinuous nature of plagioclase zoning and irregular shapes of the cores.

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