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Basement gneiss domes in the Svecokarelides of eastern Finland: discussion

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A recent paper in this journal (J.-P. Brun, The cluster-ridge pattern of mantled gneiss domes in eastern Finland: evidence for large-scale gravitational instability of the Proterozoic crust, Earth Planet. Sci. Lett. 47 (1980) 441–449) resurrects Eskola's [1] concept of the mantled gneiss dome in the early Proterozoic Svecokarelian fold belt of Finland. The author cites amongst others, the Kuopio, Juojärvi, Maarianvaara, Kontiolähti, Liperi, Oravisalo and Sotkuma domes (see Fig. 1) as examples of the diapiric upwelling of lower-density, granitic Archaean basement rocks, into more dense, overlying Karelian metasedimentary formations, The distribution of these basement structures is interpreted as reflecting a periodicity, which by analogy with the centrifuge experiments of Ramberg [2], is a function of the interlayer density contrast and the layer thicknesses.

This interpretation takes no account of a large mass of information relating to structural characteristics of both basement and cover rocks in the vicinity of the domes listed above. Neither does it take into account the stratigraphy and sedimentation history of the cover rocks, or the isotopic systems of the Archaean rocks of the domes themselves. In addition, conclusions are drawn on the basis of assumptions relating to the gross properties of the rocks that are not only unproven, but highly improbable. The following aspects indicate the untenable nature of the interpretation.

(1) Where the Archaean gneisses are exposed in the domes, such as at Sotkuma and Kuopio, they show many successively-formed structural and metamorphic features [3, pp. 485–486 and figs.; 4] and igneous intrusions that are not seen in the surrounding cover formations. Fine fracture cleavages as well as prominent composite foliations and folds of varying size and successive development, maintain consistent geometrical relationships, thus indicating the existence of corresponding structural and metamorphic histories. These Archaean features correspond in expression, orientation and sequential development to those of the main mass of gneisses in the Presvecokarelides of eastern Finland: deflection and disruption such as would result from rheidic flow movement are not seen [3–5].

(2) U-Pb isotopic systems of zircons from the gneisses of the cores of some domes (e.g. Sotkuma) indicate very little disturbance during the Svecokarelian episode; they are close to those expected if samples had lost Pb continuously by diffusion. For zircons from other domes (e.g. Kuopio) a two-stage model, including disturbance at 1.9 Ga is indicated [6]. Neither the very little disturbance of some U-Pb systems, nor the marked differences in disturbance shown from dome to dome appear to be consistent with the *T-P* conditions implied by the diapiric model of dome formation.

(3) The unconformity between the cover and basement remains intact over a considerable part of its outcrop, particularly along the eastern contact with the Presvecokarelian gneisses (Fig. 1). In places palaeosols (satrolites) are developed; representatives of A, B and C soil horizons occur with gradations into fissure-rotted gneiss, through blocky and rubbly material with extensive kaolin

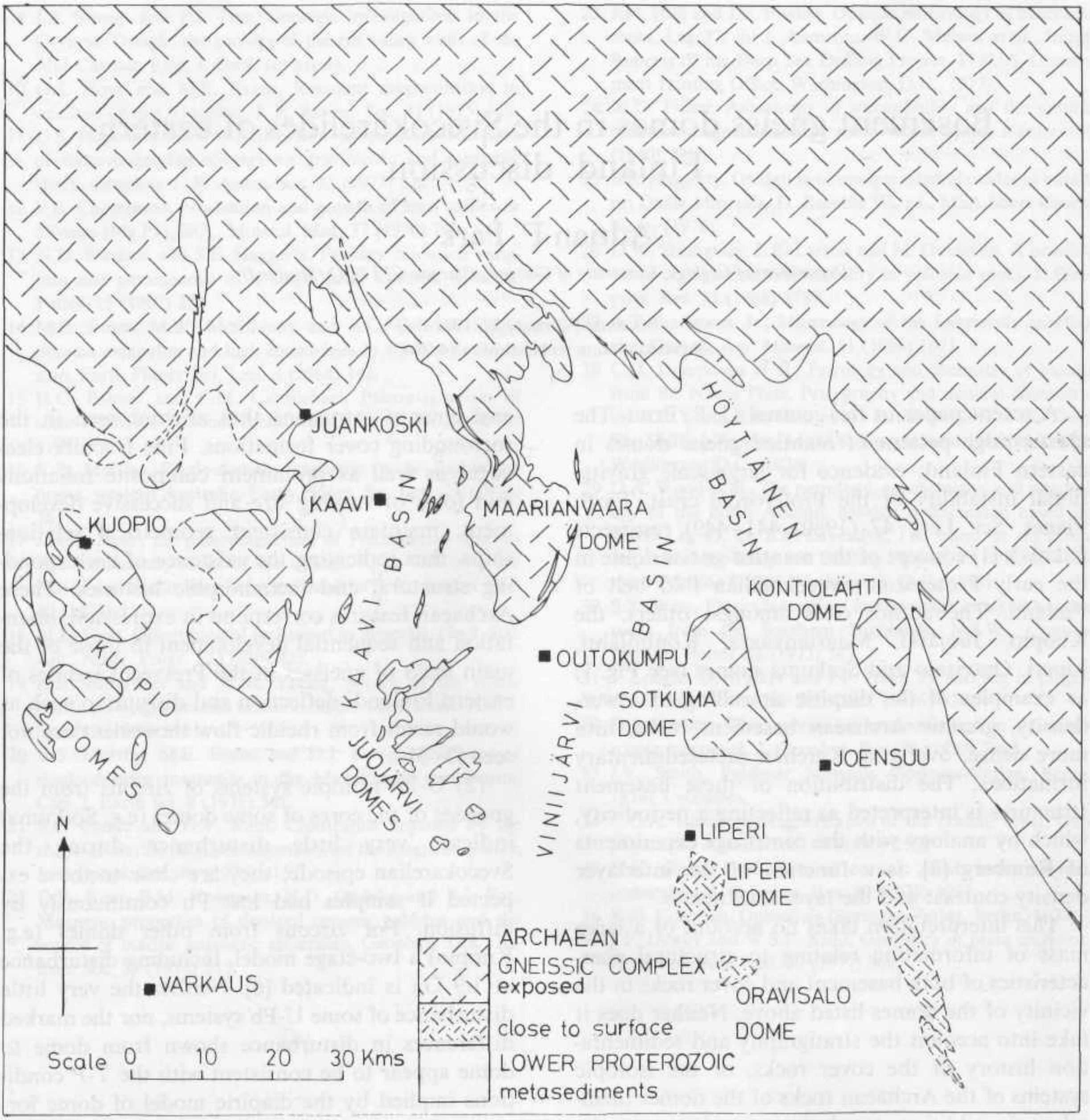

Fig. 1. Simplified geological map of eastern Finland showing the distribution of the domes of Archaean basement gneiss in part of the early Proterozoic Svecokarelides (after Gáal et al. [11], and Huhma [9,10].

development. Fissures with kaolin (plus K-feldspar, muscovite and scapolite) extend for several metres into undisturbed basement gneiss while representatives of the aligned mineral fabrics and fracture cleavages in the basement gneiss can be traced into the massive rock between the rotted areas and veins. These fabrics die out across the boundaries of the kaolin-bearing fissures and are not represented in the lowermost members of the cover assemblage. Thus the fabrics of the gneisses of the Archaean basement must predate the basal unconformity of the Karelian sediments. This means they must also predate the tectono-thermal peak of the Svecokarelian orogenic episode by 300–400 Ma.

The preservation of the satrolites, and of late Archaean brittle structures, and the demonstrable absence of rotation or disruption of the Archaean structural patterns of the domes [4] indicates that they have behaved predominantly as rigid and passive elements during subsequent episodes. Only at Kuopio and Maarianvaara do either the isotopic systems or the Archaean structures show signs of marked Proterozoic reheating or tectonic overprinting, respectively.

(4) The basal conglomerates of the Karelian sedimentary assemblage around the domes, first noted in 1907 [7] but accommodated within Eskola's model, have been shown to consist almost entirely of material derived from the adjacent basement [8]; N.M. Clark, personal communication). These source areas for the most part correspond with the present domes, indicating their existence as areas of positive relief from earliest Proterozoic times (ca. 2.4 Ga) [8]. Hence the initial rise of the basement masses cannot be attributed to density-induced instability, as envisaged by Brun [15], as the more dense metasediments had yet to be deposited. These observations are, however, consistent with the deposition of the earliest sediments (Sariolian) being controlled by fault-bounded basins in a graben and horst tectonic regime ([8]; N.M. Clark, personal communication).

(5) Despite the regionally pervasive deformation and metamorphism during the Svecokarelian orogeny, the metasedimentary cover in the vicinity of some of the domes and the eastern basement contact, show remarkably little disruption. A combination of low-strain rates (locally) and distinctive lithologies has allowed detailed stratigraphic and sedimentological work to be carried out ([8]; N.M. Clark, personal communication). The stratigraphic sequence of the rocks of the cover, in the vicinity of the domes is punctuated by a number of unconformities. In addition there are intraformational conglomerates, whose clasts were derived locally from the Archaean assemblage of the areas in which the domes now occur. Both from their regional distribution and from their positions within the succession, these conglomerates indicate episodic uplift of the domes in an unsynchronised fashion over a period of some 200–350 Ma, during which the domal structures must have been unroofed and eroded. Accordingly, the analysis of Brun [15] based on the present spatial distribution of the resultant domes as shown on a geological or tectonic map, ignoring the evidence presented by the stratigraphy (i.e. on the assumption that the features do not have an extended history and are co-eval) cannot be accepted.

(6) Deformation in the cover rocks took place during at least seven phases [5] whose imprint is shown in seven major fabrics, with static mineral growths between some of the dynamic phases. The first five sets of fabric elements are regionally penetrative and the cleavage and lineation maps of Huhma [9,10] only appear "tortuous" to Brun [15, p. 442] because they do not distinguish between five prominent planar mineral growths and as many conspicuous lineations. The so-called "anomaly" of Brun [15, p. 442] in the Outokumpu serpentinite-ore belt is entirely consistent with the regional fabrics, representing a belt of D_1 and D_2 structures showing no subsequent rotation [11].

(7) Horizontal or sub-horizontal tectonism associated with crustal shortening dominated the earliest recognisable deformational phase in the cover rocks (D_1,D_2). The disposition of D_1 and D_2 planar and linear fabric elements indicates post-D_2 formation of the prominent dome-and-basin pattern (see the stress trajectory maps of Gáal et al. [11] which allow for the deflection of the D_1 and D_2 structures around the later domes.) Interpretation of the domes as fold interference patterns resulting from F_3 (steeply inclined, N-S axial planes) and F_4 (vertical, ENE-WSW axial planes) movements [5,11,12] may be essentially correct for some of the domes. But for others there is an earlier component and for some the history is clearly composite. The D_3-D_4 interference pattern is superimposed upon a basement cover interface surface with an uneven topography, resulting from the block faulting, in turn controlled by reactivated N-S fractures of late Archaean age. The

situation is further complicated by the apparent lack of any structures (other than fractures) within the basement "domes" that would result from the inevitable compression should any folding have taken place. It is apparent that basement and cover reacted to Svecokarelian orogenic activity in very different ways. The basement rocks have adjusted to changing strain by brittle failure, rather than by rheidic flow.

(8) Disposition of basement and cover rocks differ within the various domal structures. The most common situation is one of cover above basement with varying degrees of dislocation of the actual unconformity (e.g. Kuopio, Sotkuma and Kontiolähti). However, in the Maarianvaara structure, basement and cover rocks are intercalated by a belt of major thrusts and their associated imbricate zones. Deformation associated with the formation of the thrusts was of ductile or semi-ductile nature and did not involve the recrystallisation or mobilisation of the rocks of the basement slices, which maintained their structural integrity, despite the coincidence of the thermal maximum (syn-D_2). Crustal shortening across the neighbouring basins during the D_1 and D_2 phases is of the order of 60–70% along an E-W vector. Brun's assertion [15, p. 448] that his thesis "... tends to prove the predominance of gravitational instability over regional shortening in the tectonic evolution of the Karelides" is inconsistent with the field evidence.

(9) The peak of metamorphism (high-amphibolite facies) occurred over the region pre- to syn-D_2, i.e. before the dome-basin interference pattern producing events in the cover rocks. Local thermal peaks existed in D_3 and pre-D_4, but these are shown in rocks outwith the domal structures [13] although Brun's model would imply that they ought to coincide with them. Regionally the metamorphic facies after the D_2 maximum was generally at greenschist facies, and under these conditions any lowering of viscosity such as to permit rheidic movement between units with such a low density contrast (average Archaean basement 2.5; average Karelian metasediments 2.75) seems very unlikely. To satisfy Brun's model, the viscosity lowering event must have left no metamorphic effect and must not have disturbed the isotopic systems in the gneisses.

The mantled-gneiss dome model of Eskola was an attempt to reconcile many disparate strands of evidence at a time when neither the polyphase deformation and metamorphic phases in both the basement and the cover rocks, nor the complex patterns of sedimentation had been recognised in the Svecokarelides. With the availability of information and techniques for the analysis of such complex geological features [14], the model of Brun [15] can be considered an interesting laboratory model, or what might have occurred had the basic assumptions in any way approximated to the crustal conditions in this area at that time in its history. However, the known geological history provides constraints which means that the assumptions used are gross oversimplifications. Accordingly the model neither impinges on the geological evolution of the Svecokarelides, nor provides a relevant basis for assessing the nature of diapirism.

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