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Local displacement of diapir contacts and its importance to pluton emplacement study: Reply

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Four major conclusions are drawn in my short article on the displacement of diapir contacts (Schwerdtner 1995). (1) The displacement field around isotropically-expanded spheres differs markedly from displacement fields around mature and immature diapirs. (2) At the crest of immature upright diapirs, the contact displacement corresponds to the vertical shortening of host rocks. (3) For points on the lateral contacts of immature diapirs, the transverse horizontal component of displacement can approach zero. This component is generally much smaller than the longitudinal strain of material lines which become normal to finally vertical contact surfaces, at the end of immature diapirism. (4) A deformed material surface, coincident with the present erosion level of a pluton, will have been initially inclined and curved if diapirism was the main emplacement mechanism. Therefore, the map pattern of deformed geologic markers or, more precisely, their deflected horizontal traces depends more on strain conditions in the material surface than displacement components in a spatial reference frame.

Paterson & Fowler address three main topics, in the discussion of my short article. Because of space limitation, I cannot deal with all of the issues raised by the discussants, but will comment on two problems.

LOW STRAIN MAGNITUDES ABOVE PLUTONS

My article (Schwerdtner 1995) considers diapir models that are relevant to mid-crustal plutons. Such models are characterized by large amounts of escape flow in the dense material above rising diapirs (Ramberg 1967, 1981, Dixon 1975). This translates into high magnitudes of vertical longitudinal strain and associated contact displacement at the crest of model diapirs (Schwerdtner 1995). By contrast, the roof zones of granitoid plutons appear to be regions of relatively low strain (Buddington 1959, Paterson & Fowler).

In their discussion and an earlier review paper, Paterson & Fowler (1993) seem to include examples of granitoid plutons emplaced at shallower levels in the earth's crust. Analogue diapirs relevant to shallow-level plutons cause an upward bending of the earth's surface, but this can be counteracted by a syndiapiric erosion process which prohibits local topographic uplift (Fletcher 1972). Such models are characterized by modest flexing rather than heterogeneous flattening of horizontal strata, and may explain the low strain above granitoid plutons. Alternatively, weakly strained roof rocks may be taken as evidence of nondiapiric emplacement mechanisms (Paterson & Fowler 1993).

MODELS OF ISOTROPIC EXPANSION ('BALLOONING')

The rise of diapirs has been modeled under different geological conditions using a variety of experimental and numerical methods. Most published models are constrained by laws of continuum physics and dimensional analysis (Ramberg 1981, Cruden 1990). By contrast, no realistic dynamic models seem to be available for the isotropic expansion of spherical magma bodies. (The same applies to the horizontal circular expansion of vertical magma plugs considered by Morgan, 1980.) Despite this deficiency, the discussants rightly recommend that the ballooning hypothesis be retained in the foreseeable future. However, they do not comment on the fact that low shortening strain in the roof zone of plutons is incompatible with large amounts of isotropic expansion.

Paterson & Fowler state that their early attempts at estimating the outward displacement of lateral contacts of granitoid plutons 'were designed to assess ballooning'. The simple *unstretching* of long material lines, drawn across the host rocks and oriented normal to steep pluton contacts, gives correct results only if the expansion centre lies on the erosion level. At the upper and lower erosion levels indicated in Fig. 1, and possibly also for future analogue models of expanded plutons, the unstretching procedure gives a good estimate, nonetheless.

In practice, the relative position of the erosion level, with respect to the expansion centre (Fig. 1), cannot simply be deduced from the local dip of pluton contacts, but may be crudely estimated by restoring the original geometry of horizontal chains of line segments drawn perpendicular to the contact trace (Schwerdtner 1985).

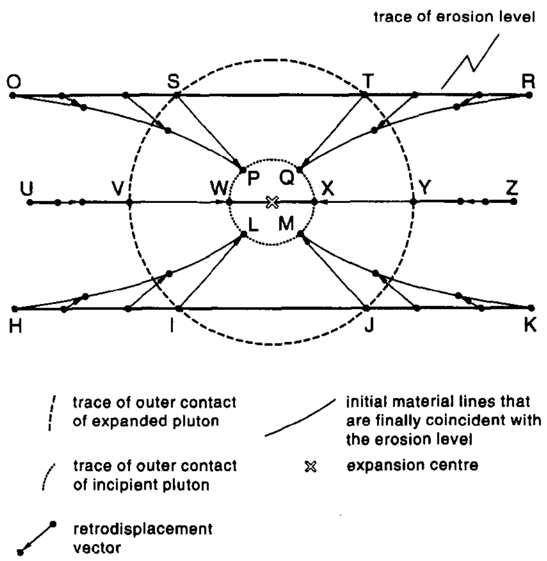

Fig. 1. Vertical section through the centre of an isotropically-expanded spherical pluton and its host rocks. Curves O–P and Q–R represent unstrained material lines corresponding to segments O–S and R–T of the trace of a high erosion level in the host rocks. Arrows are retrodisplacement vectors for material points if the pluton centre is fixed during the spherical expansion. (Otherwise the arrows represent retrodisplacement differences.) U–Z is the trace of an erosion level through the pluton centre, with segments U–V and Y–Z on the partly eroded host rocks. V–W and Y–X represent the retrodisplacement of points at vertical contact segments. Similarly, H–K is the trace of a low erosion plane, and its retrodisplacement vectors are mirror images of those for trace O–R. In geologic practice, curves O–P, R–Q, H–L and K–M may be approximated by chains of line segments (Schwerdtner 1985).

If the expansion centre lies on the erosion level, then the pluton contacts are vertical and the restored chains of lines are straight and horizontal. Demonstration of the existence of such erosion levels and chains of line segments would support the ballooning hypothesis. The existence of low erosion levels (H–K in Fig. 1) and associated chains of line segments would be difficult to reconcile with diapirism, and cast doubt on the supposed prevalence of magma diapirs.

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