Kinematic evaluation of a finite-element model of a diapiric ridge

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The strain pattern is determined of a two-dimensional finite-element model of an immature diapiric ridge. The state of plane strain is calculated for each distorted element by using transformation coefficients. The strain pattern is compared with that of other computer and centrifuge models, and with evaporite and gneiss diapirs.

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Introduction

Diapirs are common in Precambrian terranes and Phanerozoic sedimentary basins. Salt diapirs are caused by high density and viscosity contrasts between the diapiric material and overburden, the salt being the lighter and less viscous material. For many gneiss domes (e.g. Schwerdtner et al., 1978; Schwerdtner and Lumbers, 1980) density or viscosity differences with the overburden are small. Anhydrite diapirs (Hoen, 1964; Schwerdtner and Clark, 1967; Schwerdtner and Osadetz, 1983; van Berkel et al., 1983, 1984; van Berkel, 1986 and 1987) are denser than their sedimentary host rocks. Natural diapiric structures may be differentiated from other structures by using their characteristic total-strain patterns and those of their host rocks (e.g. Dixon, 1975; Schwerdtner et al., 1978).

Dynamically scaled models are an important tool in understanding the evolution of geologic structures. To simulate diapiric structures, centrifuge models have been made (e.g. Ramberg, 1967 and 1981; Stephansson, 1972; Dixon, 1974 and 1975; Talbot, 1977, Schwerdtner and Tröeng, 1978; Schwerdtner et al., 1978; Dixon and Summers, 1983; Morgan, 1986) and also finite element models (Fletcher, 1972; Mareschal and West, 1977 and 1980; West and Mareschal, 1979).

Mareschal and West (1977, 1980) did not determine the state of total strain for each distorted element in their finite element models. One of their models simulates immature diapiric ridges with interdiapiric synclines. The total strain pattern of this model has important applications because many immature diapiric structures seem to have similar amplitudes, and criteria to identify diapiric structures especially apply to immature diapiric ridges (Schwerdtner and Lumbers, 1980).

Mareschal and West's finite-element model of a diapiric ridge

Mareschal and West (1977 and 1980; pers. comm., 1984) made several two-dimensional finite-element models of diapiric ridges with various amplitudes and boundary conditions. The ridges are of infinite length and their elements strained in two dimensions. The diapiric ridges and interdiapiric synclines are infinitely periodic.

One model was chosen for an analysis of its total strain pattern. The model (Fig. 1) simulates immature diapiric ridges in Archean granite-greenstone terranes (e.g. Schwerdtner et al., 1979). Boundary and physical conditions of this model are as follows: (1) densities of 2.9 g/cm^3 and 2.7 g/cm^3 respectively for the metavolcanic overburden and granitoid basement rocks; (2) a temperature gradient (highest temperature at depth) within the model which changes the initially-uniform viscosity and creates lower viscosities at depth; and (3) an initial perturbation in the subhorizontal interface between dense overburden and diapiric granitoids (Fig. 1a). These conditions controlled the geometry and strain patterns in the diapiric ridge and syncline generated in the model.

Strain pattern

Bedding-parallel shear and orientation of the principal extension axis (X-axis) were calculated for each deformed element in the finite-element grid by

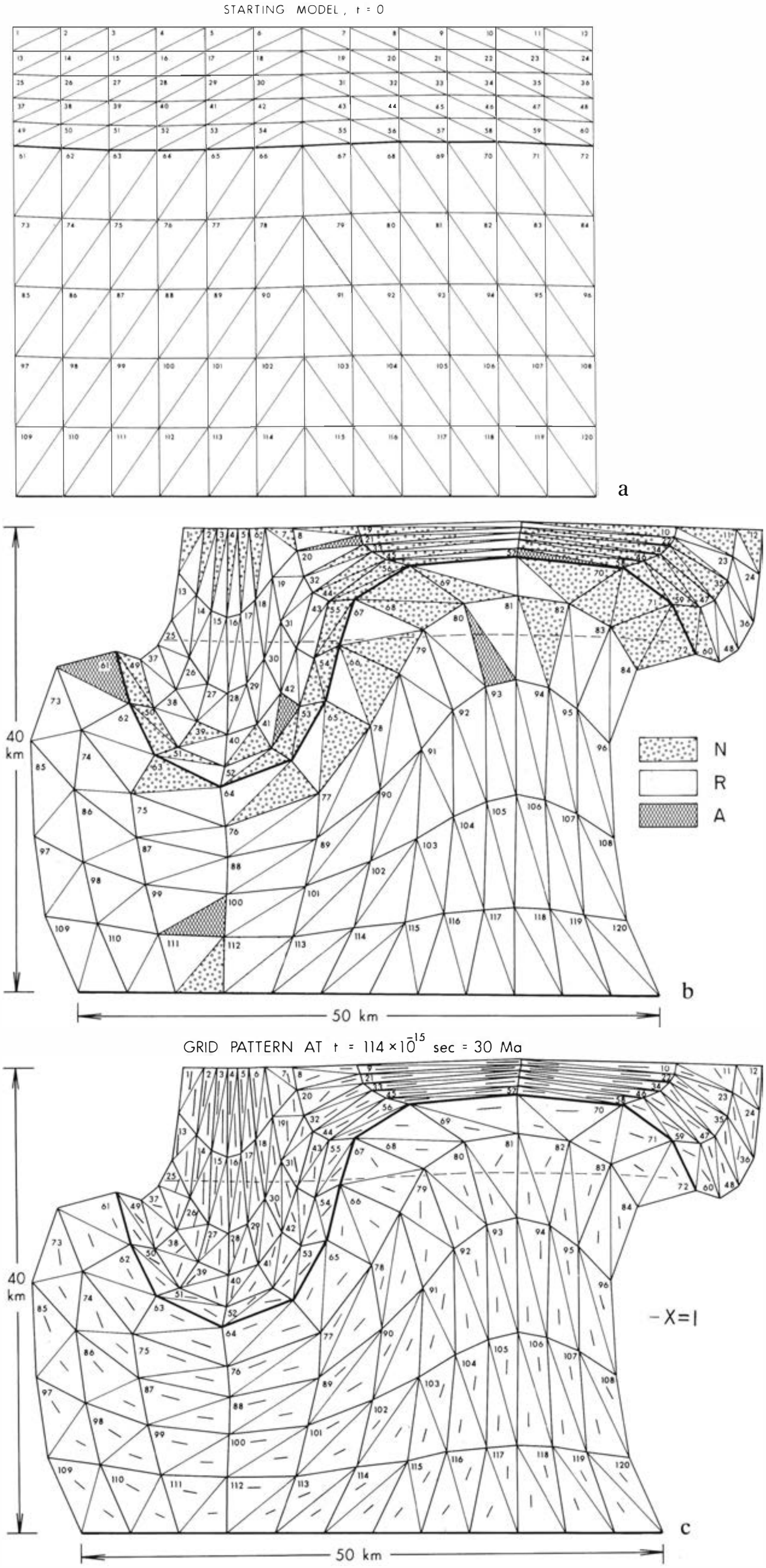

Figure 1. A finite-element model of a diapiric ridge made by Mareschal and West, 1977. Heavy line separates the diapiric material (bottom and large rectangles) and overburden (top and small rectangles). **a.** Initial state. Note that the initial perturbation is slightly asymmetric. **b.** Final state with sense of shear along initially subhorizontal layers. **N** − normal sense; **R** − reverse sense; **A** − no shear. **c.** Final state with the length and orientation of the principal extension axis (−) for each traingle.

using transformation coefficients (Fig. 1; Jaeger, 1962, p. 25–28; Ramsay, 1967, p. 57–63; Dixon, 1974; Ramsay and Huber, 1983). In the overburden layer, just above the diapiric ridge, the sense of bedding-parallel shear is generally normal (hanging-wall block down) and the principal extension axes dip gently away from the steeper anticline flanks. Reverse sense of shear is caused by a slight assymmetry in the initial perturbation. In the overburden of the synclinal structure, bedding-parallel shear is generally reverse (hanging-wall block up) and the principal extension axes dip steeply toward the contact with the diapiric material. The asymmetric strain pattern in the syn- and antiform is caused by an imperfectly symmetric initial perturbation combined with the large size of the elements.

A neutral surface of total longitudinal strain is present within the diapiric ridge as well as in the adjacent syncline of dense material (Fig. 1c). The first neutral surface has been noted in other models (e.g. Dixon, 1975; Schwerdtner and Troeng, 1978), whereas the second neutral surface is rarely documented (e.g. Dixon and Summers, 1983). Within the syncline, the neutral surface exists in the extension axis plot because the axes are subhorizontal in the lower portions and subvertical in the higher portions. This configuration resembles the inverted pattern of extension axes within the diapiric ridge. The maximum principal extensions are greatest near the axial planes of the structures, as Dixon and Summers (1983) observed in their isotropic models. There is, however, one major difference, probably caused by a difference in tightness of the syncline. At the inflexion point of the syncline and ridge the orientations of principal extension axes change very rapidly, from a low to a high angle with respect to the interface (heavy line).

Comparison with other diapiric models

Finite-element Models

Fletcher (1972) constructed analytical models to simulate diapiric anticlines of gneiss and salt domes. Compared to the model analyzed here, his models have a lower amplitude, and the same viscosities for the diapiric and mantling members. The strain distribution in his models is similar to that in the model analyzed in this paper.

Centrifuge Models

Dixon's (1975, Figs. 10 and 11) centrifuge models have comparable boundary conditions with the model analyzed. The strain pattern is very similar to that found in the present model as well as those of Fletcher's (1972) analytical models. Dixon and Summer's (1983) centrifuge models of interdiapiric synclines are too tight for direct comparison with the present model.

Comparison with geologic exampels

Gneiss Diapirs

Schwerdtner and Sutcliffe (unpublished data) determined the strain pattern of an Archean gneiss dome (Ash Bay Dome; Schwerdtner, 1984). These workers used deformed mineral aggregates to determined k-values (Flinn, 1962) and compared the results with magnetic susceptibility analyses. The crestal-portion of the gneiss dome is characterized by a prevailing mineral fabric (i.e. oblate ellipsoids of total strain). Linear mineral fabrics are rare, although they are predicted by the model analyzed in this paper. In the outer zone of the gneiss dome, many parasitic Z and S folds occur. Only 75 % of the measured asymmetric folds (with a subhorizontal fold axis) in the gneiss dome indicate a normal sense of shear between the gneissic layers (hanging-wall block down). It is possible that the present strain pattern only reflects a large final increment of strain and that older stretching fabrics are obliterated by recrystallization. Alternatively, the present strain pattern could be the result of diapirism superimposed on an older prediapiric strain fabric (Schwerdtner, 1986).

Evaporite Diapirs

The model analyzed in this paper may have an important application for evaporite diapirs in unmetamorphosed Phanerozoic basins. Anticlines composed of clastic sediments mantling evaporite ridges were studied by the author in the Sverdrup Basin, Canadian Arctic Archipelago (van Berkel, 1985, 1986 and 1987). The sense of bedding-parallel shear and the orientation of pressure solution cleavage in the sandstones are compatible with the strain pattern in the diapiric model analyzed but incompatible with that of folds formed by lateral compression (cf. Ramsay, 1967, Fig. 7–68).

Conclusions

The finite element model analyzed has characteristic patterns of total strain in the diapiric material and overburden. The results of the strain evaluation are in agreement with those of other computer and centrifuge models. Strain patterns and structural features occurring in natural domes, antiforms and synforms can be compared with that in the finite element model to test if a diapiric model may be valid.

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