Internal-Flow Mechanism of Salt and Sylvinite in Anagance Diapiric Anticline Near Sussex, New Brunswick

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ABSTRACT

Within the evaporite domes of the U.S. Gulf Coast and northwestern Germany, rock salt and sylvinite are generally composed of nearly equant grains, in spite of severe macroscopic deformation (such as tight folding). The sub-equant grain shapes have been attributed to annealing or syntectonic recrystallization, with or without intragranular gliding.

Rock salt and sylvinite from the Anagance diapiric anticline, however, are characterized by highly inequant grains. Depending on the average shape of the mineral grains, one finds all transitions between ideally lineated and predominantly foliated rock. We assumed that the inequant shape of the mineral grains is a result of diapiric flow, and that it reflects the local state of finite distortion.

Lattice orientations of halite and sylvite were determined on the optic universal stage, by measuring the attitude of two cleavage planes per grain. Conventional fabric diagrams were constructed for ((100)), which exhibit prominent textural patterns defined by great-circle girdles and low-density maxima. These natural patterns are similar to model fabric patterns due to intragranular gliding, developed for specific types of finite distortion.

It would thus appear that intragranular gliding is the dominant mechanism of diapiric flow, and that the evaporites of the Anagance anticline experienced recovery rather than recrystallization. One may hypothesize that the subequant crystals of the Gulf Coast salt resulted from annealing recrystallization—a probable process in deep-rooted evaporite domes.

INTRODUCTION

In their literature review on the tectonic flow mechanism(s) of rock salt, Carter and Heard conclude that the (then available) petrofabric data do not permit an unambiguous interpretation of the deformation mode of halite (1970, p. 243). One difficulty of interpretation rises from the fact that domal salt and sylvinite are generally composed of subequant grains, in spite of severe macroscopic deformation (such as tight folding). This rules out the combined mechanism of translation gliding and recovery (polygonization), but does not allow a distinction between (1) syntectonic recrystallization and (2) translation gliding with subsequent annealing. The present investigation features domal salt and sylvinite, whose mineral fabric is comprised of aligned inequant grains.

The average shape of the mineral grains is presumably related to the local state of finite distortion. Thus one may select specific model fabrics of $\langle 100 \rangle$ for translation gliding, constructed for different types of finite deformation (Schwerdtner, 1968), and compare them with corresponding natural fabrics of $\langle 100 \rangle$. Even if the inequant grain shapes of halite and sylvite are due to crystal growth rather than translation gliding, their overall symmetry (Flinn, 1965) will still provide a clue as to the actual type of deviatoric tectonic stress, as specified by Lode's paramter μ (Nadai, 1950, p. 106). This limited information will drastically reduce the number of possible model fabrics, which posed a serious problem in a previous study (Schwerdtner, 1968).

ANAGANCE DIAPIRIC STRUCTURE

The elongate core of the Anagance anticline (Gussow, 1953; Burke, 1971) is comprised of a diapiric salt ridge, from which a pair of small domes have emerged (Fig. 1). This tectonic configuration is familiar from the salt diapirs of northern Germany (Trusheim, 1960), and has been reproduced experimentally by Ramberg (1967, p. 55). The presence of small domes suggests that the diapiric rise of Windsor salt near Sussex was chiefly due to differential

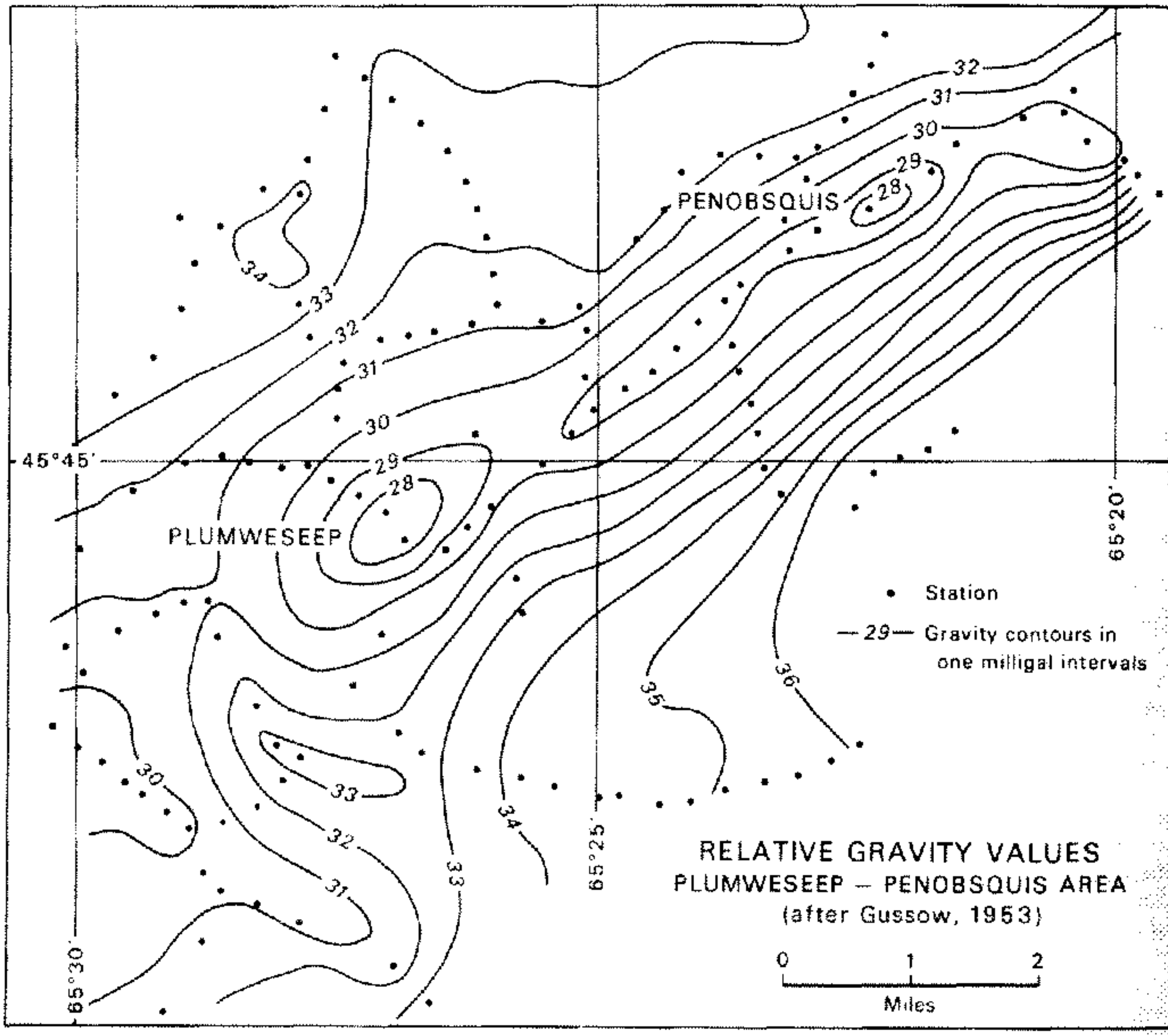


Figure 1. Anagance diapiric anticline with Plumweseep and Penobsquis domes.

buoyancy rather than regional tectonic compression in a northwesterly direction.

Rock salt and sylvinite in the small domes of the Anagance structure (hence labeled "Plumweseep" and "Penobsquis") are characterized by highly inequant grains (Schwerdtner, 1971). Depending on the average shape of the mineral grains, one finds all transitions between ideally lineated and predominantly foliated rock. If the inequant grain shapes are generated during the diapiric rise of the salt, then their fabric should reflect the finite distortion at any point in the structure. This may be shown by comparison with model domes for which the finite-strain distribution has been determined.

The states of finite strain near the axis of model domes can be represented by subvertical prolate ellipsoids (Fletcher, 1972, Fig. 4). Closer to the conformable contact of model domes, however, the shape of the finite-strain ellipsoids becomes more general due to differences in viscosity between the diapiric salt and the sedimentary overburden (Fig. 2). Adjacent to the domal contact, the magnitude of finite strain is rather small (Fletcher, 1967, p. 137 and 138). This effect in the models is due to the transition from subvertical extension within a dome to subhorizontal extension within the overburden (above the dome).

The central axial portions of the Plumweseep and Penobsquis domes exhibit vertically lineated salt, with or without complimentary subvertical foliation. The mineral foliation is commonly weaker than the lineation, i.e. the average grain shapes tend to be prolate.

Near the crest of the Plumweseep dome, however, the diapiric material is schistose sylvinite. The schistosity,

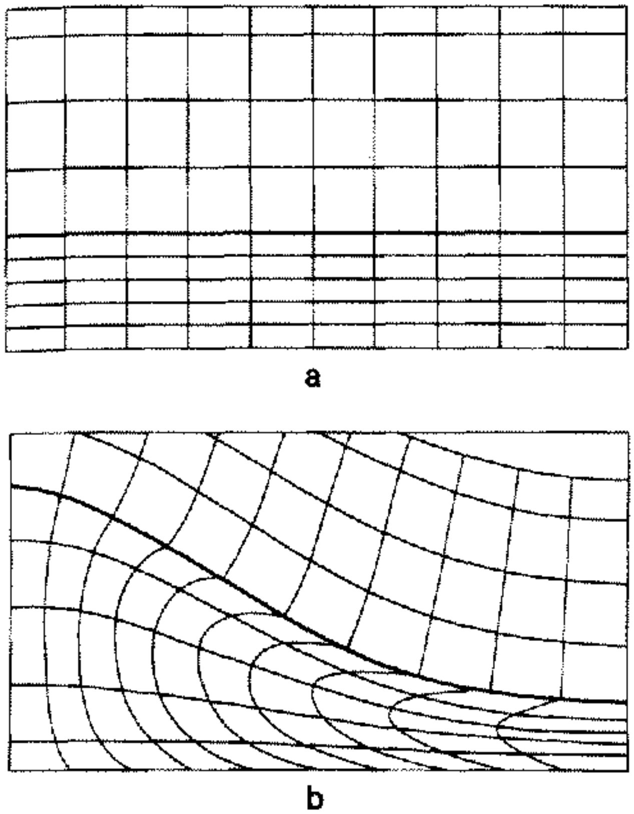


Figure 2. Distortion of a rectangular lattice due to doming. Initial cross section through a two-layer model (a), and radial section through a circular dome (b). Heavy line is interface between the low-density diapiric material and the high-density overburden (after Fletcher, 1967 and 1972).

complemented by a moderately strong mineral lineation, tends to be virtually horizontal. It is clear that these structures are at variance with those predicted from Fletcher's (1967, 1972) models. It should be noted, however, that the amplitudes of these simple models fall short of those for natural domes, which tend to have mushroom shapes. Moreover, the models are composed of homogeneous diapiric material, which cannot be claimed for the Plumweseep dome.

Thus except for the crestal region of the Plumweseep dome, one sees a qualitative agreement between the theoretical models and the observed mineral fabrics. This suggests that the inequant grain shapes of halite and sylvite, for both domes, are in fact due to diapiric flow. A more rigorous analysis would require strain models for diapiric materials which initially migrated into elongate anticlines, and subsequently entered into local domes.

FABRIC MODELS FOR HALITE AND SYLVITE

Based on Dillamore and Roberts' (1964) theory, a number of model fabric patterns for translation gliding of halite were constructed (Schwerdtner, 1968). These patterns depend on (1) the magnitude of progressive finite strain which the rocks have undergone, (2) the value of μ (Nadai, 1950, p. 106), which is a function of the principal components of deviatoric stress, and (3) possible rotations of the principal axes of stress during progressive deformation. Thus Dillamore and Roberts' theory is well-suited for application to real tectonites, as it is capable of taking into account the deformational history of a given domain of rock.

Fabric models for two values of μ were constructed (Schwerdtner, 1968), i.e. for $\mu = 0$ and $\mu = -0.6$ (compressive stress is positive). These groups of models correspond to the cases of pure shear (mineral lineation as prominent as foliation), and compression with differential extension in the "flattening" plane (foliation more prominent than mineral lineation). It was assumed that a given value of μ does not change during progressive deformation, although Dillamore and Roberts' theory can be adapted to discrete variations in μ. Unfortunately, no model for $\mu > 0$ was constructed, which would be required in the present study (cf. Schwerdtner, 1968).

Principal magnitudes of rock strain may be estimated from the overall shape of the mineral grains, which were presumably quasi-spherical before deformation. If the mineral fabric recrystallized syntectonically, then the finite strain recorded by the grain shapes will be smaller than the total strain (cf. Fletcher, 1967). The average grain shapes for all samples, analyzed from the Anagance anticline, suggest that the finite compressive strain was apparently greater than 50 per cent. (No accurate determinations of grain shapes were made in this study.) For this reason the fabric models for "very large strain" and "extreme strain" (Schwerdtner, 1968) would appear to be most applicable to the natural fabrics.

It is not difficult to find the local rotation axes of the stress directions within diapiric model structures (Fletcher, 1967, 1972), owing to the plane deformation in the diapiric anticlines and the axial symmetry of domes. Thus it can be readily shown that the local intermediate directions of finite strain coincide with the rotation axes throughout Fletcher's models. This would rule out the general fabric models for translation gliding of halite (Schwerdtner, 1968, Figs. 9, 12 and 15), and favour these models for which rotation of the principal stress directions occurs about a unique axis, i.e. the intermediate principal direction. One such model could be constructed by superimposing the patterns of Figures 3–6.

We must not forget, however, that the present small domes developed form a diapiric ridge, and that the transition from the first structural form to the second requires a deformation path with additional rotation components of the principal stress directions. During this transformation the direction of the ridge axis became a radial direction for certain locations within the domes. There one may

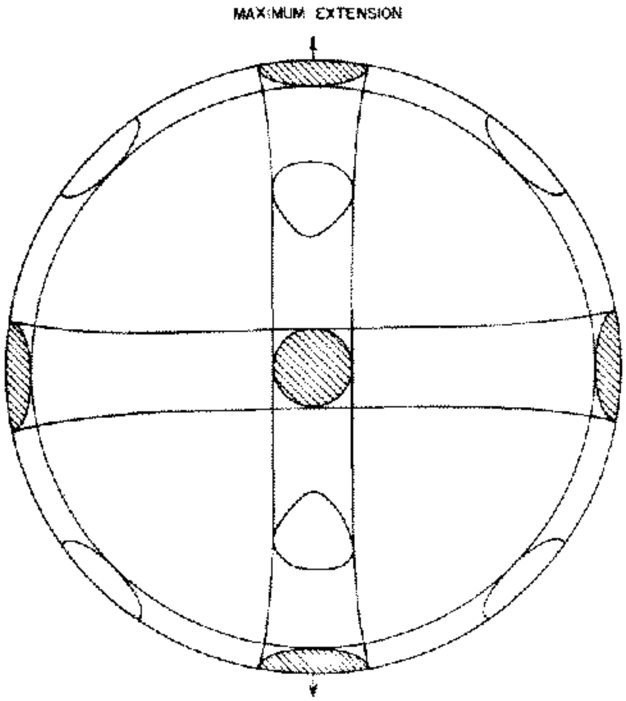


Figure 3. Model fabric pattern of <100> for translation gliding due to pure shear deformation. Rotation about the direction of maximum tension and the intermediate principal direction.

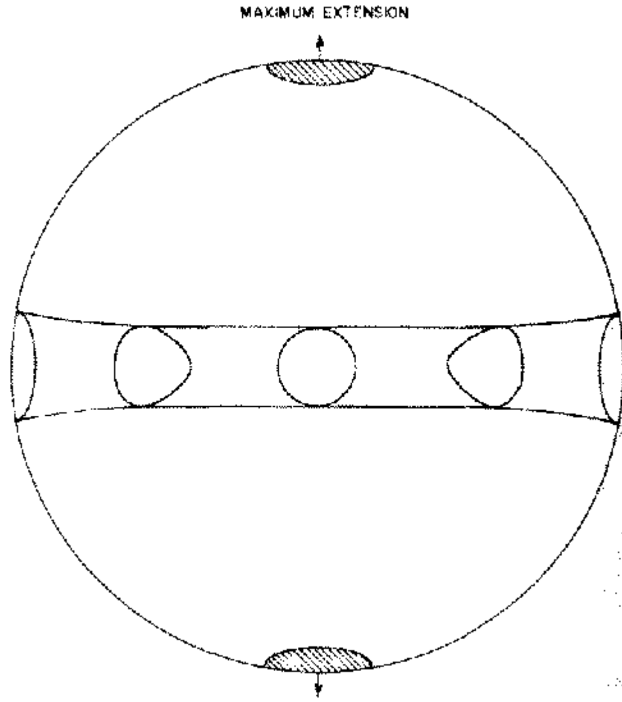


Figure 5. Model fabric pattern of <100> for pure shear and triaxial flattening strain. Rotation about the direction of maximum compression as well as about the intermediate principal direction.

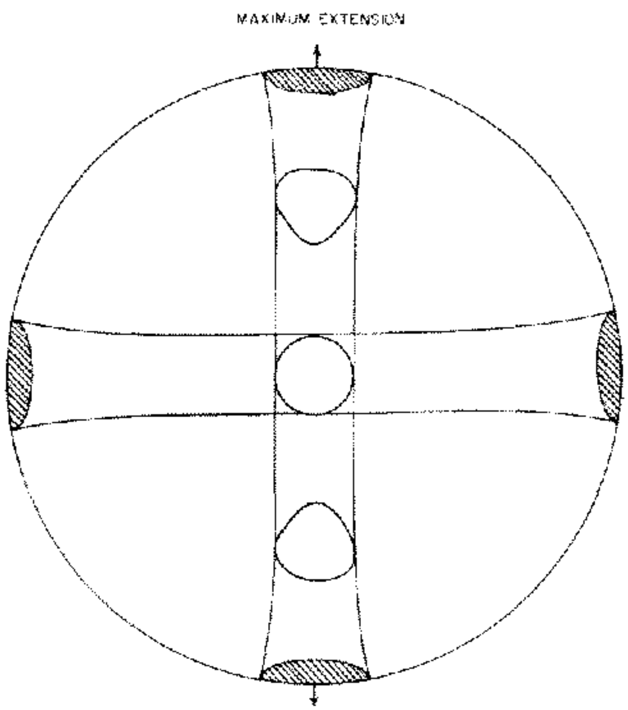


Figure 4. Model fabric pattern of <100> for triaxial flattening strain. Rotations as in Figure 3.

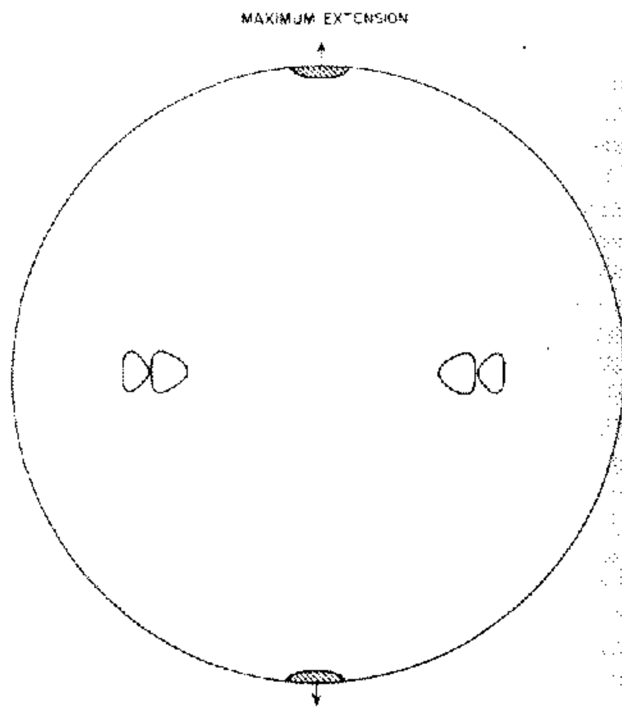


Figure 6. Model fabric pattern of Figure 5 after extreme strain.

infer that the formerly axial direction of minor longitudinal strain became a principal direction of compression (Fig. 2). Presumably the change in the direction of principal compression was relatively continuous, i.e. it involved a rotation about the local subvertical axis of principal tension. This consideration leads to models that allow rotations about two perpendicular axes, (1) the direction of maximum deviatoric tension and (2) the intermediate principal direction (Figs. 3 and 4). Where the subvertical principal axis is compressive, as appears to be the case for the horizontal schistose sylvinite in the Plumweseep dome, one might select a model in which rotation occurs about the direction of maximum compression as well as the intermediate principal direction (Fig. 5).

Model fabric patterns for syntectonic recrystallization of halite and sylvite according to Kamb's (1959) theory have been presented elsewhere (Clark and Schwerdtner, 1966) and need not be discussed here. Note, however, that these model patterns do not show maxima for <100> which are oblique to the principal directions of stress. Such oblique maxima characterize the fabrics at all four locations in the present domes.

NATURAL FABRICS

The evaporite samples available for study were taken from two drill cores (Plumweseep #1 and Penobsquis #1) located near the domal axes (Fig. 1). Two sets of thin sections were cut for each location, one parallel to the axis of the core, the other perpendicular to it.

Lattice orientations of halite and sylvite were determined on the optic universal stage by measuring the attitude of two cleavage planes per grain. Owing to the absence of conspicuous cleavage traces in some crystals it was impossible to measure every grain. Other grains exhibited only one cleavage set. Thus one must consider the possibility of a preferrential cleavage development, perhaps depending on the lattice orientation of individual grains with respect to the plane of sectioning. In order to avoid this effect and also to increase the number of points per fabric diagram, we combined the orientation data for both sets of sections at each location. Conventional fabric diagrams were constructed for <100>, which exhibit prominent textural patterns, such as great circle girdles and triple maxima at 90 degrees to each other (Fig. 7–17). Note that the combined diagrams do not always resemble the (partial) diagrams for the individual sets of sections (cf. Figs. 7–16). The apparent differences may be caused by the small sample size for the partial diagrams, or else by preferrential cleaving for a given set of sections (probable example: Figs. 9 and 10).

COMPARISON BETWEEN MODEL PATTERNS AND NATURAL FABRIC DIAGRAMS

It appears doubtful that enough grains have been measured per location to eliminate the effect of random sampling (Stauffer, 1966). Thus it may be advantageous to employ a method of subjective comparison between fabric

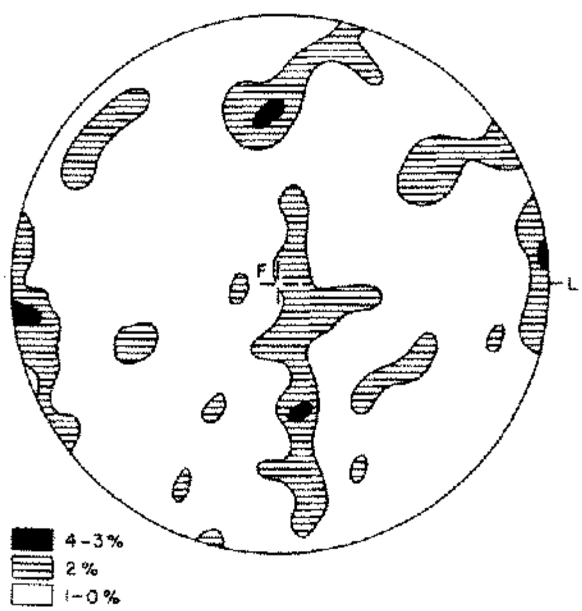


Figure 7. Natural fabric for <100> of halite in sylvinite from Plumweseep dome (957'-958' depth in Plumweseep #1 drill hole). Diagram contoured by free contour method and a standard counter circle of 1 cm radius. Total number of poles is 454.

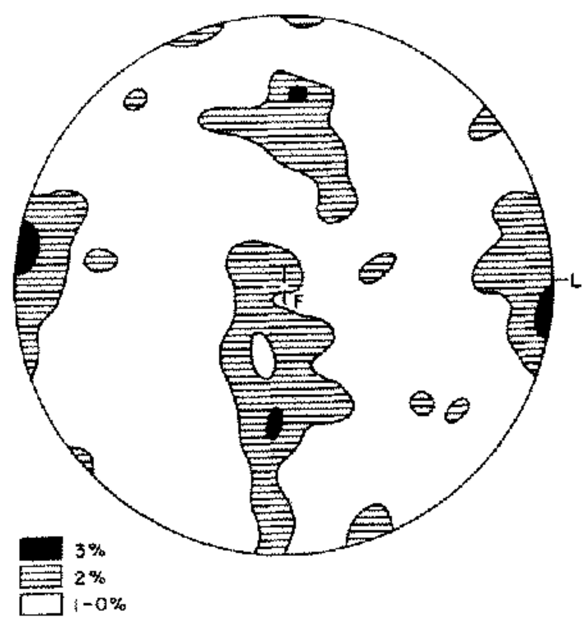
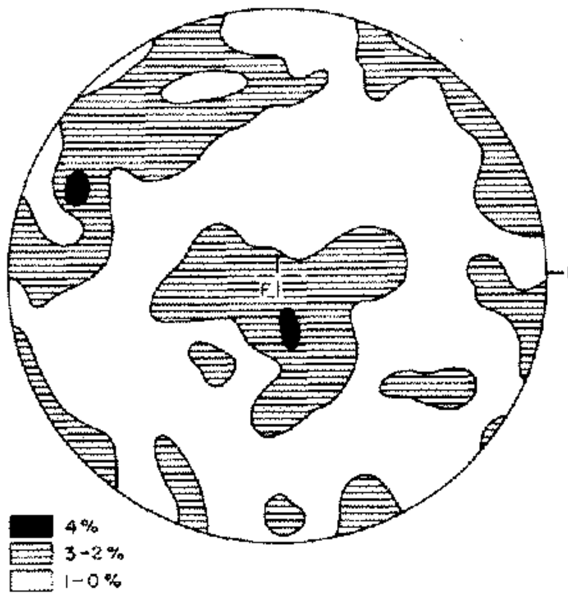
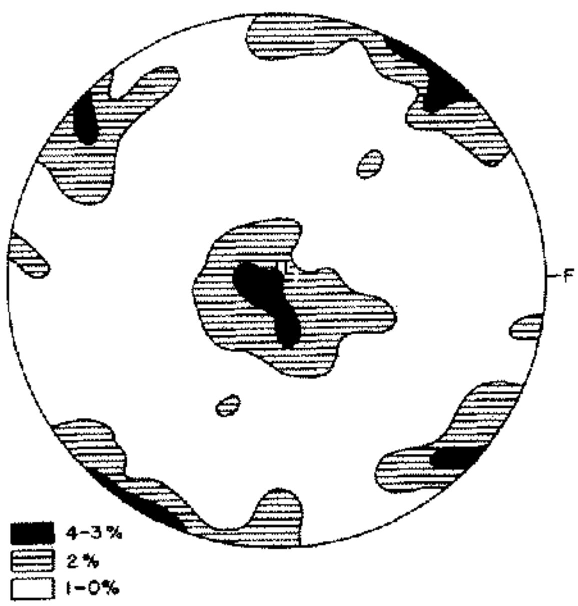


Figure 8. Fabric diagram for sylvite in Plumweseep sylvinite (see legend of Figure 5). 453 poles.





Figures 9 and **10.** Partial diagrams for Figure 8 (Plumweseep sylvite), 197 and 256 poles, respectively. Note differences between the two contour patterns.

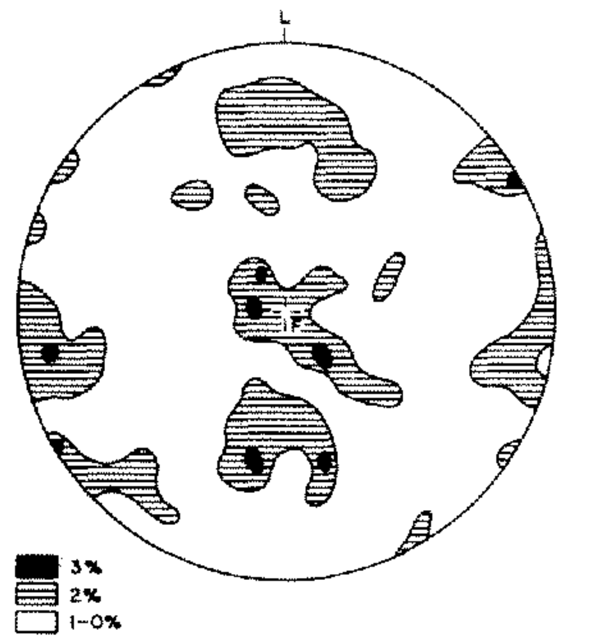


Figure 11. Fabric diagram for brownish salt in Plumweseep #1 (895'-896' depth). 433 poles.

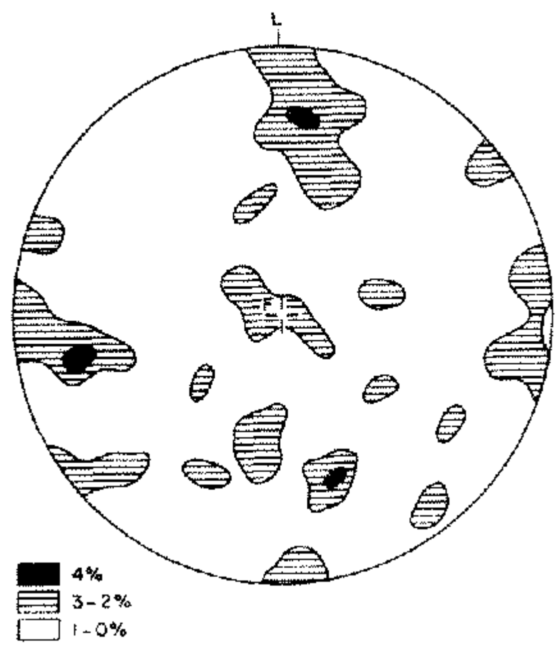


Figure 12. Partial diagrams for Figure 11, 205 and 228 poles, respectively.

diagrams and model patterns. Let us first consider the sylvinite from the Plumweseep dome (Figs. 7 and 8), for which the model of Figure 5 had been suggested. Note that the comparison is relatively good, except for the orthogonal submaxima perpendicular to direction of maximum extension. Perhaps the natural fabrics for halite and sylvite represent a transitional stage between the models for "very large strain" and "extreme strain" (Figs. 5 and 6). The same models should be applicable to the brownish foliated salt above the sylvinite zones (Figs. 11–13), but one finds instead that the natural fabric is similar to the model patterns which had been selected for the vertically lineated axial portions of the domes (Figs. 3 and 4). Again there seems to be a transitional stage between the models for "very large strain" and "extreme strain."

Finally, we note that the natural fabric diagrams for the vertically lineated salt from the Penobsquis dome resemble one of the pre-selected model patterns (Fig. 4). The

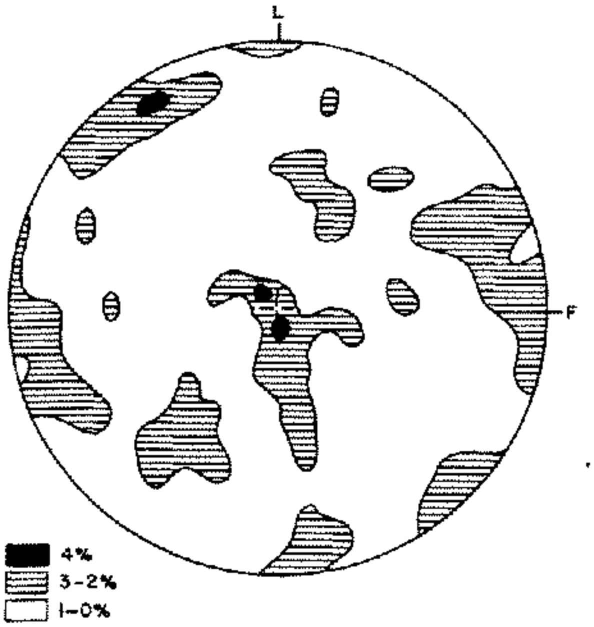


Figure 13. Partial diagrams for Figure 11, 205 and 228 poles, respectively.

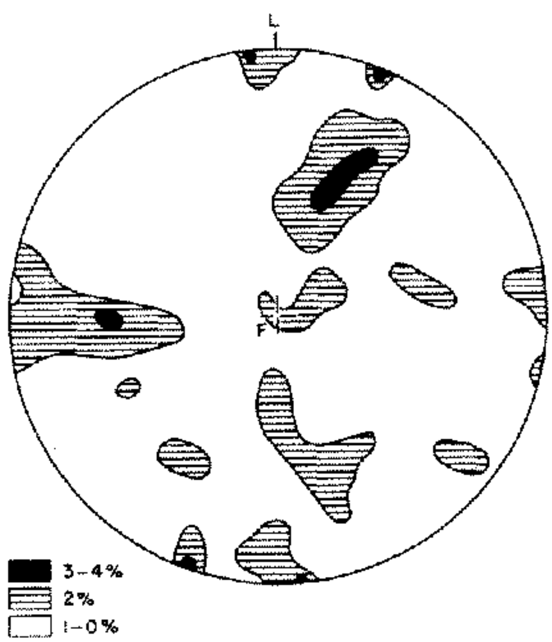
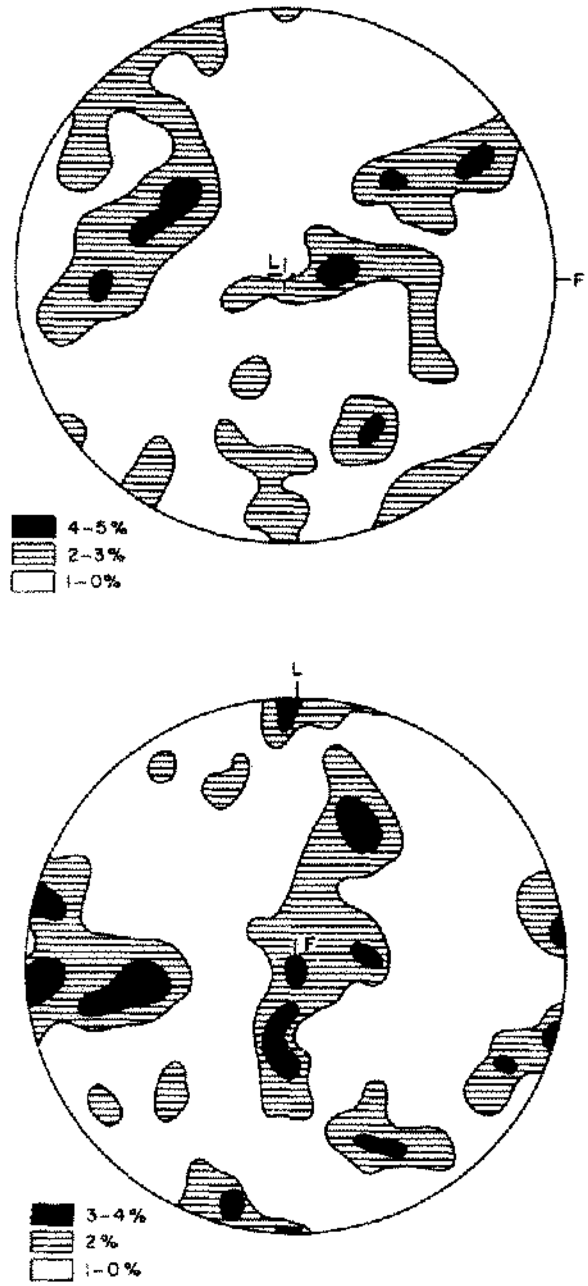


Figure 14. Fabric diagram for vertically lineated salt for Penobsquis #1 (2870'-2880' depth). 431 poles.

comparison is particularly good for the thin sections parallel to foliation (Fig. 15), and we wonder whether the small sample from the sections normal to foliation does not introduce some experimental bias, perhaps due to preferential development of crystal cleavage (Fig. 16).

Another difficulty lies in the fact that no model fabrics for $\mu > 0$ are available, which would be required for



Figures 15 and 16. Partial diagrams for vertically lineated salt from Penobsquis #1 (Fig. 14). 190 poles and 241 poles, respectively.

predominantly lineated salt. It may be expected, however, that the published model patterns for pure shear and triaxial flattening strain would still apply for constriction-type deformations (Schwerdtner, 1968). Indeed one sees only a few differences between the models for $\mu = 0$ and $\mu = -0.6$. These differences are caused by changing the deformation scheme for a single metastable lattice orientation, labeled DG in the original paper (Schwerdtner, 1968). We therefore determined the most favoured gliding systems for this lattice orientation and $\mu = 6$, which are needed for choosing between the model patterns for pure shear and flattening strain. As might have been expected the models for $\mu = 6$ (constrictive deformation) are apparently similar to those for $\mu = -6$ (triaxial flattening strain). This in turn suggests that Figure 4 should indeed be used for comparison with Figures 14–17. We feel that the agreement between model and natural fabrics is rather good.

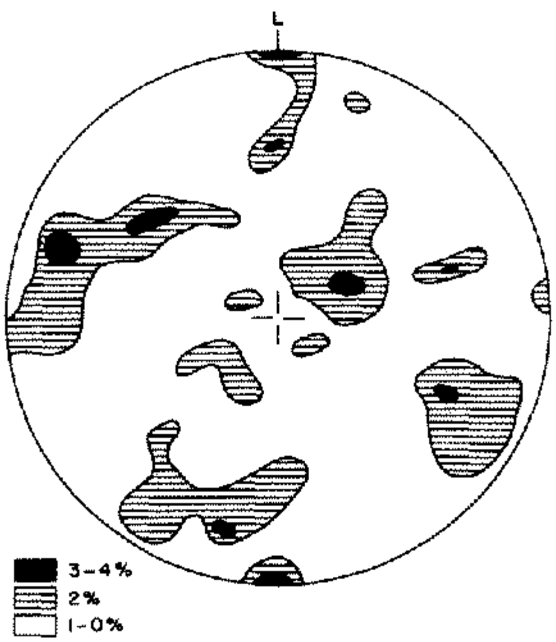


Figure 17. Fabric diagram for subvertically lineated salt from Penobsquis #1 (2865'-2866' depth). 355 poles.

CONCLUSIONS

The natural fabric patterns for halite and sylvite from the Anagance anticline are characterized by oblique submaxima, which are incompatible with the model patterns predicted by Kamb's (1959) theory of syntectonic recrystallization, but resemble certain model patterns for translation gliding (Schwerdtner, 1968). Based on theoretical dynamic models of diapiric structures (Fletcher, 1972), specific fabric models could be selected for comparison with the natural fabric patterns.

Rock salt and sylvinite in the Anagance anticline are generally composed of aligned inequant grains, whose elongate shapes appear to be due to plastic deformation (intragranular gliding) and subsequent recovery (polygonization). Rock salt and sylvinite from the Gulf Coast domes and German salt stocks, on the other hand, are characterized by equant or subequant grains. Nevertheless one will obtain natural fabric patterns, for instance in the Gulf Coast domes (Schwerdtner, 1968, Fig. 20), which appear to be indistinguishable from those for the Anagance anticline. If the Gulf Coast salt deformed by translation gliding, then the present (subequant) grain shapes must be due to annealing recrystallization. Such a drastic process would tend to operate in deep rooted salt structures such as the Gulf Coast domes (due to the high thermal conductivity of salt), but may be of lesser importance in shallow-level structures, such as the Anagance anticline (cf. Hamilton, 1971, Schwerdtner, 1971).

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