New Methods in Textural and Fabric Analyses of Rock Salt Related to Mechanical Test Data, Tostrup Salt Dome, Denmark

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ABSTRACT

Two new methods for textural and fabric analyses are described and some preliminary relationships between petrographical data and uniaxial strength of rock salt are given.

For textural analysis a rock slab is polished and placed in a slightly oversaturated NaCl brine where the crystals of the sample are allowed to grow. Their surfaces will be covered by stacked Haüyian cubelets with the same crystallographic orientation as the mother crystal. Acetate repli of this surface are produced and they can be used as large thin sections where both grain boundaries and crystallographic orientations are reproduced.

For fabric work, samples covered by the Haüyian cubelets are mounted on a universal stage and reflection measurements are performed. A quick statistical method for producing complete fabric diagrams from half-spheres and spherical samples is advanced.

The uniaxial strength of the rocks studied here shows a clear inverse correlation to the dip of foliation, and deviations from this relationship can be explained by textural parameters like crystal size, flattening and degree of intergrowth between the crystals.

INTRODUCTION

The present paper is a progress report on the petrography of the Tostrup salt dome in northern Jutland (see location in Fabricius, this volume, pg. xx, Figure 1) partly in order to relate textural and fabric data to the mechanical tests of the rock salt and partly as a contribution to the general description and structural interpretation made by Jacobsen (1982). Dansk Olie og Naturgas A/S (D.O.N.G.) has selected this salt dome for storage of natural gas, and seven wells have been drilled in the search for pure rock salt of Zechstein 1 and 2. In addition, some textural analyses have been carried out on core material from the nearby Mors salt dome.

Conventional petrographical work on thin sections is generally hampered by the coarse grained and friable nature of rock salt and the use of cut surfaces is not satisfying for more detailed work. Furthermore, fabric studies are tedious, especially by using thin sections on a universal stage. Goniometer reflection measurements on cleavage surfaces on rock samples (Clabaugh, 1962; Clarke and Schwerdtner, 1966) also appear to be rather time consuming, and X-ray and neutron diffraction methods can be used only on fine-grained samples. During the present work a new preparation technique was developed for both textural and quick fabric analyses: Haüyian cubelets are grown on polished samples and acetate replicas can be produced of the surface for textural work, and reflection measurements can be performed on the sample for fabric work. These methods together with some preliminary results obtained so far will be given below.

ANALYTICAL METHODS

The method is based on the fact that NaCl can be precipitated on ground surfaces of rock salt in optical continuity with the existing crystals below. The sample (e.g., rock slab) is ground with a fine grade corundum paper and is placed one to two hours in a saturated sodium chloride brine. The brine is allowed to evaporate and the crystals in the sample start to grow along the groove marks, producing stacked cubelets (Figure 1). For textural work, the treated rock slab is covered with acetone, and a transparent acetate film (e.g., 0.2 mm in thickness) is rolled on, so that air bubbles are removed. The film is removed after some minutes, dried and later ironed. Because holes in the sample will spoil the replica, care must be taken in its production. It can be used directly as large thin sections. In order to enhance the contrast between each grain the film can be photographed on a black background with side illumination from below. An example is

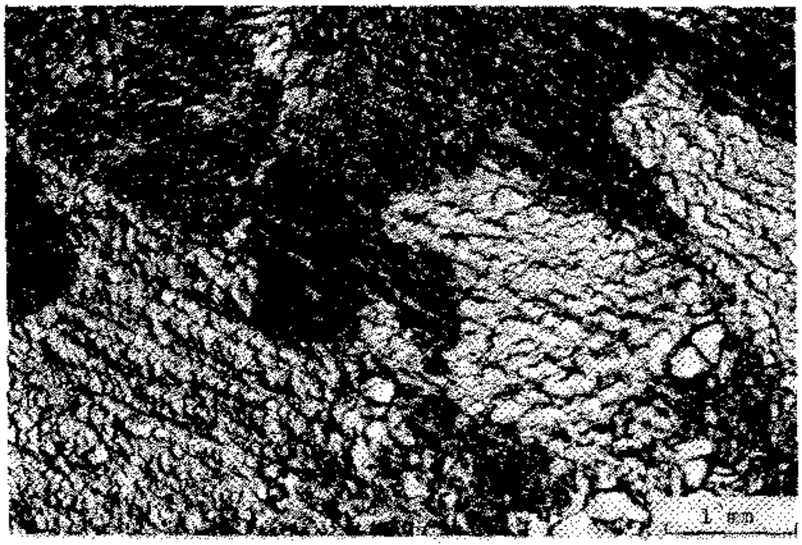

Figure 1. Surface of a replica produced from a rock salt slab covered with stacked Haüyian cubelets as produced by the method described in the text. Transmitted light photograph.

shown in Figure 2. In order to show the textures more clearly and for image analysis work the grain boundaries have been contoured with a tusch pen (Figure 3).

Fabric analyses have been performed on half-spheres about 5 cm in diameter mounted on an ordinary universal stage. The set up of the universal stage is shown in Figure 4. The use of a Wild, model number M7s, with the front lens removed, will give some uncertainties (ca. 5%) on reflections measured 2.5 cm away from the microscope axis. Ideally the front lens should be at least equal to the sample in diameter to ensure that vertical light from all parts of the sample is detected. The advantage by using half-spheres is that the measurements can be performed in a statistical way along prescribed steps of inclination (2–5°) covering the whole Smith net and at even measuring reflections for inclinations above 90°. In general, however, only two reflections from each crystal will be detected. The reflection method can also be used for exact measuring and construction of the cubic surfaces of each crystal. In this case the method will still be relatively rapid.

FABRIC ANALYSES

Reflection measurements were performed on some vertically foliated specimens from the Tostrup-8 well and were carried out partly by the statistical method and partly by determining the orientation of each crystal (Figures 5 A-D). The maximum concentrations of reflections are, in general, poorly defined by concentration levels of 1.5 to 3 per cent of the total number of reflections. The fabric diagrams show fairly well defined maxima along the a, b, and c axes as well as oblique to these directions within each plot. It should be noted that inclination of the universal stage will reduce the visible area and number of crystals. This problem has partly been overcome by measuring reflections in the overturned position. For future work preparation of spherical samples is in progress. Measurements on single crystals demonstrated that many crystals show undulating reflections in the order of 5 to 10°, showing that they are strained.

These preliminary data do not indicate any strong preferential orientation of the fabric. This may be due to recent differential movements or to gliding along cubic and dodecahedral planes in different crystals within the mass of the sample measured (Muehlenberger and Clabaugh, 1968). The latter explanation was not favoured by these authors, but it cannot be excluded in the present case: Muehlenberger and Clabaugh (op. cit.) state that two (100) pole maxima in the foliation plane suggest slip along the cubic planes, whereas one maximum in the foliation plane suggests dodecahedral gliding. Both these fabric types appear to be present in Figures 5 A, B and D. It is not certain whether the strained crystals are the result of recent differential movements or are related to the change in physical conditions from core depth to ground level.

TEXTURAL ANALYSES

Different textures of the rock salt from the Tostrup and Mors salt domes are shown in Figures 6 A-J as reproduced from the acetate peels. The textures range from hypidiomorphic-granular to strongly foliated. The foliation may be overprinted by cataclastic-like textures as in Figure 6 G, whereas syntectonic crystal bending and recrystallization

Figure 2. A replica of rock salt photographed with a black background.

have occured along shear planes as seen in Figure 6 H. The shearing here took place at the interface between anhydrite poor and anhydritic rock salt due to differential movements between rocks of different competance. In some places (e.g., Figures 6 E and H) large lentil-shaped areas are composed of several grains whose boundaries do not influence the curvature of the large form. Such areas may represent polygonarized crystals.

The form of the grains in the foliated rocks is that of a flattened ellipsoid with the a-axis parallel to the foliation dip, the b-axis parallel to the strike direction and the c-axis at right angle to the foliation plane. In some cases, however, the position of the a and b axes or the b and c axes may be reversed in relation to the foliation plane. Measurements of the axes are given in Table 1. Although the shape of the crystals may be compared with an ellipsoid, it is obvious that the crystals show different degrees of interlocking textures which appear to be related to the degree of flattening (compare Figures 6 C, D and F). These textural differences must have an influence on the strength of the rock salt, and image analyses are in progress in order to determine the grain dimensions, size distribution and form factors.

TEXTURAL DATA RELATED TO THE MECHANICAL STRENGTH OF THE ROCK SALT

Uniaxial tests of the rock salt have been performed at the Danish Technical University (DTH) and Lehrgebiet für Unterirdisches Bauen, Hannover University (LUB-HU).

The uniaxial strength of the rock salt combined with the geological data show that the steeply foliated samples are weaker than samples with low dipping foliation, lack of foliation or of fine grain size. The fractures generated in the uniaxial tests followed the foliation in samples where it is dipping more than 50°. In order to show this relationship more clearly, the dip of the crystal foliation was measured on the tested samples where these (or good photographs) were available. Also the remaining core material was reinspected to check the relationship between the crystal foliation and bedding orientation obtained from the anhydritic bands. Figures 7 A-C show the relation between the dip of foliation and the uniaxial compression strength: Rock salt from Tostrup-3-5-6-7 and Erslev-1-2 (from the Mors salt dome) show an inverse correlation along the same line, whereas Tostrup 8-9-10 correlate with a steeper inclined line. Thus vertically foliated samples from the latter wells are stronger than those of the former Tostrup wells. The fine grained specimens are unusually strong (24-34 MPa). These rocks originate from cores recovered close to the salt mirror, and their texture may reflect a high level recrystallization.

Although the different correlation lines have been produced from data obtained in different laboratories, and thus could be due to different measurement conditions, test results for the Tostrup-6 well give similar low strength. It has not been possible to relate the strength differences to the anhydrite content or chemical composition, and for this reason textural factors are believed to be the explanation. The different textures of the Tostrup-6 and Tostrup-8 wells are shown in Figures 6 C, D and E, F. It is obvious that the Tostrup-6 salt is much more flattened and has more straight grain boundaries than the Tostrup-8 salt. To some extent the scatter in the strength of the Tostrup-6 salt can be explained by different degree of interlacking grain boundaries; e.g., Figure 6 E represents core material with an uniaxial strength of 17.9 MPa and Figure 6 F a core with a uniaxial strength of 14.4 MPa (DTH results).

Thus factors such as the a/c ratio and the form factor

Figure 3. Crystal boundaries marked on a replica of rock salt.

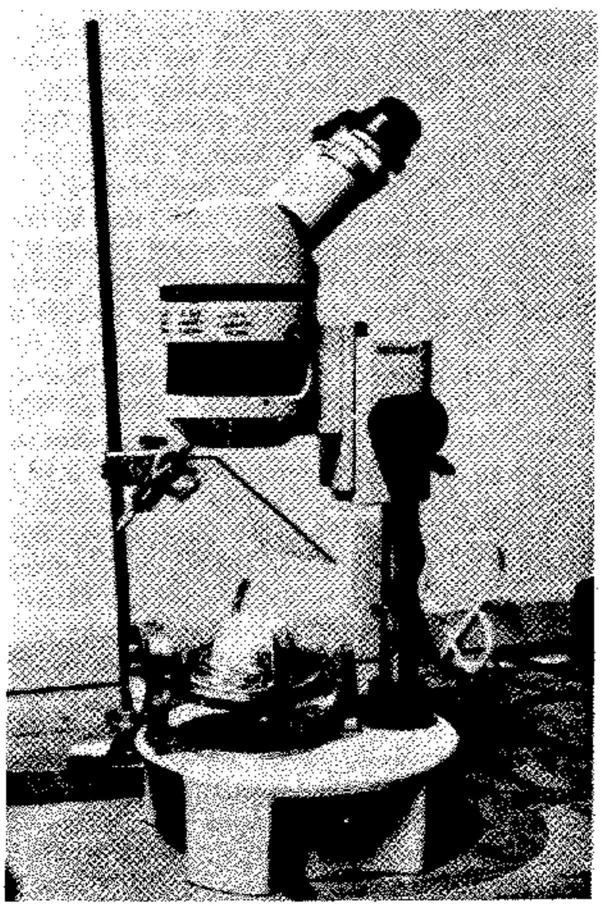

Figure 4. A setup for fabric reflection measurements. The parallel light is produced by a condensor lens and is reflected onto the half-sphere rock salt sample.

(perimeter/area) related to the total length of the grain may be important parameters for the strength of steeply foliated rock salt. For foliation dip below 40° the crystallographic orientation of the halite may play an important role, especially if there is a tendency for two cleavages to be orientated at right angle to the foliation plane as indicated by the fabric data.

CONCLUSIONS

During the petrographical work on the Tostrup salt dome some new methods have been developed which make it possible to produce large peels of rock salt for textural and crystallographic studies and samples for fabric analysis by reflection measurements. It is hoped that these new methods will initiate further petrographical work in order to expand our knowledge about the mechanical behavior of rock salt.

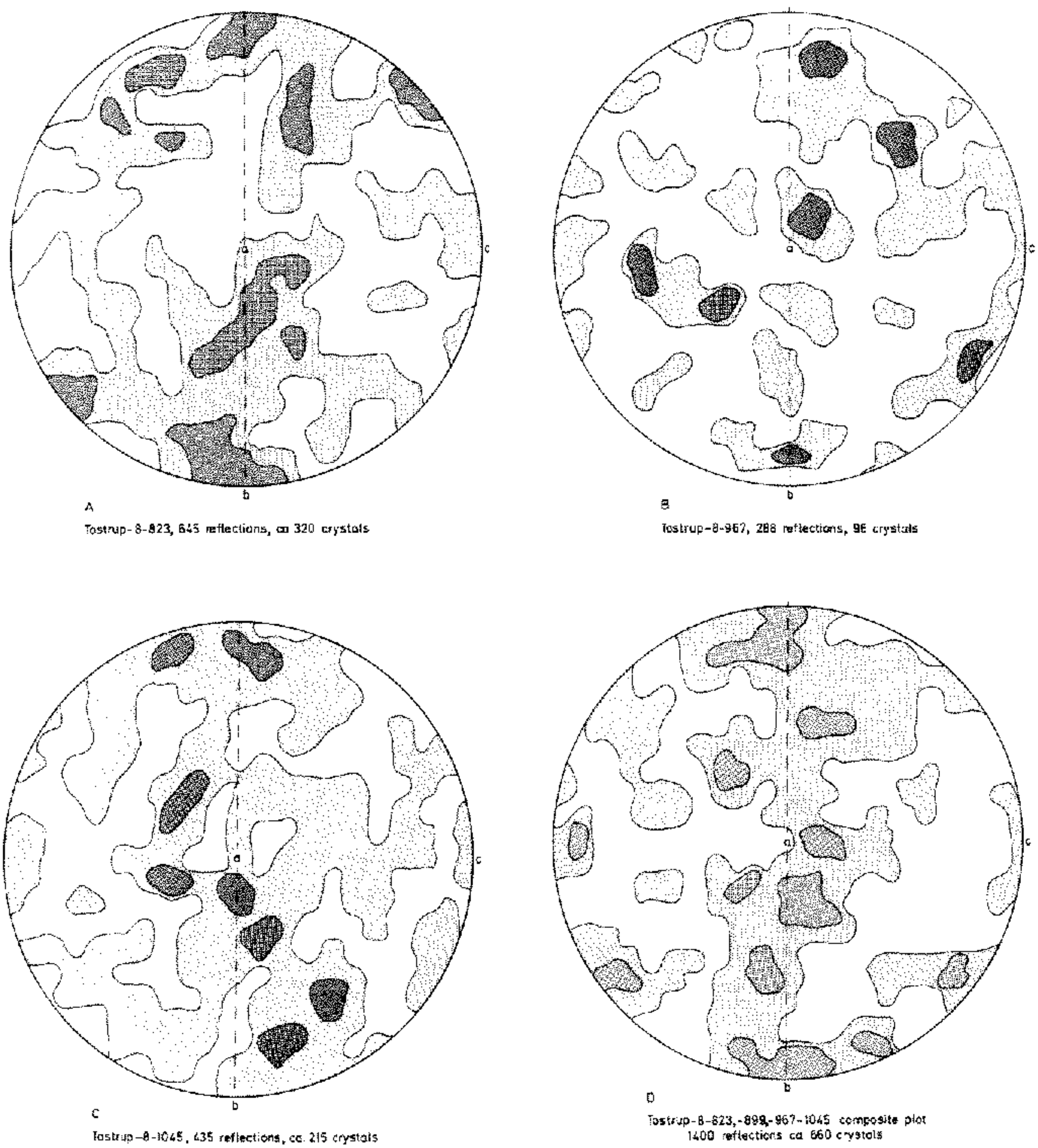

Figure 5ABCD. Fabric reflection measurements after the statistical method (A and C) and after exact measurements on each crystal (B). Both methods are included in the composite plot (D). Smith net plot of the upper sphere. White areas: below 1% reflections; light dotted: 1-2% reflections in A, B and C, and 1-1.5% in D; medium dotted: above 1.5% reflections; heavy dotted: above 2% reflections. In all cases the values give per cent reflections within 1% of the total area. Stippled line: foliation plane; a, b, and c are the axes in the strain ellipsoid.

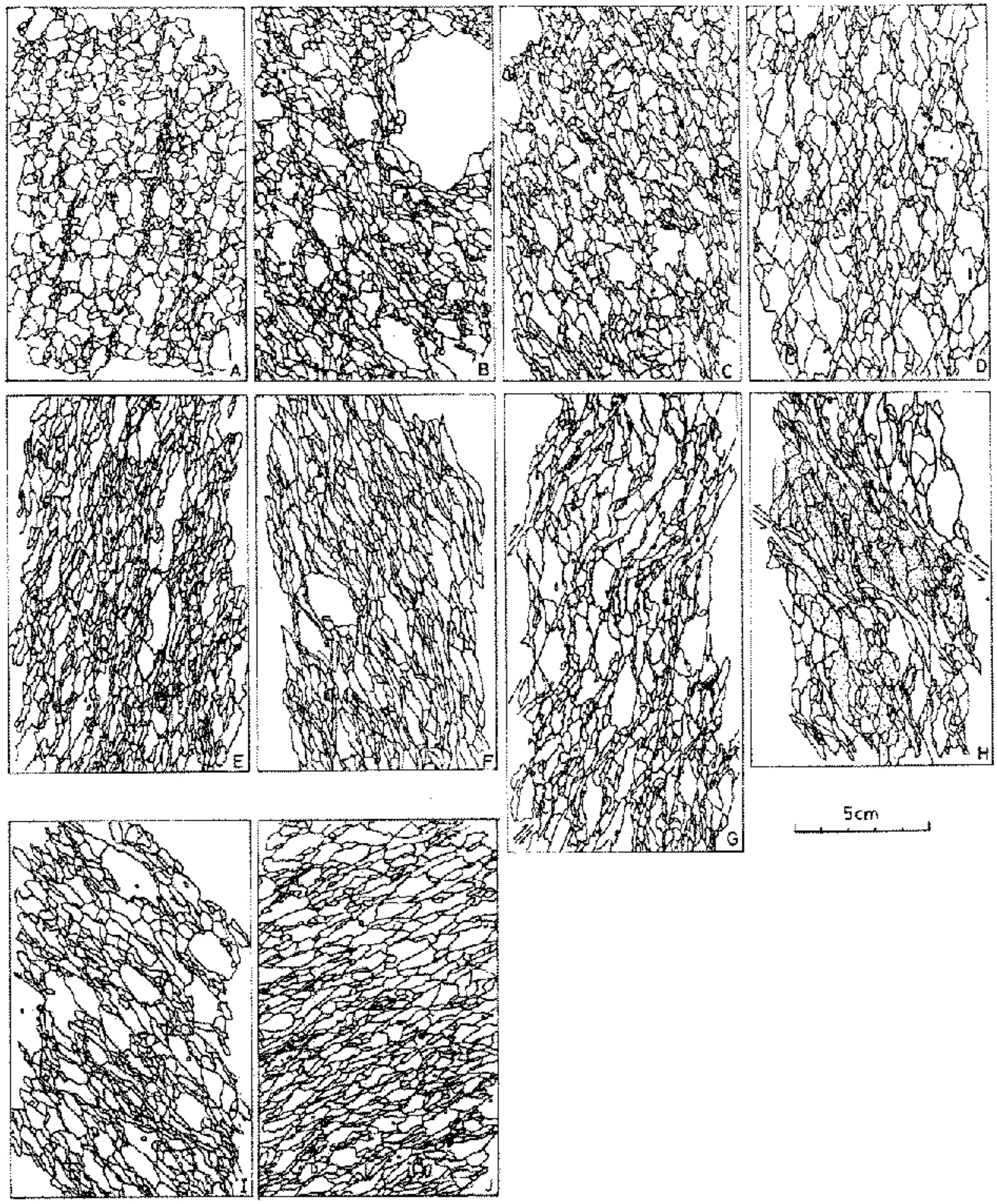

Figure 6. Textural types from the Tostrup and Mors salt domes: A. Tostrup-8-1402m: Hypidiomorphic-granular, red Z3 salt. The fine grained streaks are parallel to the bedding. Uniaxial compression strength: 24.2 MPa. B. Tostrup-5-0799m: Weakly foliated, porphyroblastic Z2 salt. Uniaxial compression strength: 20.0 MPa. C. Tostrup-8-1046m: Weakly foliated Z3 salt with uneaven grain boundaries. Uniaxial compression strength: 19.8 MPa. D. Tostrup-8-0873m: Foliated Z2 salt with angular to ellipsoid grain boundaries. No mechanical data. E. Tostrup-6-0550m: Strongly foliated Z1 salt with somewhat interlocked grain boundaries. Uniaxial compression strength: 17.9 MPa. F. Tostrup-6-1216m: Strongly foliated, porphyroblastic Z1 salt with even grain boundaries. Uniaxial compression strength: 14.3 MPa. G. Tostrup-8-1354m: Cataclastic overprinted, foliated Z2 salt. Uniaxial compression strength: 20.9 MPa. H. Tostrup-8-1306m: Steeply foliated Z2 salt sheared along an anhydritic band. Note the bended crystals. ?Polygonatized crystals are set off by a thicker line. Uniaxial compression strength: 21.1 MPa. I. Erslev-2-2477m: Foliated heteroblastic Z salt. Uniaxial compression strength: 22.3 MPa. J. Erslev-2-1281m: Well foliated Z salt. Uniaxial compression strength: 20.6 MPa.

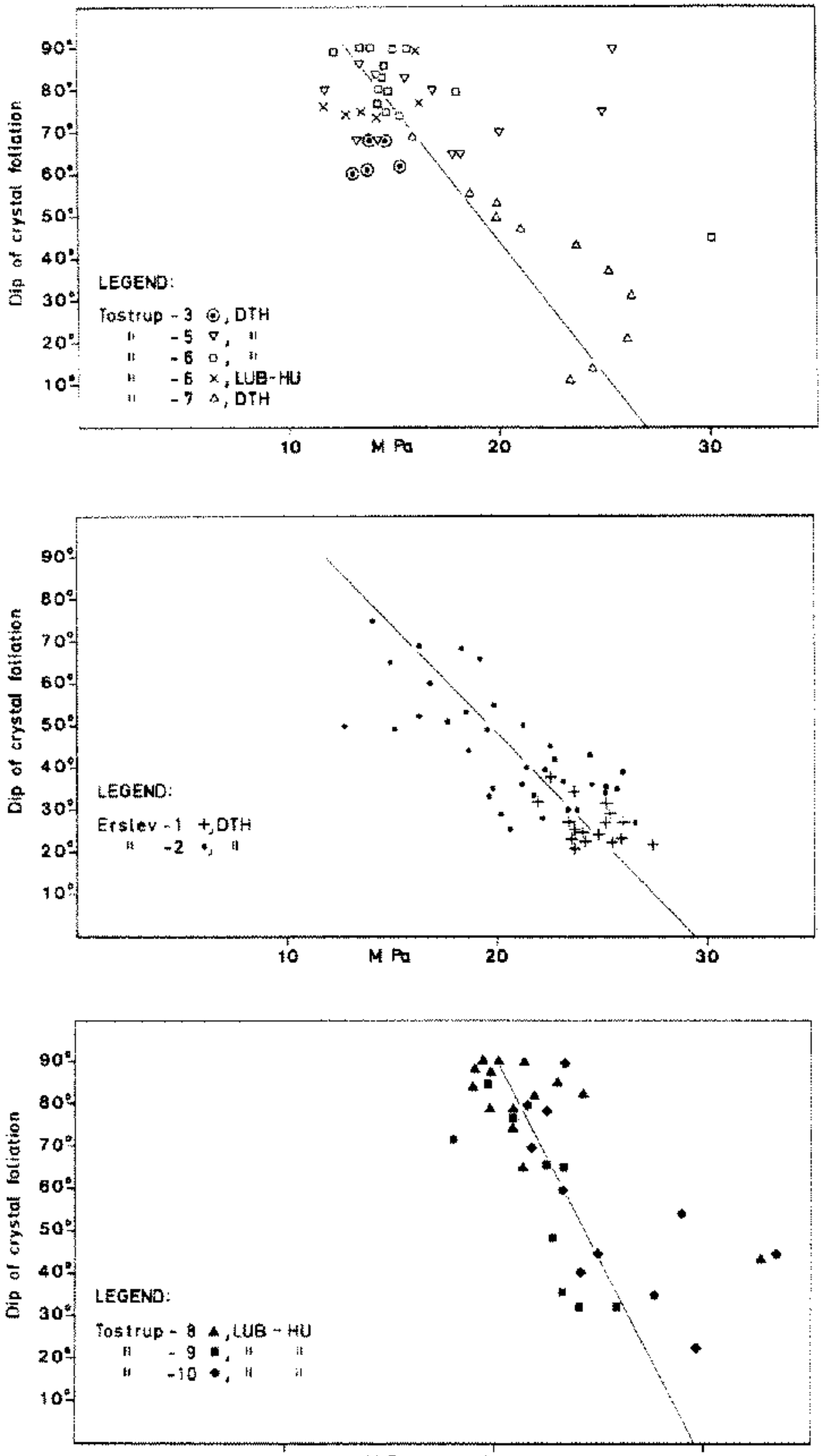

Figure 7abc. Dip of foliation versus uniaxial compression strength. Linear regression gives the following results: a. MPa intercept: 27.1, slope: −6.32, correlation coefficient: −0.83. (three data points excluded). b. MPa intercept: 29.4, slope: −5.15, correlation coefficient: −0.78. c. MPa intercept: 29.7, slope: −9.43, correlation coefficient: −0.75. (two data points above 30 MPa are excluded).

TABLE 1

Preliminary Strain Ellipsoid Measurements, Foliation Dip and Uniaxial Compression Strength

Well	Depth m	a mm σ	c1 mm σ	b mm σ	c2 mm σ	a/c1	b/c2	Fol. Dip	u.s. MPa
Tostrup-5	799	3.2 ± 3.1	1.1 ± 0.8	5.0 ± 5.1	1.3 ± 1.0	2.9	3.8	20°	20.0
Tostrup-6	550	5.1 ± 5.8	1.0 ± 0.6	4.9 ± 5.0	1.1 ± 0.8	5.1	4.5	80°	17.9
Tostrup-6	806	11.6 ± 5.1	2.5 ± 0.8	4.2 ± 3.5	1.2 ± 0.8	4.6	3.5	90°	15.1
Tostrup-6	1022	11.0 ± 5.7	2.2 ± 0.8	7.5 ± 3.7	2.2 ± 0.9	5.0	3.4	90°	13.5
Tostrup-6	1216	5.7 ± 5.3	1.0 ± 0.7	4.2 ± 4.2	1.2 ± 0.8	5.7	3.5	80°	14.3
Tostrup-8	1402	6.3 ± 3.2	2.8 ± 1.1	3.4 ± 3.0	1.4 ± 1.0	2.2	2.4	78°	24.2
Tostrup-9	898	9.7 ± 3.6	3.7 ± 1.2	7.7 ± 3.6	4.0 ± 1.5	2.6	1.9	62°	18.0
Tostrup-9	1046	8.9 ± 4.0	2.8 ± 0.9	3.8 ± 3.9	1.3 ± 0.9	3.2	2.9	66°	22.5

a: longest grain length in the dip direction (average of more than 200 grains)
c1: average grain thickness obtained from grain area/a (average as above)
b: longest grain length in the strike direction (average as above)
c2: average grain thickness obtained from grain area/b (average as above)
σ: standard deviation. u.s.: Uniaxial compression strength.
The results were obtained on a Leitz TAS image analyser at Institute of Technology, Tåstrup.

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