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NATURAL CENTRIFUGAL DEFORMATION

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Abstract: The paper describes deformation structures in paragneisses, occurring in form of isolated centres of extension deformation attributable to the direct action of centrifugal push of fluids. The structures are named explosive structures. The mechanism of their formation is explained in terms of hydraulic fracturing.

Key words: hydraulic fracturing, explosive structure, endogenous stress, exogenous stress, effective stress.

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DESCRIPTION OF EXPLOSIVE STRUCTURES

Paragneisses occurring in SW metamorphic cover of the Strzelin massif, in vicinities of Doboszowice (Foresudetic Block, SW Poland; Wójcik, 1968) reveal microstructures that can be regarded as isolated centres of extensional deformation (Pl. I: 1, 2). The structures are composite, they consist of a central part and of radially directed extension fissures surrounding it. The central parts are pores or pseudomorphs after non-identified mineral, now filled with Fe-hydrated oxides. They are usually ovoid, 0.5—1.5 mm in size. The fissures are numerous, 19—37 in one microstructure, rectilinear, 0.2—1.7 mm long. The fissures are also filled with Fe-hydrated oxides. Individual microstructures occur at distances of 4—7 mm and more from one another, so that interference of radial fissure aureoles from neighbouring microstructures was not observed in the thin sections examined.

The form of described structures is intuitivaly associated with forms resulting from explosions, in agreement with their inferred origin. For this reason they are referred to as "explosive structures".

The mineral background of the explosive structures consists of quartz and feldspar grains. Epidote and partly chloritized biotite occur in subordinate quantities (2—5% vol.). The quartz and feldspar display irregular reaction to polarized light. Undulatory extinction is observed in some grains. It varies from very weak to banded undulatory extinction. This kind of substructures is characteristic for intermediate phases of the deformation leading to formation of subgrains and dislocations in quartz and feldspar (White, 1973; Olsen & Kohlstedt, 1985). The boundaries of undulatory extinction display regular arrangement with respect to the centres of explosive structures. The boundaries are grouped in two sets. One set is oriented tangentially to the phase boundaries rock—void space, and the other is radially oriented (Figs. 1, 2).

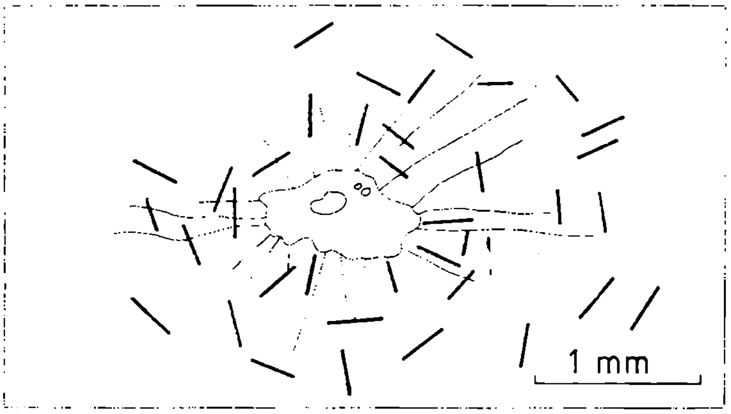

Fig. 1. Distribution of banded undulatory extinctions in quartz grains around the explosive structure from Pl. I: 1

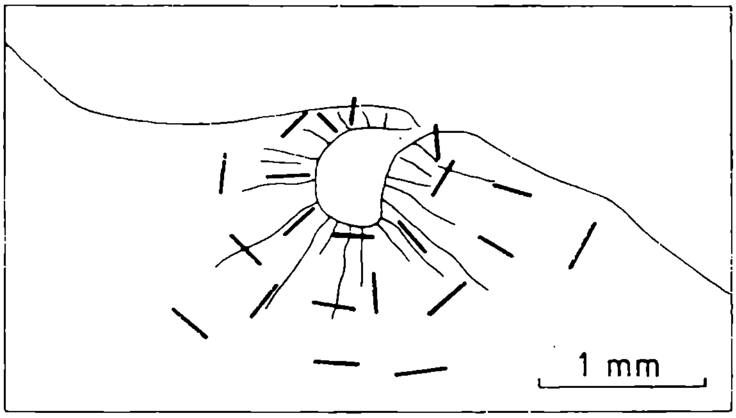

Fig. 2. Distribution of banded undulatory extinctions in quartz grains around the explosive structure from Pl. I: 2

The undulatory extinction and banded undulatory extinction substructures are dissected by extension fissures (Pl. II: 1). The resultant grain fragments are neither rotated nor displaced when compared across the fissures.

The microscopic observation revealed incompletely developed explosive structures. They lack the aureoles of extension fractures. The proposed explanation is that they represent an intermediate stage of the deformation. A fragment of the phase boundary in one of such structures is shown in Pl. II: 2. The deformation proceeded from right to left. Three zones can be distinguished in this direction, each displaying different degree of mineral deformation. First is the crushed zone (*cf.* Pl. II: 1). This is relatively narrow and contains fine, strongly rotated fragments embedded in a ground mass composed of pulverised minerals and Fe-hydrated oxides. Much broader is the zone of brecciation. This is composed of mineral fragments, earlier plastically deformed, then rotated to a different degree. Towards the left the rotation disappears, and plastic deformation takes place of the brittle deformation; the third zone is that of the plastic deformation.

The extension fissures of separate explosive structures display similar spatial arrangement (Fig. 3). The fissures dip steeply at 70—90° with respect to the plane of thin section. The constant dip and the radial disposition of the fissures determine their tendency to form a common transect edge.

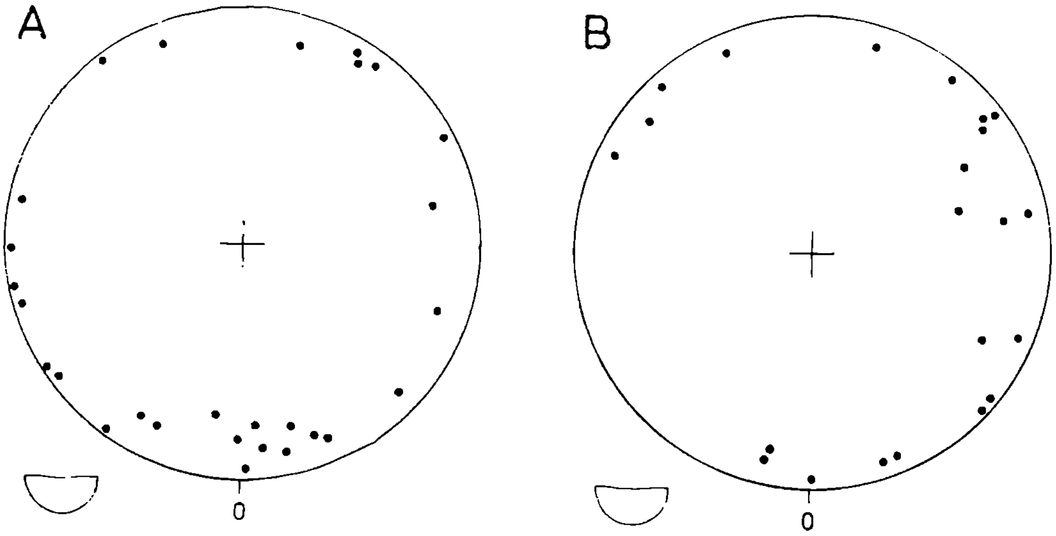

Fig. 3. Diagrams of extension fissures of explosive structure: *A* — from Pl. I: 1, *B* — from Pl. I: 2

INTERPRETATION

The interpretation is limited to analysis of local effective stresses and their application to characterization of the mechanism of centrifugal deformation. The question of the source of the energy causing the centrifugal deformation will be elaborated elsewhere.

The described structures result from deformation of rock in natural conditions. The extension fissures are radially disposed, indicating that the deformation proceeded from the central void outwards. The destruction of the mineral surrounding of the void took place in presence of fluids and in general it corresponded to hydraulic fracturing (*sensu* Hubbert & Willis *fide* Jaroszewski, 1980; Secor, 1968). In terms of the destruction theory of Griffith (1921, 1925), the void spaces may be considered as elementary fissures. Their transformation into extension fissures is controlled by critical effective stress (Hubbert & Rubey, 1959; Jaeger, 1962; Secor, 1968). It was hitherto assumed in considerations of the hydraulic fractuning phenomenon that the effective stress equals the difference between the total stress and the pore pressure (Jaeger, 1962, 1963; Hubbert & Willis *fide* Jaroszewski, 1980; Secor, 1965, 1968) or the difference between the total stress and the effective value, variously considered of the pore pressure (Nur & Byerlee, 1971; Skempton *fide* Fyfe *et al.*, 1978; Narasimhan *et al.*, 1980).

In the author's oppinion, for the consideration of the centrifugal mechanism of deformation proposed here, it is important to explain the provenance of the deforming effective stress, and to define the formula that can describe it. For this purpose we shall examine local stresses existing in any point of the phase boundary before the initiation of an extension fissure in this point (Fig. 4A).

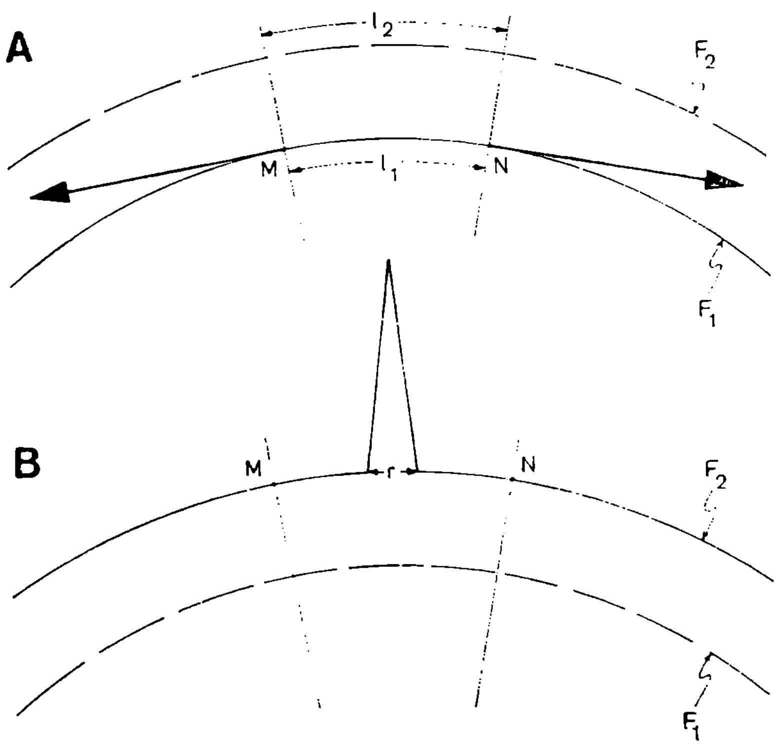

Fig. 4. Scheme showing development of radial tension fracture in fragment of void margin. *A* — before elastic enlargement of void filled with expanding fluid. *B* — after expansion of fluid, enlargement of void space and initial opening of tension fracture. F_1, F_2 — positions of void margin at stages *A* and *B* respectively; *M*, *N* — points on void margin; l_1, l_2 — distance from *M* to *N* measured along void margin at stages *A* and *B* respectively; *r* — width of tension fracture at void margin; thick arrows — tensile endogenous stresses tangential to void margin

Exogenous and endogenous stresses are acting here. The first group comprises the total stress originating from the lithostatic pressure or tectonic forces, the second group comprises the pore pressure and tensile stress. The pore pressure acted perpendicular to the phase boundary in the point discussed. The tensile stress resulted from the centrifugal push of pore fluids, it acted in tangential plane and was a physical expression of the tendency of the fluid to increase its volume.

The increase in volume required increase in area of the surface delimiting the void space filled with fluids. For the sake of simplicity the phenomenon is discussed in a plane system. Eliminating the *Z* axis we obtain that the increase in area from F_1 to F_2 corresponds to the increase in arc length from l_1 to l_2. The resultant difference $l_1 - l_2$ was compensated by the width *r* of the extension fissure after its initiation (Fig. 4B). In turn the pore pressure increased, in the author's oppinion, due to the difference between the minimum compressibility of the fluids, and the exceeding it susceptibility of the rock medium to linear elastic distortion. In conditions of triaxial compression, which could result from lithostatic pressure or tectonic forces, the linear strain of the rock medium was greatest along the greatest total principal stress axis (Fyfe *et al.*, 1978). It is in this direction where the tendency to reduce the void space was the greatest. This resulted in uniform increase of fluid pressure in all directions.

This interpretation considers only rheological changes in stressed rock medium. The possible mineralogical causes of the pressure increase of the medium filling the centres of the explosive structures are not discussed here.

The radial arrangement of fissures indicates that they were formed along the planes including vectors of pore pressure, and perpendicularly to the endogenous tensile stresses. Let us introduce a local coordinate system (xyz) beginning in the discussed point, such that its y axis is parallel to the direction of pore pressure, and the axes x and z correspond to the direction of endogenous tensile stresses (Fig. 5).

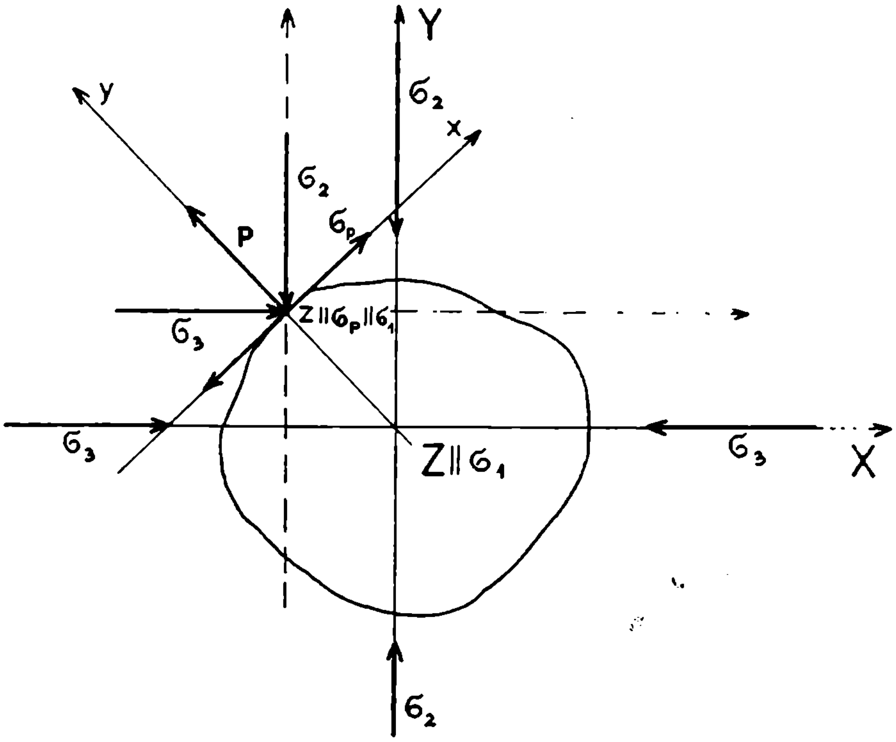

Fig. 5. Exogenous ($\sigma_1, \sigma_2, \sigma_3$) and endogenous ($p$, σ_p) stresses on fluid-rock boundary, XYZ – general system of coordinates, xyz – local system of coordinates

The effective principal stresses in the local system (xyz) are as follows:

$$\sigma_{ey} = (\sigma_{2y}+\sigma_{3y})-p,$$
$$\sigma_{ex} = (\sigma_{2x}+\sigma_{3x})-\sigma_p,$$
$$\sigma_{ez} = \sigma_1-\sigma_p,$$

where: $\sigma_{ey(x,z)}$ – effective stress along $y(x, z)$ axis;
$\sigma_{2y(x)}$ – component of the intermediate total principal exogenous stress along $y(x)$ axis;
$\sigma_{3y(x)}$ – component of the least total principal exogenous stress along $y(x)$ axis;
σ_1 – the greatest total principal exogenous stress;
σ_p – tensile endogenous stress;
p – pore pressure.

The magnitudes of these efective principal stresses were critical for determining wheather a tension fissure will be initiated in a given point. The fissure was initiated when the effective stress along the x axis (*cf.* Fig. 5, Pl. I: 1, 2) was at least equal — R (Jaeger, 1963; Secor, 1965). The extension fissure is parallel to the plane determined by the σ_{ey} and σ_{ez} stresses. In the coordinate system XYZ (Fig. 5) the values of effective principal stresses are still defined as differences between respective total stresses and pore pressure. This mode of defining the local destructive effective stresses is the basic difference between the mechanism of centrifugal deformation and that of hydraulic fracturing.

The hydraulic nature of the described deformation implies also another important physical condition. The solutions could not be drained from the rock before the onset of the deformation. This resulted in the increase of the rock's ability to the brittle behavior (Mead, 1925; Martin & Durham, 1975; Jaroszewski, 1980).

The geometrical arrangement of the boundaries of undulatory extinction and extension fissures (Figs. 1—3; Pl. I: 1, 2) suggests that both types of substructures resulted from the same deformation proceeding from the centre of explosive structure. The observed interference of both substructures (Pl. II: 1) records their temporal sequence. First formed undulatory extinction substructures. They may indicate more ductile conditions of deformation, when plastic deformation still could take place. The extension fissures formed after them and may indicate more brittle conditions of deformation (*cf.* Martin & Durham, 1975).

CONCLUSIONS

1. Explosive structures are described for the first time in Poland from naturalln deformed rocks. The structures resulted from extensional centrifugal deformatioy at the presence of fluids. A model of this phenomenon, on much greater scale, providing opportunities for more detailed observations, may be underground nuclear explosions (*cf.* Short, 1966) or, in half-space, meteorite impacts (*cf.* Wood, 1983) and ground-level nuclear explosions.
2. The centrifugal mechanism differs from the phenomenon of hydraulic fracturing in its mode of inducing the destructive effective stresses.
3. During the centrifugal deformation of rocks the trajectories of the intermediate effective principal stresses diverged radially, and the trajectories of the least effective principal stresses encircled closed figures.
4. The uniform radial distribution of the extension fissures indicates that the exogenous field was characterized by the following proportions of the total principal stresses: $\sigma_1 > \sigma_2 = \sigma_3$.

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Streszczenie

NATURALNA DEFORMACJA ODŚRODKOWA

Stanisław Achramowicz

W naturalnie zdeformowanych gnejsach rejonu Doboszowic (blok przedsudecki) występują mikrostruktury będące oddzielnymi centrami deformacji ekstensyjnej, wywołanej odśrodkowym parciem roztworów. Geometria i natura tych struktur upodabnia je do form powstałych podczas wybuchu i dlatego zaproponowano dla nich termin struktury eksplozywne. W pracy został przedstawiony mechanizm ich powstawania na tle zjawiska pękania hydraulicznego.

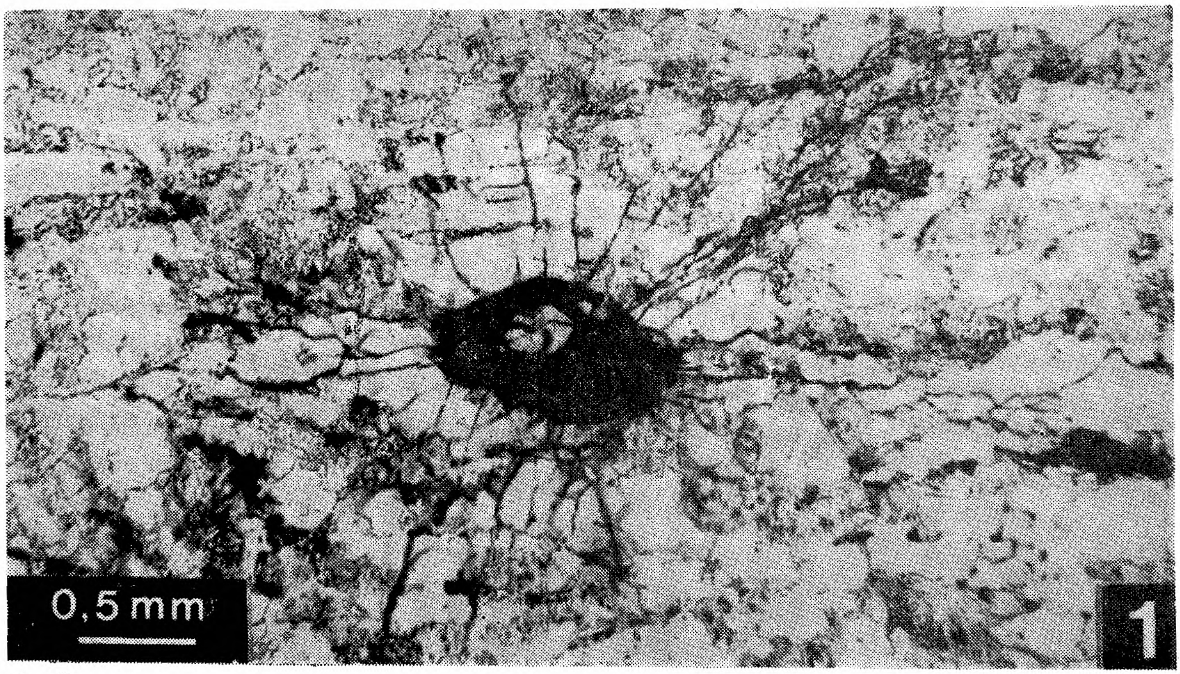
EXPLANATIONS OF PLATES

Plate I

1 — Example of explosive structure. 25×
2 — Explosive structure partly destroyed by a younger slip zone. 25×

Plate II

1 — Example of interference of banded undulatory extinctions and extension fissures. 65×
2 — A fragment of incompletely developed explosive structure. 15×. Explanation in text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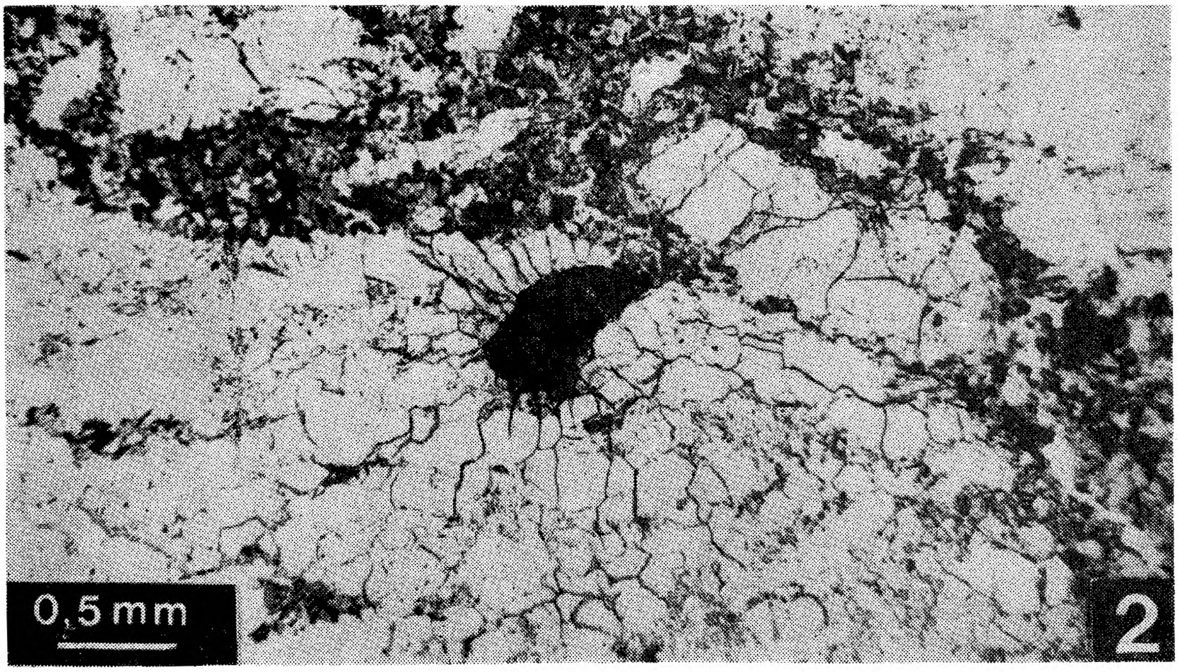
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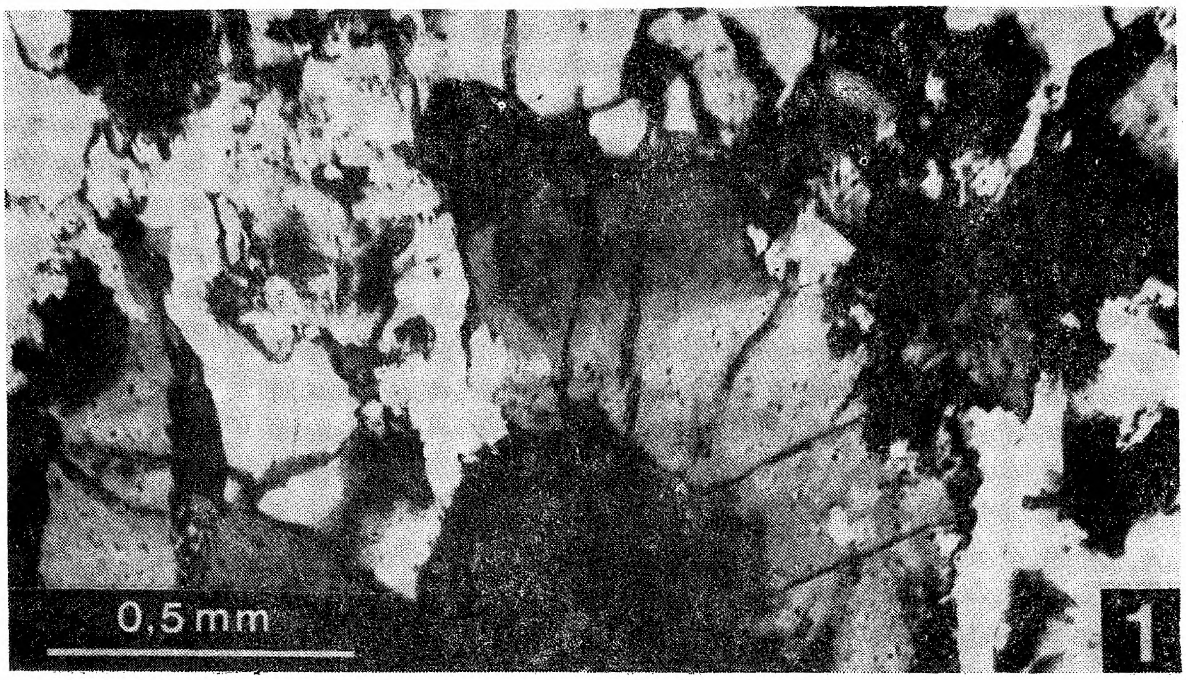
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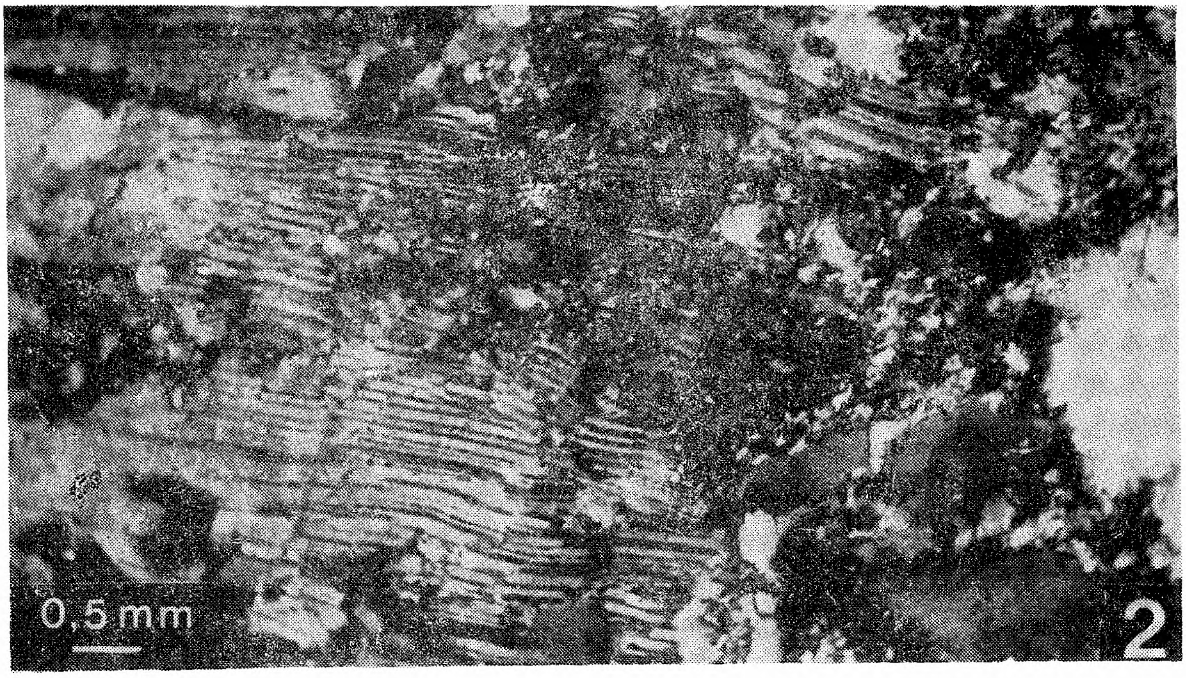
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