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VOLCANIC GAS-DRIVEN CLASTIC INTRUSIONS NEAR THE CHEŁMIEC RHYODACITE MASSIF, INTRASUDETIC TROUGH (SW POLAND)

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Abstract: Numerous, small clastic sills and dikes occur in fine-grained sediments near the contact with the Chełmiec rhyodacite massif in the Intrasudetic Trough. They are composed of sand to granule grade clasts dispersed in an abundant fine-grained martix. The formation of these clastic intrusions is related to the Late Carboniferous subvolcanic activity and took place after the main stage of the host-rock consolidation. The emplacement of the Chełmiec subvolcanic body increased stress in surrounding rocks and, consequently, caused displacements, berecciation, and filling of open fissures with loose clastic material. Volcanic gases episodically released from the igneous intrusion caused fluidization of the brecciated material. The mobilized particles driven by gases invaded the sedimentary rocks along fissures and bedding surfaces. The temperature inside the clastic intrusions could have locally attained 450 to 480°C while at the channel walls it oscillated around 350°C. The thickness of thermally altered zones and the character of alterations indicate a very short time of effective heating and a high rate of injection and emplacement processes. Transport conditions and sedimentation from suspension facilitated the segregation of clasts with respect to size, shape, and density. Locally, due to the plastic behaviour of intruding clastic material and its cohesive freezing, fold-like structures were formed and preserved.

Key words: clastic intrusions, fluidization, thermal alterations, Intrasudetic Trough.

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INTRODUCTION

The hypothesis concerning the influence of volcanic activity upon clastic intrusion formation is derived from the studies undertaken in the early 40's. Geologists emphasized the role of volcanic gases forcing their way along fissures in brecciation, mobilization, and transportation of clastic material and also its subsequent injection into surrounding rocks (Farmin, 1934; Cloos, 1941; Fairbairn & Robson, 1942; Hoehne, 1942). The rapid increase in steam pressure due to ground water heating at the contact with igneous bodies can bring about similar effects (Walton & O'Sullivan, 1950; Campbell, 1904 *fide* Shrock, 1948). The mechanisms of clastic material injections were widely discussed by Reynolds (1954). She presented the model of fluidization as an important geological factor causing mobilization of detrital material and subsequent injection of resulting mixtures of gas and solid particles (intrusive fluidized systems).

The sedimentary succession of the Intrasudetic Trough also contains rocks related to injections of fluidized clastic material due to volcanic activity. Hoehne (1942) suggested that so-called "Kohlenriegel" kown from local coal mines represents breccias driven by volcanic gases and vapours. Krawczyńska-Grocholska & Grocholski (1958) described similar rocks as subvolcanic breccias. The coarse-grained massive sediment filling large volcanic pipes in the vicinity of Rusinowa referred to by Nemec (1979, 1981) as pipe breccias is another example. The autoclastic breccias (*sensu* Fisher, 1961) of Zamkowa Hill and some rock of the Niedźwiadki Range volcanoclastic complex may have a similar origin (Grocholski, 1965; Nemec, 1979). Tuffisites were described to occur near the contacts with the large subvolcanic bodies of the Permian andesitic rocks and were related to the perforative action of volcanic gases and fluidization in front of intrusions (Dziedzic, 1980).

The purpose of this paper is to describe clastic sills and dikes occuring near the Chełmiec rhyodacite massif in the Wałbrzych Basin. The transport and emplacement mechanism, timing, and pressure/temperature conditions during their formation are discussed on the basis of the spatial relationships, geometry, textural characteristics, segregation and fabric of the grain framework, and thermal alterations at the contacts.

GEOLOGICAL SETTING

The Wałbrzych Basin is a small sedimentary basin in the NE periphery of the Intrasudetic Trough (Fig. 1). The sedimentary strata generally dip towards the basin center and they are disrupted by large volcanic bodies in the western and eastern part of the unit. The largest of them, the Chełmiec laccolith, subdivides the Wałbrzych Basin into the Gorce and Sobięcin synclines.

During the Early Carboniferous the Intrasudetic Trough was occupied by an extensive alluvial system (Teisseyre, 1966a, 1975). In the Late Visean marine transgression spread over the entire basin. At the beginning of the Late Carboniferous the Wałbrzych Basin was an area favouring phytogenic sedimentation. It resulted in the deposition of coal-bearing strata, up to 1300 m in thickness, which are subdivided into three units: the Wałbrzych Formation (Lower Namurian), the Biały Kamień Formation (Upper Namurian – Westphalian A), and the Żacler Formation (Lower Westphalian). In the mid-Westphalian a rearrangement of the basin connected with tactonic and magmatic activity coused a change of the dispersal pattern and depositional conditions (Grocholski, 1965; Dziedzic, 1971; Nemec, 1979). The overlying Glinik Formation (Upper Westphalian – Stephanian?) has restricted lateral extent and does not contain coal seams.

Sedimentary processes in the Intrasudetic Trough were often disrupted as

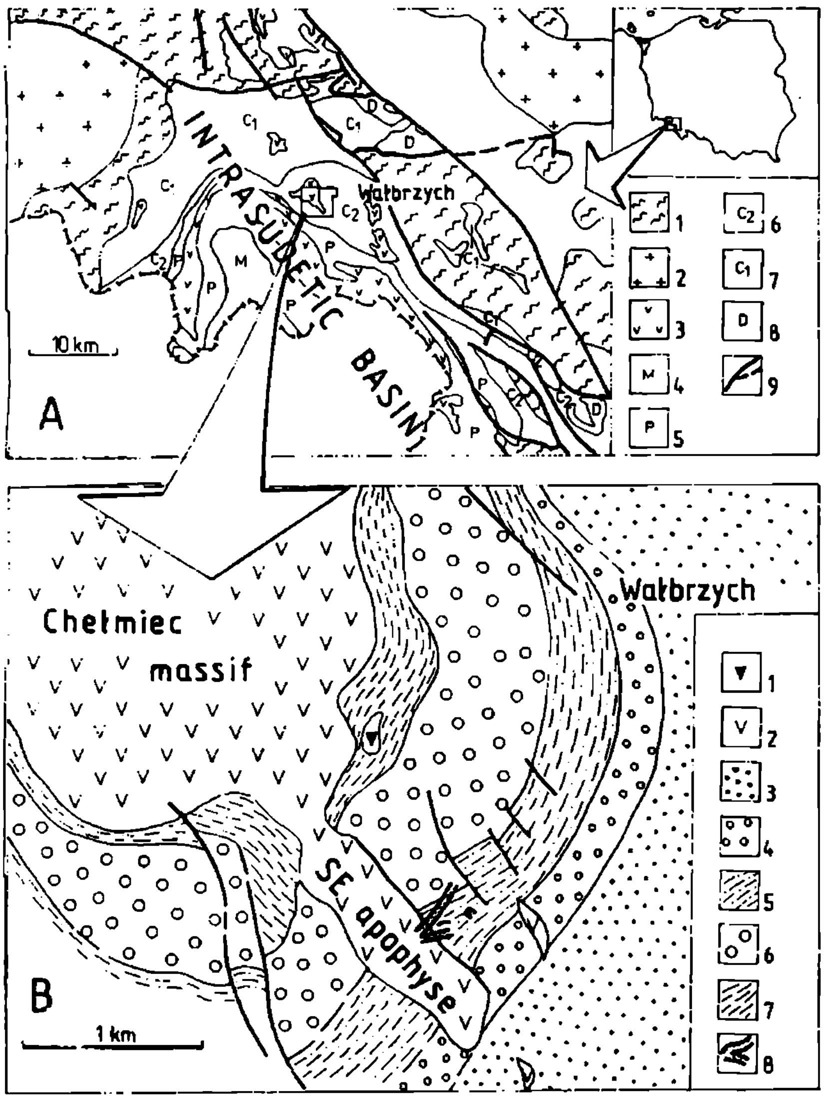

Fig. 1. A. Geological sketch-map of the Intrasudetic Trough. *1* — metamorphic rocks; *2* — plutonic rocks; *3* — volcanogenic rocks; *4—8* — sedimentary rocks: *4* — Mesozoic, *5* — Permian, *6* — Upper Carboniferous, *7* — Lower Carboniferous, *8* — Devonian; *9* — major dislocations. **B.** Geological map of the study area SE of the Chełmiec massif. *1* — andesitic rocks; *2* — rhyodacites; *3—5* — Żacler Formation: *3* — upper member, *4* —middle member, *5* — lower member; *6* — Biały Kamień Formation; *7* — Wałbrzych Formation; *8* — outcrops studied

the result of volcanic events. The age of volcanics in the Intrasudetic Trought has not been determined precisely (Grocholski, 1974; Nemec, 1979, 1981) due to poor biostratigraphic controls and difficulties in genetic classification of igneous bodies (subvolcanic *vs* volcanic). Paleomagnetic studies (Birkenmajer *et al.*,1968; Westphal *et. al.*, 1987) were not helpful in this matter either. The dating of volcanic rocks in based solely on their position within the sedimentary succession and regional lithostratigraphic correlations.

Thin tuff layers in the Lower Carboniferous succession are the first manifestations of volcanic activity in the Intrasudetic Trough (Teisseyre, 1966b). The Early Westphalian explosive volcanism resulted in the formation of a diachronous maar system along the eastern part of the Wałbrzych Basin (Nemec, 1979, 1981). Magmatic activity at the Westphalian B/C transition generated the subvolcanic intrusion of the Chełmiec massif and lava flows in the SW part of the Wałbrzych Basin (Grocholski, 1965; Nemec, 1979).The veins cutting the Chełmiec massif were probably formed in the Stephanian (Nemec, 1979). The final episode of volcanic activity occurred in the Early Permian when numerous andesitic bodies, probably of subvolcanic origin, were emplaced (Dziedzic, 1980).

CLASTIC INTRUSIONS

Numerous intrusive clastic bodies have been found near the contact of the sedimentary rocks with the Chełmiec massif (Fig. 1). They are most abundant in the lower member of the Żacler Formation. The intrusions are usually associated with a fine-grained, thin-bedded sediment which is often slightly tactonically disturbed. They are concentrated within 50—100 m off the contact with volcanic rocks and become less abundant away.

Geometry. The clastic intrusions appear mainly as essentially conformable sill-like froms, the thickness of which does not exceed several centimeters. However, some irregularities due to small-scale bending, pinching, and swelling are noticeable. The clastic sills most often follow bedding surfaces between layers of different lithology (e.g. coal/mudstone, mudstone/sandstone etc.). Their lateral extent is restricted to a few meters. The contacts with surrounding sediments are mostly sharp, but locally irregular and blurred. The intrusions pinch out showing tapered or blunt margins. They often disappear at the surfaces of intraformational displacements and fissures but sometimes follow them and cut the bedding (Pl. I: 1). Occasionally, small clastic sills separated from each other by thin laminae of the host sediment occur in tight clusters (Fig. 2A).

Unconformable dike-like intrusions are less abundant. They occur as tabular, not folded bodies, the thickness of which corresponds to that of the sills. Contacts with surrounding rocks are sharp but locally, where the host rock is more strongly fractured, they become blurred and the intrusion becomes thicker. The dikes commonly terminate by thinning and pinching out. However, sometimes they split into a few veins (Pl. I: 2) which may occasionally be slightly distorted and form branching structures. The sills and dikes are often clustered forming systems of clastic veins.

Texture. The clastic intrusions are filled with sand to pebble grade particles dispersed in an abundant fine-grained martix (Pl. II, Fig. 2). Mudstone. fine-grained sandstone, and coal clasts predominate while medium-grained sandstone, quartz, and feldspar grains are subordinate. Martix-supported fabrics prevail and the matrix content ranges from 20 to 90%. The matrix consists of fine quartz and feldspar grains, mica and chlorite flakes, and clay minerals. The cement is of a clay-ferruginous type, locally rich in carbonates.

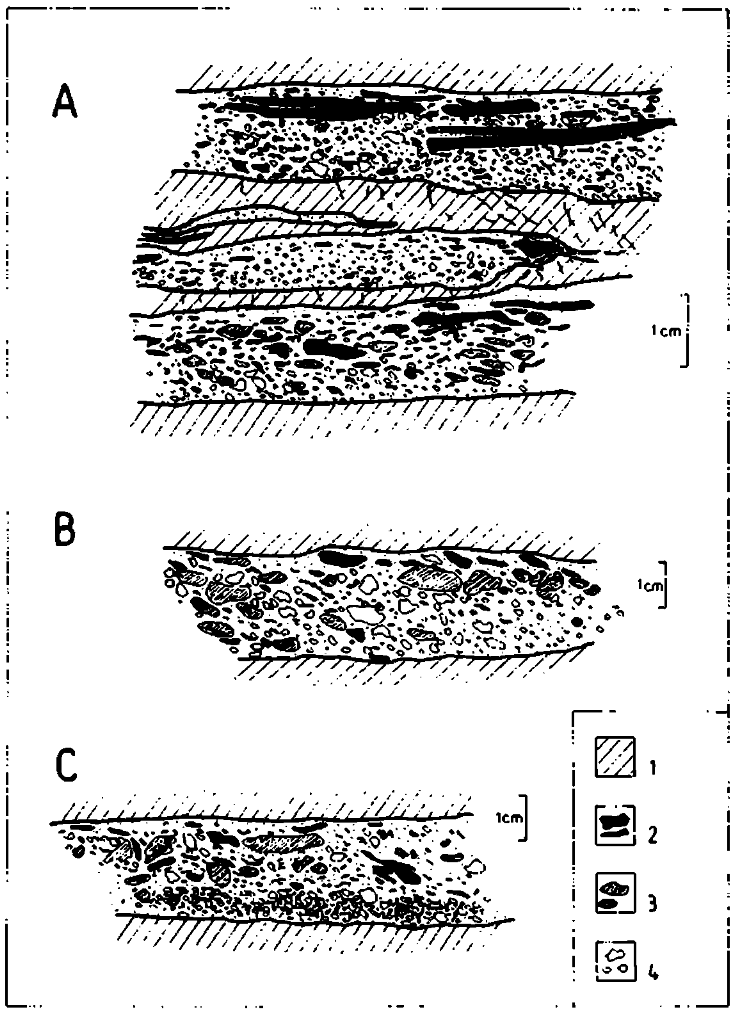

Fig. 2. A. Group of parallel clastic sills separated by thin coal laminae. B. Size segregation of clasts and their slight imbrication in a clastic sill. C. Bipartite clastic sill and fluidal structure in its upper part *1* – host-rock; *2* – coal; *3* – mudstone/siltstone; *4* – sandstone/quartz/feldspar

Clastic fragments within the intrusions are poorly sorted. The largest reach a few centimeters in length, often exceeding the vein width. They are usually subangular to angular, flat clasts of coaly shale and coal. Smaller clasts are frequently those of subrounded to subangular mudstone and sandstone, while the finest components of the grain framework include quartz and feldspar grains which are subangular to subrounded (Pl. II, Fig. 2).

There is a strong linear relationship between maximum particle size (MPS) and the vein thickness (BTh) in most intrusions, but this tendency becomes weeker in the thicker ones. The inverse relationship between sorting of coarser clasts and MPS can also be observed (Fig. 3).

Clast segregation. There are marked vertical changes in the texture of some sills (Pl. II, Fig. 2). Their basal and uppermost zones (less than 1–2 mm thick) are often deprived of coarser grains. In addition, the sill breccias show an inverse coarse-tail grading accompositional by compositional segregation of clasts and an upward increase of the matrix content. Higher density clasts (sand-

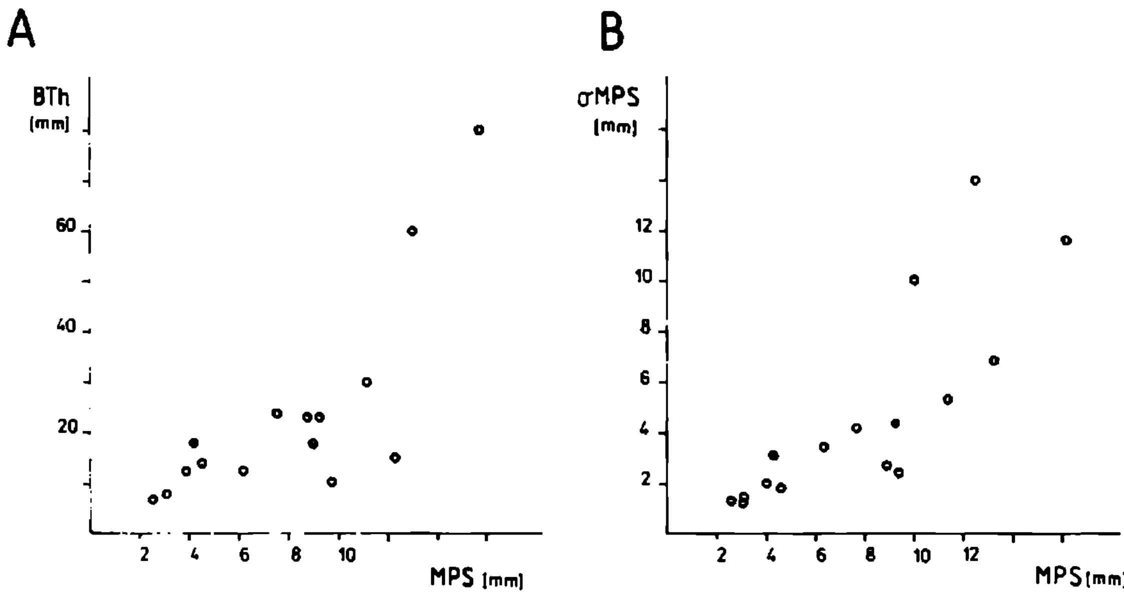

Fig. 3. A. Relationship between maximum clast size (MPS) and dike/sill thickness (BTh) of clastic intrusions; open circle – sill, full circle – dike. B. Sorting of the largest clast population (σMPS) against maximum particle size (MPS)

stone, quartz, feldspar) are concentrated in the lower parts of the sills while towards the top larger intraclasts of mudstone, coaly shale, and coal tend to prevail. The compositional segregation and textural grading are either discernible across the entire sill thickness or, occasionally, they are focused within a thin zone subdividing the sill into two bands (Pl. II: 1, Figs. 2C, 4A).

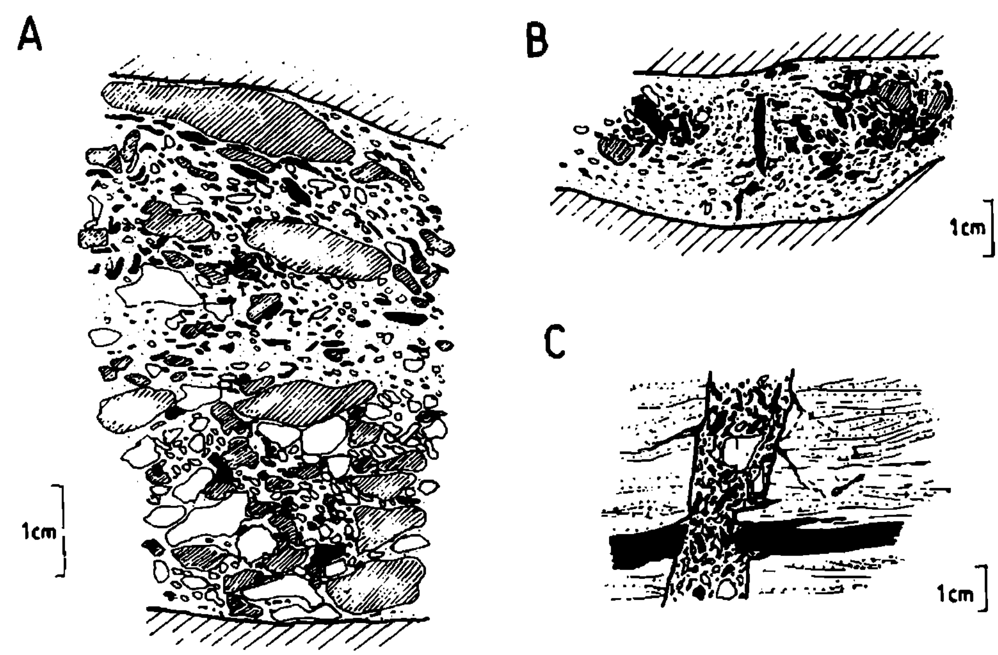

Fig. 4. A. Bipartite thick sill with large mudstone and coal clasts floating in upper, matrix-rich zone. B. Fold-like structures in a clastic sill near its tapering. C. Internal structure of a clastic dike. For explanations see Fig. 2

There are also lateral changes of grain size, sorting and matrix content within the sills.

Fabric. Elongated clasts show roughly sill-wall parallel orientations but slightly imbricated fabric is found as well (Pl. II, Figs. 2, 4, 5). The latter fabric is particularly well developed in martix-poor parts of the sills. Where the injection direction had been proved, it was found that the longest axes of clasts were either up-flow dipping or bipolarly inclined with an up-flow mode prevailing (Fig. 5). In some sills clast orientation shows a great variability and

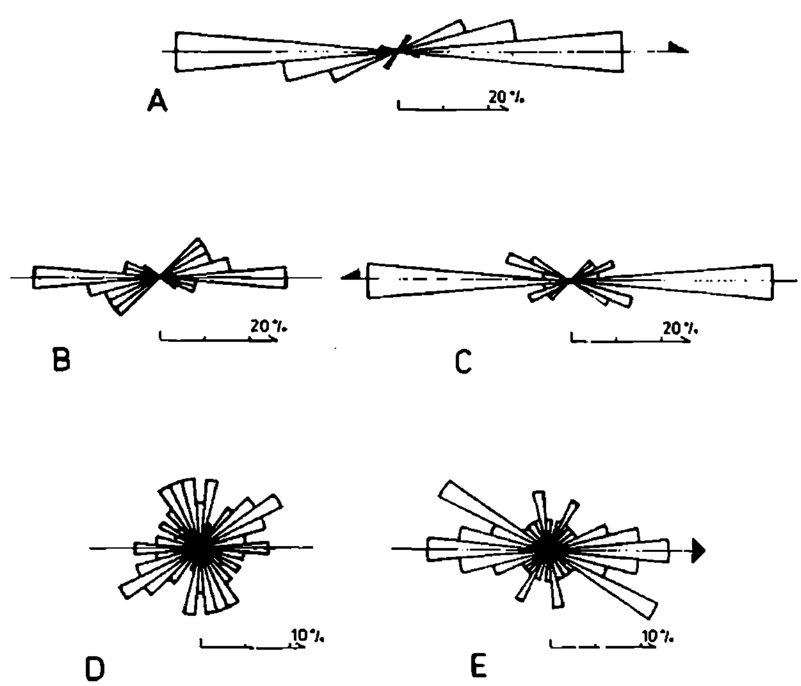

Fig. 5. Rose diagrams of an elongated clast orientation in clastic intrusions with respect to wall orientation (horizontal lines). Arrows show injection direction

locally fold-like structures or chaotic fabrics are found (Pl. III: 1, Figs. 4B, 5). This occurs mostly in the peripheral parts of martix-rich sills. In places folded material forms flow bands around matrix-poor domains; these were probably more rigid during injection. Shale and coal clasts are often plastically deformed in these zones (Pl. III: 1, Fig. 4B). Sometimes the lower, matrix-poor parts of the sills are slightly undulated and the clasts of the upper, matrix-rich parts are aligned parallel to these undulations resembling a fluidal structure (Fig. 2C).

The dikes are apparently structureless. Larger clasts are usually concentrated in their middle part, however, some of them are found close to the walls. The elongated clasts are oriented roughly parallel to dike axis but relatively large dispersion in usually noticed. BTh/MPS relationship is similar to that of the sills (Figs. 3, 4C, 5).

THERMAL AND PRESSURE EFFECTS

Some features of the clastic intrusions and the host-rocks are believed to indicate elevated pressure/temperature conditions. The majority of coal clasts show higher reflectance (1.1 to 5.0%*Ro* mean) than the coal seams in the proximity of intrusions (0.8 to 1.0% *Ro* mean). Primary vesiculation (Pl. III: 3), increased bireflectance and anisotropy, and mosaic structure are typical evidence of thermal alterations of vitrinite particles (see also Jones & Creaney, 1977). The vesicles are filled with carbonates, silica or pyrite (Pl. III: 3). The matrix of the clastic intrusions is typified by considerably higher carbonate contents as compared with those of the host-rock (Pl. III: 4). The abundance of newly-formed minerals suggests hydrotermal activity.

The fine-grained host rock along the intrusion contacts shows no evident signs of thermal alterations. However, where the intrusion contacts with coal a distinct thermally affected zone is present. The thickness of this zone ranges from 1 to a few mm. Alterations become stronger towards the intrusion walls.

A few zones passing gradually one into another were distinguished at the contact of a 10 cm thick sill (Fig. 6). At the very contact, irregular secondary vesiculation of vatrinite is observed (Pl. IV: 1). In this internal zone, up to 0.15 mm thick, exinite macerals are not visible while inertinite ones are sporadically present. The middle, not vesiculated zone, averaging 0.2 mm in thickness, is characterized by a slight microbrecciation and increased reflectance. Exinite macerals are still not visible in this zone. The outer zone reaches up to 0.9 mm in thickness and reveals distorted lamination and slight vitrinization of exinite, increasing towards the contact (Pl. IV: 2). Sometimes there is no vesiculated zone and then the middle one shows stronger microbrecciation.

On the walls of small fissures adjacent to the intrusions, the cracking of the gas-phase of carbonaceous material took place and resulted in the formation of anisotropic pyrolytic carbon (Pl. IV: 3).

There is some evidence of stress increase. Numerous clasts within the intrusive breccias are deformed (Pl. III: 1). The bending of them, particularly of coal and shale clasts, points to a ductile style of deformation, while splitting of other clasts along lamination surfaces suggests a brittle one (Fig. 2A). Microbrecciated grains and undulose extinction of quartz are commonly observed. Also coke and coal fragments showing high bireflectance and anisotropy indicate increased pressure. In the zones of sill termination the invading material pressing on surrounding rocks caused their opening along lamination surfaces (Pl. V: 1).

Discontinuous bands of the material in the initial stage of brecciation and mobilization are associated with gently folded laminae of the host-rocks. Occasionally, there are single extraneous clasts pushed into unbrecciated rocks (Pl. V: 2).

While within the clastic intrusions the stress is mainly manifested by plastic deformations, the surrounding rocks show only effects of brittle one, while fractures

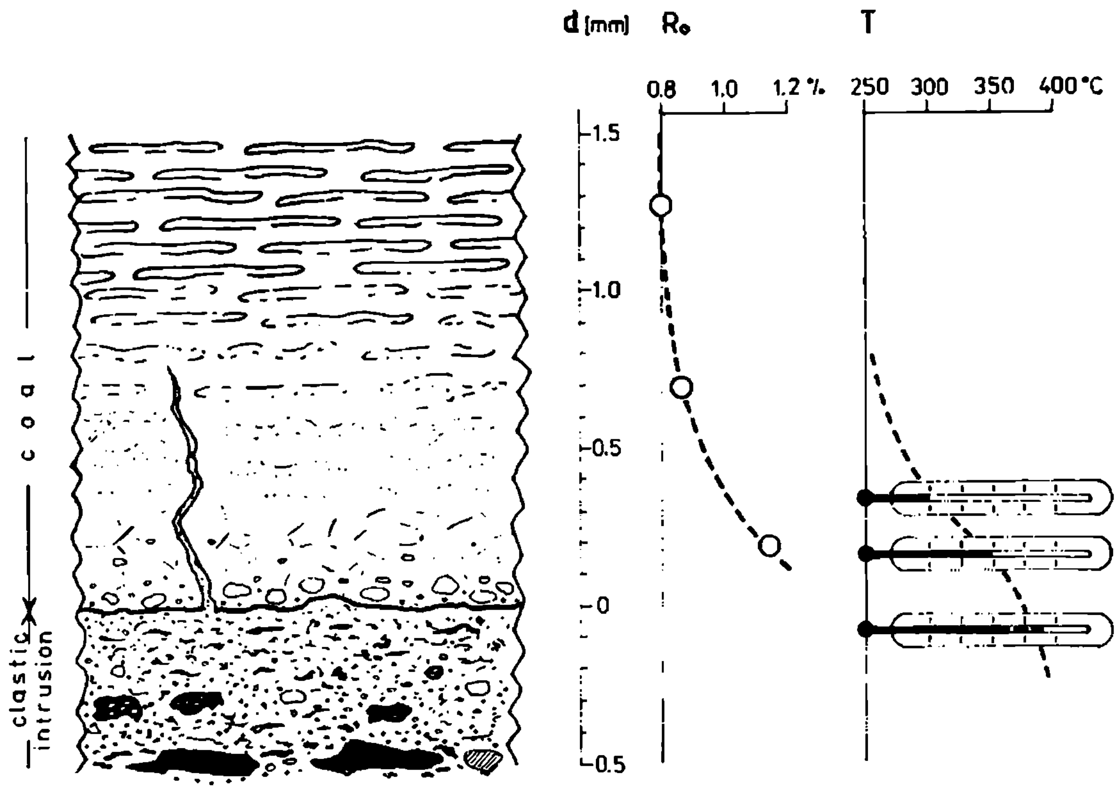

Fig. 6. Idealized sketch of a thermally altered zone of a coal lamina at the contact with a clastic intrusion: *d* – distance; *Ro* – reflectance; *T* – temperature

and small-scale dislocations are the only evidence of the deformation outside intrusions. This difference style may be attributed to the contrast in rock competence and the elevated temperature of the clastic intrusions.

EMPLACEMENT OF THE CLASTIC INTRUSIONS

The above features suggest that the clastic intrusions were formed as a fluidized intrusive system injected into the sedimentary rocks in connection with the emplacement of the Chełmiec rhyodacite massif. The subvolcanic intrussion increased stress in the surrounding rocks and caused the formation of numerous extentional discontinuities and faults in the cover. The resulting displacements led to brecciation and the filling of open fissures with loose clastic material.

Volcanic gases were intensely relased during cooling of the rhyodacite body and migrated towards the zones of lower pressure along pores and fissures. They heated ground water and caused its transformation into steam, which further increased the pressure. Gases were also generated by heated carbonaceous material. The migration of high-pressure fluids along discontinuities caused a further brecciation. Finer particles easily became fluidized and elutriated, forming, with fluids a high density mixture of increased competence. At sufficiently high pressure and flow-velocity conditions, larger clasts could also have been suspended and transported. The resulting mobile mixture invaded further and made the fissures wider. When the process progressed the mobilized material could have filled channels under decreased pressure conditions. But if the escaping gases met a thick, clay-rich unit on their way, then a zone of abnormal pore pressure was formed (Rieke & Chilingarian, 1974). In such zones clastic sills were intensively formed due to the strength anisotropy of sedimentary rocks, which facilitated the intrusion of the fluidized material along bedding surfaces.

Elutriated fine particles were often concentrated near the top of sills and at thier heads. Larger clasts underwent segregation in respect to size, density and shape. The effect of density segregation could have been enhanced by gas generation from heated coaly clasts, which caused their flotation and concentration in the upper parts of the sills.

Under high pressure/temperature some clasts were easily deformed and fissure opening took place. In the head parts of injections, the mixture probably had a higher viscosity. Plastic behaviour of the material under high pressure conditions facilitated the formation of fold-like structures.

The intrusive flow waned along its margins due to the friction resistance of the walls. The decrease of fluid pressure and transport capacity of the dispersing medium brought about the sedimentation of clasts. Locally the continued flow of a diluted suspension promoted an imbrication of clasts. The rate of the flow/pressure decrease could have been variable both in particular channels and their parts. The abrupt decrease of these parameters caused cohesive freezing while the steady decrease of pressure favoured suspension sedimentation of larger clasts and, thus, better size segregation.

The process of injection was probably rapid. It could have proceeded in a number of separate pulses. Since the cross-cutting relationships of the intrusions were not observed in the study area, it is difficult, if not impossible, to establish temporal relations between particular, unconnected bodies and their systems.

DISCUSSION

A crucial problem concerning the clastic intrusions studied has been the determination of their age and pressure/temperature conditions. There are many examples of clastic dikes which invaded fresh sediment and were deformed and folded together with it, due to differential compaction (e.g. Dżułyński & Radomski, 1956; Hesse & Reading, 1978). The geometry of the clastic dikes near the Chełmiec massif indicates that they originated after the main stage of compaction of the host rock. The compilations by Weller (1959) and Rieke & Chilingarian (1974) allow us to assess the minimal thickness of the sedimentary cover at the time of injection. Mudrocks become efficiently compacted under a cover 40 – 50 m thick, while extra hundreds of meters diminish their volume only insignificantly. However, it seems reasonable to assume, that the sedimentary cover, during the injection of the described dikes and sills, was much larger than a few tens of meters. The formation of clastic intrusions was connected with an episode of subvolcanic activity nearby. Assuming the Westphalian B/C transition as the time of emplacement of the Chełmiec subvolcanic body (Grocholski, 1965; Nemec, 1979), a cover of about 600 – 700 m is a reasonable estimate (middle and upper members of the Żacler Formation). A somewhat lower thickness, about 480 m, was calculated from reflectance curve in the borehole GV-14 located in the nearest vicinity (Mastalerz & Jones, in press). Taking into account the maturity of sediments in modern thermally active areas (Barker, 1979) the value of about 650 m can also be accepted. Assuming the time of effective coalification of the coal seams around the intrusions as 10 million years (Westphalian A + B) one can obtain a coalification temperature of 160 to 170°C. However, the clastic intrusions studied seem to be spatially related to the SE apophyse of the Chełmiec massif rather than to the main body (Fig. 1). As suggested by Nemec (1979), this apophyse was formed in the Late Stephanian. It does give a much longer coalification time (about 30 ma), thus, coalification temperature decreased to about 120°C (Karweil, 1956).

There is other evidence indicating that the clastic intrusions were emplaced into consolidated host rocks. The mosaic structure of both vitrinite and exinite in some coked clasts suggests that the thermal alterations took place when the coal was of bituminous rank (Creaney, 1977). Similar coal rank is also indicated by the homogeneity of vitrinite in contrast to thermally altered huminites (subbituminous rank macerals) which often preserve remains of their original cell structure (Goodarzi, 1985a). Actually, coal clasts may have been derived from deeper stratigraphic levels than the invaded rocks but the transport distance was not considerably long.

The thermal aureole around the SE apophyse is manifested by high reflectance (*Ro*) and bireflectance (ΔR) of vitrinite. Near the contact *Ro* max equals 4.7% and ΔR is 0.64%, while 50 m away from the contact they decrease to 1.5.% and 0.21% respectively. However, in the zone where clastic dikes are present (50 – 100 m from the contact) *Ro* max does not exceed 1.0 – 1.2%. Assuming 700°C as the temperature of intrusion one can obtain the temperature of about 430 – 500°C at the contact and 350°C at a distance of 50 m away, on the basis of Jaeger's studies (1957, 1959). Nevertheless, this igneous body did not affect the rocks in the zone of clastic intrusions so intensely. Except for the thin thermal halo around the contacts with the clastic intrusions there are no other signs of thermal alterations.

It is likely that the formation of the igneous apophyse and the clastic intrusions were tectonically controlled. The apophyse is bordered by steep NW – SE trending surfaces, corresponding to the dislocations located SE of the Chełmiec massif (Fig. 1). The majority of clastic dikes fill steep fissures of similar orientation.

The character of thermal alterations of the carbonaceous material allows us to evaluate the temperature inside and at the contacts of the clastic intrusions. The presence of the coked clasts suggests that the temperature of intruding material was not less than 350°C (Goodarzi & Murchison, 1978; Goodarzi, 1983). Some of the clasts show mosaic structure which indicates that locally the temperature must have exceeded 450°C (Goodarzi & Murchison, 1978). It may locally have reached even 480°C, as suggested by the presence of pyrolytic carbon (Kisch & Taylor, 1966; Goodarzi, 1985b). However, at the injection walls the temperature could have only slightly exceeded 350°C. Thermal alterations are found only at the contacts where coal laminae were present. The zone of altered coal is very thin, with only slightly elevated vitrinite reflectance (Ro = 1.1%) compared to unaffected coal nearby (Ro = 0.8 – 0.9%). The vesicles in vitrinite are relatively large though sparse and there is no mosaic structure there. The zone of exinite disappearance is also thin. The fact that the invaded rock was not strongly affected by elevated temperatures is also confirmed by the dominance of brittle deformations. The effectes of ductile strain were only observed inside the intrusions and at their very contacts.

Thus, the thin thermal halo must be an effect of not only relatively low temperature but of the short duration of thermal influence as well. Knowing the physical properties of the contact material (Wasilewski & Kobel-Najzarek, 1973; Jeager, 1959), the contact temperature, and the thickness of particular altered zones, one can assess the duration of the thermal event and roughly the duration of the gas flow in the clastic intrusions. To account for the effective temperature 350°C, responsible for the alterations in the vesiculated zone, and 300°C in the middle one, and a contact temperature between 360 and 400°C, the outer boundaries of these zones must have reached suitable temperatures in a few seconds. This duration appears reasonable since the above calculations refer to the marginal part of a thin sill. The period of increased temperature was probably longer, as indicated by the abrasive nature of the sill walls (sometimes the internal zone is missing). The abrasion, however, could not have been very intense because considerable swelling of invaded zones is associated with only slight thinning of invaded laminae at the contacts (Fig. 2A).The evaluation of the thickness of the altered zones, using Jaeger's graph (1959), indicates that the thickness could not have been much larger than at present. Although the time of emplacement of the particular clastic intrusions was very short, the period of the formation of the dike and sill system and the duration of the volcanic gas supply must certainly have been longer.

Fine-grained sedimentary rocks are still considerably porous and fissured when buried at 600 – 700 m. Such a cover implies hydrostatic pressure of about $6.9 \cdot 10^6$ N/m^2(Weller, 1959; Rieke & Chilingarian, 1974). The boiling temperature of water reaches 280°C in such conditions and, consequently, the fissure water affected by volcanic gases evaporates becoming an additional factor facilitating the fluidization of clastic material.

The strong positive BTh/MPS relationship in thin intrusions indicates that the maximum particle size of intruding material was controlled by fissure width. For thicker sills (above 4 cm) this tendency is no longer valid and the MPS increases much more slowly. This may suggest that there was not a sufficient amount of coarser clasts in the intrusive system.

CONCLUSIONS

On the basis of the present study the following conclusions should be emphasized:

1. The clastic intrusions near the Chełmiec rhyodacite massif were formed in connection with Late Carboniferous subvolcanic activity, which took place after the main stage of consolidation of the host sediment. The sedimentary cover was certainly not less than several tens of meters but more likely it reached about 600 – 700 m.

2. The rapid flow of volcanic gases released during the cooling of the Chełmiec body and forcing their way throughout the fissures were responsible for mobilization of clastic material and partly, for its brecciation. The steam generated due to heating of ground water by percolating gases aided these processes.

3. Fluidized clastic particles were mainly transported in dense suspensions and subsequently injected under high pressure along the fissures and bedding surfaces. The decrease of pressure and the rate of fluid flow led to rapid suspension sedimentation and/or cohesive freezing. Transport and depositional conditions favoured the segregation of larger clasts in respect to size, density, shape and the elutriation of finer particles.

4. The temperature inside the clastic intrusions must have exceeded 350°C, locally it reached 450 to 480°C, however, at the walls it balanced around 350°C.

5. Effective heating of the intrusion walls and the clastic injecting were of very short duration and near the zones of termination of the sills it lasted few seconds. This suggests a high rate of fluidization, transport, and injection processes.

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Streszczenie

INTRUZJE KLASTYCZNE GENEROWANE PRZEZ GAZY WULKANICZNE W OKRYWIE MASYWU CHEŁMCA (NIECKA ŚRÓDSUDECKA)

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Abstrakt: Celem pracy było krytyczne omówienie warunków i mechanizmu tworzenia się intruzji klastycznych stwierdzonych wśród osadów warstw żaclerskich w rejonie ryodacytowego masywu Chełmca. Są to niewielkie formy typu sillów i dajek wypełnione ostrokrawędzistym, gruboklastycznym materiałem tkwiącym w obfitej masie wypełniającej. Powstanie intruzji klastycznych związane było z późnokarbońską działalnością subwulkaniczną w zachodniej części niecki wałbrzyskiej i nastąpiło po głównym etapie konsolidacji osadów otaczających na głębokości kilkuset metrów. Gorące gazy pochodzenia wulkanicznego przepływające pod wysokim ciśnieniem wzdłuż spękań i szczelin były głównym czynnikiem powodującym upłynnienie i transport zbrekcjowanego materiału skalnego. Upłynniony materiał w postaci gęstej zawiesiny intrudował w szczeliny oraz wykorzystywał powierzchnie międzyławicowe wypełniając powstające wolne przestrzenie. Warunki transportu i sedymentacji w sillach sprzyjały powstawaniu segregacji klastów ze względu na ich gęstość, wielkość i kształt. Efektywna temperatura w obrębie intruzji klastycznych przekraczała 350°C, a lokalnie osiągała 450–480°C. Znikoma miąższość strefy zmian termicznych oraz ich charakter wskazują na bardzo krótki czas oddziaływania strumienia cieplnego oraz bardzo szybkie tempo intrudowania i depozycji upłynnionego materiału klastycznego.

Wśród węglonośnych osadów dolnej części warstw żeclerskich w pobliżu kontaktu z ryodacytami Chełmca stwierdzono liczne intruzje klastyczne (Fig. 1, Pl. I). Osiągają one od kilku do kilkunastu centymetrów miąższości. Najczęściej mają formę zgodnych sillów wykorzystujących powierzchnie międzyławicowe. Ich rozciągłości nie przekraczają kilku metrów. Kontakty ze skałami otaczającymi są na ogół ostre, choć miejscami mogą być zatarte. Sille zanikają na powierzchniach niewielkich dyslokacji lub. wyklinowują się. Niezgodne formy typu dajek są mniej powszechne. Wykorzystują one często strome szczeliny o przebiegu NW–SE, zgodne z głównym systemem dyslokacji w SE okolicy masywu Chełmca.

Intruzje klastyczne zawierają słabo wysortowany, przeważnie ostrokrawędzisty materiał gruboklastyczny tkwiący w obfitej zazwyczaj masie wypełniającej (Fig. 2, Pl. II). W skład szkieletu ziarnowego wchodzą okruchy skał pochodzących z bliskiego otoczenia intruzji. Są to mułowce, łupki, węgiel i piaskowce oraz ziarna kwarcu i skaleni. Klasty osiągają maksymalnie do kilku centymetrów średnicy, przeważnie jednak nie przekraczają frakcji drobnego żwiru. Zaznacza się wyraźna, prosta zależność liniowa pomiędzy grubością ciał intruzywnych a maksymalną średnicą ziarna (Fig. 3).

W większości sillów klastycznych obserwuje się segregację ziarn szkieletu ze względu na wielkość, gęstość i kształt składników (Fig. 2, 4, Pl. II). Z inwersyjnym uziarnieniem frakcjonalnym związany jest zazwyczaj wzrost liczby spłaszczonych klastów mułowcowych i węglowych ku stropowi sillu. Towarzyszy temu także wzrost zawartości masy wypełniającej. Miejscami przy stropie i spągu sillu zaznaczają się cieniutkie strefy pozbawione większych klastów (Pl. II). W obrębie dajek klastycznych większe klasty koncentrują się w strefach osiowych przewodów.

Wyraźnie wydłużone i spłaszczone klasty układają się najczęściej dłuższymi osiami w przybliżeniu równolegle do ścian intruzji klastycznych (Fig. 2, 4, 5, Pl. III). Niekiedy jednak są one łagodnie zimbrykowane lub wykazują orientację bimodalną (Fig. 5). W niektórych sillach, a zwłaszcza w ich peryferycznych strefach obserwuje się chaotyczną orientację najdłuższych osi klastów oraz struktury fałdowe (Fig. 4, 5, Pl. III). Klasty mułowcowe i węglowe są często w tych strefach zdeformowane plastycznie.

Intruzje klastyczne powstawały w warunkach podwyższonej temperatury, w czasie, gdy osady otaczające były już w znacznym stopniu skonsolidowane. Oznakami zmian termicznych są: podwyższona refleksyjność, porowatość (Pl. III) oraz struktury mozaikowe w klastach węglowych. Znacznie podwyższona zawartość węglanów oraz powszechne wypełnienia porów w skoksowanych klastach węglanami, pirytem i krzemionką (Pl. III) mogą sugerować aktywność hydrotermalną. Na kontaktach intruzji klastycznych z węglami obserwuje się wyraźne, choć cienkie strefy zmian termicznych (Fig. 6). Zmiany te objawiły się postępującą w stronę kontaktu witrynizacją egzynitu, wzrostem refleksyjności witrynitu, mikrobrekcjacją oraz obecnością nieregularnej porowatości wtórnej w bezpośrednim sąsiedztwie ścian intruzji (Pl. IV). Ponadto w niewielkich szczelinkach w pobliżu kontaktów obserwuje się skupienia pirolitycznego węgla (Pl. IV).

Liczne klasty szkieletu ziarnowego wykazują deformacje, które mogą być efektem zarówno podatnych (wygięcia), jak też kruchych (pęknięcia) odkształceń (Fig. 2, Pl. III). Wskaźnikami podwyższonych naprężeń oraz ciśnienia mogą być mikrobrekcjacja i faliste wygaszanie ziarn kwarcu oraz silna anizotropia witrynitu. W strefach wyklinowywania się sillów obserwować można efekty wdzierania się uruchomionego materiału klastycznego pomiędzy pakiety skał osadowych, wzdłuż powierzchni laminacji (Pl. V). Pojedyncze, duże, ostrokrawędziste klasty tkwiące wśród cienko laminowanych osadów i towarzyszące im łagodne zaburzenia laminacji (Pl. V) mogą być efektem oddziaływania sprężonych gazów przed frontem postępujących iniekcji klastycznych.

Brak deformacji wywołanych kompakcją sugeruje, że opisane intruzje klastyczne powstały po głównym etapie konsolidacji osadów otaczających. Przewaga klastów ostrokrawędzistych wskazuje, że powstawały one wskutek brekcjowania sztywnego ośrodka skalnego. Podobnie jednorodność zmienionego termicznie witrynitu oraz struktury mozaikowe w koksach dowodzą, że impuls termiczny miał miejsce w okresie, gdy materia pochodzenia roślinnego reprezentowała już przynajmniej stadium węgla bitumicznego. Objawy oddziaływania podwyższonej temperatury, naprężeń i zmian hydrotermalnych pozwalają łączyć genezę opisanych intruzji klastycznych z procesem powstawania subwulkanicznej intruzji Chełmca. Nastąpiło to po zakończeniu sedymentacji warstw żaclerskich w niecce wałbrzyskiej. Zatem miąższość pokrywy osadowej w czasie intrudowania materiału klastycznego wynosiła przynajmniej 500—700 metrów.

Cechy intruzji klastycznych sugerują, że powstawały one w rezultacie upłynnienia i iniekcji zbrekcjowanego materiału skalnego w szczeliny i spękania otaczających skał osadowych. W związku z intrudowaniem ryodacytów Chełmca w nadkładzie intruzji powstawały znaczne naprężenia, które rozładowywały się w postaci spękań i dyslokacji. Przemieszczenia powodowały kruszenie skonsolidowanych już w znacznej mierze skał, a rozluźniony materiał gromadzony był w szczelinach.

Głównym czynnikiem powodującym upłynnienie i transport materiału był przepływ gorących gazów i roztworów pochodzenia wulkanicznego, które pod ciśnieniem przedzierały się wzdłuż spękań i szczelin. Upłynniony materiał w postaci gęstej zawiesiny intrudował w szczeliny oraz wykorzystywał powierzchnie międzyławicowe wypełniając powstające wolne przestrzenie. Dodatkowym czynnikiem wspomagającym procesy fluidyzacji i iniekcji było rozprężanie się pary wodnej powstającej z wód szczelinowych. Grubość ziarna transportowanego materiału klastycznego przypuszczalnie determinowana była w znacznym stopniu szerokością przewodów. Warunki transportu i sedymentacji w sillach sprzyjały w pewnym zakresie powstawaniu segregacji klastów. Równoległa do osi intruzji orientacja wydłużonych klastów jest zapewne wynikiem oddziaływania ścian przewodów na przepływ upłynnionego materiału.

Charakter zmian termicznych substancji organicznej pozwala oszacować maksymalną efektywną temperaturę osiągniętą w czasie intrudowania materiału klastycznego. W pobliżu ścianek intruzji jedynie nieznacznie przekraczała ona 350°C, lecz lokalnie w obrębie intruzji osiągała 480°C. Miąższość strefy zmienionej termicznie i charakter zmian na kontakcie wskazują, że proces intrudowania upłynnionego materiału był gwałtowny i krótkotrwały, a w peryferycznych strefach sillów czas efektywnego oddziaływania podwyższonej temperatury (czas przepływu gorących głazów) nie przekraczał sekund.

EXPLANATION OF PLATES

Plate I

1 – Clastic sill in fine-grained sediments. Note translations of the sill along small-scale displacement surfaces (arrows). Pen is 85 mm long

2 – Splitting at the clastic dike termination. Lens cap is 44 mm in diameter

Plate II

1 – Internal structure of a clastic sill. Note inverse coarse-tail grading, compositional segregation of clasts, and abrupt change in matrix content (arrow)

2 – Internal structure of two tightly clustered clastic sills

Plate III

1 – Fold-like structure in a clastic sill. Note the plastically deformed clasts. Arrow shows the direction of injection

2 – Coked clast in a clastic sill. Reflected plane-polarized light, oil immersion

3 – Vesiculation of a coal clast. Note pyrite filling the vesicles. Reflected plane-polarized light, oil immersion

4 – Carbonate rhomboedral crystals in the matrix of a clastic dike. Transmitted plane-polarized light

Plate IV

1 – Vesiculation and brecciation of vitrinite near the contact a clastic sill. Arrow points towards the contact. Reflected plane-polarized light

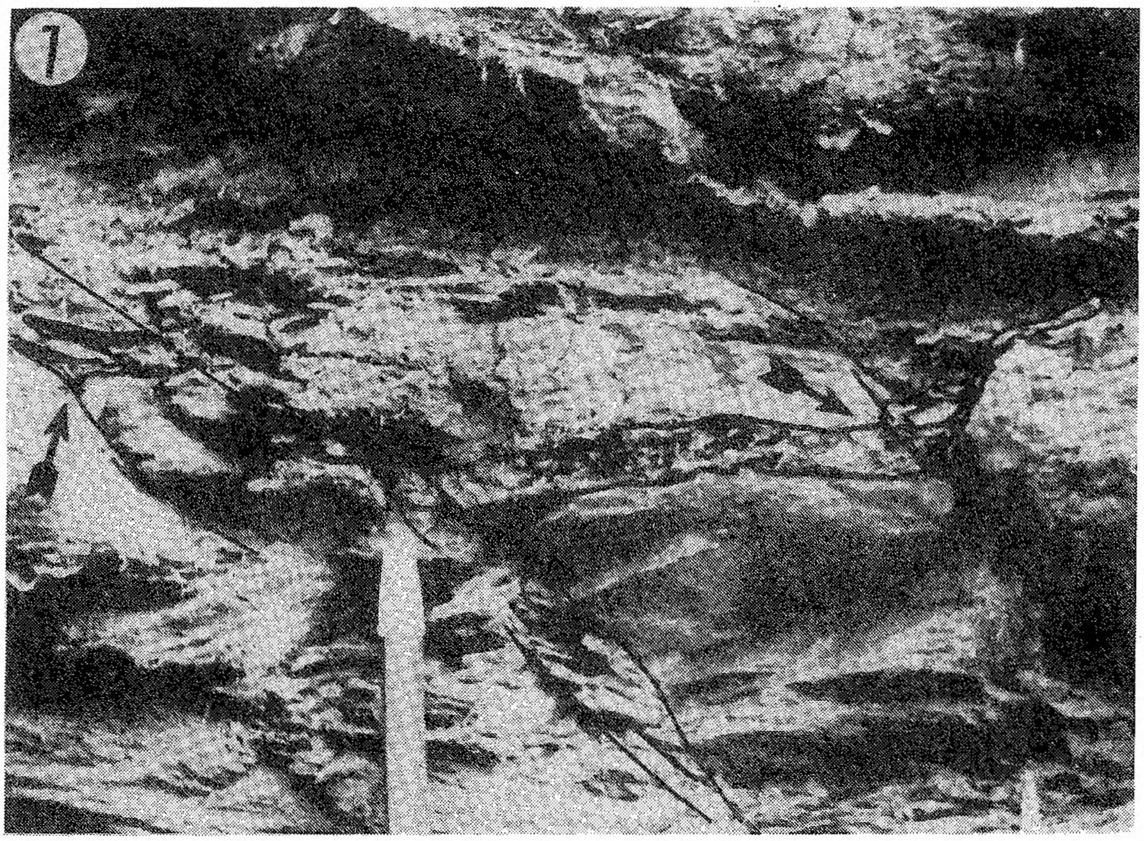
2 – Disappearance of exinite and distorted lamination in external contact zone. Reflected plane-polarized light, oil immersion

3 – Thin layers of pyrolytic carbon occurring along microfissures. Reflected plane-polarized light, oil immersion

Plate V

1 – Clastic sill invading inbetween lamination surfaces

2 – Initial stage of clastic intrusion. Note the folded lamination of the host-rock and the diffuse boundaries of the brecciated zone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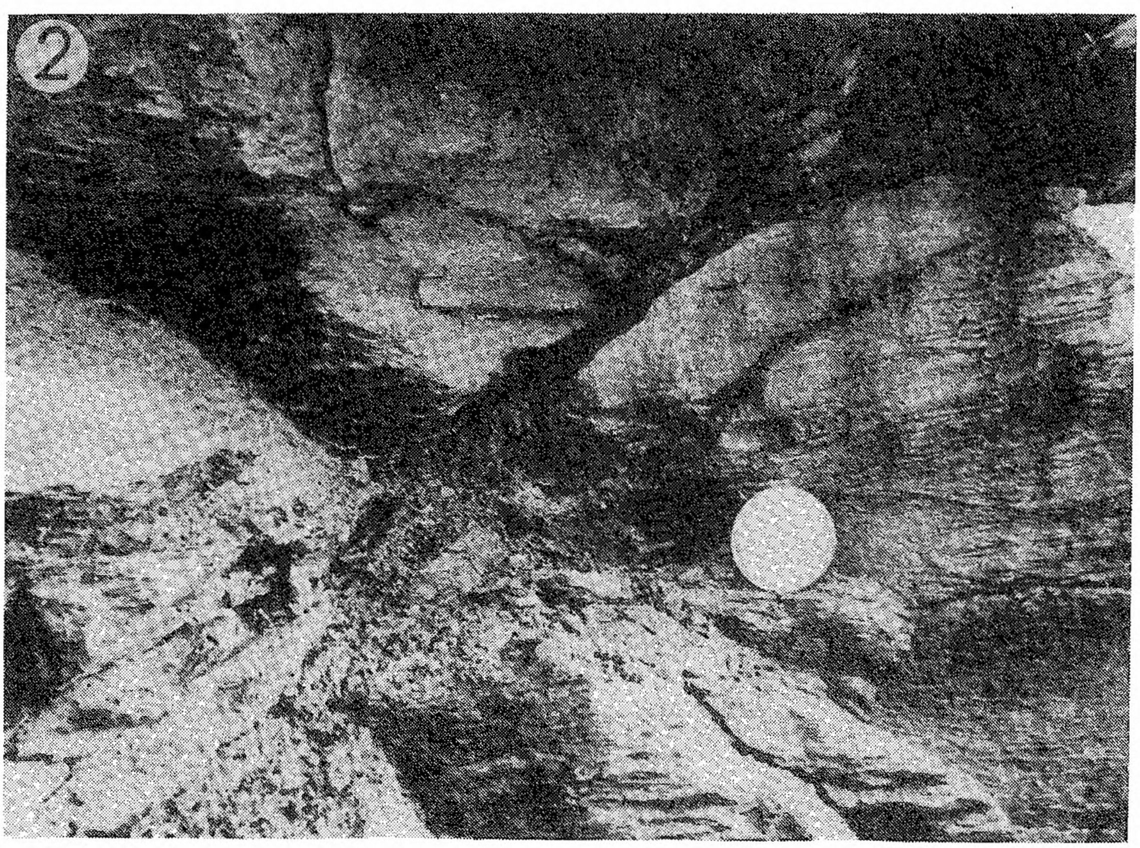
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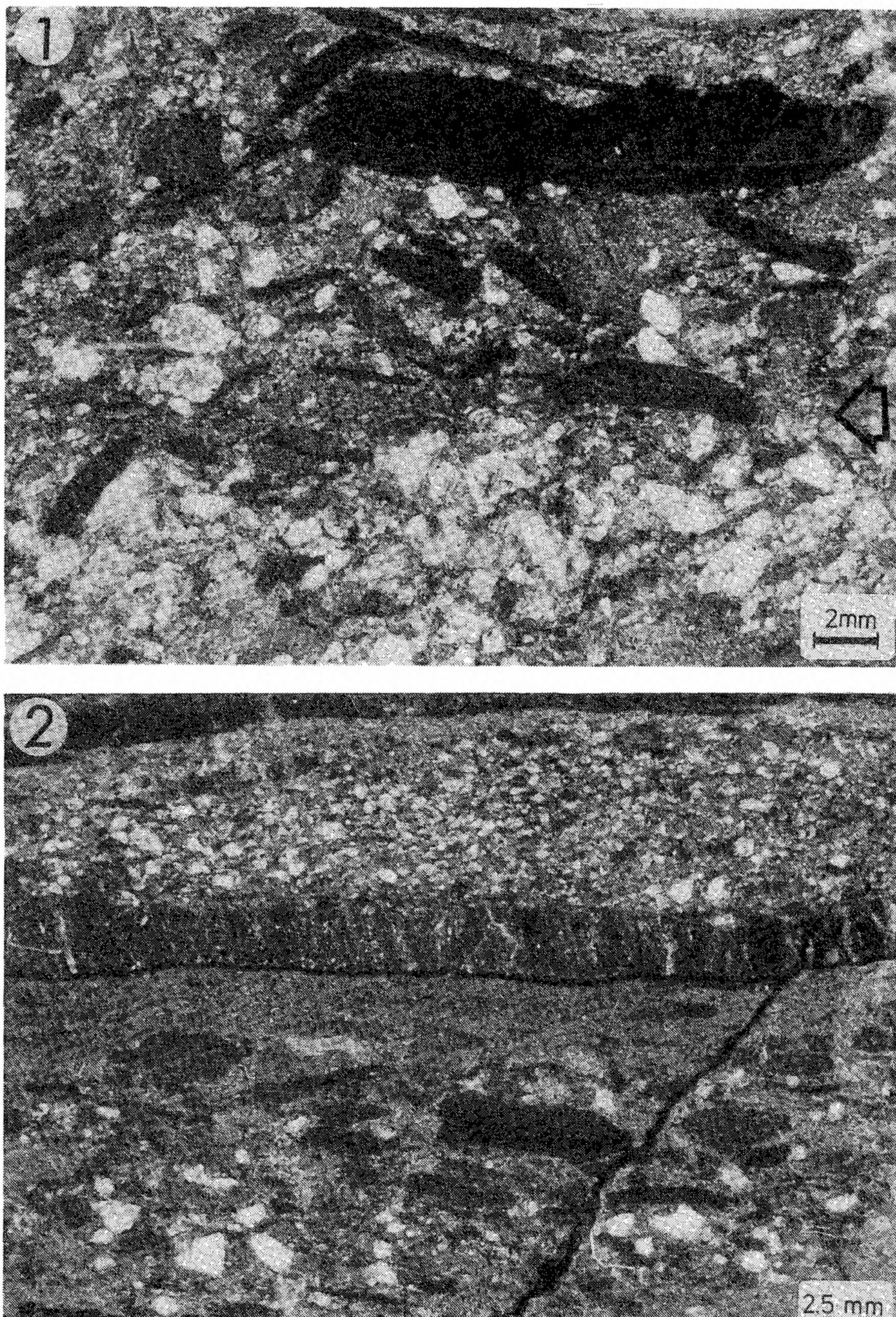
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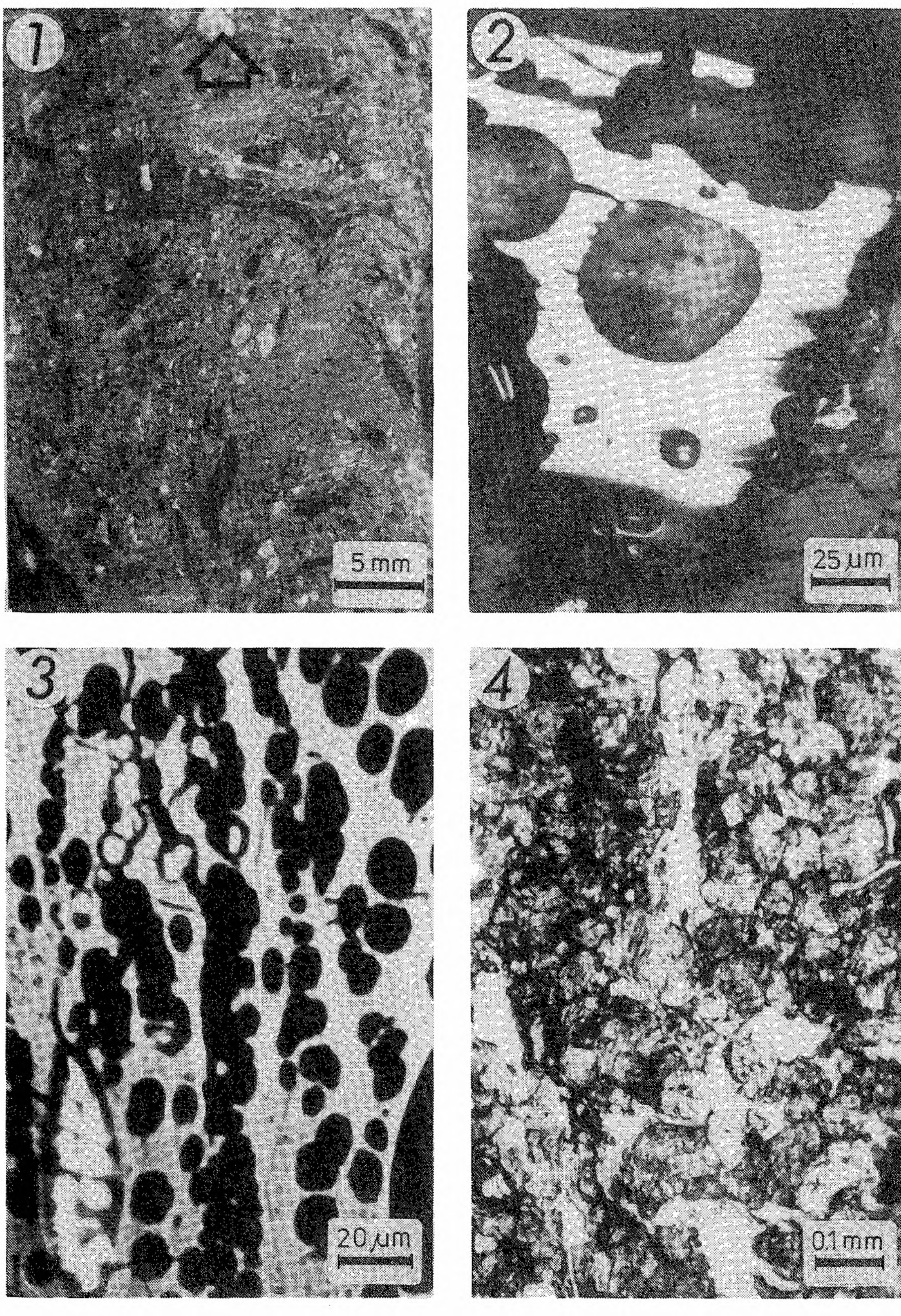
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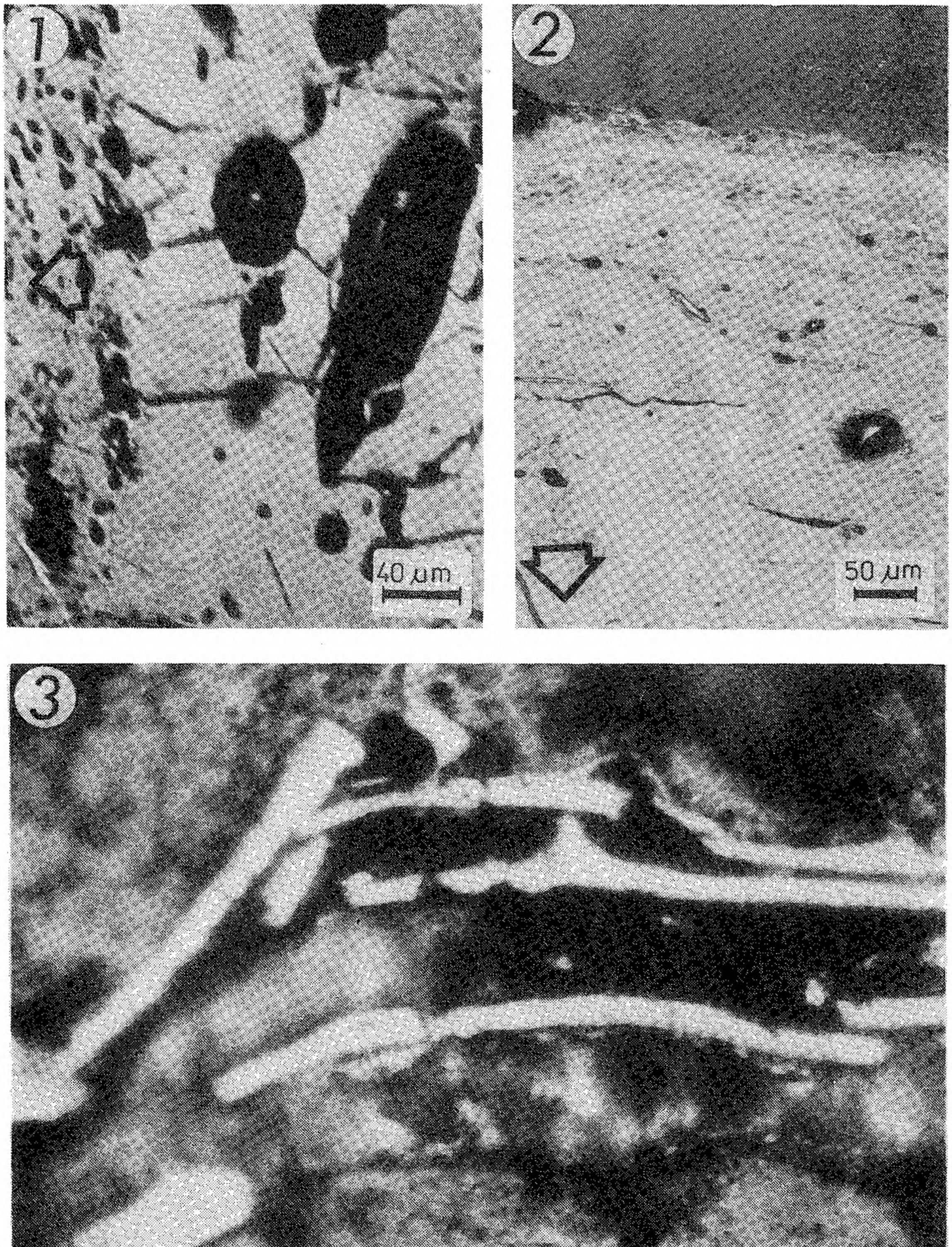
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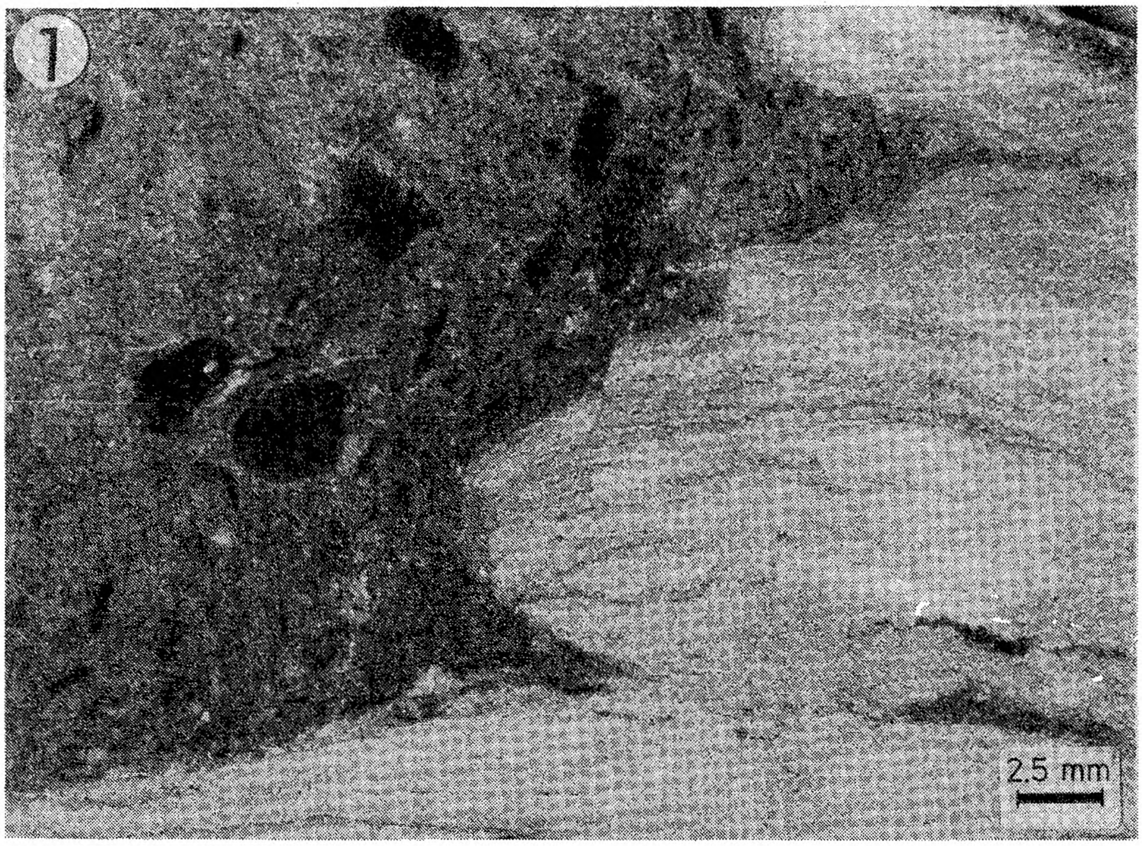
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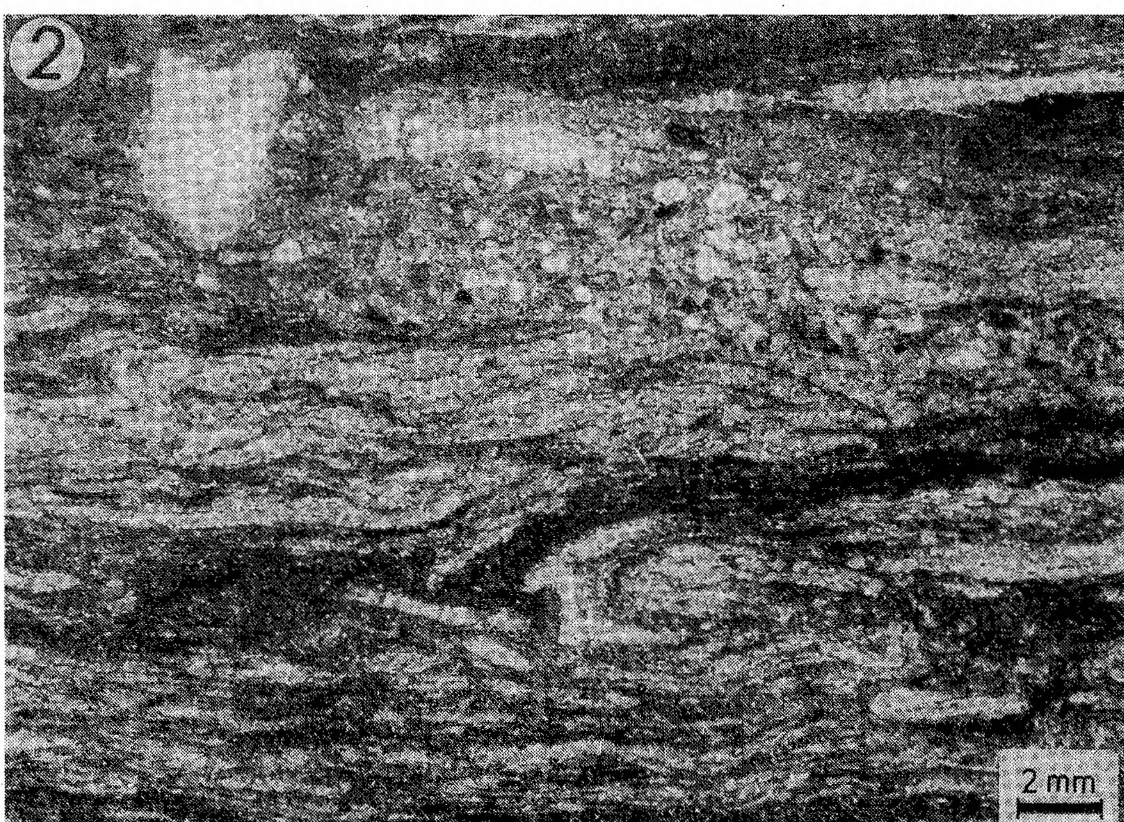
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