GEOLOGICA CARPATHICA, 49, 4, BRATISLAVA, AUGUST 1998
271–287

PECULIAR TYPES OF THIN VEINS IN THE MESOZOIC CARBONATES AND SILICITES OF THE WESTERN CARPATHIANS

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(Manuscript received March 9, 1998; accepted in revised form June 16, 1998)

Abstract: Many veinlets in carbonate rocks considered as open crack fillings, are the result of recrystallization (dashed veinlets formed by the shear, whitened veinlets). Synsedimentary and early diagenetic veinlets may be folded in a soft sediment deformation or deformed by brittle fragmentation. They may also fill desiccation cracks, bedding - parallel joints and synsedimentary cracks with internal sediment (microdykes). Synaeretic cracks in bedded silicites and nodular cherts can be filled with calcite partially infiltrating the still reactive silica mass (pearl-string type veinlets, bordered veinlets), filled by chalcedony, or can disappear being healed by neighbouring silica mass. Relative dating of veinlets with regard to the formation of authigenic minerals, formation of chert nodules, conglomerate deposition, calcite twinning, microstylolites etc. is possible. Authigenic quartz, feldspars, pyrite, illite, baryte, fluorite and galena found in calcite veinlets are mentioned. From the commonly occurring dedolomitized saddle dolomite in calcite veinlets, the burial depth of the Krížna Nappe was estimated.

Key words: Western Carpathians, Mesozoic, silicites, limestones, dolomites diagenesis, synsedimentary cracks, veinlets.

Introduction

Veinlets register a lot of the geological history of carbonate and silicite complexes since their deposition through early diagenesis and deep burial up to their final uplift to subsurface depth. They reflect strain field, tectonic events, render possible the estimation of the burial depth, record changes in the composition of fluids. This contribution is focused upon the types of veinlets derived from thin-section study and the perspectives for further investigations. The types of veinlets recognized in the following paper are summarized in the Fig. 1.

Questions concerning veins are dispersed in many papers. A review of them can be found in Groshong (1988).

Types of veinlets

Recrystallization veinlets. According to the current opinion thin veins in limestones originated by the filling of opened cracks that is by filling of an empty space. In an older contribution (Mišík 1971) I demonstrated that a considerable part of these veinlets of millimetres thickness was formed by recrystallization. That is clear mainly in such cases when fossils (bioclasts) cross the veinlet without being torn and both their ends put off, e.g. the aptychus at the Pl. I: Fig. A. The upper veinlet seems to be formed still in the unlithified sediment and the fossil could have been torn off the matrix. Relics of echinoderm plates are frequently preserved in the recrystallized veinlets (Pl. I: Fig. B). They originated mostly as so-called dashed veinlets (see in the further text). The penetration of the echinoderm plate into the veinlet on Pl. I: Fig. C is clearly visible, the recrystallization (removal of inclusions) was perfect and the dashed structure totally disappeared. Another veinlet (Pl. I: Fig. D) also seems to represent a normal filled crack but it branches by entering the crinoidal plate and so betrays its origin by the coalescence of thin veinlet array.

Several veinlets caused only lightening of the crossed part of fossil (aptychus — Pl. I: Fig. E, echinoderm plates and ooids — Pl. I: Fig. F), see further as whitened veinlets. The fibrous calcite aggregate of the veinlet crossed by undisturbed juvenile bivalves (Pl. II: Fig. A) also belong to the recrystallization veinlets.

Dashed veinlets (definition by Mišík 1971) originated by recrystallization, by amalgamation of an array of subparallel hair-thin veinlets formed by the shear. Their origin was later explained by Ramsay (1980) by the crack-seal-mechanism (repeated cracking and sealing). Bons & Jessell (1997) suggested an alternative explanation of fibrous veins, formed by diffusional transport, by dissolution-precipitation creep, without fracturing. Our cases indicate the origin of dashed veins from an array of thin subparallel cracks which is not compatible with the process supposed by Bons & Jessell (1997).

A considerable part of the thickness of dashed veins proceeds from the recrystallization of the micritic host rock. The remnants of micrite dividing former subparallel veinlets are concentrated in stripes or only as inclusion trails parallel to the vein (Pl. II: Figs. B–E; Pl. III: Fig. A). Some larger calcite grains were totally cleaned of these remnants during the recrystallization (aggrading neomorhism, Folk 1965), while they are well preserved in the neighbouring grains(Pl. II: Fig. C). The new-formed aggregates use to have a columnar or fibrous structure with fibres normal to the veinlet walls. The origin of the asbestos-like calcite aggregate could probably have been initiated by the process of forming the array of very thin veinlets as can be seen in Pl. III: Figs. B, C. Some

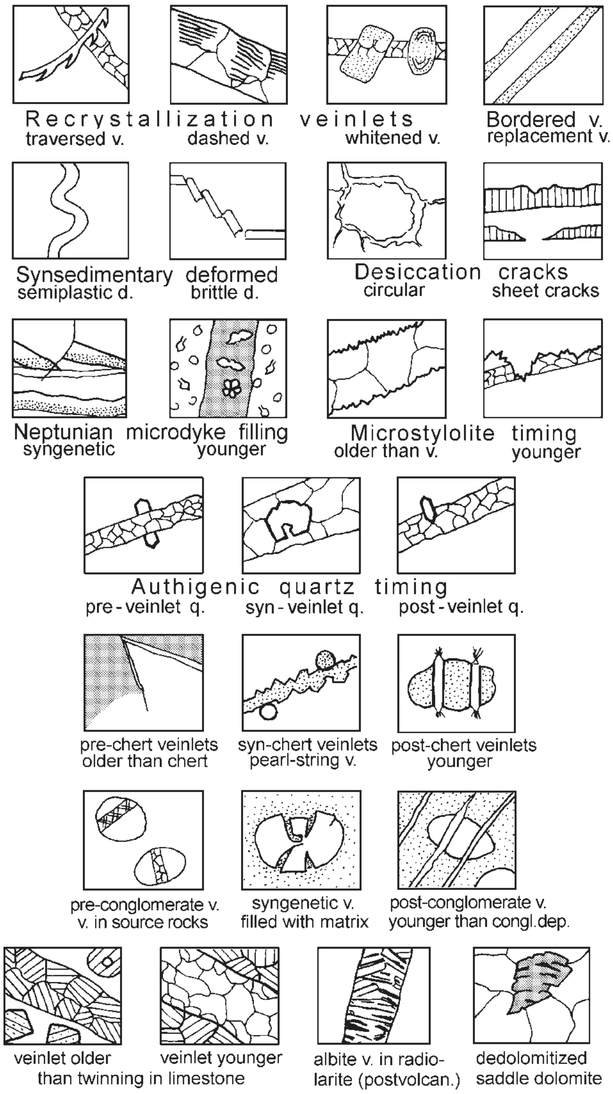

Fig. 1. Described types of veinlets.

of dashed, originally fibrous veinlets can acquire after recrystallization an aspect of elongated-blocky veins of Fisher & Brantley (1992).

The mutually cut dashed veinlets register the change in the direction of extension (Pl. II: Fig. F). The dashed veinlets are sometimes folded (Pl. III: Fig. D), perhaps contraction affected still semiconsolidated and later compacted sediment.

The dashed veinlets also occur in dolomites. In the two following cases the remnants of dashed structure were preserved due to authigenic quartz replacing a part of the veinlet before its final recrystallization (e.g. in a Carboniferous dolomite — Pl. II: Fig. E and the Triassic dolomite — Pl. III: Fig. F). These examples again show that the recrystallized veinlets are much more wide spread than was estimated before, because frequently no phantoms of their dashed nature were preserved.

Recrystallized dashed veinlets also occur in silicites, e.g. quartz veinlet in Triassic radiolarites (Pl. IV: Figs. A, B), calcite veinlet in Oxfordian radiolarites (Pl. IV: Figs. C–E). An albitic dashed veinlet was exceptionally found in the acid tuffites. Similar veinlets were illustrated by Ramsay & Huber from greywackes (1987, Fig. 25.16) and calcareous phyllites (Fig. 25.17). Augustithis (1973, Fig. 12.12) illustrated dashed veinlets from granites; he explained them surprisingly as colloform structures.

Bordered veinlets belong to a rare type. They represent a combination of normal veinlet with recrystallization veinlet. Their central part originated by filling of an empty space (open crack) and lacks inclusions. The recrystallization part was developed along both sides by replacement of the sediment and therefore is full of inclusions. Bordered veinlets were found in limestones (Pl. IV: Fig. F), radiolarites (Pl. IV: Fig. G), and chert nodules (Pl. V: Fig. A).

Whitened veinlets. In these cases the recrystallization is manifested by whitening (removal of inclusions during the recrystallization) of the matrix, ooids and bioclasts crossed by the veinlet in limestone (Pl. I: Fig. F). In another case the recrystallization veinlet cleared an aptychus by removing of its pigment without tearing it (Pl. I: Fig. E).

Limpid phantom veinlets occur very frequently in the dolomites (Pl. V: Fig. B). They possess sharp boundaries but pass independently of the new-formed mosaic of larger grains (aggrading neomorphism). They are phantoms of normal veinlets filled with clear dolomite cement which lost their individuality during the recrystallization of the dolomite rock. The same explanation was suggested by Bose (1979, p. 690, Fig. 8F).

Granulation veinlets in dolomites, in contrast to the preceding category, originated by degrading neomorphism (Folk 1965). They represent thin zones of the tectonic trituration of a coarser-grained dolomite (Pl. V: Fig. C). The pseudodolomicritic matrix of dolomite tectonic breccias originated by increasing the amount of their products.

Syngenetic (or very early diagenetic) veinlets deserve special attention. Five types of them will be described.

Veinlets folded by compaction are frequent in marls and marly limestones (Pl. III: Fig. D), but also occur in rapidly accumulated silicites. Two examples will be mentioned. Tri-

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Plate I: Thin-section microphotographs in plane-polarized light. **Fig. A.** Aptychus crosses the upper recrystallization veinlet without being disturbed; it was partly dislocated in the lower one. Upper Tithonian limestone, Manín Unit, klippe Butkov, 6. gallery. Magn. 43×. **Fig. B.** Recrystallization veinlet formed by the coalescence of parallel hairline cracks shown by the remnants of dashed structure in the place where it is crossed by the crinoidal plate. Liassic limestone, Krížna Nappe, Donovaly, Nízke Tatry Mts. Magn. 55×. **Fig. C.** Partial penetration of an echinoderm plate in a calcite recrystallization veinlet shows that it did not originate from an open crack. Upper Tithonian limestone, Manín Unit, Butkov, borehole LC-5, 25 m. Magn. 55×. **Fig. D.** Recrystallization veinlet penetrating the crinoidal plate. The ghosts of its pore structure and preceding thin veinlets array are visible inside the veinlet. Liassic limestone, Krížna Nappe, Donovaly, Nízke Tatry Mts. Magn. 43×. **Fig. E.** Recrystallization veinlet crossed by aptychus. At the crossing the aptychus lost pigment during the recrystallization (whitened veinlet). Tithonian limestone, Krížna Nappe, Padlá Voda near Smolenice, Malé Karpaty Mts. Magn. 43×. **Fig. F.** Whitened veinlets with phantoms of crossed ooids and bioclasts (their pigment was partly removed during the recrystallization). Rhaetian limestone, Krížna Nappe, loc. 114 near Rajec, Malá Fatra Mts. Magn. 20×.

PLATE I

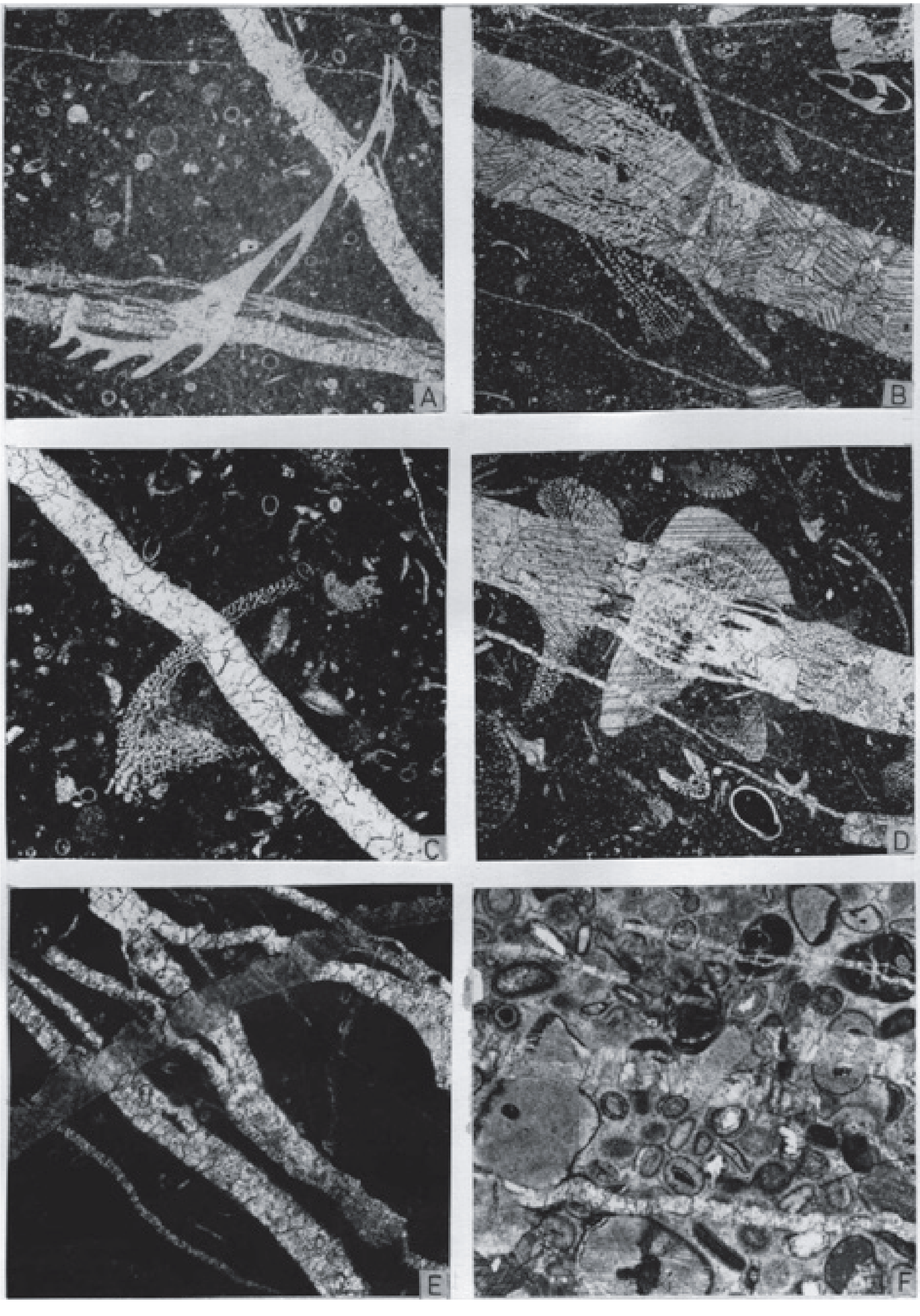
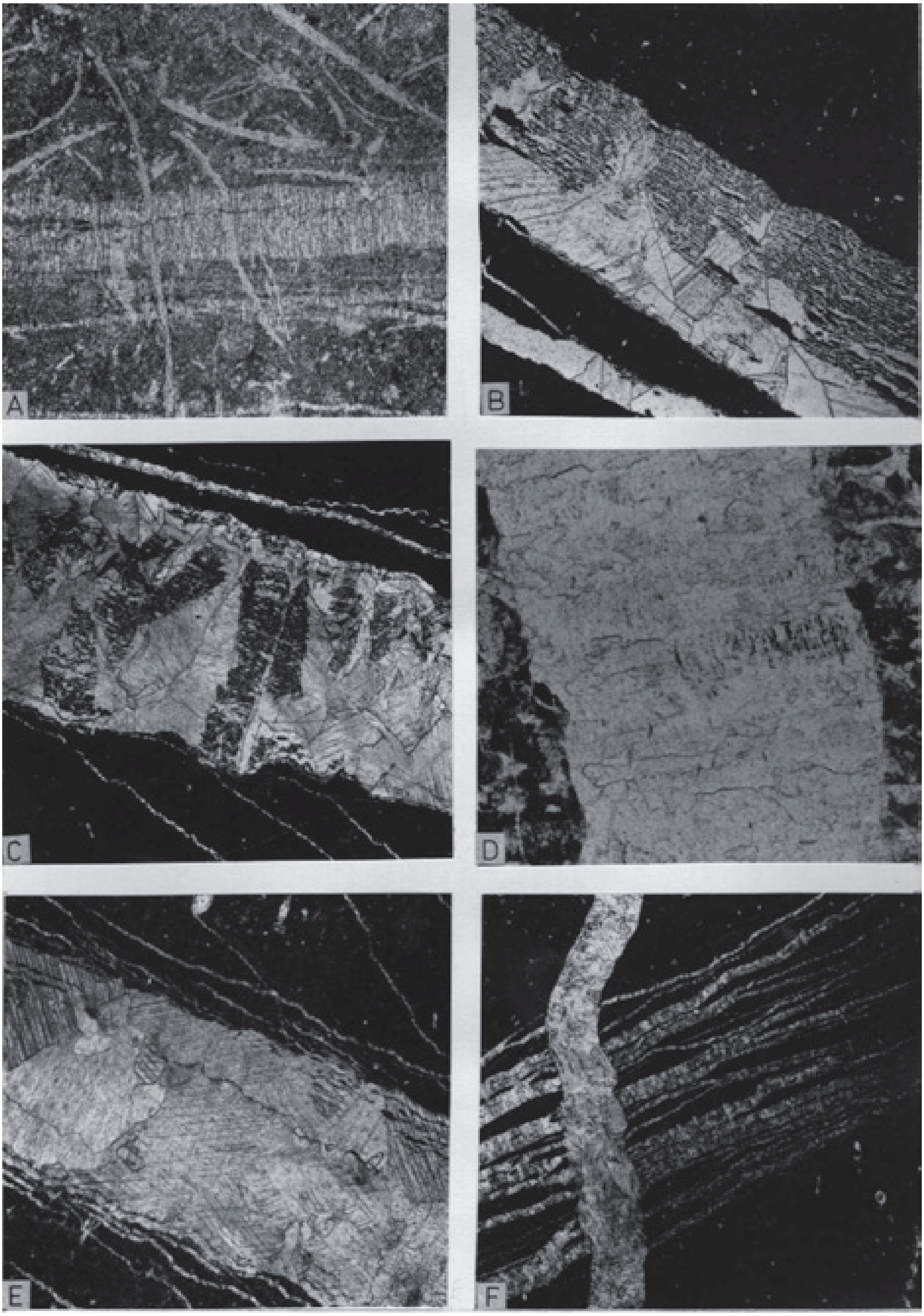


PLATE II



assic radiolarites of the Meliata Unit are sometimes associated with hematite and baryte deposits proceeding from hydrotherms penetrating through the ocean bottom. Deformations of the net of chalcedony veinlets caused by the movement of non-consolidated mass have been found at the locality Bradlo (Pl. V: Fig. D). Another case is represented by the Oxfordian radiolarites (Pl. V: Fig. E), from the locality Trstená bowling alley (Mišík et al. 1991a). The participation of hydrotherms in the silica accumulation was documented there by rare baryte crystals, roof-like lifting of radiolarite laminae by ascending fluids (Pl. V: Fig. F) and large spheroids (their sole locality in Slovakia). From the folded vertical veinlet (Pl. V: Fig. E) compaction at least 20 % can be deduced. In other localites radiolarites were deposited slowly (about 5 mm/1000 y) and do not contain such compactional deformations.

Extremely folded calcite veinlets were found in a Mn-crust from the Oxfordian limestone (Pl. VI: Figs. A, B). It is an exceptional case for Mn-crust. The early filled dehydratation cracks were deformed by the movement of semiconsolidated colloidal mass rapidly accumulated by supposed hydrotherms.

Fragmented veinlets originated by breaking of a rigid veinlet within the semiconsolidated mass. The doubling of part of a veinlet may be documented from the above mentioned radiolarite locality Bradlo (Pl. VI: Fig. C). The second locality for radiolarites at Trstená bowling-alley also contains fragmented syngenetic veinlets (Pl. VI: Fig. E). Such broken veinlets also illustrated Soták & Ožvoldová (1993, pl. XXXII: Figs. 1–2) from the radiolarites of the Carpathian Flysch Belt and Hattori et al. (1996, Fig. 6A, p. 169) from the Japanese Miocene silicites. Fragmented syngenetic veinlets rarely occurred in spiculite limestone (Pl. VI: Fig. D) and fresh-water Upper Cretaceous limestone (Pl. VI: Fig. E — with imbricated fragments).

Desiccation veinlets were formed during temporary emersion, e.g. circular veinlets from dehydratation cracks in fresh-water limestone (Pl. VI: Fig. G), or from cracked lithoclasts in the Keuper Dolomite (Pl. VII: Fig. C). Veins parallel to the bedding filled with prismatic or fibrous calcite aggregate were named sheet cracks by Fischer (1964, p.114). In the Western Carpathians they occur in dolomites (Pl. VII: Fig. D); the cases of their partial erosion support their origin near the surface.

Plate II: Fig. A. Shells of juvenile bivalves cross the recrystallization veinlet, formed by fibrous calcite, without being torn in two pieces. Middle Triassic limestone, Choč Nappe, quarry near Čierna, Strážovské vrchy Mts. Magn. 43×. **Fig. B.** Dashed veinlets with parallel inclusions of the marly micritic limestone, originated by recrystallization from parallel hairline fractures (crack-seal mechanism). Neocomian limestone, Manín Unit, Butkov. Magn. 43×. **Fig. C.** Vestige of dashed structure; the impurities were partly removed by aggrading crystallization. The same locality. Magn. 43×. **Fig. D.** Rare remnants of the dashed structure make it possible to identify a recrystallization veinlet. Thin section from a pebble of Barremian – Lower Aptian limestone in the Cenomanian conglomerate. Shear cracks with the following recrystallization veinlet were formed in the time span Upper Aptian – Albian. Manín Unit, Praznov. Magn. 43×. **Fig. E.** Remnants of dashed structure near the lower margin of the veinlet and neighbouring parallel hairline veinlets betray the recrystallization. Neocomian marly limestone, Kysuca Unit of the Klippen Belt, Horné Sŕnie. Magn. 43×. **Fig. F.** Array of subparallel veinlets penetrated by a dashed veinlet. Neocomian limestone, Manín Unit, Butkov, gallery 6, 32 m. Magn. 23×.

Dewatering veinlets and voids may be formed within the covered sediment, e.g. circular cracks in a coal fragment (Pl. VII: Fig. A), in limestone (Pl. VII: Fig. B — perhaps formed due to fluid overpressure). Subaqueous shrinkage cracks were described Donovan & Foster (1972).

Veinlets from the dehydratation of opal-chalcedony mass. Shrinkage cracks sealed usually by chalcedony occur in radiolarites (Pl. V: Fig. D) or chert nodules (Pl. VII: Fig. E — some parts of the veinlets are filled with calcite, others with chalcedony). More examples will be demostrated further by discussing syngenetic veinlets in chert nodules.

Syngenetic neptunic microdykes also represent the products of syngenetic cracking of sediment. If such cracks were partly filled by sediment and the remaining space by calcite, a polarity structure originated (Pl. VII: Fig. F). Neptunian microdykes filled with sediment of a different age (Pl. VIII: Fig. A) are not the subject of this contribution. A special case was registered in Pl. VII: Fig. G where the infilling of a microdyke was repeatedly cracked forming an array of very thin veinlets parallel to the microdyke walls.

Timing of veinlet formation

Timing of veinlets in the conglomerates. It is possible to discern three groups of veinlets: (1) preconglomerate veinlets occur only in the pebbles, they reflect older tectonic processes (Pl. VIII: Fig. D), (2) synchronous with the deposition — these veinlets proceed from the cracking of pebbles under the load (Mišík et al. 1991a,b,c), the matrix was entrained in the cracks and the rest eventually filled by calcite cement (Pl. VIII: Figs. A, C), (3) post-depositional veinlets formed after the solidification of the conglomerate; they cross not only pebbles but also the matrix in parallel systems.

Timing of veinlets formation in chert nodules. Three groups can be defined:

(1) **Pre-chert calcite veinlets** limit in straight lines the chert nodules in thin sections; they represented an obstacle to the growth of the nodule and stopped the migrating silica solutions (Pl. VIII: Figs. E, F). They are very frequent. The opposite case of pre-chert shear joints serving for the small chert accumulations was observed only once (Pl. IX: Fig. A). It might be a case of diastasis cracks (Cowan & James 1992) originated by differential mechanical behaviour of interlayered stiff mud under stress.

(2) **Syngenetic veinlets,** already mentioned (Pl. VII: Fig. E), were formed in the stage when silica accumulation contained a considerable amount of water and was still reactive. Solutions of calcium bicarbonate penetrated in the submicroscopic synaeretic cracks, calcite rhombs grew from them as if hanging on a string (Pl. IX: Figs. C, E) — **pearl-string type** of veinlets (Mišík 1971, 1993). Radiolarians were filled by calcite monocrystal but only in their immediate neighbourhood (Pl. IX: Fig. D).

PLATE III

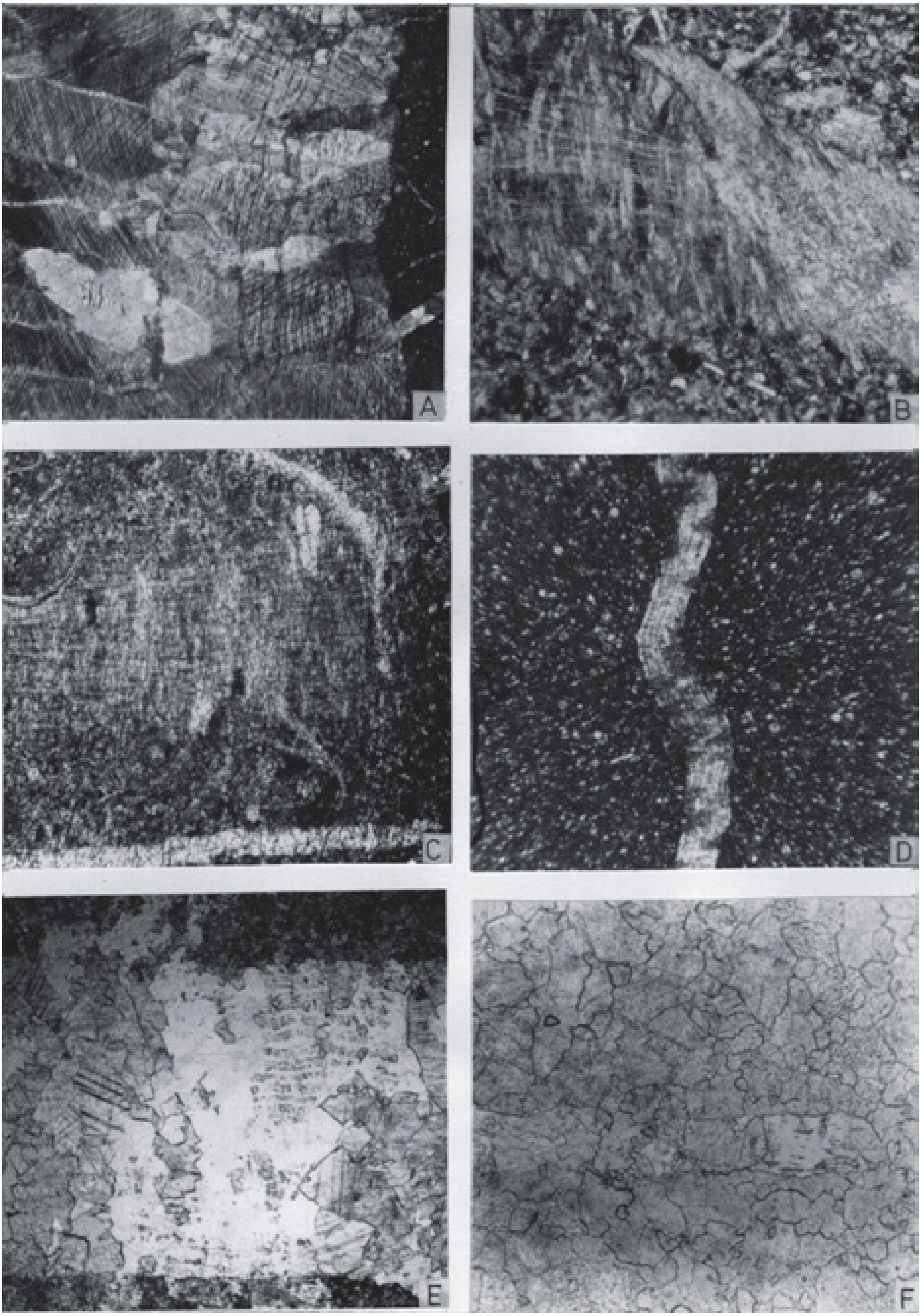


PLATE IV

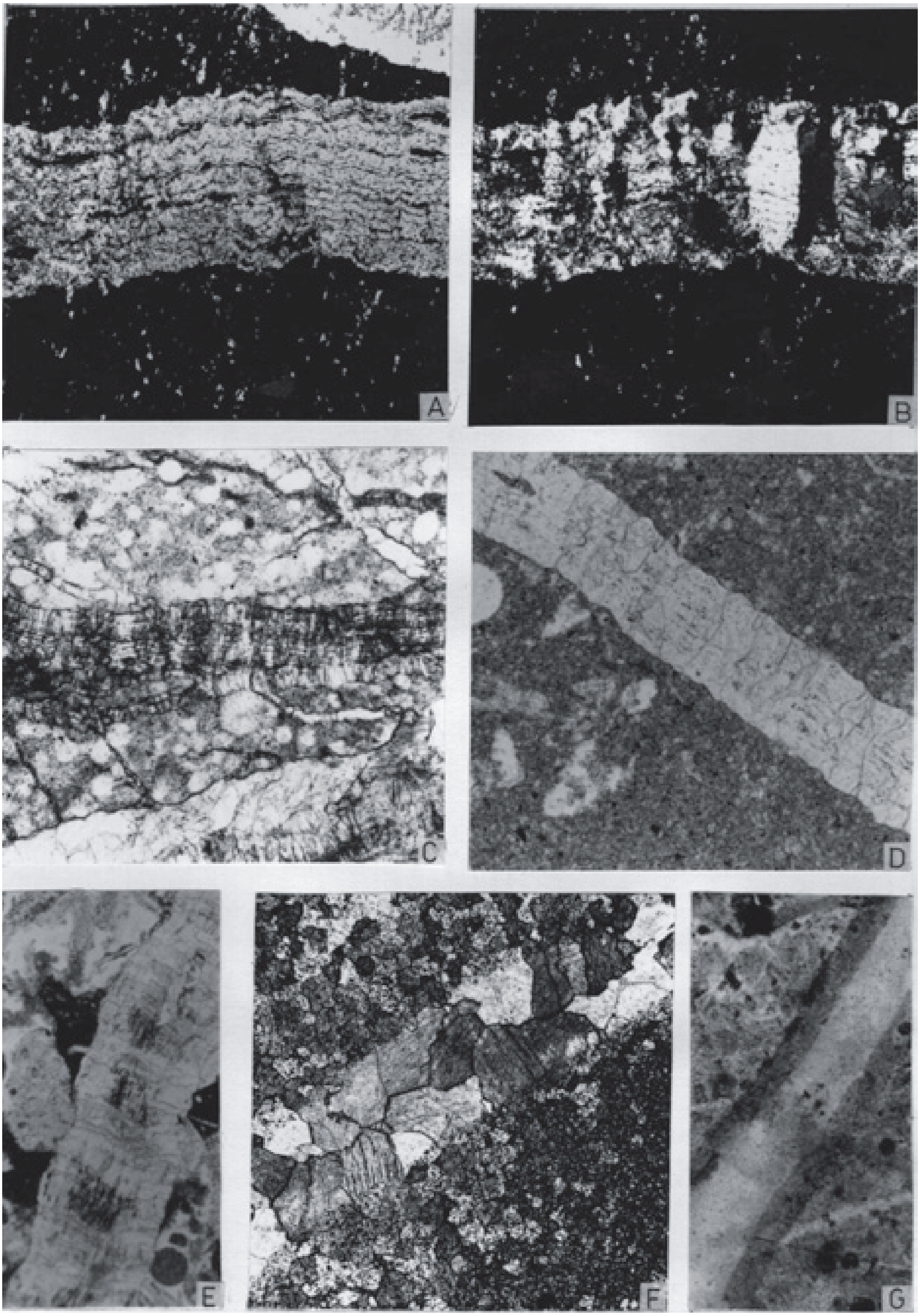


PLATE V

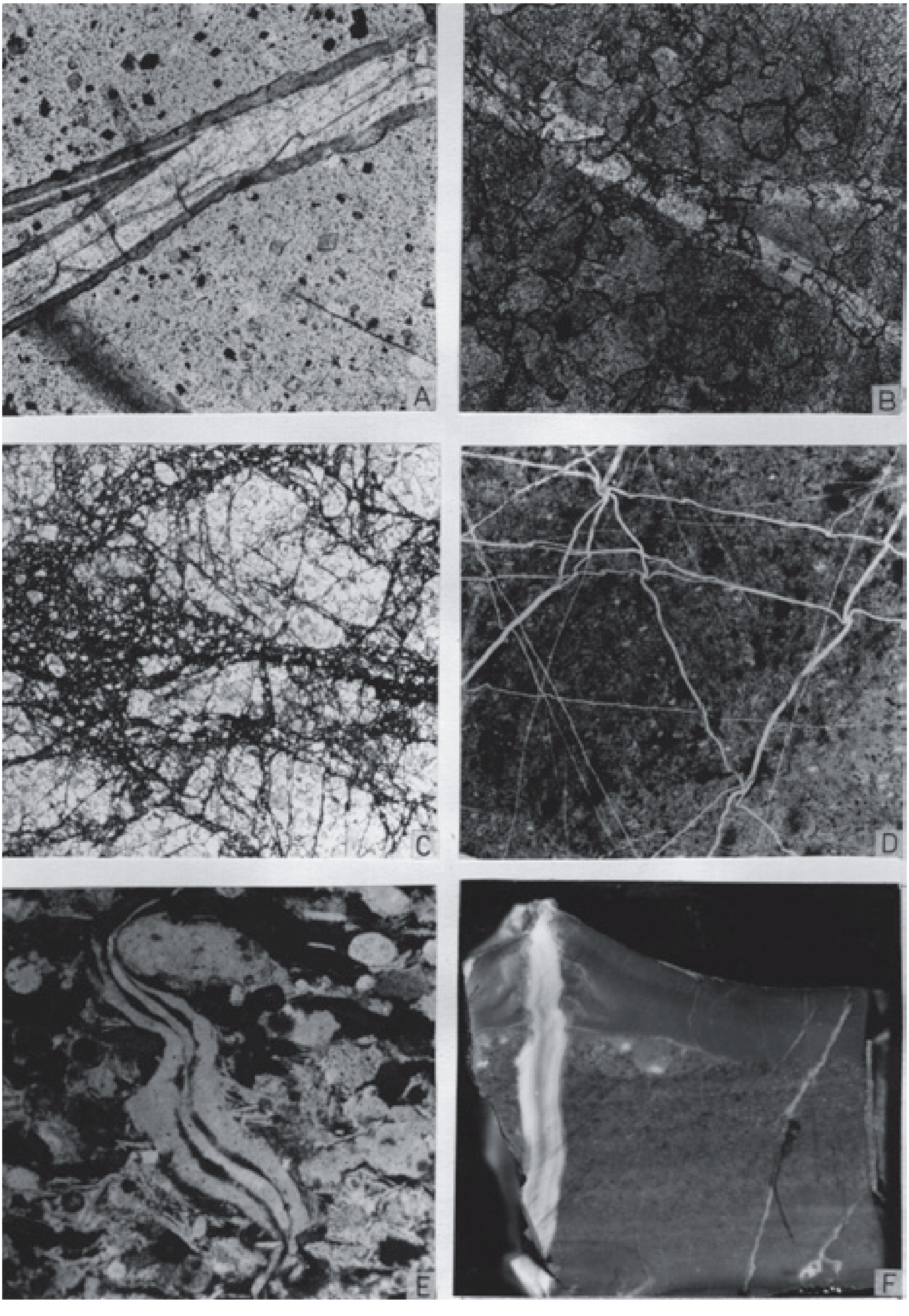


PLATE VI

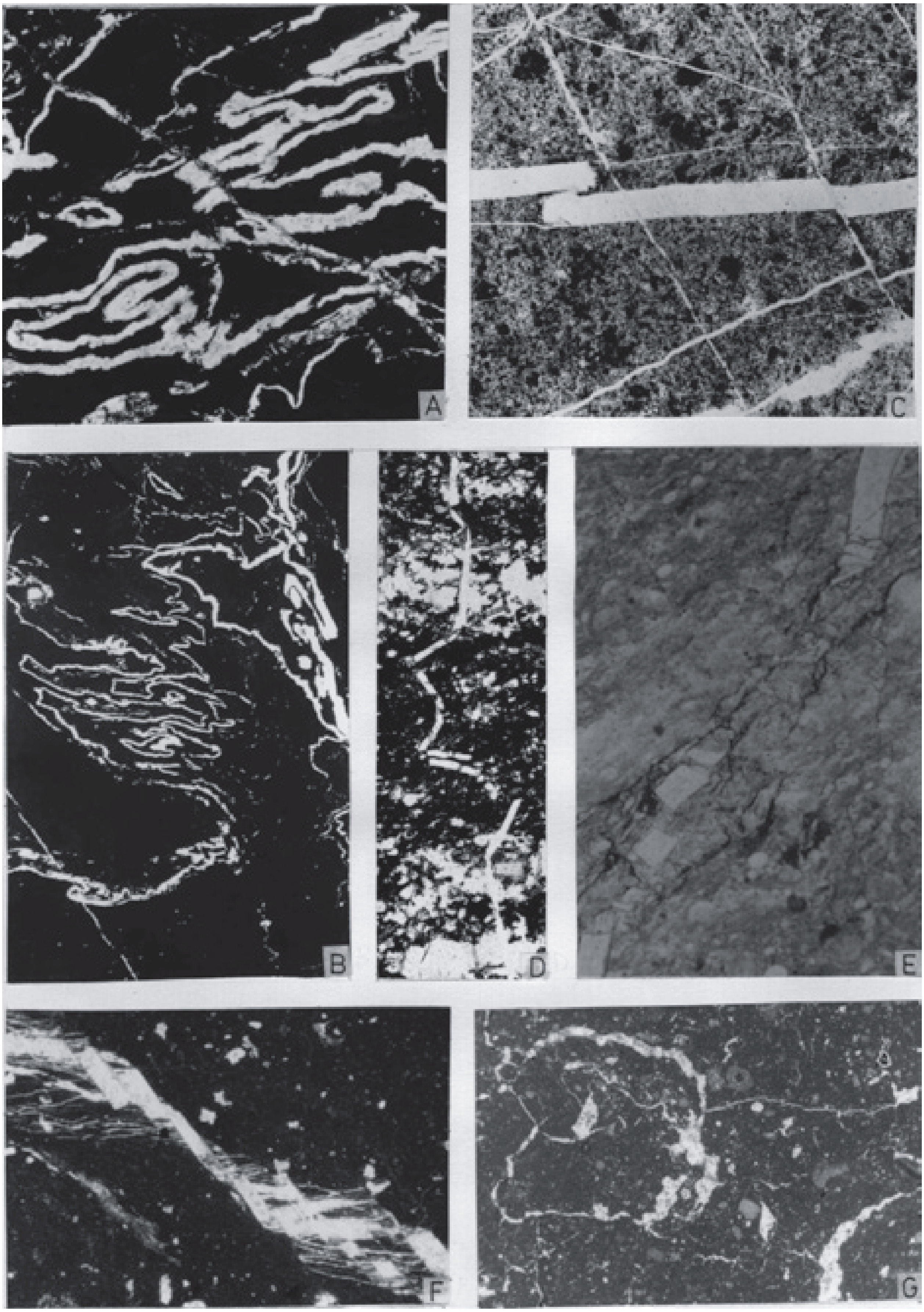


PLATE VII

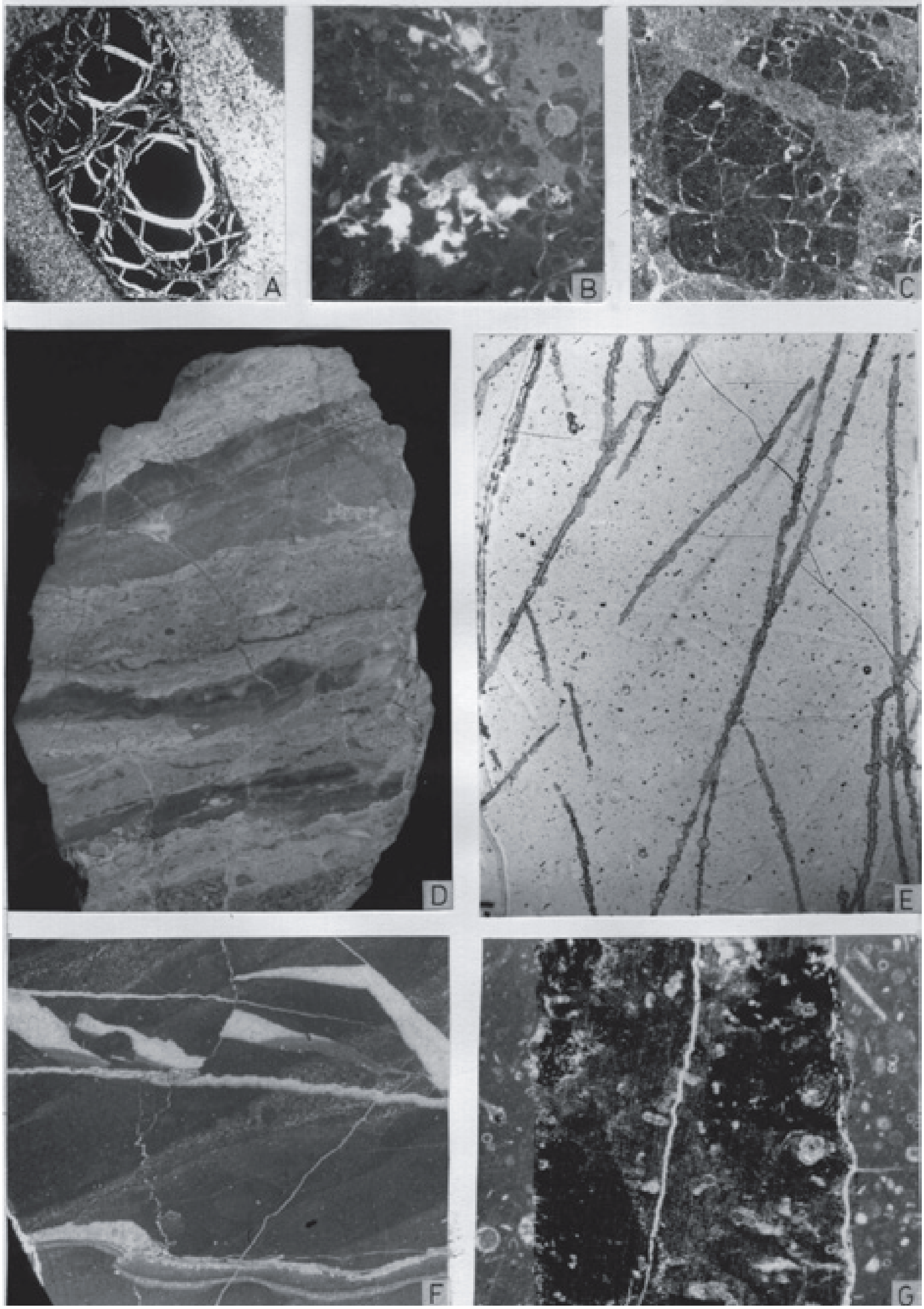


Plate III: Fig. A. Another thin vein which did not originate by the filling of an open crack. The true extension was only about half the thickness of this dashed veinlet. Pebble of the Upper Tithonian limestone from the Eocene Strihovce Conglomerate, Magura Unit of the Flysch Belt. Starina. Magn. 30×. **Fig. B.** New-formed calcite fibres approximately perpendicular to the array of hairline veinlets. Pebble of the Senonian limestone from the Lower Miocene Jablonica Conglomerate. Prievaly. Magn. 30×. **Fig. C.** Calcite fibres (pseudosparite) grown perpendicularly to the array of hairline cracks. Norian Hallstatt Limestone, Silica Nappe, Silická Brezová. Magn. 55×. **Fig. D.** Folded dashed veinlet indicates that the crack-and-seal mechanism took place still in a non-consolidated sediment. Lower Tithonian marly limestone, uppermost nappe, quarry in Šipkovský Haj near Krajné, Čachtické Karpaty Mts. Magn. 30×. **Fig. E.** Thin calcite vein partially replaced by authigenic quartz (white). Remnants of the dashed structure are preserved only in quartz due to the early replacement. Upper Visean – Lower Namurian dolomite, Gemeric Superunit, Ochtiná. Magn. 30×. **Fig. F.** Part of a carbonate veinlet in dolomite was early replaced by the authigenic quartz; its dashed structure was preserved only there. Pebble of Triassic dolomite in the Albian Ludrová Conglomerate, Tatric Superunit, Malá Magura Succession. Čavoj-20. Strážovské vrchy Mts. Magn. 95×.

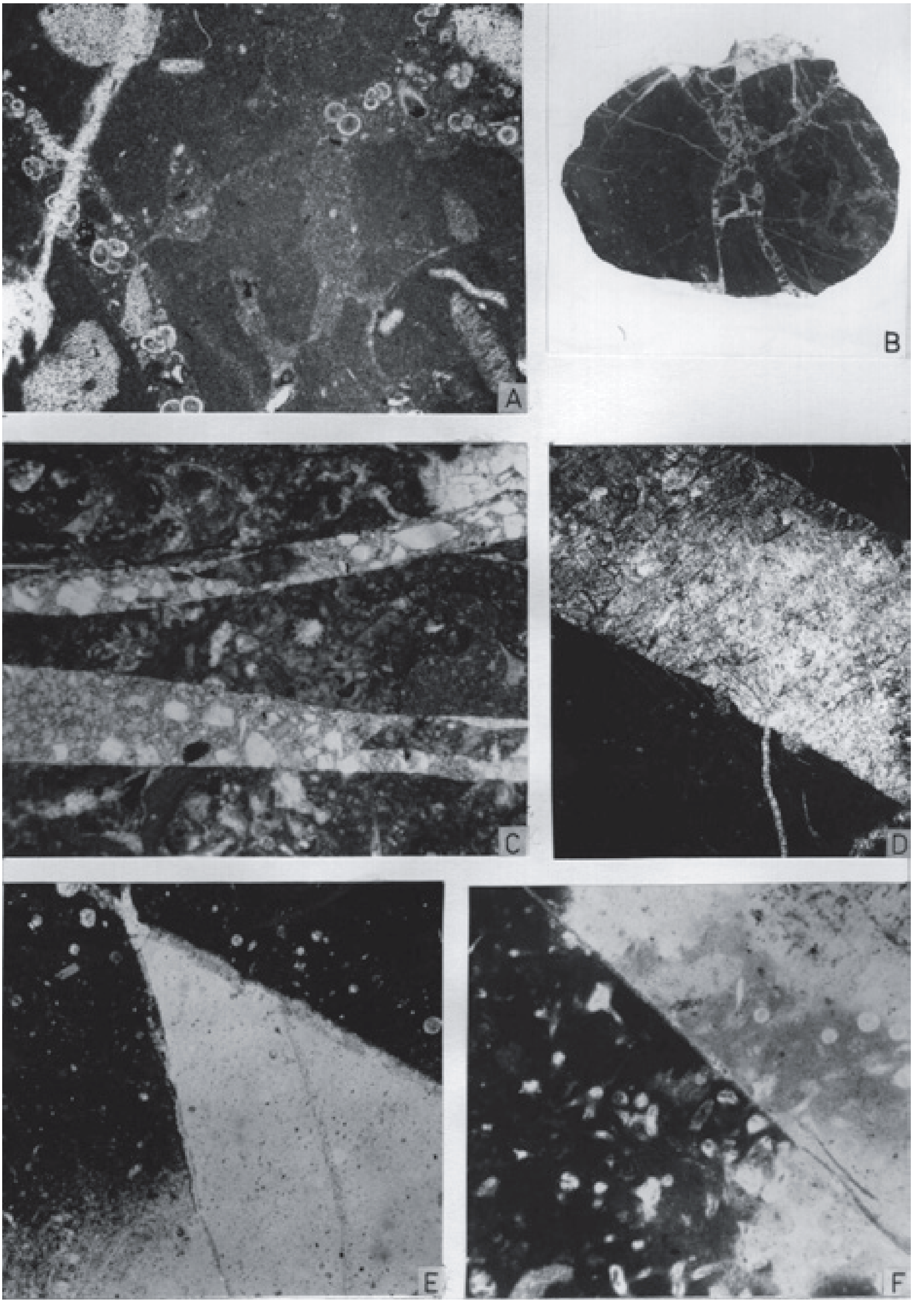
Plate IV: Fig. A. Quartz dashed veinlet in the radiolarite. Ladinian-Carnian of the Meliata Unit, Bradlo, South-Slovak Karst. Magn. 55×. **Fig. B.** The same in cross-polarized light; perpendicularly recrystallized quartz grains are clearly visible. **Fig. C.** Dashed calcite veinlet in the radiolarite, formed by coalescence of hairline cracks. Oxfordian radiolarites of the Pieniny Succession, Klippen Belt, Dúbrava near Stará Turá. Magn. 48×. **Fig. D.** Dashed calcite veinlet in the radiolarite. Oxfordian of the Pieniny Succession, Klippen Belt, Trstená bowling alley. Magn. 48×. **Fig. E.** Calcite dashed veinlet in a radiolarite. Recrystallization of hairline veinlets to perpendicular calcite fibres and prismatic grains eliminated the dashed structure except for some remnants of host rock in the calcite vein. The same locality. Magn. 30×. **Fig. F.** Bordered veinlet in dolomitic limestone. Its pigmented margins were formed by syntaxial growth of calcite grains from the veinlet at the expense of the host rocks, partially dolomitized limestone. Anisian Gutenstein Limestone, Tatric Succession, Veľký Kriváň, Malá Fatra Mts. Magn. 25×. **Fig. G.** Bordered calcite veinlet in radiolarite. Its clear middle part was formed by the filling of an open fracture with chalcedony. Grey pigmented borders were formed by calcite replacing the host Oxfordian radiolarite. Pieniny Klippen Belt. Trstená, bowling alley. Magn. 48×.

Plate V: Fig. A. Bordered veinlets in the chert nodule are syngenetic with the chert forming process. Their middle limpid parts had been open cracks filled by calcite. Its grains grew syntaxially through the walls into the surrounding silica mass with high content of water. The replaced margins are grey, filled by inclusions. Chert nodule in the Upper Tithonian limestones of the Kysuca Succession, Peniny Klippen Belt, quarry near Brodno. Magn. 55×. **Fig. B.** Lightened veinlets in dolomite do not disturb the grain mosaic. They are ghosts of normal veinlets (open cracks filled by limpid dolomite) in the completely recrystallized dolomitic rocks with grains full or inclusions. Ladinian dolomite of the Krížna Nappe, Demänová, Pod Lúčkami, Nízke Tatry Mts. Magn. 136×. **Fig. C.** Network of granulation veinlets in dolomite representing fine cracks filled by cataclastic pseudodolomicrite. Triassic dolomite breccia. Vojtová Valley near Rajec, Strážovské vrchy Mts. Magn. 13×. **Fig. D.** Synsedimentary folded network of chalcedony veinlets in radiolarite. After the filling of thin synaeretic cracks, sliding of non-consolidated silica mass took place. The hydrothermal activity caused the rapid accumulation of silica. Ladinian-Carnian radiolarite of the Meliata Unit, Tri Peniažky, Bradlo, South Slovak Karst. Magn. 14×. **Fig. E.** Compactional deformation of the chalcedony veinlet in distal turbidite intercalation within the Oxfordian radiolarites. Pieniny Succession, Klippen Belt, Trstená bowling alley. Magn. 30×. **Fig. F.** Vertical veinlet filled with chalcedony penetrating laminated radiolarite. The filling proceeds from a hydrothermal source at the bottom; the ascending fluids heaved the uppermost part of the sediment which was not yet consolidated. The same locality. Polished section, slightly magnified (1.7×).

Plate VI: Fig. A. „Ptygmatic“ folding of calcite veinlets in a hardground Mn-crust occurred during the Albian. Early filled dehydratation cracks were deformed by the movement of semiplastic colloidal manganese mass. Czorsztyn Succession, Vršatec-castle klippe. Magn. 48×. **Fig. B.** The same. Magn. 16×. **Fig. C.** Fragmented chalcedony veinlet formed by the breaking of its consolidated filling within still semiplastic silica mass; fragments are partially overthrust. Ladinian-Carnian radiolarites of the Meliata Unit, Bradlo — Tri Peniažky. Magn. 43×. **Fig. D.** Early vertical calcite veinlet (perpendicular to the lamination) fragmented during compaction. Liassic limestone pebble from the Eggenburgian conglomerate, quarry near Podbranč (material of I. Baráth). Magn. 14×. **Fig. E.** Fragmented veinlet with early consolidated chalcedony filling, broken by extension of the still semiplastic silica sediment. Oxfordian radiolarites, Trstená, bowling alley, Pieniny Succession. Magn. 30×. **Fig. F.** Syngenetic fragmented calcite veinlet with partial imbrication of its fragments, diagonally crossed by a set of thin younger veinlets. Fresh-water Coniacian limestone, pebble in the Santonian-Campanian conglomerate. Dobšinská Ľadová jaskyňa. Magn. 30×. **Fig. G.** Circular veinlets originated by the calcite filling of desiccation cracks in fresh-water Lower Coniacian limestone. Betlanovce, Stratenská hornatina Mts. Magn. 7×.

Plate VII: Fig. A. Dewatering circular calcite veinlets (filled desiccation cracks) in a coal fragment. Senonian marlstone with silt laminae. Borehole Gajary G-125, 4842 m, basement of the Vienna Basin. Magn. 13×. **Fig. B.** Dewatering veinlets — synsedimentary cracks filled with calcite cement and partly by younger micrite. Upper Berriasian limestone of the Horná Lysá Succession, Pieniny Klippen Belt, Vršatec. Magn. 22×. **Fig. C.** Desiccation veinlets (thin cracks formed during temporary emersion) with dolomitic infilling in a dolomite intraclast. Norian Keuper dolomite of the Krížna Nappe, quarry between Ždiar and Tatranská Kotlina. Magn. 11×. **Fig. D.** Desiccation veins of the sheet-crack type. Stratabound joints filled by asbestos-like calcite fibres, locally affected by the erosion. Ladinian Wetterstein Limestone, quarry near Krásna Ves, Strážovské vrchy Mts. Polished section, natural size. **Fig. E.** Network of syngenetic dehydratation veinlets in a chert nodule. Synaeretic cracks were partially filled with calcite and partially refilled with silica mass. Chert from the Upper Tithonian limestone of the Kysuca Succession, Pieniny Klippen Belt, quarry near Brodno. Magn. 20×. **Fig. F.** Neptunic veinlets (microdykes) — syngenetic cracks filled partially by internal micritic sediment; the remaining empty space was sealed by calcite cement. Polarity structure shows inclination with regard to the laminated infilling of a void, larger than the figure. Callovian-Oxfordian limestone, klippe Kostelec. Magn. 6×. **Fig. G.** Neptunic microdyke formed as an open vertical fracture in Berriasian limestones with tintinnids which was filled by red Albian marl with *Hedbergella* and *Ticinella*. The microdyke filling was later disturbed by a set of hairline veinlets subparallel to the fracture. Czorsztyn Succession, Klippen Belt, quarry near Kamenica. Magn. 30×.

PLATE VIII



(3) **Post-chert veinlets** represent younger tectonic phenomena. They originated by cracking of already non-reactive solidified chert nodules. These open joints were filled with clear calcite aggregates. Due to the higher plasticity of the limestone compared to the silicite, the veinlets in chert nodules are always thicker and more frequent (Pl. IX: Fig. B).

Timing of veinlets with regard to authigenic minerals and other diagenetic phenomena. If the authigenic quartz or feldspar is younger than the veinlet, it extends from the rock into the veinlet (Pl. X: Figs. C, D). The veinlet is cut by the younger stylolite (Pl. IX: Fig. F). A younger vein filled an opened stylolite after the change of compression into extension (Pl. X: Fig. A); the opposite explanation is impossible, because the coarse-grained filling of the veinlet would not render possible the formation of a stylolite. Similar solutions exist in relation to veinlets and microslickensides. If the grains of a limestone were affected by pressure twinning, the veinlets older than twinning will also be affected; the calcite filling of the younger veinlets would not be disturbed.

Influence of veinlets on the colour of limestones. Calcite veinlets formed an obstacle to the late diagenetic migration of pigments (Pl. X: Fig. B). On the other hand, veinlets younger than the pigment of the red limestones cause the well-known decoloration (or green coloration) in their immediate surrounding, due to the reducing nature of fluids.

Some other minerals from veinlets

Veinlet minerals other than calcite were not the subject of this contribution, therefore only some examples from the Western Carpathians will be presented. Authigenic quartz limited to the calcite veinlets is not rare; macroscopic crystals occur in the Liassic Borinka limestones (Turan & Vavro 1970), Liassic limestone of the Orešany Succession, quarry NW from Dolany, Malé Karpaty Mts. and in Paleogene sandstones („Marmarosch diamonds“ — Hurai et al. 1995). Authigenic feldspar (microscopic size) is exceptional, e.g. Neocomian limestones, locality Butkov. Pyrite is frequent, baryte rare (e.g. in Keuper Dolomite, Zázrivá), fluorite exceptional (e.g. Carnian Opponitz Limestone, basement of the Vienna Basin, borehole Závod-93, in the depth 5306 m), galena occurred only once in a calcite veinlet from Liassic limestones of the Malá Fatra Mts. (Mišík 1964, p. 85). Albite veinlets in radiolarites are probably connected with postvolcanic activity (Triassic radiolarites of the Meliata Unit, Jaklovce — Pl. X: Fig. E, and in a pebble of Jurassic radiolarites from Strihovce conglomerates, Flysch Belt — Mišík et al. 1991b, p. 23, Pl. III: Fig. 1).

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Plate VIII: Fig. A. Neptunic microdykes — cracks in the Oxfordian limestone filled with Albian limestone sediment with *Hedbergella* and *Ticinella*. Czorsztyn Succession, Vršatec-castle klippe. Magn. 43×. **Fig. B.** Veins in synsedimentary cracked pebble filled with the matrix of the conglomerate. Limestone pebble from the Paleocene Proč Conglomerate, Pieniny Klippen Belt, Beňatina. Natural size. **Fig. C.** Synsedimentary cracks in a limestone pebble were filled with the not yet consolidated matrix. These „clastic“ veinlets, synchronous with the deposition of conglomerate, are peculiar for the abundant quartz grains totally absent in the surrounding limestone. Their distal wedging-out parts were filled by calcite cement. Pebble of the Paleocene biohermal limestone in the Eocene Strihovce Conglomerate, Flysch Belt. Matiaška. Magn. 30×. **Fig. D.** Pre-conglomerate veinlet in the pebble of Middle Triassic limestone from the Coniacian „Upohlav“ Conglomerate of the Kysuca Succession, Pieniny Klippen Belt. The calcite veinlet was formed in the time span Upper Triassic – Middle Cretaceous probably during the Cretaceous tectonics in the accretionary wedge. Zádubnie. Magn. 20×. **Fig. E.** Pre-chert calcite veinlets originated in the micritic radiolarian limestone before the forming of chert nodules. They acted as obstacles for the migrating silica and limit the chert nodule in straight lines. Neocomian cherty limestone, Manín Unit, quarry Butkov. Magn. 23×. **Fig. F.** Another pre-chert veinlet. Berriasian-Valanginian Horná Lysá Limestone, Kysuca Succession, Vršatec. Magn. 13×.

Illite veinlets do not attract due attention in spite of their frequency. In the Western Carpathians they occur mainly in Liassic and Tithonian-Neocomian limestones. They consist of large light-brown aggregates with uniform extinction, oriented parallel to the walls of veinlets; their birefringence is comparable with that of the illite. The material from a veinlet about 1 mm thick from Neocomian limestones was identified (V. Šucha personal communication) by X-ray analysis as a mixture of illite and chlorite. It is probable that at least some of the illite veinlets represent microslickensides. The material for the new-formed illite probably originates from the tiny submicroscopic clastic illite in limestone, mobilized during pressure solution.

Veinlets with dedolomitized saddle dolomite. They offer possibility of approximate estimation of temperature. The temperatures from isotopic study of host limestones are much lower than those from the calcite of veinlets, for example the red nodular Hallstatt Limestone, locality Silická Brezová (Kantor & Mišík 1992) had $\delta^{18}0 = -0.87$ ‰, the calcite from a veinlet of the same specimen $\delta^{18}0 = -7.38$ ‰ corresponding to the temperature of about 60 ^{o}C.

The Jurassic and Cretaceous limestones of the Krížna Nappe frequently contain veins (up to 2 cm in thickness) filled by a mixture of white calcite and brown carbonate grains. In all the analyzed cases the brown grains belonged to the dedolomitized baroque dolomite (Pl. X: Figs. F, G). The saddle or baroque dolomite originated under temperatures mostly between 90 and 160 ^{0}C (Spötl & Pitman 1992) which reflects the minimum burial depth. Supposing an average value of 33 m/1 ^{o}C the burial depth could be estimated as 2.3–4.6 km. The baroque dolomite with characteristic curved crystal planes and sweeping exctinction was in all cases „dedolomitized“, and replaced by secondary calcite. The brown colour proceeds from Fe^{2+} isomorphe admixture in Mg^{2+} which was liberated by the calcification and oxidized. The dedolomitization was caused by groundwaters charged with sulphate ions during the erosional uprise to subsurface level.

Summary

The modern methods for studying thin veins such as stable isotope analyses, cathodoluminiscence, microprobe analyses of calcite, study of inclusions and structural measurements must be preceded by a serious thin-section study. Various

PLATE IX

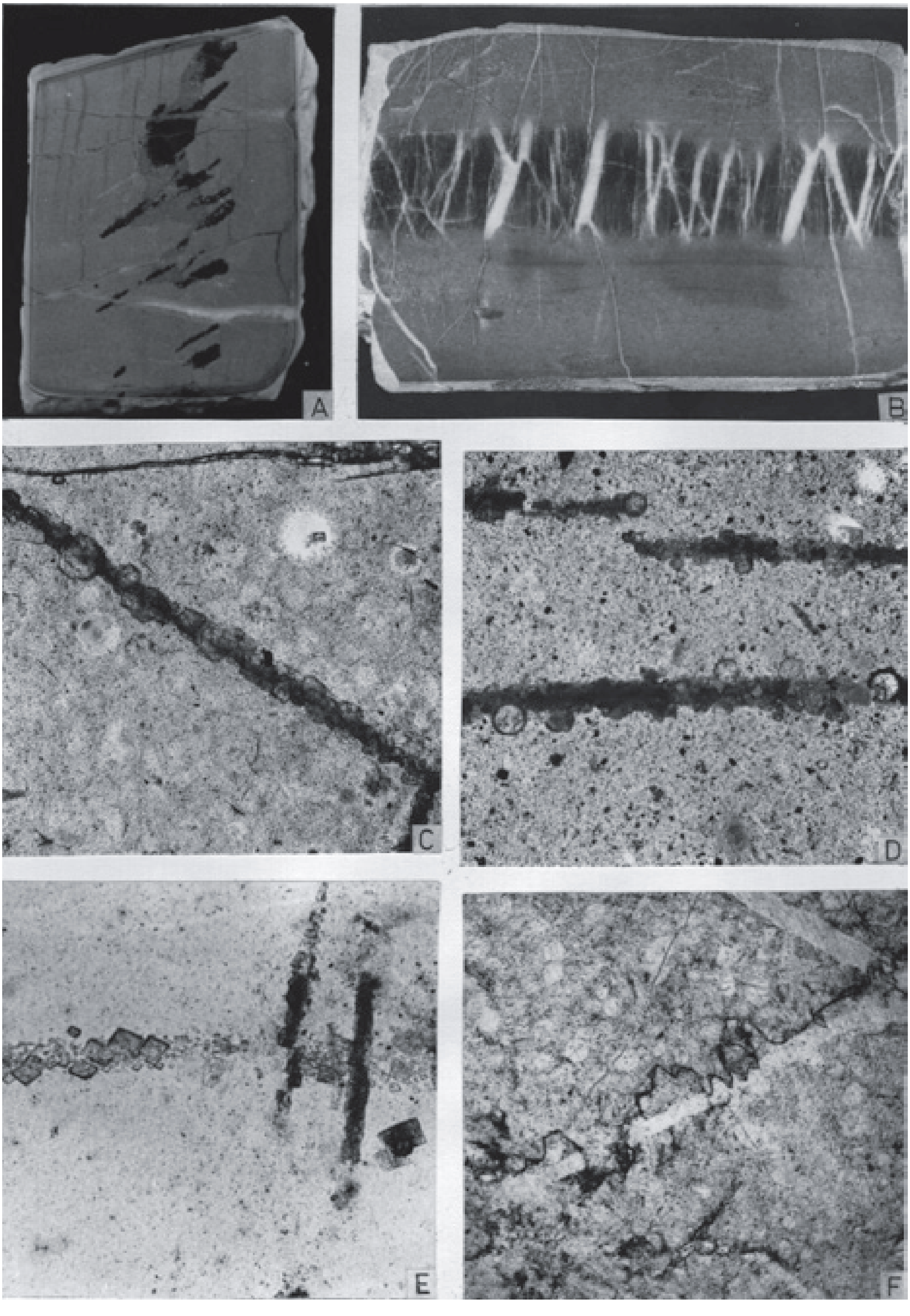
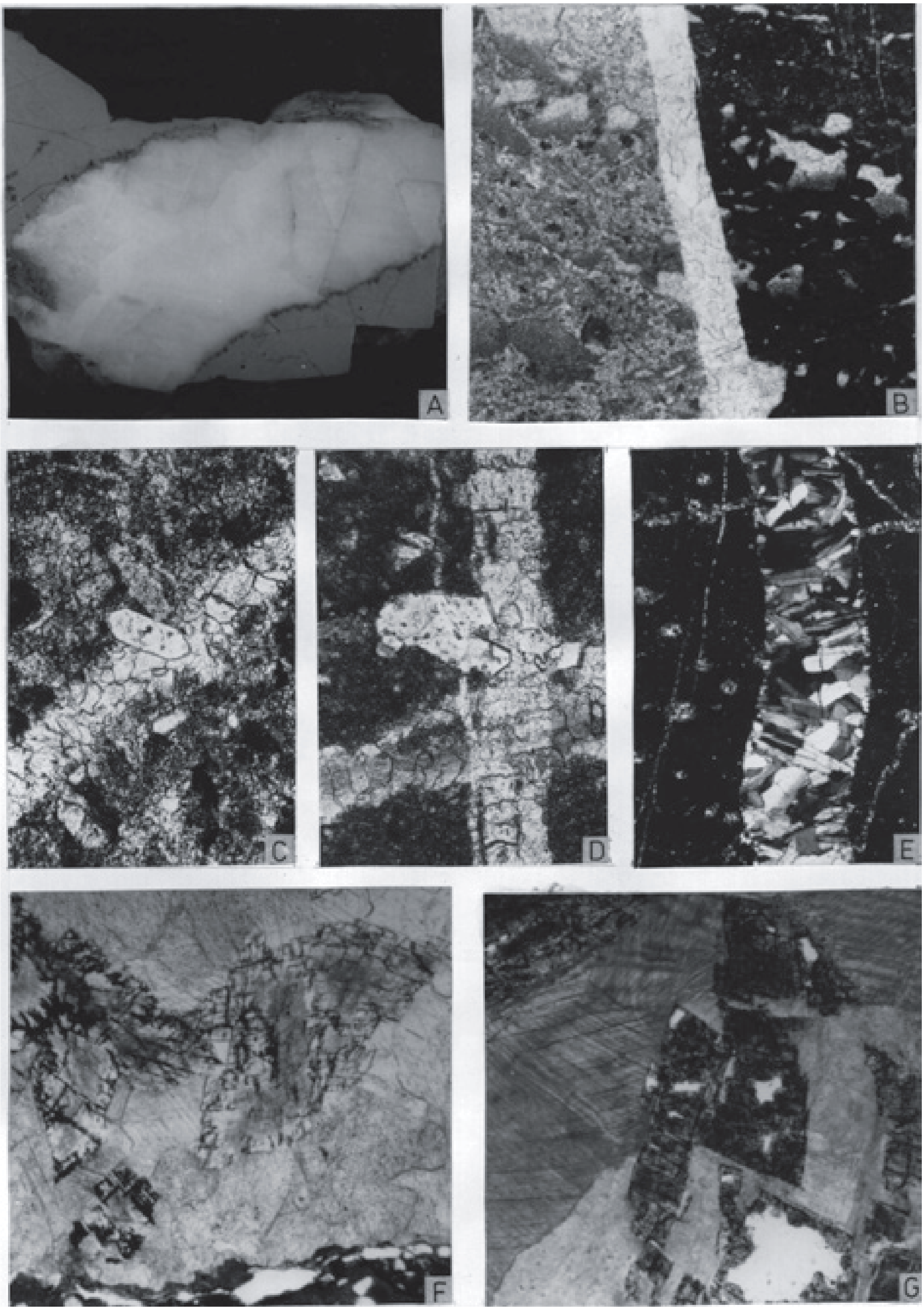


PLATE X



types of veinlet are described in this contribution (Pls. I–X and Fig. 1).

It was shown that a lot of veinlets regarded as „normal“ (open cracks originated by extension) are really the recrystallized veinlets formed by shear. Recrystallized veinlets can be identified by fossils traversing them without being torn, by remnants of an array of coalescing hairline shear veinlets (dashed or crack-and-seal veinlets), by whitening — removal of inclusions during the recrystallization.

Synsedimentary veinlets in carbonate and silicic rocks may be deformed in the semiplastic state of sediment („ductile“ deformation) or by brittle fragmentation. Syngenetic and very early diagenetic veinlets fill desiccation cracks, bedding–parallel joints (sheet cracks), neptunic microdykes (partly filled with internal sediment), subaqueous dewatering cracks, synaeretic cracks in silicites (bordered veinlets with replacement margins and pearl-string type).

We are handicapped by the impossibility of calcite radiometric dating (except of Quaternary calcites), therefore numerous possibilities for relative dating of veinlets must be used: with regard to authigenic minerals, formation of nodular cherts, deposition of conglomerates, calcite twinning, formation of microstylolites etc.

The large extension of dedolomitized saddle dolomite in calcite veinlets within the Mesozoic limestones of Krížna Nappe shows the burial depth about 2.3–4.6 km. The abundance of thin illite veinlets in the studied limestones is suprising. The formation of albite veinlets in Triassic radiolarites are considered to be a post-volcanic feature.

A team study of thin veins can substantially contribute to the deciphering of the diagenesis, subsidence, fluid migration and tectonic history of carbonate and silicite complexes.

Acknowledgements: The author is indepted to Prof. Franz Neubauer (University Salzburg) and Doc. RNDr. Dušan Plašienka,CSc. (Geological Institute of Slovak Academy of Science) for many improvements of the manuscript.

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Plate IX: Fig. A. Pre-chert veinlets filled with silica. Tensional cracks inclined to the stratification were probably formed in the not yet consolidated calcareous sediment and immediately used by the migrating silica solutions. Upper Tithonian limestone of the Choč Nappe, Šipkovský háj near Krajné. Polished slab, natural size. The photo is rotated 90°. **Fig. B.** Set of post-chert calcite veinlets is limited to the chert nodule. The rigid chert was disturbed by extensional fractures in difference to the more plastic host limestone. Neocomian cherty limestone, Hradská Valley near Podhradie, Veľká Fatra Mts. Polished slab, natural size. **Fig. C.** Veinlet of the string-pearl type syngenetic with the chert. The solutions of calcium bicarbonate penetrated through the synaeretic cracks in the time when the silica mass rich in water was still reactive. Calcite grains usually of rhombic shape grew from the cracks replacing the silica mass. Upper Jurassic cherty limestone, Pieniny Succession, Klippen Belt, Lubina. Magn. 55×. **Fig. D.** Another veinlets syngenetic with the chert nodule. Molds of radiolarians in their immediate neighbourhood were also filled by calcite; other radiolarians in the chert were dissolved mostly without any trace. Tithonian cherty limestone of Kysuca Succession, Klippen Belt, quarry near Brodno. Magn. 43×. **Fig. E.** Pearl-string type veinlets syngenetic with the chert nodule in dolomite. They consist of a row of calcite rhombs replacing silica (their calcitic nature was verified by the staining with alizarine). Red chert nodule in Norian Keuper dolomite. Magn. 95×. **Fig. F.** Microstylolite is younger than the veinlet in Middle Jurassic radiolarites of the Meliata Unit. Meliata, near the mill. Magn. 45×.

Plate X: Fig. A. The calcite veinlet is younger than the stylolite. During the compressional phase the stylolite was formed. In the course of the following extension the stylolite was opened and the crack sealed by coarse-grained calcite aggregate. Tithonian limestone of the Kysuca Succession, quarry near Brodno. Polished section, natural size. **Fig. B.** The vertical calcite veinlet was an obstacle for the late diagenetic migration of pigment-bearing solutions. Stromatolitic limestone (loferite) with desiccation pores partly filled with internal sediment. The right side and the left side of the same layer are differently coloured. Norian limestone from the basement of the Vienna Basin. Borehole Studienky-95, 4195 m. Magn. 30×. **Fig. C.** The authigenic idiomorph quartz is younger than the calcite veinlet. Ladinian Reifling Limestone of the Choč Nappe. Hradkovo, Choč Mts. Magn. 136×. **Fig. D.** The authigenic feldspar is younger than the calcite veinlet. Rhaetian limestone pebble from the Cenomanian-Turonian conglomerate of the Klape Unit. Oravský Podzámok. Magn. 136×. **Fig. E.** Albite veinlet in the Carnian radiolarite of the Meliata Unit, probably formed by post-volcanic activity of near by diabase (basalt) bodies, approximately of the same age. Jaklovce. Magn. 30×, crossed polars. **Fig. F.** Dedolomitized (calcified) grains of saddle dolomite with curved crystal planes, pigmented by iron hydroxides. They partially replaced the older calcite filling of the veinlet. Liassic limestone of the Krížna Nappe, Kraviarske, Malá Fatra Mts. Magn. 27×. **Fig. G.** Dedolomitized saddle dolomite grains (dark) replacing the older calcite filling of the vein. Neocomian limestone, Krížna Nappe, Motyčky, Nízke Tatry Mts. Magn. 26×.

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