ROCZNIK POLSKIEGO TOWARZYSTWA GEOLOGICZNEGO
ANNALES DE LA SOCIÉTÉ GÉOLOGIQUE DE POLOGNE

Tom (Volume) XLIII Zeszyt (Fascicule) 4 Kraków 1973

ANDRZEJ K. TEISSEYRE [1]

DIAGENETIC CARBONATIZATION DUE TO KAOLINIZATION: A HYPOTHESIS (WITH EXAMPLES FROM SUDETIC CARBONIFEROUS SANDSTONES)

(Pl. XLVII—LII, 2 Figs.)

Diagenetyczna karbonatyzacja jako efekt kaolinizacji na przykładzie piaskowców śródsudeckiego kulmu

(Tabl. XLVII—LII, 2 fig.)

Abstract: The purpose of this paper is to put forward a working hypothesis explaining an existing paragenesis (and origin) of kaolinite and siderite in some coal-bearing sections of non-marine formations, but especially those in which both minerals could not have been of detrital- or simply-biogenic origin. In rocks studied sideritization (or carbonatization in general) appears to be a direct response to or a by-product of kaolinization. Kaolinization and sideritization were followed by an incipient silicification and all the three stages are ascribed here to a shallow-burial stage of diagenesis.

INTRODUCTION

It was observed during the petrographic study of Lower Carboniferous sandstones from the regions of Szczepanów and Ciechanowice (the Central Sudetes, the Intrasudetic Trough) that the content of carbonates in these rocks is in a favourable correlation with the kaolinite content. The microscope has also revealed that at least in some profiles the both minerals are in a negative correlation with the grain size and with the metastable components. It has also appeared that early diagnetic carbonates and kaolinite occur in greater numbers only in coal-bearing sections of the Kulm. These observations seem to point to the fact that early diagenetic carbonatization of the rocks under examination is, at least to a certain degree, genetically connected with immediately preceding processes of kaolinization of some detrital metastable components.

[1] Laboratory of Geology, Institute of Geology of the Polish Academy of Sciences, 50-205 Wrocław, Cybulskiego 30.

The problems of cementation, authigenesis and mutual replacement of such minerals as carbonates, feldspars, quartz and kaolinite have already been discussed by many authors and rich bibliography on the subject is recapitulated in "Diagenesis in Sediments" (Developments in Sedimentology 8, in "Sedimentology", vol. 15 special issue devoted to lithification in sediments, Elsevier) and in the latest book "Sand and Sandstone" by F. J. Pettijohn, P. E. Potter and R. Siever (1972). It has been also known for a long time that carbonates can be formed (and, in fact, they are often formed) in the process of kaolinization of some aluminosilicates, e.g. feldspars. The basic conception of the work is, as far as I know, original. According to it carbonate components of some coal-bearing, fresh-water or nonmarine sedimentary series may be exclusively or mainly the product of early diagenetic kaolinization.

GEOLOGIC SETTING

The Dinantian Group of the western part of the Intrasudetic Basin (the Central Sudetes, SW Poland) is composed of three formations: the lower, or the Bogaczowice Formation (? Lower Visean), the middle, or the Lubomin Formation and the upper, or the Szczawno Formation (Upper Visean). The first two formations are of exclusively terrestrial origin and they come up to 4000 metres in thickness. They consist mainly of fanglomerates and conglomerates interbedded, to a large degree, with sandstones and silt shales. Except for a few localities (Figlów, Jarkowice), the cyclic sedimentation is usually well developed in these deposits. The cyclicity is based on alteration of deposits of alluvial fans (mainly alluvia of the distributive system of braided rivers) with more fine-grained deposits of the basin floor. The latter are mostly alluvia of the contributive river system, in most cases of meandering streams. The youngest formation, called the Szczawno Formation, contains conglomerates, sandstones and shales (2000—3000 mtrs in thickness). Shales of the basal portion of this formation are fossiliferous in the northern part of the Intrasudetic Basin and they provide index fauna of the Upper Visean there (horizon G_0 alpha). In comparison with older formations, the Szczawno Formation is more fine-grained and richer in sandstones and shales. As it could be expected, rhythmic sedimentation is better developed in the youngest deposits of the Dinantian than in the underlying coarser ones. All the deposits were accumulated in a downfaulted intramontane basin, limited by faults, while the sedimentation itself developed under conditions of strong vertical movements of the Bretonian Orogeny (cf. A. K. Teisseyre, in press). The detrital material came mainly from Early Paleozoic metamorphic rocks and, to a smaller degree, from the Upper Devonian (?) sedimentary rocks and was transported at a distance ranging from several hundred metres to several tens of kilometres.

FIELD RELATIONSHIPS, PROCEDURE, SCOPE

Observations presented here come from two profiles. The first profile is composed of outcrops in the area directly south of the Szczepanów village (Kamienna Góra county, 12 km southwest of Kamienna Góra), displaying sandstones, conglomerates and silt shales of the highest section of the Szczawno Formation. The other profile, or the Ciechanowice Profile (11 km north-west of Kamienna Góra) had been previously described in a detailed way (A. K. Teisseyre, 1970a, b; 1971a, b). In this profile there are outcropped sandstones, silt shales and coals of the Bogaczowice Formation, accordingly overlying fanglomerates and sandstones of the Ciechanowice Formation [1]. Apart from them, in the Ciechanowice Profile there occur such rocks as pseudomorphosen-tonsteins, gainster-looking rocks and siderite bands, all very rare in the Intrasudetic Kulm. In both profiles, mentioned above, diagenetic carbonatization (mainly sideritization) and kaolinization are well developed only in coal-bearing, fine-grained sediments.

In the Ciechanowice Profile sideritization and kaolinization have been found, above all, in coal-bearing sediments, which constitute the upper members of three following major cyclothems. The first cyclothem belongs to the highest parts of the Ciechanowice Formation, while the two following ones constitute the lowest part of the Bogaczowice Formation.

Jointly, the coal-bearing sediments reach nearly 200 metres in thickness and contain at least some scores of fining-upward sequences (sensu J. R. L. Allen, 1965), as well as at least a dozen or so, now unworkable, coal seams. Above the coal seams, clustered mainly in the second cyclothem of the Bogaczowice Formation, there often occur coarsening-upward sequences. It seems that the latter were chiefly formed in more or less permanent bodies of fresh water (shallow lakes). It also looks as if the very flooding of the basin floor was a factor that put plant vegetation to a sudden stop. After the lakes had been filled with sediment, there began again a period of intensive, truly subaerial alluviation, responsible for the following fining-upward sequence closed by a coal seam or a carbonaceous silt shale (A. K. Teisseyre, in press). In the Ciechanowice Profile there is a favourable correlation between the degree of kaolinization and sideritization and the quantity and thickness of coal seams.

Detrital material of the described sediments was mainly eroded from metamorphic terrains, immediately surrounding the basin (greenschists, albite-gneiss of Paczyn, phyllite). Most of biotite, a part of quartz and feldspars, and also of what was originally glass (?) are representative of volcanic material, probably of pyroclastic origin (cf. A. K. Teisseyre 1970a, b; 1971a, b). These sediments were accumulated in a rift valley, directed W-E, the width

[1] The Ciechanowice Formation (? Upper Tournaisian) reaches locally 700 metres in thickness and is now visible only in a small area near Ciechanowice. It is the oldest Dinantian sediment of the Intrasudetic Basin.

of which did not exceed a few kilometres. Greenschists were mainly carried to the rift valley from the north, while gneisses, phyllites and greenschists came from the south.

The Szczepanów Profile uncovers alternating sandstones, pebble-conglomerates, silt shales and thin coal seams along a righthanded tributary of the Bóbr River which has no name. Sandstones and conglomerates usually occur in beds of less-than-a-metre in thickness. Trough cross-beddings (usually clustered in co-sets) are most frequently observed here, unlike in the Ciechanowice Profile, where graded bedding and flat lamination often prevail. In conglomerates and coarse- or medium-grained sandstones there are large-scale dune cross-beddings (a genetic term, proposed for large-scale cross-beddings, resulting from dune migration), as well as microdelta type cross-beddings. Fine-grained sandstones and silt shales reveal mainly small-scale cross-beddings (ripple cross-stratification). Coals and carbonaceous silt shales are homogeneous or horizontally laminated. They often occur as sediments of cut-off channels. The profile under examination comprises a certain number of fining-upward sequences, and the thickness of respective sequences generally ranges from 2 to 5 metres. These sediments are interpreted here as alluvia of meandering streams (but having also braided reaches) that flew towards NW. Channel deposits predominate over flood-plain sediments, which need not necessarily correspond to original situation.

The sediments under examination were accumulated in the prolongation of apron of alluvial fans, surrounding the basin from SE. This area probably took a transitional position between alluvial fans and flood-plains of the basin floor and, maybe, was of a marginal character in relation to both sedimentary environments, mentioned above. The composition and origin of detrital material are entirely different here than in the Ciechanowice Profile. The mean pebble composition (500 pebble counts) is, as follows: quartz, 40·3%; mica-schist, 29·2%; gneiss, 22·4%; meta-quarzite, 5·2%; metachert, 1%; phyllite, 1%; others, 0·9%. The gneisses are typical microcline gneisses here and they are staurolite-bearing; they do not resemble, in any part, the gneisses of Paczyn.

This article aims only at putting forward a working hypothesis, according to which concretions, cements and certain siderite bands of, at least, several coal-bearing series may be formed in processes of early diagenesis, as a result of kaolinization liberating metallic ions, necessary for the formation of carbonates. At the same time, this hypothesis especially refers to those coal-bearing series, in which the origin of carbonates is unknown and, above all, to these ones, in which carbonates may be of neither detrital nor biochemic origin. This idea is based on the microscopic examination of about 100 thin sections, on chemical analyses and on DTA determinations. However, the author is aware that this hypothesis will still need a lot of investigations, especially geochemical ones. It also seems that such investigations might be of vital importance for studying cementation processes and early diagenetic modifications of coal-bearing sediments. At present, however, when works concentrating on diagenesis of fresh-water sediments are certainly underrepresented in comparison with respective works on marine sediments, any article may enrich the existing knowledge. Maybe the hypothesis presented here can be of certain importance for studying the genesis, protection and exploitation of mineral waters (chiefly carbonated springs). Theoretically, mineral waters should be in equilibrium with the assemblage of clay minerals originating from aquifers under the influence of circulation of these waters (cf. R. A. Garrels, 1967; W. D. Keller, 1970).

The DTA determinations revealed the occurrence of both kaolinite and dyckite in the rocks under examination. However, considering the difficulty in differentiating these minerals under the microscope, the term "kaolinite" in the further part of this work should be understood as a "mineral of the kaolinite group". The presence of halloysite in these rocks is not very likely; on the other hand, also anauxite probably occurs in some strongly kaolinized sediments (exposed to strong leaching).

PETROGRAPHY OF SANDSTONES [2]

The Ciechanowice Profile

The petrographic study of sandstones of this profile had been partly published before (A. K. Teisseyre, 1970a, b; 1971a, b). Sandstones, which are the main lithology in upper members of coal-bearing cyclothems, are almost exclusively subgraywackes. They are sediments rich in metastable rock fragments (mainly metamorphic rocks and acid volcanic rocks), as well as in micas (muscovite, detrital sericite, biotite, hydrobiotite) and chlorites (chiefly penninite). Some of them contain a remarkable amount of feldspars (up to 26% in volume), mainly acid plagioclases (albite, chessboard albite, oligoclase). The mineral and chemical composition of these sandstones change, in fact, according to the composition of detrital material and the sandstone grain size (Table 1; Attention: samples selected for chemical analyses were carbonate-free). Calcite, siderite, quartz, kaolinite and chlorite occur as main cementing minerals. Kaolinite is usually accompanied by scaly illite. As a rule, these sandstones are more or less kaolinized and the microscope shows feldspars, biotite, and something that probably was originally volcanic glass, as the main source of kaolinite in these rocks.

Feldspars were kaolinized from grain margins inwards, as well as along cleavage planes, and minute fractures resulting from compactional grain-on-grain pressures. Partly sericitized feldspars [3] are quite numerous, while

[2] Terminology for sandstones — according to F. J. Pettijohn, 1957; and for silt shales — according to C. O. Dunbar and J. Rodgers, 1957.

[3] Most probably, the sericitization of feldspars did not always need to be a weathering process, preceeding kaolinization. Strongly sericitized feldspars occur, for example, in many kaolinite-free sandstones. In sandstones of the Ciechanowice Profile such feldspars may be (and, at least in part,

Tabela — Table 1

Chemical composition of some Lower Carboniferous sandstones and silt shales from the Intrasudetic Basin (in per cent by weight)
Skład chemiczny niektórych dolnokarbońskich piaskowców i mułowców z niecki śródsudeckiej (w %% wagowych)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	73.74	51.92	67.16	71.26	53.90	56.80	59.74	75.30	68.48	82.46	68.56	60.94	66.48	59.82
TiO_2	0.50	1.15	1.15	0.57	1.27	0.95	0.65	0.42	0.52	0.02	0.05	0.56	0.35	1.97
Al_2O_3	11.53	18.85	12.95	12.07	15.66	19.90	18.83	11.64	14.11	8.58	17.08	17.01	13.37	16.10
Fe_2O_3	1.74	4.73	1.45	2.77	5.33	3.88	1.21	0.54	3.36	0.71	3.71	1.27	3.01	3.42
FeO	3.19	4.62	4.51	1.55	5.78	3.59	5.46	3.46	2.26	1.10	0.14	4.59	3.12	3.92
MnO	0.05	0.14	0.06	0.01	0.08	0.08	0.03	0.03	0.05	0.01	0.03	0.05	0.08	0.09
MgO	1.54	3.89	3.33	1.99	4.80	2.87	2.43	1.68	2.05	0.73	1.90	3.27	2.98	3.16
CaO	0.42	0.79	0.71	0.99	3.89	0.35	0.34	0.25	0.23	0.17	0.31	2.51	2.88	1.64
Na_2O	1.86	3.08	3.37	4.67	3.83	1.40	1.75	3.32	3.76	3.63	2.05	2.79	4.11	4.70
K_2O	2.00	3.05	2.00	1.70	1.18	3.82	3.13	1.21	1.51	0.86	2.55	2.37	0.40	3.10
P_2O_5	0.09	0.14	0.14	0.07	0.10	0.41	0.45	0.46	0.51	tr	tr	0.27	0.26	0.05
CO_2	—	0.53	—	—	—	—	—	—	—	—	—	—	—	—
H_2O^+	2.84	5.27	2.68	1.68	3.38	4.90	5.24	2.04	3.01	1.36	2.83	3.20	2.04	2.14
H_2O^-	0.42	1.75	0.42	0.40	0.74	1.54	0.76	0.14	0.19	0.20	0.66	0.64	0.76	0.36
S	—	—	—	—	—	—	—	0.04	0.02	tr	tr	0.02	tr	0.02
Total	99.92	99.91	99.93	99.73	99.94	100.49	100.02	100.53	100.06	99.83	99.87	99.89	99.84	99.92

Sample location:

1. Quartz-rich subgraywacke, ?Upper Tournaisian, Sady Górne village, 1055 m SE of hill 510.1 m
2. Feldspar-rich subgraywacke, ?Upper Tournaisian, Sady Górne village, 515 m WNW of hill 490.0 m
3. Phyllite-rich subgraywacke, ?Upper Tournaisian, Ciechanowice village, 940 m W of point 409.5 m
4. Feldspatic subgraywacke rich in gneiss material, ?Upper Tournaisian, Ciechanowice village, 615 m W of point 409.5 m
5. Greenschist-rich subgraywacke, ?Upper Tournaisian, Ciechanowice village, 815 m SE of point 409.5 m
6. Silt shale, ?Upper Tournaisian, location same as for 2
7. Silt shale, ?Upper Tournaisian, Ciechanowice village, 370 m NW of point 409.5 m
8. Feldspatic subgraywacke, ?Upper Tournaisian, Ciechanowice village, 390 m NW of point 409.5 m
9. Silt shale, ?Upper Tournaisian, location as above
10. Quartz-rich subgraywacke, ?Lower Visean, Ciechanowice village, 1300 m S of point 409.5 m
11. Biotite-rich subgraywacke, ?Lower Visean, location as above
12. Silt shale, ?Lower Visean, Jarkowice village, 1030 m WNW of hill 624.7 m
13. Greenschist-rich tilloid, ?Lower Visean, Miszkowice village, 135 m NW of hill 710.8 m
14. Greenschist-rich subgraywacke, ?Lower Visean, Pisarzowice village, 125 m SSE of point 639.6 m

perfectly fresh individuals are only occasionally found. It is clear from the microscopic observations that partly sericitized feldspars were more easily kaolinized than fresh feldspars; also plagioclase underwent kaolinization more easily than microcline microperthite. Partly altered feldspars become not quite clear and are strongly clouded with tiny, randomly oriented kaolinite scales and tiny sericite flakes. It allows us to understand the appearance of kaolinite pseudomorphs after feldspars, consisting of a great number of tiny, randomly oriented kaolinite scales.

Products of alteration of feldspars have been readily and easily attacked by carbonates. The latter tend to cccur at the innitial stage as isolated rhombohedrons. "Ghost-grains", containing only relics of original feldspar usually with a distinct outline of original detrital grain, are also found. To a smaller degree, carbonates also attack unaltered feldspars.

Kaolinization of biotite has led to characteristic changes in the appearance of flakes themselves (Pl. XLVIII): "From place to place the biotite underwent partial kaolinization giving rise to the formation of typical sheaf-like textures. Kaolinization of biotite is an especially common phenomenon within subgraywackes... and all intermediate stages have been observed from almost unaltered biotite to growths of mica-free kaolinite. The initial stage corresponds to flakes of partly kaolinized biotite with the sheef-like texture and enclosed small lens-shaped bodies of crypto- to microcrystalline kaolinite. Then the progressive kaolinization tends to eliminate the biotite completely, giving rise to the growths of oval pellets or rouleaux of brown-stained kaolinite (up to 1 mm). Within the subgraywacke from bed No. 36 pellets of kaolinite formed in this way had subsequently undergone replacement by microcrystalline siderite" (A. K. Teisseyre, 1970b, p. 164—165).

It is possible that tiny aggregates of vermicular kaolinite (up to 0·2 mm) were, at least in part, formed as a result of recrystallization of scaly or "fibrous" kaolinite, formed at the expense of feldspars or micas, respectively.

It is striking in the microscopic picture that despite strong kaolinization of biotite — and sometimes also despite partial kaolinization of muscovite — detrital chlorites are usually quite fresh and do not display any alteration .

---

they probably are) the result of sericitization under conditions of deep burial (cf. M. Teichmüller and R. Teichmüller, 1967). A detailed microscopic investigation shows, however, that the chlorite cement of these sandstones was formed at the phyllomorphic stage of diagenesis at the expense of some original clay material — probably kaolinite and also partly sericite, mentioned above (on formation of chlorite at this stage of diagenesis — see E. C. Dapples, 1962; 1967; D. M. Triplechorn, 1970, and others). It seems then that, in general, sericitization of feldspars preceded alterations of the phyllomorphic stage; yet in other cases it seems that a similar mineral (illite?) was formed nearly simultaneously with chlorite. The problem of these alterations — as it still needs some further investigations — will not be the subject of the present work. It is worth noticing, however, that the kaolinite group of minerals probably prevailed in original sediments. It could be partly justified by the fact that eroded areas were high, deeply sculptured mountains, while the Kulm sediments were exposed to strong leaching on alluvial fans, under conditions of good drainage, which should follow formation of kaolinite (cf. Tardy, 1969, in J. I. Drever, 1971).

Some chlorites are associated with carbonates (Pl. XLVIII, Fig. 1), but such association can be also frequently found in parent metamorphic rocks. It is not unlikely, however, that processes of incipient kaolinization of detrital chlorites had been obliterated at the stage of late diagenesis (i.e., the phyllomorphic stage), when the authigenic chlorite was formed at the expense of the original assemblage of clay minerals.

Among heavy minerals, at least a part of apatite displays its authigenic origin.

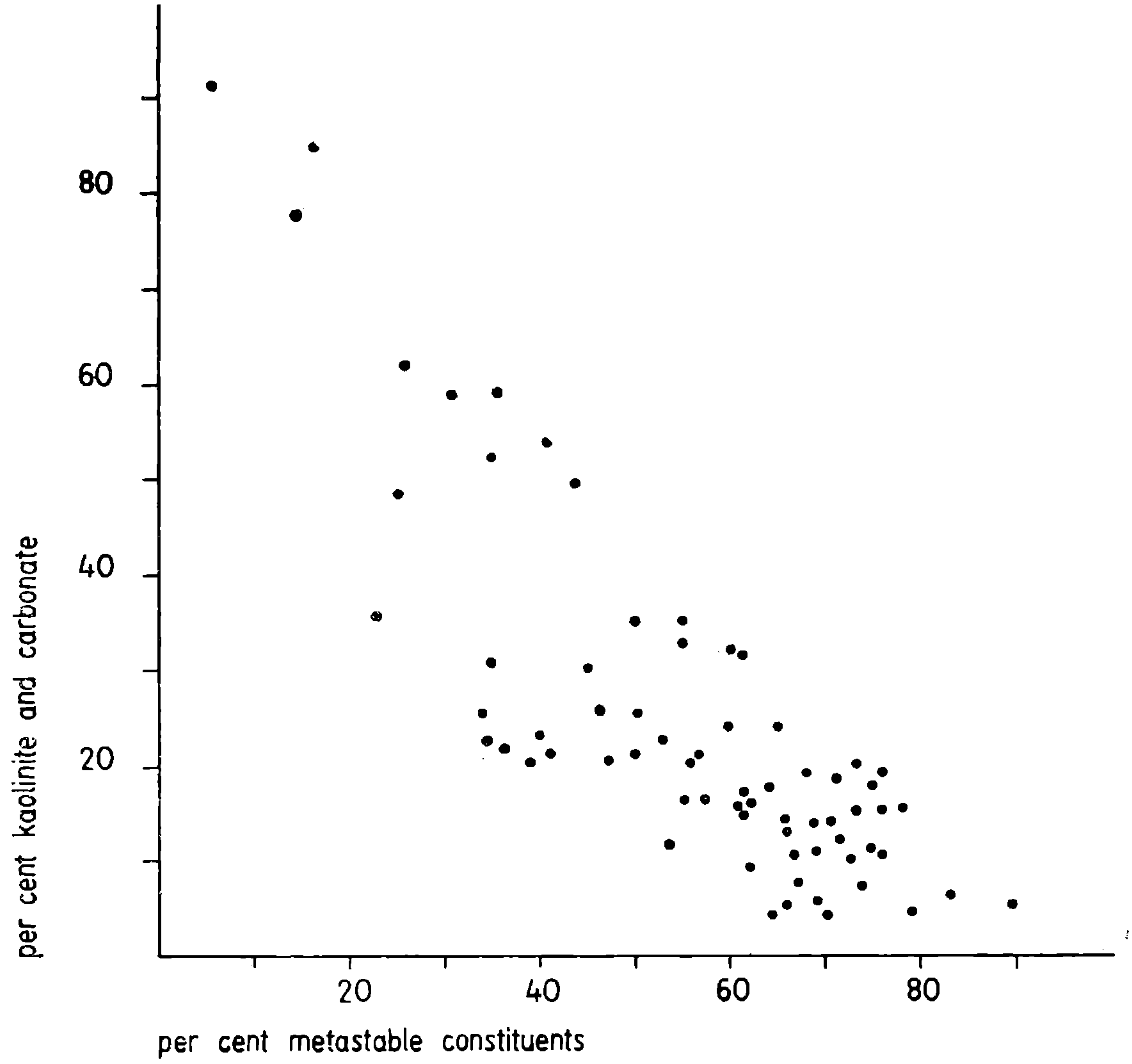


Fig. 1. Showing content of kaolinite and carbonate versus metastable detrital components in Lower Carboniferous deposits from the western Intrasudetic Basin. Data from concretionary bodies cluster in the upper half of the figure, whereas that from carbonate-cemented sandstones are grouped in the lower half. Samples involved were originally carbonate-free and their kaolinite content was low. Based on thin section data

Fig. 1. Wykres ilustrujący zależność między zawartością kaolinitu i węglanów a zawartością składników metastabilnych. Badane skały nie zawierały pierwotnie węglanów a zawartość kaolinitu w nich była mała. Dane mikroskopowe

The cementational evolution of sandstones under examination is rather complicated. The earliest cement is quartz I (discontinuous overgrowths, small prisms in the direction of c-axis, Pl. LII, Fig. 6). The crystallization of the quartz did not essentially influence the diminution of porosity and permeability of these sandstones. In particular, it did not stop the processes of kaolinization that had probably lasted for a longer period of time; thus many minerals (micas, feldspars) had undergone considerable compactional deformations before kaolinization occured. The kaolinite cement was crystallized, at least in part, from true solutions. It is not unlikely, either, that illite accompanying kaolinite is a product of the late-diagenetic reconstruction of degraded micaceous material. The carbonate cement, if present, expands at the expense of kaolinite-illite cement and kaolinite pseudomorphs after feldspars, micas, and glass. Any intermediate stages can be observed here: from carbonate-free kaolinite pseudomorphs to aggregates of fine-grained siderite containing only scarce relics of the original clay material or minute mica remnants (Pl. XLVIII and XLIX). In some sandstones there occur kaolinite cements only, in others — chiefly carbonate cements but, most frequently, the two kinds of cements occur together. The carbonate is most frequently siderite; however, some sandstones contain considerable amounts of calcite. In extreme cases sandy limestones were formed; they had already been almost completely devoid of metastable detrital components (Fig. 1). "Ghost-grains", as well as carbonate individuals with distinct, dark-gray pseudopleochroism, can be often observed in such rocks. Such pseudopleochroism as observed under the microscope is characteristic of carbonates that are formed by replacement of detrital aluminosilicates, especially feldspars, glass, and felsite fragments (Pl. XLVIII, Fig. 5). From the second extreme, when a small amount of carbonates is concerned, they often concentrate inside kaolinite pseudomorphs after biotite.

The crystallization of carbonates was followed in many samples by crystallization of quartz II, which replaces both carbonates and kaolinite (Pl. LII). The following stage was a partial chloritization of these rocks, referred here to alterations under conditions of deep burial at the phyllomorphic stage of diagenesis (Pl. XLVII, Fig. 6).

The Szczepanów Profile

Sandstones are mostly quartz-rich subgraywackes here (Table 2; Pl. XLVII, Fig. 2). Parent rocks for these sandstones were mostly microcline-staurolite gneisses and mica-schists; in consequence, these sandstones have been very abundant in micas (Table 2; Pl. XLVII, Fig. 3). The original feldspar content in these sandstones is difficult to evaluate because of diagenetic modifications and, especially, because of kaolinization and carbonatization. It is striking in the microscopic picture that a microcline is usually perfectly fresh, while a microcline microperthite is generally more or less sericitized and partly kaolinized. It is clear, however, that patches and lamellae of plagioclase are attacked first in the process of sideritization and kaolinization of microperthite. Being a fresh material, biotite is practically unknown from these

Tabela — Table 2

Summary of textural characteristics of selected Kulm sediments, Szczepanów profile, top portion of the Upper Visean Szczawno Formation, Intrasudetic Basin. Mineral composition in per cent by volume

Charakterystyka teksturalna kulmowych osadów profilu Szczepanowa, stropowa część górnowizeńskiego kulmu ze Szczawna, niecka śródsudecka. Skład mineralny w procentach objętościowych

	Sample							
	K 1682-1	K 1682-2	K 1685-1	K 1685-2	K 1685-3	K 1685-4	K 1685-5	K 1688-1
Monocrystalline quartz	21.9	15.5	7.8	10.1	22.9	22.6	25.1	3.3
Polycrystalline quartz	16.1	1.3	22.5	25.1	19.8	6.4	5.5	15.2
Metachert, fine mosaic quartz	0.1	—	tr	tr	tr	—	—	4.0
Microcline, K-feldspar	0.2	0.5	0.1	1.3	2.4	1.9	2.0	tr
Plagioclase feldspar	0.5	0.2	0.3	—	0.6	tr	0.4	—
Microperthite	tr	—	1.5	1.9	1.6	tr	tr	tr
Kaolinite pseudomorphs after feldspars	4.3	0.2	1.5	5.3	4.2	1.4	0.7	0.8
Metastable rocks fragments (gneiss, mica-schist)	6.7	—	27.5	7.9	6.2	2.1	0.7	49.3
Biotite	—	0.3	—	—	0.1	—	—	—
Muscovite	6.9	9.4	10.1	15.8	11.6	22.3	14.7	11.9
Kaolinite pseudomorphs after micas	26.3	12.6	7.5	8.9	7.3	13.2	26.9	6.2
Heavy minerals (translucent)	0.5	tr	0.1	0.3	0.2	0.5	0.2	tr
Opaque heavies	0.2	0.1	0.4	0.2	0.1	0.4	tr	0.1
Coalified plant matter	3.0	3.2	0.2	0.6	0.3	1.3	6.6	—
Kaolinite monocrystals	0.9	—	—	—	—	—	—	—
Cement								
Kaolinite	1.1	tr	0.7	0.8	0.5	0.5	0.7	1.3
Siderite » calcite	6.7	56.7	19.4	20.2	19.5	25.8	15.1	0.6
Fe-oxides and hydroxides	2.3	—	—	0.3	1.6	0.5	1.2	7.3
Quartz	2.3	—	0.4	1.3	1.1	1.1	0.2	tr
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mean diameter, quartz grains (mm)	0.12	0.074	0.35	0.27	0.13	0.095	0.094	Granule
Range	0.02–0.29	0.04–0.15	0.02–4.61	0.071–1.03	0.02–0.34	0.03–0.34	0.017–0.30	conglo-merate
Per cent quartz grains								
angular	70	92	71	60	83	93	94	
subangular	30	8	27	40	17	7	6	
rounded	—	—	2	—	—	—	—	
Per cent quartz grains, wavy extinction	28	21	14	14	24	22	31	
Per cent mosaic quartz	18	8	49	52	15	11	14	
Mineralogical maturity index	0.85	n. d.	0.62	0.86	1.25	0.71	0.68	0.33

sandstones, unless it occurs in the form of intergrowths in quartz grains. Nevertheless, hydromicas with characteristic dark-grey or black pseudopleochroism (and even kaolinite pseudomorphs after micas) occur quite abundantly there. It could be observed in some places that it is a characteristic inherited from the original biotite. It also seems that a large part of kaolinite pseudomorphs after micas (Table 2) was formed mostly at the expense of biotite and, to a smaller degree, at the expense of muscovite. Sagenite formed during the process of alteration of biotite is readily inherited by hydromica and sometimes also by intergrowths of hydromica and kaolinite. In places, sagenite is incorporated even in the authigenic quartz II (Pl. XLII, Fig. 2). The alteration of micas was most easily realized along cleavage planes and was, as a rule, carried on from the margins of flakes towards their inside. In consequence, both sheaf-like and fan textures have been formed. These textures are then readily inherited by kaolinite textures and they remain at least at the initial stage of their development. It seems, however, that the inherited fan textures differ from vermicular growths of kaolinite. The former may come up to considerable sizes, sometimes to a few milimetres across, and they contain, as a rule, relics of hydromica as minute plates lain according to the cleavage of the original mica. On the other hand, vermicular growths are smaller, as a rule (usually less than 0·3 mm), and contain no relics of hydromica; it seems that they were formed as a product of recrystallization of scaly or "fibrous" kaolinite, or were crystallized from solutions.

All the examined sandstones contain bigger or smaller amounts of carbonates, mainly siderite, secondarily calcite (Pl. XLVII, Fig. 3; Pl. XLIII—XLIX). Some samples were, however, calcite-free. Carbonates occur as a cement and as pseudomorphs after micas, feldspars, and quartz. Pseudomorphs of "fibrous" kaolinite after micas and any intergrowths of kaolinite and hydromica are especially liable to replacement by carbonates. Any intermediate stages can be observed under the microscope: from flakes of hydromicas with individual, scattered, small rhombohedrons of siderite to siderite aggregates containing only relics of unaltered mica, often in the shape of complicated and delicate intergrowths of the two minerals (Pl. XLVII and XLIX). Unaltered light mica is basically resistant to processes of carbonatization. Also direct replacement of fresh biotite by carbonate seems to be impossible or very limited here. It is possible, however, that in compactionally deformed flakes the carbonate could crystallize along microscopic tensional fractures, which had been formed along mica cleavage planes, and it could thus split the unaltered flake (Pl. XLVIII, Fig. 6).

The degree of recrystalization of carbonates (mainly siderite) depends on the sandstone grain size, and the existing correlation is favourable, as a rule. However, calcite is, as a rule, more recrystallized than siderite and it is often twinned, unlike siderite. On the other hand, siderite often occurs as microcrystalline aggregates, while calcite never does so.

Apart from siderite and calcite, the sandstones under examination are also often partly cemented with kaolinite and quartz. The authigenic quartz occurs at least in two generations. Prisms and discontinuous overgrowths of quartz I (Pl. LII, Fig. 6) belong to the first generation; quartz I had crystallized on some grains of detrital quartz before kaolinization passed the incipient stage. On the other hand, quartz II crystallized after kaolinization had taken place; it occurs mostly in the form of irregular growths most frequently replacing kaolinite or siderite (Pl. LII). The kaolinite cement occurs in small quantities and it might have partly crystallized from true solutions. The existence of such solutions may be deduced from the fact that cell cavities of undamaged plant tissues are just filled with kaolinite as original filling (cf. A. Bolewski and J. Kubisz, 1959; Pl. L)[4] Among heavy minerals, at least a part of apatite is of authigenic origin.

PETROGRAPHY OF SILT SHALES

The Ciechanowice Profile

Silt shales are composed mainly of detrital micas and hydromicas here (muscovite, detrital seritite, biotite, hydrobiotite), as well as of chlorite (penninite, prochlorite). These minerals may constitute up to 80% of the whole rock. The remaining minerals are quartz, feldspars, scattered chips of fine-grained metastable rocks, heavy minerals and coalified plant matter. Some silt shales are almost unaltered, but the majority of them reveal moderate or even strong kaolinization of micas and feldspars. Especially strongly altered rocks underlie coal seams. Most feldspars are more or less sericitized. Some silt shales and fine-grained sandstones, underlying directly coal seams, are so strongly altered that the name "kaolinite-mudstones" seems most appropriate for them. These strongly kaolinized rocks usually do not exceed a few centimetres in thickness.

The main authigenic minerals in these silt shales are kaolinite, illite and carbonate (mainly siderite). The kaolinite was usually formed as a result of kaolinization of micas, mostly biotite. Sericitized feldspars were, on the other hand, a secondary source of kaolinite. Not all silt shales are siderite-bearing, but in places where this mineral appears in greater quantities, it has grown mainly at the expense of kaolinite. It is especially visible in the characteristic kaolinite growths, which are simply intergrowths of more or less isotropic kaolinite with hydromica or even with biotite. These intergrowths are very characteristic of tonsteins, above all (A. K. Teisseyre, 1970a, b; 1971a); they also appear in smaller quantities in some kaolinized silt shales and sandstones. It has been often observed in these sandstones that the kaolinite com-

[4] Plant tissues filled with kaolinite, quartz, hydromica, carbonates and also chlorite were observed in sandstones and silt shales of the coal-bearing Kulm of the Ciechanowice vicinity (A. K. Teisseyre, 1970a, b; 1971a, b). Later investigations, however, have confirmed me in my opinion that only kaolinite is the original substance in these tissues (in a petrographic sense).

ponent of the intergrowths is usually to a high degree or even completely replaced by siderite. The replacement of kaolinite by siderite has been also observed in the case of aggregates of a well crystallized kaolinite. The aggregates are composed of a few or more randomly oriented kaolinite crystals, sometimes surrounded with a thin rim of coalified plant matter (cf. A. K. Teisseyre, 1970b). These aggregates are accidental or tabular in shape and are arranged at various angles to lamination, although some of them stand vertically to stratification. Rugged margins of these aggregates and irregular embayments of siderite, which force their way inwards, are a strong proof that kaolinite was being intensely replaced by carbonate. The kaolinite that forms these aggregates is colourless or distinctly brown in colour. Dimensions of these aggregates exceed many times the biggest detrital grains observed in the silt shales. The replacement of kaolinite by carbonates (mainly by siderite) is best visible in concretions. The latter measure up to 30 cm from end to end and are oval, elliptic, ball-shaped or flattened. The microscope reveals that these concretions are composed mainly of micro- and even crypto-crystalline siderite; small amounts of angular or coroded detrital quartz grains, individual muscovite or, more rarely, hydromica flakes are associated with the latter.

Uncoroded kaolinite pseudomorphs (after micas or feldspars) are only exceptionally found. In ball-shaped concretions there also occur well preserved plant tissues with cell cavities filled with carbonates (Pl. L). However, despite my earlier opinions (A. K. Teisseyre, 1970b), I want to stress that these carbonate fillings seem, in general, to be later substitutes. Instead, there has been a growing evidence that these tissues had been originally preserved in kaolinite (Pl. L, Pl. LI, Fig. 1). In fact, bigger or smaller remnants of the original kaolinite, sometimes well crystallized, some other time almost isotropic [5], appear here and there in cell cavities filled with carbonates. Sometimes the kaolinite fills completely a number of adjacent cells.

Finally, a good example of replacing kaolinite by carbonates are kaolinite veinlets (0·03—2·8 mm), in which the original kaolinite had been undoubtedly replaced, to a high degree, by siderite and, to a smaller degree, also by calcite and quartz (Pl. LI). The fact that such kaolinite veinlets are present in some concretions is especially important, as it undoubtedly proves early diagenetic migration of kaolinite (in solutions). This kaolinite had filled tensional fractures in siderite concretions. The pattern of these fractures did not resemble that what is described as septaria (fractures were, most frequently, roughly perpendicular to the surface of a concretion). The fractures often faded out at the margin of a concretion, some others suddenly ceased on its surface. It has not been possible, however, to find out whether they had extended in the surrounding silt shale. The above observations point to the fact that these concretions were formed at the stage of diagenesis later than the stage of main

[5] The preservation of plant tissues in kaolinite is especially characteristic of tonsteins (cf. A. Bolewski and J. Kubisz, 1959; A. Bolewski and B. Ostrowicki, 1960). Similar kaolinite incrustations were also observed by me in tonsteins from Ciechanowice (A. K. Teisseyre, 1970a; 1971a).

kaolinization (cf. A. K. Teisseyre, 1970b). It also seems that these concretions had been especially easily and abundantly formed in these sections of sediments that had undergone the strongest kaolinization. On the other hand, it is clear that ball-shaped concretions were most probably formed under conditions of shallow burial and in only slightly compactionally affected sediments.

It should be also noted that the favourable correlation between the kaolinite content and the coal content (in the whole section, not in a particular bed) is so close, that in coal-free sediments of the same age neither kaolinite nor siderite is generally found [6].

The Szczepanów Profile

Silt shales are unaltered or only slightly kaolinized here, and this characteristic is in considerable contrast with substantial alteration of sandstones. These silt shales are composed mainly of muscovite and biotite flakes, and grains of quartz and feldspars; chlorite has not been observed anywhere. The feldspars are usually fresh; only individual grains are sericitized or kaolinized. A lot of silt shales contain a considerable amount of tiny, coalified plant matter in the form of shreds, root-like streaks and fine detritus. Plant tissues are preserved only in places, and then cells happen to be filled with brown, often almost isotropic kaolinite. The coalified plant matter is, as a rule, associated with very fine crystals of pyrite. Similarly as in Ciechanowice, a favourable correlation is marked between the degree of kaolinization and the coal content in the rock (or, strictly speaking — in the whole profile). The observed kaolinization is usually only an initial process and it comprises, almost exclusively, sericitized feldspars and biotite.

Unlike sandstones, silt shales may contain up to 20% in volume of fresh or only slightly altered biotite. Pseudomorphs of "fibrous" kaolinite after biotite are to a smaller degree replaced by carbonates in silt shales than in sandstones. Moreover, carbonates (siderite, secondarily-calcite) did not occur in all thin sections. In siderite-bearing silt shales this mineral occurs as pseudomorphs after aluminosilicates-(feldspar, biotite), and in the form of various aggregates, the size of which often exceeds the mean size of quartz

---

[6] It is absolutely true only for the Ciechanowice Profile. Elsewhere in the Intrasudetic Basin, the kaolinization and sericitization of feldspars seem to be weathering processes, such as had probably occured on alluvial fans (cf. A. K. Teisseyre, in press). On the other hand, most probably hydrothermally kaolinized rocks are widely spread in the Middle Visean Lubomin Formation (A. K. Teisseyre, 1972); still apart from kaolinite, they contain a considerable admixture of dickite. It seems then that in Kulm of the Intrasudetic Basin kaolinite was formed at least in three ways: as a weathering mineral at the pre-burial stage (tonsteins; weathering on alluvial fans); as a product of early diagenetic kaolinization (chiefly rocks described in the present work); and as a product of much later hydrothermal alterations (kaolinite-dickite-bearing rocks of the Middle Visean).

and feldspars. The siderite cement does not occur in the form known from sandstones in silt shales. The muscovite is most frequently unaltered. I have observed quite numerous laths of plagioclase (albite, oligoclase) in some silt shales. It seems then that in the time of sedimentation the relation of potash feldspar to plagioclase was lower in these silt shales than in the sandstones associated with them. It is partly due to the fact that microcline in parent rocks, being the main potash feldspar of these rocks, occured in the form of much bigger crystals than plagioclase.

DISCUSSION OF RESULTS AND CONCLUSIONS

In the examined sediments of the Intrasudetic Kulm the kaolinite and carbonate (mainly siderite) content is in the negative correlation with the content of metastable components, especially micas, feldspars and fragments of metastable rocks abundant in these deposits (Fig. 1).

Such a correlation allows an assumption that both kaolinite and siderite were being formed in the described rocks in situ, not long after sedimentation, at the expense of original detrital components, such as mentioned above. This conception was essentially formed during the field work and microscopic studies, and it is well confirmed geologically (at least as far as the described profiles are concerned). At the same time, however, a new problem arises, namely how, when, and under what conditions the diagenetic modifications, observed in these rocks, had been realized. The other question is whether all these processes were taking place simultaneously and, if not, in what order they had occured. I have not solved the problem definitely, as it was not my aim to do so, leaving it especially to geochemists. In this article I intend to limit myself only to giving a working hypothesis and to presenting its principles, which have been obtained mainly under the microscope.

The main reagents in the processes of formation of authigenic kaolinite and siderite were alumina and silica, which had been brought by detrital aluminosilicates, and ferrous iron, brought by biotite; water and carbon dioxide had been, at least in part, added from the outside (this view will be still discussed furter on, below). The carbon dioxide originated probably from bacterial decomposition of plant matter. A considerable content of plant matter and a relatively small intensity of detrital sedimentation (in comparison with other profiles of Kulm) under conditions of assured good leaching had probably been the main requisite factors of the processes under consideration, but especially those of kaolinization. In fact, in sediments of the same age, yet more coarse-grained, which do not contain any plant matter, the kaolinite content is only slight, as a rule, while the siderite is most frequently quite absent. There also exists a general negative correlation between the kaolinite and siderite content and the grain size of detrital framework (Fig. 2). In this way the degree of diagenetic modification of the rocks under examination appears as the function of permeability and porosity; similar relations have been reported by very many authors from many profiles. The vital influence of permeability and porosity (other factors being constans) allows us to understand frequent co-occurrence of poorly altered silt shales with strongly diagenetically altered sandstones in the described profiles. The sandstones served as avenues by which formation waters were drained (F. J. Pettijohn, et al., 1972) and carbon dioxide extracted from the surrounding silt shales. It should be also stressed that secondary minerals included in the sediments under examination can be neither of detrital (kaolinite, siderite) nor, simply, biogenic (carbonates) origin.

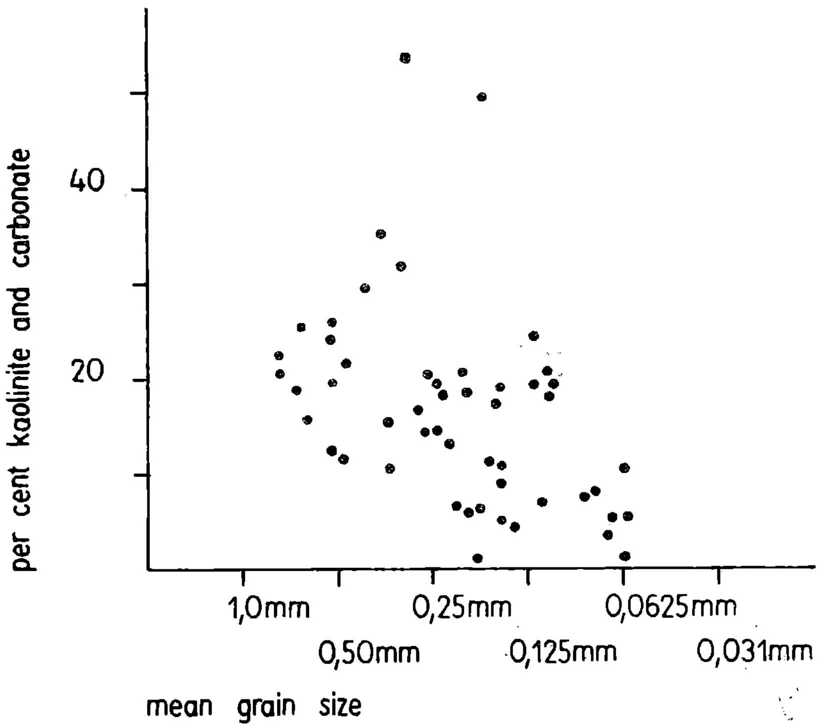


Fig. 2. Showing content of kaolinite and carbonate versus grain size (microscopic data)
Fig. 2. Wykres ilustrujący zawartość kaolinitu i węglanów w zależności od rozmiarów ziarna (dane mikroskopowe)

On the basis of results of the carried out investigations and data from bibliography, the diagenetic evolution of the examined sandstones looks as follows (Table 3). The first process was crystallization of quartz I, which preceded the main stage of kaolinization (unlike quartz II, quartz I has no intergrowths of kaolinite). Silica, necessary to it, might have been liberated by pressure solution or, perhaps, might have been, in part, also of abrasional origin (?). The crystallization of quartz I has not essentially reduced porosity and permeability of these sandstones (incipient simple cementation).

The first process, essential for cementation of these rocks, was kaolinization. Some metastable components such as biotite, sericitized feldspars and, to a smaller degree, muscovite (Szczepanów, Ciechanowice), and glass fragments (Ciechanowice) were the subject for kaolinization. The kaolinization was

Tabela — Table 3

Summary of inferred diagenetic processes and modifications in the Lower Carboniferous coal-bearing sandstones
Zestawienie procesów i przemian diagenetycznych w węglonośnych piaskowcach kulmu niecki śródsudeckiej

Process	Materials involved	Environment (Eh and pH)	CO_2	Product		Diagenetic stage (Dapples, 1962; 67)
Crystallization of quartz I	Dissolved and colloidal silica in original pore waters	Mildly oxidizing; increasingly acid	Partial pressure of CO_2 increasing	Very incomplete simple quartz cement (quartz I)		Simple cementation, early redoxomorphic stage
Main (subsurface) kaolinization	Glass, biotite, feldspar, metastable rock f-s, muscovite	Increasingly reducing; increasingly acid		Kaolinite as pseudomorphs after aluminosilicates (K^+, Na^+, Ca^{++}, Mg^{++} removed in solution; Fe^{++} partly removed and partly combined to $FeCO_3$; some silica and alumina in solution). Crystallization of kaolinite from solution (kaolinite cement)	Veinlets of kaolinite	Later redoxomorphic stage
Main carbonatization and partial dekaolinization	Saturated pore solutions, kaolinite, hydromica, detrital quartz and feldspar	Slightly to moderately reducing; increasingly alkaline	decreasing	Carbonate (mainly siderite, also calcite, ankerite) replacing kaolinite and also detrital feldspar as well as quartz. Alumina in solution, some silica in solution		Early locomorphic stage
Silicification	Pore solutions rich in silica; kaolinite, carbonate	Neutral to weakly reducing; decreasingly alkaline		Formation of quartz II replacing kaolinite and carbonate. Cementation and induration of sandstones		Later locomorphic stage
Formation of authigenic chlorite and sericite (partly from original clay)	Kaolinite, illite, ?mixed-layered clays?	Neutral to moderately reducing; moderately alkaline		Formation of authigenic chlorite and sericite from original clays; sericitization (and albitization?) of feldspars, chloritization of biotite — only in Ciechanowice profile		Phyllomorphic stage (not discussed in this paper)

probably caused by acid swampy waters [7] and it proceeded mainly under conditions of shallow burial.

The presence of uncrushed plant tissues filled with kaolinite on the one hand (early diagenetic incrustation), and mica flakes tending to kaolinization in places compactionally deformed — on the other — show that the processes of kaolinization had been going on for a longer time and proceeded under conditions of increasing burial, simultaneously with compactional processes.

However, effective kaolinization needs compliance with certain special conditions, of which effective leaching should be mentioned first, as it allows efficient removal of metallic ions (especially of K^{+}ion) and also abduction of a certain amount of silica in order to enrich the residue in alumina (cf. W. D. Keller, 1970).

These conditions were distinctly fulfilled in both profiles under examination, especially in the Szczepanów Profile. Sediments considered to be lacustrine in the Ciechanowice Profile are characterized by a considerably smaller kaolinite content than those typically alluvial ones. On the other hand, also mixed-layered clays should theoretically occur beside kaolinite in the most fine-grained and richest in coal sediments of the Ciechanowice Profile. Their absence (maybe, except vermiculite) might be caused, however, by late diagenetic conversion to authigenic chlorite at the phyllomorphic stage of diagenesis (cf. E. C. Dapples, 1962; 1967; D. M. Triplechorn, 1970).

The behaviour of ferrous ion at this early stage of diagenesis is not quite clear; it must have been kept, in some way, in the environment of reaction, being necessary to siderite formation. The microscope shows that tiny siderite rhombohedrons are often so closely associated with kaolinite (especially with "fibrous" kaolinite after biotite) that it looks as if those two secondary minerals were being formed almost simultaneously. It would be theoretically possible if we assumed that chemical reactions in these sandstones had been taking place under microenvironmental conditions (cf. W. D. Keller, 1970), i.e. under conditions allowing considerable differences in Eh and pH, as well as in the ion concentration at considerably small distances.

According to this conception, ferrous ions might have been removed in effect by being combined with $FeCO_3$. Referring to Keller (1970, p. 798), one may say that "siderite, although in physical contact with clay, is in chemical effect outside the argillizing system". The siderite under examination might be called "siderite I", to differentiate it from the main body of siderite crystalliz-

[7] As it is suggested by later investigations, the acid character of swampy waters is, by no means, the rule (cf. Baas Becking et al., 1960). On the other hand, it has been also found out that kaolinite is formed even in the marine environment (W. D. Keller, 1970), under suitable conditions (especially under conditions of low concentration of K^{+}ion). It is thus difficult to reconstruct, even in outline, the geochemical conditions that had existed in the Kulm swamps. Paragenesis of kaolinite, siderite and pyrite, observed in the sediments under examination, allow an assumption that the Eh values ranged from 0 to about —0·3 mV, and pH — from 5—9 (cf. F. M. Swain, 1956; Baas Becking et al., 1960; R. M. Garrels, 1960; and others).

ing at the following stage of diagenesis; however, I have abandoned such differentiation because of many doubts in the process of examination of thin sections. Coming back to the discussed microenvironmental conception, it should be added that it is well confirmed by microscopically evidenced great variability of sandstones under examination, as far as both the paragenesis of authigenic minerals and the quantitative content of individual minerals are concerned. The variability may be found not only between adjacent beds but also within a single bed, often at a distance of a few centimetres. The association of kaolinite and pyrite may serve as an extreme example of paragenesis, characteristic of microenvironmental conditions.

The kaolinization proceeded selectively, and the microscope has allowed a determination of the following series of minerals, listed according to the increasing resistance to processes of kaolinization: glass; sericitized feldspar [8] (mainly plagioclase); biotite; plagioclase; microperthite; muscovite; microcline. The position of chlorite in this series is not clear and difficult to specify, because of late diagenetic chloritization (Ciechanowice), or because of the absence of chlorites, in general (Szczepanów). Most probably, after all, the above series is not of universal importance, yet the order of components, mentioned above, depends on local geochemical conditions. The kaolinite showed certain mobility at the discussed stage of diagenetic modifications, called the main stage of kaolinization. It can be evidenced by the occurrence of kaolinite inside undamaged plant cells (crystallization from true solutions, cf. A. Bolewski and J. Kubisz, 1959), as well as by the occurrence of kaolinite as a fracture-filling mineral. Probably the detrital quartz was also, to a certain degree, attacked and replaced at this stage of diagenesis by authigenic kaolinite crystallizing from solutions (cf. A. K. Teisseyre, 1970a, Fig. 2).

It has not been quite clear yet what factors and in what circumstances had caused the extinction of processes of kaolinization. The microscopic observations show that at a certain stage of diagenesis kaolinization had been replaced by no other argillization process but carbonatization, especially sideritization. Perhaps the advancing cementation of sandstones was of a certain importance here (the formation of scattered kaolinite cement), as well as the following cutting off the sediment from the inflow of fresh swampy waters. In consequence, it must have caused the increase in concentration of metallic ions and a gradual alkalization of formation waters.

Siderite (or main siderite, or siderite II) crystallized in open interstitial

[8] Having considered the fact that scaly sericite very easily undergoes kaolinization under favourable geochemical conditions, it is clear now why the sericitized feldspars had undergone kaolinization more easily than the unaltered ones. Moreover, it seems that the kaolinization of fresh feldspars (if such have ever occured) is considerably slowed down in the acid environment. It is clear that the kaolinization of fresh feldspar must be preceded by its hydrolitic breakdown, needing respectively high values of pH, at which the kaolinization dies away. It would allow an explanation of the fact that fresh feldspars are present in such strongly kaolinized rocks as tonsteins (cf. e.g., J. Środoń 1972).

pore spaces, but it also replaced clay minerals from the preceding stage, mainly kaolinite. In both cases there was a tendency to form bigger or smaller rhombohedrons and, generally, there has been a favourable correlation between the siderite grain size and the detrital one. The siderite crystallized from more or less alkaline pore solutions [9], probably under conditions of decreasing amount of carbon dioxide (Table 3). The ferrous ion, necessary to siderite formation probably came, to a high degree, from alteration of detrital biotite (and, possibly, other Fe-rich detritals) in a swampy environment. According to the microenvironmental conception, alkalinity of pore waters have been achieved at least locally. The alkalinity of pore solutions at this stage of diagenesis can be evidenced by strong corosion of detrital quartz and feldspars by siderite, and also by replacement of kaolinite by carbonates. The quartz might have been carried away as an easily dissolved silicate, while the kaolinite — as calcium alluminium hydrate or a similar compound (cf. J. L. Eades and R. F. Grim, 1960). It can be also added that the replacement of quartz and feldspars by carbonates did not necessarily need high pH values, as partial pressure of carbon dioxide, as well as temperature (and geologic time), also play a significant role in the process (cf. Th. E. Walker, 1962). Adoption of the view that kaolinite had been removed in this way from the environment of carbonate crystallization would allow an explanation of the long-known negative correlation between the kaolinite and carbonate content in carbonate concretions and shales (cf. G. Mueller, 1967). In fact, it seems that in the described profiles such processes had really taken place on a larger scale and led to formation of siderite concretions and some deeply carbonatized sandstones, mainly at the expense of previously deeply kaolinized sediments. I shall, in short, name these processes "diagenetic differentiation", after F. J. Pettijohn (1957). The diagenetic differentiation in the profiles under examination caused the greater changes, the greater the grain of original sediment was or, more strictly speaking, the greater original permeability and porosity were, and the more metastable components it contained. Also the geologic time and the depth of burial played a very important role in these processes, and the existing correlation seems to be favourable; compare diagenetic modifications in the Ciechanowice Profile (at least 10,000 metres of overburden) with those in the Szczepanów Profile (no more than 2,000—3,000 metres of overburden).

The diagenetic modifications took a different course in some fine-grained sandstones and silt shales. A very advanced early diagenetic kaolinization must have made these rocks practically inpermeable and, in consequence of it, no further processes could already proceed. It especially concerns so

[9] High alkalinity is not a rule for siderite to develop diagenetically from aqueous pore fluids. It is clear from stability diagrams that in an environment containing SiO_2 and CO_2 there are two distinct fields of stability of siderite, and that the mineral can form in a wide range of pH (6·2—10·2) and Eh (0·0 to —0·6 mV) (F. M. Swain, 1956; Baas Becking et al., 1960; R. M. Garrels, 1960).

called kaolinite-mudstones and pseudomorphosen-tonsteins, described by me from Ciechanowice (A. K. Teisseyre, 1970a; 1971a). They are carbonate-free or almost carbonate-free rocks, characterized by a slight amount of quartz II. It seems, however, that the formation of these tonsteins was conditioned mainly by the appearance of such unusual materials as volcanic ashes in the fluvio-lacustrine environment. Another additional factor, conditioning the formation of these tonsteins, was deposition of ashes in some areas of the basin floor with especially retarded intensity of detrital sedimentation. The formation of such rocks as siderite bands, also described from the Ciechanowice Profile (A. K. Teisseyre, 1970b), had been connected with similar conditions. It is not quite clear whether these bands had been originally built of siderite or of ferric hydroxides; it is sure, however, that these bands represent a really syngenetic accumulations of iron.

According to the microscopic observations, sideritization was followed by crystallization of quartz II, also described here as the stage of incipient silicification. The quartz II probably crystallized from solutions saturated in silica, as a result of reactions that had taken place at the preceding stages (especially at the stage of carbonatization). It is also likely that saturation of pore solutions in silica and crystallization of quartz II, resulting from it, might have been an effect of gradual pH decrease in pore solutions under conditions of diminishing CO_2 content. (It had previously been the cause of crystallization of carbonates at higher pH values). Still, since quartz II replaces both carbonates and kaolinite, it seems that further on pore solutions had been rather of a mildly alkaline character than of an acid one. The explanation of paragenesis observed under the microscope also needs an additional assumption, namely that the sandstones under examination had not been completely cemented during the crystallization of quartz II, and that a considerable amount of pore spaces was still accessible for solutions to circulate freely through the sandstones. It also seems that the solutions, from which a considerable amount of quartz II crystallized, had come from fine-grained rocks, from which they were compactionally squeezed out to sandstones.

The processes of silicification have achieved an exceptional completeness in case of secondary protoquartzites resembling, it their nature, the ganister-type of sandstones. They are lenses and thin, discontinuous bands, white and light-gray in colour, enclosed within dark, "normal" subgraywackes or silt shales. The microscope reveals that those protoquartzites had originally been more abundant in quartz than "mean Kulm subgraywacke", and then they underwent thorough kaolinization (micas, feldspars) folowed by silicification. The silicification has always been combined with strong dekaolinization, and plenty of tiny relics of the original kaolinite are visible inside quartz II. The process of quartzification has been never accomplished and the mineral content of these rocks changes from place to place, also within a single thin section. It is not clear, however, whether carbonates had ever occured in these rocks, or if the carbonate stage has been omitted here.

The crystallization of quartz II finished, in general, the stage of early diagenetic modification and cementation of the rocks under examination. It should be stressed, however, that the sequence of events, presented above, is really very simplified. In fact, at least some processes, ascribed here to separate stages, might have occurred almost simultaneously in adjacent parts of the rocks (microenvironmental conditions, W. D. Keller, 1970).

The evolution, which can be read from fracture fillings in siderite concretions, seems to point to the fact that the processes of kaolinization and carbonatization, following each other, might have repeated several times. Observations of the veinlets also seem to point out that some stages might have been omitted or distinctly reduced to the advantage of others, in certain diagenetic sequences. These frequent changes in the geochemical environment seem to correspond well to the conditions that were postulated by E. C. Dapples (1962; 1967) for the shallow-burial redoxomorphic stage of diagenesis. It is also clear that, while using Dapples's criteria and therminology, the redoxomorphic and locomorphic stages overlapped each other, in a considerable degree, in the processes of early diagenesis of the rocks under examination. Thus the crystallization of quartz II would appear a typically locomorphic process, as it led to primary cementation and induration of the studied sediments.

In the examined Kulm profiles the cementation might have been achieved in a considerably short time. The fact that seems to point it out is that the thickness of the kaolinized and carbonatized zone in the Szczepanów Profile (revealing the same diagenetic modifications as the Ciechanowice Profile) seems not to exceed 50 metres. Higher in the Szczepanów Profile, however, there is a stratigraphic hiatus, probably equal to a considerable part of the Namurian.

The processes of kaolinization and carbonatization have been also known to me from sandstones of the Lower Permian Fore-Sudetic Block. Core samples have revealed that the formation of secondary subfeldspatic-lithic wackes, so characteristic of this formation, was due to the early diagenetic argillization (mainly kaolinization) of some original impure arkoses or subgraywackes. The kaolinization was followed by a more or less advanced carbonatization, with dolomite as the main carbonate replacing clay material [10].

Unfortunately, the sedimentary environment of these sandstones has not been finally explained, so far, and it is not quite clear what connections existed between the processes of kaolinization and carbonatization. On the other hand, it is clear that similar phenomena had occurred on a regional scale in sandstones and silt shales of the Lower Permian (cf. A. Ostromęcki, 1972a, b). In the Lower Permian sandstones, similarly as in the case of the Kulm sand-

[10] These unpublished investigations were carried out by the collective body composed of: A. K. Teisseyre, A. Pacholska and B. Wajsprych, all from the Laboratory of Geology of the Polish Academy of Sciences in Wrocław. Similar phenomena were also described from other regions by G. A. Rusnak, 1957.

stones, one can ascertain the presence of two generations of quartz, separated by the stage of kaolinization, followed (in some profiles at least) by the stage of carbonatization.

Laboratory of Geology
Institute of Geology of the
Polish Academy of Sciences
Wrocław

translated by B. Smolak

REFERENCES
WYKAZ LITERATURY

J. R. L. Allen, 1965. Fining-upwards cycles in alluvial successions. *Geol. Journ.*, Vol. 4, p. 229—246.

L. G. M. Baas Becking, I. R. Kaplan, D. Moore, 1960. Limits of the natural environment in terms of pH and oxidation-reduction potentials. *Journ. Geol.*, Vol. 68, p. 243—284.

A. Bolewski, J. Kubisz, 1959. Mineralbestand von Pflanzeninkrustaten aus Tonsteinen aus dem süd-östlichen Teil des Oberschlesischen Steinkohlenbeckens. *Bull. Acad. Pol. Sci., Sér. Chim., Géol. et Géogr.*, Vol. 7, p. 427—432.

A. Bolewski, B. Ostrowicki, 1960. Kaolinization einiger Arkosen-Sandsteine im Oberschlesischen Steinkohlenbecken und die Entstehung von Tonsteinen. *Bull. Acad. Pol. Sci., Sér. Géol. et Géogr.*, Vol. 8, p. 191—196.

E. C. Dapples, 1962. Stages of diagenesis in the development of sandstones. *Bull. Geol. Soc. Amer.*, Vol. 73, p. 913—934.

E. C. Dapples, 1967. Diagenesis of sandstones. In: *Developments in sedimentology* 8, *Diagenesis in sediments*, Edited by G. Larsen and G. V. Chilingar, p. 91—125. Elsevier Publ. Co., Amsterdam—London—New York.

J. I. Drever, 1971. Chemical weathering in a subtropical igneous terrain, Rio Ameca, Mexico. *Journ. Sed. Petrol.*, Vol. 41, p. 951—961.

C. O. Dunbar, J. Rodgers, 1957. Principles of stratigraphy. *John Wiley and Sons, Inc.* p. 1—356. New York.

J. L. Eades, R. E. Grim, 1962. The reaction of hydrated lime with pure clay minerals in soil stabilization. In: *Applied Clay Mineralogy*, Edited by R. E. Grim, p. 1—268, McGraw-Hill Co., New York.

H. Füchtbauer, H. Goldschmidt, 1963. Beobachtungen zur Tonmineral-Diagenese. *Proc. Intern. Conf. Clay*, 1st, p. 99—111, Stockholm.

R. M. Garrels, 1960. Mineral equilibria at low temperature and pressure, p. 1—254. *Harper and Row*, New York.

R. M. Garrels, 1967. Genesis of some ground waters from igneous rocks, In: *Researches in geochemistry*, Edited by P. H. Abelson, Vol. 2, p. 405—420, John Wiley and Sons, Inc., New York.

W. D. Keller, 1970. Environmental aspects of clay minerals. *Journ. Sed. Petrol.*, Vol. 40, p. 788—813.

G. Müller, 1967. Diagenesis in argillaceous sediments, In: *Developments in sedimentology* 8, *Diagenesis in sediments*, Edited by G. Larsen and G. V. Chilingar, p. 127—177, Elsevier Publ. Co., Amsterdam—London—New York.

A. Ostromęcki, 1972a. Piaskowce tufitowe warstw marczowskich w okolicach Świerzawy. Tuffaceous sandstones of Marczów Beds (Westphalian? Stephanian?) near Świerzawa — West Sudetes. *Geol. Sudetica*, Vol. 6, p. 307—313.

A. Ostromęcki, 1972b. Tufy i otoczaki skał wylewnych w profilu górnego karbonu okolic Świerzawy. Tuffs and eruptive rock pebbles in the Upper Carboniferous near Świerzawa. *Geol. Sudetica*, Vol. 6, p. 315—321.

F. J. Pettijohn, 1957. Sedimentary rocks. p. 1—718. *Harper and Brothers*, New York.

F. J. Pettijohn, P. E. Potter, R. Siever, 1972. Sand and sandstone. p. 1—618. *Springer-Verlag.* Berlin—Heidelberg—New York.

G. A. Rusnak, 1957. A fabric and petrologic study of the Pleasantview sandstone. *Journ. Sedim. Petrol.*, Vol. 27, p. 41—55 Sedimentology, Special issue, Lithification of clastic sediments 2, Edited by H. Füchtbauer, Vol. 15, p. 207—440.

F. M. Swain, 1956. Stratigraphy of lake deposits in central and northern Minnesota. *Bull. Am. Assoc. Petrol. Geol.*, Vol. 49, p. 600—653.

J. Środoń, 1972. Mineralogy of Coal-tonstein and K-bentonite from Coal-seam No. 610, Bytom Trough (Upper Silesian Coal Basin, Poland). Bull. *Acad. Pol. Sci. Sér. Sci. de la Terre*, Vol. 20, p. 155—164.

M. Teichmüller, R. Teichmüller, 1967. Diagenesis of coal (coalification). In: *Developments in sedimentology 8, Diagenesis in sediments*, Edited by G. Larsen and G. V. Chilingar, p. 391—415. Elsevier Publ. Co., Amsterdam—London—New York.

A. K. Teisseyre, 1970a. Kaolinized Sandy Tuff from the Lower Carboniferous of Ciechanowice (Intrasudetic Basin). *Bull. Acad. Pol. Sci., Sér. Géol. et Géogr.*, Vol. 18, p. 13—19.

A. K. Teisseyre, 1970b. Pyroclasts in the Bottom Portion of the Lower Visean (?) in Ciechanowice (Intrasudetic Basin). *Bull. Acad. Pol. Sci., Sér. Géol. et Géogr.*, Vol. 18, p. 161—168.

A. K. Teisseyre, 1971a. Pseudomorphosen-tonstein Altered from Volcanic Ash, Lower Carboniferous, Ciechanowice (Intrasudetic Basin). *Bull. Acad. Pol. Sci., Sér. Sci. de la Terre*, Vol. 19, p. 85—90.

A. K. Teisseyre, 1971b. Charakterystyka sedymentologiczna kulmu z Ciechanowic i paleogeografia najniższego kulmu niecki śródsudeckiej. Sedimentology of the Kulm of Ciechanowice and palaeogeography of the lowest Kulm of the Intrasudetic Basin. *Geol. Sudetica*, Vol. 5, p. 237—280.

A. K. Teisseyre, 1972. O regionalnej kaolinizacji klastycznych osadów wizenu środkowego w północnej części niecki śródsudeckiej (with English summary). *Przegląd Geol.*, 1972, No. 4, p. 191—193.

A. K. Teisseyre, in press. Sedymentologia i paleogeografia kulmu starszego w zachodniej części niecki śródsudeckiej. Sedimentology and paleogeography of the Kulm alluvial fans in the western Intrasudetic Basin (Central Sudetes, SW Poland). *Geol. Sudetica*, Vol. 9.

D. M. Triplechorn, 1970. Clay mineral diagenesis in Atoka (Pennsylvanian) sandstones, Crawford county, Arkansas. *Journ. Sed. Petrol.*, Vol. 40, p. 838—847.

Th. R. Walker, 1962. Reversible nature of chert-carbonate replacement in sedimentary rocks. *Bull. Geol. Soc. Amer.*, Vol. 73, p. 237—242.

STRESZCZENIE

W węglonośnych piaskowcach kulmu śródsudeckiego (Sudety Środkowe) zawartość kaolinitu i węglanów (głównie syderytu) jako głównych minerałów autigenicznych jest odwrotnie proporcjonalna do zawartości składników metastabilnych. Zależność ta sugeruje, że zarówno kaolinit jak i syderyt powstawały w wyniku procesów diagenetycznych skutkiem przeobrażenia na miejscu takich składników detrytycznych jak biotyt, skalenie, okruchy szkliwa, muskowit i fragmenty niektórych skał metastabilnych. Dalej, ścisłe stowarzyszenie kaolinitu i syderytu prowadzi do wniosku, że jon żelazawy niezbędny do utworzenia syderytu był uwalniany głównie w procesach in situ kaolinizacji detrytycznego biotytu, spowodowanej przez kwaśne wody bagienne. Inaczej mówiąc, w badanych skałach syderytyzacja (lub ogólnie — karbonatyzacja) wydaje się być bezpośrednim oddźwiękiem (lub produktem ubocznym) kaolinizacji. Należy tu podkreślić, że w badanych skałach ani kaolinit ani syderyt

nie mogą być pochodzenia detrytycznego. W procesie diagenetycznej ewolucji badanych skał kaolinizacja i karbonatyzacja ustąpiły miejsca wstępnej sylifikacji i wszystkie te trzy stadia są tutaj traktowane jako przeobrażenia wczesnodiagenetyczne w warunkach płytkiego zagrzebania. Badania mikroskopowe ujawniły ponadto, że porowatość i przepuszczalność należały do głównych czynników kontrolujących przebieg omawianych procesów i zawartość kaolinitu oraz syderytu jest odwrotnie proporcjonalna do rozmiarów ziarna. Istnieje też podobna zależność między wielkością kryształów syderytu a rozmiarami ziarna. Celem tego artykułu jest postawienie hipotezy roboczej wyjaśniającej istniejącą paragenezę (i pochodzenie) kaolinitu i syderytu w węglonośnych niemorskich osadach, a w szczególności w takich, w których oba te minerały nie mogły być ani detrytycznego ani po prostu biogenicznego pochodzenia.

Pracownia Geologii
Instytutu Nauk Geologicznych PAN
Wrocław

EXPLANATION OF PLATES
OBJAŚNIENIA TABLIC

Plate — Tablica XLVII

Fig. 1. Large aggregate of cryptocrystalline kaolinite-looking mineral, interpreted as altered from acid (? rhyolitic) volcanic glass. Note that lamination underneath the aggregate is bent as if it had dropped in directly from the atmosphere and was at once incorporated in the sediment. Very fine-grained subgraywacke, Ciechanowice profile, thin section number C 747-26. Bar equals 0·2 mm. Nicols partly uncrossed

Fig. 1. Agregat kryptokrystalicznego minerału o wyglądzie kaolinitu interpretowany jako pochodzący z przeobrażenia kwaśnego szkliwa (?). Poniżej agregatu charakterystycznie wygięta laminacja. Bardzo drobnoziarnisty subszarogłaz, profil Ciechanowic

Fig. 2. Microcline-gneiss in medium-grained subgraywacke (Szczepanów profile, K 1685-1). Composed of quartz, microcline, biotite, microcline microperthite, plagioclase feldspar, and muscovite. Bar equals 0·2 mm

Fig. 2. Fragment gnejsu mikroklinowego z średnioziarnistego subszarogłazu. Profil Szczepanowa

Fig. 3. Mica-rich subgraywacke, Szczepanów profile (K 1685-4). Composed of muscovite, hydromica (hm), quartz, and scattered feldspar. Many mica plates are split along their cleavage planes by lens-shaped bodies of siderite that crystallized (at least in part) at the expense of previously formed hydromica and kaolinite-looking minerals. Bar equals 0·1 mm

Fig. 3. Bogaty w miki subszarogłaz, profil Szczepanowa. Liczne blaszki mik i hydromik (hm) są rozszczepione wzdłuż płaszczyzn łupliwości przez syderyt krystalizujący (przynajmniej częściowo) kosztem kaolinitowo wyglądającego minerału i hydromiki

Fig. 4. Secondary protoquartzite (over 90 per cent quartz) resulted from diagenetic silicification of quartz-rich subgraywacke. Some detrital mica and chlorite together with scattered feldspar act as impurities. Note quartzite texture. Ciechanowice profile (C 747-18e). Bar equals 0.1 mm

Fig. 4. Wtórny kwarcyt powstały w skutek diagenetycznej sylifikacji bogatego w kwarc subszarogłazu. Profil Ciechanowic

Fig. 5. Calcite-cemented medium-grained subgraywacke with pseudopleochroic calcite (dark rims and patches) developed diagenetically by superficial replacement of detrital feldspars

by the carbonate. Note altered biotite with lens-shaped bodies of carbonate in the upper right. Ciechanowice profile (C 747-34b). Bar equals 0·2 mm. One nicol only

Fig. 5. Subszarogłaz o spoiwie węglanowym. Widoczny pseudopleochroiczny węglan w formie ciemnych obwódek dookoła częściowo wypartych ziarn skaleni. Profil Ciechanowic

Fig. 6. Authigenic pale-green chlorite (at center) developed as a deep-burial diagenetic mineral from early diagenetic shallow-burial kaolinite (gray). Ciechanowice profile (C 899-14). Bar equals 0·1 mm. One nicol only

Fig. 6. Autigeniczny chloryt powstały w procesie późnej diagenezy kosztem wczesnodiagenetycznego kaolinitu. Profil Ciechanowic

Plate — Tablica XLVIII

Fig. 1. Detrital penninite (p) partly replaced by calcite (rimmed arrows). Outside the flake carbonate is strongly replaced by quartz II (Q1, Q2). M is muscovite associated with the chlorite. Medium-grained subgraywacke, Ciechanowice profile (C 747-35). Bar equals 0·1 mm. Nicols partly uncrossed

Fig. 1. Blaszka detrytycznego penninu wypieranego przez kalcyt (strzałki). Poza blaszką węglan jest silnie wyparty przez kwarc II (Q1, Q2). M jest blaszką muskowitu stowarzyszoną z tym chlorytem. Profil Ciechanowic

Fig. 2. Pseudomorph of „fibrous" kaolinite-looking mineral (dark) after a mica (possibly biotite). Kaolinite is strongly associated with siderite (white-to-gray patches, in various positions of light extinction). Medium-grained subgraywacke, Szczepanów profile (K 1685-1). Bar equals 0·1 mm

Fig. 2. Pseudomorfoza „włóknistego" minerału o wyglądzie kaolinitu po jakiejś mice (może biotycie). Kaolinit jest ściśle stowarzyszony z syderytem (białe i szare pola). Profil Szczepanowa

Fig. 3. Diagenetically deformed aggregate composed of hydrobiotite (dark streaks), kaolinite-looking mineral (medium gray), and carbonate (white). Kaolinite, originally present throughout the aggregate, is now strongly replaced by calcite and restricted mostly to the central portion of the aggregate. Pseudopleochroic calcite (c) replaces kaolinite (k; lower right). The four isolated patches of kaolinite were originally a single kaolinite pseudomorph, possibly after feldspar. Fine-grained subgraywacke, Ciechanowice profile (C 747-34b). Bar equals 0·1 mm. One nicol

Fig. 3. Agregat złożony z hydrobiotytu (ciemny), kaolinitowo wyglądającego minerału (szary) oraz węglanu (biały). Kaolinit jest w znacznym stopniu wyparty przez węglan. Pseudopleochroiczny kalcyt (c) wypiera kaolinit (prawy dolny róg) występujący w formie 4 izolowanych płatków (k), pierwotnie należących prawdopodobnie do jednej pseudomorfozy kaolinitowej po skaleniu (?). Profil Ciechanowic

Fig. 4. Sagenite in a flake made up of kaolinite-looking mineral (colorless) and hydrobiotite (medium gray). Fine-grained subgraywacke, Ciechanowice profile (C 899-11). Bar equals 0·05 mm

Fig. 4. Sagenit w blaszce złożonej z minerału o wyglądzie kaolinitu (bezbarwny) i hydrobiotytu (szary). Profil Ciechanowic

Fig. 5. Aggregate of biotite (B) and hydrobiotite (HB) and kaolinite-looking mineral (dark). Fine-grained subgraywacke, Ciechanowice profile (C 747-33). Bar equals 0.1 mm. Nicols partly uncrossed. Compare Fig. 3

Fig. 5. Agregat biotytu (B), hydrobiotytu (HB) i minerału o wyglądzie kaolinitu (ciemny). Profil Ciechanowic

Fig. 6. Muscovite (altered from biotite??) with lens-shaped bodies now occupied by siderite and ferric hydroxide. At Q1 both detrital and euhedral authigenic quartz are replaced by carbonate, whereas at Q2 the reversal is true (authigenic quartz II replaces carbonate). Kaolinite

(black, lower center, labelled K) is replaced by siderite and, to a lesser extent, also by neighbouring quartz individuals. Fine-grained subgraywacke, Szczepanów profile (K 1685-3). Bar equals 0·1 mm

Fig. 6. Blaszka muskowitu z soczewkowatymi wtrąceniami syderytu i wodorotlenków żelaza. Autigeniczny i detrytyczny kwarc są miejscami wypierane przez węglan (Q1), miejscami zaś autigeniczny kwarc II wypiera węglan (Q2). Kaolinit (K) jest wypierany przez syderyt i kwarc. Profil Szczepanowa

Plate — Tablica XLIX

Fig. 1. Flake of hydromica (white) partly transformed to kaolinite-looking mineral (dark patches). Secondary matrix of kaolinite between quartz grains labelled Q1 and Q2 is mostly replaced by siderite (gray). Quartz Q1 is also partly substituted. Fine-grained subgraywacke, Ciechanowice profile (C 899-71c). Bar equals 0·1 mm. Nicols partly uncrossed

Fig. 1. Hydromika (jasna) częściowo zastąpiona przez minerał o wyglądzie kaolinitu (szare plamy). Wtórne tło kaolinitowe między ziarnami kwarcu Q1 i Q2 zastąpione w dużej mierze przez syderyt; kwarc Q1 jest też atakowany przez węglan. Profil Ciechanowic

Fig. 2. Relic flakes of biotite and hydrobiotite (gray) in turbid microcrystalline carbonate (impure siderite?). The carbonate has replaced original kaolinite, whose relic is seen at K and elsewhere, outside the place shown in the figure. Microperthite (bottom right center) is incipiently kaolinized and superficially attacked by the carbonate. Patches of better crystalline carbonate (calcite; note relief) are seen throughout the feldspar. Ciechanowice profile, medium-grained subgraywacke (C 747-35). Bar equals 0·2 mm. One nicol only

Fig. 2. Blaszki biotytu i hydrobiotytu tkwiące w mikrokrystalicznym, mętnym węglanie (syderyt?). Widoczne resztki pierwotnego kaolinitu (K). Ziarno mikropertytu u dołu jest częściowo skaolinizowane i miejscami wypierane przez lepiej wykrystalizowany kalcyt. Profil Ciechanowic

Fig. 3. Pseudomorph of „fibrous" kaolinite-looking mineral (white) after a mica. Kaolinite is replaced by siderite (medium-to-dark patches). Note intimate association of kaolinite and small crystals of siderite. Larger siderite crystals attack the kaolinite from the outside. Medium-grained subgraywacke, Szczepanów profile (K 1685-1). Bar equals 0·2 mm. One nicol only

Fig. 3. Pseudomorfoza minerału o wyglądzie kaolinitu (biała) po jakiejś mice. Widoczne liczne drobne kryształki syderytu (ciemne) a także większe kryształy tego węglanu atakujące kaolinit z zewnątrz. Profil Szczepanowa

Fig. 4. Sheaflike texture in hydromica subjected marginally to kaolinization. Kaolinite-looking mineral (black) is strongly replaced by siderite (s) as well as authigenic quartz II. Medium-grained subgraywacke, Szczepanów profile (K 1685-1). Bar equals 0·2 mm. Nicols partly uncrossed

Fig. 4. Tekstura snopowa w blaszce hydromiki ulegającej na brzegach kaolinizacji. Minerał o wyglądzie kaolinitu (czarny) jest wypierany przez syderyt (s) i kwarc II (Q). Profil Szczepanowa

Fig. 5. Siderite-quartz-kaolinite cemented subgraywacke, Szczepanów profile (K 1685-2). Note kaolinite cement between quartz grains Q1 and Q2. Kaolinite is partly replaced by siderite and a grain of feldspar (F) is also substituted for the most part. Bar equals 0·1 mm

Fig. 5. Subszarogłaz o spoiwie węglanowo-kwarcowo-kaolinitowym, profil Szczepanowa. Spoiwo kaolinitowe widoczne między ziarnami kwarcu Q1 i Q2. Kaolinit jest wypierany przez węglany; skaleń oznaczony F jest w dużej mierze wyparty przez syderyt.

Fig. 6. Paragenesis of pyrite and kaolinite-looking mineral (gray). Pyrite contains several dust-sized quartz grains as inter-growths. Fine-grained subgraywacke, Ciechanowice profile (C 899-14). Bar equals 0·1 mm. One nicol only

Fig. 6. Parageneza pirytu i minerału o wyglądzie kaolinitu. Piryt zawiera bardzo drobne ziarna kwarcu jako wrostki. Profil Ciechanowic

Plate — Tablica L

Fig. 1. Plant tissue from an early diagenetic siderite concretion. In cells labelled 1—5 the interiors are still in kaolinite (white); this is, however, marginally replaced by siderite (gray). Other cells preserved in siderite. Ciechanowice profile (C 899-16e). Bar equals 0·2 mm. One nicol only

Fig. 1. Tkanka roślinna zachowana w kaolinicie (komórki oznaczone 1—5) i w syderycie. Wczesnodiagenetyczna konkrecja syderytowa, profil Ciechanowic

Fig. 2. Similar plant tissue, but with destroyed central portion (broken cell walls) in which original kaolinite (dark) is strongly replaced by somewhat later siderite. Ciechanowice profile (C 899-16b). Bar equals 0·2 mm. Nicols partly uncrossed

Fig. 2. Podobna tkanka roślinna ze zniszczoną partią wewnętrzną, w której resztki pierwotnego kaolinitu są silnie wypierane przez syderyt. Profil Ciechanowic

Fig. 3. Thin shell of kaolinite developed diagenetically around plant fragment (pollen?). Very-fine-grained quartz-rich subgraywacke, Ciechanowice profile (C 747-18h). Bar equals 0·05 mm. One nicol only. Inset shows (under the same magnification as in Fig. 2) cross-section through a pollen (?) filled by pale brown-stained kaolinite. Black is carbonized plant matter. Note a triple rim around the carbonized matter with first shell of slightly brown-colored kaolinite followed by intermediate shell of deeply brown-stained kaolinite and outer shell of pale brown-stained kaolinite together with minute quartz grains. From a resedimented silt shale fragment incorporated within coarse-grained subgraywacke, Ciechanowice profile (C 899-71c). One nicol only

Fig. 3. Spora (?) otoczona obwódką kaolinitu. Profil Ciechanowic. Wkładka w lewym górnym rogu przedstawia sporę (?) wypełnioną lekko brunatno zabarwionym kaolinitem. Dookoła materii węglistej (czarna) utworzyła się potrójna otoczka złożona kolejno z lekko brunatno zabarwionego kaolinitu od wewnątrz, silnie brunatno zabarwionego kaolinitu w środku i lekko brunatno zabarwionego kaolinitu razem z drobnymi ziarenkami kwarcu na zewnątrz. Profil Ciechanowic

Fig. 4. Fan-textured growth of kaolinite-looking mineral. Possibly the fan-shaped texture is inherited from an original mica or hydromica and relic hydromica threads are still present (white). Both fan-shaped kaolinite and secondary kaolinite matrix (K) are partly replaced by quartz II (Q1, Q2, Q3). Quartz Q2 is full of very small relics of kaolinite. Dashed line marks portion of an original outline of fan-textured mineral. Fine-grained subgraywacke, Szczepanów profile (K 1685-3). Bar equals 0·05 mm. Nicols partly uncrossed

Fig. 4. Kaolinit o teksturze wachlarzowej, prawdopodobnie odziedziczonej po pierwotnej mice lub hydromice; kwarce Q1, Q2 i Q3 wypierają kaolinit. Pierwotny zarys tekstury wachlarzowej zaznaczony przerywaną linią. Profil Szczepanowa

Fig. 5. Broken, coalified plant fragment with minute fractures filled by kaolinite (gray). At Q1, Q2, and Q3 an original kaolinite-looking mineral is partly replaced by quartz II (white). Fine-grained subgraywacke, Szczepanów profile (K 1682-1). Bar equals 0·1 mm.

Fig. 5. Fragment zwęglonego szczątka roślinnego z szczelinkami wypełnionymi minerałem o wyglądzie kaolinitu. W miejscach Q1, Q2 i Q3 pierwotny kaolinit jest wypierany przez kwarc. Profil Szczepanowa

Fig. 6. Minute fracture at the margin of coalified plant fragment filled by kaolinite-looking mineral (white). There are at least three minute crystals of quartz (Q). The relationship of these quartz prisms to kaolinite is not quite clear. Medium-grained subgraywacke, Ciechanowice profile (C 747-34a). Bar equals 0·05 mm

Fig. 6. Drobna szczelinka przy brzegu zwęglonego szczątka roślinnego, wypełniona kaolinitem. Widać trzy słupki kwarcu (Q). Profil Ciechanowic

Plate — Tablica LI

Fig. 1. Coalified plant fragment with cells filled by kaolinite-looking mineral. Kaolinite is associated with scattered minute flakes of illite-looking mineral. Very fine-grained subgraywacke, Ciechanowice profile (C 899-3). Bar equals 0·1 mm. Nicols partly uncrossed

Fig. 1. Zwęglony fragment roślinny z komórkami wypełnionymi minerałem o wyglądzie kaolinitu stowarzyszonym z pojedynczymi łuseczkami minerału o wyglądzie illitu. Profil Ciechanowic

Fig. 2. Thin veinlets filled originally by kaolinite-looking mineral (gray). Kaolinite is strongly replaced by quartz II (white) associated with small rhombohedrons and haphazard grains of carbonate. The quartz contains also minute scales and tiny vermicules of kaolinite (up to 0·008 mm). Most likely kaolinite was first replaced by carbonate (at least in part) and then both kaolinite and carbonate were substituted by quartz. Early diagenetic siderite concretion, Ciechanowice profile (C 899-16e). Bars equal 0·05 mm. One nicol only

Fig. 2. Cienkie żyłki kaolinitowo-kwarcowo-syderytowe. Kaolinit (szary) jest wypierany przez syderyt i kwarc. Profil Ciechanowic

Figs 3 and 4. Vein of kaolinite (dark in Fig. 4) in which original kaolinite is attacked and strongly replaced by siderite and calcite. Note minute rhombohedrons of carbonate (upper vein margin) constituting a first lining to the vein. Similar linings are seen at the lower vein margin in at least three various distances off the margin itself, thus marking at least four stages of reopening of the vein (due to tension stress, note dashed lines in Fig. 3). Each shell constituting the vein has its kaolinite stage followed by a carbonate stage; the youngest i.e., the most external shell distinguishes itself in having a poorly developed kaolinite stage, but well developed carbonate stage. Sometimes it also has a well-developed quartz stage (that seems to follow the carbonate stage). Scattered prisms of quartz, however, are also present in a more central portion of the vein. Early diagenetic siderite concretion, Ciechanowice profile (C 899-16b). Bars equal 0·2 mm. Fig. 3 — one nicol only, Fig. 4 — nicols partly uncrossed

Fig. 3—4. Żyła kaolinitowo-kwarcowo-węglanowa, w której pierwotny kaolinit jest silnie wypierany przez węglany (syderyt, kalcyt) oraz przez kwarc. Widać szereg drobnych kryształków węglanu przy górnej krawędzi szczeliny; w dolnej części szczeliny szeregi podobnych kryształków pozwalają zrekonstruować co najmniej 4 stadia kolejnego otwierania się szczeliny. Wczesnodiagenetyczna konkrecja syderytowa, profil Ciechanowic

Figs 5 and 6. Another portion of the same vein. Here, at least six stages of vein reopening are evident, some being continuous throughout the vein, others wedging out on a short distance. Note also thin veinlet of kaolinite now almost totally replaced by quartz (upper left). Bars equal 0·2 mm

Fig. 5—6. Ta sama żyła kaolinitowo-kwarcowo-węglanowa w innym miejscu. Widać co najmniej sześć etapów ponownego otwierania szczeliny, a także cienką żyłkę kaolinitu teraz niemal gruntownie wypartego przez kwarc. Profil Ciechanowic

Plate — Tablica LII

Fig. 1. Authigenic quartz II (gray, Q) replaces kaolinite-looking mineral (K) and siderite (s). Kaolinite has developed at the expense of muscovite (lower center); note numerous relics of muscovite scattered throughout the quartz. Siderite (s) is strongly attacked and mostly transformed to opaque iron oxide. Swarms of minute rhombohedrons of fresh siderite are associated with partly decomposed mica (hydromica). S is recrystallized siderite cement. Medium-grained subgraywacke, Szczepanów profile (K 1685-1). Bar equals 0·1 mm. Nicols partly uncrossed

Fig. 1. Kwarc II wypierający minerał o wyglądzie kaolinitu (K) oraz syderyt (s). Kaolinit powstał kosztem blaszki muskowitu, której resztki są widoczne poniżej środka zdjęcia. S oznacza spoiwo syderytowe. Profil Szczepanowa

Fig. 2. Detail of compound pseudomorph after biotite. Note sagenite preserved in kaolinite-looking mineral (dark), siderite (gray; s), and quartz (white). White threads are relics of

hydromica. The quartz replaces both kaolinite and siderite and is classed here as quartz II. Some sagenite needles project from quartz into either neighbouring siderite or kaolinite or both the two. Granule conglomerate (sandy phase), Szczepanów profile (K 1688-1). Bar equals 0·05 mm

Fig. 2. Sagenit w kwarcu wypierającym kaolinit (ciemny) i syderyt (szary; s). Fragment złożonej pseudomorfozy po biotycie. Profil Szczepanowa

Fig. 3. Authigenic quartz II deposited on grains of detrital quartz (Q1—Q3) replaces carbonate (white patches — all in the same optic orientation). The boundary between detrital core and authigenic quartz is not perceptible. Portions of authigenic quartz in optic continuity with neighbouring detrital quartz are visualized by dashed line: differences in light extinction between the three portions are rather small. HM is flake of hydromica. Fine-grained subgraywacke, Ciechanowice profile (C 899-11). Bar equals 0·05 mm

Fig. 3. Wypieranie węglanu (białe plamy) przez kwarc II. Węglan w jednolitej orientacji optycznej. Granica między detrytycznymi kwarcami Q1—Q3 a kwarcem autigenicznym II niedostrzegalna. HM to blaszka hydromiki. Profil Ciechanowic

Fig. 4. Thin veinlet of kaolinite-looking mineral in fractured detrital quartz. Interpreted as developed due to reaction between free alumina and quartz in an early diagenetic stage. Very small grains of carbonate (?) are embedded in kaolinite in the vein as well as in strongly kaolinized micaceous material seen just outside the quartz (lower left). Medium-grained subgraywacke, Ciechanowice profile (C 747-35). Bar equals 0·05 mm

Fig. 4. Żyłka kaolinitowo wyglądającego minerału w kwarcu detrytycznym interpretowana jako powstała w wyniku reakcji między wolną glinką a kwarcem wzdłuż pęknięcia we wczesnym etapie diagenezy. Profil Ciechanowic

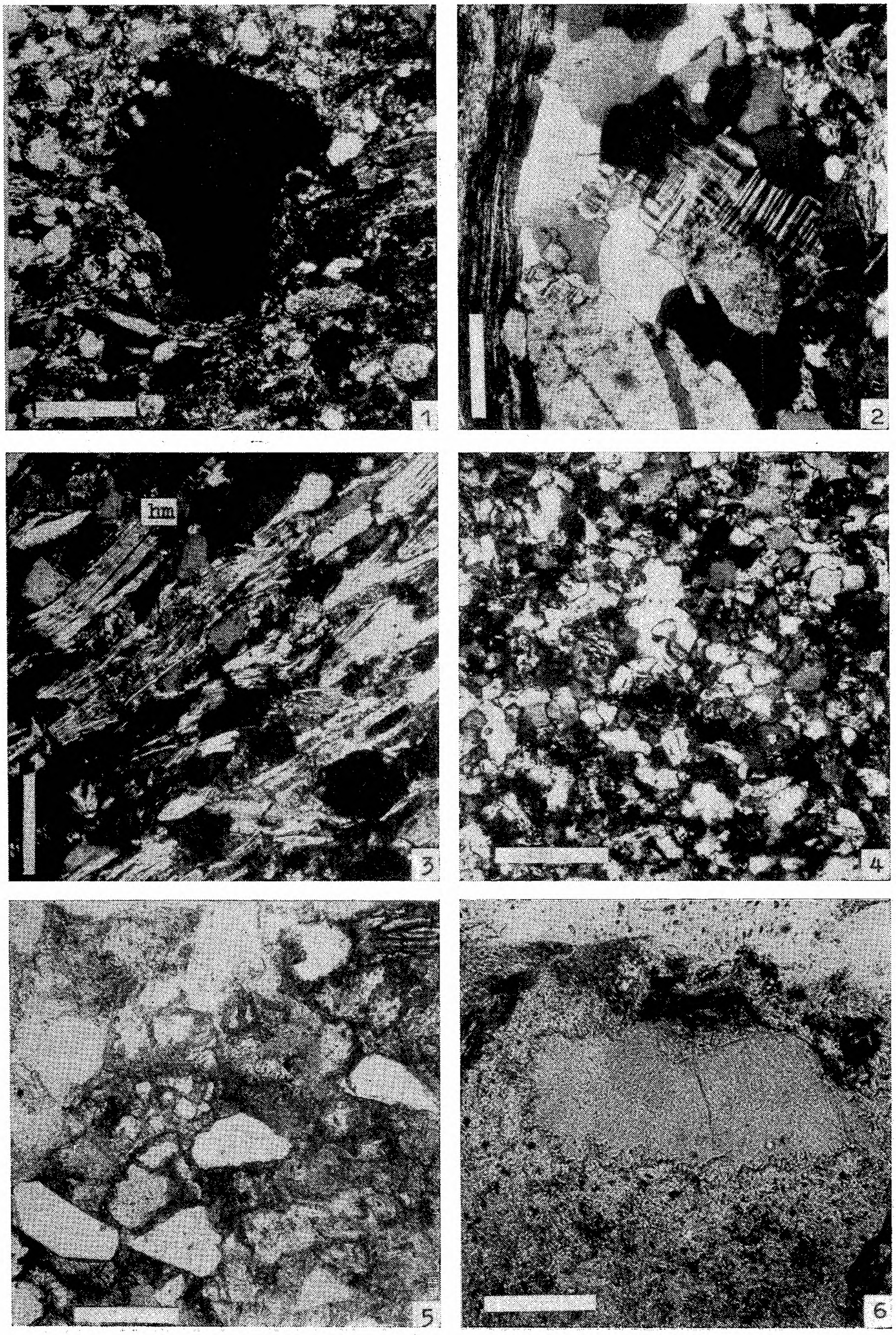
Fig. 5. Authigenic quartz II (white-to-gray) replacing kaolinite-looking mineral (dark). The quartz is partly in contact (and in optic continuity) with detrital quartz seen at the lower one-third. White threads are hydromica and relic mica; note that some of them project from quartz II into kaolinite. Gray mineral is siderite (in various positions of light extinction). Quartz II contains numerous relic of kaolinite ranging from relatively large patches to nearly submicroscopic scales, whereas carbonate relics are absent. Granule conglomerate, Szczepanów profile (K 1688-1). Bar equals 0·05 mm

Fig. 5. Autigeniczny kwarc II wypierający minerał o wyglądzie kaolinitu (czarny) i węglan (szary). Profil Szczepanowa

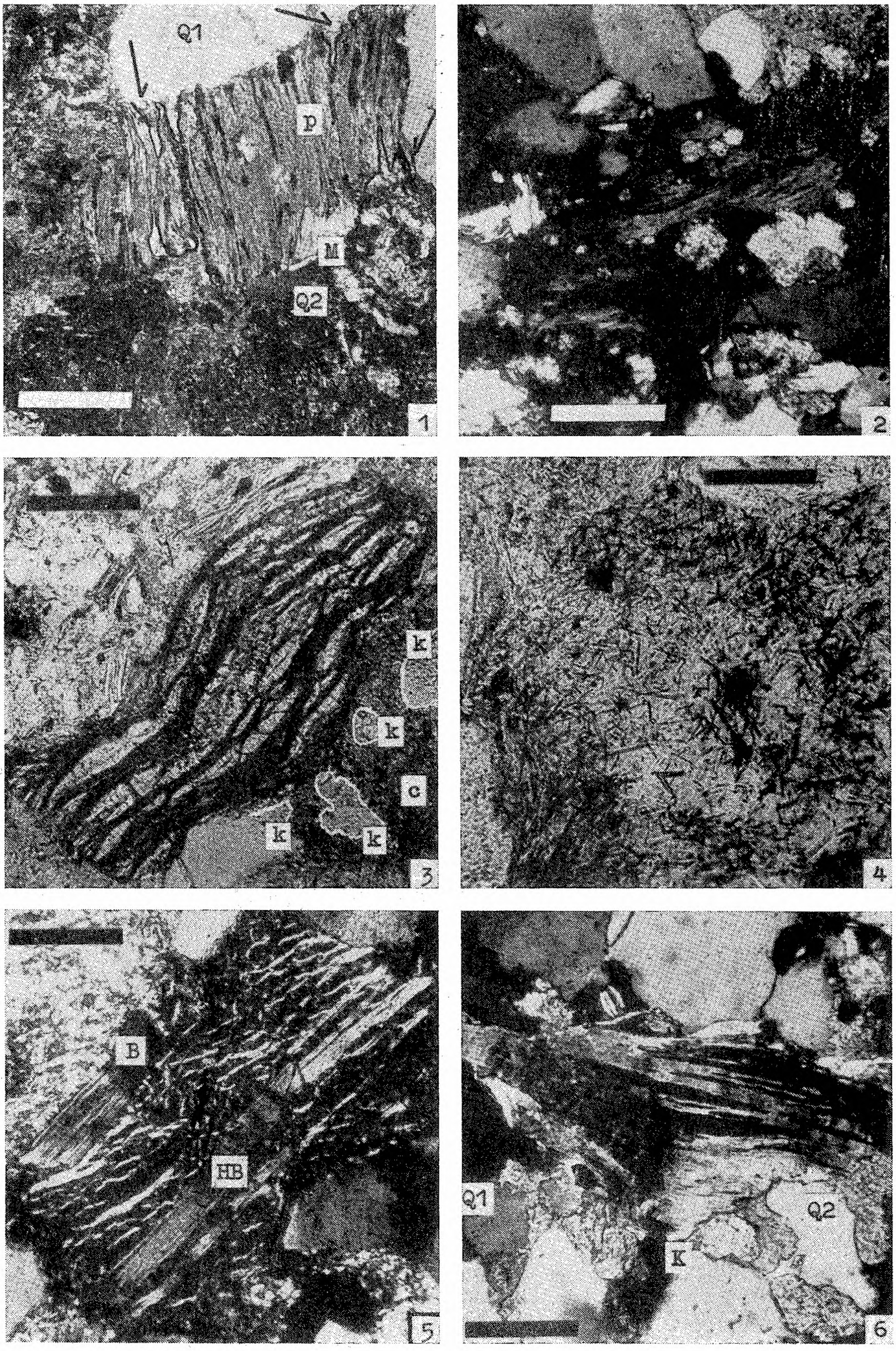
Fig. 6. Early diagenetic pyrite (black) in fine-grained subgraywacke, Szczepanów profile (K 1685-3). Note quartz overgrowths on detrital quartz grains (authigenic quartz I). S is siderite and Q is quartz II as a cement. The contact between quartz grains Q1 and Q2 is sutured. Locally, quartz overgrowths led to the formation of quartzite texture. Bar equals 0·1 mm

Fig. 6. Wczesnodiagenetyczny piryt (czarny) w drobnoziarnistym subszarogłazie (profil Szczepanowa). Widoczne narośla kwarcu I oraz spoiwo kwarcowe (kwarc II, Q). S oznacza spoiwo syderytowe. Lokalnie rozwinięta tekstura kwarcytowa; między ziarnami Q1 i Q2 kontakt jest suturowy

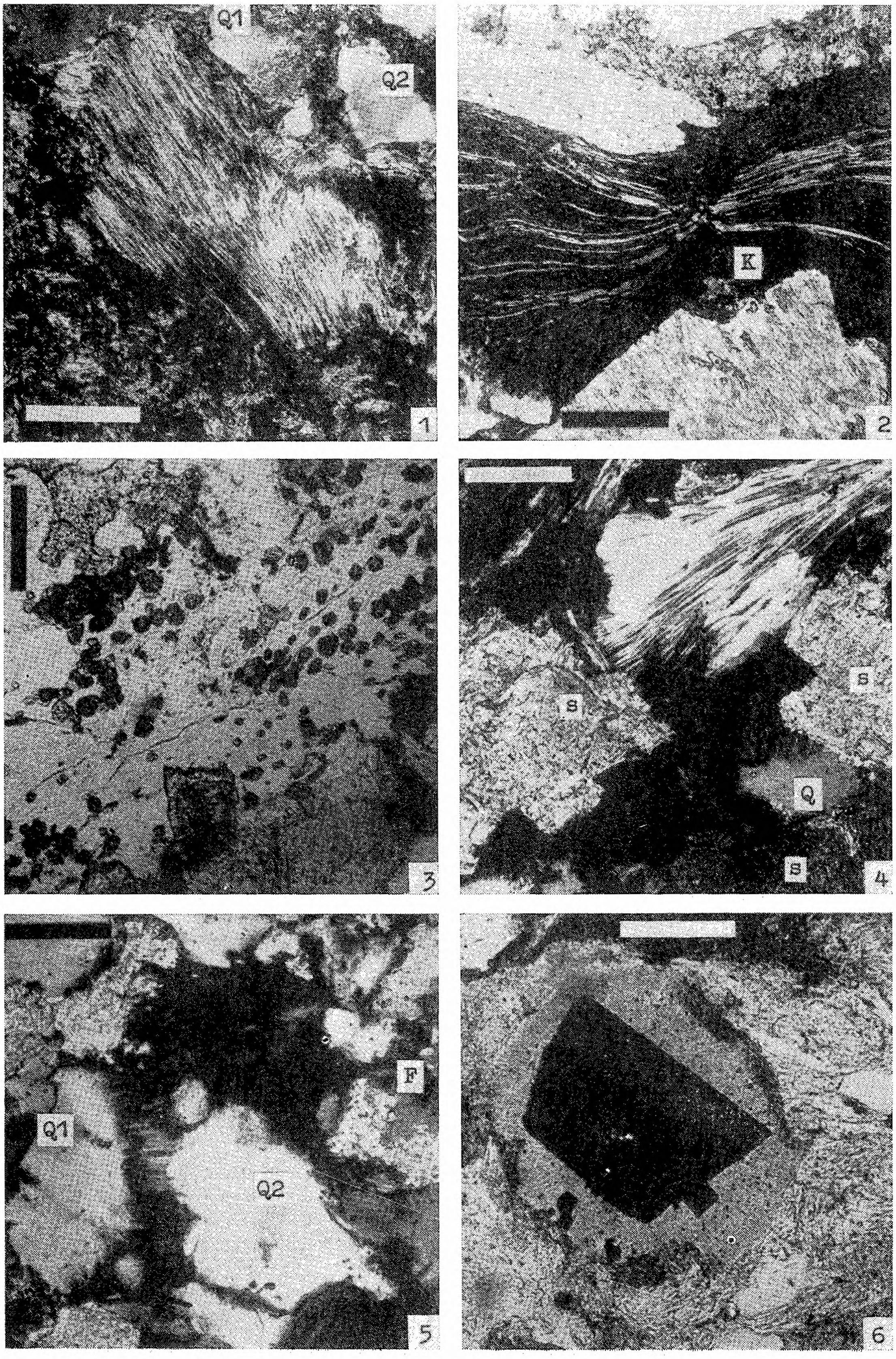
All photos taken by the author
Wszystkie zdjęcia autora



A. K. Teisseyre

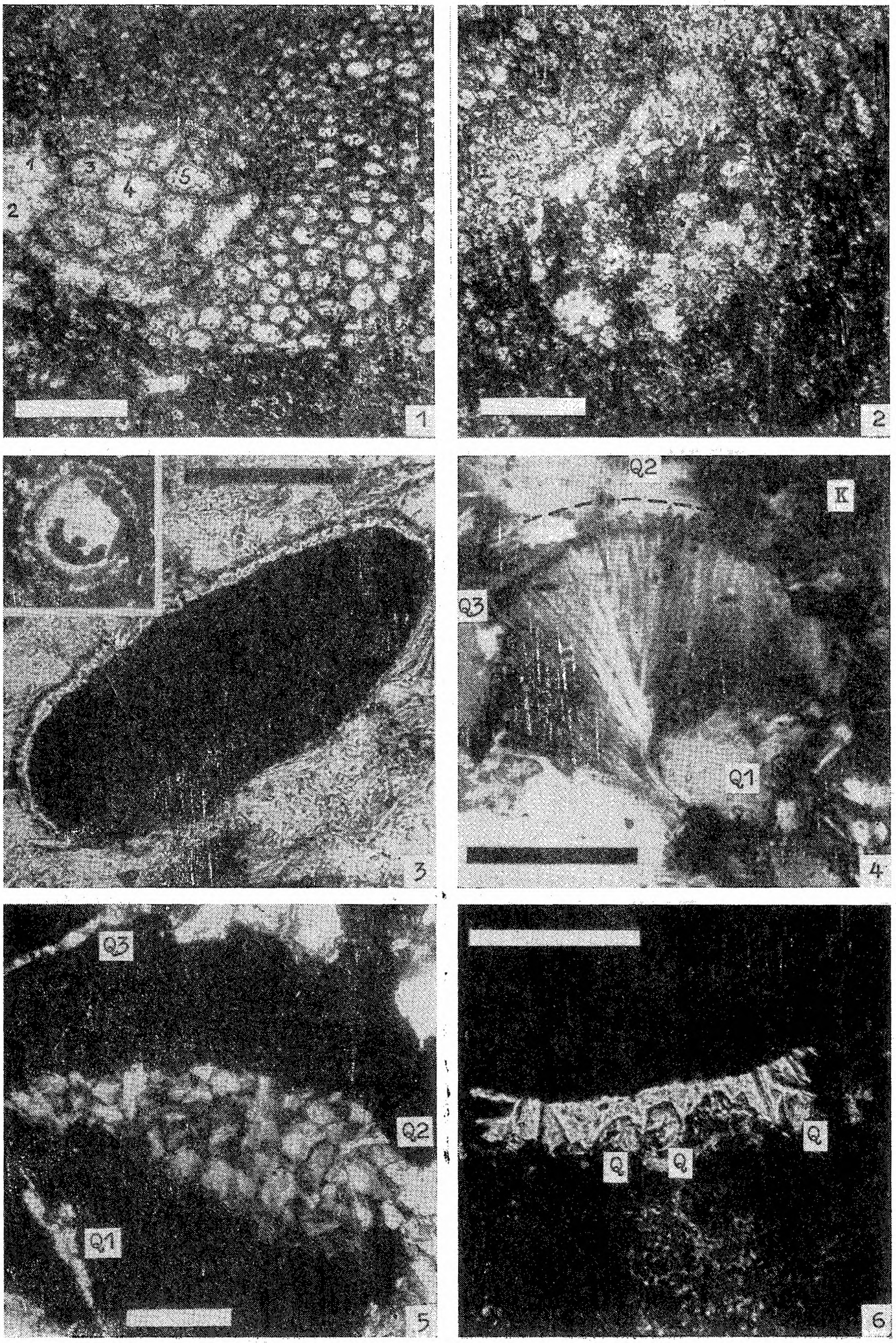


A. K. Teisseyre

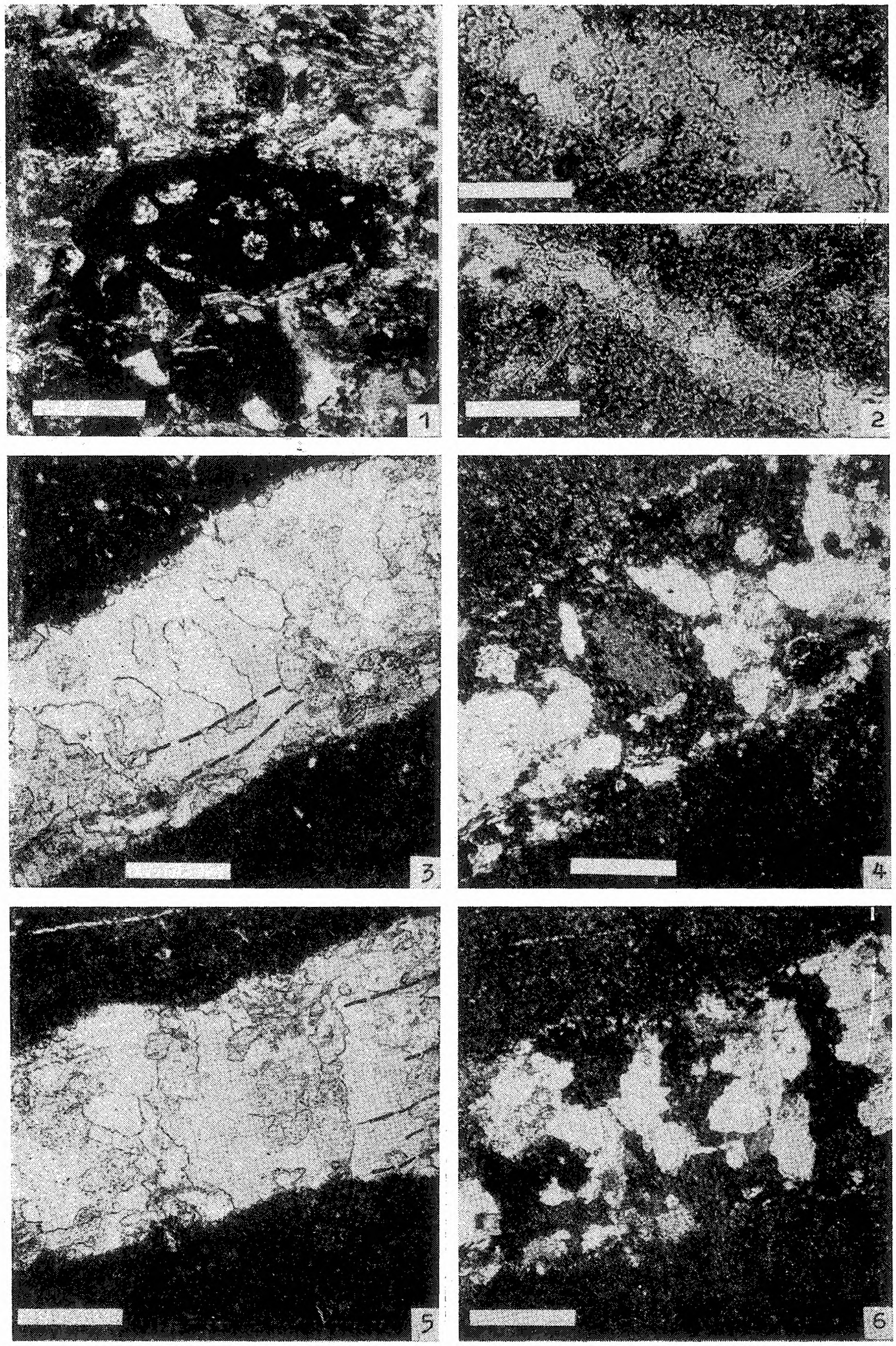


A. K. Teisseyre

Rocznik Pol. Tow. Geol., t. XLIII, z. 4

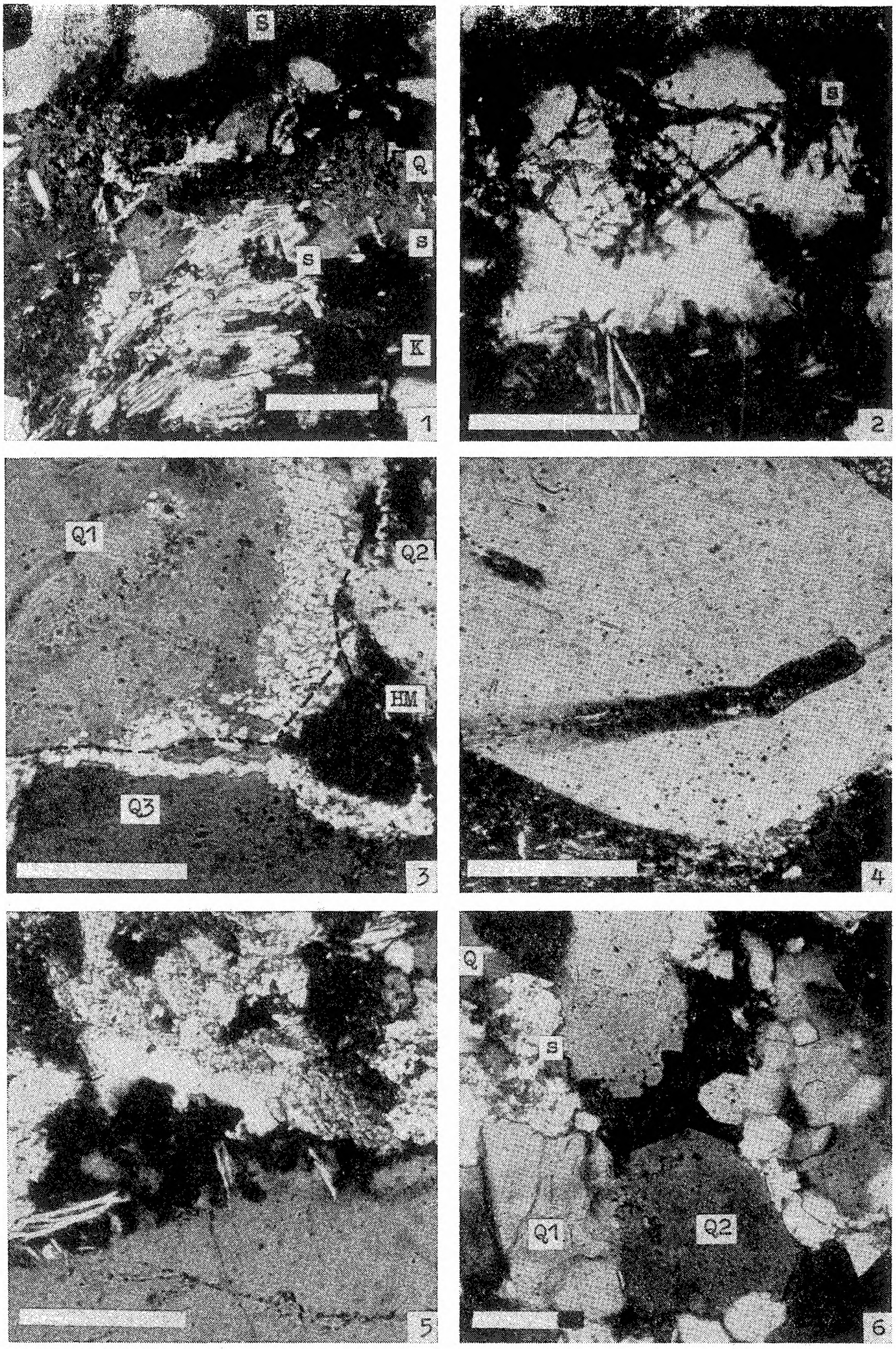


A. K. Teisseyre



A. K. Teisseyre

Rocznik Pol. Tow. Geol., t. XLIII, z. 4



A. K. Teisseyre