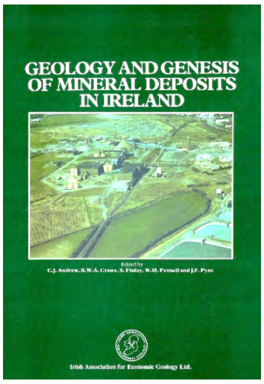

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Ore textures and structures resulting from diagenetic crystallization processes in ore deposits, and their use in exploration: a short review and an example from the Navan mine, Ireland.

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Abstract

The nature and significance of diagenetic crystallization fabrics is reviewed. Attention is drawn to the fact that the diagenetic crystallization process by itself is able to produce manifold micro- and megascopic textures and structures which make it possible to determine the relative time of crystallization of ore minerals. In addition, this information is an excellent tool in exploration.

One example of a special diagenetic texture from the Navan mine is used as an illustration. This texture appears to be the product of diagenetic replacement of a framework of calcite and barite crystals and rosettes.

Introduction

The significance of synsedimentary textures and structures of ores in sediments has been previously well accepted. Examples of load casts, slumping, synsedimentary and diagenetic fracturing, etc. involving ore minerals formed in early stages of diagenesis have been described from many sediment-hosted ore deposits, including the Irish deposits (e.g. Tynagh; Riedel, 1980).

In contrast, many megascopic and microscopic textures and structures produced by the process of diagenetic crystallization *per se* are still unknown or overlooked, and their significance for exploration is not generally appreciated. Examples of these types of fabrics are diagenetic crystallization rhythmites (DCRs), and orbicular textures, and they are common in carbonate-hosted ore deposits, but are often misunderstood or not recognized. Therefore, a systematic description and interpretation is very useful, especially for exploration, when it is realized that they are major sources of information at the outcrop and drill-core scale. In addition, investigation of these textures takes little time and may result simultaneously in a sedimentologic facies determination.

This paper is a short review of some of the most common diagenetic crystallization features. An example of a type of reticulate texture from the Navan mine is used as an illustration.

Textures and structures produced by the process of diagenetic crystallization

Aspects of diagenetic crystallization in relation to ore minerals have been described in previous papers. The present state of knowledge can be summarized very briefly as follows:

(1) Sulphides and other ore minerals can, in most cases, be assigned a definite paragenetic position within diagenetic crystallization sequences (Amstutz et al., 1964; Amstutz and Bubenicek, 1967).

(2) In virtually all of the nonmetamorphic ore provinces in sediments investigated in the past thirty years, basically identical paragenetic sequences have been found, and the same paragenetic sequences are recognized in different types of textures and structures in different lithologies (carbonate rocks, shales, sandstones, etc.).

(3) The similarity, and in part identity, of these crystallization sequences can only be explained in terms of a universal mechanism for fractional crystallization differentiation during diagenesis (Amstutz and Park, 1971).

(4) Differentiation by crystallization fractionation implies that this crystallization has essentially taken place in a partly closed system, i.e. in a system with no substantial introduction of material and only subtraction of the phases which could not be fixed during crystallization (water, hydrocarbons, and material still dissolved in them) (Amstutz and Fontboté, 1983).

(5) The diagenetic crystallization process is able by itself to produce manifold textures and structures.

Figure 1 is an attempt at a geometric classification of the most basic patterns originating by diagenetic crystallization. In these patterns, identical or similar sequences of diagenetic crystallization are observed. The following is a brief description of the main patterns, whereby the terms "generation I, II, and III" are used as defined in Table 1 (Fontboté and Amstutz, 1983a and b).

(1) Homogeneous texture ("massive", directionless rockmass).

(2) to (4) **Patterns with a subhedral cement of generation II, or of generation II with a xenomorphous filling of generation III (contact between generations I and II is gradational in detail):**

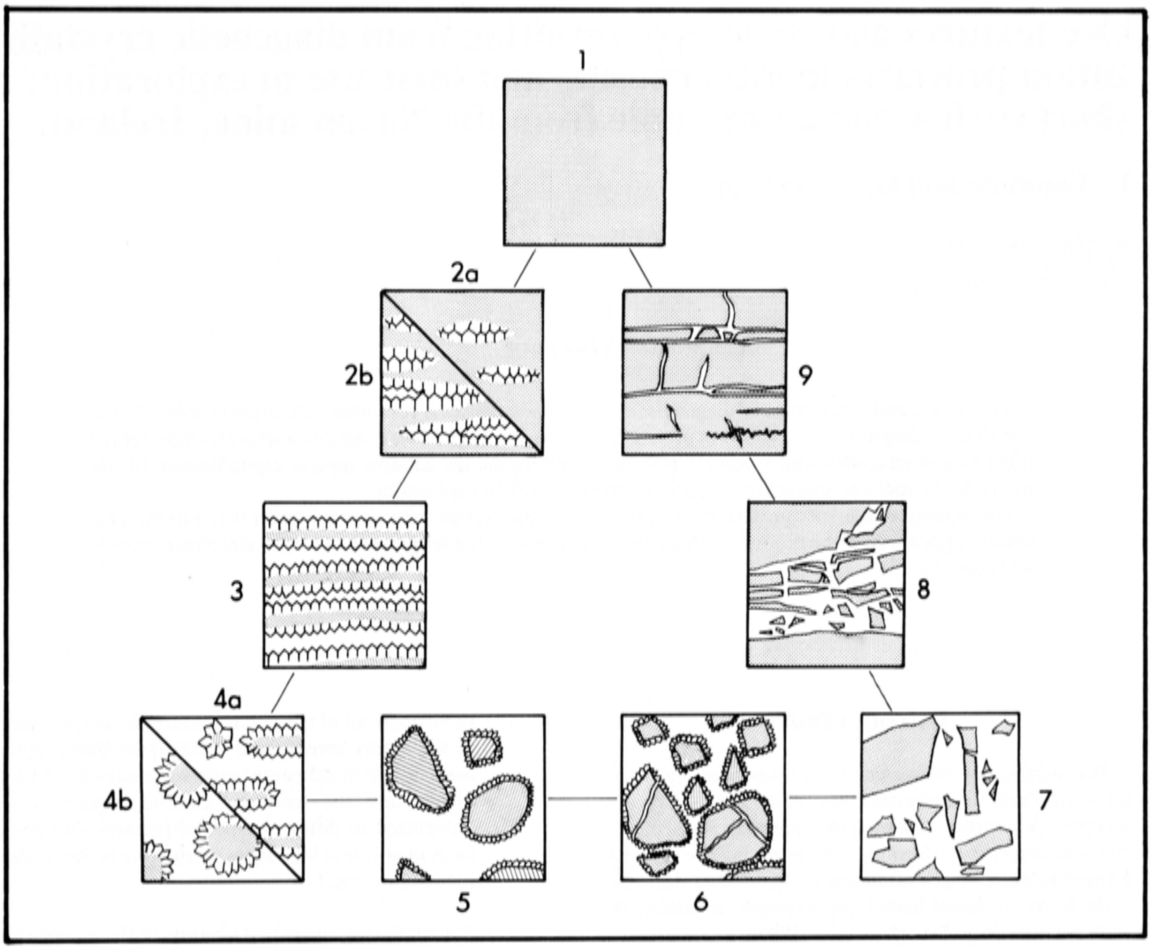


Figure 1. Geometric classification of the basic megascopic patterns in which diagenetic crystallization textures and structures are observed (detailed descriptions in the text). Patterns (1) to (4b) are wholly or partly produced by the crystallization processes themselves, (5) to (9) are essentially diagenetic disruption features in the matrix of which the same diagenetic crystallization sequences are seen as in (2) to (4b). Transition between all patterns are observed in nature. Patterns (5) to (9) often overlap (2a) to (4b) as somewhat later diagenetic events. Of course, these disruption features may also form from later micro- or megatectonic events, but in these cases the paragenetic crystallization features in their matrix are, as a rule, different in composition and texture from those of diagenetic age in the same rock.

(2a) a geode-like texture,

(2b) transition to a rhythmic texture,

(3) a diagenetic crystallization rhythmite (DCR),

(4a) a rhythmic texture gradational to an orbicular texture,

(4b) an orbicular texture.

(5) and (6) Diagenetic breccias with subhedral cement of generation II (sharp contact between fragments and generation II; cockade textures),

(5) the rock fragments belong in part to patterns (2) to (4),

(6) the rock fragments belong to patterns (6) to (9) and (1).

(7) to (9) Diagenetic patterns without subhedral cement of generation II,

(7) diagenetic breccia,

(8) diagenetic veining and brecciation,

(9) diagenetic veinlets.

This is primarily a geometric classification. However, the different patterns may also indicate a different diagenetic history. For example the nine patterns can be subdivided into the following two groups.

—Patterns which formed *in situ;* for example DCRs, geode-like and orbicular textures (classes 2 to 4 in Fig. 1). They are characterized by a complete transition between the subsequent crystallization generations I and II and are formed within the same crystallization cycle. These patterns are more directly consequences of diagenetic crystallization.

Table 1.

Main features in crystallization generations of DCRs (as defined in Fontboté and Amstutz, 1983a)

Generation I or starting sheet (often with several "sub-generations", i.e., several phases)	—*Fine-to medium-grained* —Many disseminated inclusions in the grains ("impure grains", therefore *dark colours;* many of these inclusions are organic in origin) —Primary depositional features are often recognized
Generation II (often with several phases or "sub-generations")	—*Medium to coarse or very coarse* subhedral crystals, arranged in a bipolar pattern, i.e., growing above and below the "starting sheets" —The limit between generation I and II is gradational in detail —In contrast to generation I, generation II contains hardly any solid inclusions (therefore usually *light coloured*) —Zonal crystal growth often observed —Perfect analogy to the subgenerations of drusy cements —Generation II or subgenerations IIa, IIb, etc., respectively, are usually monomineralic —*Geopetal* features are frequent in that generation II is often better developed above than below the "starting sheets"
Generation III (often missing)	—The remaining central space or its xenomorphous filling which is *coarse or very coarse grained* —Usually *light colours,* no solid inclusions in crystals —The limit between generation II and III is sharp in detail —Occasionally this generation consists of tarry or oily substances.

—Disruption patterns such as veining and brecciation (shown as classes 5 to 9 in Figure 1). Sharp boundaries between crystallization generations, including cross-cutting and replacement features, often indicate more than one fracturing and/or crystallization event.

Between the nine geometric patterns pictured in Figure 1 there are, of course, transitional or mixed textures and structures; some tepee structures for example, could be placed somewhere between classes 3 and 8. (Incidentally it should be stressed that tepee structures are not always surface features.) More complex patterns produced by diagenetic crystallization (such as the example from the Navan mine described below) cannot be included in this diagram.

The crystallization sequence observed in these textures and structures is a further source of information. For example, simple, one-cycle crystallization sequences generally indicate crystallization in a partly closed system. On the other hand, sequence repetitions may indicate that the system was open during certain periods of crystallization.

The determination of diagenetic textures and structures can give valuable information on many aspects, including (a) depositional characteristics of the ore-bearing horizons (for example by recognizing vanished evaporites on the basis of certain reticulate ore textures), (b) diagenetic dating on the basis of crystal-growth patterns (i.e. the paragenetic position of an ore mineral), and (c) physico-chemical conditions during the different stages of diagenesis.

Some examples from Ireland

Stalactitic ore textures in the Navan mine

A type of botryoidal texture, in part approaching a reticulate texture, occurs in the Navan mine and serves as an example of a texture produced by the diagenetic crystallization process described above. This texture (Figs. 2 and 3) displays a characteristic geopetal orientation and is known in the mine as "stalactitic texture" (Ashton et al., this vol.). The hand specimens described here were sampled in the 1315 level at the base of the 2-1 Lens W (211W Stope Bottom-cut).

Taking the bottom contact of the ore lens shown in Figure 3a as an example, the following layers can be identified (from bottom to top):

(a) Calc-siltstone with disseminated pyrite (in part framboidal).

(b) Sulphide layer consisting of the following sublayers:

- (b1) Marcasite with botryoidal texture.
- (b2) Fine-grained sphalerite as matrix between authigenic quartz, barite, galena and pyrite (the latter mostly framboidal).
- (b3) Massive sphalerite with zonal growth and idiomorphic terminations, oriented upwards.
- (b4) Xenomorphic filling of calcite.
- ($b3^1$) Identical to (b3), but oriented downwards.
- ($b1^1$) Identical to (b1), but oriented downwards.

(c) Fine-grained sphalerite as matrix between detrital grains of quartz, and subordinate plagioclase, some framboidal pyrite.

(d) Fine-grained sphalerite and subordinate marcasite, galena, authigenic quartz, and framboidal pyrite.

(e) Massive sphalerite, including a thin galena layer,

(f) Sphalerite layer similar to that described under (d) but also including some barite rosettes.

(g) Semi-reticulate texture (stalactitic texture) (Figs. 3b, c and d).

- (g1) Thin layer of pyrite (mostly framboidal) and galena. These sulphides partly replace barite rosettes oriented roughly upwards.
- (g2) Sphalerite with some relicts of barite filling the space between (g1) and ($g1^1$). The sphalerite displays clear overgrowth patterns over the barite rosettes of (g1) and ($g1^1$), as seen in Figures 3a and c.

(gl[1]) Vertical sulphide aggregates "hanging" apparently from the (h) layer. The sulphides are pyrite (partly framboidal), and galena. They replace large barite crystals and rosettes (up to 2cm in length). One of these large former barite crystals can be recognized in Figures 3c and d. All the isolated small barite relicts display the same extinction angle indicating that they belonged to the same crystal.

(h) Fine-grained sphalerite as matrix between authigenic quartz, barite and framboidal pyrite, also some galena. This layer is very similar to (f).

(i) New layer of semi-reticulate ore as described in (g).

It appears that the peculiar stalactitic texture in this sample is the product of diagenetic replacement of former barite crystals and rosettes, locally preserved as isolated barite grains. It should be pointed out that layers (gl) and (gl[1]) show the same paragenetic and crystallization sequence but with inverse orientation.

A similar pattern is shown in Figures 2b, c and d. The vertical sulphide aggregates, equivalent to those described under (gl[1]), consist here of mainly pyrite (partly framboidal) growing over more-or-less isolated grains of barite and calcite. Both the calcite and the barite grains are relicts of larger crystals as indicated by their optical orientation (Figs. 2c and d). An overgrowth of sphalerite equivalent to (g2) fills the remaining space. Xenomorphic calcite is the last crystallization generation (Fig. 2b).

Microprobe analyses of sphalerite and barite of different layers of these samples displayed no systematic differences in composition. The sphalerite contains between 0.1 and 0.5% Fe. The Mn and Cd values are below 0.03%. The SrO content in barite ranges between 1.8 and 8.5%. Some representative barite analyses are summarized in Tables 2 to 4. The analysed grains are marked in Figure 3.

Soft-sediment deformation affecting ore minerals formed in very early diagenetic stages is a widespread feature in the Navan mine (Ashton et al., this vol.). This can also be seen in Figures 2a, 2b and 3a. The "stalactitic textures" occur between sphalerite-bearing layers showing obvious soft-sediment deformation. This rules out any hypotheses based on open-space filling processes unless the remnant space of a diagenetically crystallizing system is termed an open space.

The textures described above indicate that this peculiar

Table 2.

Microprobe analyses of the barite grains marked in Figure 3a.

	1	2	3
SO_3	34.9	36.4	36.3
BaO	56.4	61.3	59.2
SrO	6.2	1.8	5.7
	97.5	99.5	101.2

Table 3.

Microprobe analyses of the barite grains marked in Figure 3b.

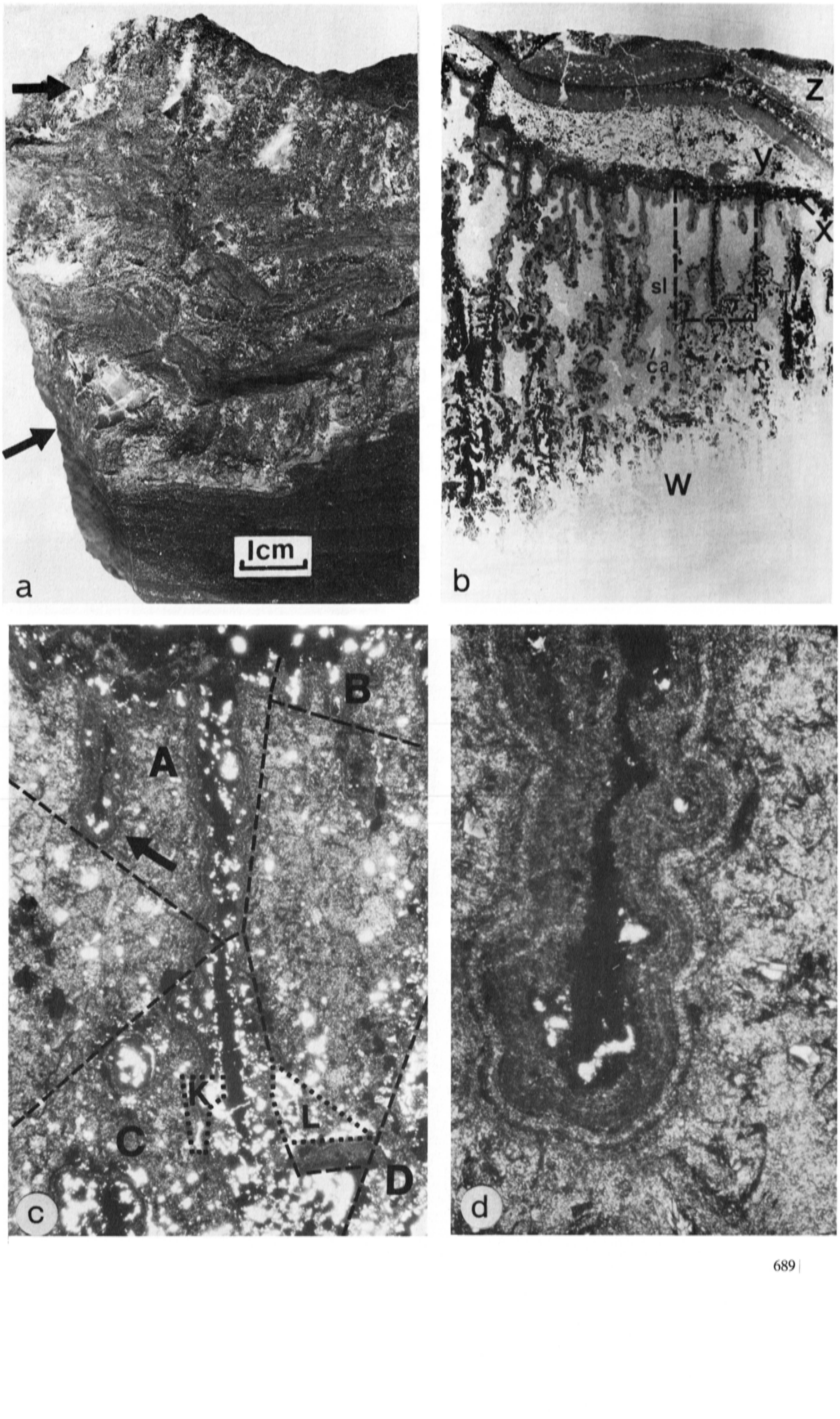
	4	5	6
SO_3	35.6	35.5	35.4
BaO	57.8	58.0	57.8
SrO	5.5	5.4	5.7
	98.9	98.9	98.9

Table 4.

Microprobe analyses of the barite grains marked in Figures 3c and d.

	7	8	9	10	11	12	13
SO_3	35.7	34.7	42.7	37.2	35.9	35.4	35.9
BaO	59.2	58.8	52.1	58.1	55.7	55.5	61.5
SrO	5.5	6.6	5.3	2.9	8.5	6.3	2.5
	100.4	100.1	100.1	98.2	100.1	97.2	99.9

Figure 2 **(Opposite page).** "Stalactitic textures" from the Navan mine. All the photographs are top-bottom oriented. **2a.** Ore specimen with semi-reticulate textures from the Navan ore deposit ("stalactitic texture" in the nomenclature of the mine). The marked layers show a semi-reticulate texture of pyrite, sphalerite, galena and calcite, illustrated in the next figures (sampled in the 1315 level at the base of the 2-1 Lens W, 211W stope bottom-cut). **2b.** Thin section of the zone marked with 2 in Figure 2a. The upper dark layer (z) consists of fine-grained sphalerite and some authigenic idiomorphic quartz. The light layer (y) is a siltstone cemented by quartz, barite, sphalerite and pyrite. The opaque layer (x) consists of fine-grained sphalerite and pyrite and some authigenic quartz. The semi-reticulate texture of the following layer (w) is shown in detail in the next two figures; (sl) sphalerite, (ca) calcite.
2c. Thin section (//N) of the area marked in Fig. 2b. The vertical opaque aggregates consist of pyrite (py) and subordinate galena (gn). The light spots are mainly calcite (ca) and subordinate barite (ba), except those in the upper horizontal dark layer which are quartz. Within the four fields A to D all the small isolated grains of calcite display the same extinction angle indicating that they are relics of four larger calcite grains. Two fields corresponding to two barite grains are also observed (K and L). They include only scarce small barite relics. **2d.** Enlargement of the area marked in Fig. 2c. The white spots within the dark grey sphalerite are calcite grains with the same optical orientation. The black minerals are pyrite, mostly framboidal.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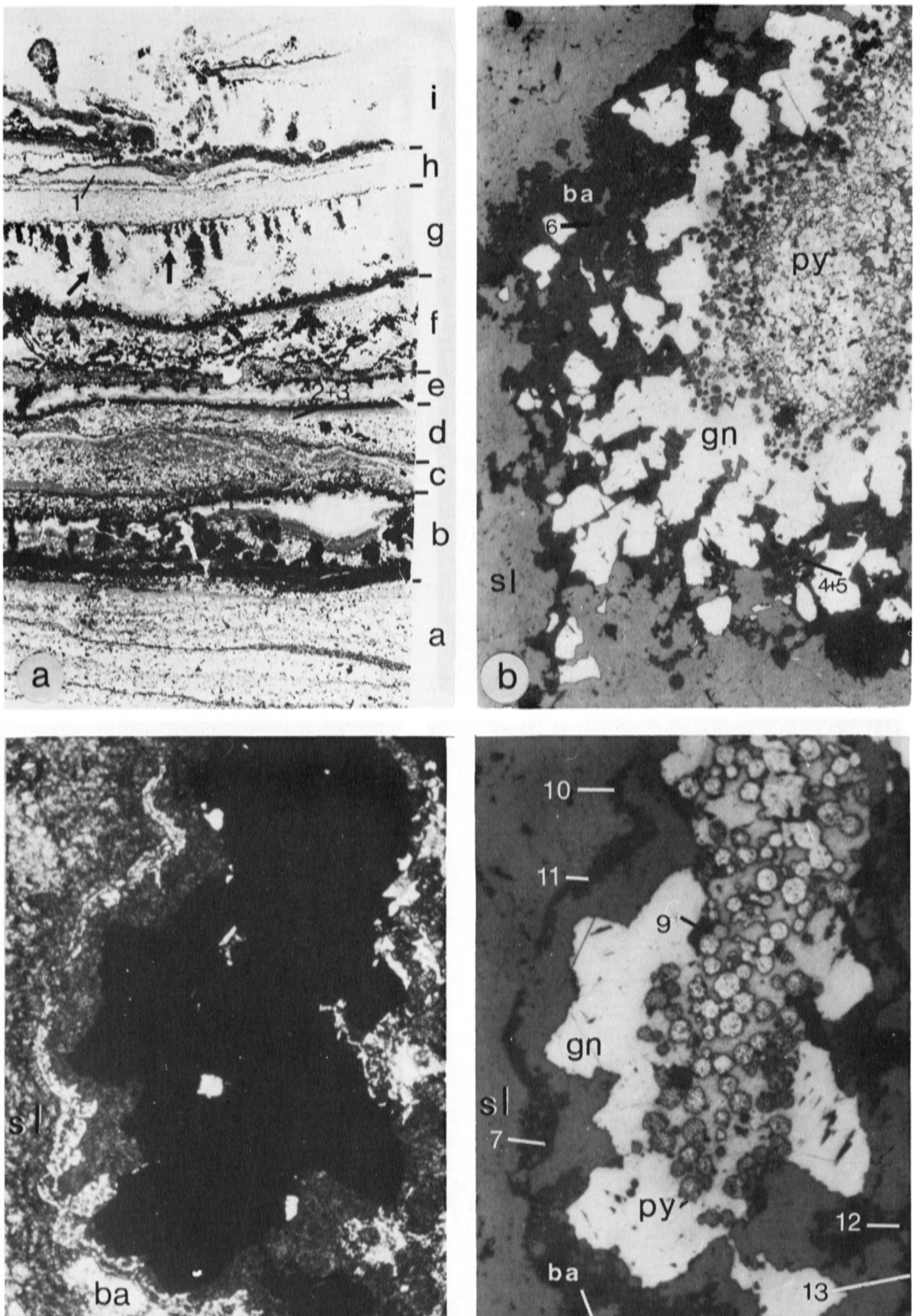
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semireticulated pattern has been formed by diagenetic replacement, in part pseudomorphic, of a framework of calcite and barite crystals and rosettes, and not by the filling of a cavity. Such a process would be consistent with the normal diagenetic evolution of a shaly carbonate sediment, including layers of fine-grained sulphides and sulphates and also of coarse-grained sulphates and carbonates, which were probably the precursor layers of the "stalactitic textures."

DCRs in Ireland

No diagenetic crystallization rhythmites (DCRs) have yet been identified in Irish mines. DCRs are only known to occur in fairly pure carbonate rocks and other chemical sediments (see Fontboté and Amstutz, 1983 a and b). Consequently, in the marly to shaly sediments at Navan, DCRs are not to be expected. However, dolomitic DCRs occur at several places in the Carboniferous of Ireland. For example, near Balbriggan (about 35km SE of Navan), about 2km south of Skerries, DCRs were found in a dolomite horizon within the Upper Holmpatrick Limestone of Arundian age (Fontboté, 1981). Other dolomitic DCRs and DCR-like textures have also been found in drill cores in the north central Midlands (J. Clifford, pers. comm.).

In this context it should be mentioned that in other similar Carboniferous shallow-water carbonate sequences, DCRs have been found, as for example in Belgium (Swennen, 1984; W. Viaene, pers. comm.), Siberia (Shilo et al., 1984), Southern Illinois, Czechoslovakia, Spain, etc.

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Figure 3 (Opposite page). "Stalactitic texture" from the Navan mine (continuation). All the photographs are top-bottom oriented (Numbers refer to the SO_3, BaO, and SrO analyses of Tables 2 to 4.
3a. Thin section (//N) of the lower area marked in Figure 2a, corresponding to the bottom contact of the ore lens. Description in the text. **3b.** Polished section of the area marked in Figure 3a by the arrow on the left. The area corresponds to the lower part of a vertical sulphide aggregate. The inner part consists of pyrite, mainly framboidal, cemented by galena. Both sulphides are diagenetically replacing a barite rosette (ba). **3c and d.** Polished thin section (//N) of the area marked by the arrow on the right in Figure 3a. 3c is taken in transmitted, and 3d in reflected, light. All the isolated barite grains (some of which have been analysed by microprobe; see Tables 3 and 4) have the same optical orientation indicating that they are relics of a unique larger barite grain. Note the framboidal texture of the pyrite and the zonal growth of the sphalerite.