GENESIS OF FILAMENTARY CRYSTALS OF GALENA AND NATIVE GOLD

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Thin straight-linear crystals (whiskers) are well known for many compounds formed from solutions or vapours in nature as well as in laboratory experiments. The length of such crystals considerably exceeds their very small thickness, which is typically in the range 1-2 up to 10-20 μm. Such morphological anisotropy in many cases strongly contradicts to their isometric (e.g., cubic) or quasi-isometric structural symmetry, which indicates special conditions of their formation. Strongly disputable are the mechanisms of their formation: dislocation controlled (Seers, Frank), vapour-liquid-solid (VLS: Wagner-Ellis) (see, Maleev, 1971; Givargizov, 1986), or directed growth at diffusion-controlled regime and high supersaturation by 2D layer nucleation (Bonev, 1990).

However, some strongly elongated crystals, similar in dimensions to the proper whiskers, have more complicated, irregular, curvilinear or tortuous shape, and they can be denoted as *filamentary crystals*. Nearly no information is reported about the crystal nature, morphology and origin of such crystal formations. For native gold, in the literature there are remarks that in rare cases it forms wire-like and fibrous crystals. Petrovskaya (1973) assigned them to a morphogenetic type of not well-bounded and rounded crystals.

We have observed such crystals of native gold and galena, formed in natural hydrothermal deposits. Based on their detailed micromorphological study we try to explain their growth mechanisms and origin, also in comparison to the straight whiskers. These two mineral phases have cubic (*Fm3m*) structural symmetry, so the morphological anisotropy of these peculiar crystals is controlled dominantly by the external growth conditions.

Filamentary galena was found together with straight whiskers in druse cavities of some Pb-Zn ore deposits (Mogilata, Gradishte, Spolouka) of the Madan ore district, Rhodope Mts., Bulgaria. They are associated with long-prismatic quartz, early large crystal cubic-octahedral galena, chalcopyrite, sphalerite and barite, and belong to the latest galena generation. In places they are overgrown by fine nontronite flakes. The galena filaments are 2-5 to 10 ìm thick and up to 0.5 mm long, occurring in close association with straight and kinked whiskers of similar size (Bonev, 1993). Some filaments are curvilinear with a gradually changing growth direction, when others are crooked and tortuous with multiple changing direction, including straight, curved and irregular segments (Fig. 1a, c). Always they are bounded by small alternating uniform flat faces of $a\{100\}$ and $o\{111\}$, forming step-wise surfaces with numerous edges and re-entrant angles (Fig. 1d). Branched filaments also occur. Thicker, irregularly shaped elongated crystals are also common (Fig. 1b). The close association of straight whiskers and tortuous filaments is evidence for their contemporaneous formation in similar conditions and by similar growth mechanisms. The morphology of the curved and irregular filaments with stepped surfaces excludes a possible dislocation growth mechanism controlled by axial screw dislocations. It is suggested that they arise by rapid diffusion-controlled growth from highly and non-uniformly supersaturated solutions.

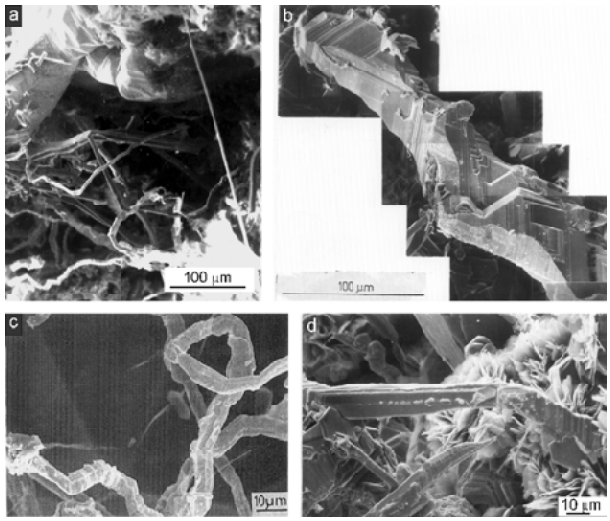

Fig. 1. SEM microphotographs of filamentary galena: a) tortuous filaments with various growth directions associated with straight whiskers; b) an irregular, elongated thick galena crystal; c) an irregular knot-like crystal; d) bent and trunk-form filaments with complex stepped surface. Gradishte deposit, Madan ore district.

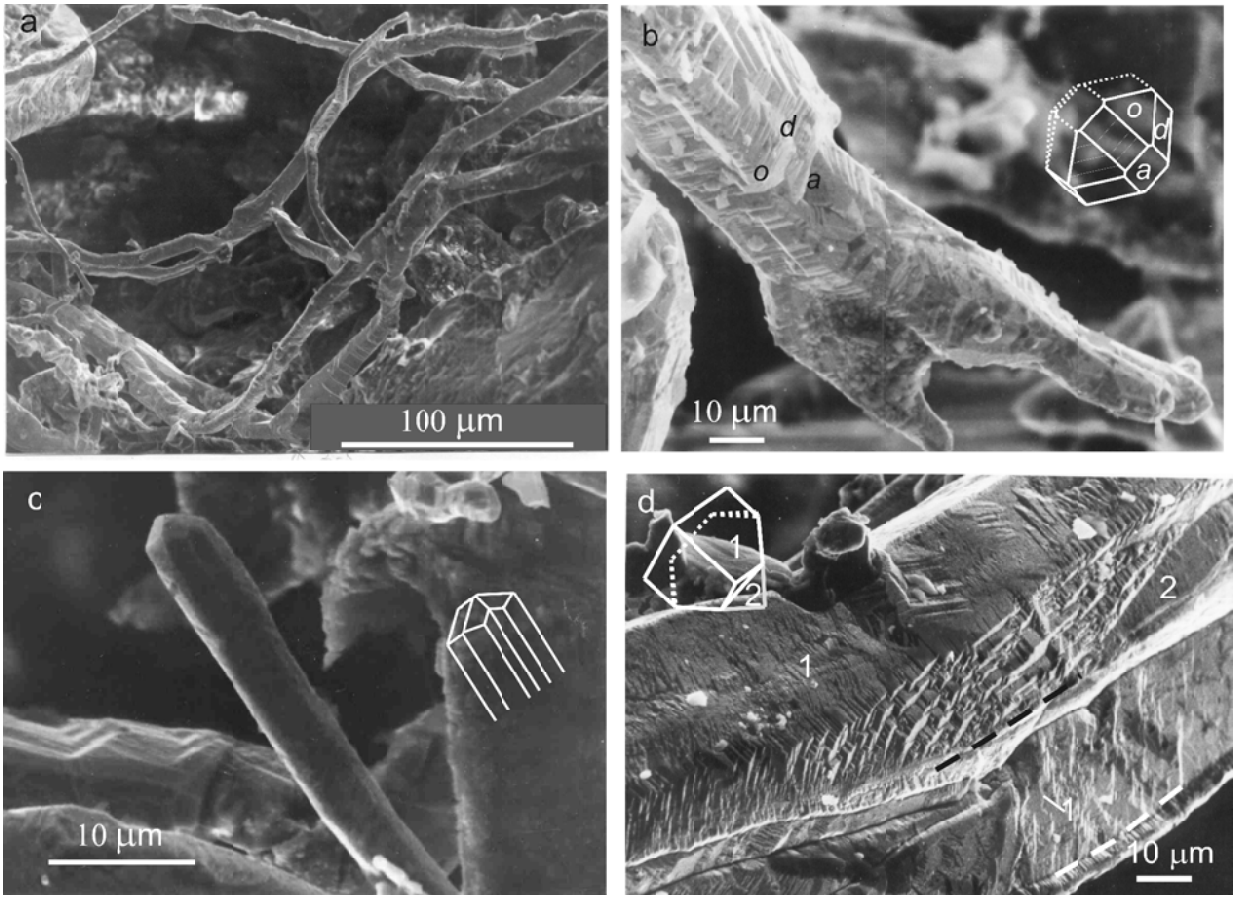

Fig. 2. SEM microphotographs of filaments of native gold: a) a group of not straight tortuous filaments in a small cavity of magnetite-bornite-chalcopyrite ore sample; b) split termination of a filament bounded by *o* 111}, *a*{100} and *d*{110} stepped faces; c) a fibre of cubic-octahedral habit with longitudinal (111) twin plane; d) twinned along (111) fibers in two orientations (1 and 2). Elatsite deposit.

Filamentary native gold was observed in small cavities of the early magnetite-bornite-chalcopyrite assemblage of the porphyry Cu-Au deposit, Srednogorie zone, Bulgaria (Petrunov et al., 1992; Petrunov, Dragov, 1993; Popov, et al., 2002; Tarkian et al., 2003; Kehayov, Bogdanov, 2005). The tortuous filaments formed bush-like clusters, usually 2-3 to 10-15 ìm wide and up to 1 mm long. Their stepped surfaces are bounded by alternating and unequally developed small flat faces of the typical crystal forms of gold: *o*{111}, *a*{100} and *d*{110}, with locally occurring *m*{311} and *f*{310} (Fig. 2). The single filaments are tortuous, changing gradually or more steeply and irregularly their direction (Fig. 2a), often developed in different planes. Straight segments are rare. Because of the symmetric distortion, the crystallographically equivalent faces are unequally developed and some of them are absent. The terminations of filaments are well formed, sometimes split (Fig. 2b). Common are the {111} twins (Fig. 2c, d).

The filamentary gold in Elatsite contains about 18.7 wt.% Ag and 1.1 wt.% Cu. Gold is closely related to the early, high-temperature (600-530°C) magnetite-bornite-chalcopyrite mineral assemblage, most probably as Au-rich bornite solid solution, which is later redeposited in native form in the close neighbourhood during formation of the main, lower-temperature (535-400°C) quartz-chalcopyrite-pyrite assemblage. It is assumed that these extremely anisometric and non-equilibrium filamentary crystals were grown from highly supersaturated heterogeneous boiling solutions.

In the Chelopech high-sulphidation Cu-Au deposit located not far from Elatsite, the native gold has been deposited mainly in the intergranular space of the sulphide ore, and usually displays more irregular morphology (Bonev et al., 2002). However, in some small open cavities, filamentary gold also can be found (Fig. 2a, b), bounded by fine-stepped faceted surfaces.

The main features of these filamentary crystals of cubic minerals are: extremely anisometric and non-

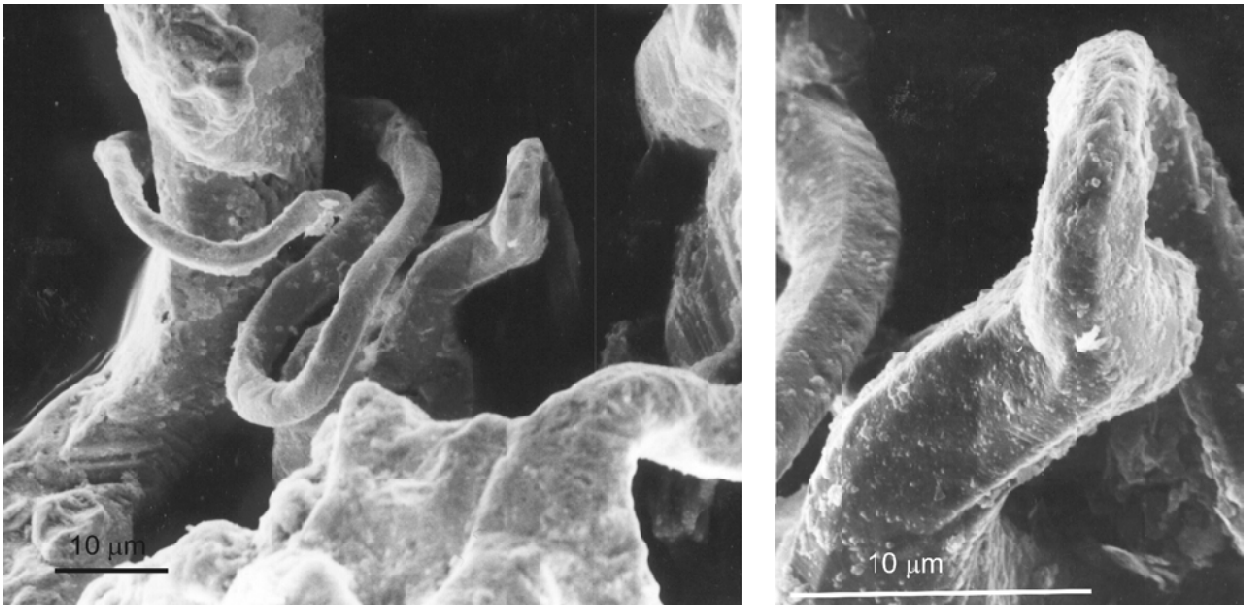

Fig. 3. Filaments of native gold with different thickness and changeable direction: a) general view; b) a detail. Chelopech deposit.

equivalent shapes, euhedral crystal forms bounded by crystal faces; stepped surfaces of alternating small flat faces of the usual crystal forms; gradual or sharp changes of the growth directions. Such morphology is not possible for growing at low supersaturation. It is a result of rapid growth from supersaturated fluids, far from the equilibrium. It is important that in the later periods such highly-energetic forms were preserved unchanged, not influenced by active fluids.

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НИШКОВИДНИ КРИСТАЛИ НА ГАЛЕНИТ И САМОРОДНО ЗЛАТО И ТЕХНИЯ ГЕНЕЗИС

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Вискерите - много тънки праволинейни кристали, са известни за много вещества, образувани от разтвори или пари в природни или лабораторни условия. Тяхната дължина съществено превъзхожда незначителната им ширина. Съществуват противоречиви мнения за техния произход. Някои силно удължени нишковидни кристали с подобни размери имат значително по-сложни неправилни, извити или криволичещи форми. Почти липсва информация за тяхната кристална природа, морфология и произход. Морфологичната анизотропия на тези кристали е в силно противоречие със структурната им симетрия, което свидетелствува за специфични условия на образуване. Изследвани бяха такива кристали от галенит и самородно злато.

Нишковидният галенит се среща заедно с праволинейни галенитови вискери в друзови празнини на някои от оловно-цинковите находища от Маданския район (Могилата, Градище и др.). Нишките са с дебелина 2-5 до 10 μm и дължина до 0,5 mm. Те имат криволинейни или зигзаговидни и сложни форми, включващи прави, извити и неправилни сегменти, запазващи еднаква монокристална ориентация. Остенени са от малки алтернириращи плоски октаедрични и кубични стени, оформящи стъпаловидни повъхности с многобройни входящи ъгли.

Нишковидното самородно злато е включено в малки празнинки на ранната магнетит-борнит-халкопиритова парагенеза в медно-порфирното находище Елаците. Представено е от групи на храстовидно разклоняващи се неправилно извити нишковидни кристали с дебелина 2-3 до 10-15 μm и дължина до 1 mm. Стъпаловидните им околни повърхности са покрити с малки алтернириращи плоски нееднакво развити стени на куб, октаедър и някои по-редки форми. Върховите части са с добре развити кристални окончания, понякога разцепени на 2 или 3 части. Чести са срастъците по {111}.

Обща характеристика на тези екстремно анизометрични и неравновесни за минерали с кубична *Fm3m* симетрия кристални форми, е тяхната идиоморфност, стъпаловидни околни повърхности, оформени от плоски стени на главните им кристални форми, постепенно или рязко изменение на растежната посока и добре оформени върхови части. Тази морфология изключва спирално-дислокационния растежен механизъм и е индикатор за формиране при повишено пресищане, далеч от равновесието, чрез двумерно зараждане на словете. И в двата случая има указания за отлагане в силно нееднородната среда на хетерогенни кипящи флуиди, газовите мехури в които ограничават праволинейния растеж.