Mineral Species of Uncertain Origin

The characterization of a potentially new mineral as natural depends on a thorough documentation of its geological context. Concerns about minerals of uncertain origin often arise from issues such as contamination, anthropogenic influences, and even fraudulent syntheses. Moreover, there are numerous cases where the origin is not well defined: the material in question is not clearly either natural or nonnatural, as discussed in detail by Hazen et al. (2017). To address these challenges, it is recommended that CNMNC guidelines be updated to include more detailed requirements for documenting the origin of a new mineral being proposed.

Suggested components include precise geographic location, sample type and size, collector details, collection date, geological mode of occurrence, associated minerals, and potential contaminants. These measures aim to provide robust evidence of natural formation and minimize doubts about the origin of a potential new mineral.

As an example of the detailed approach necessary to characterize a new mineral, we have chosen the case of tewite ($(K_{1.5}\square_{0.5})_{\Sigma 2}$ $(Te_{1.25}W_{0.25}\square_{0.5})_{\Sigma 2}W_5O_{19}$, wumuite ($KAl_{0.33}W_{2.67}O_9$), and liguowuite ($WO_3$) in order to highlight the importance of textural evidence and contextual associations to support claims of natural origin. It emphasizes that clear documentation and compelling evidence, such as mineral intergrowths or inclusions, are essential to avoid suspicions of contamination or fraud. By improving guidelines, CNMNC can facilitate more credible and transparent assessments of new mineral species.

Recommendations for documentation of new mineral material

The geological setting and mode of occurrence are fundamental to defining a mineral as a natural material. Given that objections to new minerals of uncertain origin often stem from questions about their mode of occurrence, the CNMNC should reexamine its guidelines and consider revising them to better explain CNMNC requirements for documenting the geological context in new mineral applications. This recommendation aims to address issues such as anthropogenic contamination and fraud more effectively in the future. A more rigorous description of the mineral material would ensure that applicants demonstrate a thorough understanding of the material's origin and have adequately assessed the potential for contamination.

Suggested components of the material description might include:

1. Ideally, the geographic locality should be specified to the nearest metre using latitude, longitude and elevation. Since such precision is rarely possible, the locality should be specified as precisely as possible. In the case of older material, such as a specimen from a museum collection, an attempt should be made to pinpoint the location.
2. Type of sample: What is the origin of the material sampled, e.g., drill core, outcrop, separate, dredge?
3. Size of sample: Give dimensions or weight.
4. Collector: Who collected the sample? If it was not the applicant, how was the sample subsequently acquired?
5. Collection date: When was the sample collected? When was it acquired by the researcher?
6. Geological mode of occurrence: Stratigraphic formation, intrusion, flow, vein, placer, metamorphosed sedimentary or igneous rocks, hydrothermally altered rocks.
7. Age of material: Give the best-known approximate age, e.g., Devonian or 400 Ma. The best-known maximum, minimum and the method of determination (with references)

could also be given. In many cases, the age of the host rock may not be the age of the new mineral.

8. Associated minerals: Give a complete list.
9. Isotope composition of the more abundant constituents such as oxygen (^{16}O, ^{18}O) and nitrogen (^{14}N, ^{15}N). Isotope composition can constrain possible origins and provides a quantitative measure of differences among the possible sources.
10. Origin of the mineral: Provide any information of how the mineral was formed.
11. Synthetic equivalents: Describe any known common industrial or synthetic equivalents of the proposed new mineral.
12. Sample processing: How was the sample processed, e.g., crushing, water table, heavy liquids and selfrag? The last originates from the name of the company SELFRAG AG that specializes in the development of high voltage pulse power products for selective fragmentation of solid materials. See Sperner et al. (2014). Please outline any multiple steps.
13. Separation methods for grains are also important:
    - Grinding, specify the alloy used (e.g., FeCr, WC, etc.)
    - Magnetic Separation
    - Electrical Separation (e.g., Selfrag, etc.)
    - Density Separation
        - In a dense liquid, specify which one (e.g., brine, bromoform, methylene iodide, sodium polytungstate, etc.)
        - In a dense aqueous suspension, specify which one (e.g., ferrosilicon, lead, magnetite, chromite, glass beads, etc.)"
14. Possible contaminants: What is the possibility of contamination? How was contamination guarded against?

The source of a proposed new mineral is rather straightforward when the mineral can be sampled and shown in its geological context, as in a rock sample or thin section. The question of the origin becomes more acute when proposed new minerals are taken from separates, in particular, mineral concentrates obtained through industrial processing. Indeed, such processing can involve a long series of steps – from drilling, blasting, extraction, transport, crushing, sorting, shaking, floating, etc. – each of them offering possibilities of contamination by anthropogenic material or by other materials treated along the same chain. In such cases, single-crystal or monomineralic samples have often lost critical context, rendering the very source rock and its exact location uncertain. In this situation, the proposer should exert the utmost effort to explain possible sources of contamination. This explanation should cover the possibility of fraudulent syntheses, for which there are precedents in the mineralogical and petrological literature, e.g. “texasite" and "albrittonite" (Peacor et al. 1982). It is our hope that addressing these issues up front will reduce doubts about the natural origin of proposed new minerals.

Worked example – mineral separates

A discussion of three minerals is presented in the spirit of highlighting how guidelines for descriptions could be improved to avoid suspicion of origin.

Tewite (IMA 2014-053) (Li et al., 2019), wumuite (IMA 2017-067a) (Xue et al., 2020) and liguowuite (IMA 2020- 097) (Xue et al., 2022) are three W-bearing minerals described from the same locality, from the same sample, which turns out to be a heavy-mineral concentrate.

According to the description paper of liguowuite:

- "Liguowuite, ideally WO_3, was discovered in a sample of new minerals (tewite and wumuite) from the Pan-Xi region, Southwest China." (…)
- "Liguowuite exhibits a triclinic appearance and pseudomorphism (0.05 to 0.1 mm in diameter). It is composed of nanoparticles with many cracks and nanovoids. The nanoparticle size varies from 100 to 200 nm. It is brittle with uneven fractures. No cleavage or parting was observed. This mineral has a Mohs hardness of about 3–4 …" "Chesnokov et al. (1998) used to report "krasnogorite" (formula: WO_3; space group: *Pmnb*) occurring as pseudomorphs after hard alloy VK8 (a type of artificial alloy) on the plates of the cutting element of a drilling machine found in burned rocks. But it is invalid because current IMA regulations do not allow such substances associated with human factors to be approved as valid mineral species. The liguowuite found in this study is naturally formed nano- monoclinic WO_3." (…)
- "Liguowuite was found as extremely rare grains in heavy mineral concentrates. It was associated with hornblende, pargasite, ferro-hornblende, annite, hydrobiotite, phlogopite, orthoclase, microcline, albite, quartz, kaolinite, ilmenite, goethite, hematite, magnetite, pyrite, zircon, zoisite, titanite, epidote, diopside, tourmaline, almandine, fluorapatite, monazite-(Ce), allanite-(Ce), bastnäsite-(Ce), xenotime-(Y), scheelite, moissanite, tellurite, tewite (IMA2014-053), and wumuite (IMA2017-067a)." (…)
- "The liguowuite found in this study is naturally formed nano-monoclinic WO_3. From a mineralogical viewpoint, liguowuite was found in the same sample as scheelite, tellurite, tewite ($(K_{1.5}\square_{0.5})_{\Sigma 2}(Te^{4+}_{1.25}W_{0.25}\square_{0.5})_{\Sigma 2}W_5O_{19}$), and wumuite ($KAl_{0.33}W_{2.67}O_9$), which also contain K, Ca, W, and Te, indicating that the formation of these three new minerals may have been related to the same geological event. The trace amounts of K, Na, Ca, and Te in the liguowuite also convincingly indicate its natural origin."

In addition to a BSE picture showing euhedral, mostly unbroken, inclusion-free triclinic prisms with smooth edges (Fig. 2 in Xue et al., 2022), the above quotes compile all the data provided by the authors to support their claim for a natural origin. But several points raise immediate suspicion:
- WO_3 is known to form from burnt excavation/cutting material.
- Moissanite SiC also occurs in the mineral concentrate, at odds with the typical granitoid mineralogy, without further discussion by the authors who may implicitly assume a pollution of anthropic origin (?).
- Can crystals of a soft, brittle, porous nanocrystalline material remain untouched through geological processes and the mineral concentration process itself?

On this basis alone, one would expect the authors to bring convincing evidence for natural formation.

However, no inclusions are sought or mentioned in the new species, the presence and nature of which could support their claim. Does a look at the description of the original sample in the tewite paper (Li et al., 2019) bring a more satisfactory answer?

"This new mineral [tewite] was found in a lightly weathered biotite adamellite. The original rock specimen was crushed, sieved, elutriated, and examined with a binocular microscope. Within the heavy-mineral concentrate, rare greenish-yellow platy crystals were noted." (…)
"Tewite occurs in the Neoproterozoic Sinian biotite quartz monzonite pluton, near the contact zone with gabbro (Fig. 1). (…) The rocks are lightly weathered, friable, forming boulders with occasional remnant fresh cores. The rock is yellowish gray, with an aplitic texture. The main

minerals include plagioclase (45%), orthoclase (35%), quartz (10%–25%), biotite (5%–10%), and hornblende (5%). The main accessory minerals are zircon, a tourmaline-group mineral, monazite-(Ce), ilmenite, allanite-(Ce), and zoisite.
The minerals associated with tewite are orthoclase, albite, biotite, hornblende, ilmenite, zircon, zoisite, tourmaline, monazite-(Ce), allanite-(Ce), scheelite, tellurite and the new mineral wumuite ($KAl_{0.33}W_{2.67}O_9$, IMA2017-067a). The grain boundaries are very sharp between the tewite and tellurite, suggesting an intergrowth of the two, and possibly that tewite is slightly later than the tellurite (Fig. 2). Apart from these minerals, we also discovered an unnamed mineral with a chemical composition of near end-member WO_3."

Impressive! As one reads it, the authors come to a locality, take one sample from a very standard rock-type, crush it and find three new minerals in it … Moreover, they add in their second paper (wumuite):
"During the further study of samples from this area, a new K–W mineral species with a hexagonal tungsten bronze structure, i.e., wumuite, was found in the same sample [as tewite]" which seems to indicate that they were not able to reproduce their findings in other samples.

At this stage of reading, the balance is rather in favour of contamination (or forgery, considering that the three minerals were also easily synthesized by the authors). What are the key elements in these three papers that can shift the balance toward a natural origin – and, identified as such, should be given more weight in future new-mineral descriptions?

- Although the formulation is a bit ambiguous, it seems that the sample was not processed in an industrial plant but rather in a laboratory.
- Figure 2 in the tewite paper shows a tewite crystal intergrown with tellurite TeO_2, which also occurs in the concentrate. This could be a strong point, but the critical reader will note that TeO_2 was also used in the synthesis experiments of the authors.
- Finally, the most convincing argument is Figure 2 in the wumuite paper (Xue et al., 2020), which shows wumuite in a polymineralic aggregate with inclusions of scheelite in wumuite and intergrowths of wumuite, tewite and scheelite. The latter phase is present in the mineral concentrate but not mentioned in the starting material of the syntheses. The size of the wumuite crystals illustrated is also distinctly larger than in the synthetic product. This textural observation alone gives full credit to the wumuite and tewite proposals.

The case of liguowuite remains questionable, in the absence of compelling textural evidence. The skeptical reader would add that K, Na, Ca, and Te impurities in liguowuite, taken as (sole) evidence for a natural origin, could as well be present in a synthetic product obtained from a mixture of oxides and natural feldspar, as used by the authors. Yet, the fact that the authors already mention a new WO_3 phase in their early tewite paper gives them the benefit of the doubt. If the authors' report were a falsified account of their investigation, the falsification would have to have been carried out over a very long time.

In summary, authors submitting proposals for a new mineral found in concentrates should clearly address the question whether there was any contamination of the separate. What measures were taken to avoid contamination? Were any measures taken to avoid fraudulent claims?
The above examples show that definitive evidence is the textural one. Best is association to other minerals in a multigrain sample, allowing one to infer a source rock; in the case of single-crystal samples, the presence of solid or fluid inclusions must be sought as possible evidence.

Although authors may understandably be tempted to show monocrystalline samples as the nicest ones, samples showing the mineral in context are much more significant, e.g., showing the whole mineral assemblage, or the host lava in the case of xenoliths or ejecta. Looking at larger grain sizes in the concentrates may yield the evidence searched for. If authors are alerted to this need through improved guidelines, this could save time and discussion.

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