

**Comments to manuscript** “Iberulite fall and formation mechanism during a Sahara dust event in Switzerland in February 2021” by Grobety et al.

## **Introduction**

Grobety et al. report an observed iberulite fall event in Switzerland and present analyses of the particles' composition, morphology, and size distribution. Based on the meteorological conditions during the event, the authors propose a formation mechanism for these particles. This study represents the first documented iberulite fall beyond Spanish latitudes, i.e., outside regions relatively close to the main dust source areas. The authors further suggest that these specific iberulites may have formed within snowflakes or ice crystals.

Reporting these events and gaining more insights into their formation mechanism is interesting. I am unsure how much additional knowledge is gained regarding their formation mechanism compared with previous literature (e.g., Díaz-Hernández and Párraga, 2008). It is undoubtedly valuable to report their sightings in northern latitudes, as this provides evidence of their abundance in the atmosphere. However, it is unclear whether these types of events have an impact beyond the anecdotal, i.e., whether they should be taken into account in models of dust deposition or whether they might have an impact on the radiation budget (Díaz-Hernández and Párraga, 2008).

I think the paper contributes incremental knowledge about the occurrence and formation mechanisms of iberulites. However, I recommend publication only after the manuscript language, scientific content, and organization are revised as suggested in the comments below.

## **General comments**

The paper presents reliable methodology for iberulite characterization and data for event analysis. However, the structuring of the information is deficient, and the language is sometimes unclear. Typos and other errors can be found throughout the manuscript. These issues give the reader the impression of an unpolished manuscript (more than just typographical errors) that should have been more thoroughly refined by the authors before submission.

I recommend refining the language and structure so that the information is presented more clearly. Specific examples of where this is particularly important are given in the specific comments.

Figures should be refined and made more homogeneous, paying attention to legibility and their role as adequate supporting material. In their current state, they look like preliminary figures rather than figures that meet the standards of a publishable paper. Light microscopy, SEM, and BSE images are of good quality. I strongly recommend improving the remaining figures. An additional map illustrating the collection sites and data provenance would also be advisable.

Another concern relates to the analysis and discussion of the proposed formation mechanism. The authors go back and forth between different formation mechanisms (snow/ice vs. in-drop formation), and the same conclusions are not consistently reflected throughout the manuscript (for example, in the abstract). This section is quite long, and the discussion should be more concise and focused. It also feels that part of the information presented there as discussion would be more appropriate in the Introduction as part of the state of the art.

### **Specific comments**

L24. Is it necessary to use the concept of the *Greenfield gap* in the abstract? Introducing it later in the results/discussion would be adequate.

L26. There is no reference to snow as the hydrometeor hypothesized to be responsible for the formation of the observed iberulites.

L31. Is it necessary to refer to the Alps as “European Alps”?

L33. Did the SDE in February-March increase only in occurrence, or also in terms of dust concentration? Please clarify whether this statement refers specifically to the Alps area or to a wider region.

L35. Please specify the threshold values established by the EU/Switzerland or WHO and how the measured values in the area exceed those.

L37. Please add examples of how dust affects climate and ecosystems.

L38. The statement about the scarcity of dust mineralogical studies is too strong. If you refer to a knowledge gap regarding source-specific mineralogy and its implications for atmospheric processes, please adjust the statement accordingly and include recent literature addressing this gap, since dust modelling efforts increasingly aim to take into account soil mineralogy atlas and their coupling with atmospheric modules. Some examples are listed below.

Jeong, G.Y. Microanalysis and mineralogy of Asian and Saharan dust. *J Anal Sci Technol* 15, 10 (2024). <https://doi.org/10.1186/s40543-024-00425-5>

González-Romero, A., González-Flórez, C., Panta, A., Yus-Díez, J., Reche, C., Córdoba, P., Moreno, N., Alastuey, A., Kandler, K., Klose, M., Baldo, C., Clark, R. N., Shi, Z., Querol, X., and Pérez García-Pando, C.: Variability in sediment particle size, mineralogy, and Fe mode of occurrence across dust-source inland drainage basins: the case of the lower Drâa Valley, Morocco, *Atmos. Chem. Phys.*, 23, 15815–15834, <https://doi.org/10.5194/acp-23-15815-2023>, 2023.

*Gonçalves Ageitos, M., Obiso, V., Miller, R. L., Jorba, O., Klose, M., Dawson, M., Balkanski, Y., Perlwitz, J., Basart, S., Di Tomaso, E., Escribano, J., Macchia, F., Montané,*

*G., Mahowald, N. M., Green, R. O., Thompson, D. R., and Pérez García-Pando, C.: Modeling dust mineralogical composition: sensitivity to soil mineralogy atlases and their expected climate impacts, Atmos. Chem. Phys., 23, 8623–8657, <https://doi.org/10.5194/acp-23-8623-2023>, 2023.*

L41. Earlier published studies (e.g., Fiol and Guijarro, 2000) already report the observation of deposited small dust spheres.

Fiol, Ll., Guijarro, J.A., 2000. Esfèrules de pols eòlica, un tipus peculiar de deposició seca a la ciutat de Palma (Mallorca). *Boll. Soc. Hist. Nat. Balears* 43, 131 – 138. (Small spheres of aeolic dust, a peculiar type of dry deposition in the city of Palma (Mallorca island)) <https://raco.cat/index.php/BolletiSHNBalears/article/view/169500>.

L43. The reported iberulite sightings are confined to Spanish territories at latitudes relatively close to the dust source (Sahara Desert). Would it be more accurate to state that no observations have been reported from regions north of 42°N? The Alps would therefore fall into that category.

L46. Please merge the information about the 2021 SDE event and its monitoring. It seems duplicated in sentences L45–L50. For example, February is mentioned three times and systematic monitoring is mentioned twice.

L51. Define IF again.

L52. Remove the observation coordinates from the Introduction.

L54. Since the in-cloud and below-cloud iberulite formation mechanisms have already been proposed in the literature, the Introduction should include a more detailed summary of them, e.g., connecting the mechanism names to the descriptions in L43–L45.

L59–62. Include here the coordinates of the iberulite collection sites. Adding a map with the collection site locations and other relevant observation sites (Jungfrauoch observatory, measurements in Payerne, weather radars, balloon soundings, etc.) would help provide a clearer overview of where the data and observations were collected. The description of the weather/remote sensing data collection (L72–79) would then be easier to follow.

L62. It is not clear whether iberulites were collected in Geneva or not. Please specify whether the observation (L59) is different from the collection.

L71. “Observational data” would be a more appropriate subsection title than “Meteorological data,” since more than weather information is presented (e.g., aerosol information). The correct numbering for this subsection is 2.2.

L72–73. Please consider including a map with scale showing where all the observational data were collected.

L86. The description of HYSPLIT should be placed under a different methods subsection (e.g., 2.3 Dust trajectory analysis).

- L99. Can you please clarify what is meant by a *bulk sample*?
- L102. What constitutes a sample in this case? “Each sample (area depending on particle load on the sample surface) was analyzed...”
- L108. Please clarify what a “ZAP correction” is.
- L112. Why are the ZAP applicability conditions not valid in your case?
- L121–122. What are the particles (nature, origin) present on the unexposed substrates? Are they biological contaminants, such as skin debris? Please clarify what you mean by *follicles*.
- L122. The optical microscope is not described elsewhere.
- L131. A summary table specifying the physical samples analyzed (loose dust and iberulites) would be beneficial.
- L144. How many HYSPLIT back-trajectory calculations were performed? Were they single calculations or an ensemble? Can you say something about the air-mass height at the dust source area?
- L146. Please indicate in Fig. 2 where the “Haut Plateau” is located.
- L152. Figure 2. Please include a color legend that helps identify the dust plume. Indicate countries or regions of interest on the map.
- L155. Figure 3 should be improved for clarity and interpretation. The arrows are difficult to read, and the overall resolution is poor. X- and y-axis labels and titles are missing.
- L159. Please clarify what “source sensitivities” means.
- L160. Define JFJ here or elsewhere when measurements at Jungfrauoch are described.
- L164. Please define what an emagram is or use instead a T/RH profile.
- L165. Can you clarify what the *zero-degree level* means?
- L169. Figure 4. Please improve the figure quality. The panels could be merged into a single plot with a double x-axis for temperature and relative humidity.
- L175. Can the below-cloud reflections located between 2500–4000 m with a streaky appearance be attributed to dust here, or could they correspond to ice particles? In L146 the strong reflection wall from 3500 m to the ground is attributed to dust. What are the differences in attribution between that feature and the reflections observed earlier than 9:00 UTC?
- L176. What is the reason for the 9:00–11:00 ceilometer recording gap?
- L180. Figure 5. What do the black dots represent? Please add this information and their location to the figure caption.

L183. When were the lidar measurements taken? Is this a single measurement or an average of multiple measurements? If averaged, over what time span? To which time in Figure 5 does it correspond? Please make this connection explicit in the text and figure.

L189. Figure 6. Improve the resolution and add a legend. Include location, time, and other relevant information in the figure caption.

L191. I suggest changing the section 3.3 title to something like *Size and morphology of iberulites* or *Morphology and microstructure of iberulites*. Were the St. L egier samples the only iberulites analyzed?

L213. Figure 9b. What do the colors indicate? Please add a legend or clarification in the caption or text.

L219. Could you clarify what is meant by spherical surface depressions being rare? Are they rare among the collected iberulites, or simply less frequent than those reported by D iaz-Hern andez and P arraga (2008)?

L221. Please clarify what “long-term particle size distribution measurements at Jungfraujoch” means in this context. The number of acronyms in the first two sentences of this subsection is quite high.

L225. I suggest adding a particle size distribution representative of non-SDE conditions for clearer comparison with the PSD shown in Figure 10 and supporting the statements made in L226.

L228. Do you mean dust plumes? If so, please modify.

L235 onwards. The equivalent volume diameter calculation and shape factor from the iberulites, and the conversion between  $d_m$  and  $d_{ve}$  (steps described in equations 1–3), should be better described in the methods or in a methodological appendix to simplify this section.

L242. What does it imply that the PSD of the iberulite components shows a minimum at the same size range where the aerosol PSD measured at JFJ shows a maximum?

L243. The aspect ratio is not defined, nor is it explained why it is an interesting parameter to analyze.

L255–265. This passage is poorly written and appears unfinished (e.g., “the ratio given by Peng et al. is the reverse of the latter one!” or “has been measured only(?)”). Please clarify how this conversion factor is derived, what value was used in the  $d_{ve}$  calculations, and whether the ratio  $C_c(d_m)/C_c(d_{ve})$  corresponding to salt particles was used.

L269. The title of this section suggests that the composition of the iberulite components and the dust (at JFJ) will be presented. However, in sections 3.5.1 and 3.5.2 only results on the mineralogy and elemental composition of the iberulite components are shown.

L270. The title of section 3.5.1 is misleading, since single-particle analysis results are not presented here.

L275. Please improve the legibility of Figure 11. Axis labels, titles, and legend are difficult to read.

L280. Can you clarify what the 1–2  $\mu\text{m}$  resolution in the EDS analysis implies for the interpretation of the results?

L291–299. It is not clear to me what dust the authors are referring to in section 4.1 (dust sampled at JFJ, loose dust collected along with the iberulites, or individual dust particles inside iberulites). Since composition is used to trace the origin of the dust, I recommend rewriting this section and connecting it more clearly with the back-trajectory analysis results.

L294. It is stated that “The general trends are increases in I/K from S to N and from E to W.” What region are the authors referring to here? Northern Africa? Please clarify.

L301. The discussion in section 4.2 presents several problems that should be addressed. First, the actual discussion of the results is obscured by extensive background information that would belong either in the Introduction (e.g., in-cloud and below-cloud scavenging mechanisms) or in methods/supplementary material (e.g., collection efficiency calculations, ice crystal aerodynamics).

The formation mechanism is not presented as a clear step-by-step scenario, and there is no clear logical flow, making the section difficult to follow. Additionally, the main hypothesis (frozen hydrometeor scavenging) emerges only after a long sequence of background explanations.

The discussion would benefit from a clearer structure focusing on the interpretation of the observations and presenting the proposed formation mechanism more concisely. The discussion could be structured around the following topics: observational constraints (meteorology and PSD comparison), evaluation of possible scavenging mechanisms, evidence for frozen hydrometeor scavenging, formation of the core–shell structure during droplet evaporation, and the proposed formation sequence. Organizing this discussion into subsections would be advisable.

## **Technical comments**

L19. Below scavenging → below-cloud scavenging

L24. I recommend using the term “iberulite constituents” to refer to the particles within iberulites. This may make clearer the comparison between the particle size distribution of atmospheric dust and that of iberulite constituents.

L60. Remove the extra closing bracket after ASL.

L83. (Ashpole and Washington, 2013) → Ashpole and Washington (2013)

L95. "The source meteorological data" → "The dust source area meteorological data"

L97. e.g. → i.e.

L242. JFJ → JFJ-measured aerosol

L250.  $d_m$  is introduced here for the first time. Please define it and clarify that it refers to the mobility diameter measured by the SMPS.

L263. Do you mean aspect ratio instead of axis ratio?