Dear Reviewers and Editors,

We sincerely appreciate your efforts in handling and reviewing our manuscript.

We have revised the manuscript according to the comments and suggestions from reviewers. The English language was checked by a native speaker of English.

The revised manuscript has been uploaded with a tracked changes version. Supplementary Information files have also uploaded.

Throughout the revised manuscript, we attempted to shorten the main text, to remove the repetition, to make stories simpler, and to improve English language. We focused on the development and fluctuation of the crystal orientation fabric at the deep sections in the DF ice core. The order of discussion was accordingly changed, and new figures were added. In addition, discussions about grain sizes and small-scale fluctuation of the fabric were added in Section 5.2 (and Figure 6) and as Section 5.4, respectively. Previous Appendices were moved to Supplementary Information and Microstructure Section was moved to Appendix.

We thank for the many comments. With the reduction of sections/paragraphs, the sentences corresponding to some comments have also been removed.

With many thanks and kind regards,
Tomotaka Saruya, Atsushi Miyamoto, and Shuji Fujita, on behalf of all authors

How the authors addressed the comments by Reviewer 3 in their responses to the revised manuscript

In this document, we explain how we addressed the comments provided by Reviewer 3 on the revised manuscript.

Explanation of the text colors:

- Black text: Comments from Reviewer 3
- Brown text: Explanations of how the authors addressed Reviewer 3's comments in the revised manuscript

Review of Development of crystal orientation fabric, microstructures and deformational regimes in the deep sections and overall layered structures of the Dome Fuji ice core, Antarctica
By Saruya et al.

This paper presents detailed and potentially interesting measurements of microstructural properties of the deepest part of the most recent Dome Fuji Ice Core. It provides comprehensive measurements of crystal orientation fabric using DTM, Laue X-ray diffraction, and an automatic thin section analyzer. It also presents complementary information about layers and microstructures.
Particularly in the deep part of the core, the crystal orientation fabric and grains size vary over short depth intervals, and these variations correspond to impurity content and thus climatic interval (as shown in other cores). The authors argue that angle between c-axis clusters and layering is evidence of simple shear in the bottom 20% of the ice sheet (as expected). They draw parallels with fabric in other ice cores, particularly EDC and GRIP.
Overall, I think this might be a meaningful contribution after further major revisions. After finishing my own read, I looked through the original reviews; although I was not an original reviewer, I agree with most of their comments, and I find it disappointing that the same issues I identified were already brought up by the previous round of review but not addressed. I detail these below but give examples here. The manuscript is still too long and lacks focus. I would argue that this is not simply a matter of style—it is the authors job to distill their results into new insights, and this paper does not do that. Important points about the orientation of the structures in 3d from Dr. Prior were essentially dismissed (in response to about 5 paragraphs, all of which I found insightful, it seems the authors only added the sentence in A2_2).

Other revisions introduced problems of their own because of the flippancy—for example, the section headers in the introduction do not match the text of the paragraphs since the structure was shoehorned on without corresponding changes to the body, which leads to confusion for the reader. Shortening this paper does not have to mean cutting content. Much of length is due to needless complex sentences, extraneous adjectives and adverbs, and a kind of personification where “comprehension” or “understanding” of phenomena are needlessly substituted for the phenomena themselves. Simplifying the language, and making it more precise in doing so, would go a long way toward letting the reader access the full range of ideas in the paper. Other opportunities for very easy shortening include the multiple places where figure captions are essentially repeated in the main text. I think that the final line of Dr. Montagnat’s original review still describes the manuscript: “At the end, the novelty of the study stands only on the fact that these deep core measurements have never been published. Care should be taken in the discussion in order to focus on what is potentially new or relevant for the community.”

Thank you for these comments. Throughout the revised manuscript, we attempted to shorten the main text, to remove the repetition, to make stories simpler, and to improve English language. English language was checked by a native speaker.

In the revised manuscript, we focus on the deep sections (below 2400 m). To simplify the story, we focused on the crystal orientation fabric and microstructures at the deep sections. Since the detailed discussions about layered structures is deviated from the main story, we shorten them to a minimum.

Discussions about detailed comparison with other ice cores, a-axis anisotropy, and overall layered structures were excluded. We will publish these topics in the future. Furthermore, Microstructure Section was moved to Appendix. Microstructural information is necessary for the discussion of crystal orientation fabric; however, it is a supporting information.

We shortened the Introduction section and focused on deep sections. Then, section headers were removed.

Regarding the 3D structures of layers and c-axis clusters, as commented on by Dr. David Prior, we examined the relative orientation between the layers and the c-axis clusters by analyzing the layer inclination angles in three dimensions, focusing on regions within or near the thin-section planes used for the Laue X-ray diffraction method (results are shown in Figure 4). Among the measured thin sections, 20 samples contained a visible layer nearby. In 15 of these samples, we confirmed that the horizontal orientation of the c-axis clusters and the normal axis of the layers lie within the approximately same vertical plane. For the remaining five samples, it is likely that either half-core inversions or thin-section inversions occurred. While we did not investigate all the layers (~500 layers in total), and there may be minor discrepancies (with maximum measurement errors estimated at around 10 degrees), we concluded that the c-axis clusters and the normal axes of the layers are generally aligned in the same (or near) vertical plane(s) throughout the lowermost 20% of the DF ice core.

We added explanations in Section 3.3.

“The relative orientation between each layer and the c-axes cluster was assessed by investigating the angle of inclination of the layer near the thin-sections used for the Laue X-ray diffraction method. These data confirmed that the horizontal direction for the c-axis cluster and the normal axis of each layer were within the approximately same vertical plane throughout the lowermost 20% of the DF ice core.”

I have additional scientific qualms as described in overall comments. I have not gone through and made an exhaustive list of detailed comments, since I think hope that structural issues will result in major changes to the text first. I am not an expert in microstructure the way that Drs. Montagnat and Prior are, so I do not focus on the rigor of methods of the observations, or their interpretation in terms of processes at the crystal scale. Instead, I focus on interpreting the results in the ice-sheet setting, the implications for ice flow and radar, and the structure and writing of the paper.

Overall comments:

The paper lacks focus. While the data are undoubtedly complex and extensive, I strongly disagree that this means that the paper cannot tell a story or stories in the way that the response to review claims (and indeed The Cryosphere's evaluation form seems to agree with me). Without better structure and clearer writing, those in very close but not identical fields (including those like myself who have worked extensively on crystal orientation fabric from other perspectives) cannot glean meaningful insight from the work. Put differently, while I agree that "Over-simplifying this paper would compromise its scientific message," the authors have instead under-synthesized and thus obscure the scientific message to all but themselves or similar experts on ice-core microstructure. Part of the issue is contextualization within the literature as Dr. Montagnat noted before. For several of the conclusions, there are citations she mentioned that make identical statements—this makes it exceedingly difficult for somebody with adjacent expertise to understand the value of the present work. I cannot see how the paper really touches on deformation the way the title suggests, other than providing some (unsurprising) evidence of simple shear in the bottom of the ice sheet. I think the paper is currently inaccessible to most of the readership of The Cryosphere, largely due to its presentation not its inherent complexity.

As answered above, we focus on the deep sections (below 2400 m), and common and unique features of the site. Our new findings of the crystal orientation fabric and microstructures obtained by dielectric tensor measurement, Laue X-ray diffraction methods, and microstructural observations can provide new knowledges about the rheology at the deep sections of ice sheets. To make it easier for readers to understand, some contents that deviated from the main stories were excluded.

As pointed, some conclusions are same as previous scientific claims from other ice core studies.
We added reference to EDML and EDC ice cores in Conclusion section.

Using the UP80% and LO20% framework leads to misinterpretation, convoluted language, and incorrect conclusions. Take the first conclusion labeled (i). It ends with "at the bottom of the UP80% and fluctuated in the LO 20%." This is not correct (the abstract really indicates that the fluctuations begin at 2650 m, as do the figures). It would be clearer and more precise to write "down to 87% of the ice thickness and fluctuated below. " The zones are confusing, both here and elsewhere, since the results described (e.g., properties to 2650 m) cross zones. Overall, getting rid of these UP80% and LO20 acronyms would reduce confusion. This is particularly important for the abstract, which currently involves tortuous language to fit the results into this artificial framework.

We agree the comment. We don't use the term "UP80%" and LO20%".

The change to structure in response to the first round of review is window dressing; in the introduction, the section titles do not match the sections in the new version, so they create confusion rather than insight. The section titles in the introduction might be okay in principle, but they would need text to match. However, they would need to be continued in some meaningful way further into the paper. As is, the section headers in the introduction suggest broad implications that the paper fails to deliver upon. I see no major implications for ice-sheet dynamics from this work. I would be happy to be wrong, but the authors would have to provide a structured argument (i.e., a story) that shows why such interpretation is supported by the work.

We shortened the Introduction section and removed section headers.

The sentence-level errors are largely fixable during production, but some are substantive and need to be fixed before acceptance. This issue is most prominent in the introduction. Some sentences are imprecise to the point of being incorrect. It is not my job to rewrite them, but here is one example: "In these studies, the influence of anisotropy on the movement of ice aggregates is so substantial that comprehending its impact on the expansive flow patterns of ice sheets is essential" (L70-71). Despite the long sentence, the authors do not argue what this influence is essential for (maybe projecting sea level rise?), define what ice aggregates are (though I surmise this means bulk ice?), or indicate why "comprehending" rather than just the impact itself is important. In this case, simplifying to "The anisotropy is sufficiently strong to affect bulk deformation" would be less wordy and remove imprecision. Again, I am not trying to say that the authors should use my version of this sentence, but ambiguities like this are not made precise in the production process, and there are enough of them that I cannot flag them all. Instead, I think some careful editing by the authors themselves, really focusing on what they can support with evidence (in the above example, that anisotropy influences bulk flow) and not opinion (in that example, that anisotropy is "essential" or that comprehension is necessary).

Throughout the manuscript, we attempted to improve English language.

I find the response to the orientation issues identified by Dr. Prior in the previous version too flippant. As he pointed out, lying in the same vertical plane is different than saying closely aligned (i.e., I do not think the changes answer the issue identified in Figure R1 in his review). For examples of continuing issues involving angles, in section 3.1.2, I had to re-read 3 times to understand how the principal-frame permittivity was identified. While I think I now understand what was done, I do not see why it was necessary to use other measurements of c-axis orientation to do the rotation if the plane matches the normal to the layers. In this vein, I do not understand why Figure 3 is worth plotting—are not these data essentially meaningless without knowing how the section was cut relative to the azimuth of the cluster maximum? Perhaps this just requires methods clarification to say how the thick sections were cut, if it was done in such a way that gives these measurements meaning, but if I understand Rev2_10 correctly then the correction happens after the DTM measurement. Dr. Prior provided great suggestions for plotting the layer normal (which he called the pole) on the same stereonet as the c axes—I really want to see these on Figure 4. They do not match the clusters very well (Fig 5f), and the reader has no idea how well they align from what is essentially a single sentence added in response to the original comment.

A major challenge in our study was that the c-axis concentration axis inclined with increasing depth. Moreover, at the time of DTM measurements, we initially did not know how much the c-axes cluster axis was inclined in the (i.e., direction orthogonal to the slab plane) of the slab plane where the electromagnetic waves were irradiated.

Since the c-axis concentration axis was inclined relative to the core axis, we intentionally rotated the core (while maintaining orthogonality with the electromagnetic waves) to capture the two birefringent resonant components obtained from the polarized wave transmission. This allowed us to measure the dielectric anisotropy.

However, the dielectric anisotropy values obtained in this manner were based solely on the components relative to the direction of electromagnetic wave irradiation. Therefore, it remained necessary to convert these values into corrected dielectric anisotropy values, assuming no inclination in the depth direction (i.e., the properly corrected values), using information on the degree of tilt in the depth direction of the c-axis concentration.

Fortunately, we had retained data on the relationship between the thin-section cutting direction used for Laue diffraction and the DTM measurement of the core. This made it possible to perform the necessary corrections for the 'depth' direction of electromagnetic wave propagation. Without the data from the Laue method, correcting for the tilt in the depth direction would have been impossible.

Thus, the initial action of tilting the core was simply to obtain the values of the two birefringent components, even when the c-axis concentration had a rotational orientation in the depth direction. It was only with the data obtained from the Laue method that we could perform corrections for the c-axis concentration's inclination in the depth direction. In other words, the first action was not a correction but a basic measurement, and the second action was the actual correction.

Additionally, in this study, the observation and measurement of visible layer inclinations were conducted independently of the Laue and DTM measurements, without specific attention to the orientation of the tilt. During the initial drafting of the manuscript, we assumed that the tilting direction of the layers and the tilting direction of the c-axis would naturally be the same, without considering any physical principles that could cause discrepancies (such as torsion). However, following Dr. Prior's suggestion, we examined differences at 20 sites with available Laue data and confirmed that there were essentially no discrepancies between the tilting directions of the layers and the c-axis concentration.

We also received a request to plot data on a Schmidt net. Drawing orientation of layers and their normal axis on a Schmidt diagram is a good way to indicate the relative relations. However, we have already spent a significant amount of time processing a large volume of data in this study. Additionally, visual inspections of layer orientation are not that accurate because of the errors involved. Although we have not plotted the data on a Schmidt net, we provided orientation information in Supplementary Information 2, which we believe will effectively convey the necessary details to readers.

We showed Figure 3 as measured raw data. As commented, these data cannot be used for the discussion of crystal orientation fabric without correction.

Observations and interpretations are still mixed. Section 4.5.3 is the clearest example—each of the paragraphs mixes observation and interpretation. Section 5.2.1 is results.

Thanks for pointing out. In the original manuscript (first submission), Microstructures section (4.5.3) was divided into two sections (in Results section and Discussion section). However, in accordance with comment of reviewer 2, we combined we merged into one section. In the revised manuscript, we move to Appendix as "Microstructures: Results and interpretations". Microstructural information is necessary for the discussion of crystal orientation fabric; however, it is a supporting information.

Section 5.2.1 (Depth-dependent variations of $\Delta\varepsilon$ in the entire core) was deleted.

The use of the phrase "statistical significance" in the paper is incorrect. At times, I think I know what it means, while at others I do not even have a guess. Usually statistical significance means an ability to distinguish between possibilities above a pre-specified level of confidence. The paper essentially uses it to mean "precise, " but with no quantification. This is unacceptable. We need clear definitions whenever the term is used. As a hypothetical, this could be "the difference between measured c-axes distributions at 2500 and 2600 m is statistically significant (p=0.001)" or something similar. Including the confidence and the alternatives considered is required for proper usage.

Thanks for pointing out. We used this term with the intention of including a large number of grains in the thick-section-measurement. We don't use the term "statistical significance" in the revised manuscript.

I do not think the authors' interpretation of the relationship between c axes and layer orientation near the bed is correct (line 511, Figure 8c). Layer slape is not solely caused by rotation. For example, this is my 30-second version in Illustrator—after rotation, subsequent pure shear in the vertical does change layer slope: The language is too muddy for me to understand if this is causing misinterpretation. Overall, no explanation that treats both layers and c axes as passive tracers can cause this deviation. Instead, this could be easily explained a result of intracrystalline slip. Particularly in the conclusions (L830), it sounds instead like the authors disagree with the cartoon version above, and instead are imagining that the pure shear has no effect on slope. Adding in the actual mechanism of c- axis rotation would help.

In the review comment figure, the ice is first rotated by 30 degrees (introducing a slope) and then subjected to pure shear, which changes the slope. However, we believe that it seems natural that the transition from pure shear to simple shear would occur progressively.

Our claim is that the observational fact (the apparent deviation between the layer and the c-axis cluster), observed only in the deeper sections, can be explained by the occurrence of simple shear. We assert that the deviation between the normal axis of the layer and the c-axis cluster is due to the nature of simple shear, which involves both rotation and pure shear.

We agree with the use of "intracrystalline slip". When an ice body undergoes simple shear deformation, it experiences rigid body rotation as a fundamental characteristic of simple shear. Within each crystal grain, intracrystalline slip tends to rotate the c-axes toward the compression axis of the simple shear. We added this explanation in the revised manuscript. (In the previous version, we referred this mechanism, i.e., dislocation creep, only in the Figure caption.) Here, we proposed the mechanism whereby normal components of the strain (both compression in the near-vertical and extension near the horizontal plane) cause the rotation of c-axes cluster toward the vertical, and the deviation between the normal axis of the layer and the c-axis cluster. We added this explanation in the revised manuscript (second paragraph in Section 5.1) as a possible mechanism.

We hope our explanation is clear and understandable.

The conclusions are excessive, variously going beyond the results, repeating themselves, and restating ideas that have long been known. I do not really understand how the first (i) and (ii) differ. Both of these conclusions look nearly identical to other locations (e.g., EDC, (Durand et al., 2009)),and given the emphasis on comparison between sites this should be cited. The second (i) is not supported by the results—at most there is evidence that right at domes climate controls the fabric, but this paper shows nothing about how that might look even 5 km off the domes. Similarly, I do not buy the second conclusion (v); the work shows very little about how large-scale deformation is taking place. The first (vii) is very similar to claims from work at EDML (Weikusat et al., 2017), and the idea was originally suggested in the 90s (Castelnau et al., 1996). While there is nothing wrong with concluding the same thing as previous work, the reader needs context. A much shorter conclusion section, focusing synthesizing rather than repeating key results and contextualizing them rather than providing so much detail, would allow the reader to see how this work fits into the literature.
We reconstructed Conclusion section. Some contents were deleted and merged, and the reference to EDML and EDC ice core was added. (We also added reference to simple shear deformation at the deep sections in the EDML ice core in Section 5.1.), Furthermore, we removed two conclusion categories.

We removed second (i) and (ii), instead, added following conclusion (as conclusion (ii)):
"*The general trends exhibited by the c-axis cluster strength and grain sizes in the present work were approximately the same as those seen in the EDC ice core (Durand et al. 2009). These similarities may be attributed to equivalent impurity concentration profiles (which in turn are associated with climate*

change) and temperature profiles. Hence, it appears that rigid body rotation does not affect cluster strength."

We consider that the commonality of the fluctuations of the cluster strength between the DF and EDC ice cores is derived from the depositional features from atmospheric aerosols. Actually, dust flux profiles of the DF and EDC ice cores are very similar (DFICPM, 2017).

As pointed out, the drilling site of DF ice core is very close (within 10 km) to but not a true dome summit at the present condition. The c-axis fabric exhibited slightly elongated single pole fabric. However, the elongation is very slight and the profiles of c-axis cluster strength between DF and EDC above 2400 m are very similar (Saruya et al. 2022b). We believe that the DF ice core can be used as dome ice core.

In the revised manuscript, the following explanation is added in the second paragraph in Section 2, "*At present, DF is far from the true dome summit and so DF is subject to deviatoric stress in the direction of maximum inclination.*"

Second (v) was deleted. As commented, this was not a conclusion but an implication.

Detailed comments:

Title: The title does not really make sense. I cannot tell if the overall layered structures are a wholly separate thing considered at all depths or whether the crystal orientation fabric is within them.

We removed "overall" and "deformation regime" from the title. We modified the title to make clearer as follows: "*Development and fluctuation of crystal orientation fabric in the deep sections of the Dome Fuji ice core, Antarctica: impacts of dust particles and migration recrystallization*"

Abstract: The abstract is too long and detailed, to point that I had to read it three times to figure out what the manuscript was showing. The paper would greatly benefit from shortening the abstract to meet normal length standards (i.e., 250 words, or at least ~300 as it was before, rather than 450). As discussed above, this does not necessarily mean cutting content. For example, it would benefit both accuracy and word count to delete the first words of the abstract "An in-depth examination of."

We shortened the Abstract in the revised manuscript.

L24,184: Statistical significance cannot stand on its own like this. I assume that the authors mean that they have measured enough grains for the results to approximate the underlying c-axis distribution with some amount of precision (perhaps that it differs from isotropy, but I truly do not know). But a measurement itself cannot be statistically significant in the sense used here.

We don't use the term "statistical significance" in the revised manuscript.

L35: "dislocation creep is the primary deformation mechanism in polar ice sheets" cannot be concluded from this work. There is no reason to think that these results can be extrapolated to the ice sheets writ large.

We removed this sentence from Abstract.

L45-50: This paragraph has multiple logical jumps to try to get from the ultra-broad (sea-level rise) to the ultra-specific (dynamic layer structure). Rather than filling all these gaps, I suggest starting less broad, since the readership of the cryosphere surely knows what ice sheets are and that they contribute to sea-level rise. I recognize that this suggestion is stylistic as well as substantive, but if not heeded then we need the gaps filled in (e.g., how is dynamic layering a process challenge that affects models, why is continuous improvement in models needed rather than one really big improvement, how does a single 11-year-old reference indicate ongoing concern).

We reconstructed the Introduction section.

L68: Abbassi is not a good reference for SPICEcore fabric, they measured fabric loosely from IceCube. Voigt 2017 is the correct reference (https://doi.org/10.15784/601057).

The relevant paragraph was deleted. Thank you for pointing out.

L70: The correct reference for the full EastGRIP fabric is Stoll et al., 2024 (10.5194/egusphere-2024-2653)

The relevant paragraph was deleted. Thank you for pointing out.

L81-85: references needed

The relevant paragraph was deleted.

L220-221: How can a plane and a vector be in the same plane unless the vector is in the plane? I think this probably means that the normal to the layer is in the same vertical plane as the COF cluster?

Yes, we checked whether the c-axes cluster and normal axis of each layer are within the same vertical plane.

L223: What are non-principal components? The components in an arbitrary xyz reference frame? I have not seen this terminology before and think it needs to be defined.

We had to measure the dielectric permittivity at an angle deviated from the principal axes of the tensor (which happened to correspond to the angle at which the sample plates were prepared), because the ice core had been rotated along with the inclination of the C-axis concentration axis. This meant that we were not directly measuring the principal components of the dielectric tensor, and it was necessary to apply corrections for the inclination and rotation of the ice core. The information required to perform these corrections was provided by fabric measurements using the Laue method. The measured values that deviated from the principal axes were referred to as "non-principal components.

We added explanations as follows in second paragraph in Section 3.1.2:

Since the electromagnetic wave used in the DTM method has a transverse electric field, if the surface of the actual plate-shaped sample does not align with the principal axes of the crystal tensor, only the components in the misaligned orientation will be obtained. This misaligned orientation is referred as non-principal."

L227: Still confused since I do not know what these are, but are they really "adjusted" or are they rotated in some way (thus changing the value)?

For the correction, we derived a correction factor that estimates how much the dielectric anisotropy would increase if the ice core with the measured dielectric anisotropy were rotated until the electric field of the incident electromagnetic wave became parallel to it.

L276-287: This is a repetition of the figure caption, not results.

We removed the description of Figure 4 from the main text.

L436-437: This sentence needs to be re-written. It is unclear if this means temporal changes or time differences that result from the depth-age relationship of ice sheets.

We removed "in the past". We believe that the steady state grain size in impurity-rich layer established after these layers reached to deep sections (i.e., warmer temperature). Therefore, the depth (temperature) is important.

L497-501: This is a repetition of a figure caption, far from the original appearance, not discussion

We removed the description of Figure 5 from the main text.

L648-655: This discussion of twinning is convoluted. Starting with a simple definition would help.

We removed the discussion of crystal twinning because this content deviated from the main story.

L725: I do not think this really differs from Durand—it is a different location, and there may simply be regional or local differences

This paragraph was removed. In the previous paper, we found the fluctuations of *c*-axes cluster at a few hundred-meter depth at Termination I. We consider that the vertical compression is predominant and the effect of simple shear is not sufficient at shallow depths.

L774-778: The implications for radioglaciology need to be clarified. The idea that recrystallization is important near the bed is not new, nor is the evidence of simple shear which also been noted previously near the bed at ice-core sites (for example, it is suggested at EDC by Durand).

The relevant paragraph was deleted.

Figure 1: Confusing to use red and blue on contours in c when they do not match the colorbar in b. If two colors are needed, it should be explained in the caption (and the colors should not be red/blue, or why not just use a single color?).

We added follow explanation in the caption:

“Thin and thick areas are shown in red and blue respectively, and the boundary is set at a thickness of 3000 m”

Figure 8f: The label is confusing. The LO20% spans almost 90% of the thickness.

This figure was removed. Thank you for pointing out.

How the authors addressed the comments by Reviwer 4 in their responses to the revised manuscript

In this document, we explain how we addressed the comments provided by Reviewr 4 on the revised manuscript.

Explanation of the text colors:

➢ Black and blue text: Comments from Reviewer 4

➢ Brown text: Explanations of how the authors addressed Reviewer 4's comments in the revised manuscript

This manuscript presents detailed data on fabric evolution and microstructures in the 3035 m long DF2 ice core from East Antarctica, drilled at the Dome Fuji station. In earlier work the same research group published similar data from the uppermost 2400 m of the core, but here the focus is mainly on the depth interval 2400-3035 m. An overview is, however, also given of the evolution of the above mentioned parameters throughout this deep ice core.

A major scientific effort lies behind the results presented and the data are of great importance for studies of the internal structure and deformation properties of large ice sheets. Both state-of-the-art methods and new techniques are used to measure and characterize fabric and grain structure at relatively high resolution down the core. Methods are mostly well described and sources of error are adequately adressed in the paper.

Although some assertions made by the authors will be met with criticism – in spite of improvements made from the initial version – the importance and detailed description of the data is such that the paper should be published in The Cryosphere. This reviewer does not have specific criticisms, but asks the authors to take into account the comments and corrections suggested below.

Saruya et al. focus on main processes believed to control the development of fabric in ice under the conditions prevailing at Dome F:

• C-axis rotation under compressive stress leading to the development of a single pole fabric

• Rotation recrystallization and subsequent splitting of a grain into 2 or more grains

• The role of simple shear in the fabric evolution

• The interplay between inclined layering (from horizontal, due to bedrock topography) and the mean direction of the single pole fabric

• The effect of impurities and grain size on c-axis rotation

• Nucleation of new grains with c-axis orientations differing from that of surrounding older grains, at relatively high temperatures in the lowest 20% of the ice sheet

A clear picture emerges on the development of c-axis orientations in the DF2 core and interesting data on a-axis orientations are presented as well.

We thank the referee for insightful reviewer.

Perhaps surprising is the fact that this paper (as well as the companion paper on the upper 80% of the ice core, Saruya et al., 2022), does not discuss the grain size development in the core in any detail. Grain growth receives fleeting mention and some insight can be gleaned from Figures 5-7 and Figure 10, but no information is given on normal grain growth rates. If the authors aim to treat this topic in another publication, this should at least be stated, since studies of crystal size and crystal orientation are closely intertwined.

We added the discussion about grain sizes in Section 5.2 as follows:

"Above 2400 m, the grain size grew steadily (but with a partial decrease during the two glacial periods) (Azuma et al., 1999, 2000). However, below 2400 m, there was no overall increase in grain size. During interglacial periods, the grain size gradually increased with depth but decreased sharply during glacial periods that were associated with higher impurity concentrations. At the lower glacial ice boundary, the grain size again became smaller, indicating that grain size growth was interrupted during glacial periods. This pattern has also been reported to occur in the EDC core (Durand et al., 2009). The reason why grain growth in deeper ice is interrupted during glacial periods remains unclear, although this effect may be due to nucleation or migration recrystallization. Figures 5c and A2 show signs of nucleation and migration recrystallization, both of which can reduce the mean grain size, in interglacial ice specimens. These phenomena may suppress normal grain growth and lead to smaller grain sizes. Furthermore, extremely large grains exceeding 10 cm in radius (~300 cm^2) were observed below 2960 m. Grains of this size have not been found in the EDC core to date (see Figure 7). Interestingly, small grains (less than 1 cm^2) were maintained at a depth of approximately 2900 m (MIS16), despite the high temperatures at that depth that were close to the melting point of ice (–5 °C). Although the concentration of dust particles was not so high in this region (less than 100 ppbv), the grain boundary pinning effect caused by dust particles remained still effective even at high temperatures."

This reviewer has access to two reviews on a previously submitted version of this manuscript, as well as to the replies given by the authors. It seems to me that the authors have made a major effort in responding to the major criticisms offered by the two reviewers, both of whom are leading experts in this field. Examples:

Reviewer 1 criticised the authors´ emphasis on grain boundary sliding (GBS) in the earlier version, stating that the evidence for this deformation mechanism in the core was very limited. The authors have responded to this by significantly toning down the potential occurrence of GBS in the revised version.

Reviewer 1 is critical of the authors´ interpretation of small grains on the boundary between two larger grains as evidence for nucleation of new grains (sometimes referred to as dynamic or migration recrystallization) – see Figure 7. It also seems like Reviewer 2 does not support the authors´ interpretations on this issue. Author responses are detailed and they defend their view by pointing out that observed c-axis fabric changes at depth support the assertion that new grains are being nucleated.

It may be added here that it is surprising how little discussion there is in the paper on the effect of higher temperatures near the bed on grain size development. Section 4.4 mentions very large crystals below 2950 m depth (blue curve in Figure 5), but there is no further interpretation. Grain size curves between DF2 and EDC are compared in Figure 10, but a comparison with the Vostok core – where very large crystals were observed in the lowest part of the meteoric ice – would have been particularly interesting here.

We added grain sized data below 2950 m as Figure 6. but could not find the grain sizes data in the deep sections of Vostok core.

Even though the authors have made efforts to shorten the text (following reviewer advice), the paper is still very long and the text is often repetitive. Actually, the repetitions are at times helpful for the reader, who gets a bit lost at times in the details being discussed, and is thankful for a recap! The Conclusions section (2.5 pages) presents a very good overview of main results and interpretations, in a better way than the bulk of the text.

The English language of the paper still needs improvement and this reviewer typed down suggestions as he read the paper through. Hopefully these suggestions can be of help in the final revision process.

Thank you for these comments. Throughout the revised manuscript, we attempted to shorten the main text, to remove the repetition, to make simple story, and to improve English language. English language was checked by a native speaker.

Specific comments:

Comments/questions directed to the authors are blue-coloured for clarity. Note that the terms grain and crystal are used synonymously by this reviewer. Numbers like L20 refer to line numbers in the manuscript version: egusphere-2023-3146-manuscript-version2.pdf

L20

To examine the distribution and texture of the c- and a-axes...

→

To examine the orientation distribution of the c- and a-axes... („texture“ refers more to grain size and shape)

We modified the sentence.

L22

detailed crystal grain orientations

→

detailed crystal orientations

We modified the sentence.

L24

as eigenvalues

→

as eigenvalues of the orientation tensor

We modified the sentence.

L28

Below 1800 m in the UP80%, layers with varying dusty impurities

→

Below 1800 m in the UP80%, layers with varying concentrations of dusty impurities

We modified the sentence.

L38-39

What are c-axis layers ??

Wording was not good. We modified to "c-axis cluster"

L53-54

whereas shearing on alternate slip systems is significantly more difficult, nearly a hundredfold

→ (suggestion)

whereas nearly a hundred times greater (shear) stress must be applied to induce deformation along other slip systems within the crystals

We modified the sentence.

L57-58

The study of anisotropic ice deformation has been conducted historically. They were done through theoretical research

→

Anisotropic ice deformation has been studied theoretically

The relevant paragraph was deleted.

L59

and through laboratory experiments

→

and in laboratory experiments

The relevant paragraph was deleted.

L61-62

These laboratory-based studies are characterized by experimental setting of strain rate by more than several orders of magnitude, and under temperature close to melting point,

→

The experimental setting in these laboratory-based studies is characterized by strain rates that are several orders of magnitude higher than in situ strain rates in ice sheets, and at temperatures close to the melting point,

The relevant paragraph was deleted.

L62-64

Therefore, these laboratory-based knowledge can be a valuable reference mainly for such conditions.

→ The laboratory results are thus, strictly speaking, not directly applicable to ice-sheet conditions.

The relevant paragraph was deleted.

L64

play another essential role. Examples of Antarctic deep ice core include

→ play an essential role. Examples of Antarctic deep ice cores include

The relevant paragraph was deleted.

L68-69

Examples of Greenland ice sheet include

→

Examples from the Greenland ice sheet include

The relevant paragraph was deleted.

L70

and among others

→

and other cores

The relevant paragraph was deleted.

L72-74

For instance, during the internal deformation of the ice sheet, the flow forms preferred orientations of crystal axes, at the same time, the ice flow is modulated based on them.

→

For instance, the internal deformation of an ice sheet leads to the development of preferred orientations of the ice crystals, which in turn influence the flow of the ice sheet.

The relevant paragraph was deleted.

L83-84

dome regions in central area of the ice sheets

→

dome regions in the central parts of ice sheets

The relevant paragraph was deleted.

L95

was presented by

→

was described by

The relevant paragraph was deleted.

L94

and it is suitable to investigate

→

and such a setting is suitable to investigate

The relevant paragraph was deleted.

L98

deepmost → deepest

The word was modified.

L104-105

composition of the deepest 1% thickness (3000–3035 m).

→

Composition of the deepest 1% of the ice sheet/ice core (3000-3035 m).

We modified the sentence.

L105-106

These properties were found to retain the basic layered structure of ice core signals except in the deepest few meters.

Not certain what this sentence means – was the size and concentration of air hydrates and the oxygen isotope ratio typical for the meteoric ice above (except in the deepest few meters) ?

Yes, we observed ubiquitous presence of air hydrate and the water isotope composition comparable to the upper part of ice core (i.e., continuous profiles from the upper part).

L108

sampled at every 11 m depth.

→

sampled at 11 m depth intervals.

The relevant paragraph was deleted.

L111-113

Dynamic recrystallization within ice sheet has been widely investigated historically, as reviewed in papers or textbooks (e.g., Poirier 1985; Humphreys and Haterly 2004; Faria et al., 2014a, b) or individual papers (e.g., De La Chapelle et al. 1998; Weikusat et al. 2009, Kipfstuhl et al. 2009, Montagnat et al. 2012, 2014; Stoll et al., 2021a).

→ (suggest change to)

Studies on dynamic recrystallization in ice sheets have been reported by e.g. Poirier 1985; De La Chapelle et al. 1998; Humphreys and Haterly 2004; Weikusat et al. 2009; Kipfstuhl et al. 2009; Montagnat et al. 2012, 2014; Faria et al., 2014a and Stoll et al., 2021a.

We modified the sentence.

L113-114

Exploring deep ice rheology and crystal properties, dynamic recrystallization is one of main focuses in this paper.

→ (suggestion)

In this paper, we take advantage of the unique opportunity that the Dome F ice core offers to study the role of dynamic recrystallization in the formation of textures and fabrics in the deeper parts of the East Antarctic ice sheet.

We modified the sentence.

L115

What does „Advancing ice sheet dynamics“ mean here? Would it not be more suitable to shorten the title of this section to: The development and role of crystal orientation fabrics

This sentence was removed.

L117

„layer structures of the c-axis fabric“ is not very clear wording.

Wording was not good. We modified to “development of the c-axis fabric”.

L131

variations in the deformational history of the vertical compression.

→

variations in the deformational history of an ice-sheet region where vertical compression is the dominant stress regime.

The relevant paragraph was deleted.

L135

across wide area of ice sheets.

→

across wide areas of ice sheets.

We added “s”.

L141-143

Following this previous study, research focusing on the lowermost (deepest) approximately 20% thickness zone (ranging from about 2400 m to the deepest ice at 3035 m) remains to be done, to examine textural data for the entire thickness of the ice sheet.

→ (suggestion)

Following this previous study, research has focused on the lowermost (deepest) approximately 20% of the DF core (depth interval 2400-3035 m), to complete the picture of textural and fabric evolution in the entire ice sheet column.

The sentence was modified.

L147

We compare textural data by these methods with various data analyzed from the ice core.

→

We compare textural data obtained with these methods with various data sets from studies of the ice core.

The sentence was modified.

L148-149 (twice)

crystal orientation fabric

→

the crystal orientation fabric

We added “the”.

L153

that correspond to ages of more than 1 million years

→

covering snow deposition over more than 1 million years

The sentence was modified.

L155

extends → extend

We removed “s”

L157

knowledge of englacial layers under various ice conditions.

→ (suggestion)

knowledge of the physical properties and the deformation history in different regions of the East Antarctic ice sheet.

The sentence was modified.

L167-168

In terms of the c-axis fabric, Azuma et al. (1999, 2000) reported that at DF1 the c-axis fabric exhibited the elongated single pole fabric as the dome undergoes deviatoric strain depending on orientations.

→

This is not very clearly worded – what does „depending on orientations“ mean here ? Are the authors referring to the mean c-axis orientation being perpendicular to the bedrock slope (line 172) ?

DF is very close (within 10 km) to but not a true summit at the present condition. Therefore, DF is subject to deviatoric stress in the direction of maximum inclination. We added this explanation in the second paragraph in Section 2.

L191

signals of dynamic recrystallization

→

signs of dynamic recrystallization

The word was modified.

L195

The principle of...have been described

→

The principles of...have been described

Or

The principle of...has been described

The sentence was modified.

L219-220

deviating from the vertical (hereinafter, inclination angle) in the same direction of the maximum layer slope.

→ (suggestion)

deviating from the vertical (hereafter, inclination angle) in the same direction as the normal to the maximum layer slope.

The sentence was modified.

L266-267

Data from both cases....in agreement

→

Data from both cases....are in agreement

The sentence was modified.

L302 (check also L304 and L306)

generally have periodicity of 60 degrees

→(suggestion)

generally display maxima at 60 degree intervals („periodicity" normally refers to regular variation with time)

The sentence was modified.

L314-315, this sentence needs improvement/rewriting to become intelligible:

„It is also very important to note that the SDρ is well synchronized with the grain size (Figure 5e), which implies underlining Physics."

Wording was not good. We removed "which implies underlining Physics".

L323-324 (Fig. 4 caption)

The vertical orientation aligns with the core axis.

According to Fig. 5 the borehole is inclined 3-6° in the depth interval being considered so the core axis hardly represents the vertical.

We modified to "*The green triangle in each diagram indicates the vertical orientation in the ice sheet, which approximately aligns with the core axis (though the borehole inclined 3–6º from the vertical).*"

L351-360

The authors outline grain sizes in the entire core, mentioning that individual grains become „extremely large" below 2950. No figures are given, though, and Fig. 10e seems to indicate grain size peaks exceeding the maximum value given on the vertical axis of that diagram. The limited size of thin sections is, of course, an issue at these great depths, but it would be good if the authors could at least mention maximum grain sizes inferred from the study.

We added the discussion about grain size in Section 5.2 and closeup up figure of grain sizes below 2950 m as Figure 6.

L361-364

Supporting references are needed for the statement that the c-axis (mean) angle will not coincide with the normal to the shear plane.

We removed these sentences from this section. They are part of discussion.

L381-382 – these two sentences need English-language improvement.

We modified as follow (in Appendix A1):

"These grains are sparsely distributed, and typically have sizes on the order of a millimetre or less. Flattened (or two-dimensionally elongated) grains having a noticeable slant are also evident."

L382

These features were unique in the impurity-rich depths

→

These features were present in the impurity-rich layers

We modified the sentence.

L386

tend to be distributed as more straight lines

→

are often displayed as straight lines

We modified the sentence.

L388-389

However, some features of impurity-rich layers observed in panels (a) and (c) are persistently present in (e). That is, flattened grains have slanting features.

→ (suggestion)

However, some features of impurity-rich layers observed in panels (a) and (c) are persistently present in (e), where flattened grains display slanting features.

We modified the sentence.

L391-394 – improve English language

We modified as follow in (in Appendix A1):

“In this regard, the coarser grains also had a greater effect compared with the more sparsely distributed smaller grains. Because the Δε values represented volume-weighted averages within the microwave beam, these values were decreased to a greater extent in the case that more and/or larger grains with c-axis orientations distinctly offset from the surrounding grains were present.”

L419

reported that → reported

We modified the word.

L435-436

We suggest that the steady grain sizes in the impurity-rich layers established themselves after these layers had reached deeper depths.

→

We suggest that the steady grain sizes in the impurity-rich layers were attained when these layers had reached greater depths.

We modified the sentence.

L484-485

The conditions of ice sheets in Antarctica, in terms of temperature and stress, are located on a boundary zone between dislocation and diffusional creep on the deformation mechanism map

→ (suggested rewording)

Due to prevailing temperature and stress conditions, the ice within the Antarctic ice sheet(s) is located in a boundary zone between dislocation and diffusional creep on the deformation mechanism map.

We modified the sentence.

L486

When ice is under temperatures → When ice is at temperatures

We modified the word.

L497-504

This description of Fig. 5 has already been given earlier on.

The description of Fig. 5 was removed from the main text.

L506-507

the consistency of the inclination angles in the visual layers and the c-axes cluster depends on glacial/interglacial periods.

→

The consistency between the inclination angles of the (normal to) the visual layers and the c-axis cluster is affected by varying conditions between ice deposited during glacial and interglacial periods.

We modified the sentence.

L525-533

Are there any results from surface-based GPS-measurements, that could confirm the assumption that ice flow has occurred towards the center of the trough? And since there is a trough there, wouldn´t the internal layers of ice sitting in the trough also be convex-shaped in the absence of basal mass loss due to melting?

There is no evidence of horizontal flow near the bedrock. Convex-shaped layers would be formed by bedrock (trough) geometry; however, we believe that inhomogeneous basal melting might be cause the anomalous thinning (increase of thinning function below 2700 m).

L546 – improvement in wording required:

the all the c-axes thus the c-axes cluster rotates

This relevant figure was deleted.

L547

total amount of inclinations

→

total inclination

This relevant figure was deleted.

L558

are plotted in entire depths figure (Figure 10).

→

are plotted for the entire depth of the core in Figure 10.

The relevant figure was deleted.

L566-567

dust particles located → dust particles are located

We modified the sentence.

L568

„Production of dislocation is one of the possibilities.“

Does this mean that the presence of microparticles leads to dislocation production? Please clarify!

We modified to “Dust particles can produce dislocations”

L570-572

Item (ii) – it is unclear how the content of this sentence relates to the issue mentioned in L569, that microparticles may act as a sink of dislocations like grain boundaries.

We modified as follow (first paragraph in Section 5.3):

"It is well known that dust particles restrict grain growth and result in smaller grain sizes (e.g., Alley and Woods, 1996). This trend was observed in the present study. The scatter plot of the Δε values, grain sizes and concentration of dust particles are given in Figure 8. The grain sizes are decreased as the concentration of dust particles increased. However, the role of dust particles in ice deformation via dislocation creep is not well understood. Dust particles can product dislocation or may act as sink of dislocations similar to grain boundaries. Saruya et al. (2022b) suggested two possible actions of particles: (i) restricted deformation due to the inhibition of dislocation by dust particles and/or (ii) the promotion of diffusion creep that does not cause c-axis rotation. Diffusion creep is known to be promoted by smaller grain sizes."

L579

In the LO20%, some thickness between 2400 m and 2650 m is

→

In the LO20%, the depth interval 2400-2650 m is

This sentence was deleted.

L601

from compressional axis → from the compressional axis

We added "the".

L602

„However, it is also noteworthy that, in Figure 5c, distribution of c-axis density approximately from 30 degrees from compressional axis (60 degrees from horizon) is always denser than 45 degrees or 60 degrees."

Wording is not clear here. Does the sentence imply that there are more c-axes located approx. 30° from the compressional axis that there are at 45° and 60° (or in between) ?

We deleted this sentence.

L603-604

„It is possible that it has some underlying mechanisms in terms of nucleation recrystallization relative to the existing c-axis cluster."

What does „it" refer to here? The sentence is unclear.

This sentence was deleted. Wording was not good.

L608

ice crystals will recover the c-axis orientations available for

→

ice crystals will develop c-axis orientations favourable for

We modified the sentence.

L612

decreasing → decrease

We modified the word.

L613

in the impurity-rich layer → in the impurity-rich layers

We added “the”.

L643-644

Be more specific on why rotation recrystallization has a minimal effect on c-axis fabrics and why you assume – seemingly ad hoc – that it does not cause a-axis organization.

The relevant section was deleted. No need to mention the rotation recrystallization here.

L714-715

the thickness of ice is approximately 10% of the original ice equivalent thickness at the time of deposition

→

the thickness of a particular ice layer is approximately 10% of the ice equivalent thickness of that layer at the time of deposition

We modified the sentence.

L726

strengthening the → strengthening of the

The relevant paragraph was deleted.

Table 2

The ice thickness at GRIP was 3029 m (the figure 3085 m is the thickness at NGRIP). The mean annual temperature at GRIP was -32°C during the 1990s, when the deep ice core was drilled. See Dansgaard et al. (1993). Evidence for general instability of past climate from a 250-kyr ice-core record. Nature, 1993, 364 (6434), 218-220.

This table was removed. Thank you for pointing out.

L746

Based on the above discussions, we propose an overview of the layered structure of ice sheets.

To “propose an overview” sounds a bit strange.

The relevant section was deleted.

L759-760

What is meant here by „two distinct conditions? The next sentence mentions „Four types of conditions“ which adds to the confusion.

The relevant section was deleted.

L766-767

However, these layered structures correlate directly with the vertical thinning of each layer,

Which „layered structures“ and how do they „correlate directly“ with the layer thinning? Are the authors referring to the effects of changing grain size, evolving fabric and variations in impurity content on the thinning rate?

The relevant section was deleted.

L775

layers of ice c-axis fabric → ice layers with a particular c-axis fabric

The relevant section was deleted.

L794-95

„changes in depth range“ almost sounds like a statement that depth increases with depth!

The sentence is probably supposed to refer to fabric changes with increasing depth.

We modified the sentence. Thank you for pointing out.

L807

The term „Growth of c-axis clustering“ appears several times in the paper. The authors should consider if „evolution“ or „development“ is not a more appropriate term than„ growth“ in this context.

We changed to “evolution or development”.

L810

The words „are observed“ need to be inserted after the word „recrystallization“, so that the sentence becomes meaningful.

We modified the sentence.

L820

Possibly, crystal twinning, which share some crystal lattice points symmetrically with the neighboring crystals

→

Possibly, crystal twinning, which leads to crystals sharing some lattice points symmetrically with neighbouring crystals

The relevant conclusion was deleted.

L829

and layers → and the normal to the layers

We modified the sentence.

L848-849

We argue that the bottom thickness of the ice sheet deeper than approximately 2600 m plays a special role in shear deformation

→

We argue that the lowermost part of the ice column, deeper than approximately 2600 m plays a special role in shear deformation

The relevant paragraph was deleted.

L852-853

Ice core drilling, aiming the ancient climatic records, at locations away from the dome area carries serious risks of layer disturbances near the bottom.

→

Ice core drilling projects aiming to retrieve climate records from ancient ice may encounter layer disturbances near the bottom if the drilling sites are located away from dome summit regions.

The relevant paragraph was deleted.

L929

within plane → within the plane

We added “the”.

L938 (and similarly in L922):

Here, the c-axes cluster of single pole fabric is inclined to an arbitrary horizontal orientation.

Shouldn´t this rather be (?):

Here, the plane perpendicular to the c-axes cluster of the single pole fabric is inclined to an arbitrary horizontal orientation.

The sentence was modified.

Section A3

The faint and thin cloudy layers are identified when oriented vertically;

What does it mean here to be „oriented vertically? Are the cores turned and inclined until the observer looks straight down ("vertically") on the edge of the cloudy layers?

Yes, layers can be identified only when viewed from horizontally.

L973-974

the aspect ratio value defined as the ratio of the short and long axis of a fitted ellipse

→

the aspect ratio value defined as the ratio of the long and short axis of a fitted ellipse [i.e. long divided by short]

Table A4, column farthest to the left:

Average → Average aspect ratio

The sentence and column were modified.

L1076-1077

Crystal orientation fabric data from the DF core and the EDC core are compared using a common age scale of the DF2021 age scale.

→ (suggestion)

Crystal orientation fabric data from the DF core and the EDC core compared using a common age scale, matching the EDC age scale with the DF2021 age scale.

Did the authors use isotope data or methane data to tie the age scales of the two cores together? If so, this should be stated.

This sentence (caption) was removed. DF2021 age scale uses Bayesian dating model and firn densification model, and constrained by various types of information such as new O_2/N_2 age markers.