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Interactive comment on "Seismic imaging across fault systems in the Abitibi greenstone belt – An analysis of pre- and post-stack migration approaches in the Chibougamau area, Quebec, Canada" *by* Saeid Cheraghi et al.

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Interactive comment on "Seismic imaging across fault systems in the Abitibi greenstone belt – An analysis of pre- and post-stack migration approaches in the Chibougamau area, Quebec, Canada" by Saeid Cheraghi et al. Fomin Tanya (Referee) tanya.fomin@ga.gov.au Received and published: 16 November 2020 General comments: 1. Well written paper with a clear objective and straightforward structure. This case study example is very useful and practical for seismic processors. In these days

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PSTM and PSDM methods become most popular and DMO technique called “old fashioned” not used broadly anymore by commercial processing companies (even some seismic software not include DMO in their packages). Reply to comment: First We would like to commend your inclusive review and the detailed comments you provided. We agree that more advanced computing systems have facilitated the application of the sophisticated methods such as PSTM and PSDM in seismic processing, in general. Most of these methods are practiced on sedimentary basins where there is less heterogeneity and scattering. The heterogeneity and scattering is naturally affecting all the seismic surveys acquired in the crystalline rock environment. Yet, the crooked pattern of surveys acquired in crystalline terrain brings more difficulties to seismic processing. We appreciate that you mentioned it is not possible to say which method is the best for crystalline rock environment before it is tested. Our goal was to compare the conventional processing method (DMO stacked migrated) with more advanced method (PSTM), where the survey is crooked, to introduce the challenges. This would help for future seismic survey design in a such environment. DMO/NMO corrected sections followed by stacking and migration is still the most efficient method in crystalline rock environment. For example, the recent seismic surveys acquired in Europe (Smart Exploration program) or 3D seismic surveys in TGI program acquired by Geological survey of Canada, all achieved their best results by standard processing, i.e., DMO corrections/stack/migration. However, we believe that what we learn from current experience would help to better survey design and apply more advanced method in future works. 2. I think one of the difficulties of this topic that you cannot provide “a recipe” what would be the best technique DMO, PSTM or something else for particular geological environment until you test it and apply all possible methods. That is not very practical. It would be good at least if you provide some recommendations on possible processing flows for different geological environments for example DMO should work for some areas and not really useful in others. Reply to comment: We would like to again mention that current experience in crystalline rock terrains recommends that the most applicable method is post-stacked migration processing. In “section 3.1 Offset

distribution for Kirchhoff and DMO correction" and also in "Appendix A. evaluating survey geometry for DMO and PSTM" we emphasized on some major points including regular offset distribution for DMO and PSTM algorithm and also seismic illumination based on subsurface geology. We noted that offset distribution and seismic illumination should be analysed to optimise seismic imaging before acquiring data during the phase of the survey design. The knowledge about the subsurface geology in the study area would improve this analyse. Section 6.1. The effect of survey geometry on seismic imaging, provides some recommendations regarding application of DMO and PSTM algorithm.

3. It is a very detailed interpretation section of seismic reflectivity which is very good but could be over interpreted. Reply to comment: We appreciate that you find the interpretation detailed. In the revised manuscript we provided more concise interpretation. (sections 4, 5, and 6). The interpretation of a regional seismic profile in Chibougamau area including the geological sections or regional models are published somewhere else by some of the co-authors of our paper: Mathieu, L., Snyder, D.B., Bedeaux, P., Cheraghi, S., Lafrance, B., Thurston, P., and Sherlock, R.: Deep into the Chibougamau area, Abitibi Subprovince: structure of a Neoarchean crust revealed by seismic reflection profiling, Tectonics, 38, 1–25, 2020.

Line 20 – methods instead of method Text has been edited (Abstract) Lines 21-22 – What was a reason of 3km increment and was a step 3km or you checked as well 2-4 km, 3-5km etc? Would be 0-3km offset recommendation or it has to be checked for every seismic survey. Reply to comments: The offset step rate of 0-3 km, 3-6 km, and 6-9 km is designed based on the distribution of CMPs for the acquired geometry in Chibougamau area. The offset step rate has to be chosen based on the geometry and could vary for each specific survey (section 3.1 Offset distribution for Kirchhoff PSTM and DMO corrections, the last paragraph) Line 27 – From the Figure 1 it looks like Profile just stops before the Doda fault and not crossing the fault.

The Doda fault is located in the south end of the Chibougamau area beyond the exten-

sion of the profile. The surface location of the Doda fault is been updated in Figure 1 based on recent finding of the one of the co-authors of our paper (P. Bedeaux). Section 6.2.2 Seismic interpretation along the south profile, paragraph 5 provides the interpretation about the Doda fault.

Line 54 – Cheraghi et al., 2012 is not on the list of References This Reference is added to the list Line 64 – Bellefleur et al., 2018 is not on the list of References The correct reference is Bellefleur et al. (2019). It is already in the list. Bellefleur et al. (2018) has been changed to Bellefleur et al. (2019) in section 1. Introduction, paragraph 2.

Line 84 – David et al., 2011 is not on the list of References David et al. (2011) has been added to the reference list. Line 103 – Dinmroth et al., 1995 spelling and is not on the list of References Line The proper reference is Dimroth et al. (1985) which is already in the reference list. Dimroth et al. (1985) is cited in section 2. Geological setting, paragraph, 3. 108 – Daigneault and Allard, 1990 is not on the list of References The proper reference is Daigneault et al. (1990) which is already in the reference list and text has been changed to properly cite this reference in section 2. Geological setting, paragraph, 3. Line 111 – Bedeaux et al., 2020 is not on the list of References This reference has been added to the list. Line 127 – How is significant to have more denser VP instead of receiver spacing (cost is more for shots not for channels) Reply to comment: The cost, economic consideration, the logistic and accessibility of the area is considered during survey design to best serve the data acquisition. The geometric consideration of the survey design is published by some of the co-authors of our paper: Naghizadeh, M., Snyder, D.B., Cheraghi, S., Foster, S., Cilensek, S., Feloreani, E., and Mackie, J.: Acquisition and Processing of Wider Bandwidth Seismic Data in Crystalline Crust: Progress with the Metal Earth Project, Minerals, 9 (145), 2019.

What is a Moho depth? Why is only 12 sec record length? Was any testing for higher ending frequencies 150Hz or even higher? The Moho depth is about 36 km ($\sim$ 12 s). A 12 s data is considered to be consistent with the regional survey in the area. The high resolution surveys are processed to image upper crust (0 -12 km). The regional

seismic survey and deeper structures (0- 36 km) in the Chibougamau area is studied in: Mathieu, L., Snyder, D.B., Bedeaux, P., Cheraghi, S., Lafrance, B., Thurston, P., and Sherlock, R.: Deep into the Chibougamau area, Abitibi Subprovince: structure of a Neoarchean crust revealed by seismic reflection profiling, Tectonics, 38, 1–25, 2020. The frequency range is considered based on several pilot tests in the field. The evaluation is explained in a paper published by some of the co-authors of our paper: Naghizadeh, M., Snyder, D.B., Cheraghi, S., Foster, S., Cilensek, S., Feloreani, E., and Mackie, J.: Acquisition and Processing of Wider Bandwidth Seismic Data in Crystalline Crust: Progress with the Metal Earth Project, Minerals, 9 (145), 2019. Line 143 – Common lower case Text has been edited (section 3.1 Offset distribution for Kirchhoff PSTM and DMO corrections, paragraph 1). Line 169- 170 – "We designed offset . . . " Was this designed only based on visual assessment or something else? Reply to comment: It has been explained in section 3.1 Offset distribution for Kirchhoff PSTM and DMO corrections, paragraph 4: These offset ranges are chosen based on analysis shown in Fig. 2 and Fig.3 and testing the seismic images of variety of offset ranges when they contribute to the process of post-stacked DMO and PSTM images (see Table 2 for the processing details). The offsets greater than 9 km did not increased the image quality and deemed unnecessary to present their images.

Line 221 – You don't need to have "The distribution. . ." sentence second time. Text has been edited (caption for Figure 4). In the Figure 4 offsets 0-3km, 3-6km and 6-9km. In the text, it is 0-3km, 0-6km and 0-9km. Am I wrong of reading that? Reply to comment: In "section 3.1 Offset distribution for Kirchhoff PSTM and DMO corrections, paragraph 4" we explain that: We designed offset planes ranging 0-3 km, 0-6 km, and 0-9 km in order to study the survey geometry (Fig. 4). These offset ranges are chosen based on analysis shown in Fig. 2 and Fig.3 and testing the seismic images of variety of offset ranges when they contribute to the process of post-stacked DMO and PSTM images (see Table 2 for the processing details). The offsets greater than 9 km did not increased the image quality and deemed unnecessary to present their images. All seismic images in Figure 5 and 6 are generated in offset range of 0-3 km, 0-6 km, and

0-9 km and it has been mentioned in text. In Figure 4 instead of overprinting of CMP distribution for offset range of 0-3 km, 0-6 km, and 0-9 km, we show CMPs of offset range of 0-3 km, 3-6 km, and 6-9 km, to present their distribution along the survey line where offset is increasing.

In Table 2 First arrivals picked up to 10 km. Is any need for that? I assume this is a one-layer refractor model? Why top muting but not just stretch with some %? Reply to comment: Top mute would help to remove first arrivals in short and longer offsets and prevents the removing the potential reflections in shallower parts. Line 251 – Why was used a constant velocity for DMO corrections? Reply to comment: The constant velocity model for DMO corrections is based on several test including constant and variable velocities. The velocity of 5500 m/s showed the best results.

Figures 5 and 6 should be Depth converted migrated sections? Both sections are time-to-depth converted after migration (Table 2).

Line 385 – See capital Text has been edited (caption for Figure 7). Figure 9 You need better arrow for the fault location (similar to figure 8) Figure 9 has been updated regarding this comment. Line 518 - shot gather 15135 but in the figure 13135 Text has been edited (Caption for Figure 12) Line 648 – Vermeer, 1994 is not on the list This reference has been added to the reference list. Line 652 – 653 " The pre-stack depth migration . . ." something missing in this sentence? Text has been edited (8 Appendix A: evaluating survey geometry for DMO and PSTM, the last paragraph) Line 697 – Is it 2018? Line 738 – I could not find this reference in the text. The correct reference is Bellefleur et al. (2019) which is already in the reference list. Bellefleur et al. (2018) has been changed to Bellefleur et al. (2019) in section 1. Introduction, paragraph 2. Final remarks It is a good and useful paper for people who process seismic data particular for hard rock data sets. We need to be very careful and not to over interpret reflection seismic data by trying to fit to geological model. Reply to comment: One again, we would like to acknowledge Mrs. Fomin for her inclusive comments which improved the quality our paper. We would like to clarify that the inclusive interpretation of seismic sections such

as fault kinematic, structural and tectonic study is beyond the scope of our study and it is published somewhere else: Mathieu, L., Snyder, D.B., Bedeaux, P., Cheraghi, S., Lafrance, B., Thurston, P., and Sherlock, R.: Deep into the Chibougamau area, Abitibi Subprovince: structure of a Neoarchean crust revealed by seismic reflection profiling, Tectonics, 38, 1–25, 2020. Some of the co-authors of our paper were contributed in this publication and helped to improve the interpretation of the high resolution seismic sections in the Chibougamau area.

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