

Interactive comment on “Seismic imaging of dyke swarms within the Sorgenfrei Tornquist Zone (Sweden) and implications for thermal energy storage” by Alireza Malehmir et al.

Anonymous Referee #1

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The paper presents results from three high-resolution 2D seismic lines acquired as a first stage characterization of the subsurface for a potential thermal energy storage site in Sweden. The focus of the paper is really on dolerite dykes which are important geological features in the study area. The topic is of interest and relevant to this special issue. In my opinion, the paper should be published after some weaknesses and loose ends are properly taken care of during revision (see main and detailed comments below).

Main comments:

1) The paper either was written quickly or did not deserve all required attention prior

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to submission. The language is often imprecise and sometimes sentences are not grammatically correct. This is not systematic through out the manuscript but prevalent enough to require proper and careful editing by a native English speaker.

2) The correspondence between log anomalies and reflections (R2 and R3) is particularly good on the un-migrated section (Figure 10b) but rather poor on the migrated section (Figure 10c, especially for R3). What makes you think that the anomalies on logs are really the signature of the dolerite dykes if logs and reflections are not at the same spatial location? Are there any other possible explanations for these log anomalies? The same observation applies to figure 11 (i.e. poor fit with log anomalies and reflection R2 on migrated section). How confident are you about the migration velocities and velocities used for T-Z conversion?

3) I suggest looking for references on physical rock properties of dolerite dykes to support the interpreted signature on logging data (especially low natural gamma) and seismic data. Specifically, the acoustic impedance of dolerite dykes and potential contrast with host rocks are not discussed in the paper. However, acoustic impedance is the only property that can unequivocally confirm the reflective (i.e., P-wave) nature of dolerite dykes. The interpretation of steeply-dipping reflections as dolerite dykes currently lacks that irrefutable argument (even though strong conjectural arguments are provided to support this interpretation).

4) The paper includes a discussion on the implications of results for thermal energy storage without really providing the key characteristics of a good site for such storage. Some details about an optimal thermal storage site should be provided. For instance, what is the size of such a site (“caverns”)? Why is this area considered suitable for thermal storage (particular rock types, geomechanical properties, close proximity to city)? It is difficult for readers to assess the implications of results for something that is not properly defined.

5) Results from the Babel seismic lines are of certainly of interest but primarily from

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a background perspective. It is not clear how results from these lines effectively help the interpretation of results at the local scale or provide information useful for the discussion. Because of this, and unless a proper case can be made, I suggest to include the Babel lines as background information as a component of the geology (i.e., deep geology in this case).

Detailed and technical comments:

Page 1 line 19: dykes cannot “express themselves”... what about “are”

Page 1 line 19. “...express themselves mostly sub-vertical. They can therefore act as a good water/fluid barrier” It is not clear why the fact that dykes are vertical makes them good water barrier. Obviously, more information is needed to support this statement. Geometry is certainly an important factor but not the only one. Please provide evidences supporting that dolerite dykes are effective water barrier.

Page 2 line26: “...and if major bedrock undulations” with “...and determine if major bedrock undulations”

Page 6 line 1: “where geological structures are favourable” please be more specific about the geological structures.

Page 8 line 2: replace “where” with “were”

Page 8 line 9: What explains the better results with diversity stack over conventional stack on line 3?

Page 9 line 12: “Migration was not employed for the data along profile 5”. Do you mean profile 4?

Figure 12 shows mostly dipping reflections, not steep but still dipping reflections. The migrated section should also be shown in the paper for a “proper” positioning of reflectors.

Page 10 line 8: replace “for where needed” with “where needed”

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Page 11 line 2: “A smooth 2D velocity model”. Please provide more information about this model (lower and upper velocities and their distribution (ie. constant gradient?)).

Page 11 line 14: “suggesting that the tomographic velocity models can be used to constrain the bedrock surface with a good level of confidence”. What velocity is the threshold to determine the bedrock surface? In addition, I suggest drawing the top of bedrock on Figure 9 (with dashed line or other).

Page 11 line 23: “. . .depression-looking bedrock is clearly observed in the tomograms suggesting a possibility for major weakness zones (likely highly fractured and/or weathered) in the bedrock.” There are other supporting evidences for this elsewhere in the manuscript. I suggest including them here (for example, caption of figure 9 mentions cuttings from bedrock with alteration). What about velocities from tomography – can they help? Also, could you please be more specific about the alteration observed in cuttings?

Page 13 line 15: “using transverse type approach”. What do you mean specifically? Survey lines orthogonal to the main structures?

Page 13 line 17: “Several northeast-dipping, approximately 60-65 degree, reflections were imaged down to 400 m depth thanks to the close shot and receiver spacing strategy of the data acquisition.” Not sure I understand what is meant by “thanks to close shot and receiver spacing”. Aren’t large offset required to image steeply dipping reflectors?

Page 13 line 19: “but at occasions are discontinuous and have different appearances”. Please be specific about the different appearances.

Page 13 line 25 “One particular reflection is associated with the topographic depression in the study area and matches well with the high-velocity zone observed under the depression.” This is somewhat contrary to what was said before on bedrock depressions corresponding to faults and/or alteration which would normally have low velocity.

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Please clarify this statement or earlier statement about depression.

Page 13 line 29: “suggest different geological structures than those observed along profiles 2 and 3”. What would be the different structures and why can’t they be observed on the two other profiles? Explanations that follow in the 4 lines after are rather vague.

Page 14 line 10: “..they are nearly equally observed in the country rock and likely can only act as a medium for other geological features..” Not clear at all what you mean. . .

Page 14 line 11: “with some adjustments and better matching. . .”. What adjustments and better matching? Please clarify? See also main comment #2.

Page 14 line 18: “. . .connected to a reduced natural gamma zone (Fig. 11c), likely a dolerite dyke.” Why would dolerite dykes have low natural gamma? Any reference to support this?

Page 19 line 8: is “appealing” the right word?

Page 19 line 8: “a pattern for the groundwater flow towards SE (Fig. 14b) and an orientation consistent with the directions of the dykes and major structures in the area (Fig. 1a). Reflections (R1-R4) greatly match this orientation”. I would argue that contour lines presented on figure 14b are more complex than described in the statement above which appears a bit oversimplified. Please provide a more precise description and location (i.e. between R3 and R4 near P2 and P3?). Also, why are lines of water table continuous across reflection R1, R2, R3, and R4 if these reflections are water barriers?

Page 21 line 21: “. . . transparent solidified, seismically homogenous upper mantle” Could you please explain the meaning of solidified in terms of seismic characteristics of the crust?

Page 21 line 23: “While there are a number of SW-dipping reflections in the lower-middle crust projecting towards the location of the Sorgenfrei Tornquist Zone, we can-

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not be sure if these are dykes or frozen magma chambers where dykes intruded to the upper crust within the Tornquist zone.” Agree. In fact, there are many possible explanations for those reflections. It might be worthwhile to add a few rather than just providing dyke-related possibilities (i.e., dykes and magma chamber that fed dykes).

Page 22 line 9: “Firstly, they are not sub-vertical everywhere within the Tornquist zone and they quickly turn steeply dipping in the subsurface as also observed at a few quarries in the area (e.g., Fig. 15...”. Could you please clearly indicate what you are referring to in Figure 15 (may be use double arrows – one at the top of cliff and the other at the base to point to the feature you are referring to on Fig. 15)?

Figure 1. Please add coordinates to a) and b).

Figure 2. It would be useful to add viewing direction for a) and b) or general orientation of the pictures.

Figure 13: The 3D perspective view is very difficult to visualize on this figure (especially for a). I suggest adding axis (x,y,z) that would improve the perspective view.

Figure 14 please add a) and b).

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