

## COMMENTS FROM REVIEWER 1 (R. BUTLER)

Reviewer comments are reproduced in italics, followed by the authors' responses.

**Comment 1:** *Seismological imaging of igneous intrusions within the continental crust is an area of extensive, global, continuing research. Much of this effort globally has used passive seismic methods applied to teleseismic arrivals. The data from deep seismic reflection profiling, much of it legacy, is an under-used resource and so I welcome this contribution by Krzywiec and co-workers. It is an interesting contribution that interprets and models results of deep seismic reflection profiling in Poland (PolandSPAN), focusing on discontinuous mid-crustal reflection packages. The authors have an opportunity here to make this study far more useful to the global community of earth scientists by drawing out the general application of their methods and making broader comparisons with other examples. It is this recommendation that underpins many of the comments in this review. As written, the paper tends to the parochial – the authors have a great opportunity here to do something more! So while this could be published with only minor modifications, I encourage the authors to reframe the text in this light.*

**Response:** We welcome comment that results of our study could be useful to the global community of Earth scientists. However, scope and focus of our paper submitted to the Solid Earth Special Issue „Seismic imaging from the lithosphere to the near Surface” is part of our overall strategy on publication of our results obtained for the newly defined Lublin-Baltic Igneous Province. Our first paper (Poprawa et al., 2023, Alkaline magmatism from the Lublin-Baltic area of Poland (SW slope of the East European Craton) – Manifestation of hitherto unrecognized early Carboniferous igneous province, *Terra Nova*, 36 (1), 77–88, doi:10.1111/ter.12681) contained summary of geochemical and geochronological results together with briefly mentioned seismic examples of magmatic intrusions from the Baltic Basin (N Poland) and Lublin Basin (SE Poland). In our paper submitted to SE we focused on geophysical aspects (seismic imaging and modelling) of deep magmatic intrusions within the basement of the Baltic Basin. It is also important to note that this paper is based on presentation that was given during the Seismix 2024 conference, i.e. for the seismic community, to a large degree interested in strictly geophysical aspects of seismic imaging, seismic modelling etc. Next paper will be devoted to similar modelling study of the Lower Carboniferous intrusions but developed within the sedimentary cover, and then we plan to prepare paper dealing with various regional geological aspects of Early Carboniferous magmatism, using PolandSPAN but also other industry data available to us. Taking this into account, we'd highly appreciate if structure of our paper could remain unchanged.

**Comment 2:** *Given then opportunities noted above, it would be useful to clarify the aims of this contribution. Of course, large igneous intrusions are exposed at outcrop, exhumed from various levels (including deep). The point here is detecting them in the subsurface, potentially linking them to coeval extrusives at outcrop. But why does this have importance for understanding anything other than the evolution of some local continental crust (i.e. beneath Poland)? As noted in the geological setting... the region has igneous rocks at outcrop. Is the point here to establish their extent at depth? If yes, say so!*

**Response:** Entire Paleozoic succession of the Baltic Basin in Poland is covered by Permo-Mesozoic and Cenozoic sedimentary cover so there are no Lower Carboniferous igneous rocks at outcrop, hence it is not possible to link seismically imaged sills to their outcrop equivalents.

**Comment 3:** *Or is it about establishing the geometry of intrusions? Do sills emplaced in the basement have the same propensity for steps and splays as they do when emplaced in layered*

*sedimentary rocks, nearer the syn-volcanic earth's surface? The abstract does a better job at setting the scene. Likewise, the general importance of this study, the opportunities provided by deep seismic reflection profiling, the methods used here, and the general interpretations could be developed much more fully in the discussion.*

**Response:** As stated at the end of Introduction chapter, “*Main aim of this study was to constrain lithology, thickness and overall geometry of inferred igneous intrusions recognized at the depths of c. 6-7 – 19-20 km, well beyond the reach of even deepest wells drilled in this area. Obtained results significantly improved understanding of the recently recognized Lublin Baltic Mississippian Igneous Province (Poprawa et al., 2024) and also deep igneous systems in general, including also geophysical approaches towards determining their petrophysical and geometrical characteristics using seismic modelling techniques.*”

**Comment 4:** *At various points in the text, the authors' approach is described as “educated guessing”. While this is very self-effacing, it is of course common to all interpretation – which naturally always carries uncertainty and assumptions. It would be helpful to be explicit about the limitations imposed by the specific assumptions adopted here*

**Response:** Paragraph explaining this has been added at the beginning of section 3.3.

**Comment 5:** *Section 3.1. It's good to see the information on the acquisition and processing parameters for the PolandSPAN survey. Presumably it is the quality of these that has allowed the detailed work here (as the authors say, these are unparalleled). But if the authors choose to broaden the vision of this paper to promote the greater use of legacy surveys elsewhere – it would be worth comparing the PolandSPAN parameters with other, historical, onshore surveys (ECORS, FIRE, various Iberian experiments etc).*

**Response:** Information on acquisition parameters of “classic” deep reflection seismic data (ECORS and POLCRUST) has been added in section 3.1 and compared to PolandSAN acquisition parameters

**Comment 6:** *Section 3.3. Introductory paragraph (lines 181-187). The arguments for adopting synthetics rather than ray-tracing methods needs referencing to justify these statements – especially as the only citation (Slonka et al) is to a study of sedimentary rocks rather than as a tool to enhance crustal imaging.*

**Response:** Our intention was to briefly explain the rationale for using full-wave forward seismic modelling (not synthetic seismograms) rather than ray-tracing approaches for analysis of seismic response of deep igneous intrusions. One of the key advantages of full-wave modelling is that, in contrast to ray-tracing methods, it simulates the complete seismic wavefield, which is particularly useful for analysis of interference effects, reflection amplitudes, and tuning phenomena associated with thin bodies such as, for example, magmatic sills. In the context of the intrusions interpreted in this study, where seismic wavefield characteristics were investigated using amplitude tuning analysis and forward seismic wedge modelling in order to estimate intrusion thickness, the use of this full-wave modelling approach was therefore fully justified. In the revised manuscript, we have clarified this paragraph and expanded the reference list to include studies that used seismic forward modelling to seismic reflection data analysis in order to investigate the seismic expression of igneous intrusions and related structures (e.g., Hansen et al., 2008; Magee et al., 2015; Eide et al., 2017; Wrona et al., 2019; Köpping et al., 2022). These studies demonstrate how forward seismic modelling and detailed analysis of seismic wavefield characteristics can be used to interpret intrusive bodies and their geometries, including those occurring within the lower crust. The text in Section 3.3 has been revised accordingly.

**Comment 7:** 3.3.1. *This discusses the selection of modelling parameters. It would be helpful to state explicitly the values (and their ranges) as used in this study (velocities, densities). And be specific in the comparisons made with the geology (end sentences of this section).*

**Response:** The velocities and densities used in the modelling were already presented in Table 1 and discussed in Section 4.2, where the three tested lithological scenarios (granite-granodiorite, basalt and dolerite) and their petrophysical parameters are described in detail but for clarity, we have indicated representative velocity and density values used for the tested lithologies and by adding a direct reference to Table 1 and Section 4.2, where these parameters are summarized. We have also slightly clarified the final sentences of this section to better explain how the comparison between synthetic and observed seismic responses was used to evaluate the most plausible lithological scenario. The text in Section 3.3.1 has been revised accordingly.

**Comment 8:** *Section 4. Line 253 – why was 500 ms used as the wavelet extraction window? What are the implications of changing this?*

**Response:** The 500 ms extraction window was selected as a compromise between statistical robustness and interval specificity of the estimated wavelet. Shorter windows provide fewer samples and tend to produce wavelets that are more sensitive to local noise and amplitude fluctuations, whereas longer windows may incorporate reflections from adjacent stratigraphic intervals and reduce the representativeness of the wavelet for the target intrusion zone. Tests performed using different window lengths indicated that a 500 ms window provides stable and repeatable wavelet estimates in the studied depth range. Increasing the window length did not significantly improve spectral stability, while shorter windows resulted in less consistent bandwidth and phase characteristics. Changing the window length primarily affects the bandwidth and phase stability of the extracted wavelet: smaller windows reduce statistical reliability, whereas larger windows tend to smooth the spectrum and may obscure interval-specific features.

**Comment 9:** *Line 260-2. Please be explicit that the tuning thickness chart is Fig. 6c (it's in the caption but it makes the text easier to follow if in there too). Maybe note that tuning thickness charts are also provided for Fig 7 and 8.*

**Response:** Information that Figures 6C, 7C and 8C contain tuning thickness chart is now clearly specified in the text

**Comment 10:** *2-D seismic modelling. It's good to contrast acid/intermediate composition (granite-granodiorite) with basic-composition igneous rocks. However, it's curious to use parameters from both basalt and dolerite. Presumably the basalt ones relate explicitly to lavas while dolerite are for intrusive rocks (the difference not being compositional but textural – as basalt may have porosity). Surely only dolerite is relevant here (e.g. rhyolite hasn't been modelled along with granite). But more critically – given the thickness of the interpreted igneous bodies (up to 200m for the wedge approximations) – these are likely to be layered – and could include ultrabasic compositions ... (And indeed the basic component is likely gabbro). So over-emphasising specific values on seismic velocity and density is un-necessary – beyond eliminating those for acid/intermediate composition rocks. Simply setting this up as a two-comparison acid/intermediate vs basic (dolerite/gabbro) test – would suffice.*

**Response:** The purpose of including both basalt and dolerite scenarios in the modelling was not to distinguish between extrusive and intrusive volcanic rocks in a strict petrological sense, but rather to test a plausible range of petrophysical parameters for basic igneous compositions. In particular, basalt and dolerite represent commonly reported end-member values of seismic

velocity and density for mafic rocks in the literature (cf. Brown and Kim, 2020). In this context, the basalt parameters were used as representative values for a lower-velocity mafic end-member, while dolerite represents a higher-velocity intrusive equivalent typical of mafic sills and dykes. Testing both parameter sets therefore allowed us to evaluate the sensitivity of the synthetic seismic response to variations in acoustic impedance within the plausible range of mafic compositions. In the revised manuscript, we have clarified that the basalt parameter scenario was introduced to test a plausible range of petrophysical properties for mafic rocks rather than to imply the presence of volcanic basaltic lithologies at the depth of the interpreted intrusions. We also note the Reviewer's comment that intrusive bodies of the thickness considered here could potentially include gabbroic lithologies. However, the seismic velocities and densities reported for gabbro overlap strongly with those of dolerite in published laboratory measurements. Therefore, the dolerite scenario used in our modelling can be regarded as representative of dense mafic intrusive rocks in general.

**Comment 11:** *I'd expect to see justification for the host rock parameters ("Precambrian basement") – as of course it is the contrast with this that is important for investigating the intrusions.*

**Response:** General description of basement geology is given in chapter 2 (Geological background), section 4.2 and Table 1 contain information on wells used to determine basement petrophysical parameters (velocity, density).

**Comment 12:** *This aside apart – the modelling section reads well. The illustrations are nice (Figs. 10 and 12, 11 not needed if you drop the basalt!)*

**Response:** As explained above, we'd like to keep the basalt as one of petrophysical scenarios

**Comment 13:** *The wedge model and the deductions of the thicknesses of the sill, together with its steps – are great (Figs. 14, 15, 16). Although the authors have chosen to reserve further comparison with outcrop "analogues", choosing only to compare with seismic examples of Cartwright et al. – I think again that this is a missed opportunity. Stepping and branch sills have been known and illustrated in the geological record for over 200 years (yes, really – Macculloch 1819) ... which are well-known to the igneous geology community... Simply citing work from the 2000s onwards isn't great!*

**Response:** We added references to papers with field examples of stepping of sills etc.

**Comment 14:** *The Discussion focusses on Poland and its geology. As noted above, this would be far more valuable if these discussions were broadened out. The final paragraph hints at this. More discussions should be made about the underpinning assumptions*

**Response:** Yes, this is the focus of the Discussion, but, as explained above, this was intentional, this paper is meant to deal with more geophysical aspects of seismic modelling of magmatic intrusions, we'd like to save more extensive discussion of various geological aspects, including global analogues, for another paper, we sincerely hope that this is justified and could be approved

**Comment 16:** *Seismic Interpretations. The seismic interpretations (figs 3, 4, 5) should include uninterpreted (clean) images.*

**Response:** Panels with uninterpreted seismic profile have been added to these three figures

**Comment 17:** *As presented – the images have very high vertical exaggerations. Is the deep normal fault in Fig 5 really dipping at just 25 degrees (as implied by this interpretation when at  $\sim v=h...$ )?*

**Response:** It should be noted that this regional profile is almost parallel to the Teisseyre-Tornquist Zone that separates East European Craton and the West European Platform so indeed at such intersection deep crustal-scale faults of this zone might have such geometry

**Comment 18:** *Figure 1 – please change the colours between extrusive and intrusive igneous rocks – they're too similar at the moment.*

**Response:** Corrected