Gravity and Seismic Tomography Joint Inversion: A synthetic study modelling magmatic massive sulphide-type bodies

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Introduction

Seismic methods provide high resolving potential for use in mineral exploration. Unfortunately, complicated hard-rock geology can make seismic data processing and interpretation difficult. The joint inversion of seismic tomography and gravity data may help overcome some of these difficulties. **We are investigating the viability of joint inversion of seismic first-arrivals and gravity data for the delineation of geological targets.**

Joint Inversion Methods

In our deterministic minimum-structure inversions, we minimize the objective function of Lelièvre et al. (2012):

$$\Phi(m_1, m_2) = \lambda_1 \Phi_{d1}(m_1) + \lambda_2 \Phi_{d2}(m_2) \ldots$$
$$+ \alpha_1 \Phi_{m1}(m_1) + \alpha_2 \Phi_{m2}(m_2) + \sum_j \Psi_j(m_1, m_2)$$

The two Φ_d terms measure the data misfit for each of the two datasets. The two Φ_m terms measure the amount of structure in each of the two physical property models, m_1 and m_2. The summed Ψ_j joint coupling terms measure the similarity between the two models in various ways. In this study, guided by physical property information (e.g. Figure 1), **we consider a linear relationship**

$$\Psi_1(m_1, m_2) = \sum_{k=1}^{M} (a m_{1,k} + b m_{2,k} + c)^2$$

and a coupling measure based on the fuzzy c-mean clustering approach of Paasche and Tronicke (2007)

$$\Psi_2(m_1, m_2) = \sum_{i=1}^{C} \sum_{k=1}^{M} w_{ik}^2 \left[(m_{1,k} - u_{1,i})^2 + (m_{2,k} - u_{2,i})^2 \right]$$

where M is the number of model cells, C is the number of clusters, u_1 and u_2 define the cluster centres, and the membership weights w_{ik} relate the physical property values for the kth cell to the ith cluster.

Earth Modelling

We are working with complicated, geologically realistic models. Two examples are presented in this poster. Both models consist of a magmatic massive sulphide body hosted in mafic intrusion which was intruded into a metamorphic footwall. The first model consists of mixed sulphides, troctolite, and gneiss (Figure 2a). The second consists of a pyrrhotite body, gabbro and quartzite (Figure 5a).

We discretize the geological models into triangular unstructured meshes, which allow for efficient generation of complicated geological structures. The meshing programs Triangle (Shewchuk, 2012) was used. Geophysical models are constructed by assigning physical property values to the different units (Figure 1), with the values taken from various sources (see Ash, 2007; Duff, 2007; Salisbury et al., 2003).

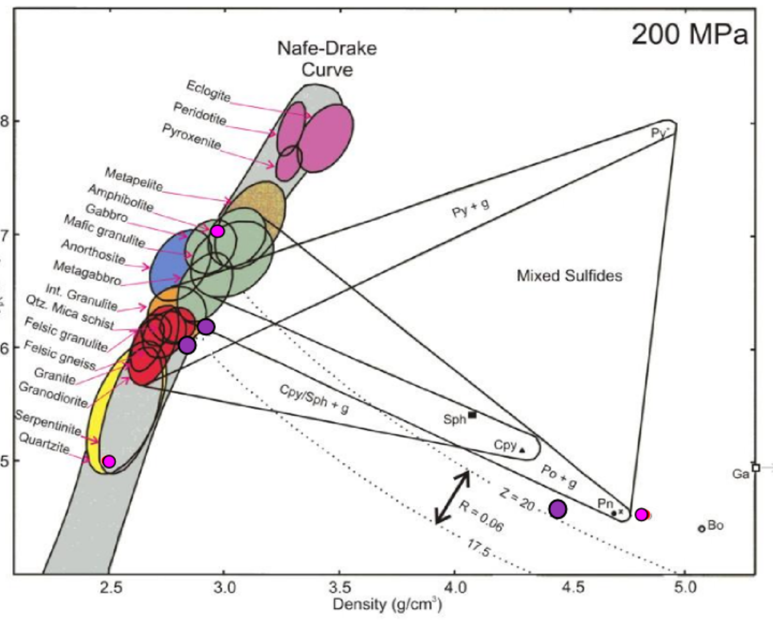

Figure 1: A velocity-density plot for common silicate rocks and sulphide minerals, showing the Nafe-Drake curve (grey), after Salisbury et al. (2003). The physical properties for Example 1 are plotted as purple dots and those for Example 2 are plotted as pink dots.

Example 1

The first-arrival ray paths for the first example (Figure 2b) tend to avoid the sulphide body because it is significantly slower than the surrounding units. Consequently, there is little first-order information about the slowness of the sulphides. The independent traveltime inversion (Figure 3d) underestimated the anomalous slowness values. The rays predicted by the inversion are therefore wrong and the inversion has trouble recovering the true shape of the sulphide body, especially the dipping top and bottom edges on the left side of the model. The independent inversion of downhole gravity data (Figure 3a) is able to recover a high density body, although it still fails to recover the true shape of the sulphide body due to the lack of resolution inherent to gravity data. By combining the travel time data with gravity in a joint inversion (Figure 3b,c,e,f), the recovered slowness is increased through its coupling with density and the inversion result is improved, especially the recovery of the dipping top and bottom edges of the left side of the sulphide body. In addition, the joint inversion adequately recovers the sulphides in the central region where there is no first-arrival ray coverage. Figure 4 shows the effect of the cluster coupling measures on the recovered physical properties.

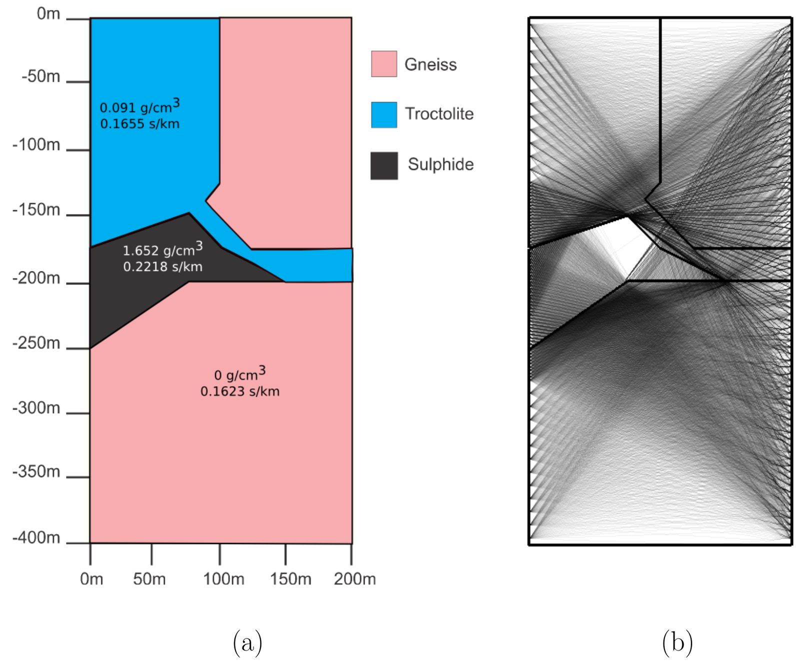

Figure 2: (a) The representative geological model for example 1: density values are relative to the background gneiss, which has absolute density 2.817 g/cc. (b) First-arrival ray traces through the true 2D slowness model.

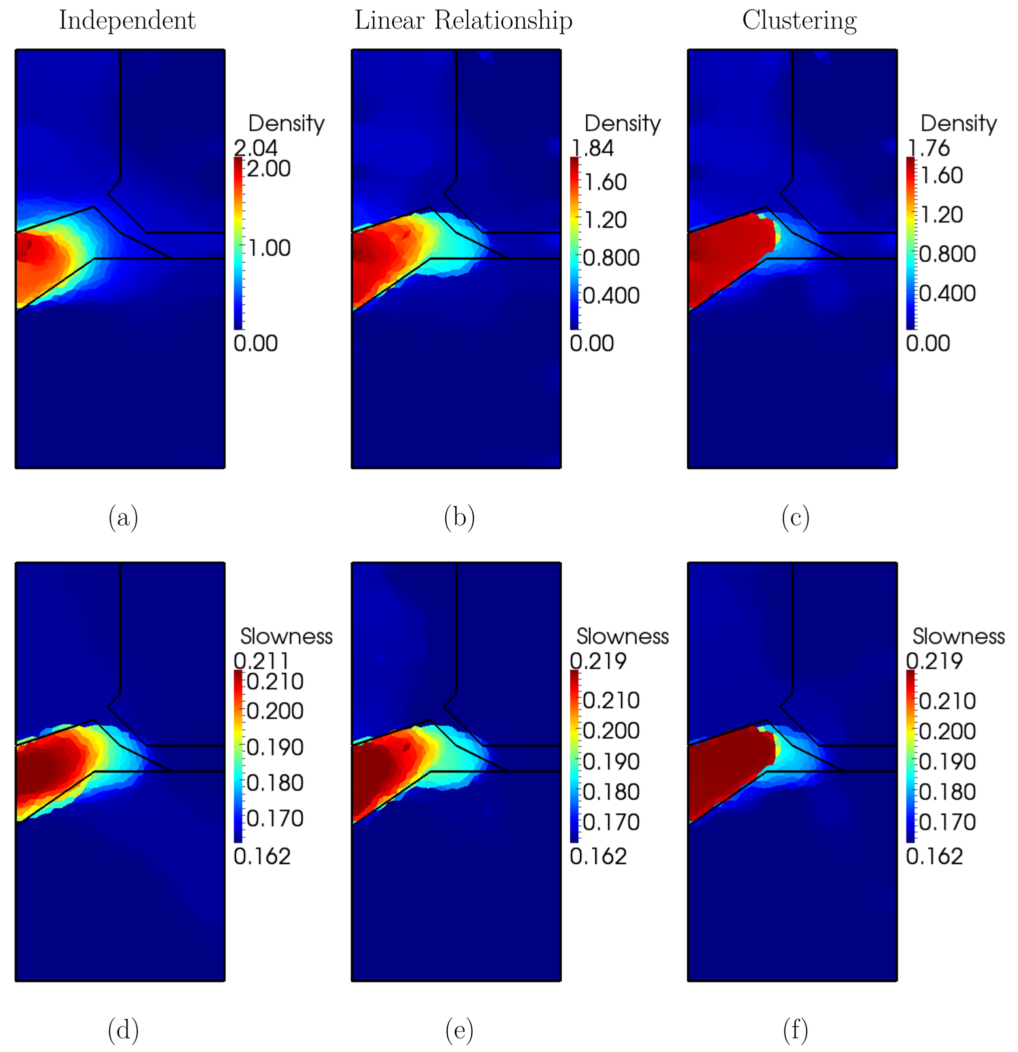

Figure 3: First example inversion results (relative density models at top in g/cc, slowness models at bottom in s/km) with no joint coupling (a and d), linear coupling (b and e) and additional cluster coupling (c and f).

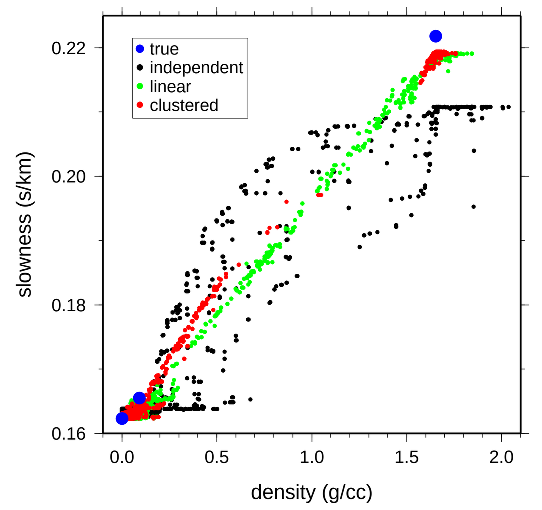

Figure 4: Recovered physical property scatter plot for the models in Figure 3.

Example 2

As in the first example the first-arrival ray paths for the second example (Figure 5b) tend to avoid the sulphide body. As such, the issue of sparsity of first-order information about the slowness of the sulphide body persists in this example. The independent traveltime inversion (Figure 6b) has located both the mafic intrusive and sulphide units. It has determined the shape of the gabbro well but has not been able to determine the true shape of the sulphide unit. The independent gravity inversion (Figure 6) has located the gabbro and sulphide units but has not determined their shapes well. The joint inversion using a cluster coupling method (Figure 6c,d) shows significant improvements from the independent inversions. Both the slowness and density models recovered have determined the location and shape of the gabbro body quite well and the resolution of the shape of the sulphide body has also been improved. Figure 7 shows the effect of the linear and clustering coupling measures on the recovered physical properties.

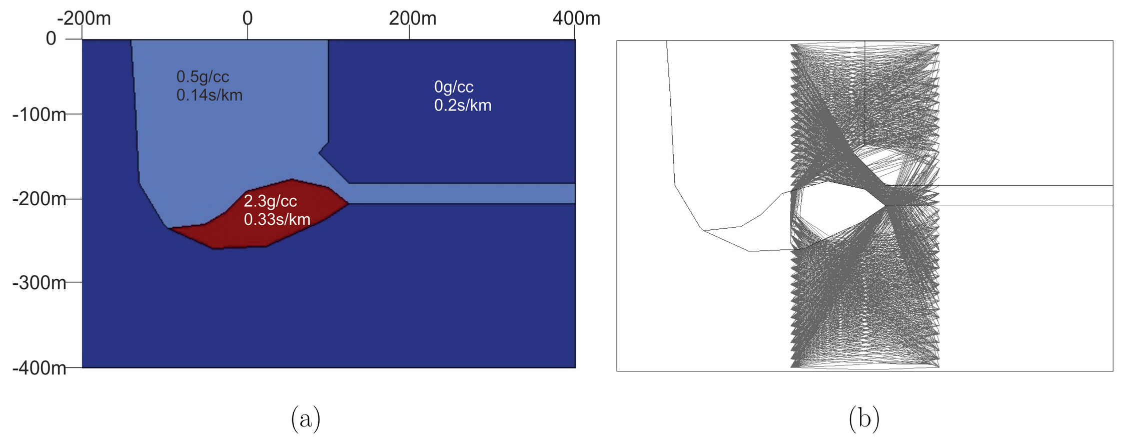

Figure 5: a) The representative geological model for example 2: density values are relative to the background gneiss, which has absolute density 2.3 g/cc. (b) First-arrival ray traces through the true slowness model.

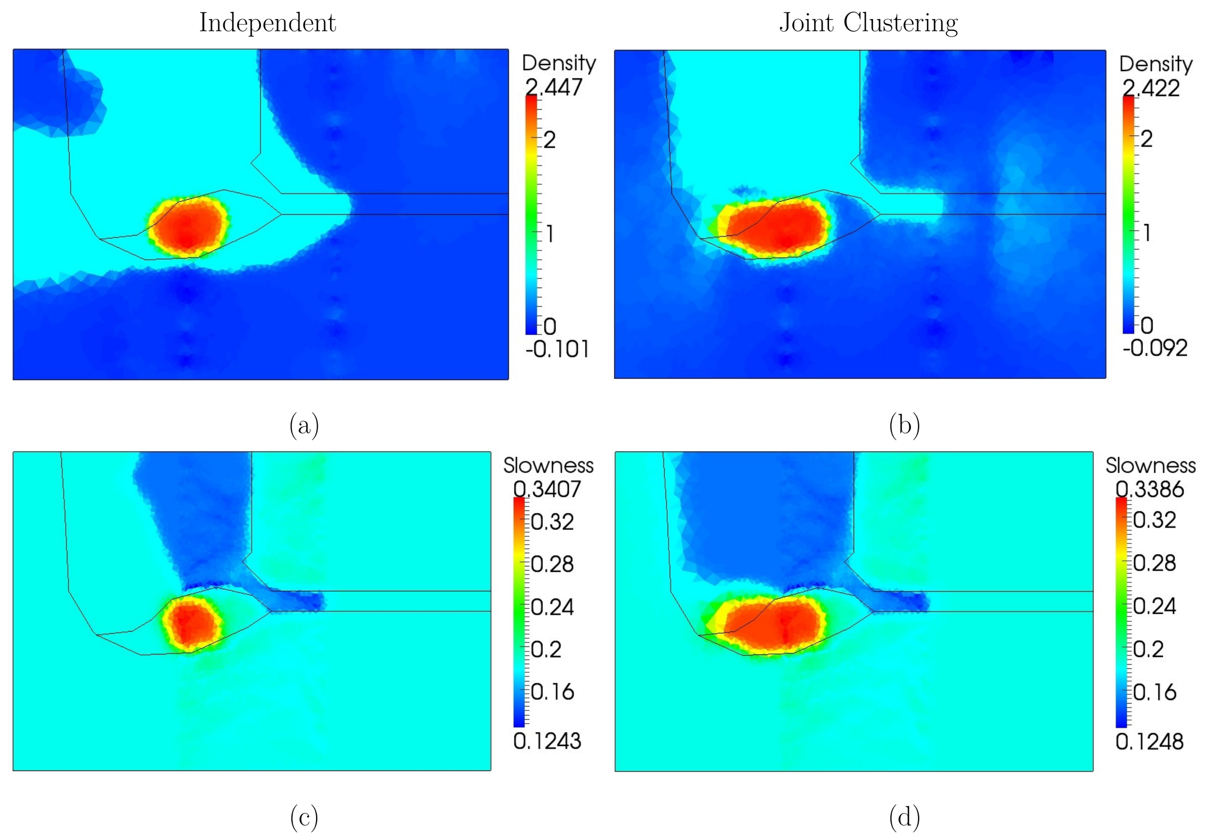

Figure 6: Results from the 2nd example inversions (relative density models at top in g/cc, slowness models at bottom in s/km) with no coupling (a and c), and cluster coupling (b and d).

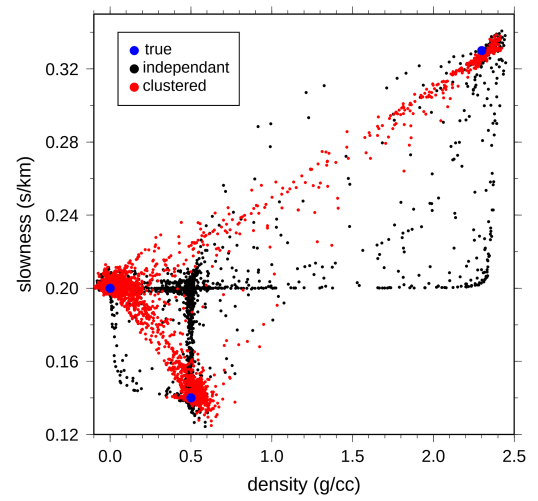

Figure 7: Recovered physical property scatter plot for the models in Figure 6.

Conclusion

These geologically realistic synthetic modelling examples have indicated some of the difficulties involved in using seismic traveltime data for mineral exploration particularly when the target body is significantly slower than the host rock. **The results show that joint inversion with gravity data is able to overcome some of these difficulties.** Different rock type distributions are best modelled using different coupling methods. If a quasi-linear relationship exists between the slowness and density a linear coupling method will suffice. **However, if the relationship deviates from a linear trend a cluster coupling method can be used to obtain good inversion results.**

Acknowledgements

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