An improved characterization of the subsurface in the Limerick Basin (Ireland) using deep generative model-based 2D gravity inversion constrained with drill hole and petrophysics data

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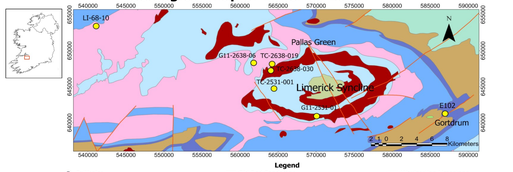
1. Introduction

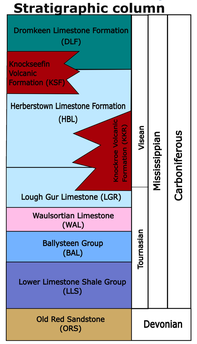
Background

Mineralization in the Limerick Basin, located in southwest Ireland, is uniquely associated with volcanic rocks—unlike other mineralized zones in the Irish Midlands, where mineral systems are typically linked to large-scale normal faults. To better model subsurface structures that may be spatially related to mineralization in this region, advanced subsurface visualization techniques are essential.

Geological map of Limerick Basin



Stratigraphic column

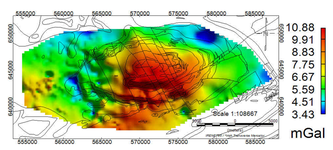


Objectives

- **Develop a petrophysically and geologically constrained gravity inversion framework.**
- **Apply this framework to field gravity data from the Limerick Basin to improve subsurface structural interpretation.**
- **Test multiple geological hypotheses to assess which hypothesis best explains the observed gravity anomalies.**

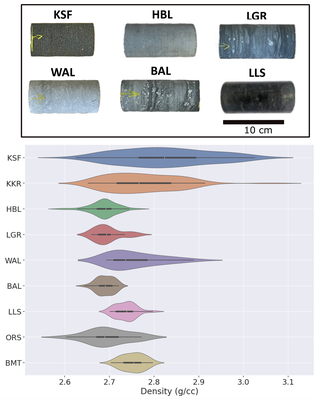
2. Datasets

Geophysics

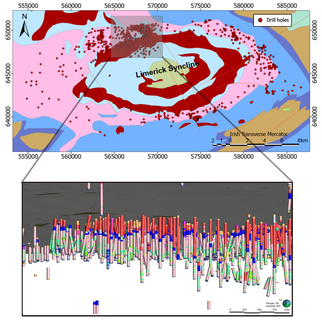


- **Merged Bouguer gravity anomaly data from DIAS and Group Eleven Resources Corp.**
- **The regional signal was removed to obtain the residual signal.**

Petrophysics



Drill hole data



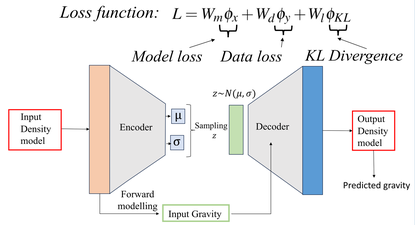
Drill hole logs retrieved from Limerick mineral exploration database.

3. Inversion using cVAE

Conditional Variational Autoencoder (cVAE) is a generative model formulated by Kingma and Welling (2013).

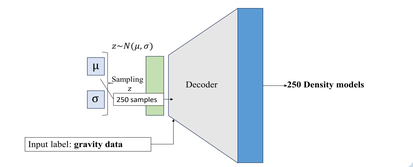
Training

- **The cVAE consists of three components- encoder, latent space, and decoder.**
- **During training the cVAE minimizes the loss function by reducing the reconstruction error between input and output density model governed by the model loss, input and the predicted gravity data governed by the data loss, and the deviation of the latent space distribution from normal distribution measured by the KL-Divergence.**



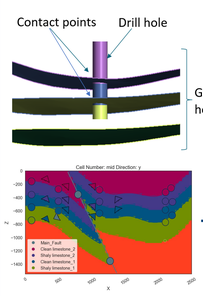
Gravity inversion

- **Once trained, only the latent space and the decoder network is used to invert the gravity data.**
- **We can sample as many latent vectors as we want from the latent space which is decoded by the decoder network into similar density models whose simulated gravity responses closely match each other.**

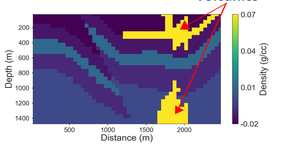


4. Synthetic study

Creating density model



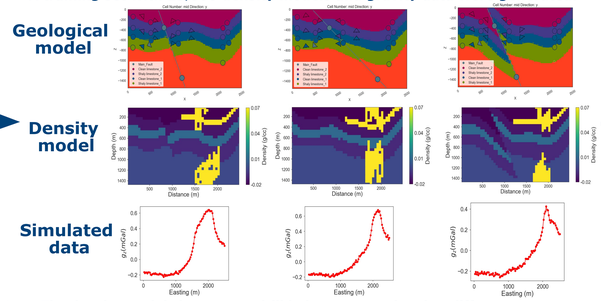
- **The contact points between drill holes and geological horizons were extracted.**
- **The contact points were kept fixed while the dip angles were randomly varied.**



The lithologies are replaced by densities analogous to the field petrophysics data.

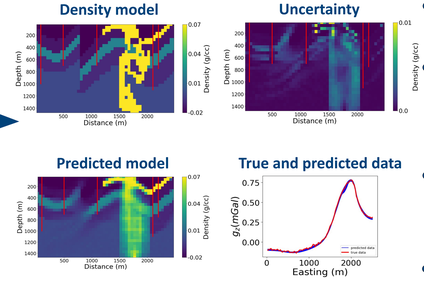
Training data generation

A training set with 25,000 density models and gravity data were generated.



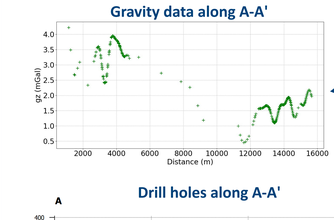
The density models have same drill hole contact points but different structures.

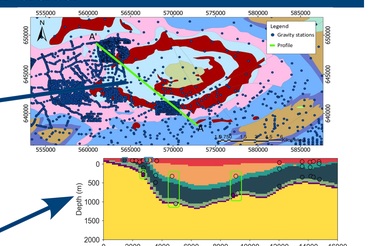
Inversion results



- **The predicted model is consistent with the true model.**
- **The densities of geological units and their predicted depths along the drill hole tracks (red line) are preserved.**
- **Uncertainty is highest at lithological boundaries, particularly at locations away from the drill holes.**
- **The predicted gravity data fits the true data well.**

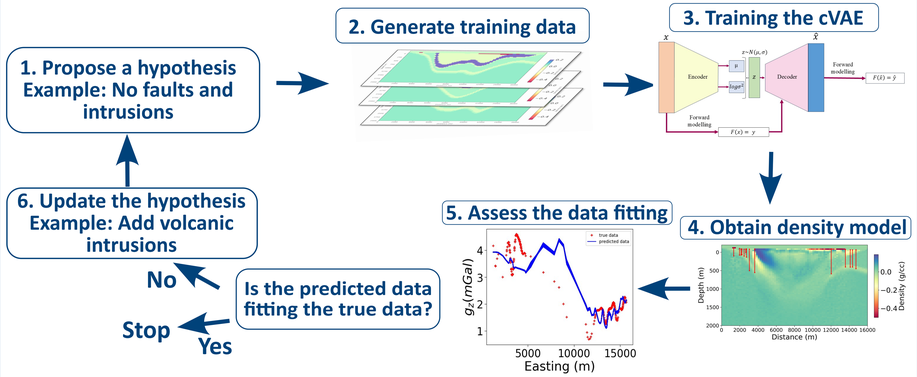
5. Field data





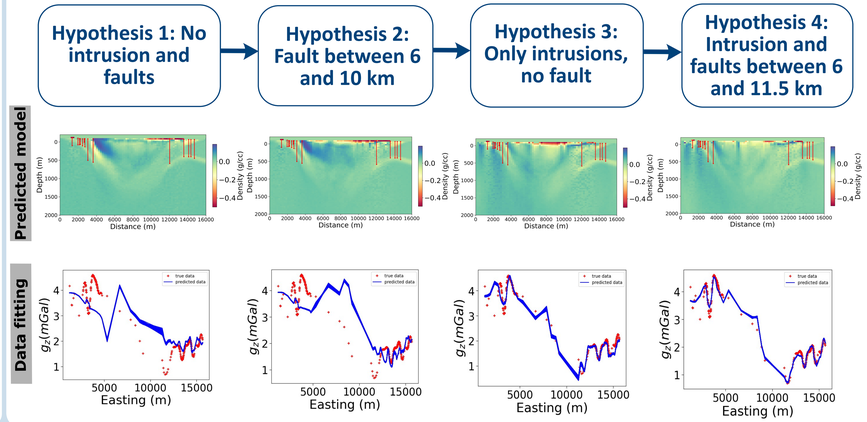
Geological models were generated from drill hole contact points.

6. Geological hypothesis testing



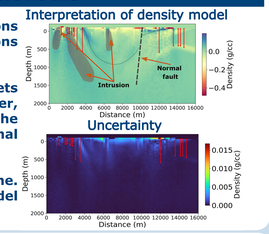
The geological hypotheses are iteratively refined and the cVAE is trained on the density models that obey the hypothesis. The hypothesis resulting in lowest data misfit is accepted.

7. Results



8. Discussions & Conclusions

- **The predicted density model reveals several volcanic intrusions between 0 and 8000 m, which align well with drillhole observations in that region.**
- **Inversion results from Hypothesis 4 indicate subtle vertical offsets around 9800 m, interpreted as a possible normal fault. However, due to the comparable data fit in both Hypotheses 3 and 4, the presence of this fault remains uncertain and requires additional drilling to confirm.**
- **Overall, uncertainty is highest at the center of the syncline. Acquiring new drillhole data in this area would enhance model accuracy and help reduce ambiguity in the interpretation.**



References

Kingma, Diederik P, and Max Welling. 2013. "Auto-Encoding Variational Bayes." https://doi.org/10.48550/ARXIV.1312.6114.

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