Optimizing Inversion for the Archean Orogenic Gold Environment

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➔ Using synthetic modeling to tailor inversions for exploration in Archean Orogenic Gold Environments

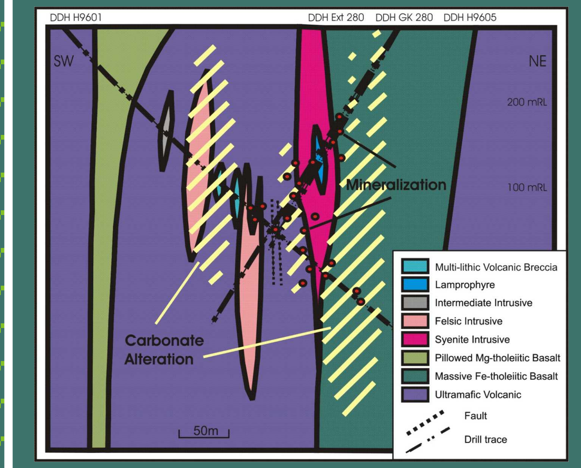
Purpose of study: to test the ability of inversion to recover expected subsurface features in the Archean orogenic gold environment.

Process: explore variations in model results from unconstrained and constrained inversions of synthetic data collected over a range of 3D geologic models representative of specific gold deposit settings.

Results of this work are expected to provide some guidelines for inverting geophysical data within an Archean orogenic gold setting, and gives an indication of the results that can be expected from inversions before and after basic geologic constraints are provided.

➔ Background

Geology



Northwest-facing cross section though the Hislop gold deposit

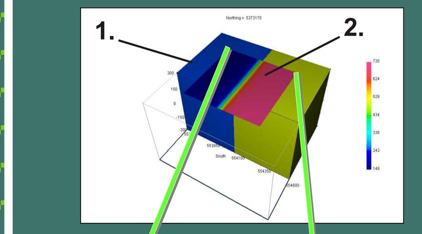
Geology and physical property information, and scales used in synthetic modeling, are based on a case study deposit - the Hislop gold deposit, SW Abitibi greenstone belt, Ontario.

Gold at Hislop has a spatial association with fault-controlled syenite dikes and carbonate alteration zones, both low susceptibility geologic features.

Because of these important relationships between geology and susceptibility, *magnetics* are the focus of this study.

Synthetic modeling process

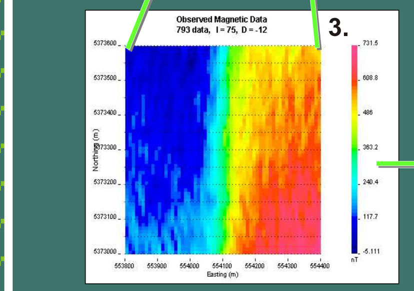
1. 3D geologic model is converted to a susceptibility model

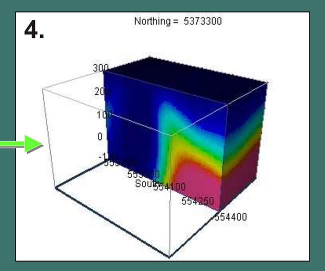


2. Susceptibility model is forward modeled to generate synthetic magnetic data

3. Noise and errors are added to the synthetic data

4. Data is inverted to yield the recovered inversion model



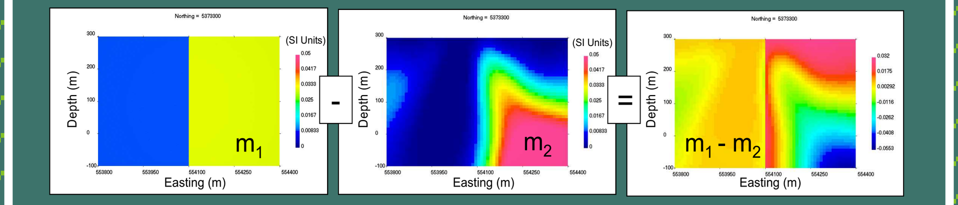


How good is the inversion result?

Closeness of the recovered model to the true model can be assessed by:

1. Calculating a L1 norm to determine a relative global measure of how well the model has been estimated $\sum|m_1-m_2|$ = L1 norm measurement

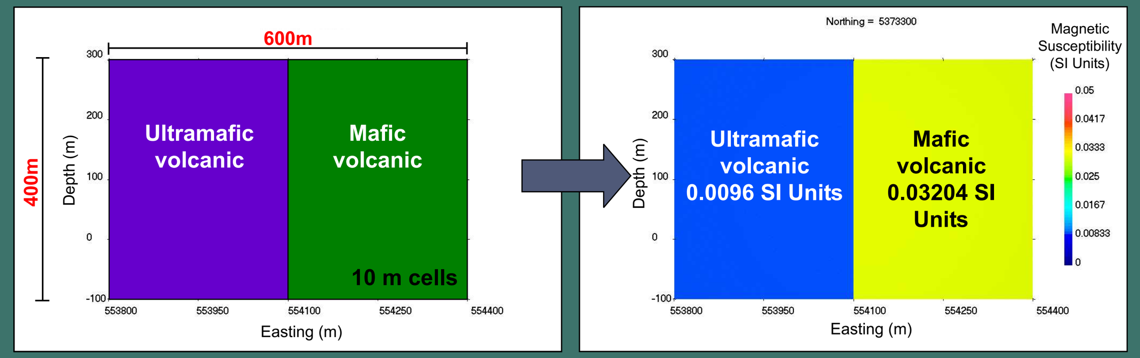
2. Subtracting one model from the other and viewing results to determine where the model is being most accurately estimated (see below)



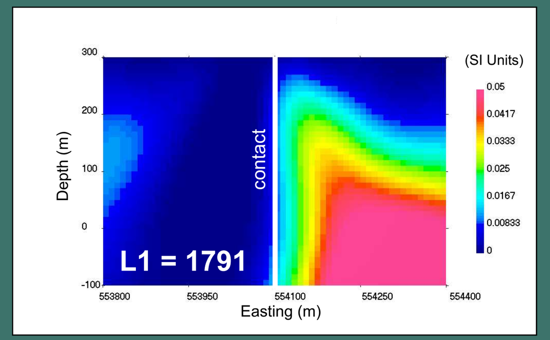
m_1= true model; m_2 = recovered inversion model

➔ Gold setting 1. "Faulted" contact model

North-facing cross section though 3D geological model — North-facing cross section though 3D physical property model



A geological model of a "faulted" contact between two different units, an ultramafic volcanic rock, and a mafic volcanic rock unit, is converted to a physical property model. This physical property model is referred to as the "true" model - the model which we hope to recover using inversion.



Default inversion parameters: reference model = 0 SI Units; bounds = 0 - 1 SI Units; alpha values = ax = ay = az = 1

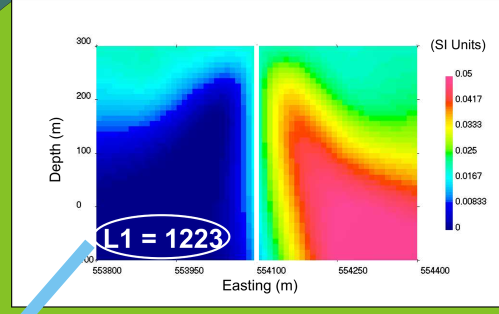
Default inversion result

The location of a faulted contact at this scale of inversion is predicted in its approximate correct location and continues to be well-located to depth. Surface cells incorrectly acquire the default reference model value of 0 SI Units. As the inversion requires a smooth result, contacts are blurred, and susceptibility values are only equilibrated at some distance from the contact.

Constrained inversions

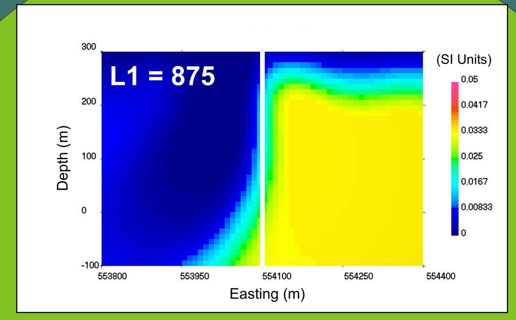
- Global constraints applied based on basic knowledge of physical properties and geology (specifically preferred structural orientations) from the region being explored

Inversion result with reference model set to 0.02 SI units (default value is 0 SI Units) — representative of known susceptibility values



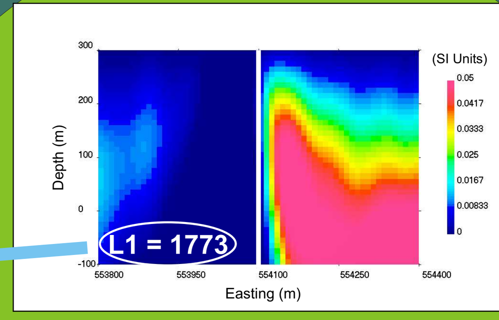
- More accurate susceptibility value estimates than default
- Location of contact well-estimated to depth
- Surface cells inaccurately assume reference value

Inversion result with bounds set from 0 - 0.035 SI Units (default bounds are from 0 to 1 SI Units) — representative of known susceptibility range



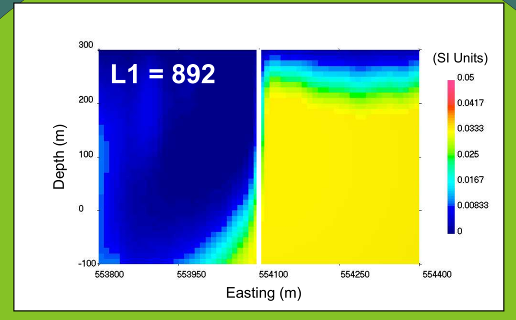
- Accurate susceptibility value estimates
- Geologically realistic model
- Location of contact well-esimated to about 300 m depth

Inversion result after αz and αy increased relative to αx ($\alpha z = \alpha y = \alpha x$ for default inversion). — directional weighting



- Contact sharper
- Unnecessary vertical exaggeration within model
- Susceptibility values no better estimated than default inversion result

Inversion result after bounds set from 0 - 0.035 SI Units AND αz and αy increased relative to αx.

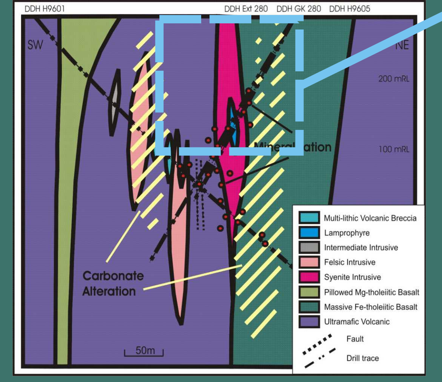


- Contact sharper
- From model difference (L1) value - result no better than model constrained solely by bounds
- Some unnecessary vertical exaggeration

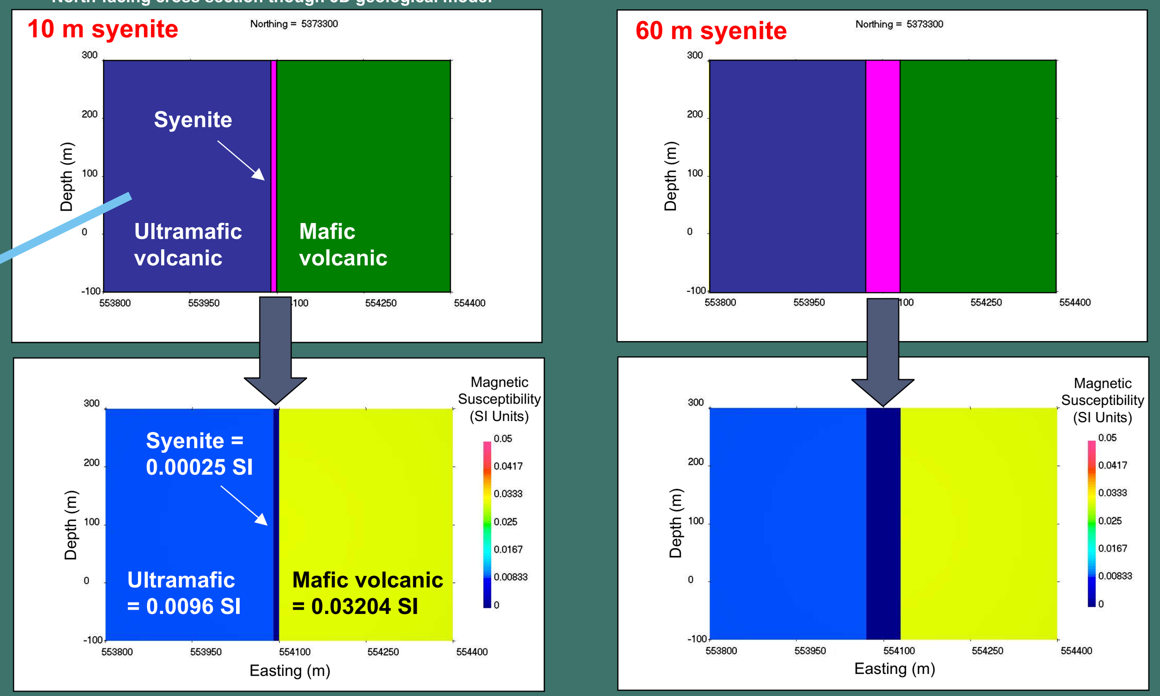
➔ Gold setting 2: Syenite dike model

The next synthetic models resemble a geological setting similar to that of the case study deposit, the Hislop gold deposit, with a syenite dike intruded along the contact between an ultramafic volcanic rock and a mafic volcanic rock. Susceptibility models are inferred from geology.

The results from inversion of magnetic data generated through forward modeling of the two syenite dike models (10 m and 60 m dikes) are compared to determine how well inversion can detect the different sized vertical intrusions.



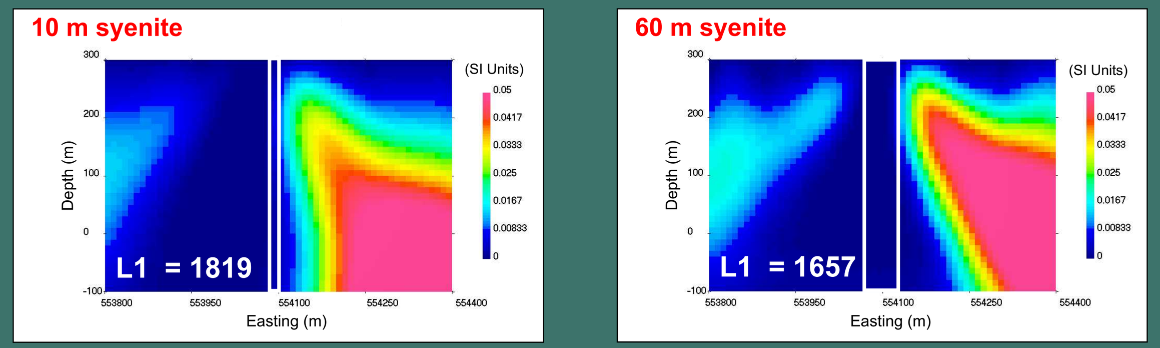
North-facing cross section though 3D geological model



North-facing cross section though 3D physical property model

Default inversion result

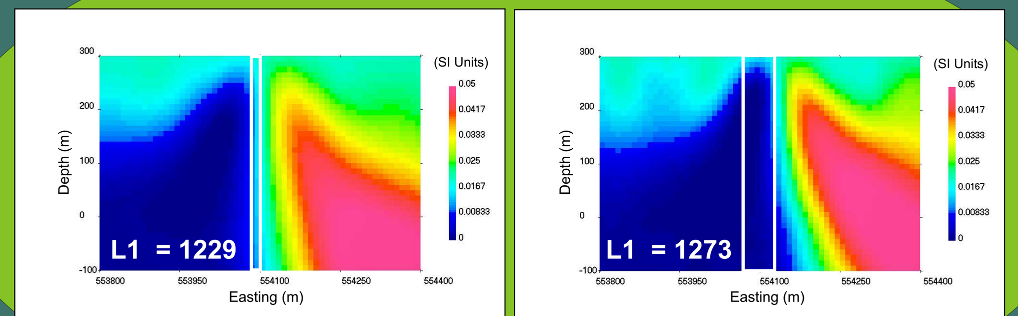
The 10 m syenite model is similar to the faulted contact model, and the narrow syenite is not detected. The 60 m syenite dike is detected near surface and may be mapped to only about 100 m depth, after which the syenite/ultramafic rock contact becomes smoothed out. Surface cells inaccurately assume reference model values (0 SI units).



Default inversion parameters: reference model = 0 SI Units; bounds = 0 - 1 SI Units; alpha values = ax = ay

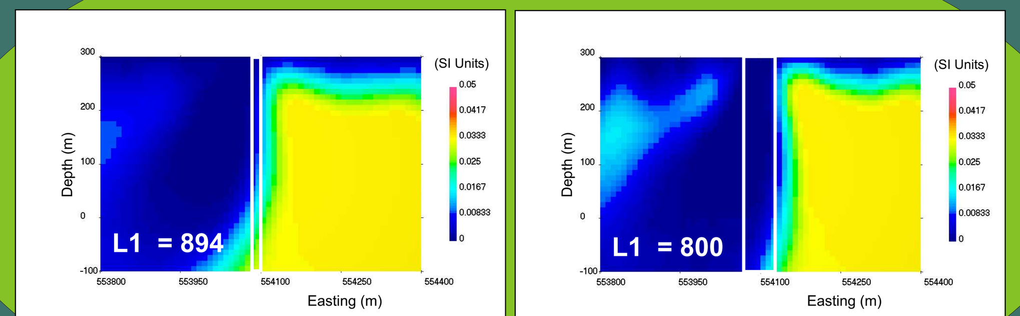
Constrained inversions

Inversion result with reference model set to 0.02 SI Units (default value is 0 SI Units)



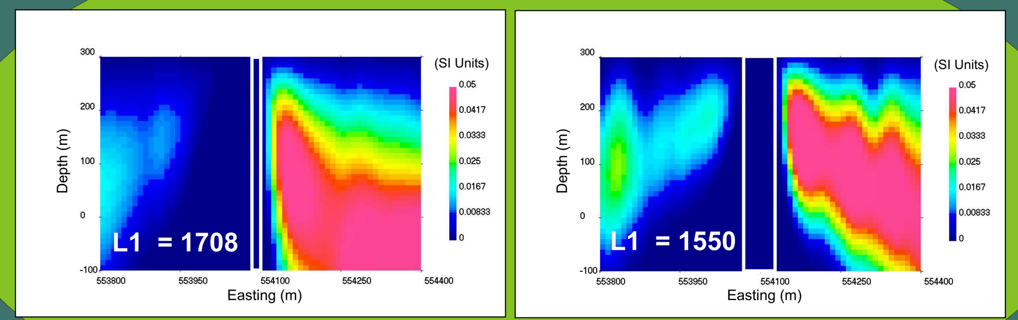
- More accurate susceptibility value estimates overall
- Location of syenite/mafic volcanic rock contact well-estimated
- Location of syenite/ultramafic rock contact only well-estimated near surface
- Surface cells inaccurately assume reference value

Inversion result with bounds set to 0 - 0.035 SI units (default bounds are from 0 to 1 SI Units)



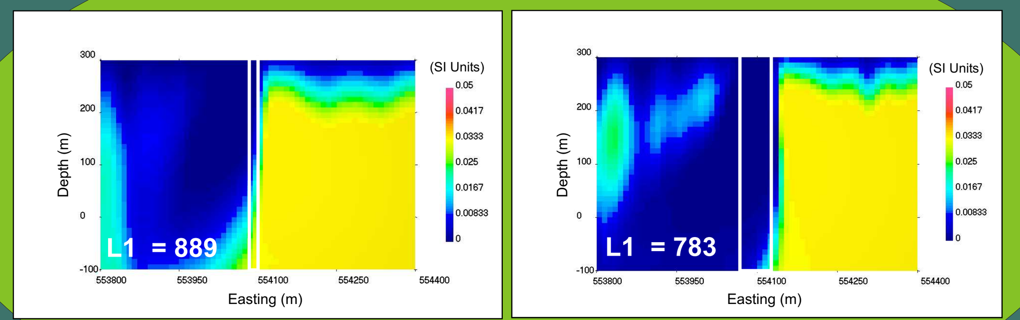
- Accurate susceptibility value estimates
- Geologically realistic models
- Location of syenite/mafic volcanic rock contact well-estimated
- Location of syenite/ultramafic rock contact poorly estimated at depth

Inversion result after αz and αy increased relative to αx ($\alpha z = \alpha y = \alpha x$ for default inversion).



- Syenite/mafic volcanic rock contact is sharper
- Syenite/ultramafic rock contact is better located to a greater depth
- Causes unnecessary vertical exaggeration
- Susceptibility values no better estimated than default model

Inversion result after bounds set to 0 - 0.035 SI Units AND αz and αy increased relative to αx.



- Syenite/mafic volcanic rock contact sharper, especially near surface.
- From model difference (L1) value - result no better than model constrained solely by bounds
- Vertical exaggeration

➔ Conclusions

Are features typical of Archean orogenic gold deposit environments imaged using unconstrained inversion?

- Vertical contacts across which there is a significant susceptibility contrast are located to depth.
- A 10 m low susceptibility syenite located between ultramafic and mafic volcanic units is not detected at this scale. A 60 m syenite is well-located near the surface of the models, but poorly located at depth. The syenite/ultramafic rock contact is less well-located due to a lack of susceptibility contrast.
- In all models, surface cells incorrectly acquire default reference model values (0 SI Units).
- Discrepancies between the true and recovered models are due to inversion sensitivities, depth weightings written into the inversion code, and choice of model norm used.

Does constraining inversions improve the result?

L1 norm values for each of the model results shown in this poster, and for additional model results with varying constraints, are displayed in Table 1. The results are consistent for the range of models, and indicate that:

- Setting a reference model close to known susceptibility values improves the accuracy of the values estimated in the recovered model
- Setting bounds on susceptibility, based on known susceptibility ranges, results in the most accurately estimated models (lowest L1 values)
- Setting alpha values in addition to bounds does not improve on models where bounds alone are set

Table 1. Model Differences (L1 norm measurement between true and recovered models)

Model name	Faulted contact model	Syenite dike model (10 m)	Syenite dike model (20 m)	Syenite dike model (60 m)
Default model				
Reference mod. = 0 SI; *Bounds* = 0 - 1 SI; *ax = ay = az* = 1	1790.80	1818.60	1781.70	1656.90
Constraints				
Reference model (SI Units) — Relative L1 norm measurements slightly lower than default				
0.01	1412.20	1438.50	1436.60	1335.40
0.02	1222.50	1228.70	1243.10	1273.10
0.03	1181.10	1213.70	1232.40	1315.00
0.04	1568.30	1591.60	1602.10	1635.70
Bounds (SI Units) — Relative L1 norm measurements lowest				
0 - 0.025	1262.20	1287.90	1310.50	1166.90
0 - 0.03	873.28	909.79	932.56	1029.80
0 - 0.035	875.16	893.62	906.04	799.92
0 - 0.04	1142.20	983.31	1002.60	1109.10
Alpha values (x,y,z) — Relative L1 norm measurements similar to default				
1, 10, 10	1764.50	1747.80	1707.90	1573.60
1, 100, 100	1772.80	1707.60	1644.30	1549.50
1, 1000, 1000	1755.80	1677.70	1603.20	1545.10
Combinations — Relative L1 norm measurements similar to results from use of bounds only				
ay=az=10, bounds 0 - 0.035 SI Units	907.39	925.89	946.11	782.40
ay=az=100, bounds 0 - 0.035 SI Units	892.09	888.94	904.51	783.22

➔ Suggestions

- Depth weightings (Li and Oldenburg, 1996), and application of "blocky" inversions (Farquharson, and Oldenburg, 1998), may be experimented with to alleviate problems with incorrect estimation of susceptibility values near surface, and smoothing across vertical contacts.
- There is always some information available that can be used to constrain inversion results. Addition of any physical property information whatsoever will improve the result (both numerically and geologically) to some degree.

Acknowledgements : The Mineral Deposit Research Unit - Geophysical Inversion Facility (MDRU-GIF) collaborative project at the University of British Columbia was sponsored by Tech Cominco, Ltd., INCO, WMC Resources Ltd., Kennecott Exploration, Anglo American, Plc, AngloGold Ashanti Ltd., Barrick, Geoinformatics Exploration, and Xstrata. Matching funds were provided by NSERC. A NSERC (2004-2006) Post-Graduate Scholarship was awarded toward work on this sub-project of the MDRU-GIF project. Input on various aspects of this research from Dick Tosdal, Nick Williams, Victoria Sterritt, Peter Lelievre, Claire Chamberlain, and Ken Hickey is gratefully acknowledged.

References:

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