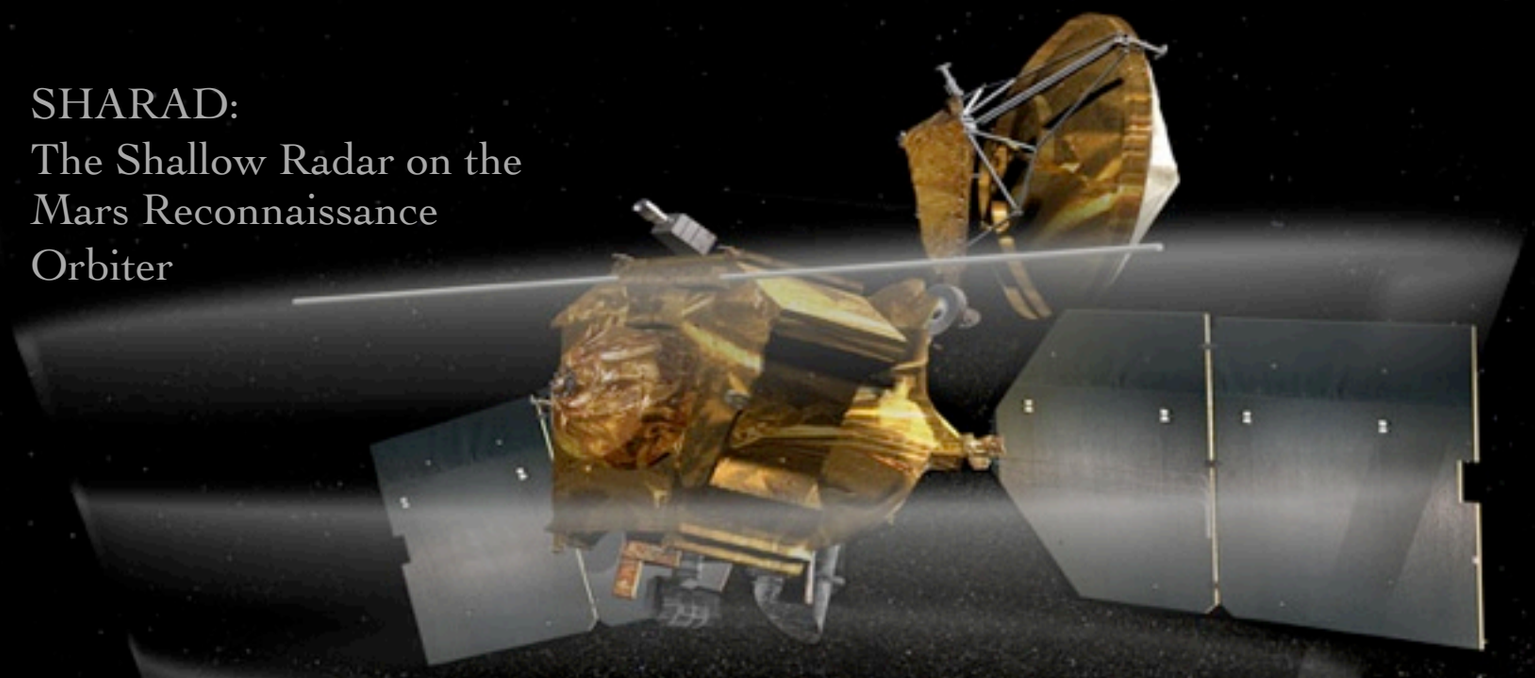
New Views of Planum Boreum Interior in a Migrated 3D Volume of SHARAD Data



SHARAD:
The Shallow Radar on the Mars Reconnaissance Orbiter

Than Putzig[1], Fritz Foss[2], Bruce Campbell[3], and Roger Phillips[1]

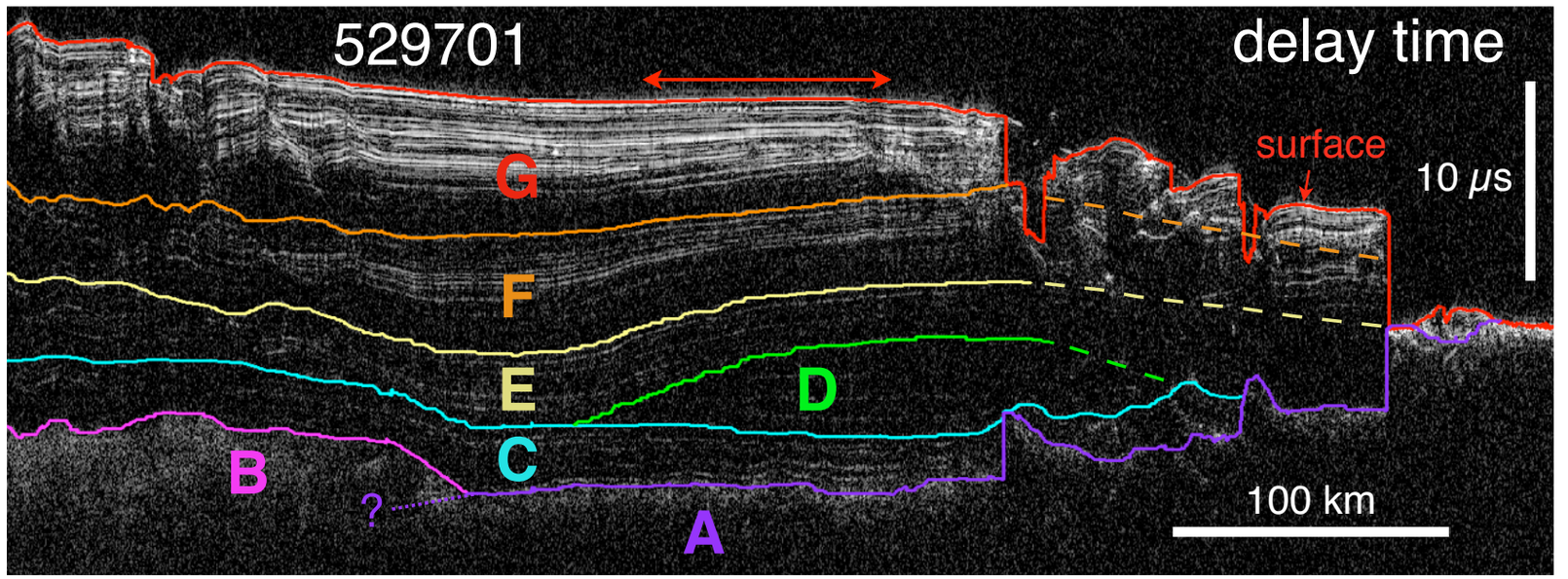
[1]Southwest Research Institute, Boulder, Colorado
[2]Freestyle Analytical & Quantitative Services, LLC, Longmont, Colorado
[3]National Air & Space Museum, Smithsonian Institution, Washington, D.C.

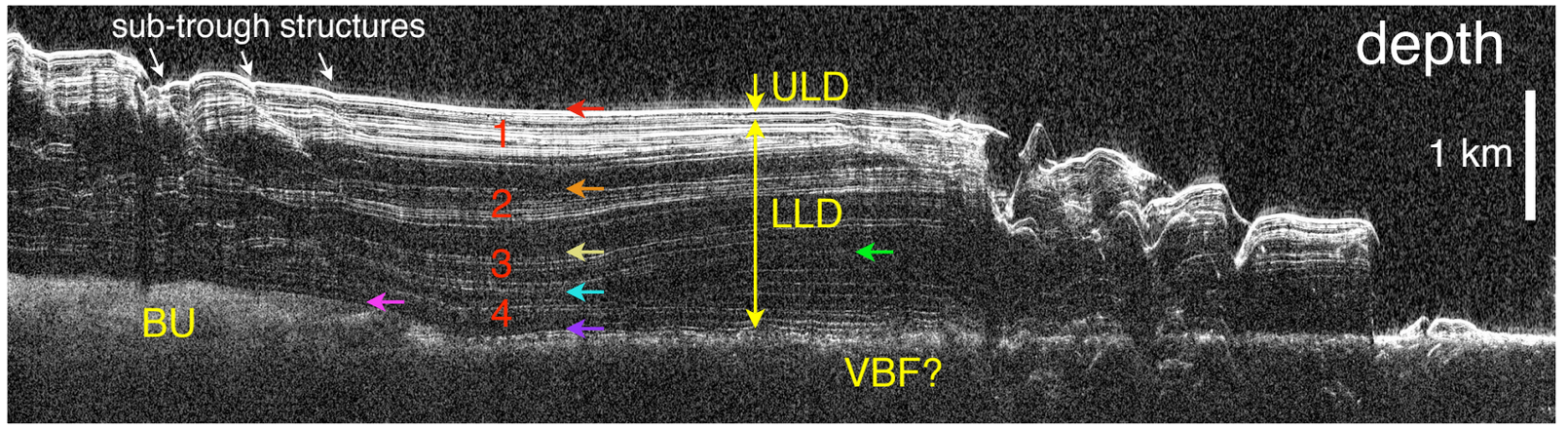
8th International Conference on Mars

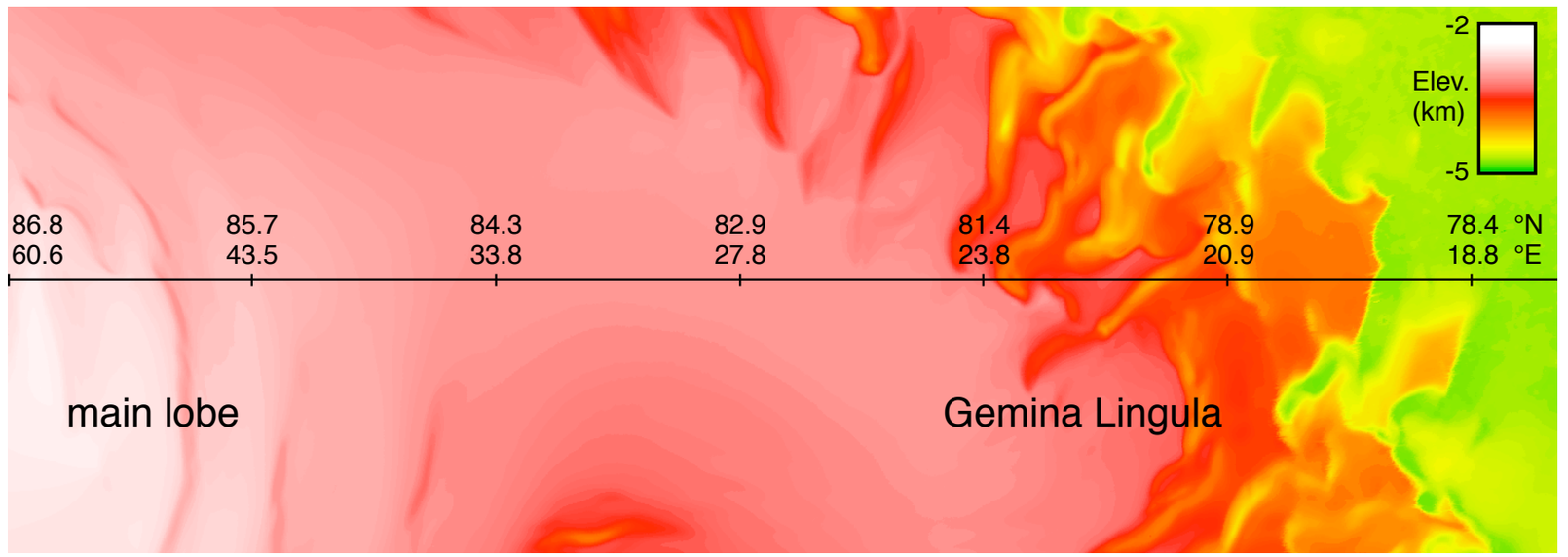
Image credit: NASA/JPL

2D SHARAD analysis

- Delineate units and reflectors.
- Interpolate through clutter and between orbital tracks.
- Map reflecting surfaces in 3D, calculate volumes.
- Drill, baby, drill!





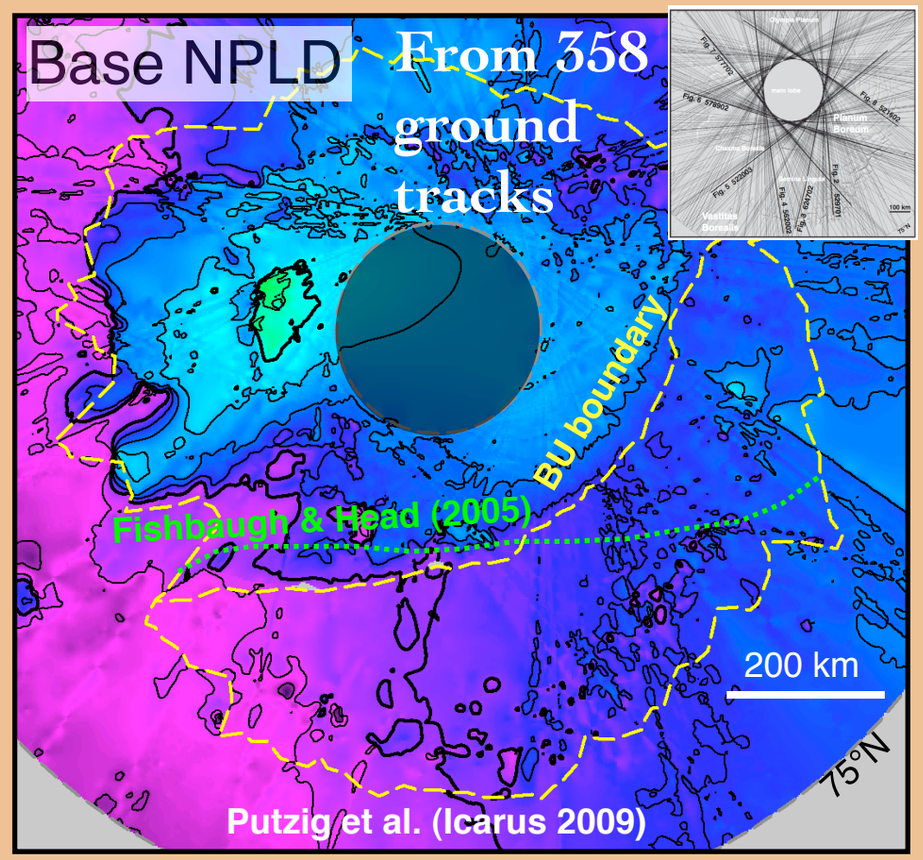


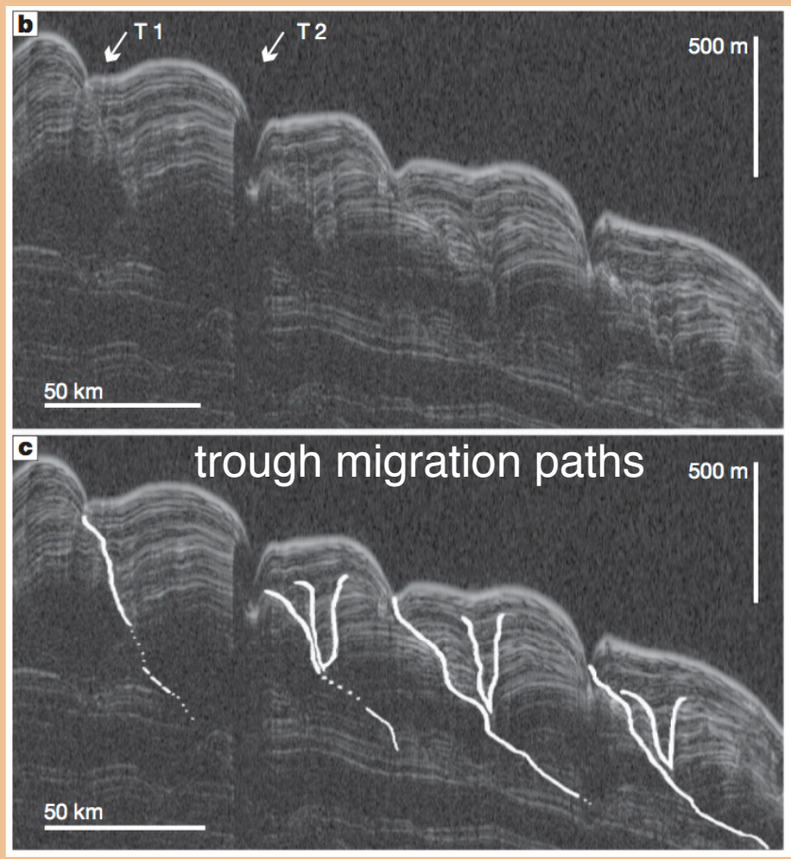
Putzig et al. (Icarus 2009)

2D SHARAD analysis is yielding great results!

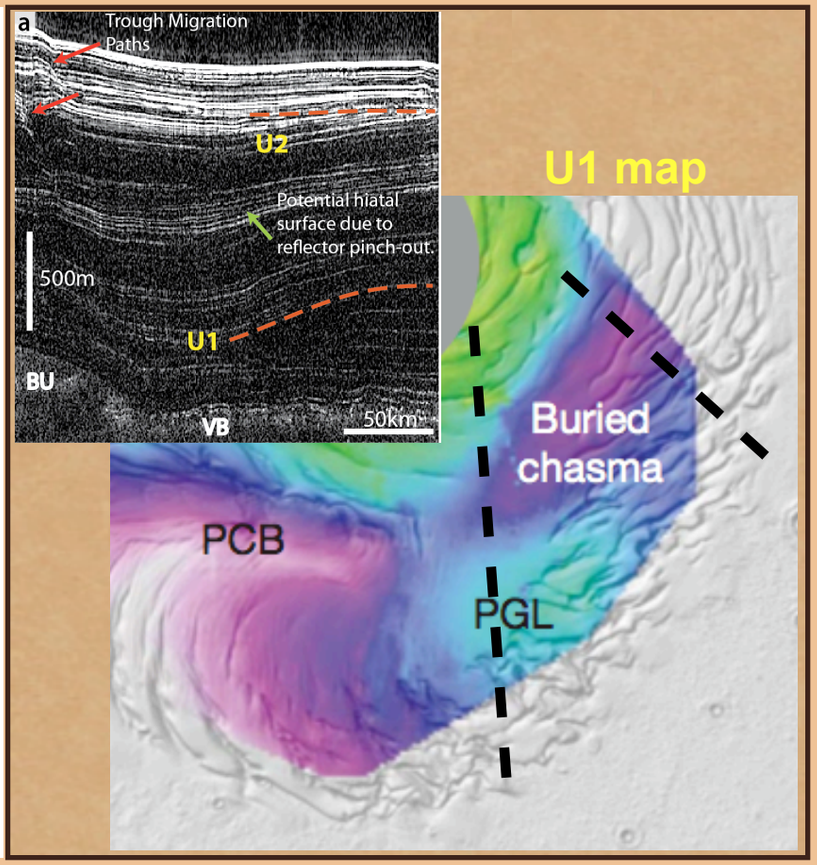
- Revised BU boundary rewrites Chasma Boreale history—it's constructional, not erosional.
- Spiral troughs proven to be wind-driven icy bedforms.*
- Buried chasma with no surface expression is revealed!

* *See next talk by Isaac Smith*





Smith and Holt (Nature 2010)

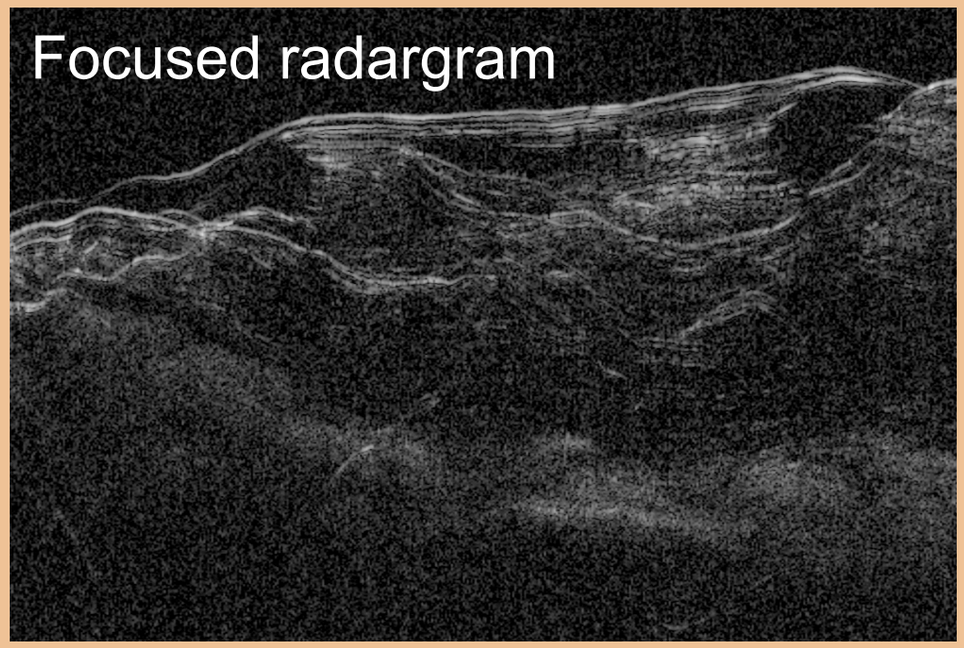


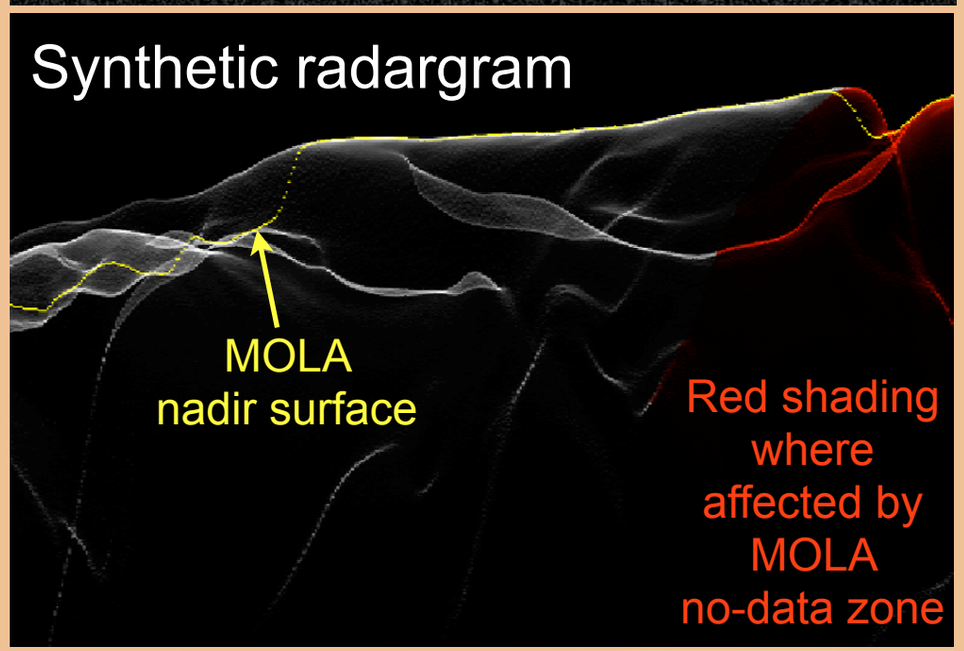
Holt et al. (Nature 2010)

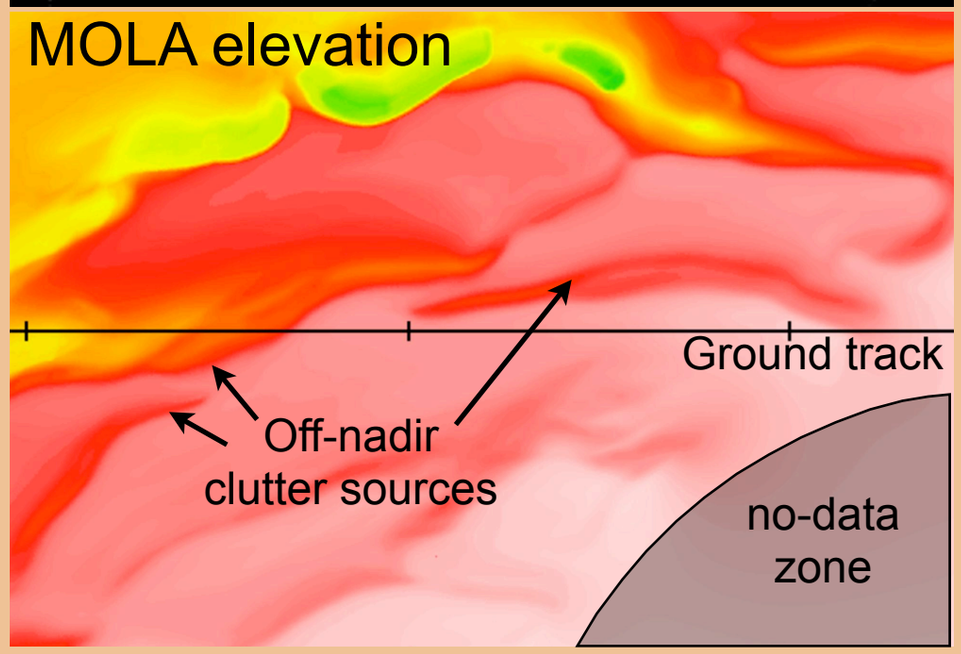
Limitations of 2D SHARAD analysis

- No returns from features at nadir that slope away from the radar.
- Off-nadir returns (clutter signals) interfere with or are mistaken for nadir returns. Synthetics help identify surface-clutter signals, which are then dismissed as "noise".
- In many areas, intense clutter makes the data largely uninterpretable.

Mapping features at depth is often challenging and tedious.





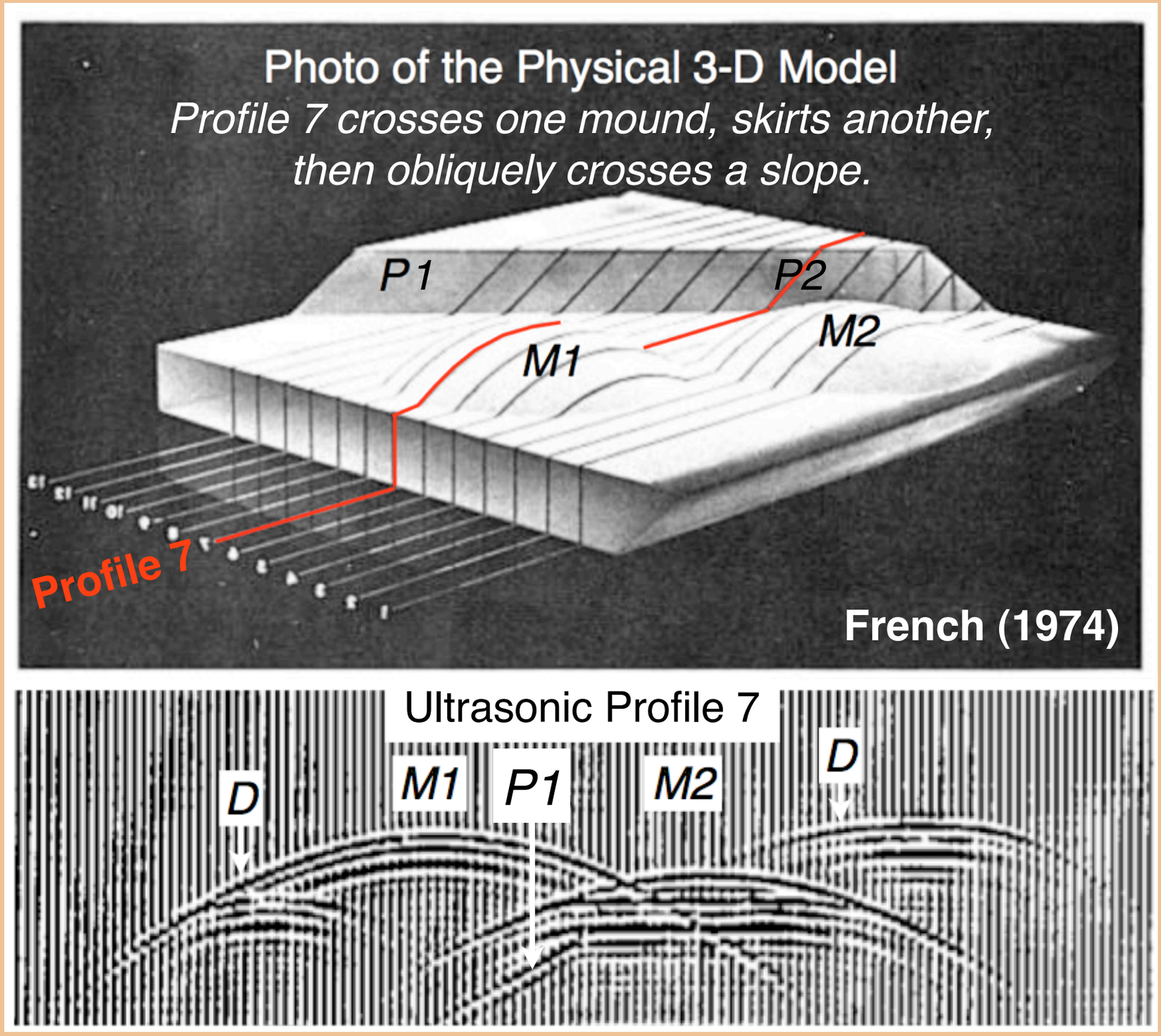


Inherent problem: 2D sampling of a 3D signal returned from a 3D structure

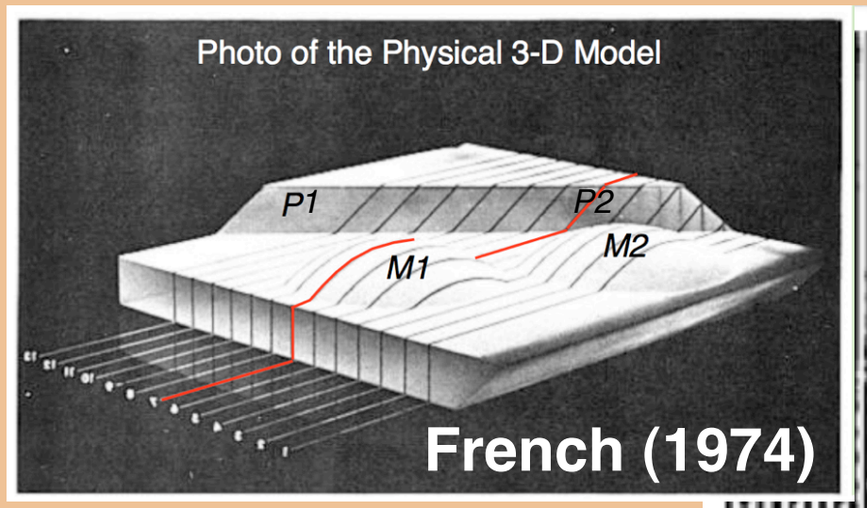
Diffractions (D) occur at edges of slope breaks.

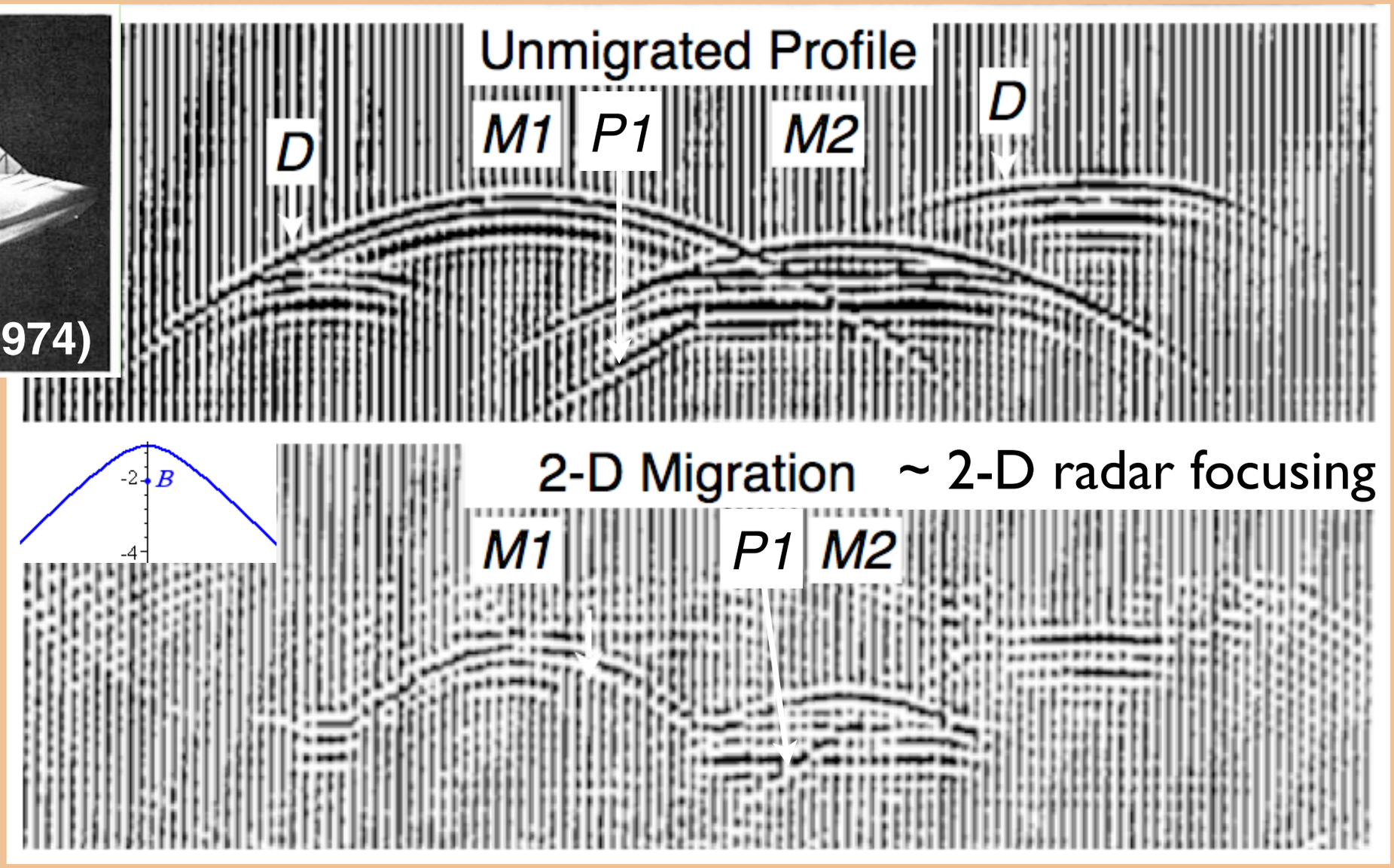
Clutter from out-of-plane structures (**M2, P1**) interferes with nadir returns.

No returns from features oriented obliquely to the profile **(P2)**.



Incomplete solution: Apply 2D migration*



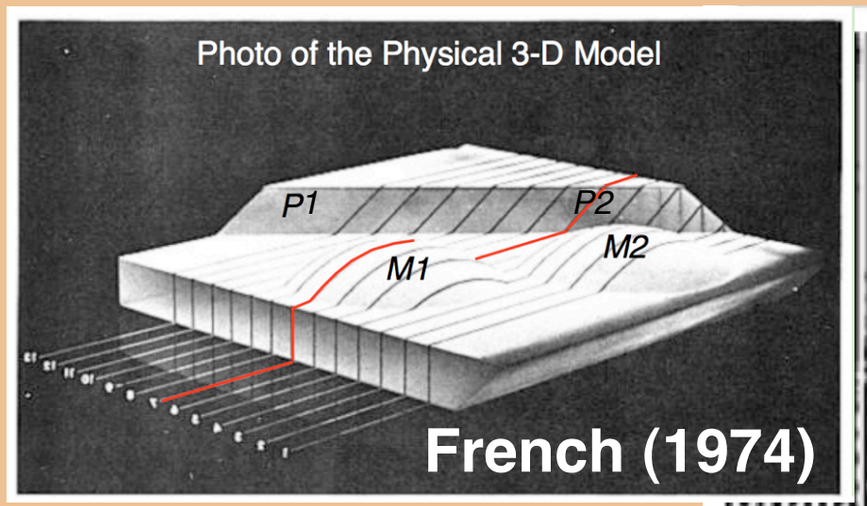


2D migration **collapses inline diffractions (D),** but it **misspositions out-of-plane returns (M2, P1).**

*Migration works in a moving window of data, summing values along an operator (in 2D, a hyperbola in a constant-velocity medium), essentially treating each point in the dataset as a potential diffractor.

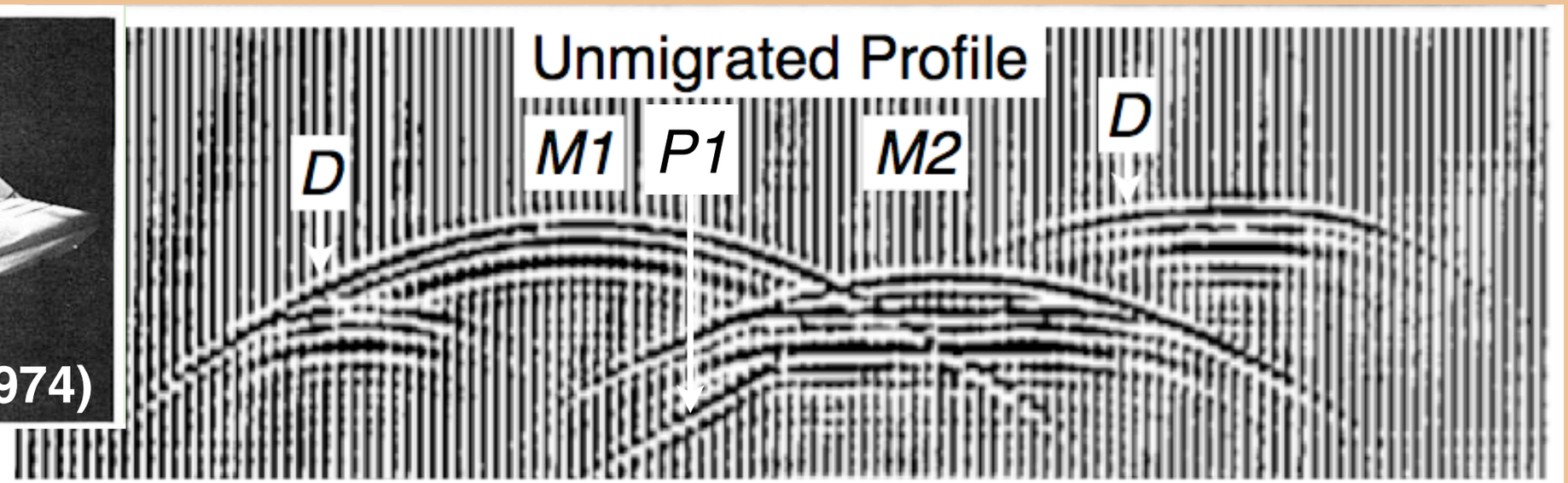
Usage note: *Migration* in processing is unrelated to trough *migration*!

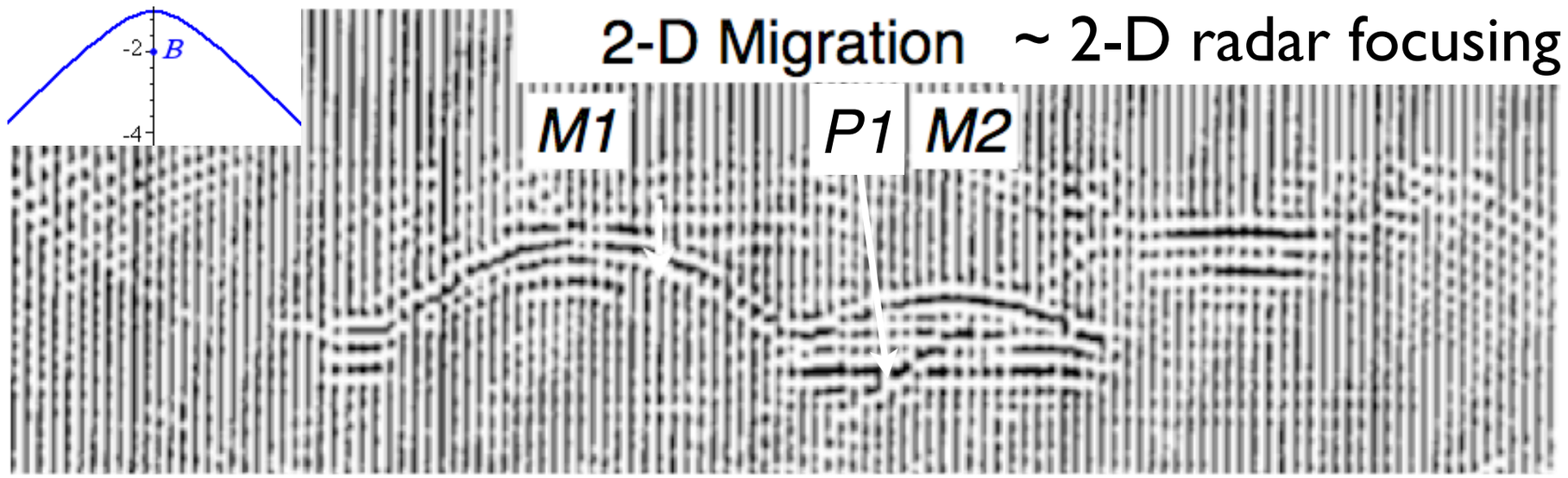
Full solution: Apply 3D migration to all data

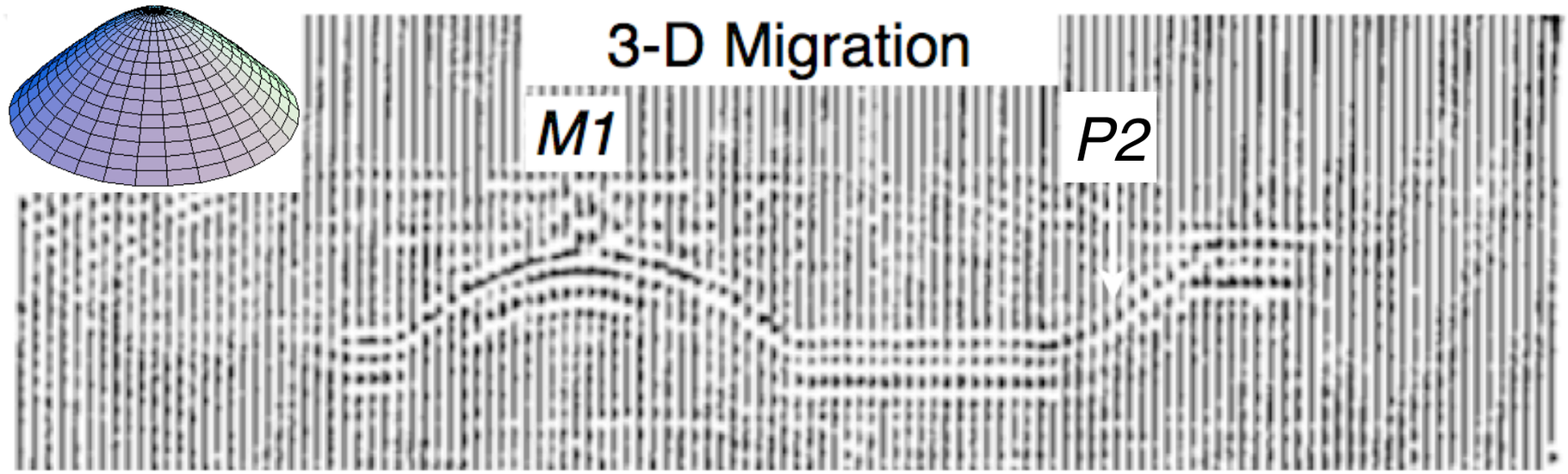


3-D migration will **collapse diffractions (D)** and **reposition out-of-plane returns (M2, P1)** to their source locations.

Energy from adjacent profiles will be restored, thereby **imaging features oriented obliquely to the profile (P2).**







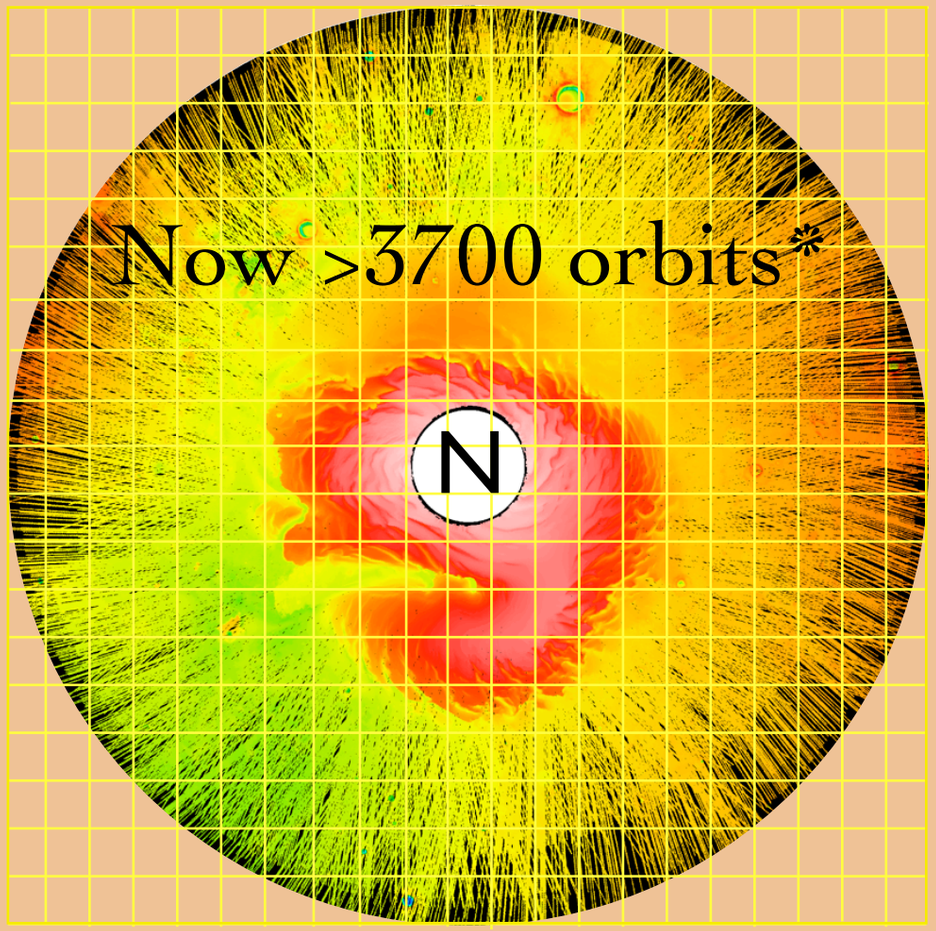
Creating a 3D volume from the 2D SHARAD data

- Apply 2D Doppler processing & autofocusing to correct ionospheric phase distortions.
- Apply demigration to reverse the 2D focusing.
- Adust the demigrated radargrams **to a common datum*** and bin them into a rectilinear grid.

* *Datuming step is complicated by along-track variable delays in the ionosphere.*

See Campbell et al. (GRSL 2014)

Coverage 70–87°N
(in MOLA elevation)



* 3-D grid covers 6073 × 5489 km, **133 million bins** of 500 × 500 m, including 1579 observations.

Larger than any terrestrial 3-D survey!

Planum Boreum base map

3-D volume grid

(9 million central bins)

Basal unit extent

2-D observation

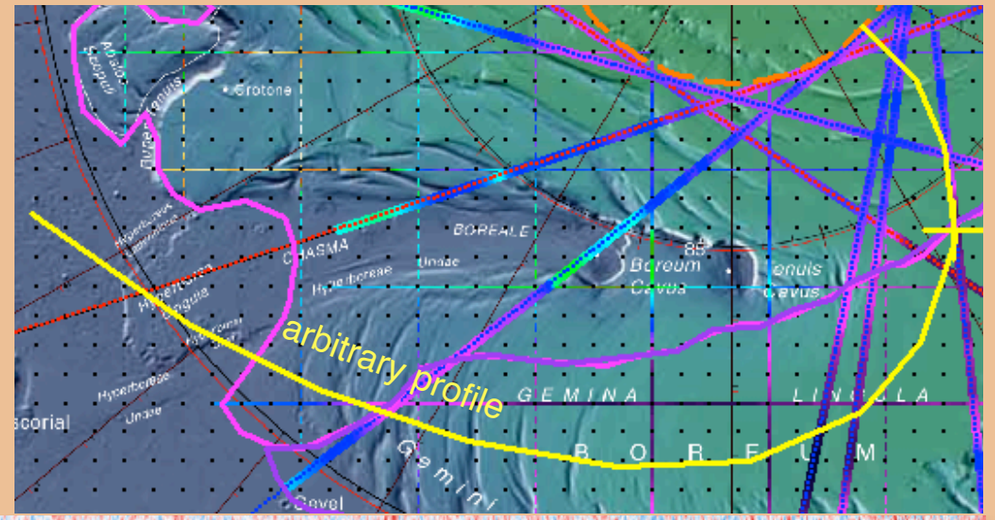
arbitrary profile

93 Basal delay time μs 108

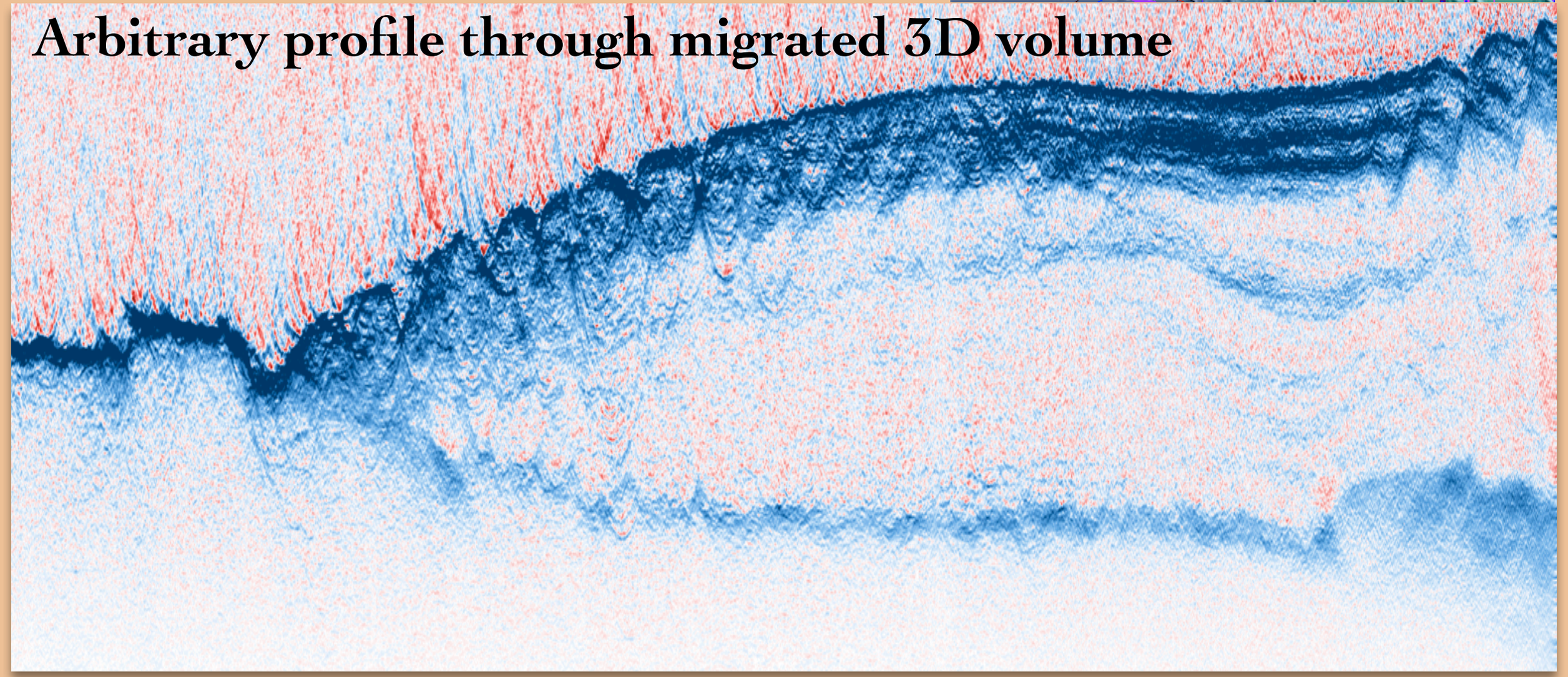
over MOLA color shaded relief

3D allows new perspectives

- Transect along Gemina Lingula apex provides a view of the data orthogonal to most of the troughs.



Arbitrary profile through migrated 3D volume



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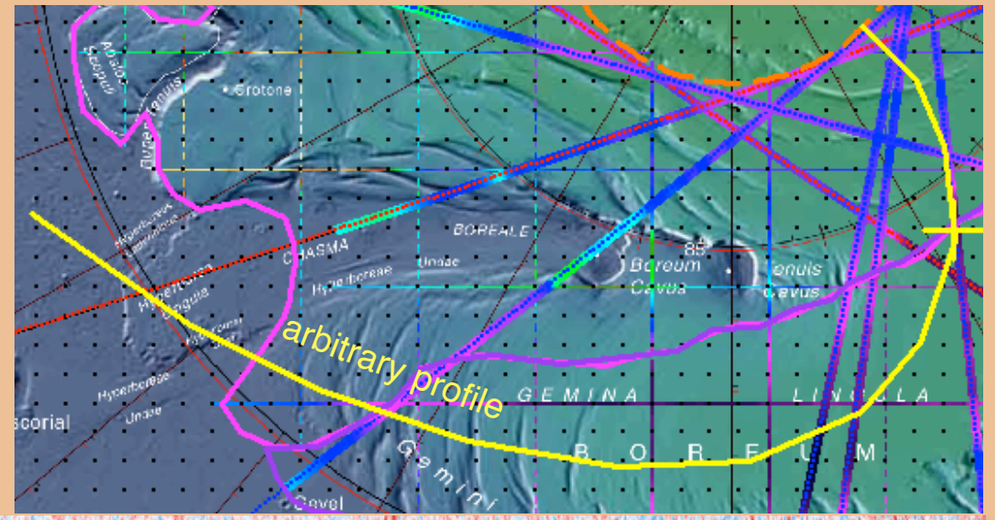

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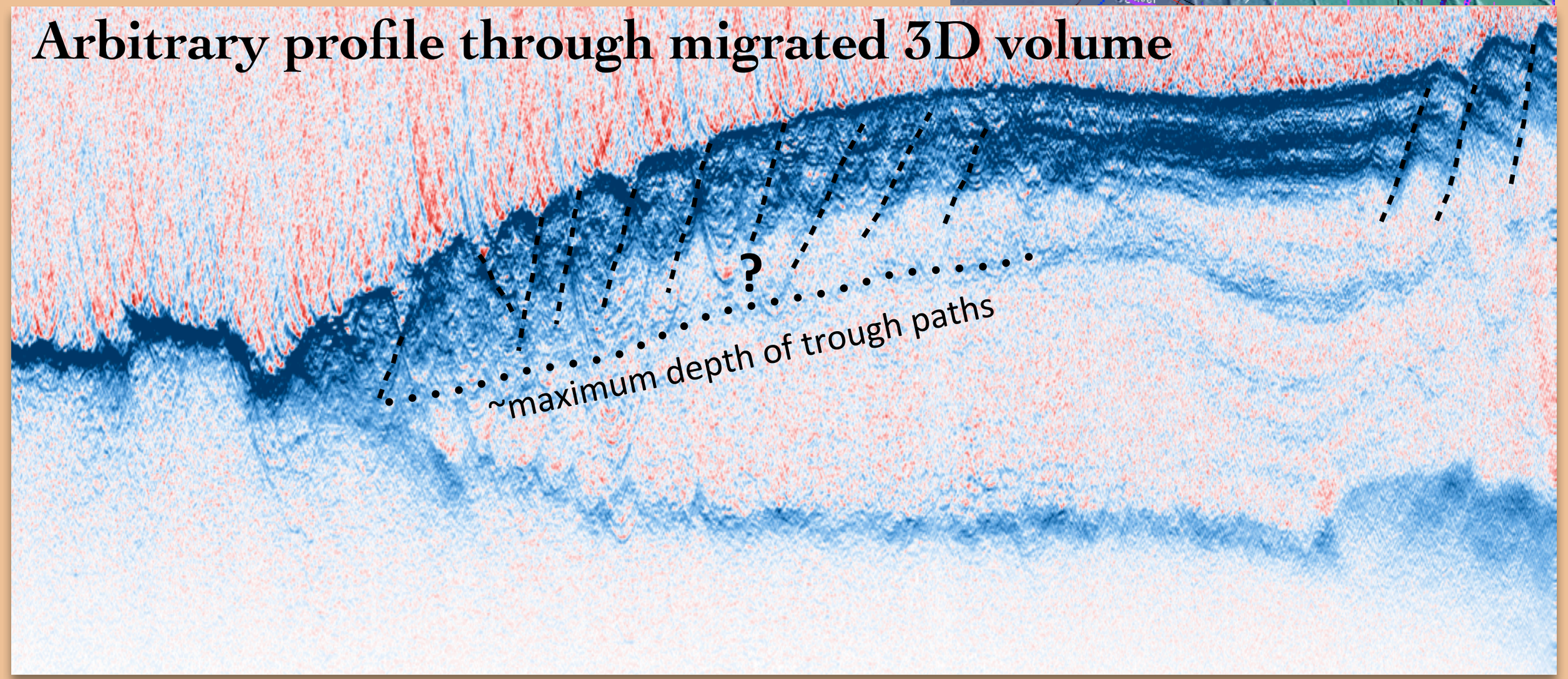


Planum Boreum base map

3-D volume grid

(9 million central bins)

2D observation

3D inline

Basal unit extent

arbitrary profile

93 Basal delay time μs 108

over MOLA color shaded relief

2-D Obs 3715-02

2-D focusing

100 km

10 μs

(a)

3715-02

MOLA no-data zone

inline 4650

(b)

3-D swath coverage in MOLA elevation

3-D inline 4650

Demigration

(c)

3-D inline 4650

3-D migration

115 μs

(d)

2-D Obs 3715-02 2-D focusing

100 km

10 μs

(a)

The 3D migration reveals
major structures not evident in 2D observations

(c)

3-D inline 4650 3-D migration

115 μs

(d)

Planum Boreum base map

3-D volume grid

(9 million central bins)

Basal unit extent

Timeslice views

arbitrary profile

Basal delay time

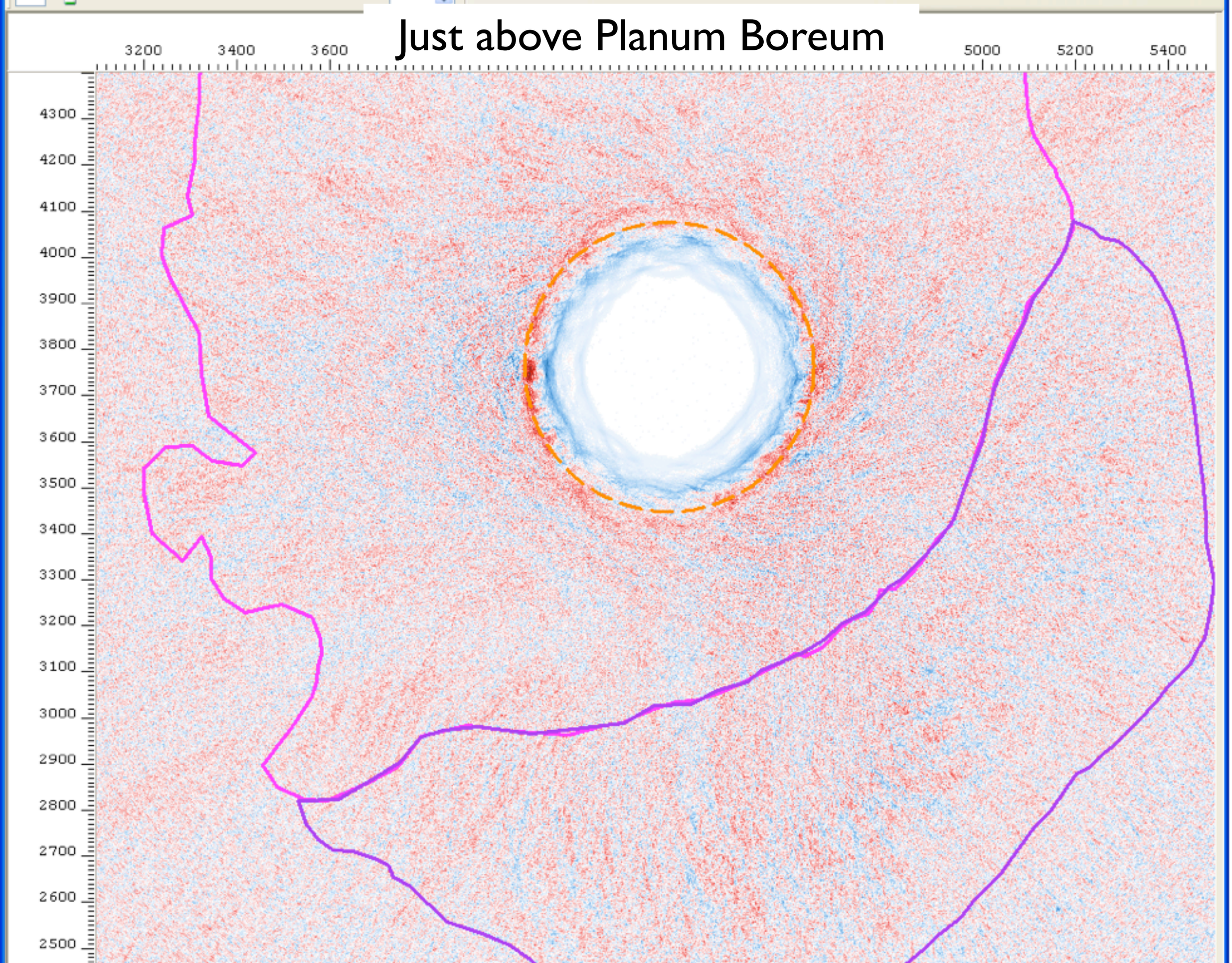
93

μs

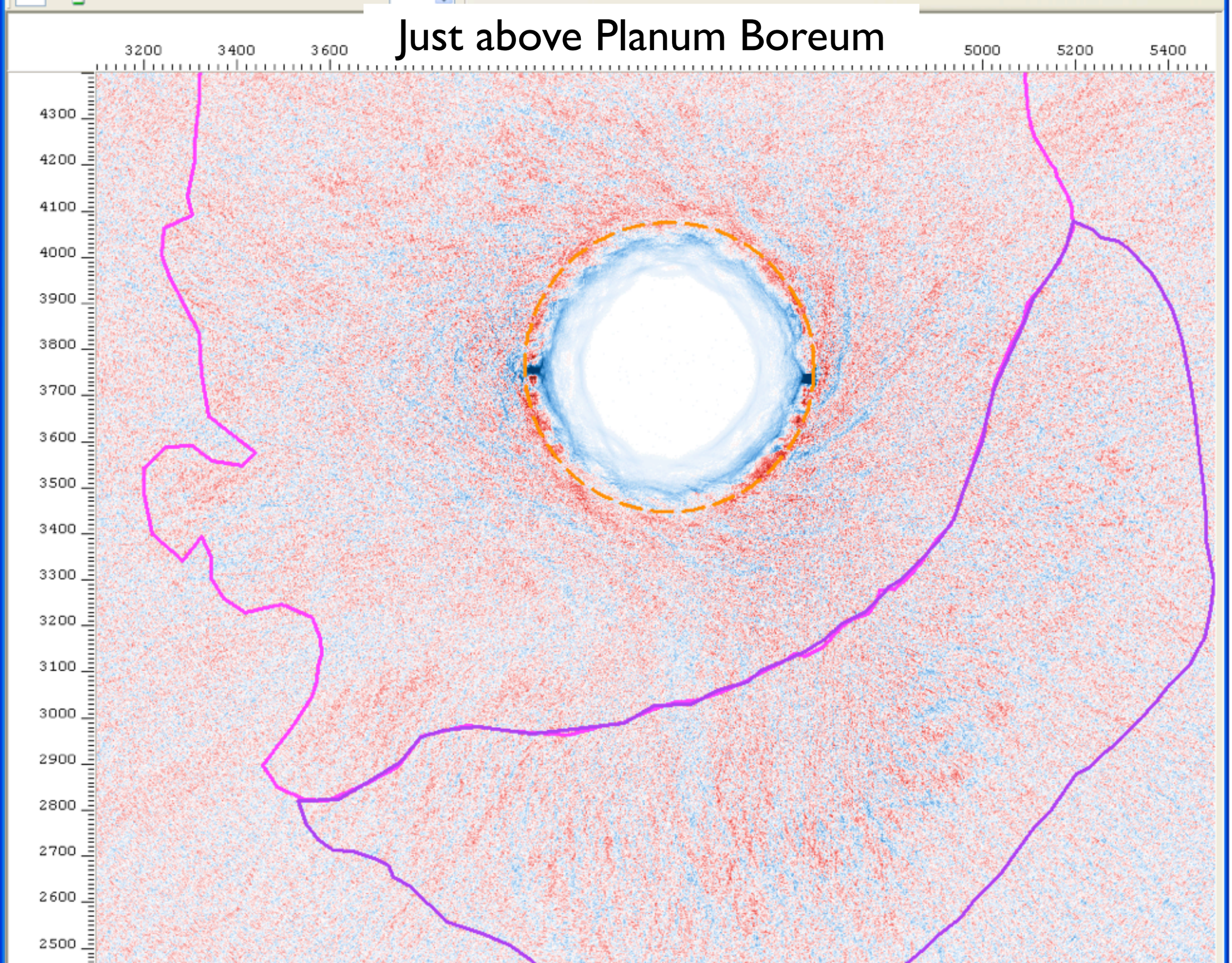
108

over MOLA color shaded relief

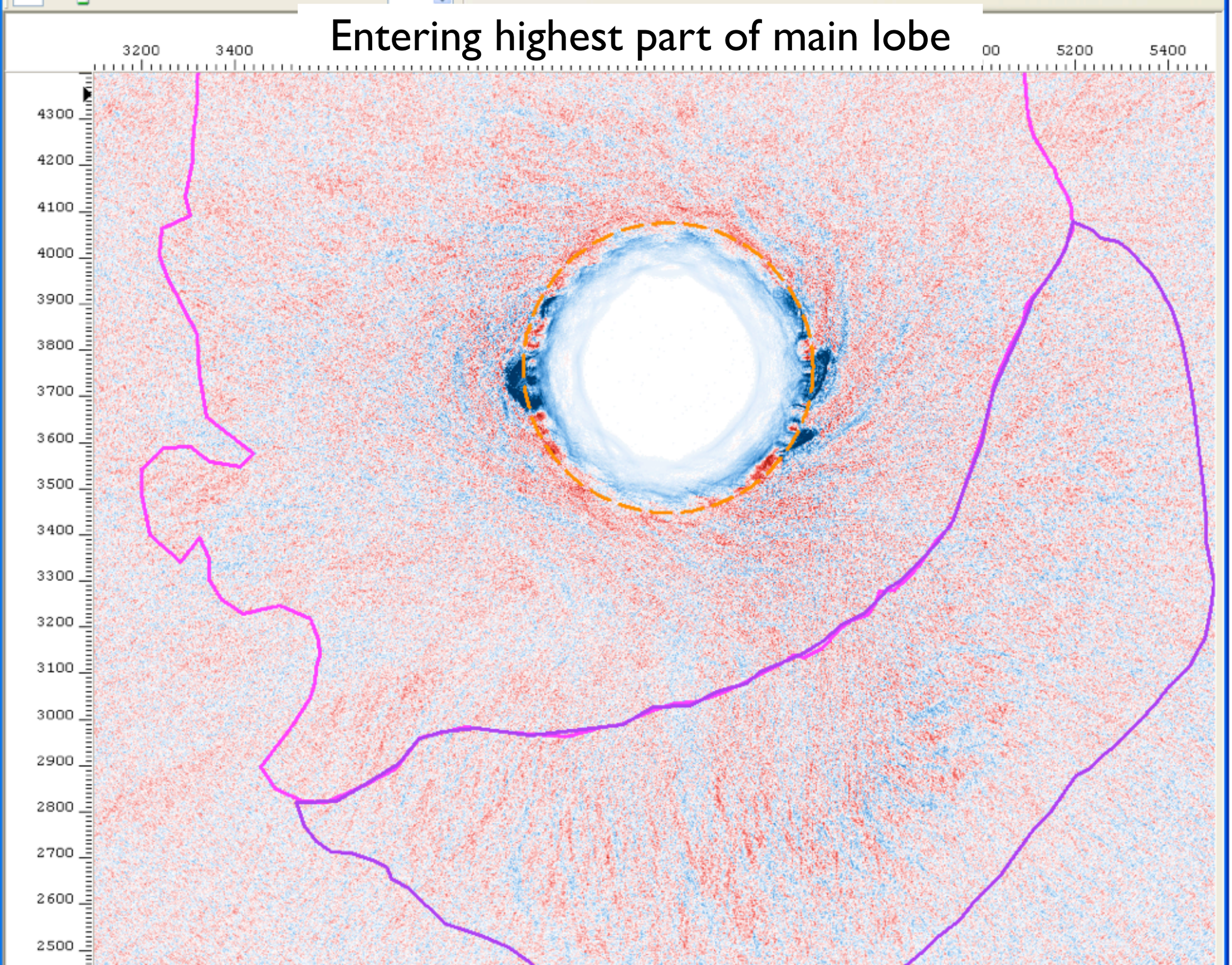
Just above Planum Boreum



Just above Planum Boreum



Entering highest part of main lobe



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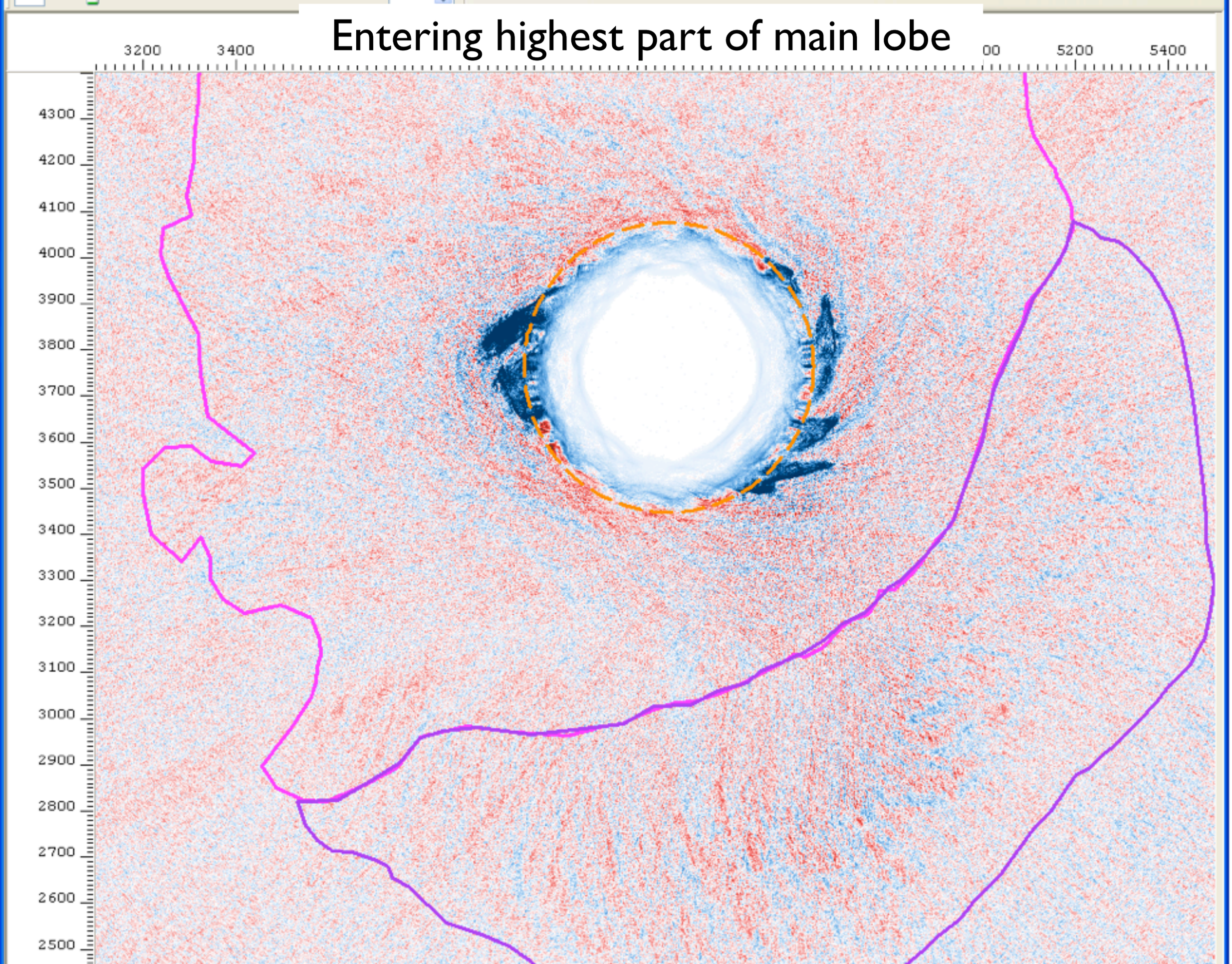

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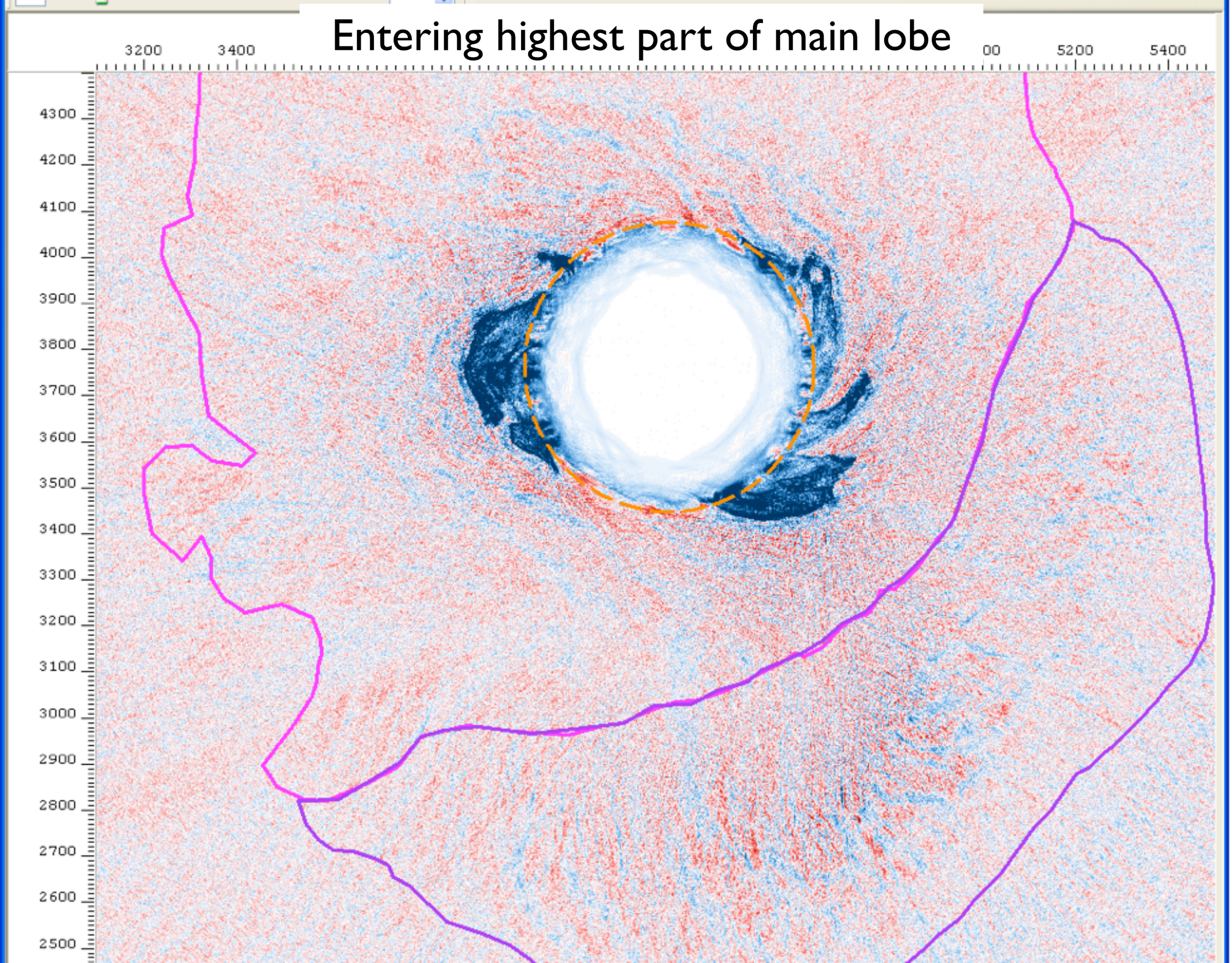
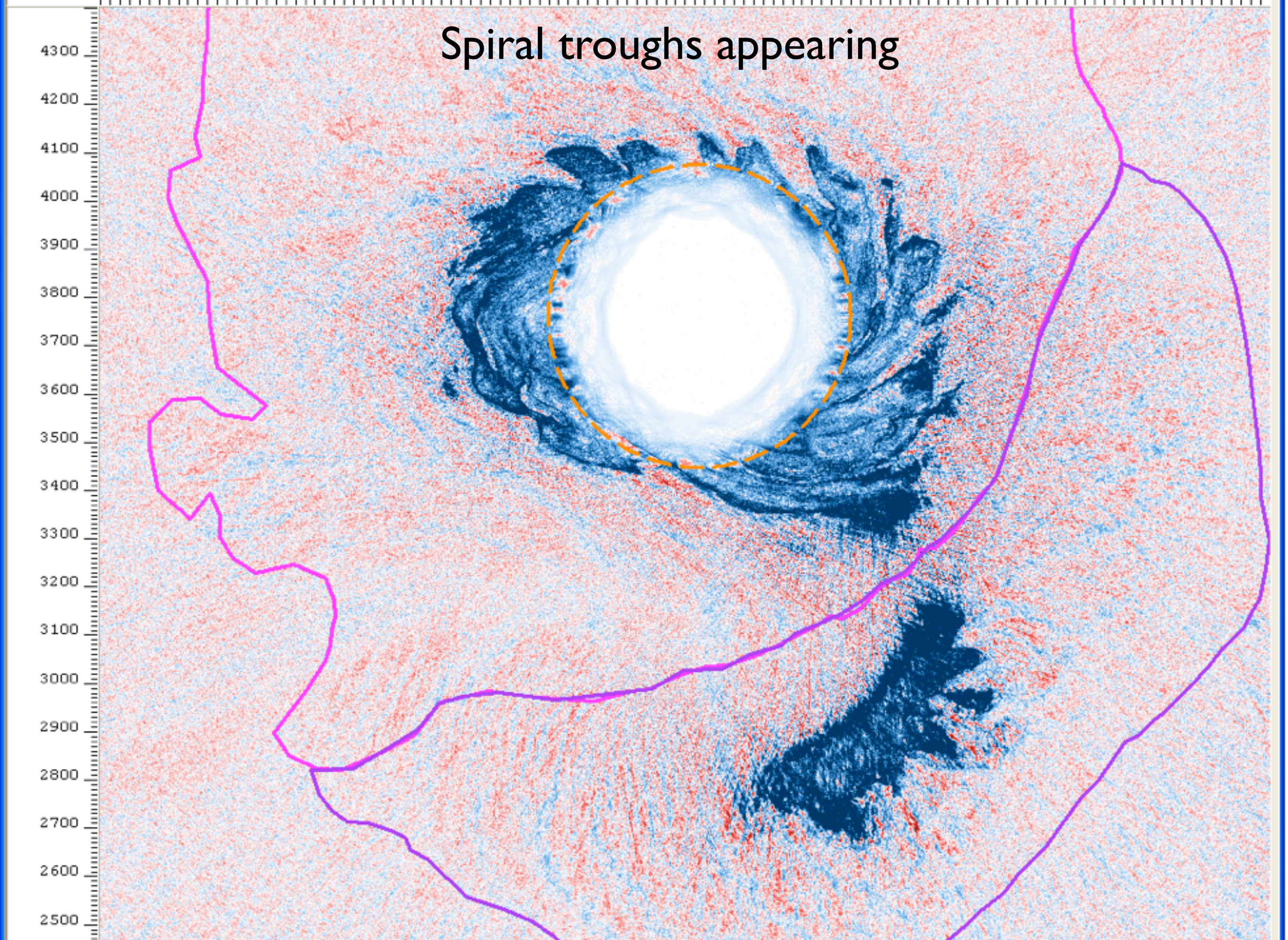


Entering highest part of Gemina Lingula

Spiral troughs appearing



Entering highest part of Gemina Lingula

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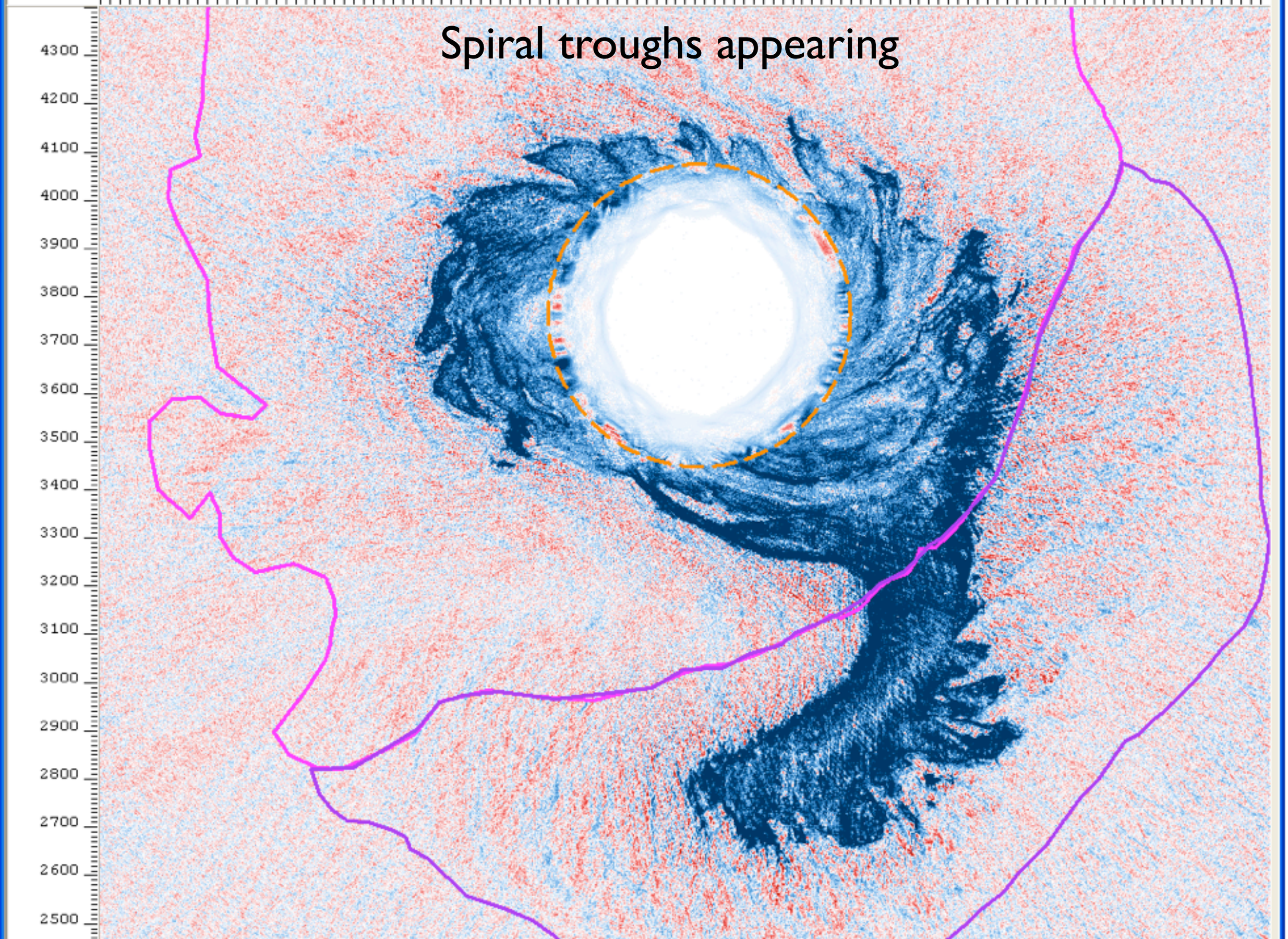
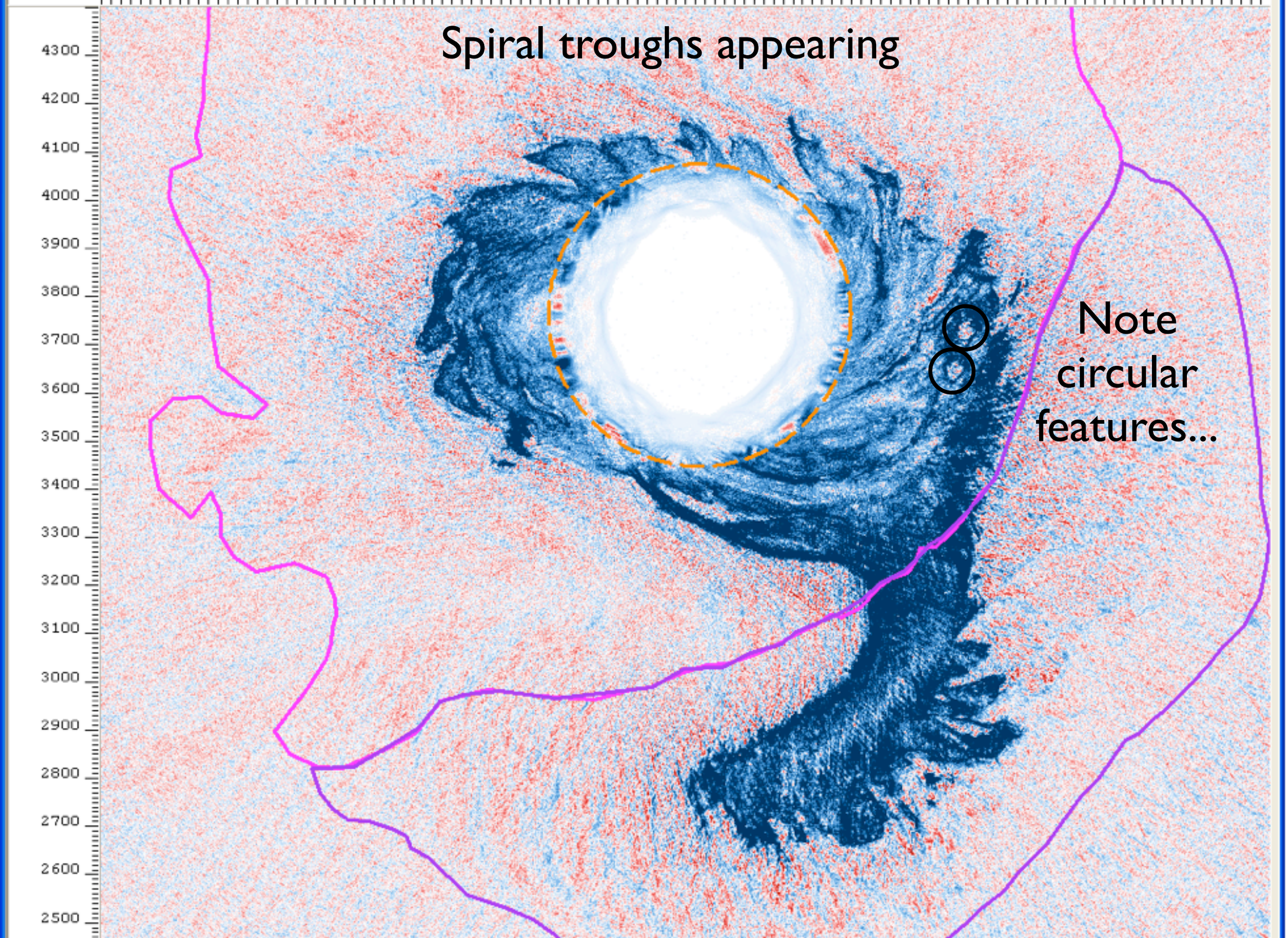
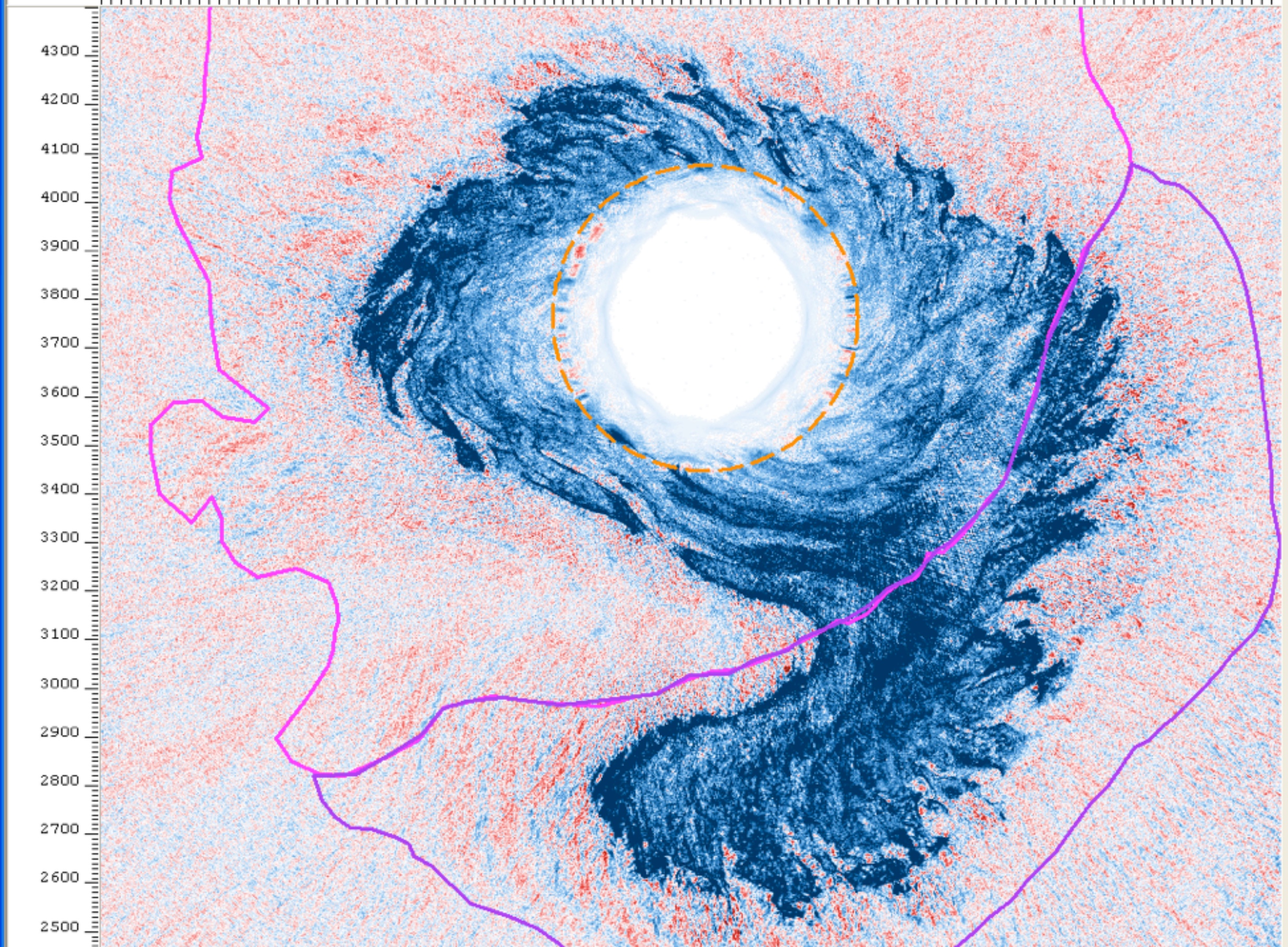


Entering highest part of Gemina Lingula



Watch movement of trough paths in subsurface



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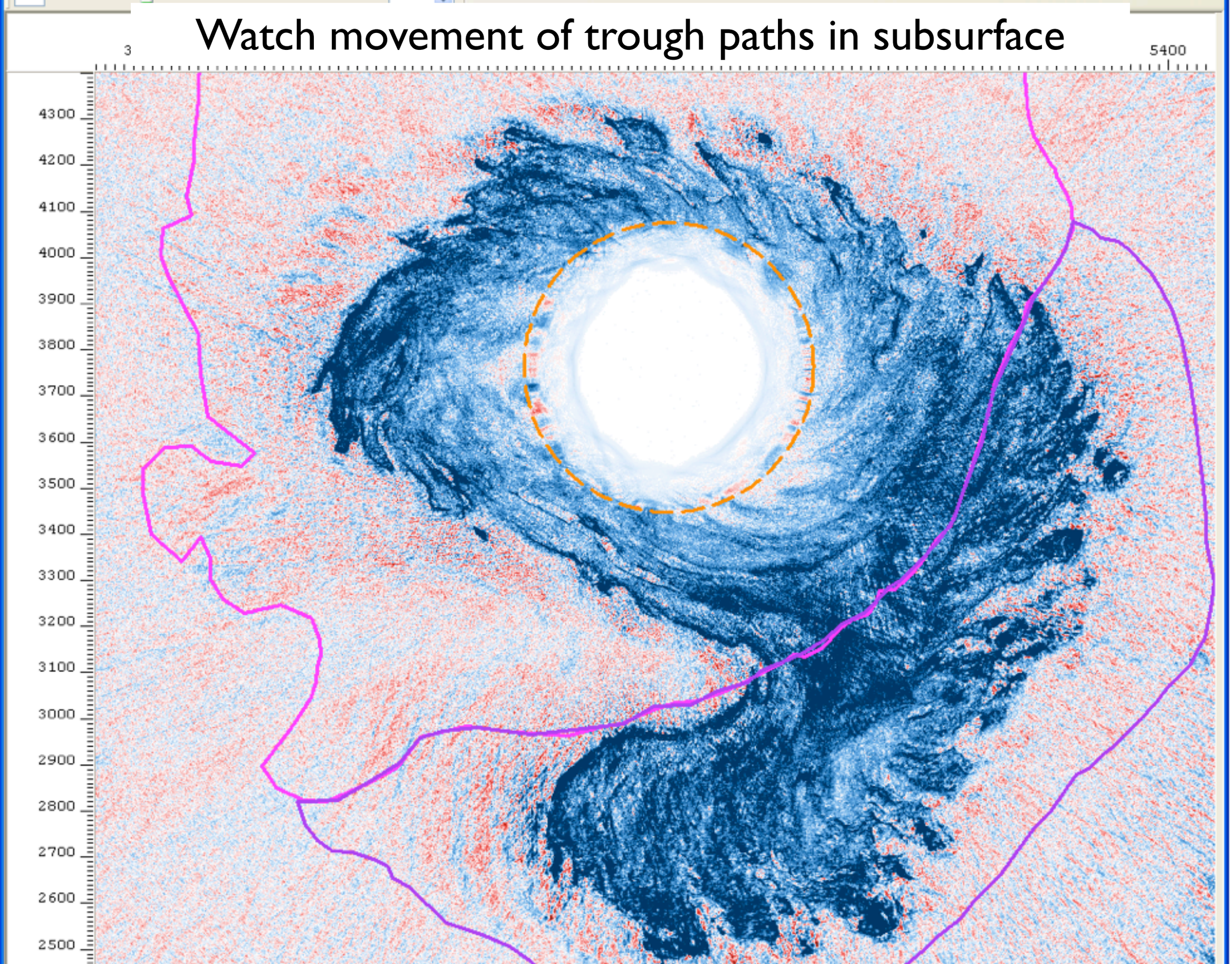

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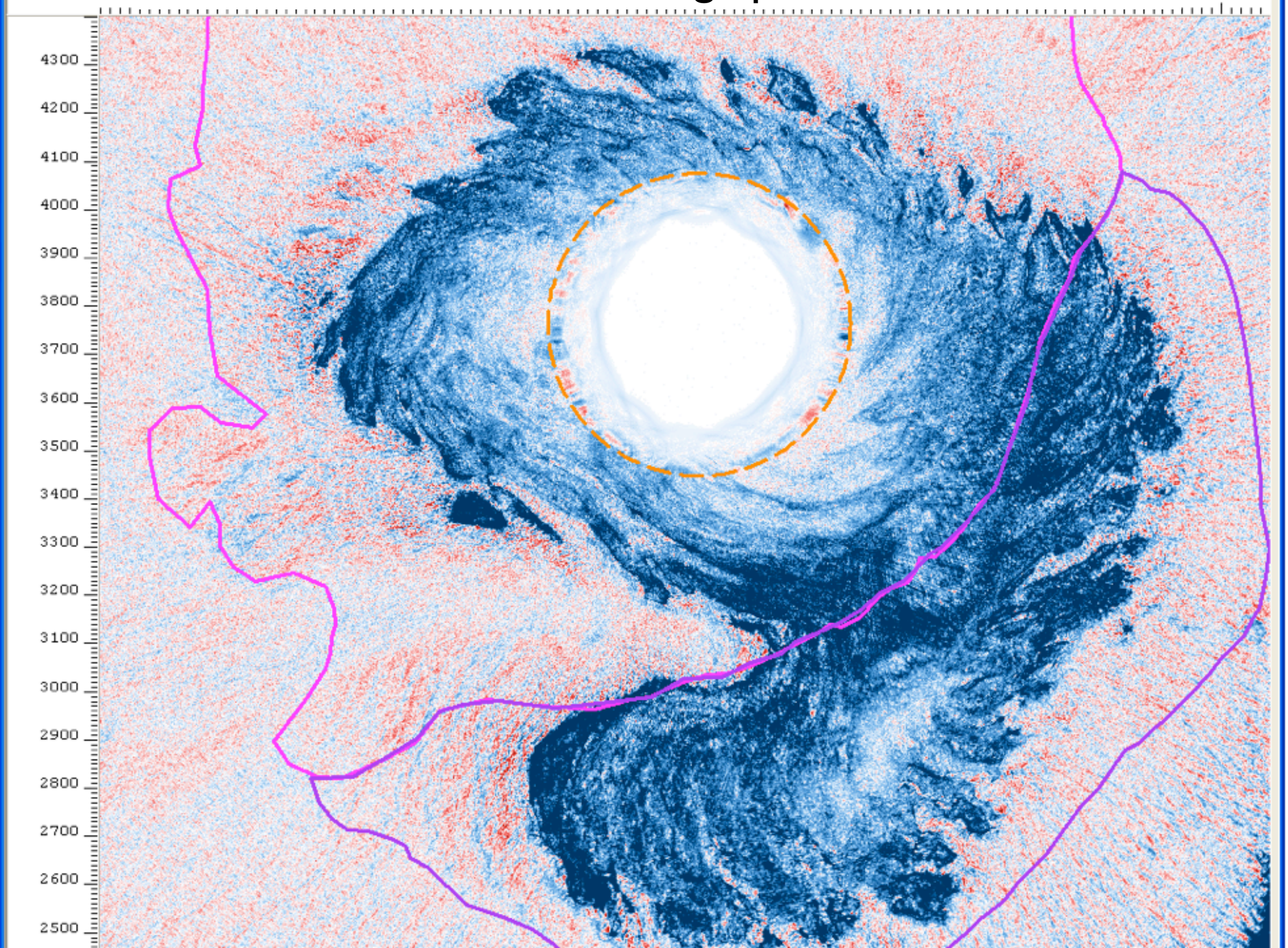

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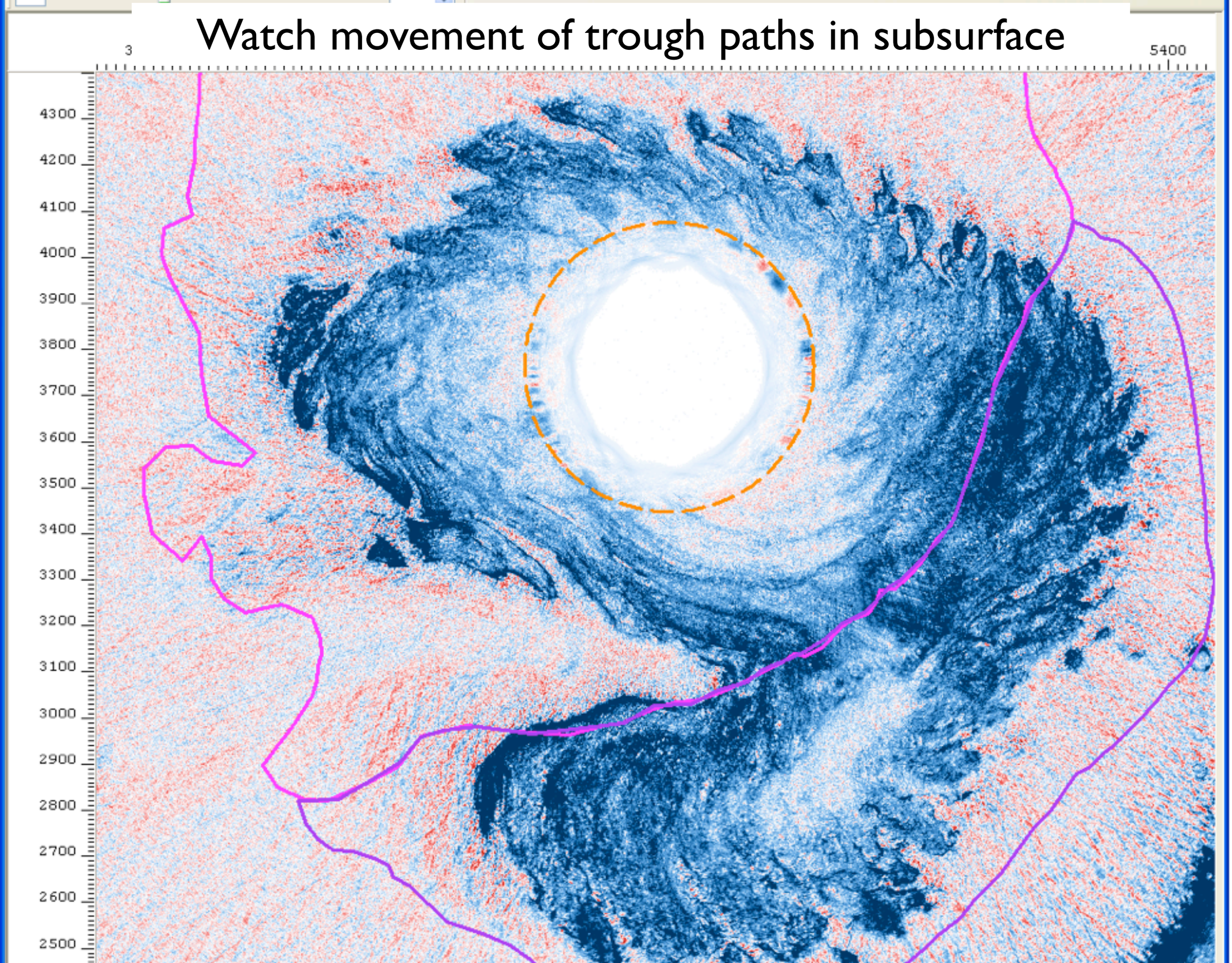

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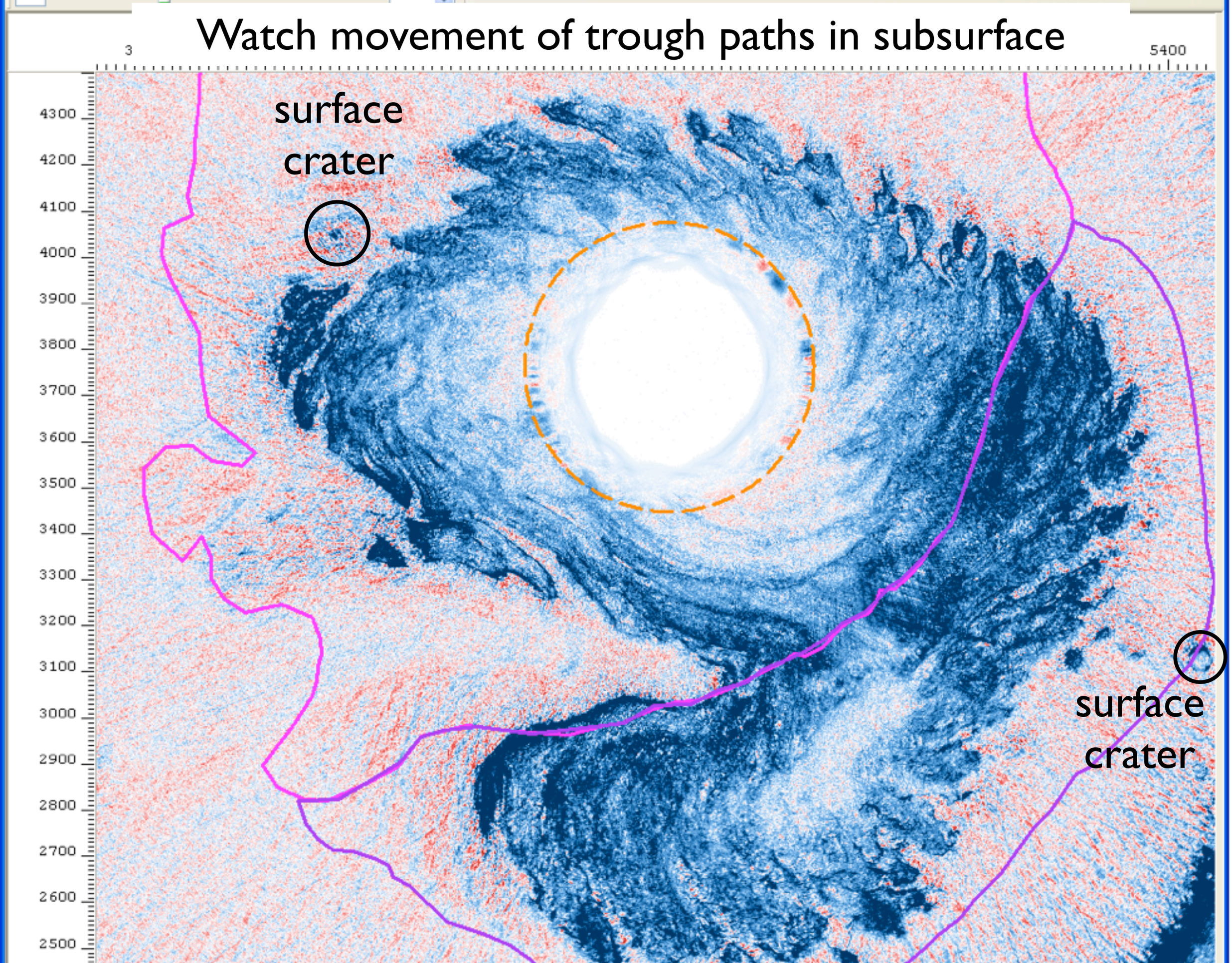

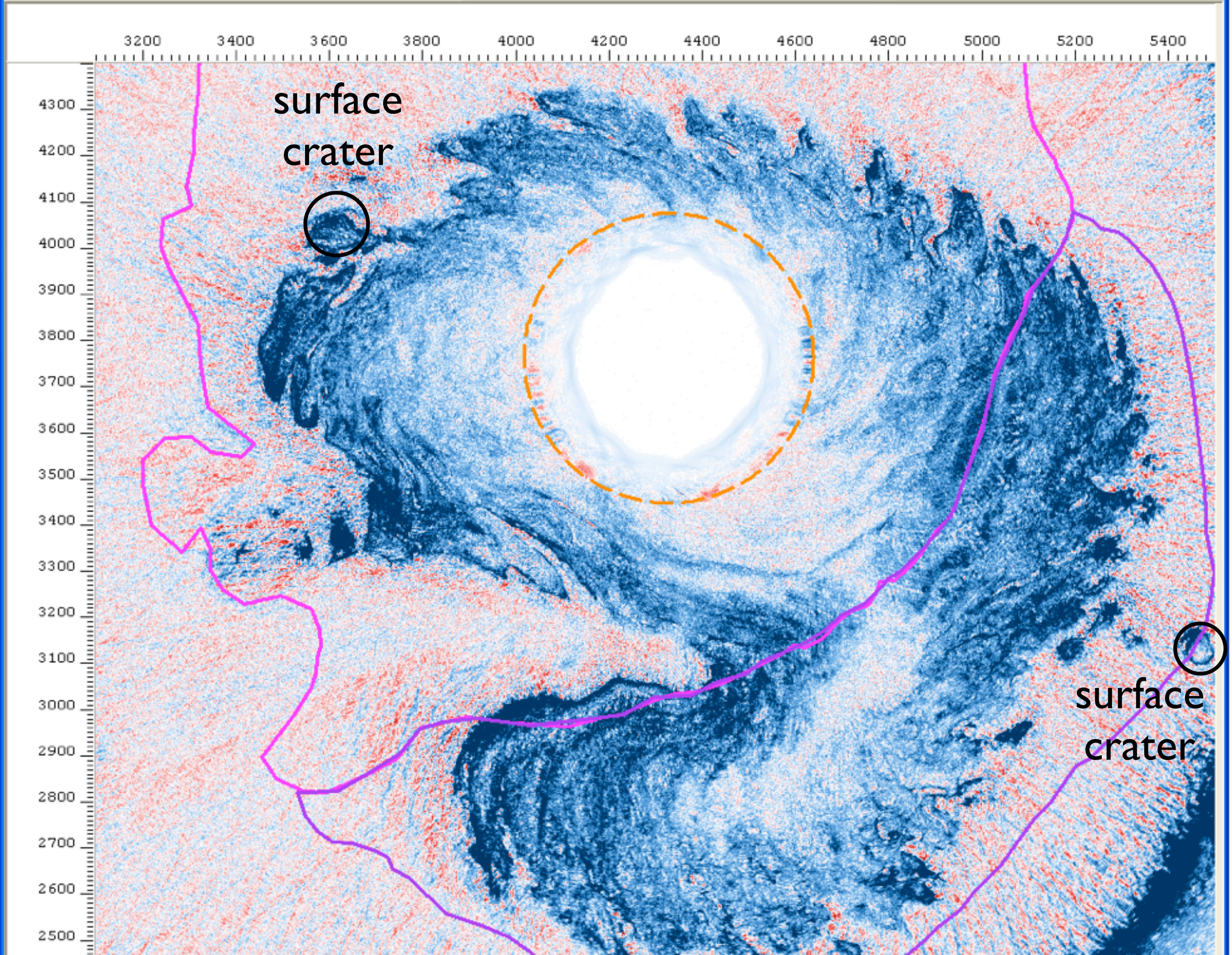
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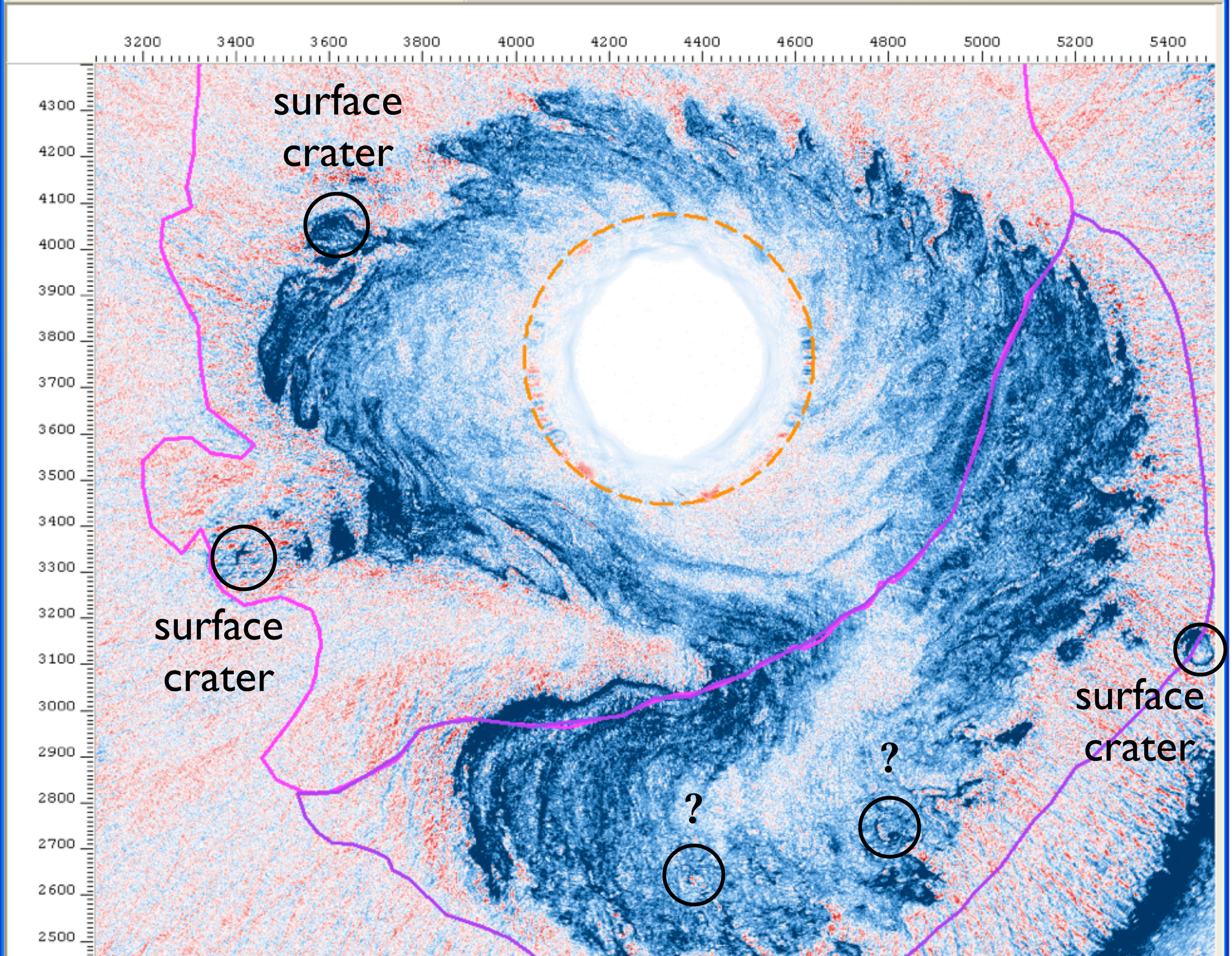
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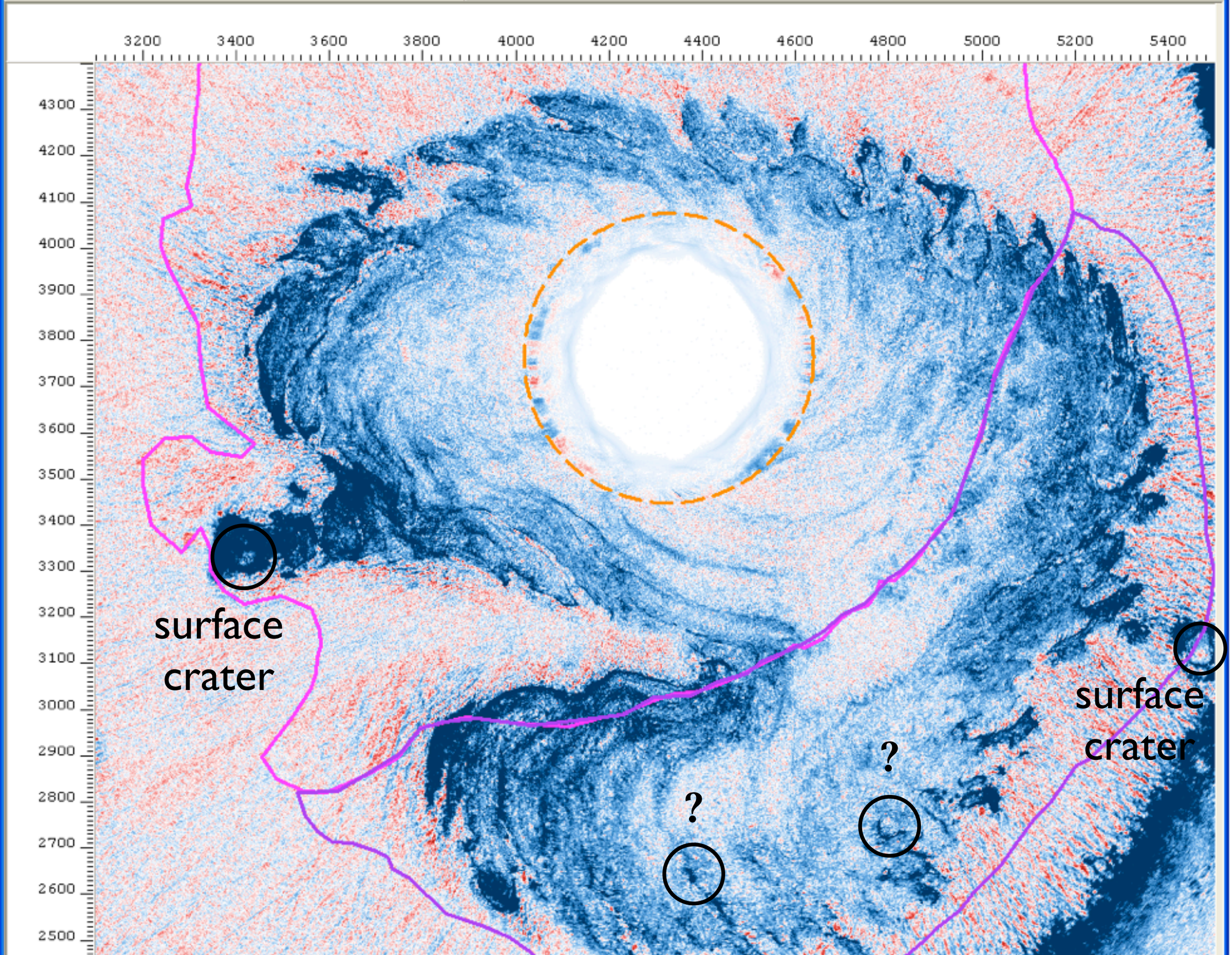
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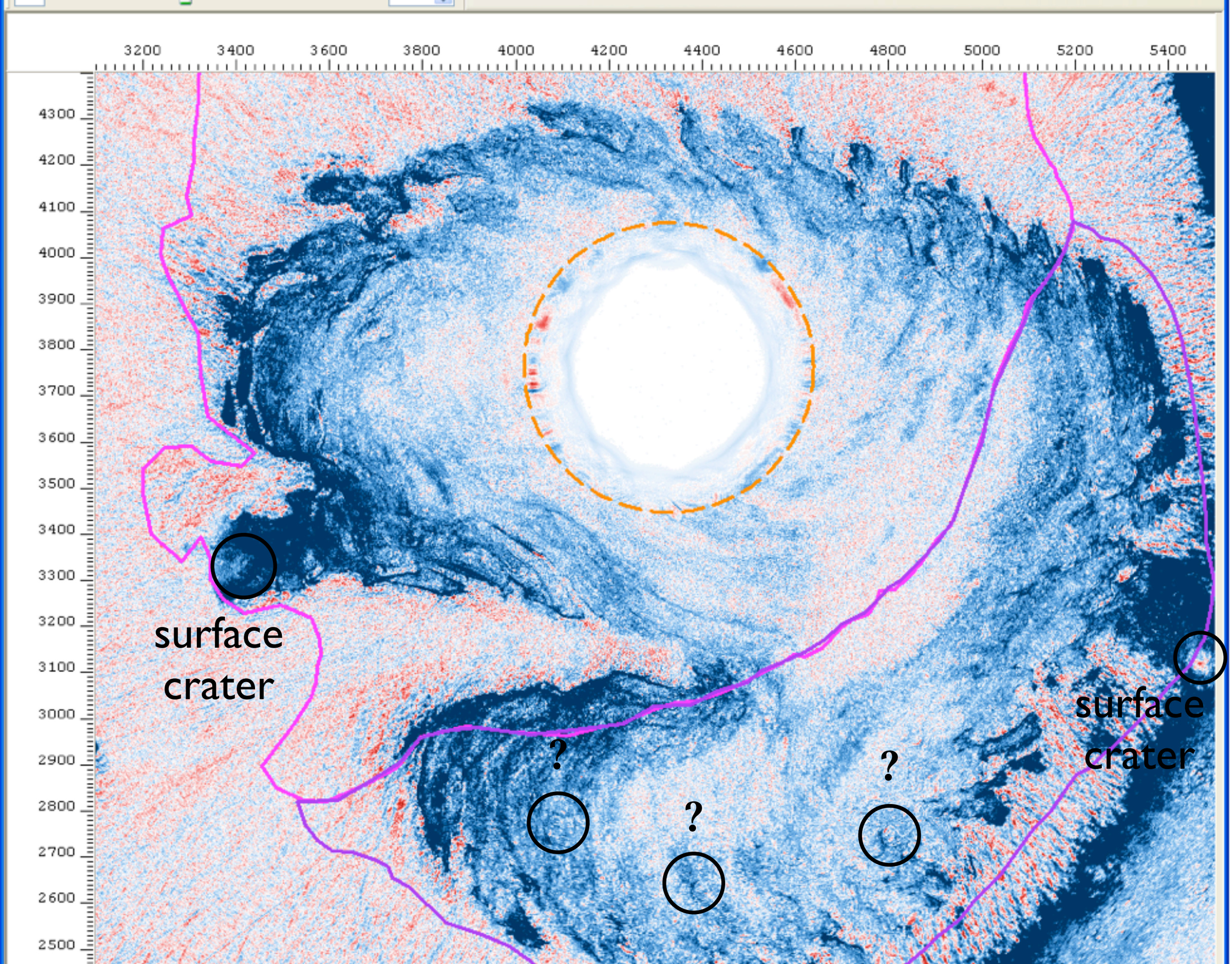
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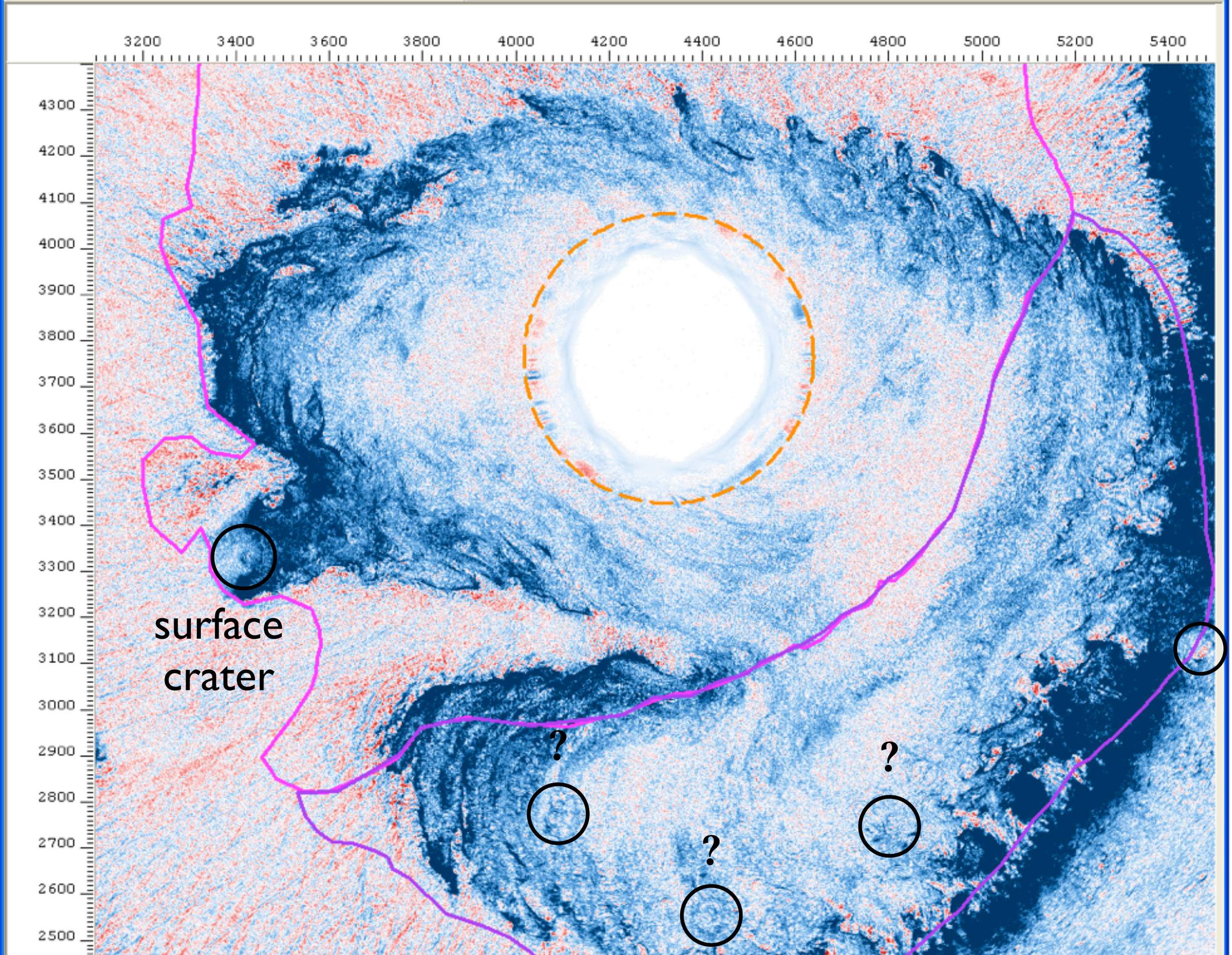
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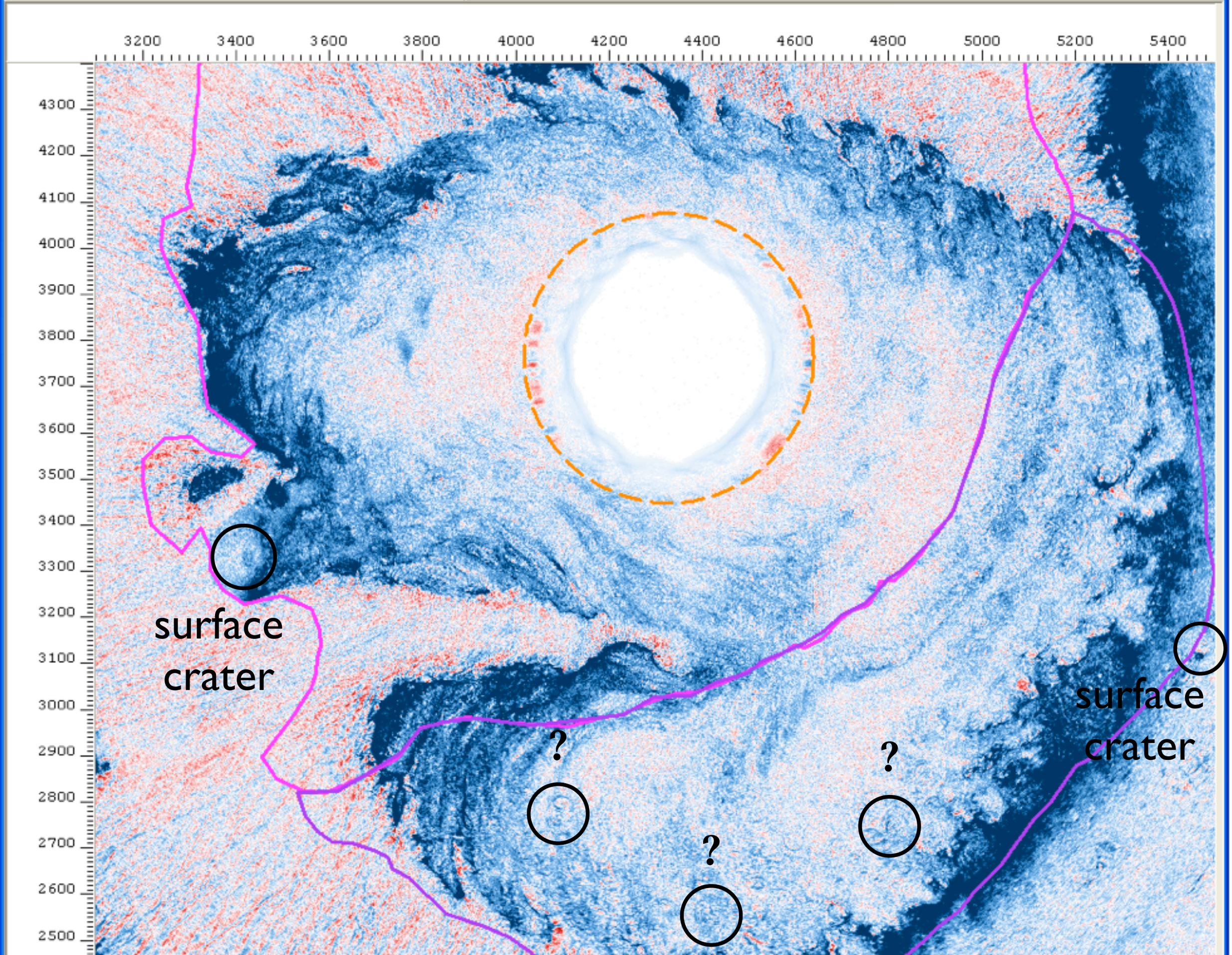
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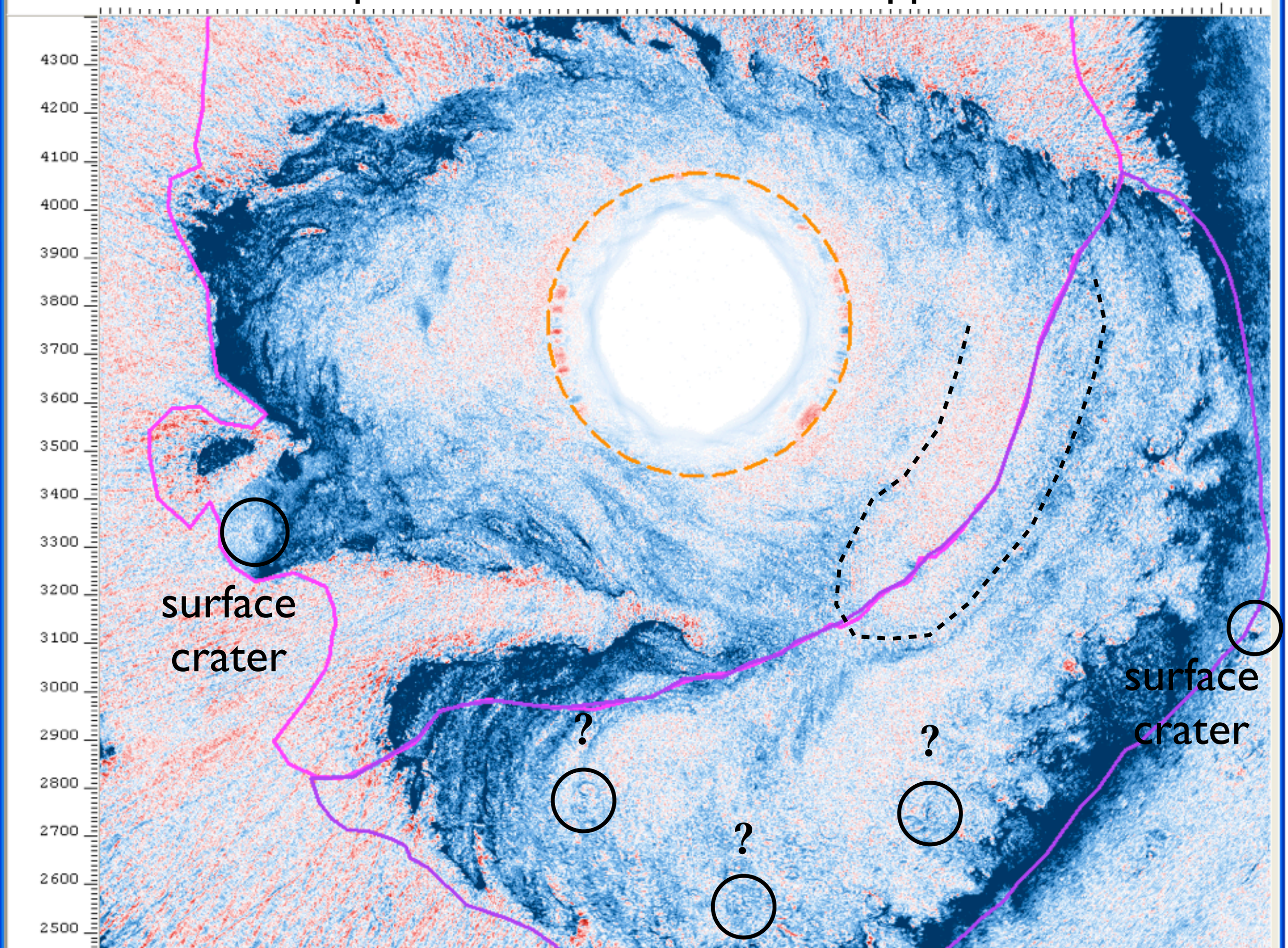
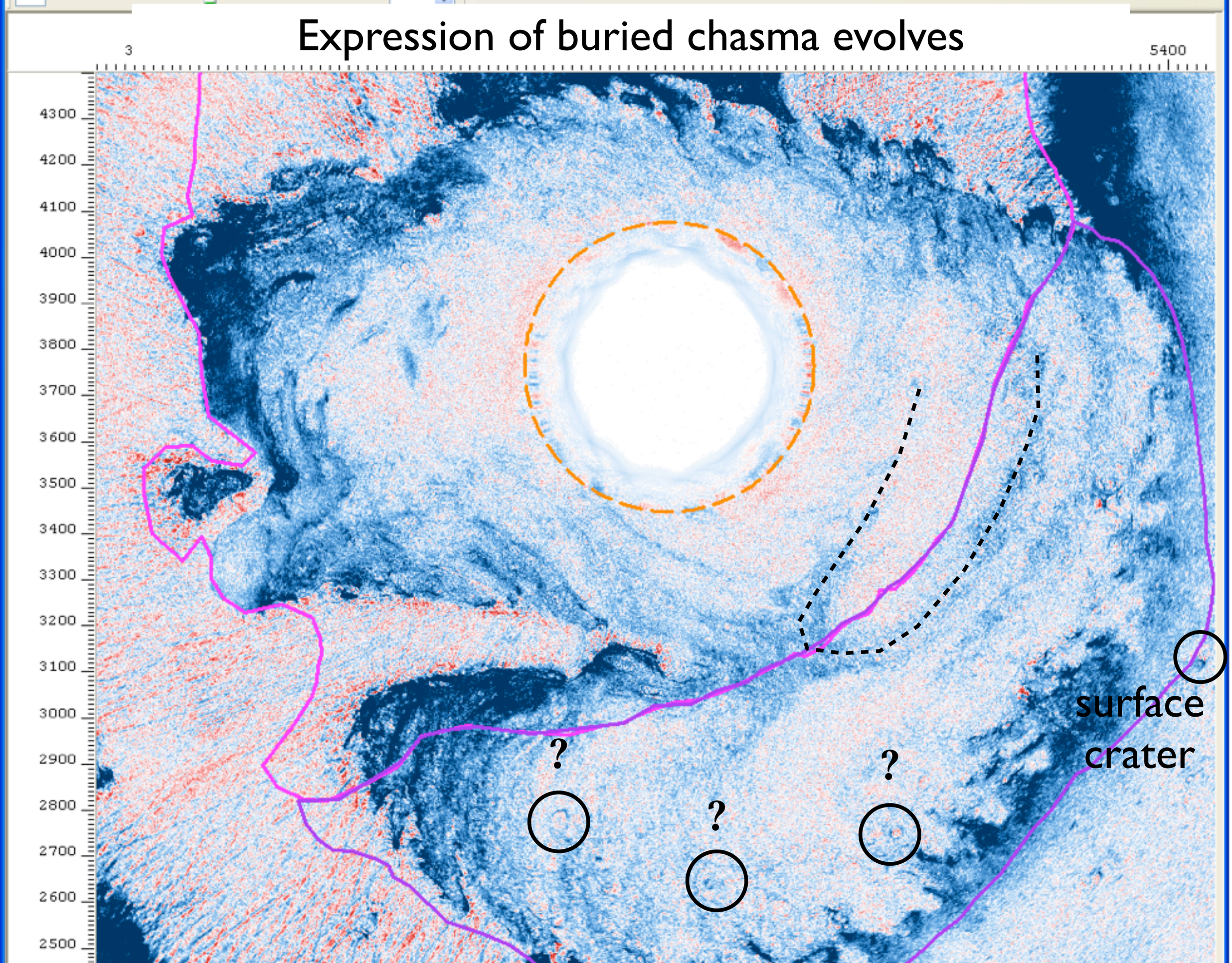
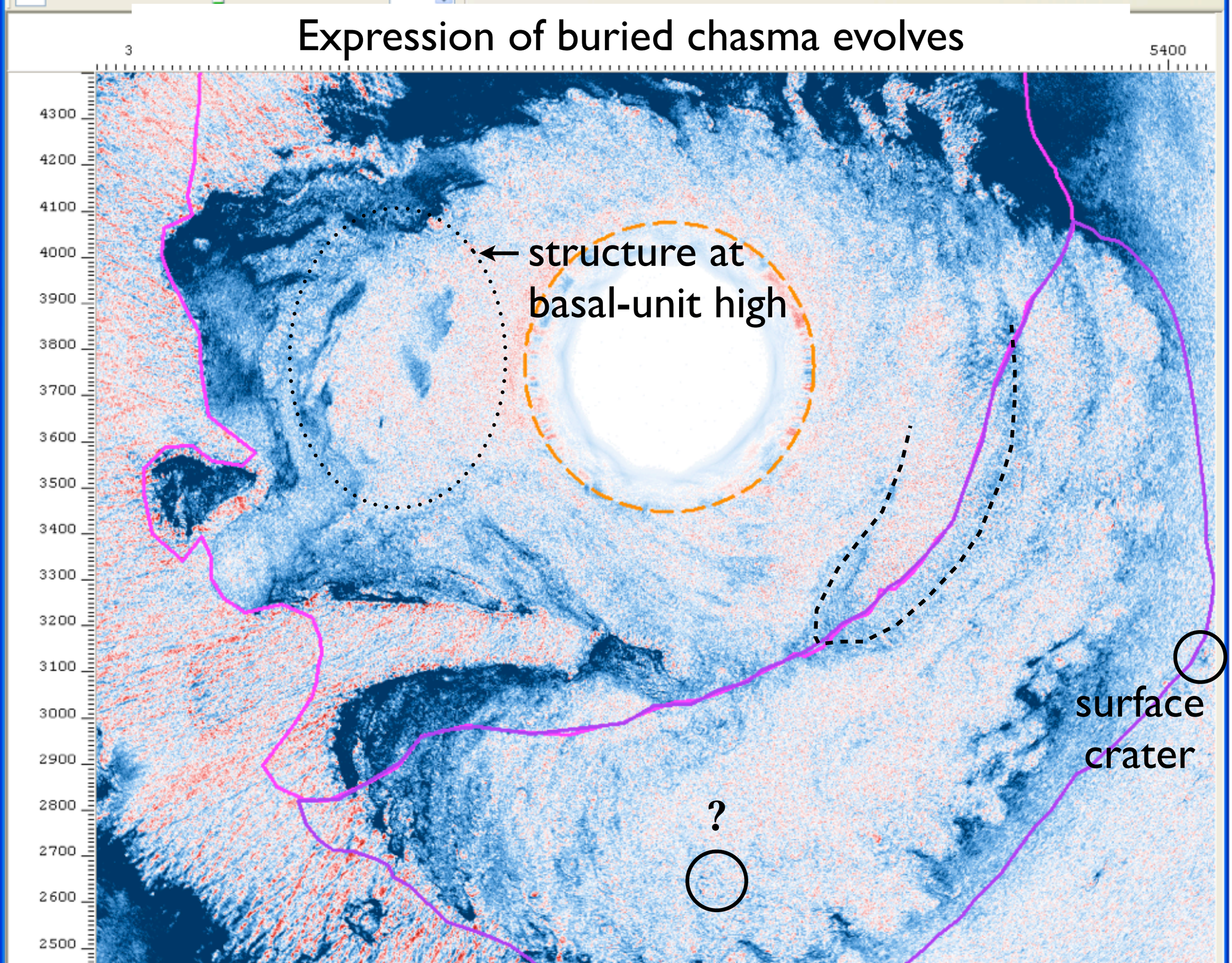
Expression of buried chasma appears



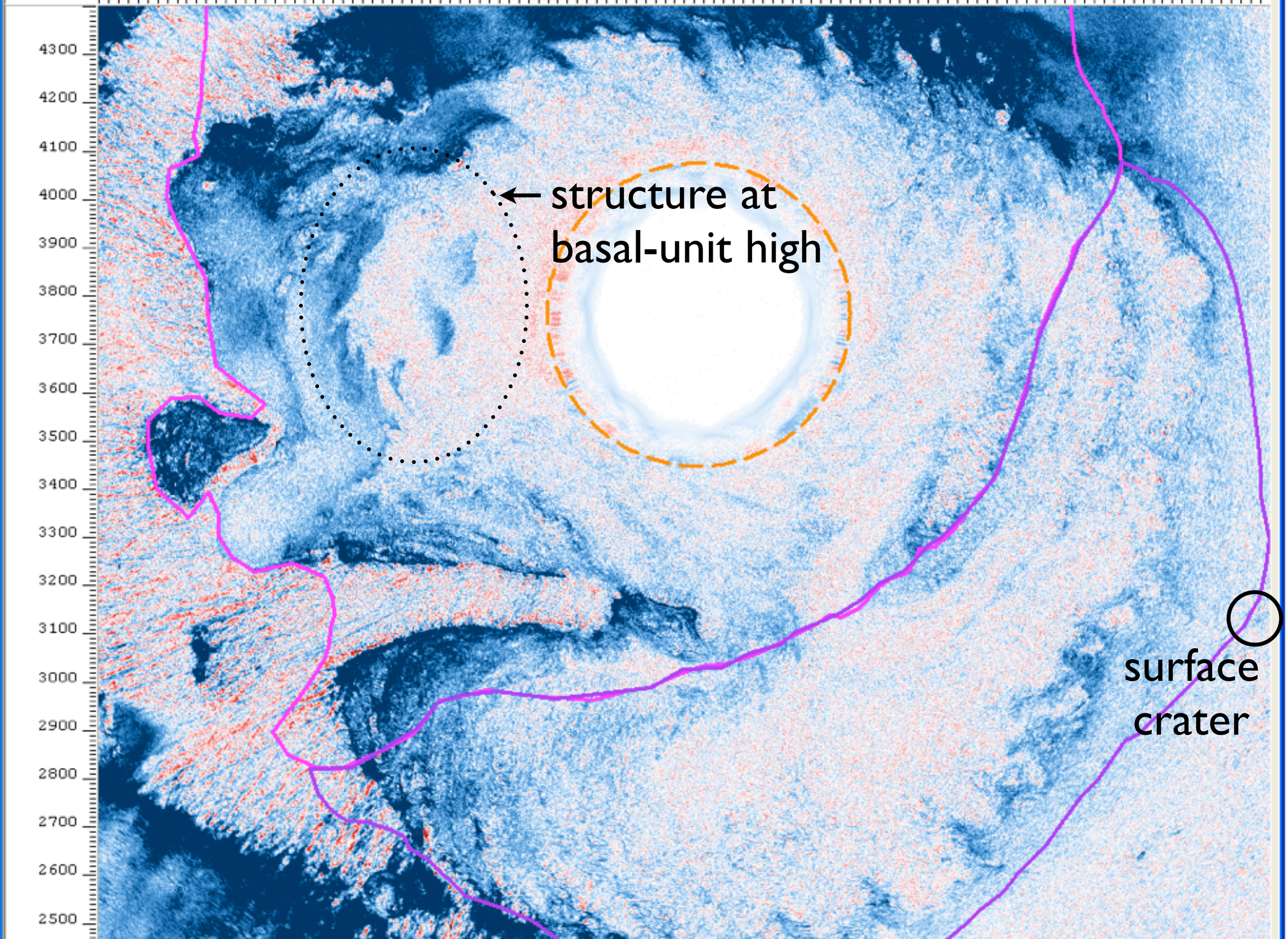
Expression of buried chasma evolves

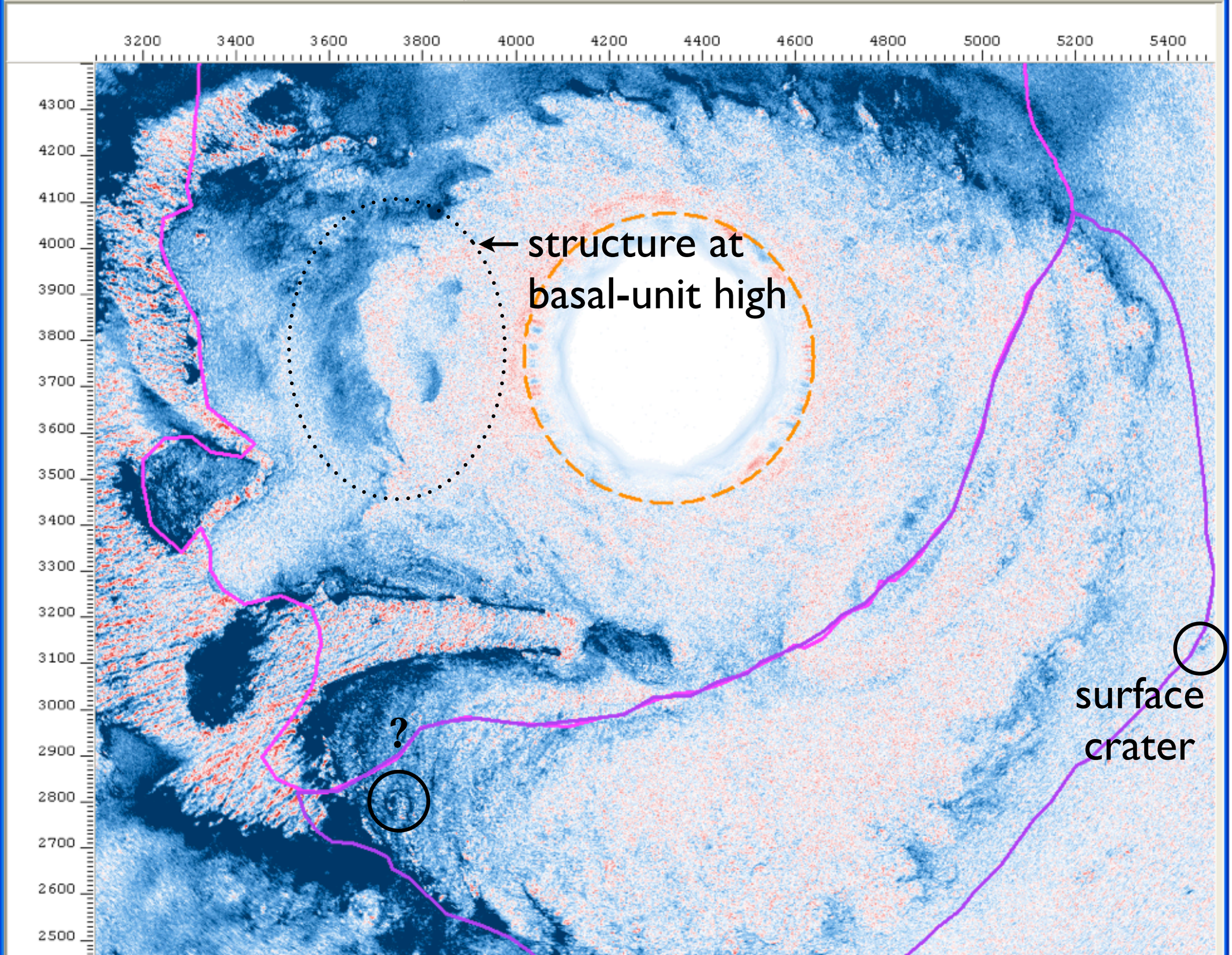


Expression of buried chasma evolves



Expression of buried chasma evolves

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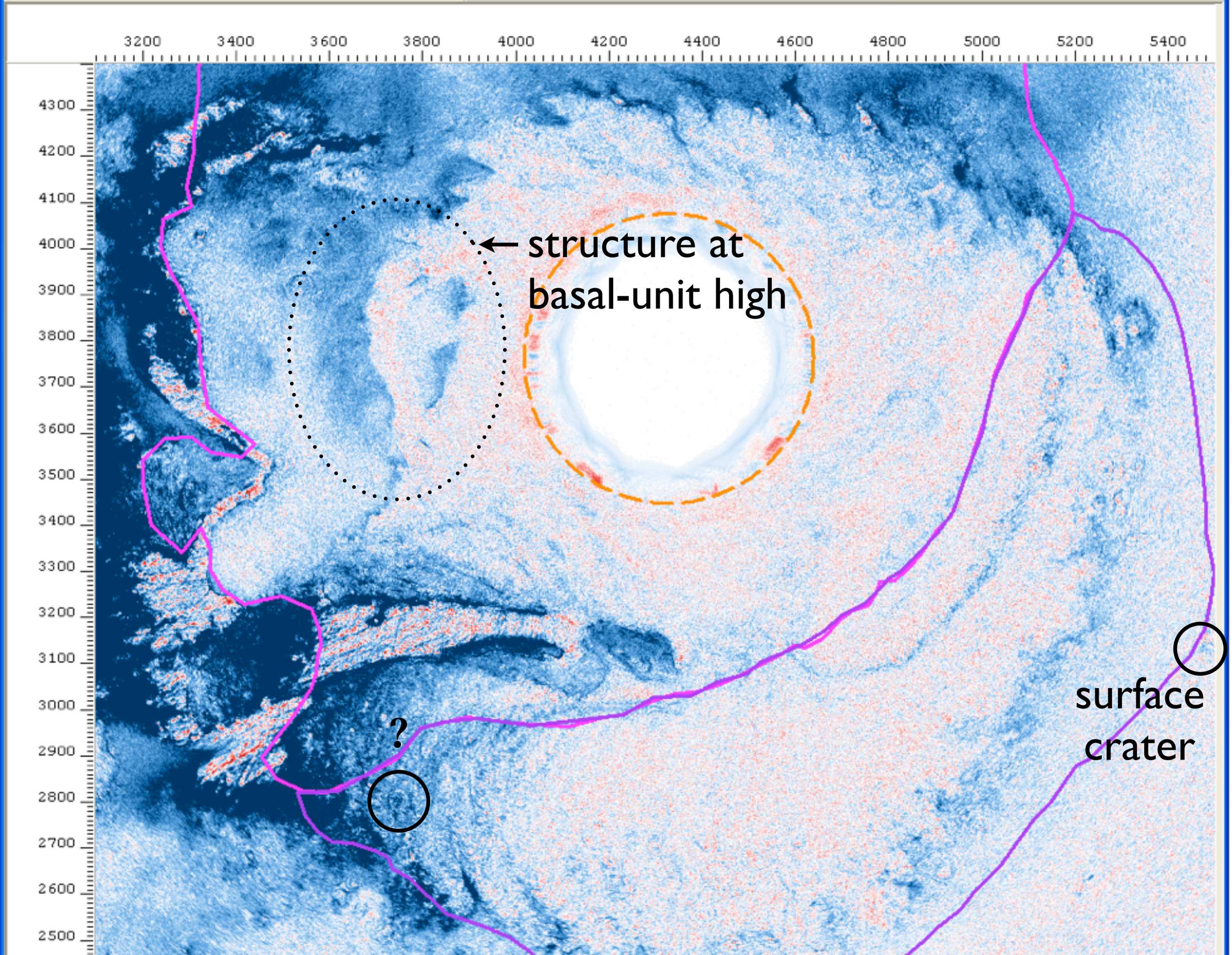
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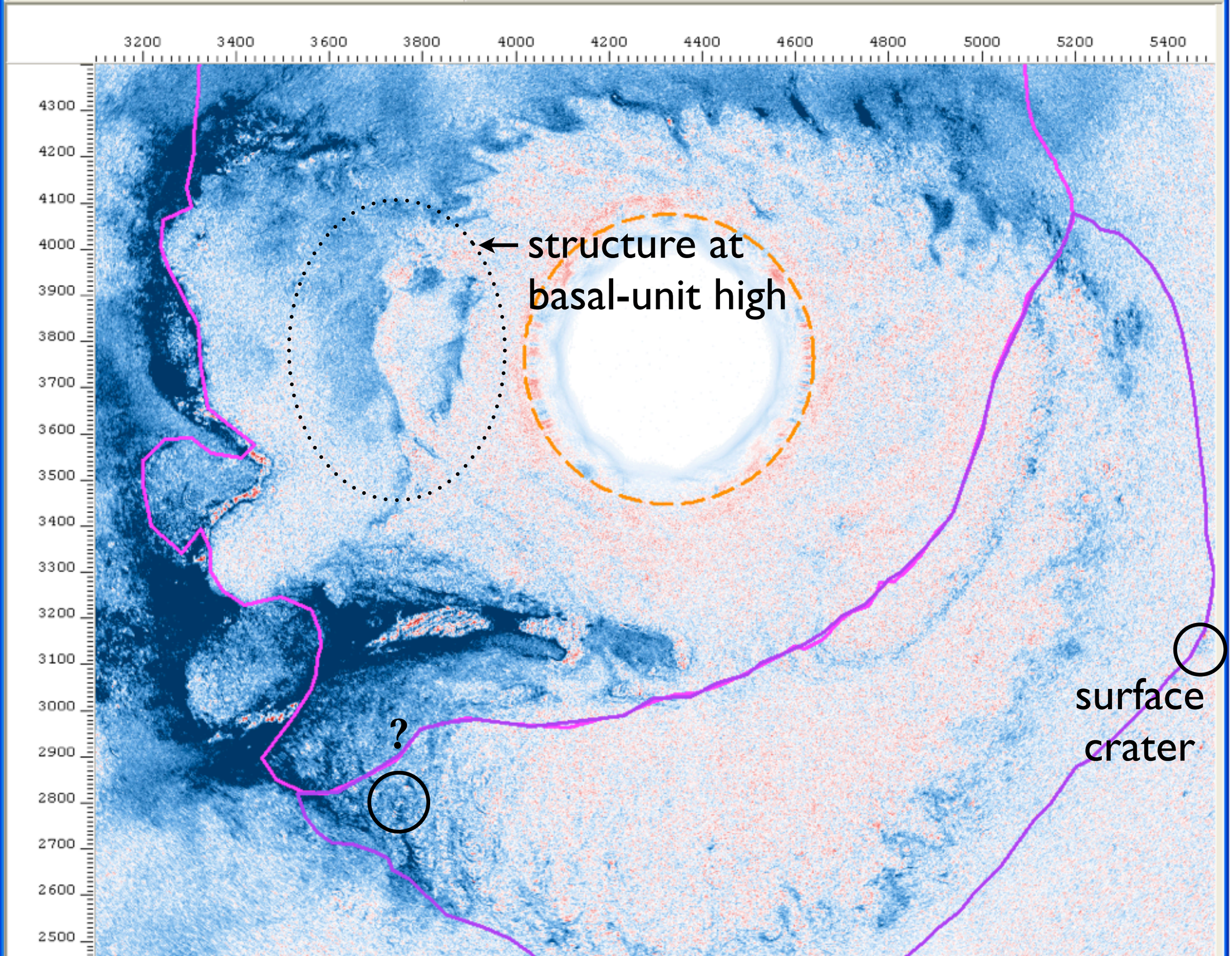
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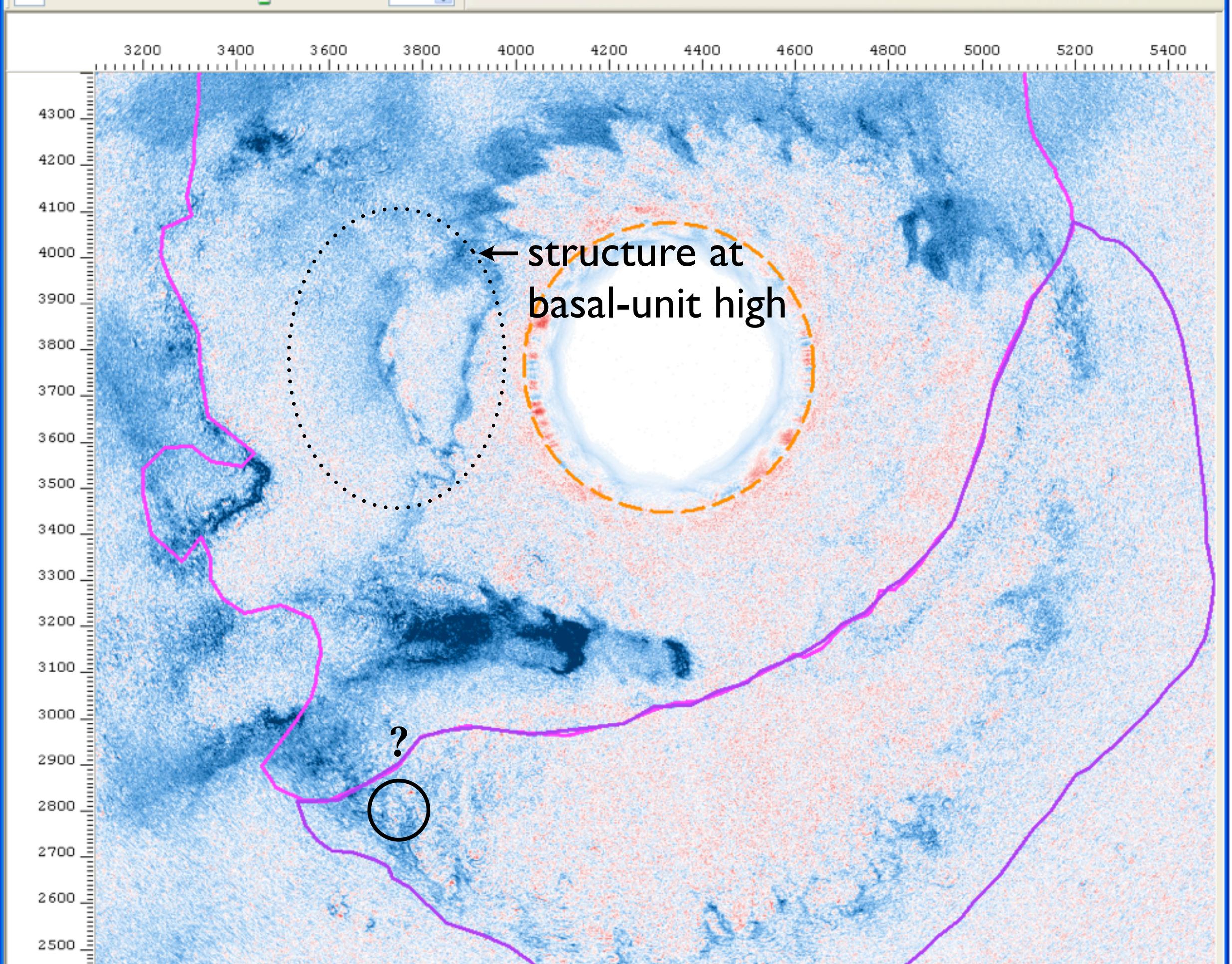
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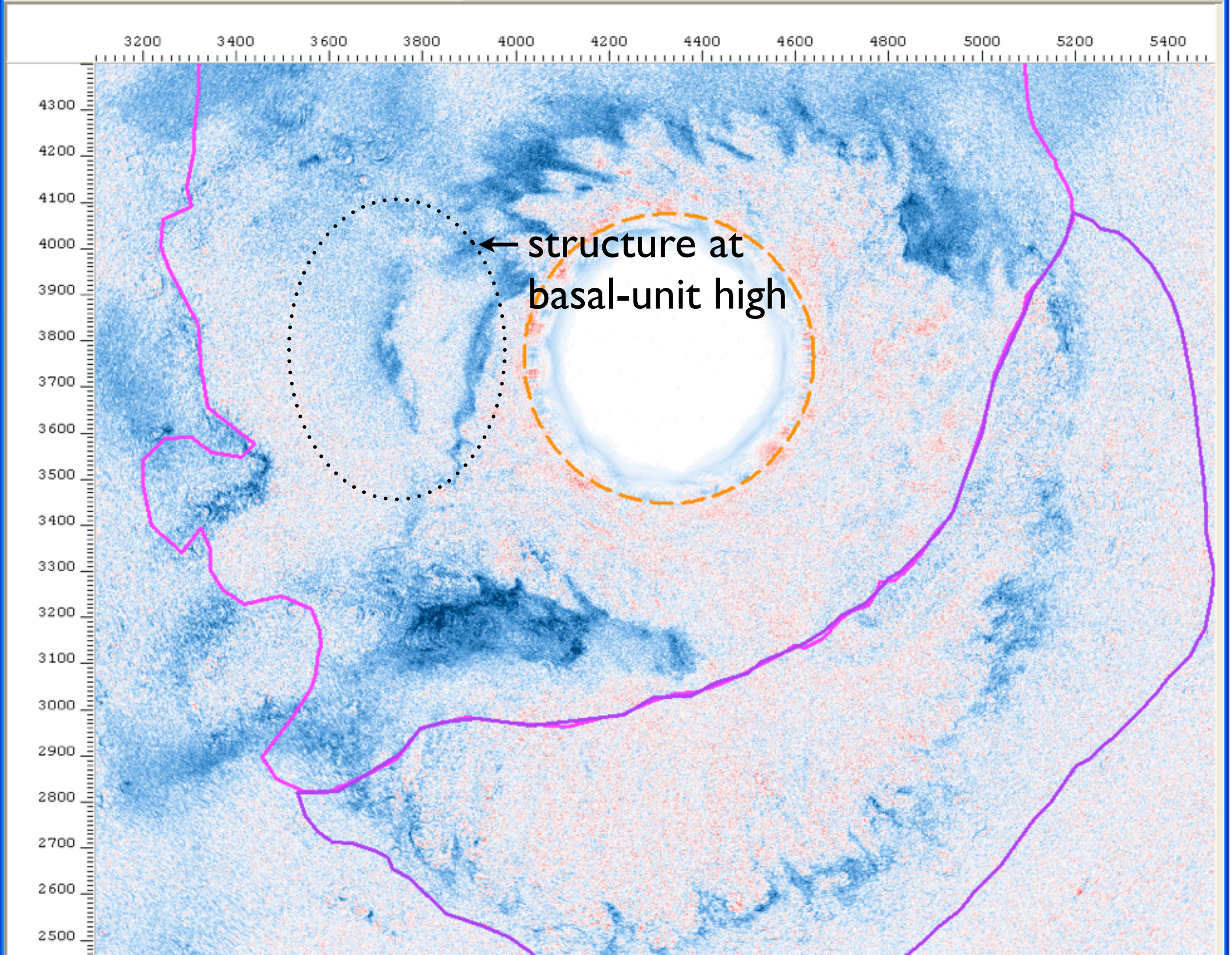
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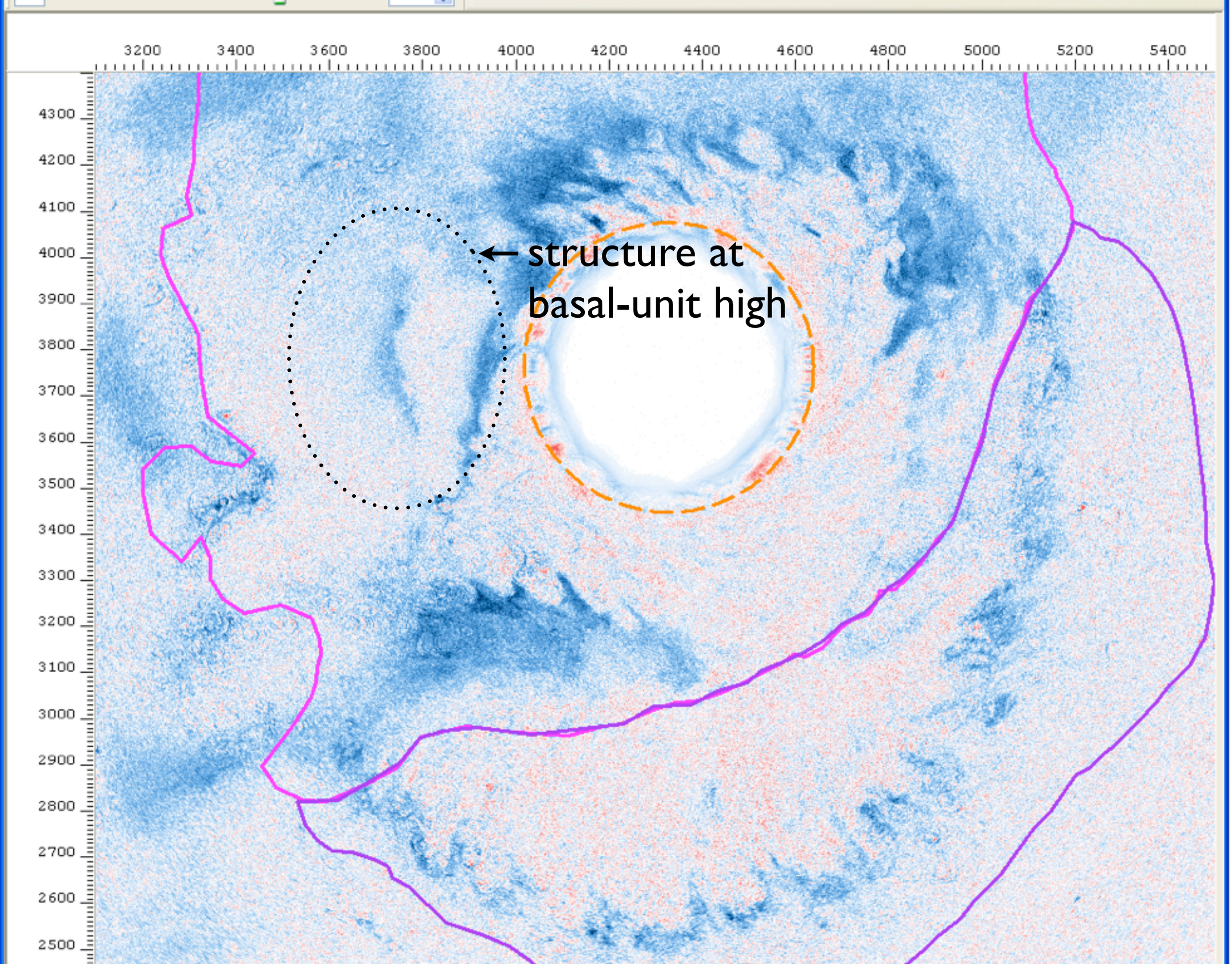
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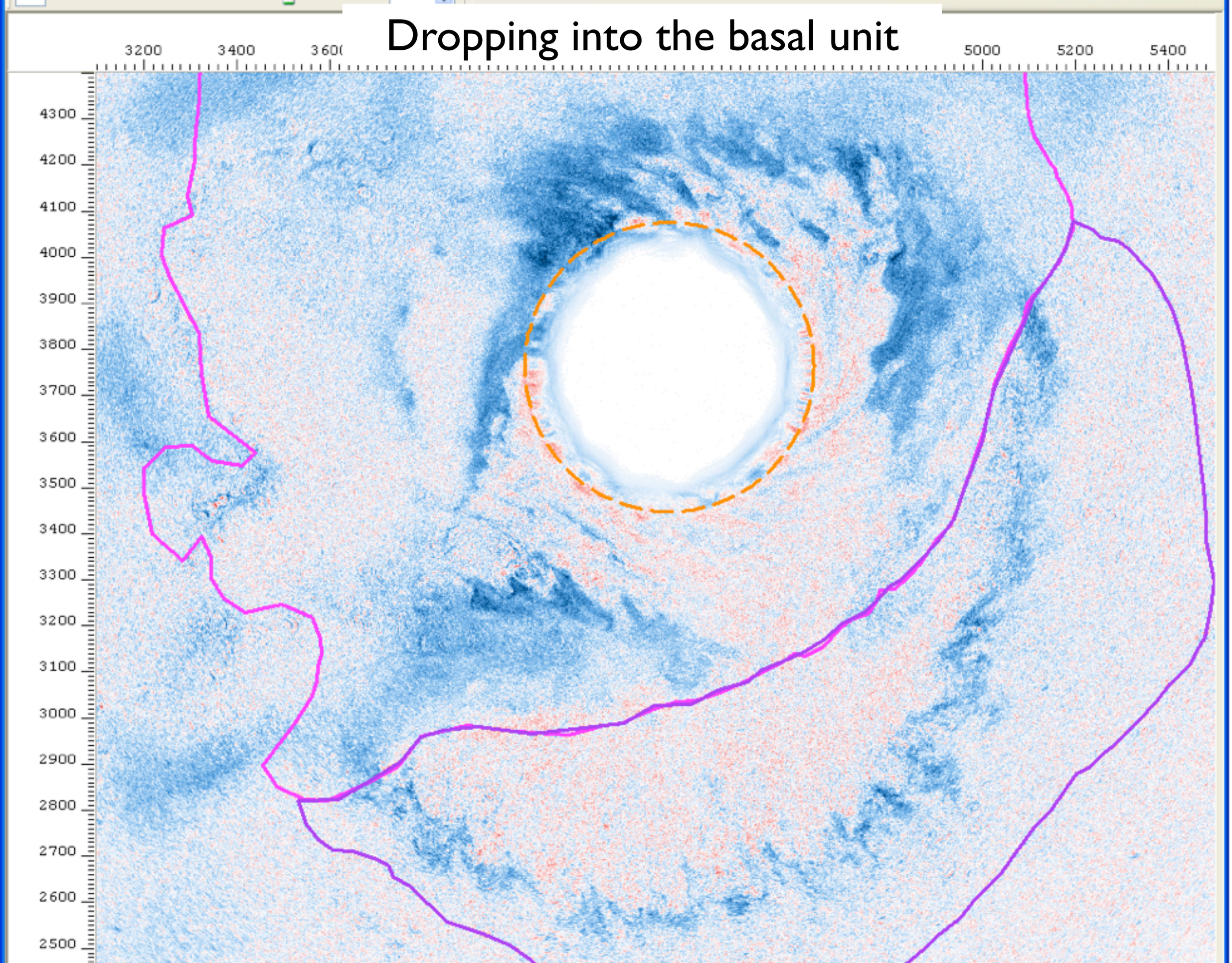
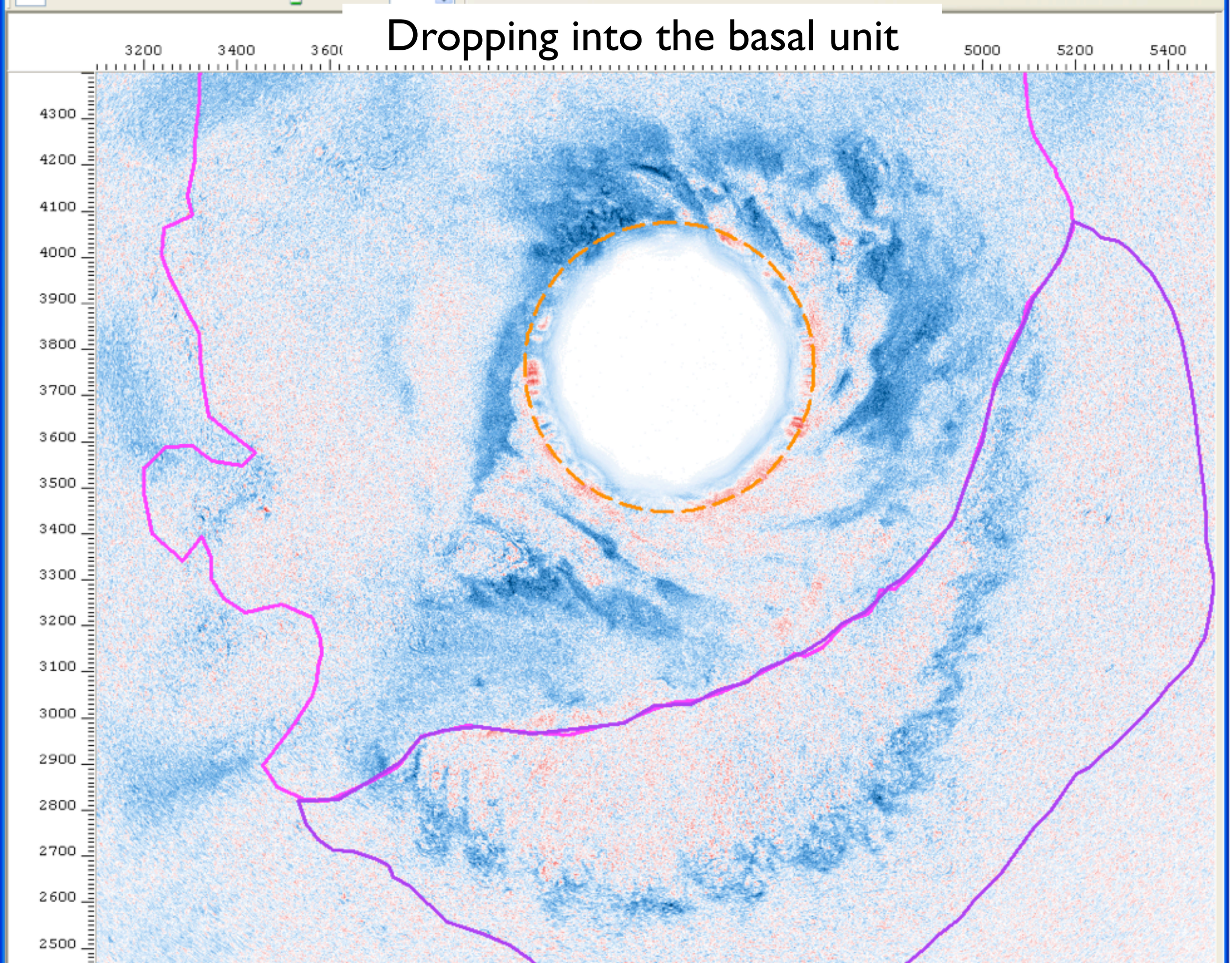
Dropping into the basal unit



Dropping into the basal unit



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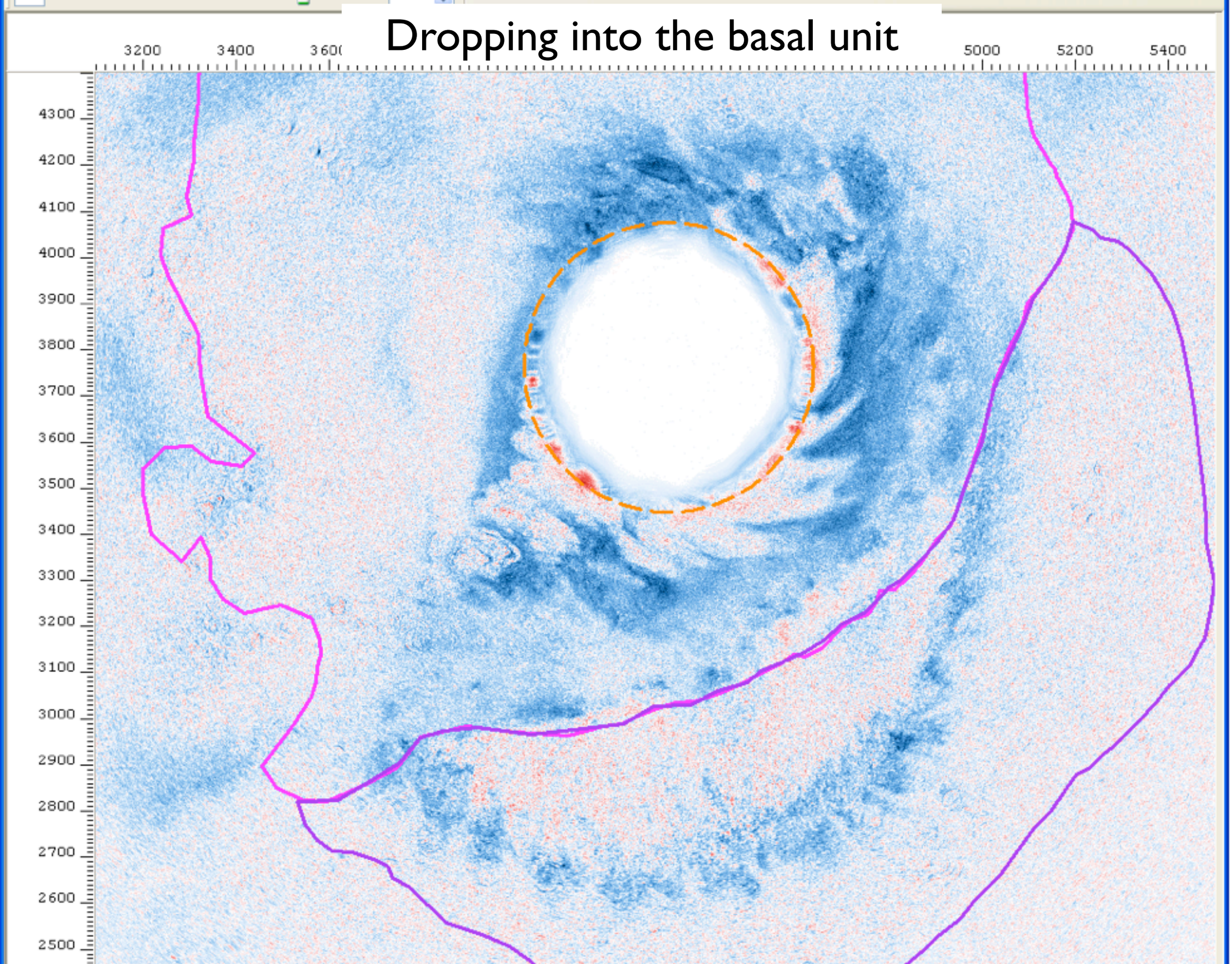

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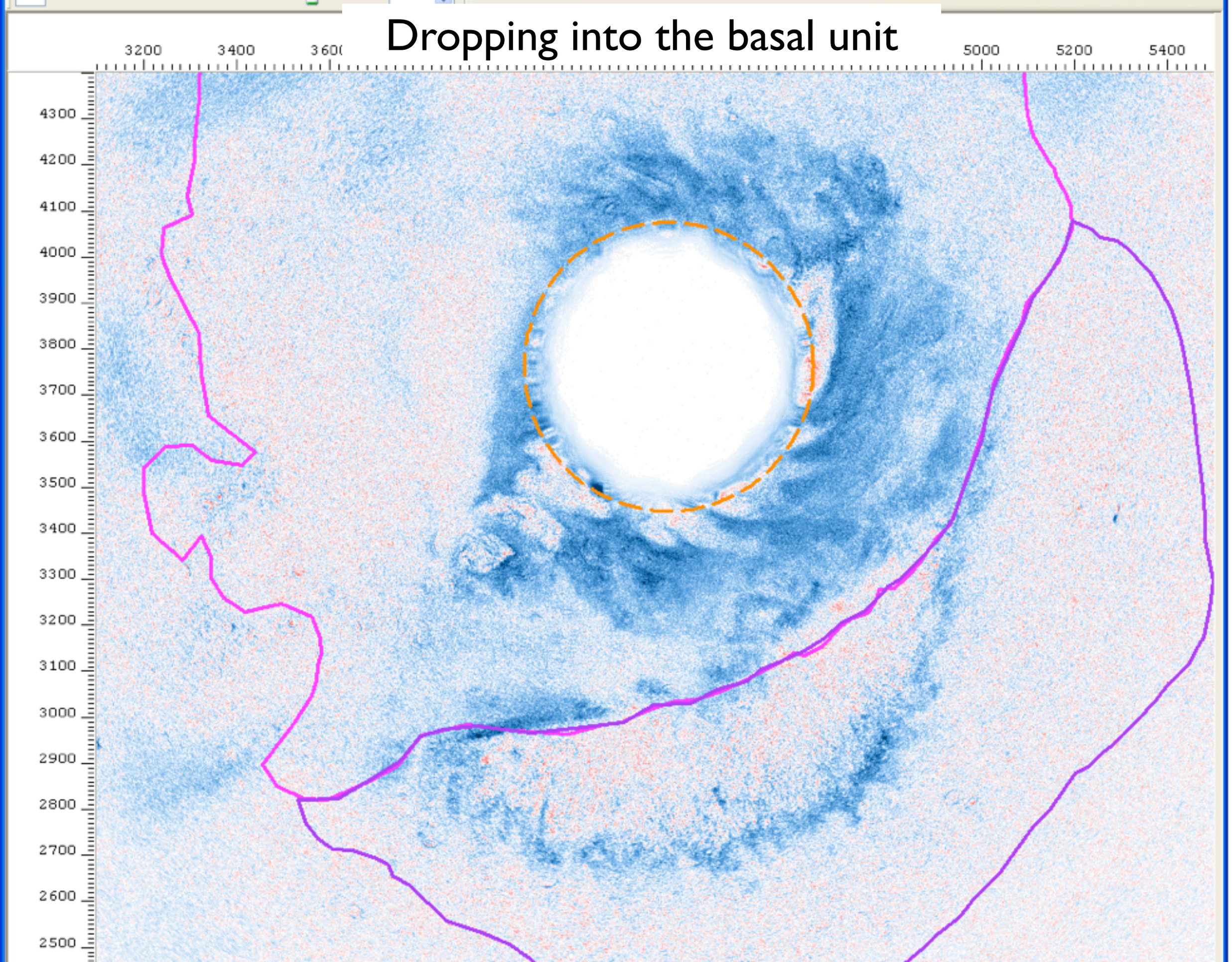

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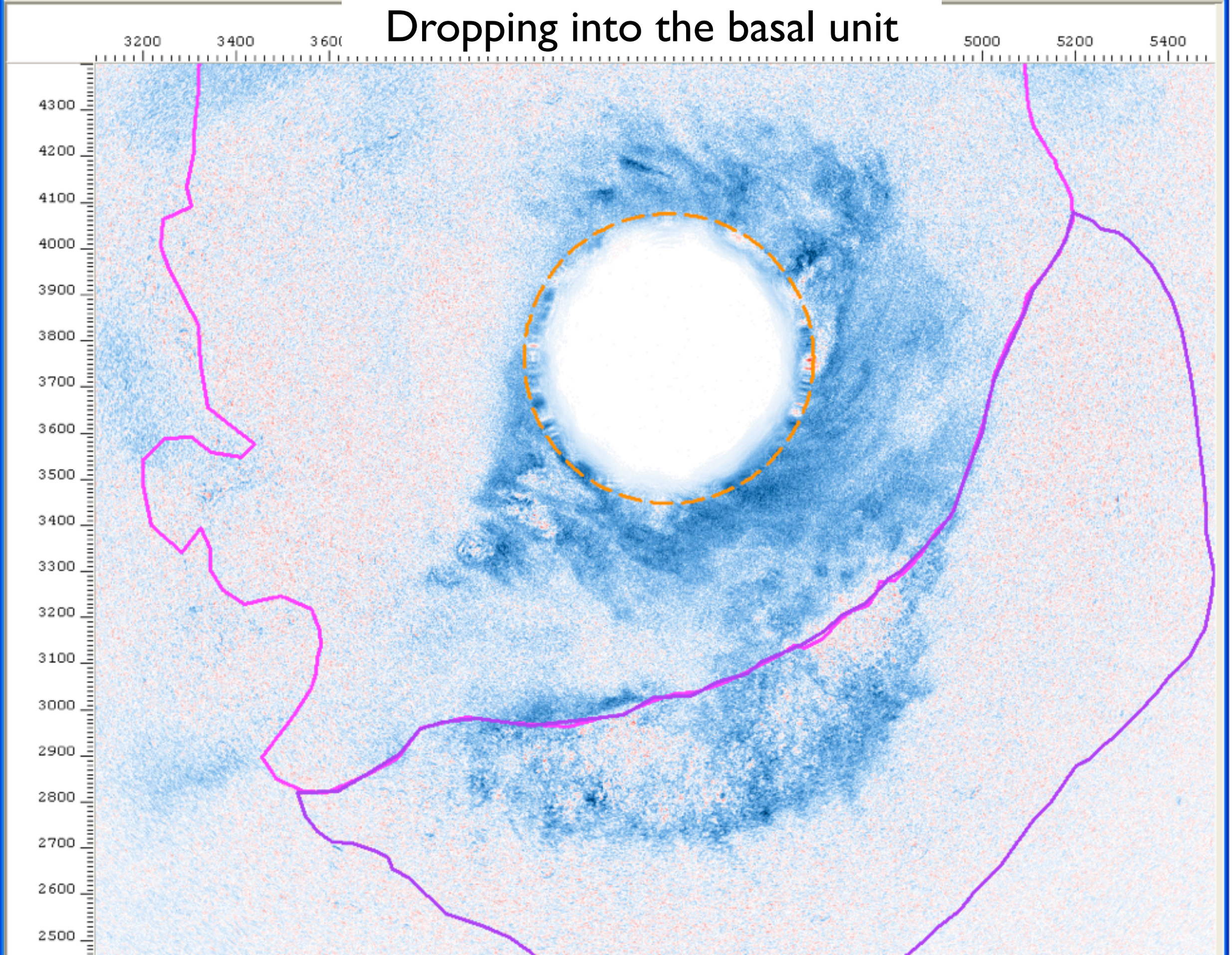

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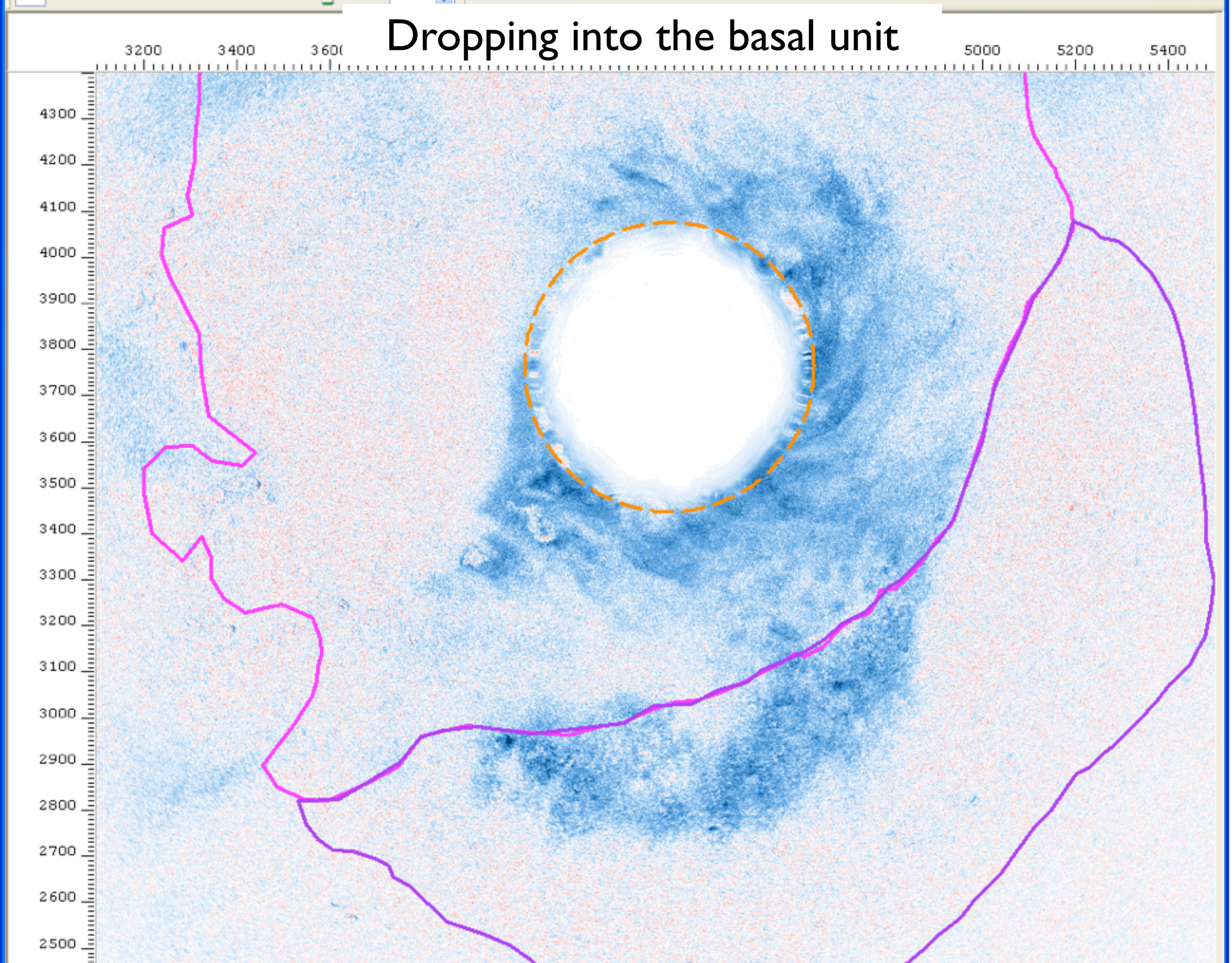

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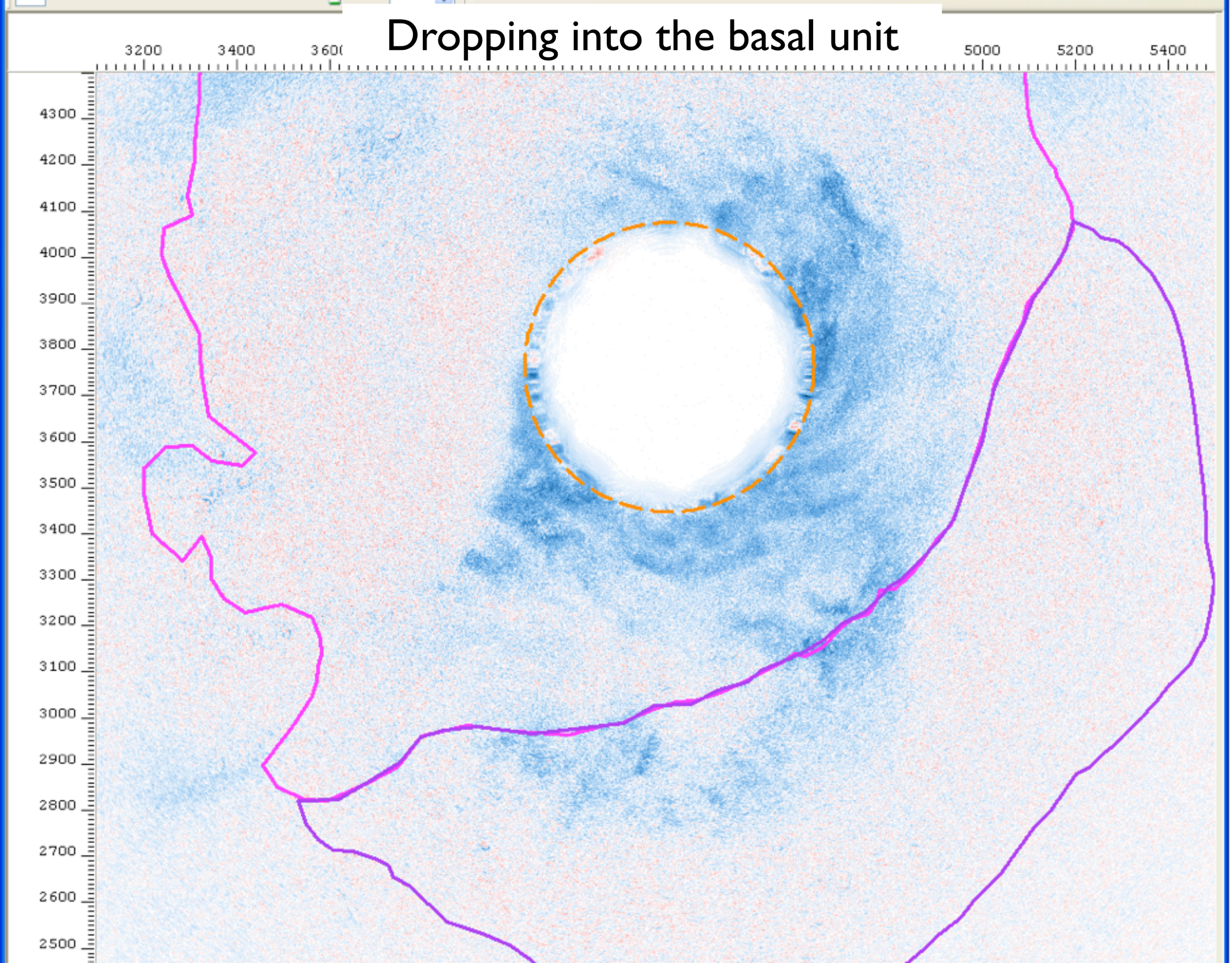
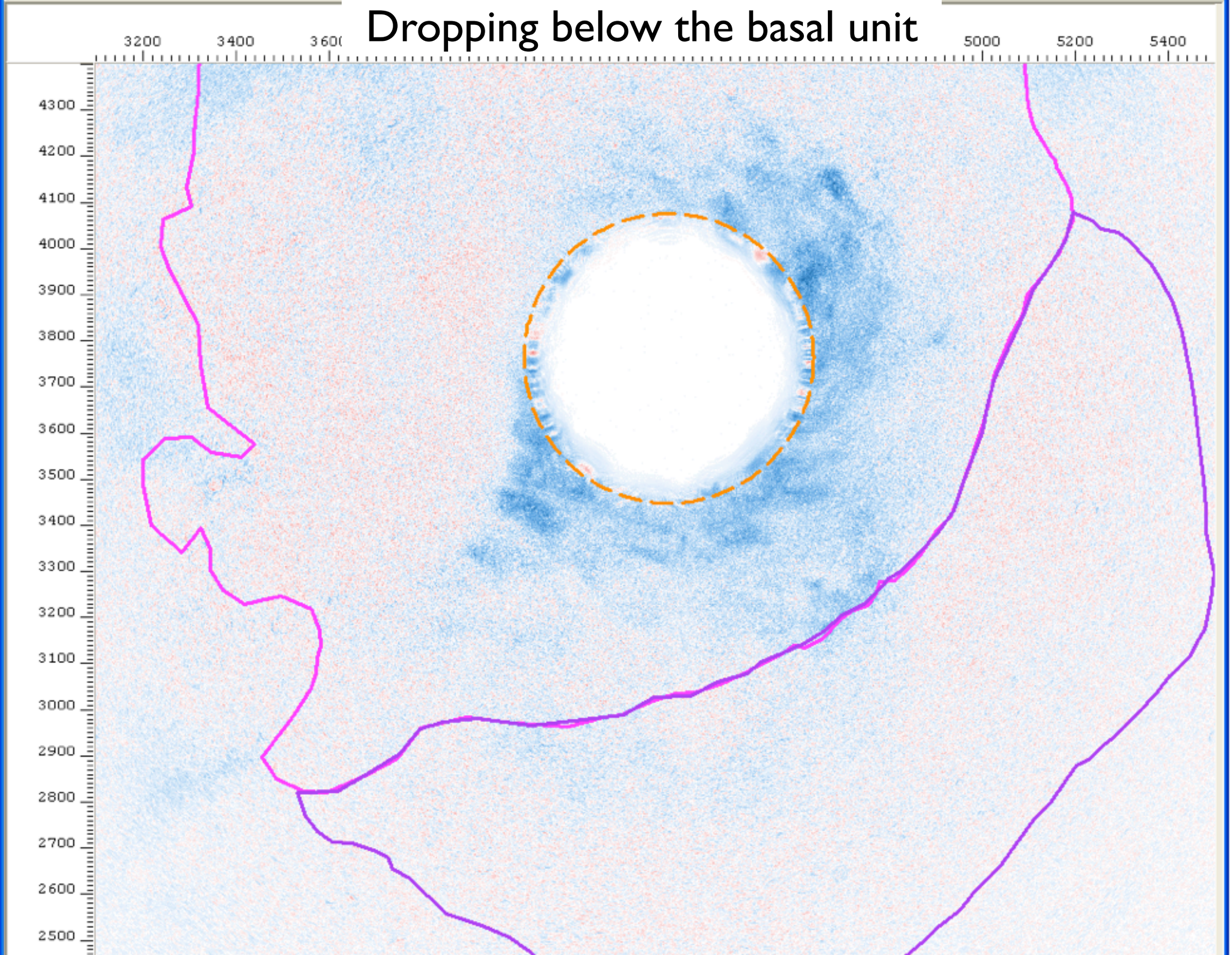


Dropping below the basal unit



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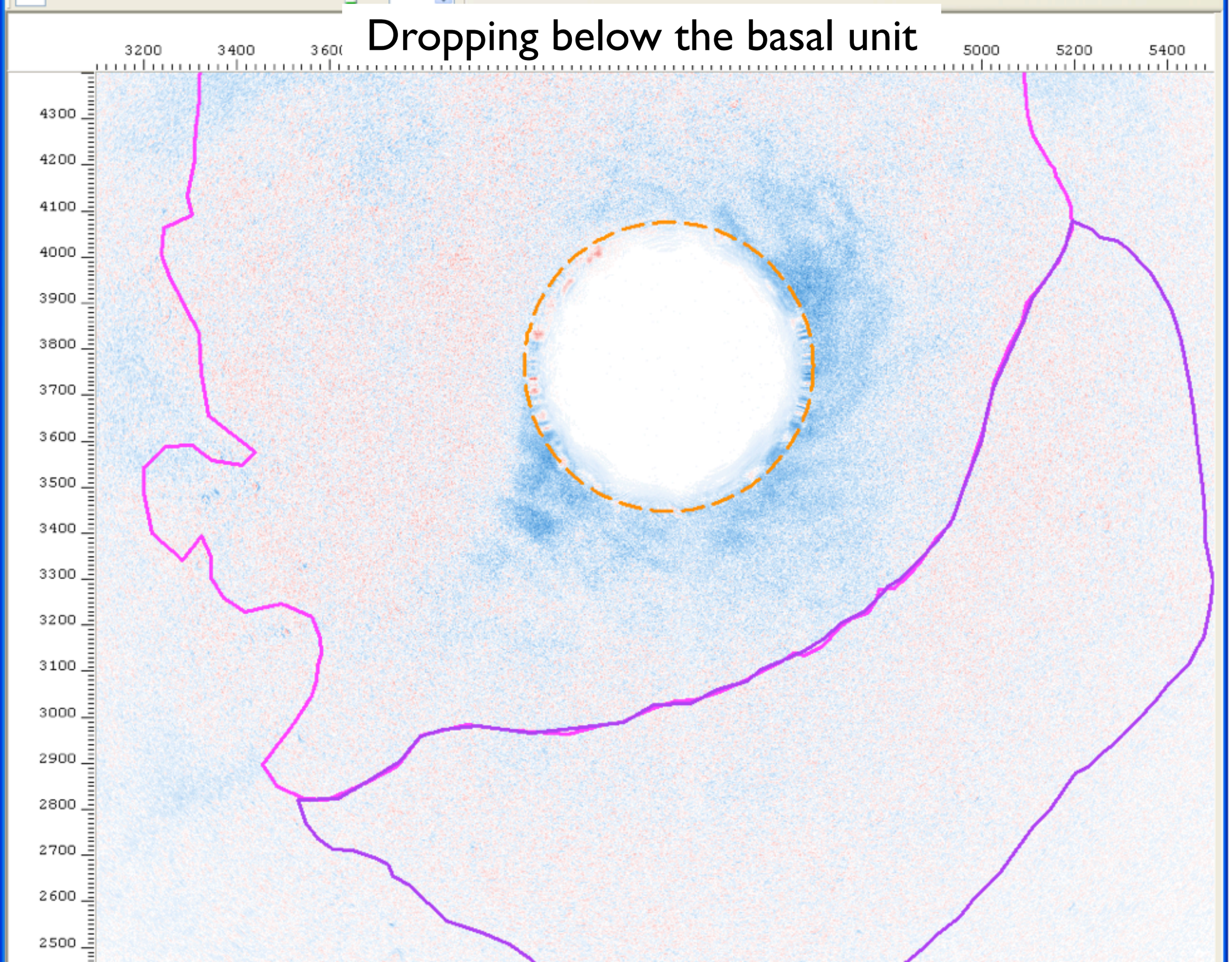

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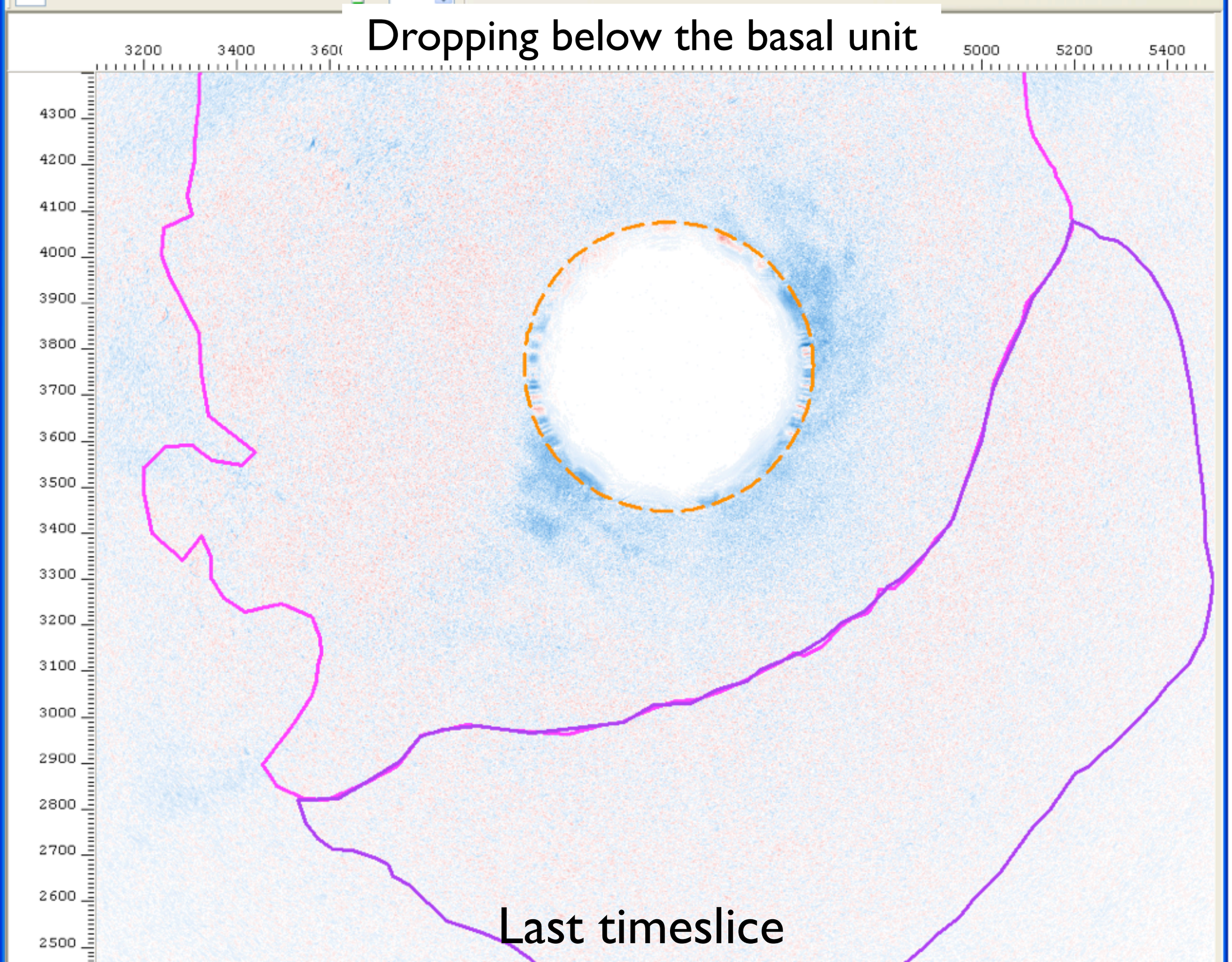
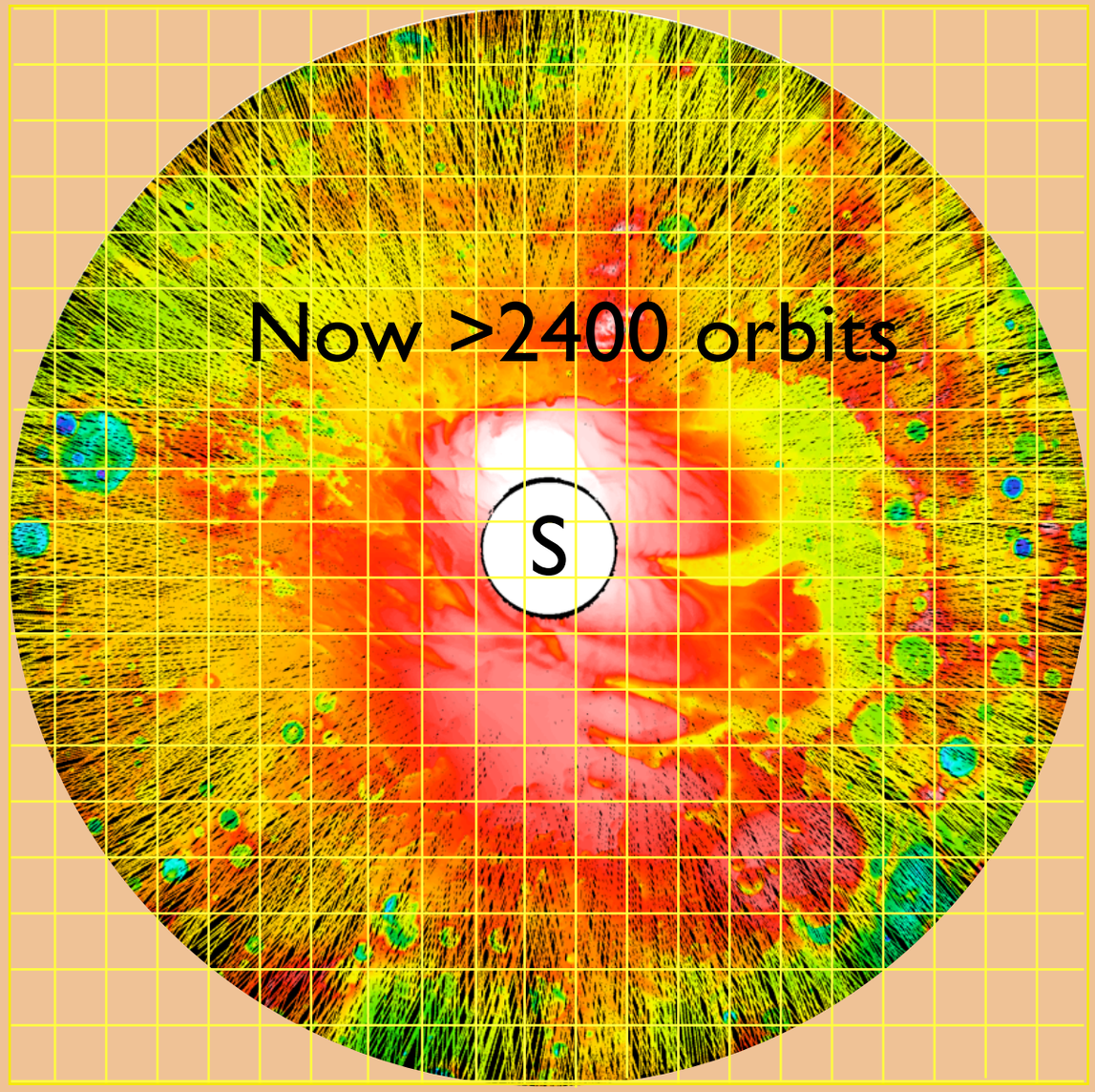


Last timeslice

What's next?

- Planum Boreum 3D will be enhanced further, converted to depth, and released for public use.
- A Planum Australe 3D will be coming in the near future!

Coverage 70–87°S
(in MOLA elevation)



Conclusions

- 2D SHARAD analysis has yielded a wealth of discoveries in the polar ices.
- 3D binning and migration are adding a new level of clarity to the data, revealing intriguing new features.
- Results will shed new light on the nature & timing of the polar deposits.

Thanks to...

- SeisWare and Landmark for software access and support.
- NASA, ASI (Italian Space Agency), MRO Project, and SHARAD Team.
- NASA's Mars Data Analysis Program for funding both 3-D studies.
- Viewers like you!