

Intracontinental Tectonics, Stresses, and Fracture Reservoirs*

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Abstract

For many years correspondence of the maximum principal horizontal stress field (σ_1) with plate motion in “hotspot” reference frames has been an active working hypothesis. σ_1 can be viewed as a background stress field, and as such, may play a significant role in controlling formation of both natural and induced fractures within intracontinental basins.

σ_1 (assumed to be equivalent to the maximum horizontal compressive stress, σ_{hmax} , based on plate-hotspot kinematics, shows distinctive variations from Cretaceous-Present, and significant correspondence with observed and dated fractures, including dated dikes, veins, and stratigraphically constrained fractures from North America and Africa. Additional work implies that plate-hotspot models represent not so much plate motions relative to hotspots as to the surrounding mantle in which hotspots are “embedded”. That is, deeper asthenospheric (which has also been termed “mesospheric”) mantle is moving very slowly, and the orientation of stress across the boundary between lithospheric mantle (plates) and the lower asthenospheric mantle is what is manifested in intracontinental σ_1 .

Other oriented stress sources overprint regional σ_1 including tectonic or active basin-margin faulting and salt tectonics. Particular basinal geohistories can produce distinctive fracture-related reservoirs with fracture orientations reflecting both regional and local paleostress orientations. In a subsiding basin, compaction and overpressuring in the absence of faulting can produce fracturing with orientations controlled only by regional σ_1 . Similarly, In basin experiencing broad, regional uplift in the absence of faulting can produce unloading-related fracturing with orientations controlled only by regional σ_1 .

In an extensive sedimentary sequence, fracture presence and orientation represent the peculiar geohistory of subsidence, compaction, overpressuring, along with hydrocarbon maturation and migration. With the apparent correspondence of plate-hotspot models and regional paleostress histories, explorationists can take regional stress fields into account while attempting to characterize potential intracontinental fracture reservoirs. Further, the predicted contemporary stress field provides critical control on induced fracturing as part of development of the reservoirs. Several exemplars of this approach can be offered to illustrate its applicability.

References

Gradstein, F., J. Ogg, and A. Smith, 2005, A Geologic Time Scale-2004:Cambridge University Press.

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Abstract

- For many years correspondence of the maximum principal horizontal stress field (σ_1) with plate motion in “hotspot” reference frames has been an active working hypothesis. σ_1 can be viewed as a background stress field, and as such, may play a significant role in controlling formation of both natural and induced fractures within intracontinental basins.
- σ_1 (assumed to be equivalent to the maximum horizontal compressive stress, σ_{hmax} , based on plate-hotspot kinematics, shows distinctive variations from Cretaceous-Present, and significant correspondence with observed and dated fractures, including dated dikes, veins, and stratigraphically constrained fractures from North America and Africa. Additional work implies that plate-hotspot models represent not so much plate motions relative to hotspots as to the surrounding mantle in which hotspots are “embedded”. That is, deeper asthenospheric (which has also be termed “mesospheric”) mantle is moving very slowly, and the orientation of stress across the boundary between lithospheric mantle (plates) and the lower asthenospheric mantle is what is manifested in intracontinental σ_1 .
- Other oriented stress sources overprint regional σ_1 including tectonic or active basin-margin faulting and salt tectonics. Particular basinal geohistories can produce distinctive fracture-related reservoirs with fracture orientations reflecting both regional and local paleostress orientations. In a subsiding basin, compaction and overpressuring in the absence of faulting can produce fracturing with orientations controlled only by regional σ_1 . Similarly, In basin experiencing broad, regional uplift in the absence of faulting can produce unloading-related fracturing with orientations controlled only by regional σ_1 .
- In an extensive sedimentary sequence, fracture presence and orientation represent the peculiar geohistory of subsidence, compaction, overpressuring, along with hydrocarbon maturation and migration. With the apparent correspondence of plate-hotspot models and regional paleostress histories, explorationists can take regional stress fields into account while attempting to characterize potential intracontinental fracture reservoirs. Further, the predicted contemporary stress field provides critical control on induced fracturing as part of development of the reservoirs. Several exemplars of this approach can be offered to illustrate its applicability.

Rationale for this study

- Characterization of intracontinental stress orientation histories
- Origin of predicted stress orientations
- Provide part of framework for fracture reservoir prospecting and decision-making

The Problems

- What is the **paleostress** history of the prospect?
 - Stress field orientation
- At what time(s) were **paleofractures** most likely to have developed?
 - Time(s) of maximum stress
 - Orientation: controlled by prevailing regional principal stress
- Which **fractures** are most likely to be **hydrocarbon-filled**?
 - Last connected fracture set after maturation

The Problems

- What is the contemporary **stress field** orientation?
 - Parallel to hydrocarbon-filled paleofractures, or
 - Oblique to hydrocarbon-filled paleofractures
- Is **hydrofracturing** an appropriate technology for the prospect?
 - If induced fractures can link up existing hydrocarbon-filled paleofractures
 - If induced fractures can drain interstitial hydrocarbons
 - If fractures can be induced in other than principal extensional stress directions

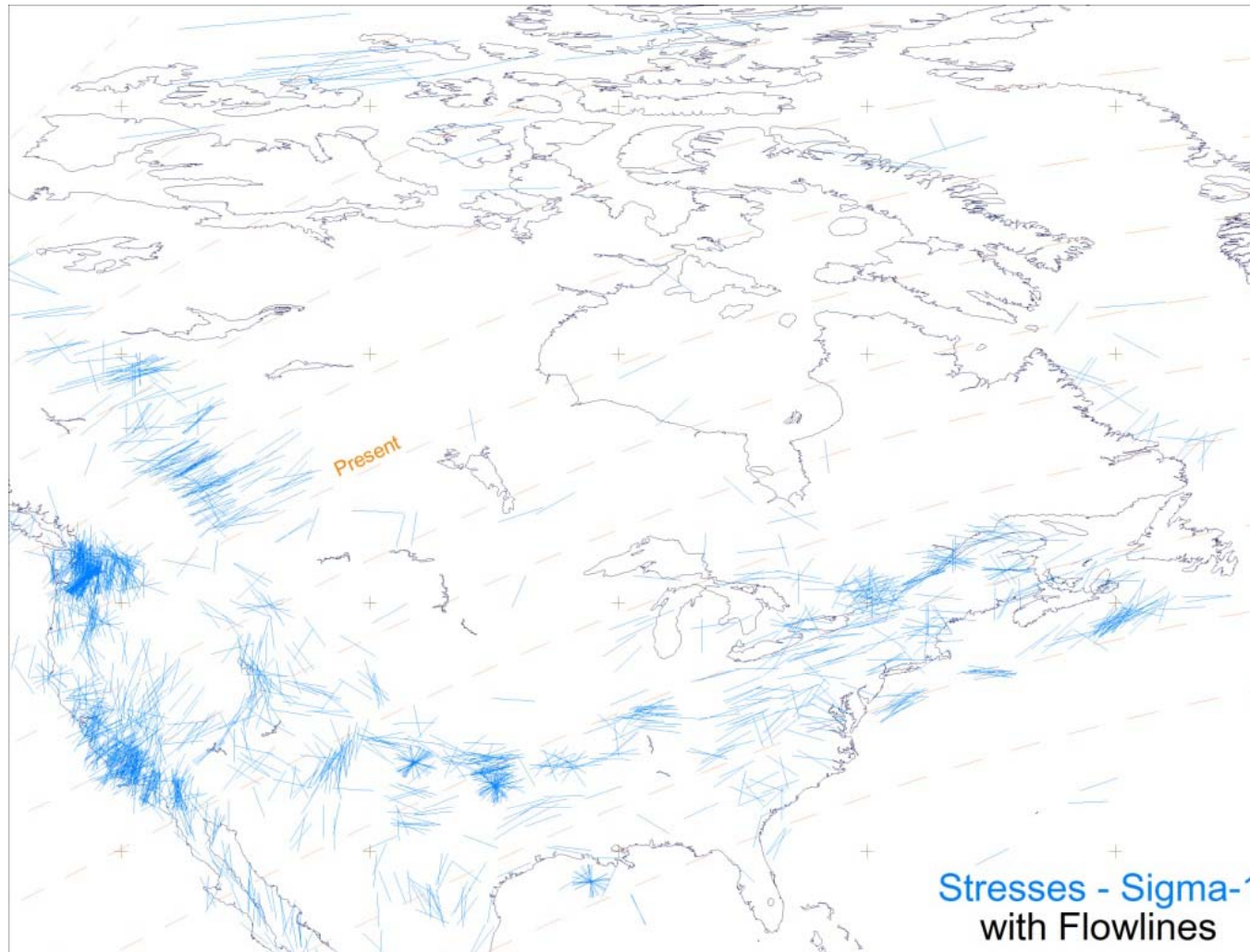
Continental Interior Prospects

- What is the **paleostress** history of the prospect?
 - In the absence of significant structural deformation (faults and folds)...
 - Regional stress fields can be important...
 - At the time of maximum vertical stress...
 - Rapid subsidence and burial producing overpressuring
 - Hydrocarbon maturation
 - Regional uplift

Plate Kinematics and Stresses

- In early 1980's contemporary maximum horizontal compressive stress measurements (σ_{hmax}) for North America were compiled
 - Earthquake focal mechanisms
 - Hydrofractures
 - *In situ* stress measurements
 - Surface joint patterns
 - Borehole breakouts (ellipticity)
 - Quarry “pop-ups”

Plate Kinematics and Stresses



σ_{hmax} orientations parallel motion of North America in hotspot reference frame*

*Gripp and Gordon, 1990; Zoback and Zoback, 1980; Zoback et al., 1989

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Plate Kinematics and Stresses

- Can paleo-plate/hotspot models predict paleostress orientations?
 - Plate hotspot model of Müller et al., 1993
 - Geological timescale of Gradstein et al., 2005
 - Spline interpolation of vectorized parameters – method of Pilger, 2003
 - Instantaneous plate-hotspot rotations – method of Pilger, 2003
 - Paleostress indicators: dated dikes, fractures, joints (compilation of Pilger, 2003)

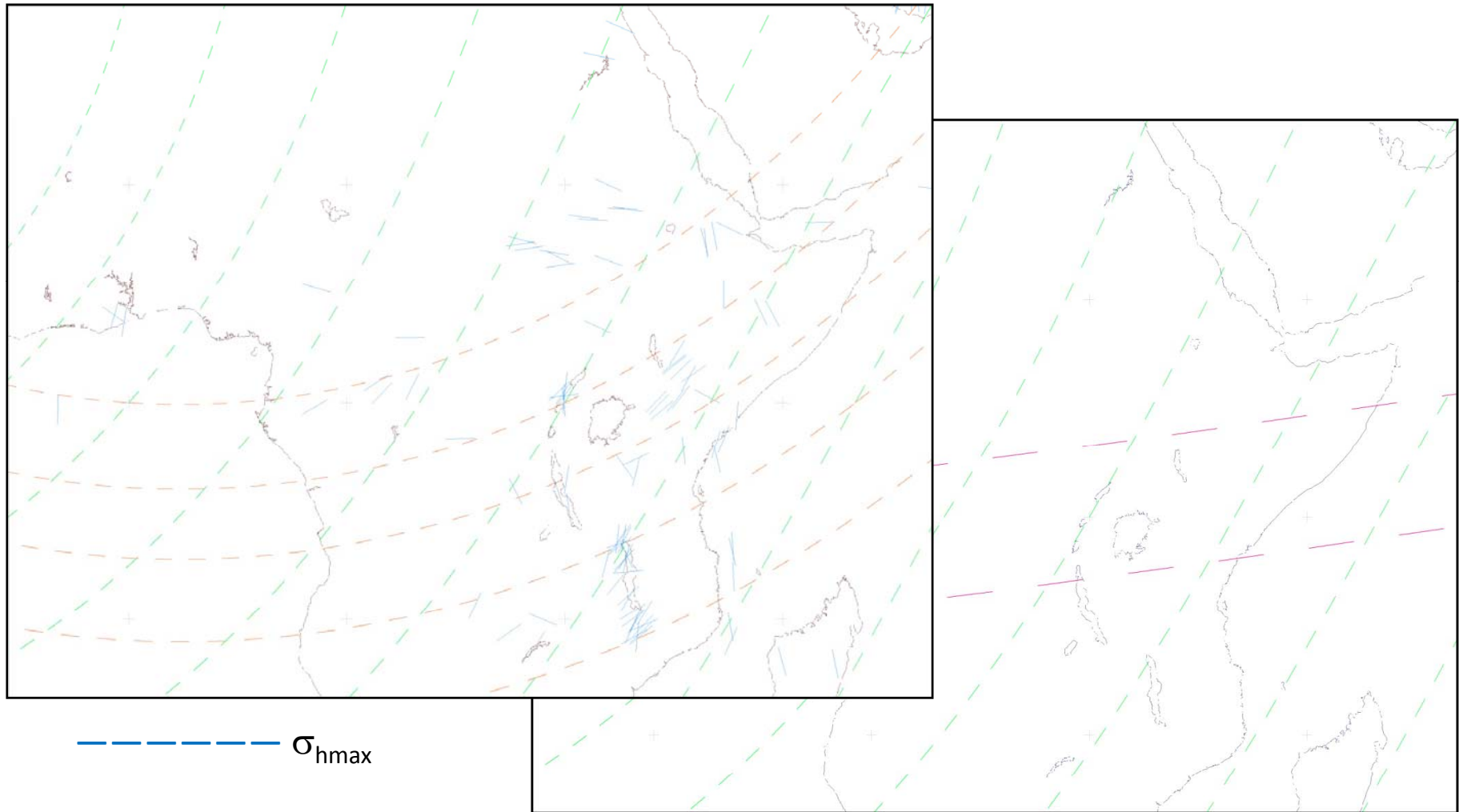
Plate Kinematics and Stresses

Plate-hotspot loci, North America fixed

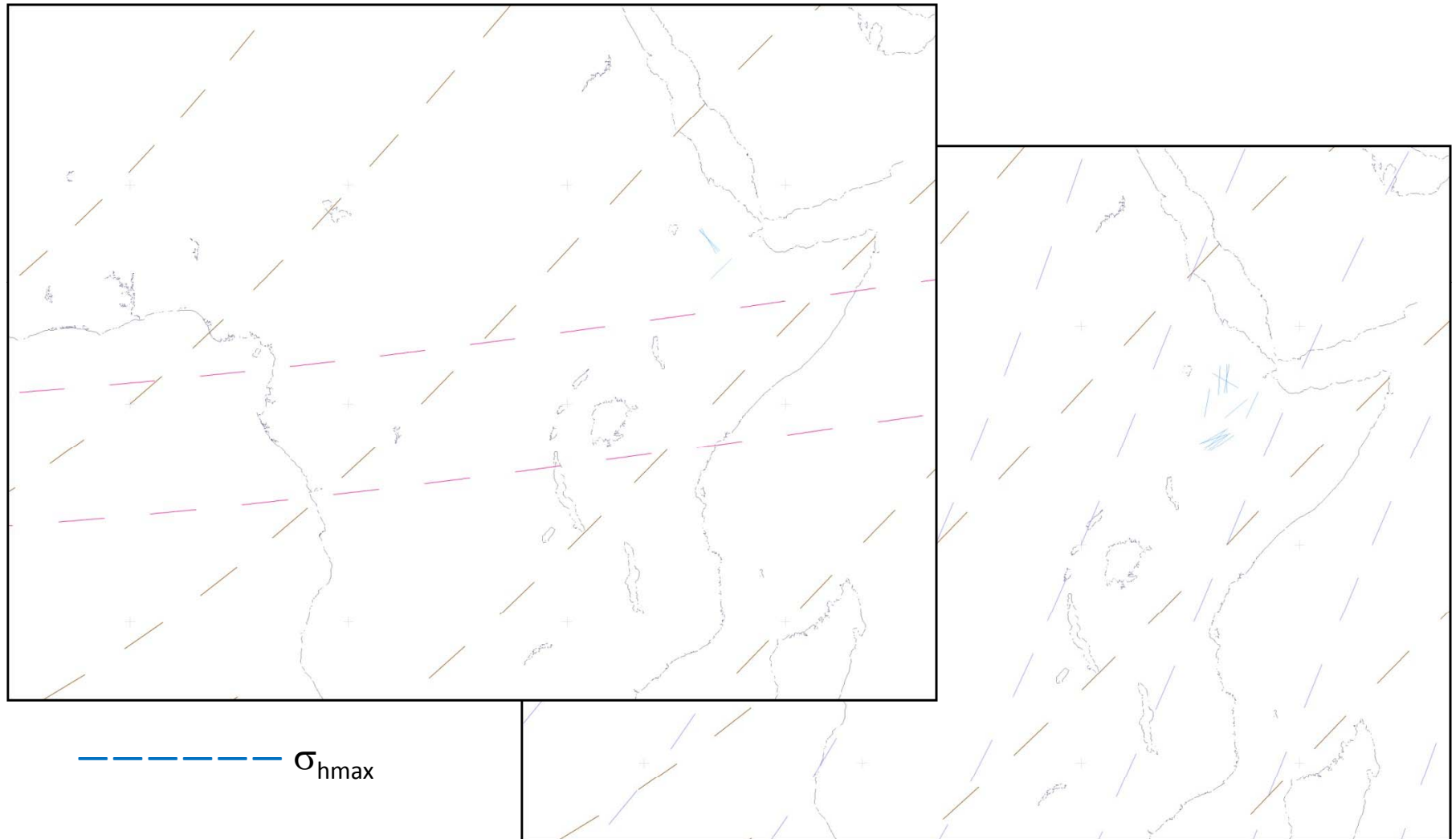


5 m.y. increments

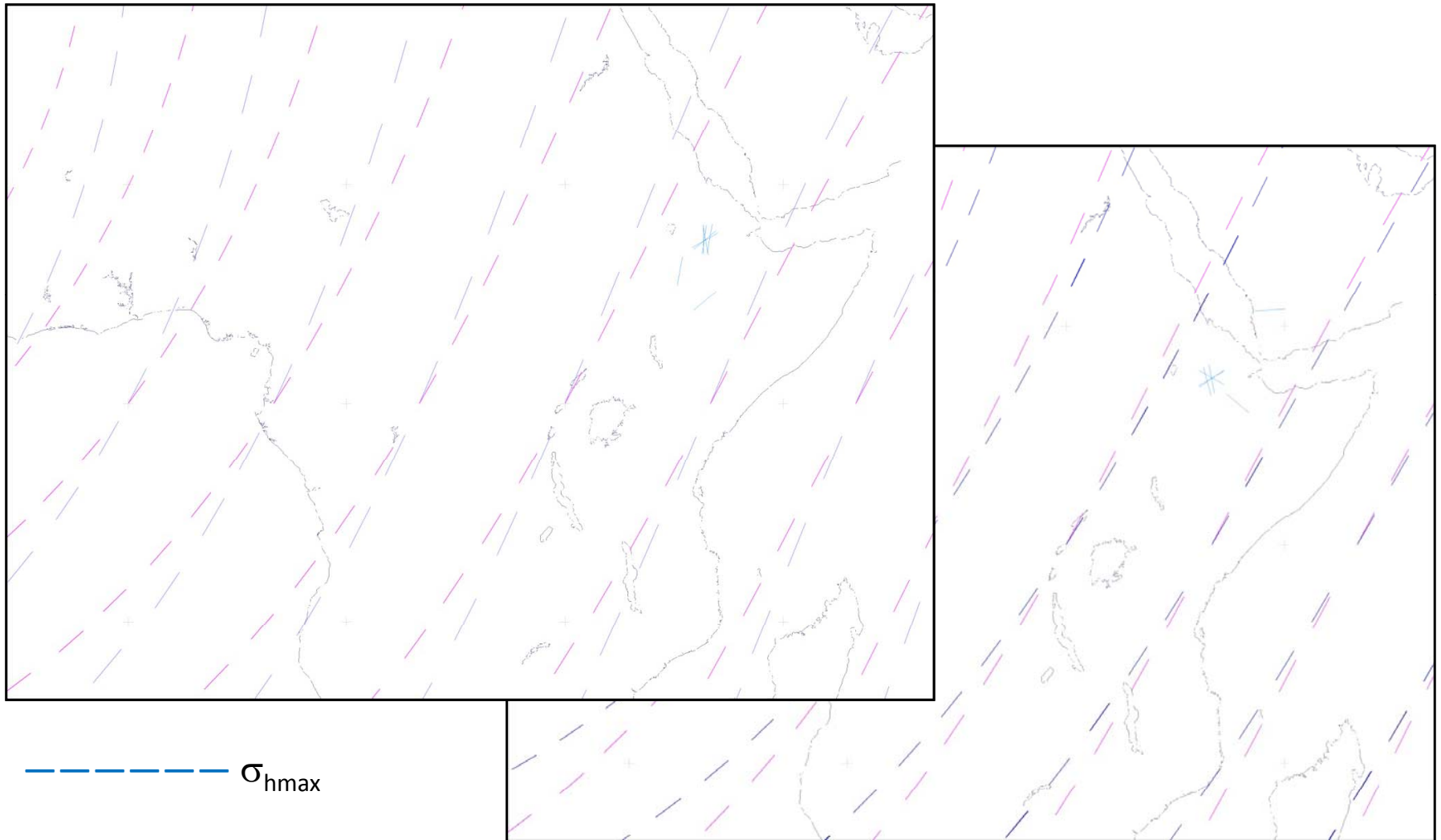
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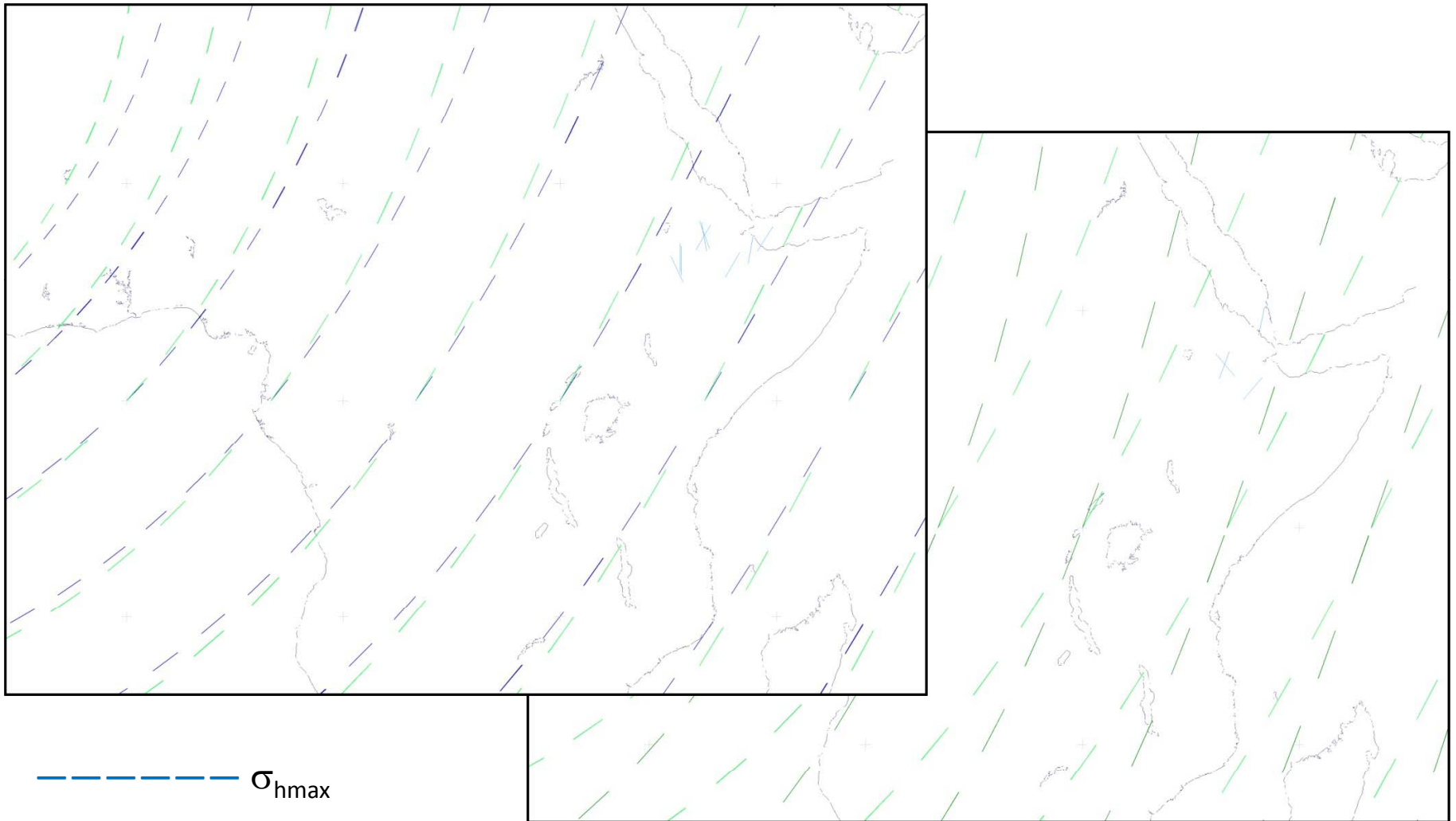
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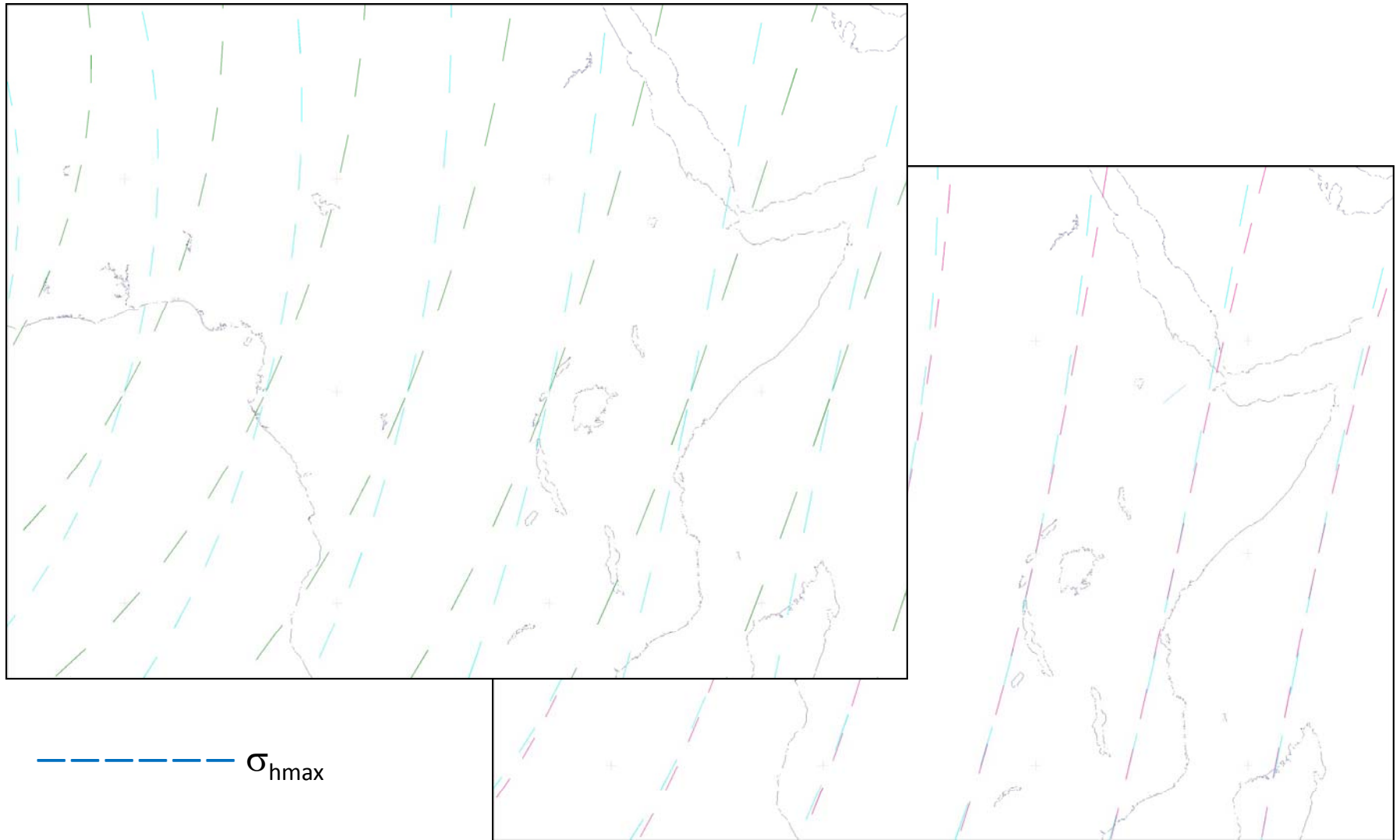
Africa 20 – 25 – 30 Ma



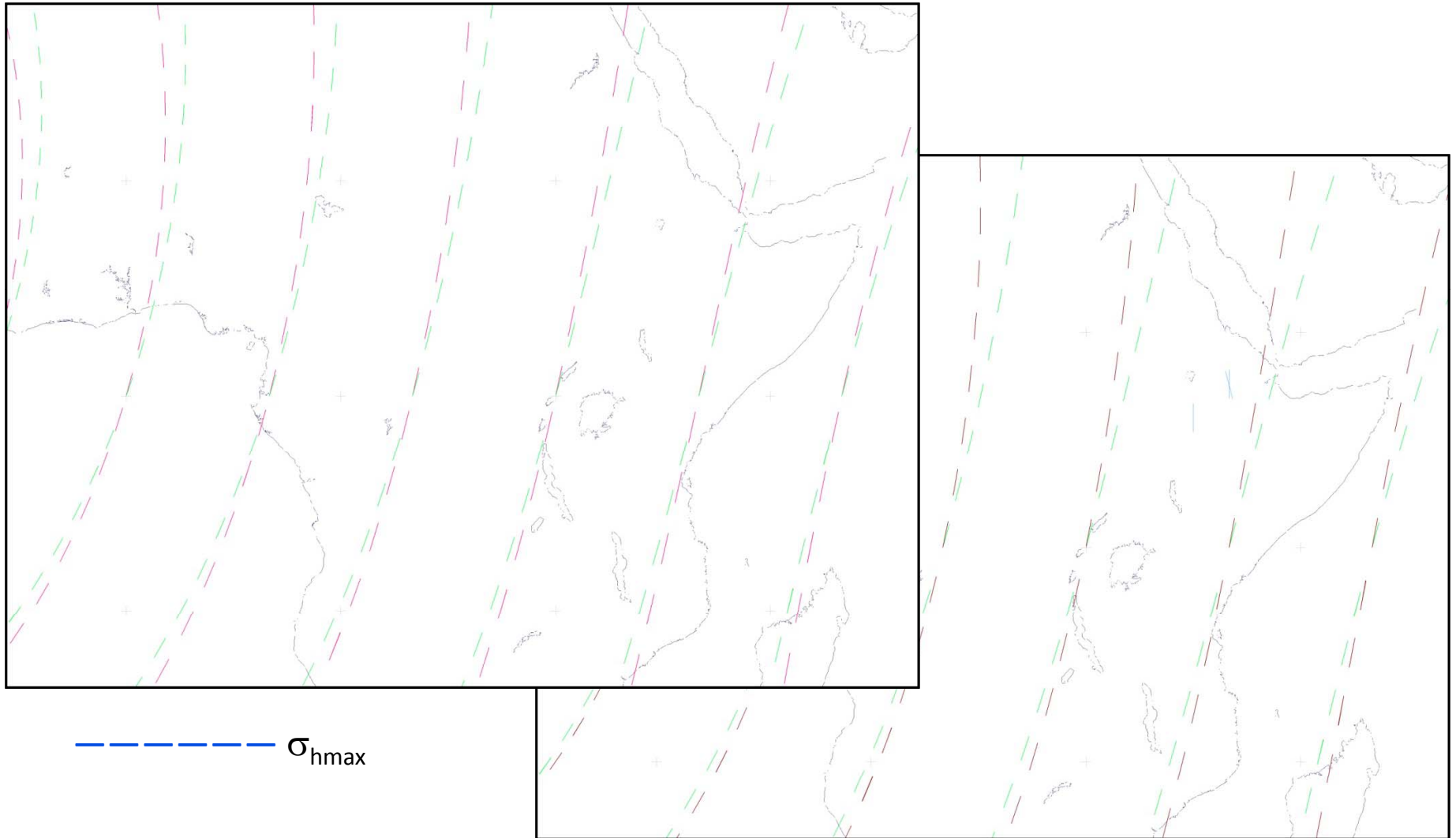
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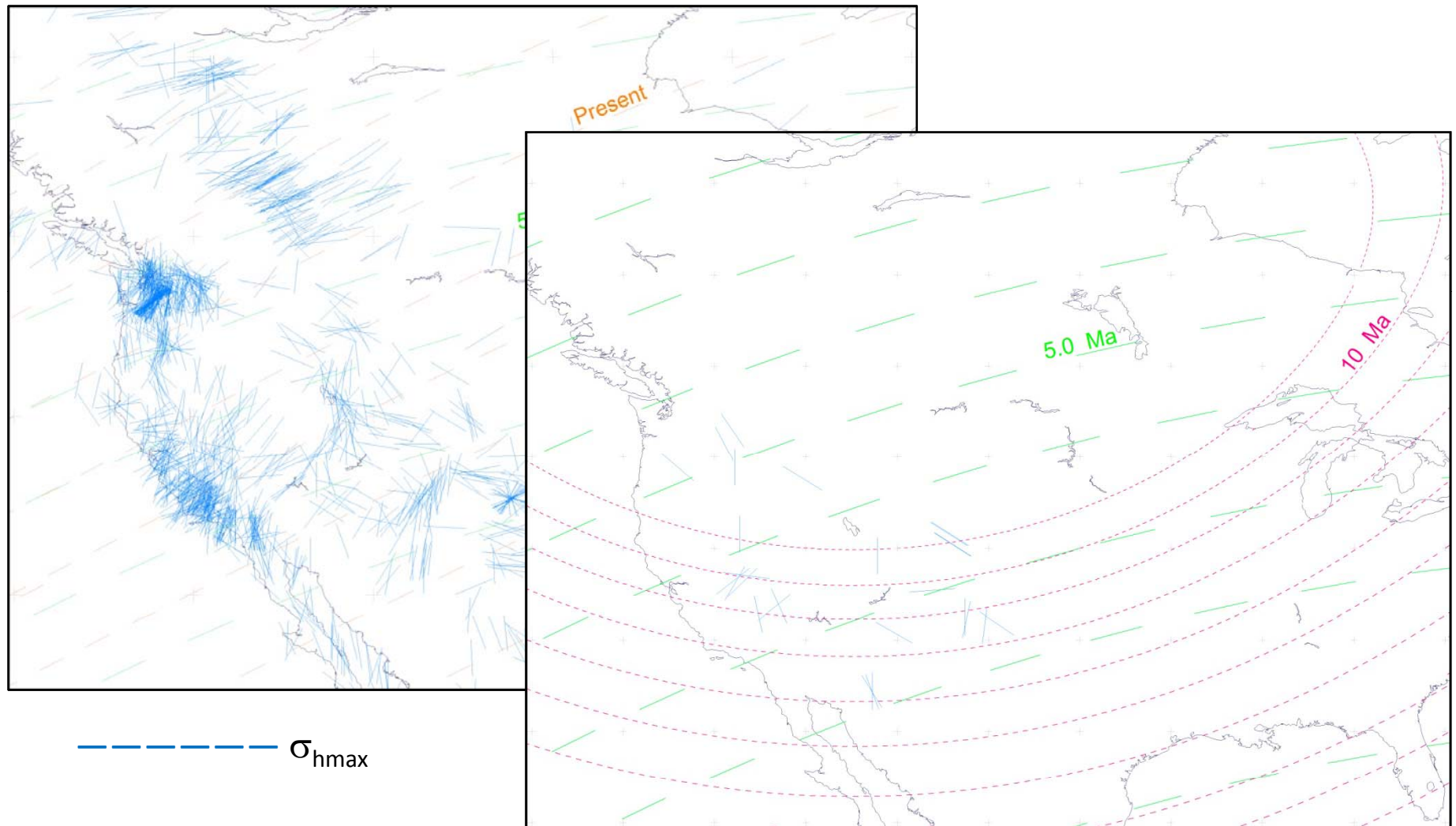
Africa 40 – 45 – 50 Ma



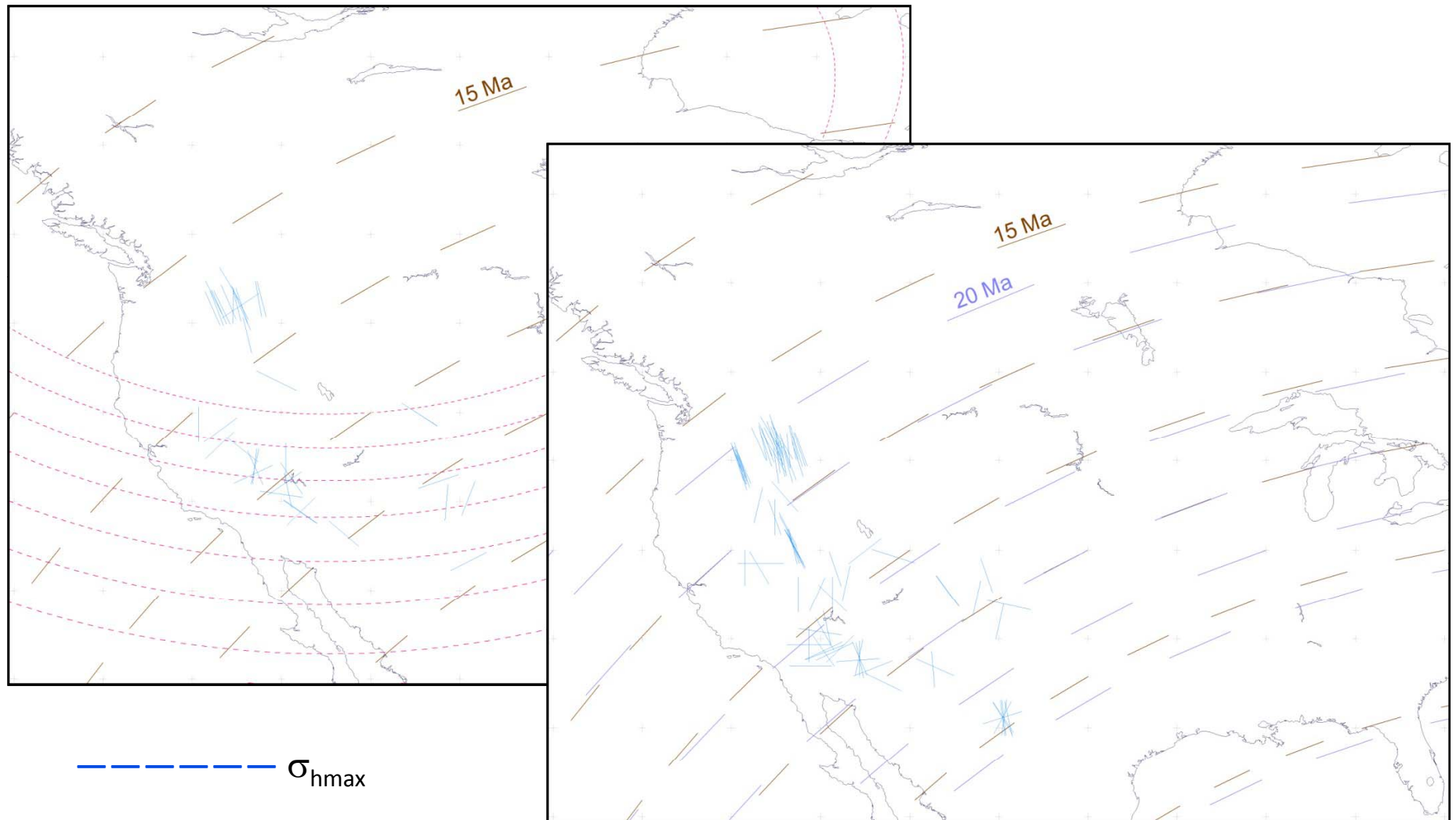
Africa 50 – 55 – 60 Ma



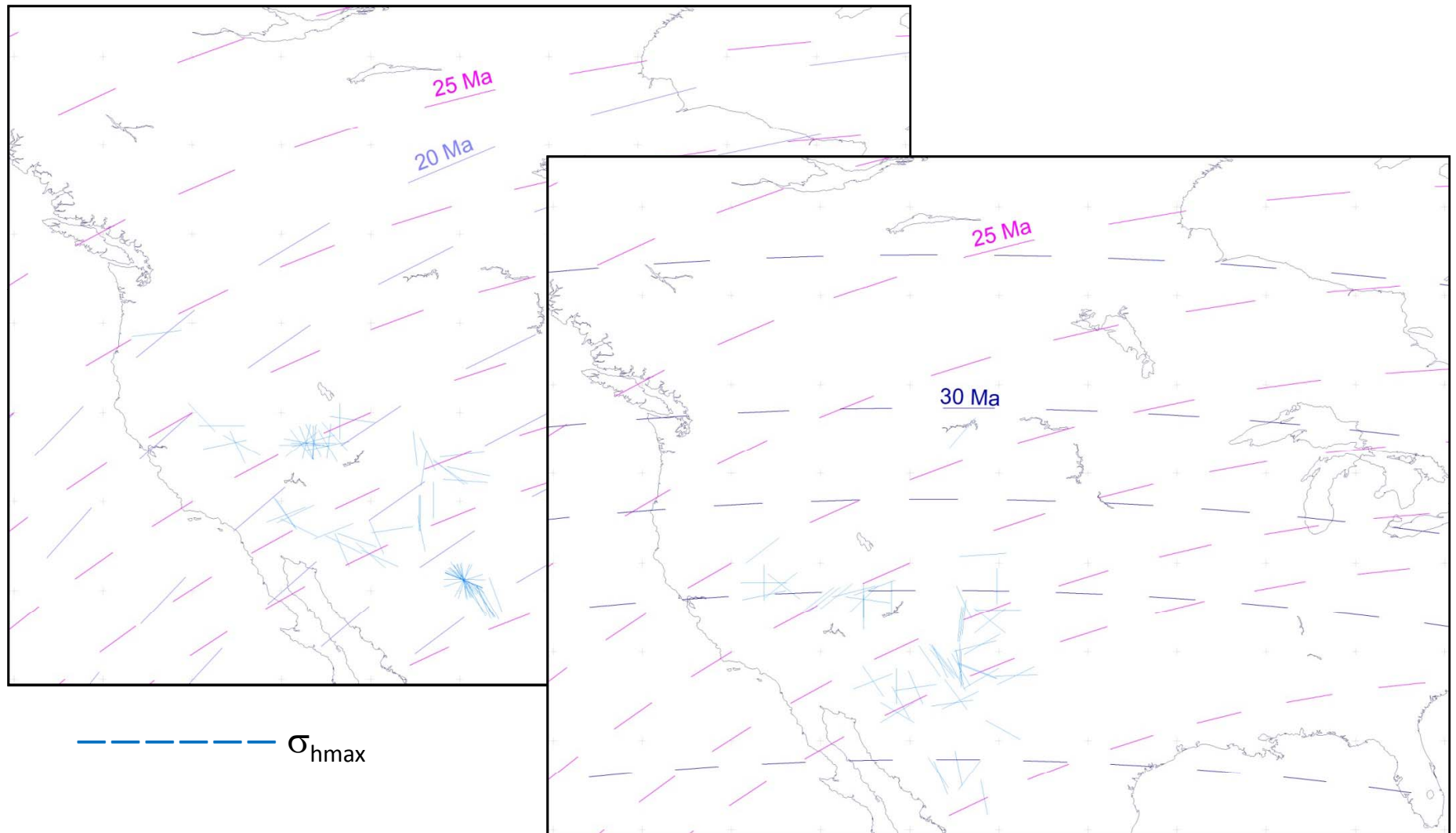
N America 0 – 5 – 10 Ma



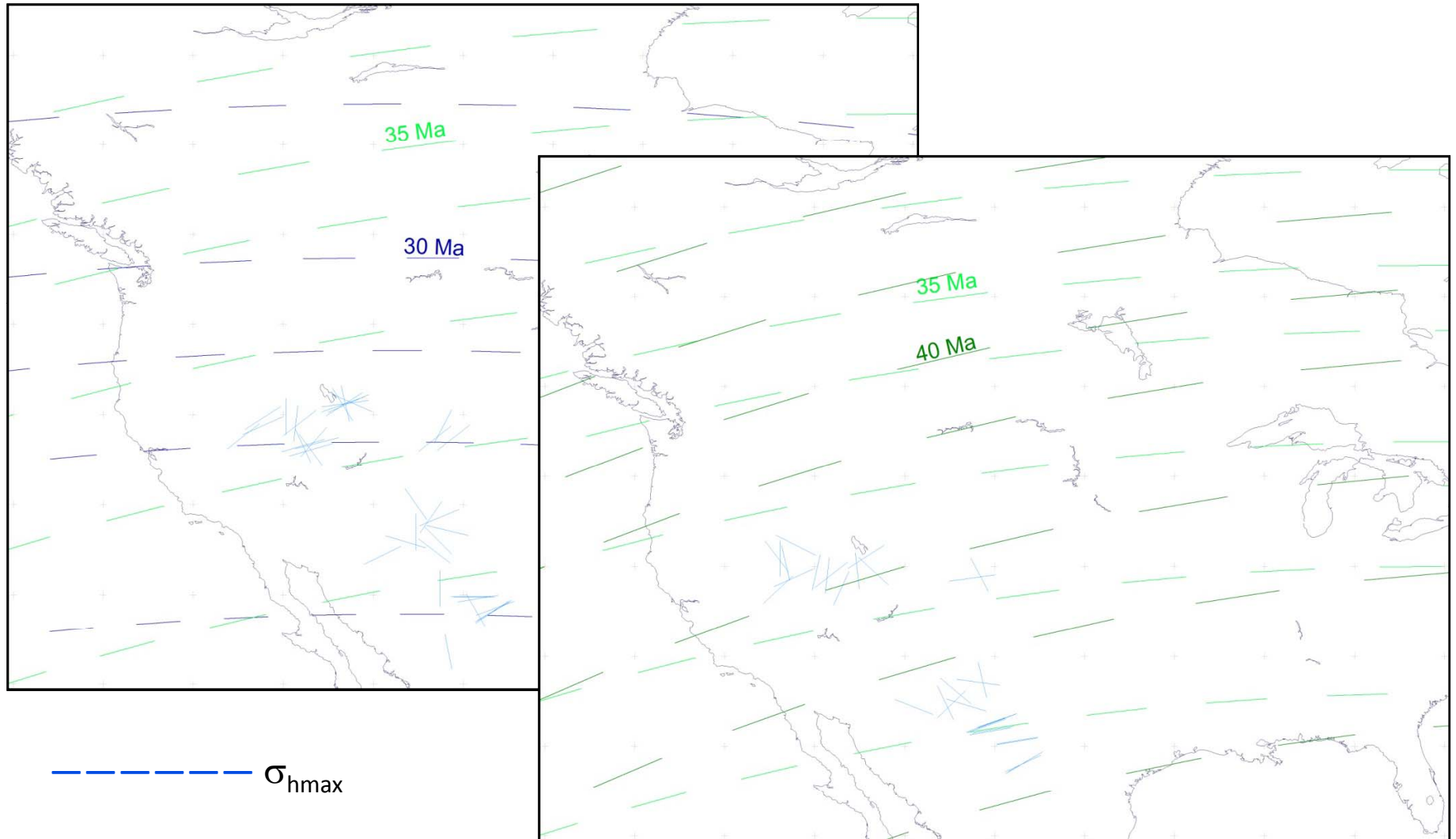
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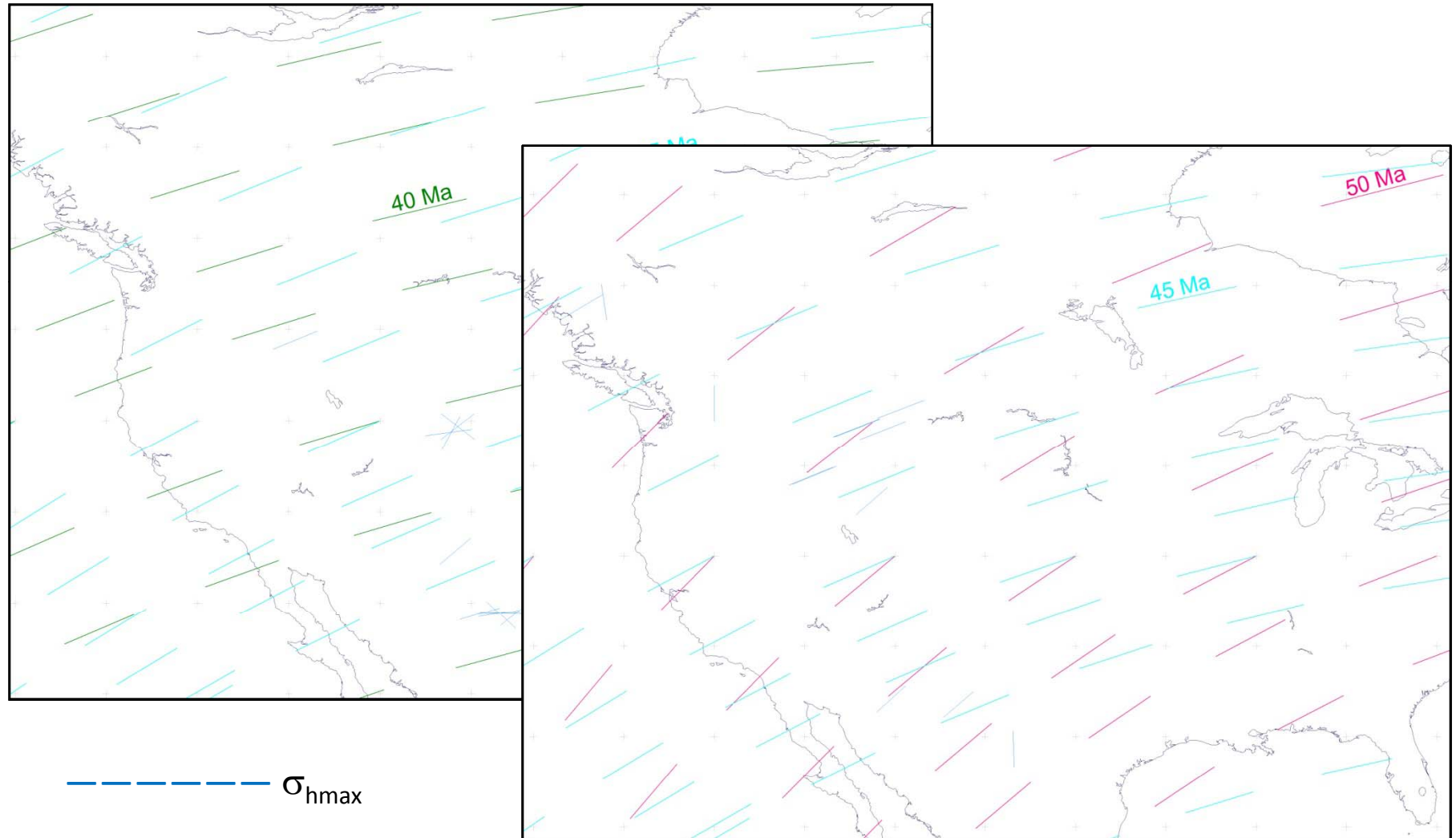
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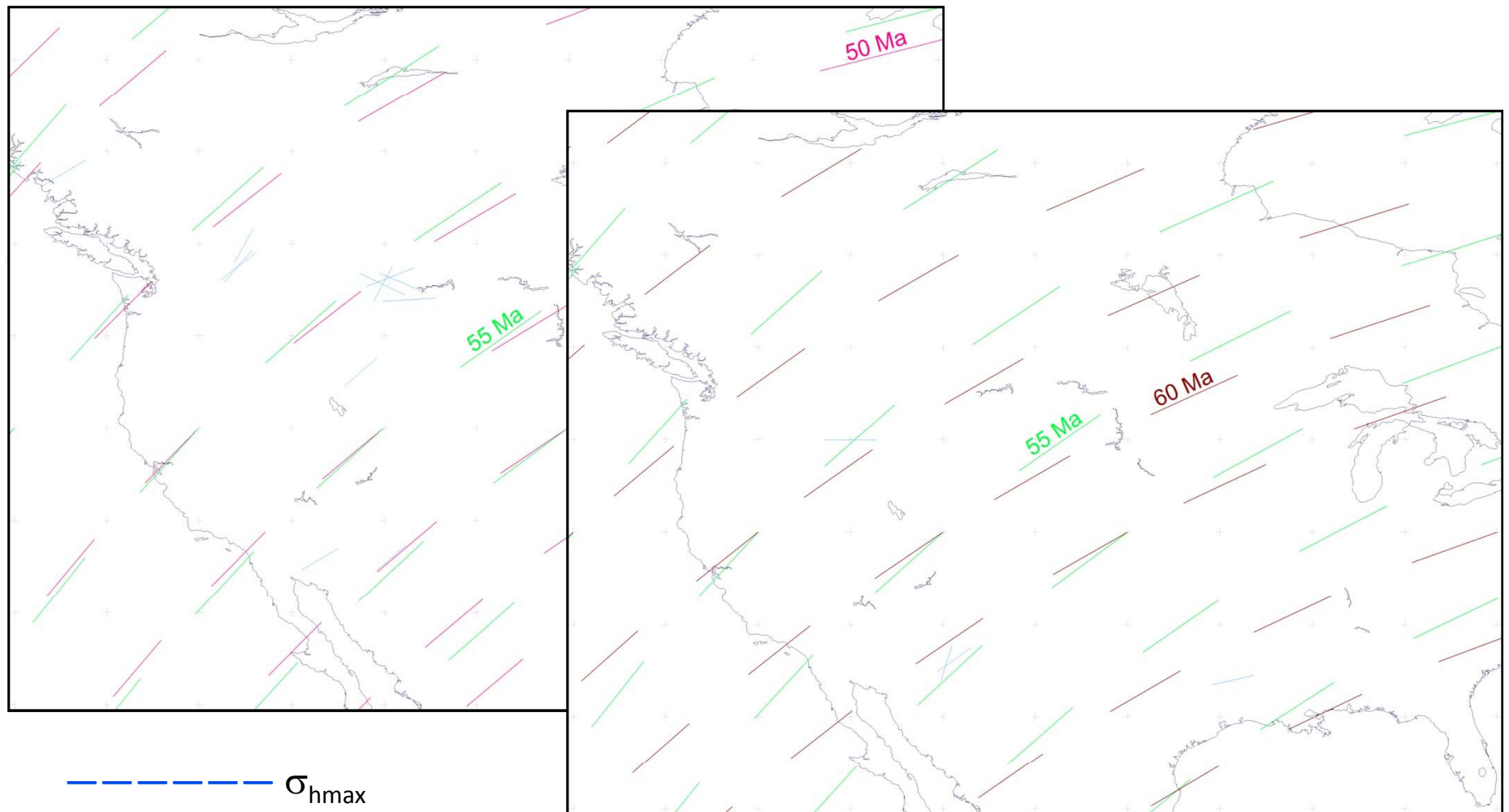
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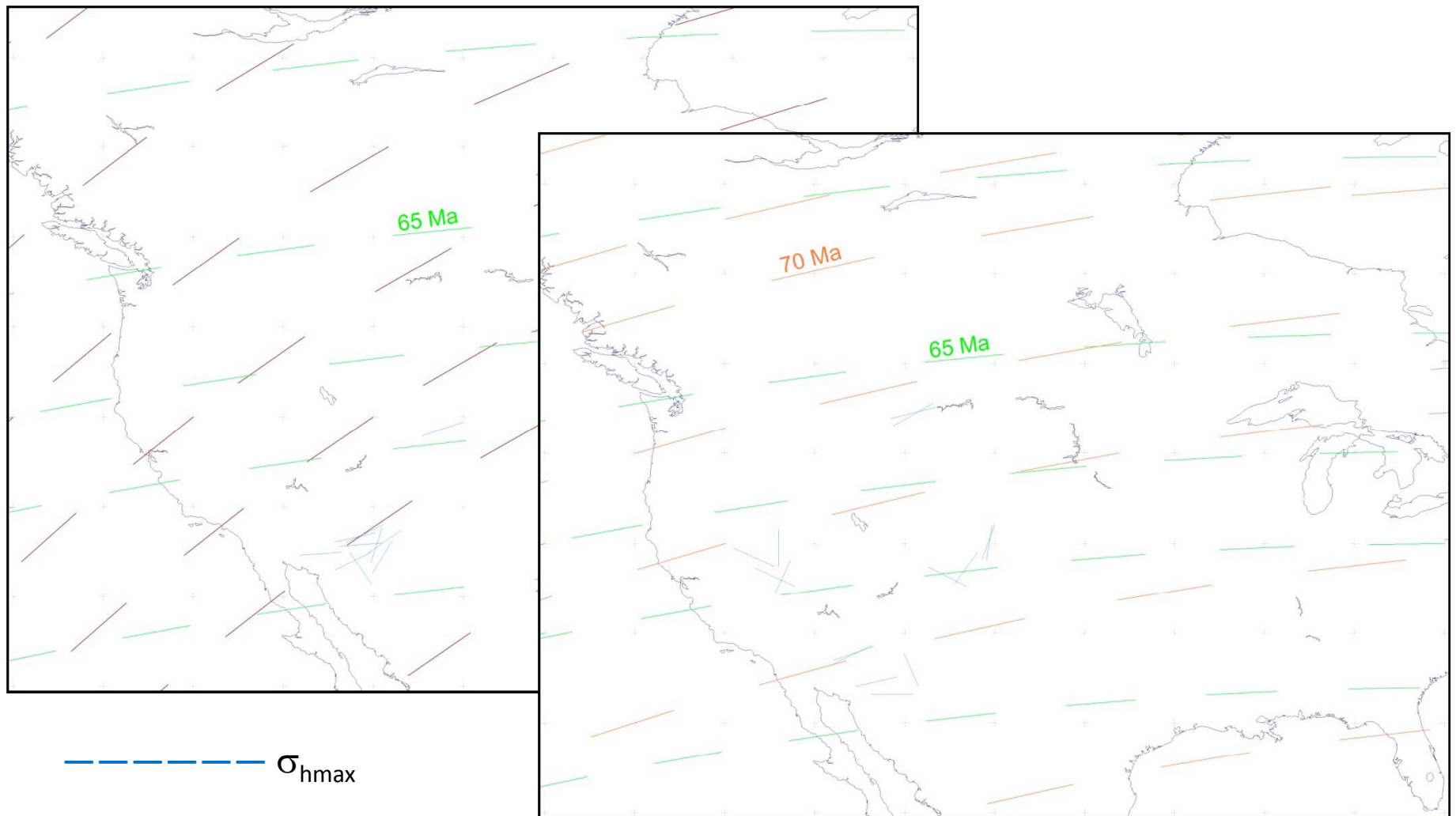
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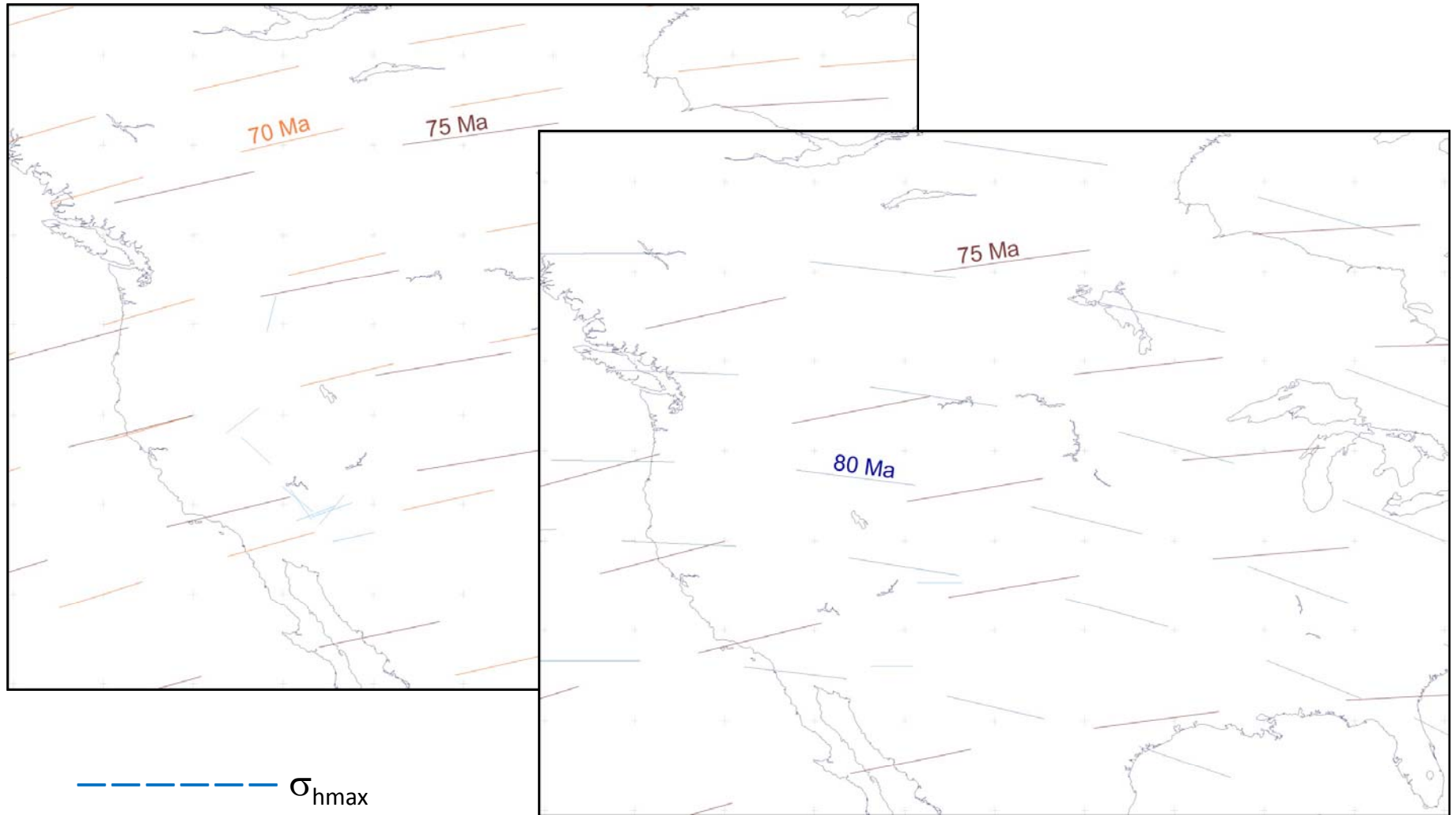
N America 50 – 55 – 60 Ma



N America 60 – 65 – 70 Ma



N America 70 – 75 – 80 Ma



What else is needed?

- Timing of highest stress magnitudes
 - Structural deformation
 - Subsidence and burial history: overpressuring
 - Thermal history
 - Maturation timing: overpressuring
- From stress timing, can infer paleofracture orientation from predicted stress field orientation

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Further Information

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