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Geological and Geophysical Expression of a Primary Salt Weld: An Example from the Santos Basin, Brazil*

Christopher A. Jackson[1], Clara Rodriguez[1], Atle Rotevatn[2] and Rebecca Bell[1]

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Abstract

Primary salt welds form at the base of minibasins in response to complete evacuation of autochthonous salt. Analytical and numerical models suggest it is difficult to completely remove salt from a weld by viscous flow alone, which is especially true in multilayered evaporites, within which flow is likely heterogeneous due to lithologically controlled viscosity variations. Welds are of importance in the hydrocarbon industry because they may provide a hydrodynamic seal and trap hydrocarbons or may allow transmission of fluids from source to reservoir rocks. Few papers document the subsurface expression of welds, principally because of they have not been penetrated or because associated data are proprietary. We use 3D seismic and borehole data from the Santos Basin, offshore Brazil, to characterise the geological and geophysical expression of a primary weld associated with the flow of Aptian salt. Seismic data suggest that, locally, presalt and postsalt rocks are in contact at the base of an Upper Cretaceous minibasin, implying that several apparent welds, separated by low-relief salt pillows, are present. However, borehole data indicate that 22 m of anhydrite, carbonate and sandstone are present in one of the welds, indicating that this and other welds may be incomplete. Our study shows that seismic data may be unable to discriminate between a complete and incomplete weld, and we suggest that, during the subsurface analysis of welds, the term ‘apparent weld’ is used until borehole data unequivocally proves the absence of salt. Furthermore, we speculate that preferential expulsion of halite and potash salt from the autochthonous layer during viscous flow and welding resulted in the formation of an incomplete weld,

which, when compared to the initial autochthonous layer, is volumetrically enriched in non-evaporite lithologies and relatively viscous evaporite lithologies (anhydrite). The composition and stratigraphy of the autochthonous layer may thus dictate weld thickness.

References Cited

Jackson, M. P. A., and C. Cramez, C., 1989, Seismic recognition of salt welds in salt tectonics regimes, SEPM Gulf Coast Section Tenth Annual Research Conference Program and Abstracts, Houston, Texas, p. 66–71.

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Geological and geophysical expression of a primary salt weld; an example from the Santos Basin, Brazil

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[1]*Basins Research Group (BRG), Department of Earth Science & Engineering, Imperial College, Prince Consort Road, London, SW7 2BP, UK*

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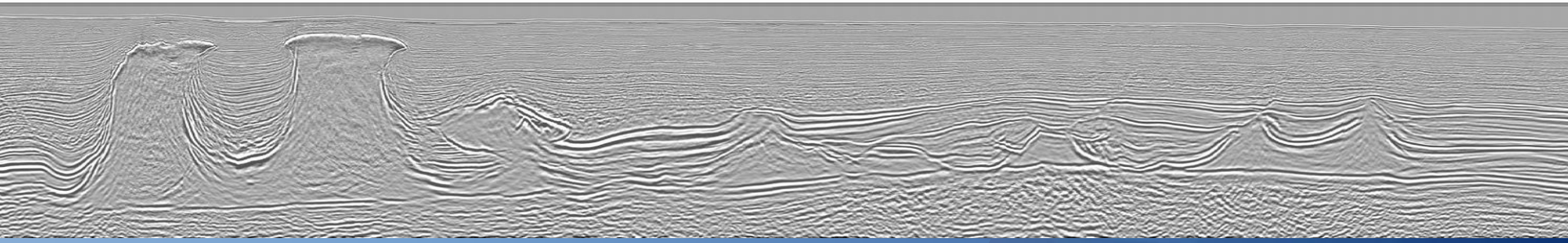

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CGGVERITAS

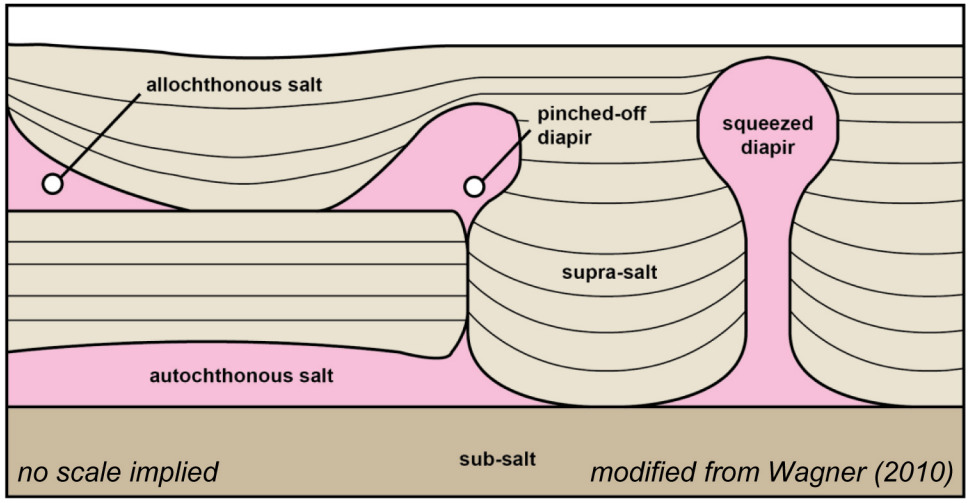
anp Agência Nacional do Petróleo

Schlumberger

What's a Weld?

"…*the structure joining two rock bodies formerly separated by salt*…" (Jackson and Cramez, 1989).

What's a Weld?


allochthonous salt
pinched-off diapir
squeezed diapir
supra-salt
autochthonous salt
sub-salt
no scale implied
modified from Wagner (2010)

What's a Weld?

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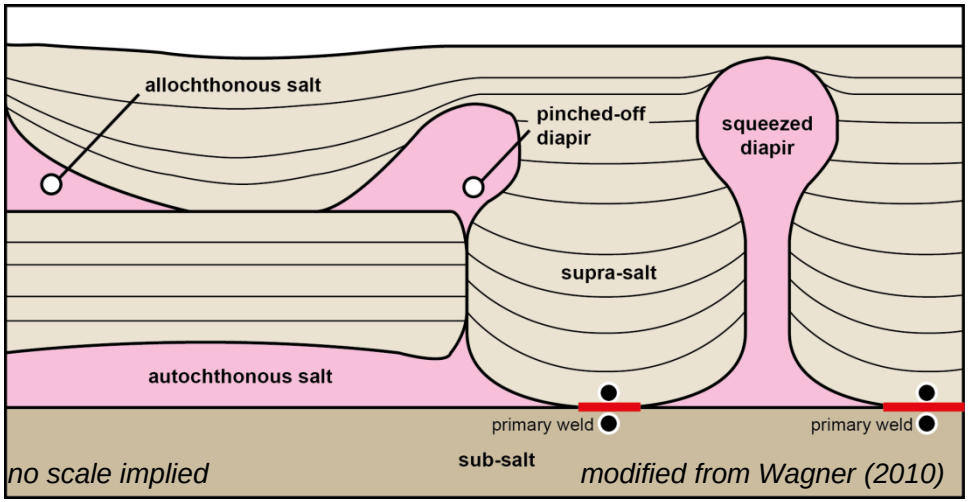

- **primary** - joins strata originally above and below ***autochthonous*** salt

What's a Weld?

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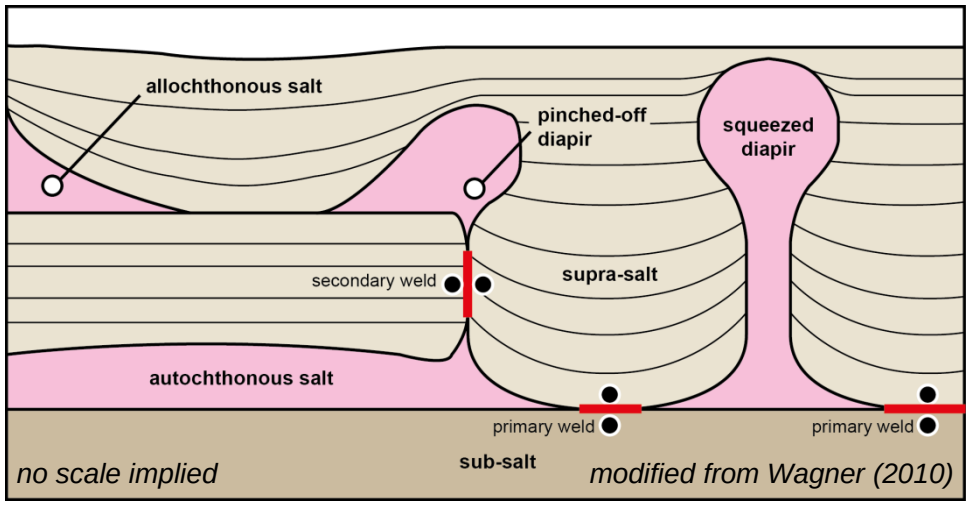

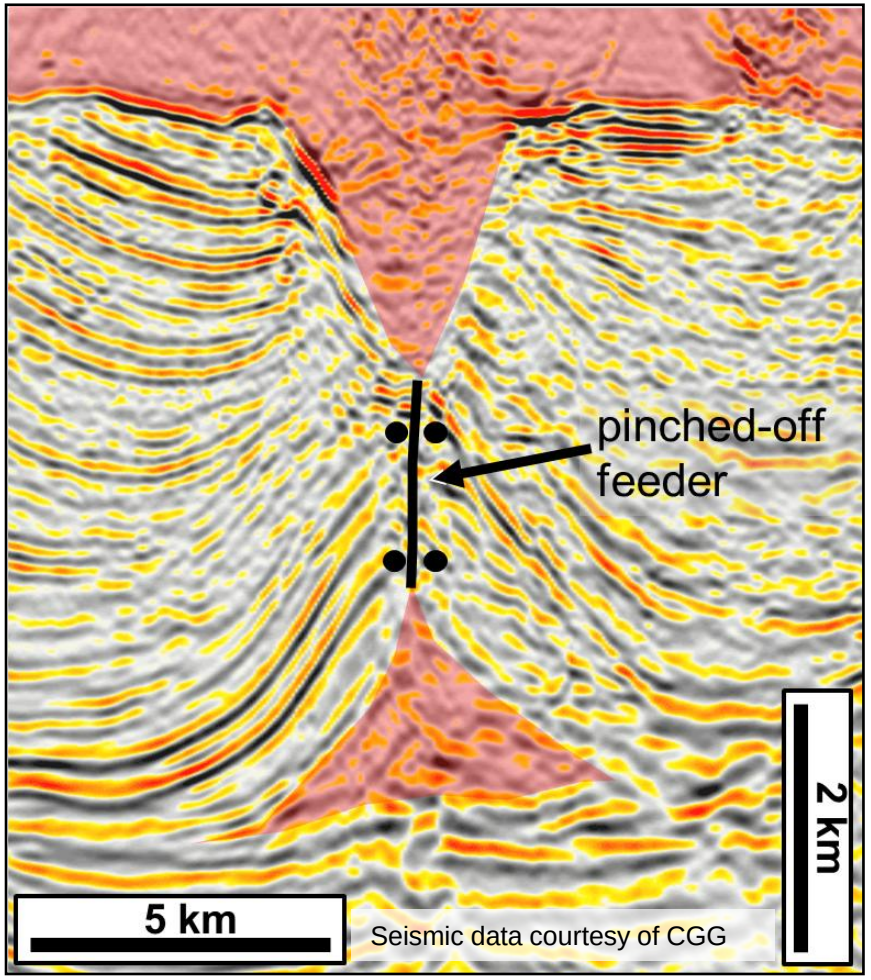

- **primary** - joins strata originally above and below ***autochthonous*** salt
- **secondary –** joins minibasins originally situated either side of diapirs

What's a Weld?

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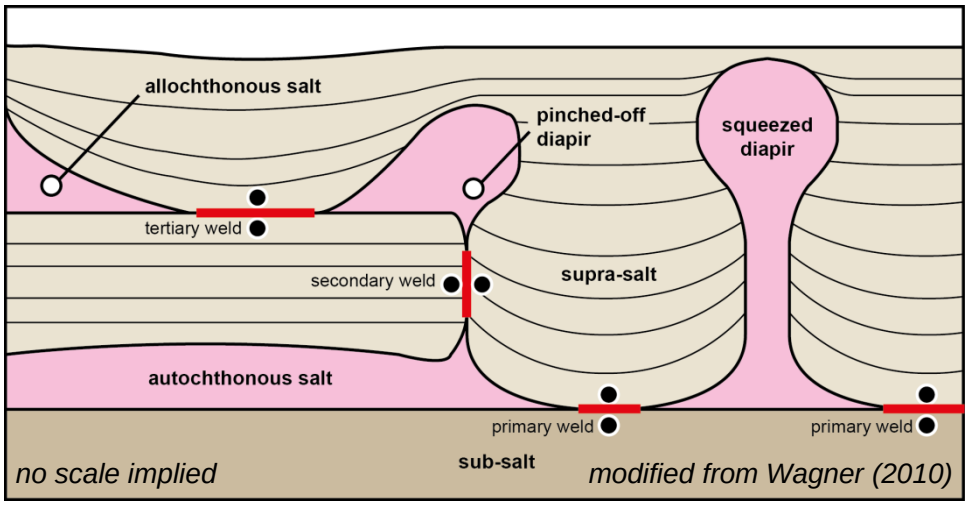

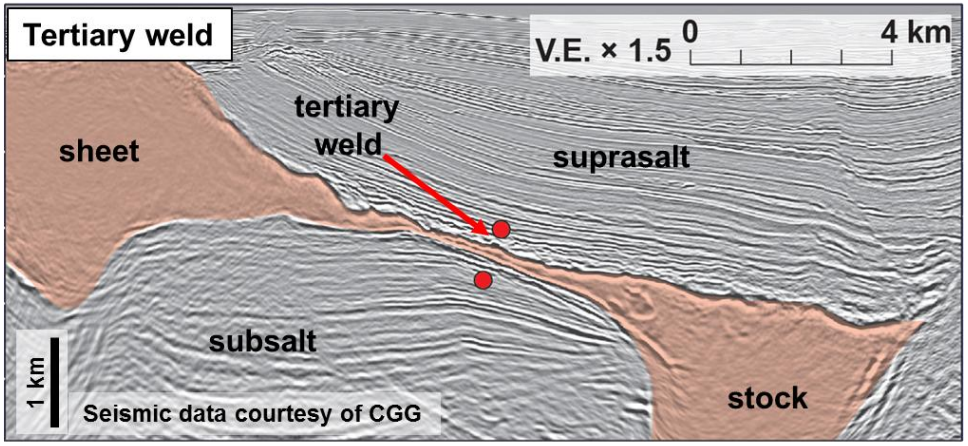

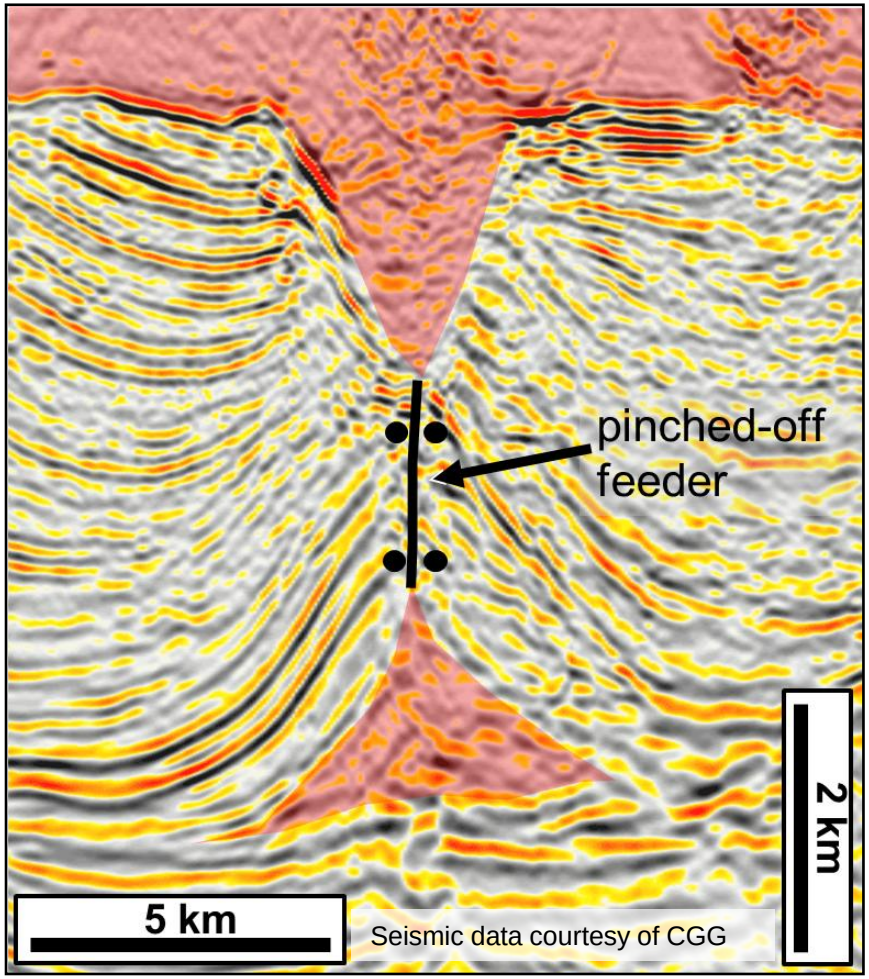

- **primary** - joins strata originally above and below ***autochthonous*** salt
- **secondary** – joins minibasins originally situated either side of diapirs
- **tertiary** – joins strata originally above and below ***allochthonous*** salt

What's a Weld?

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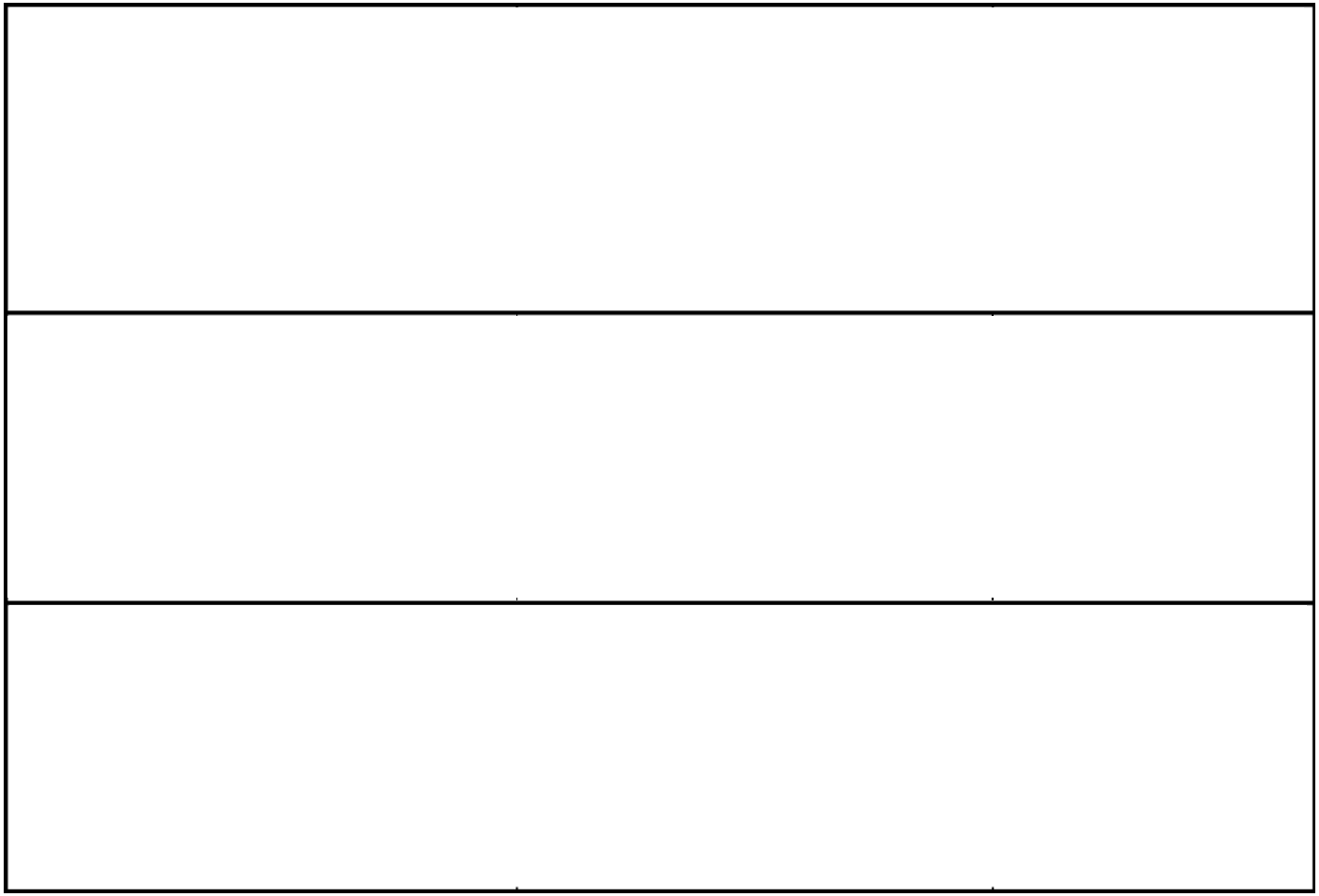

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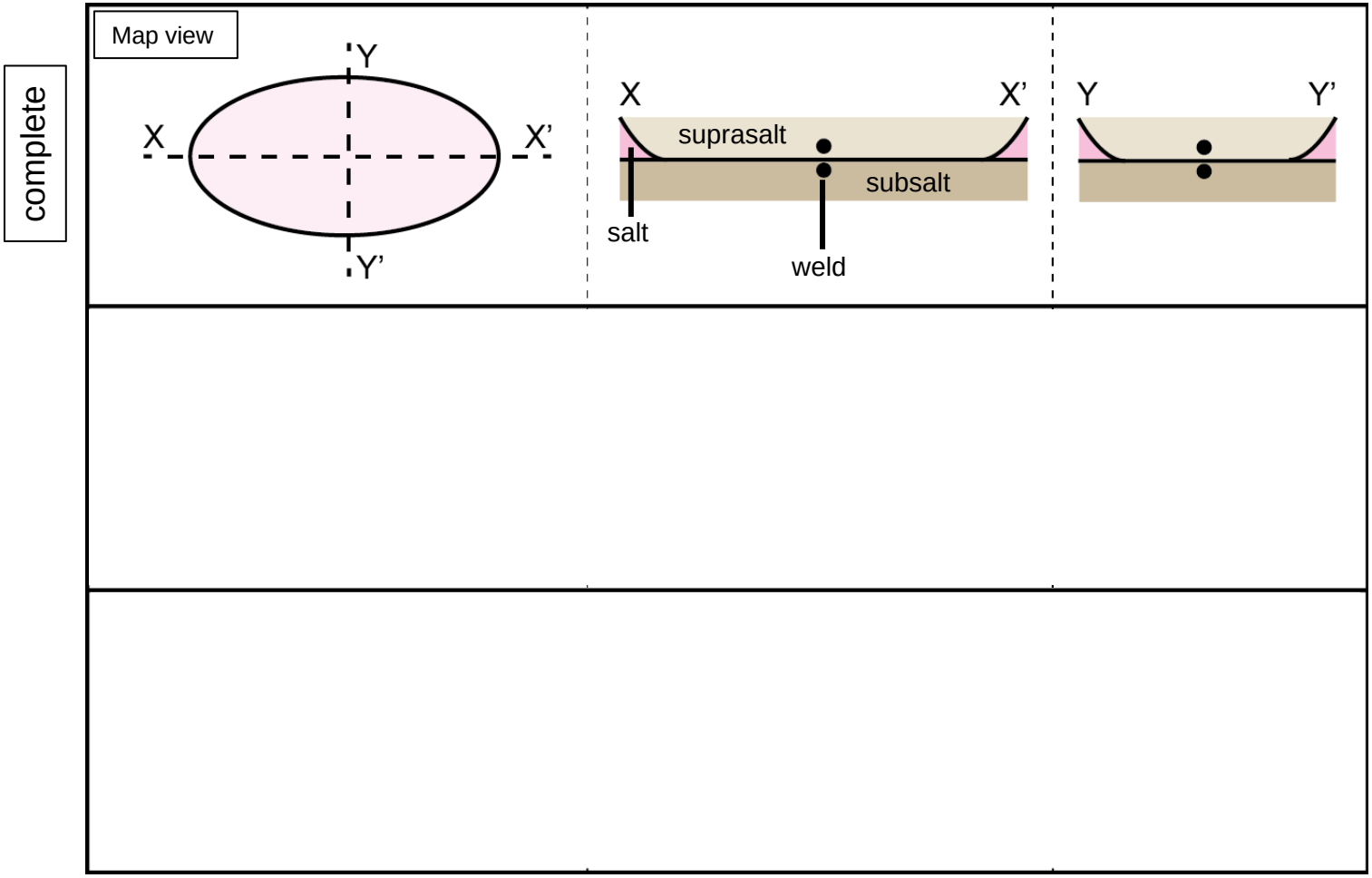

- **complete** - contains **no** remnant salt

What's a Weld?

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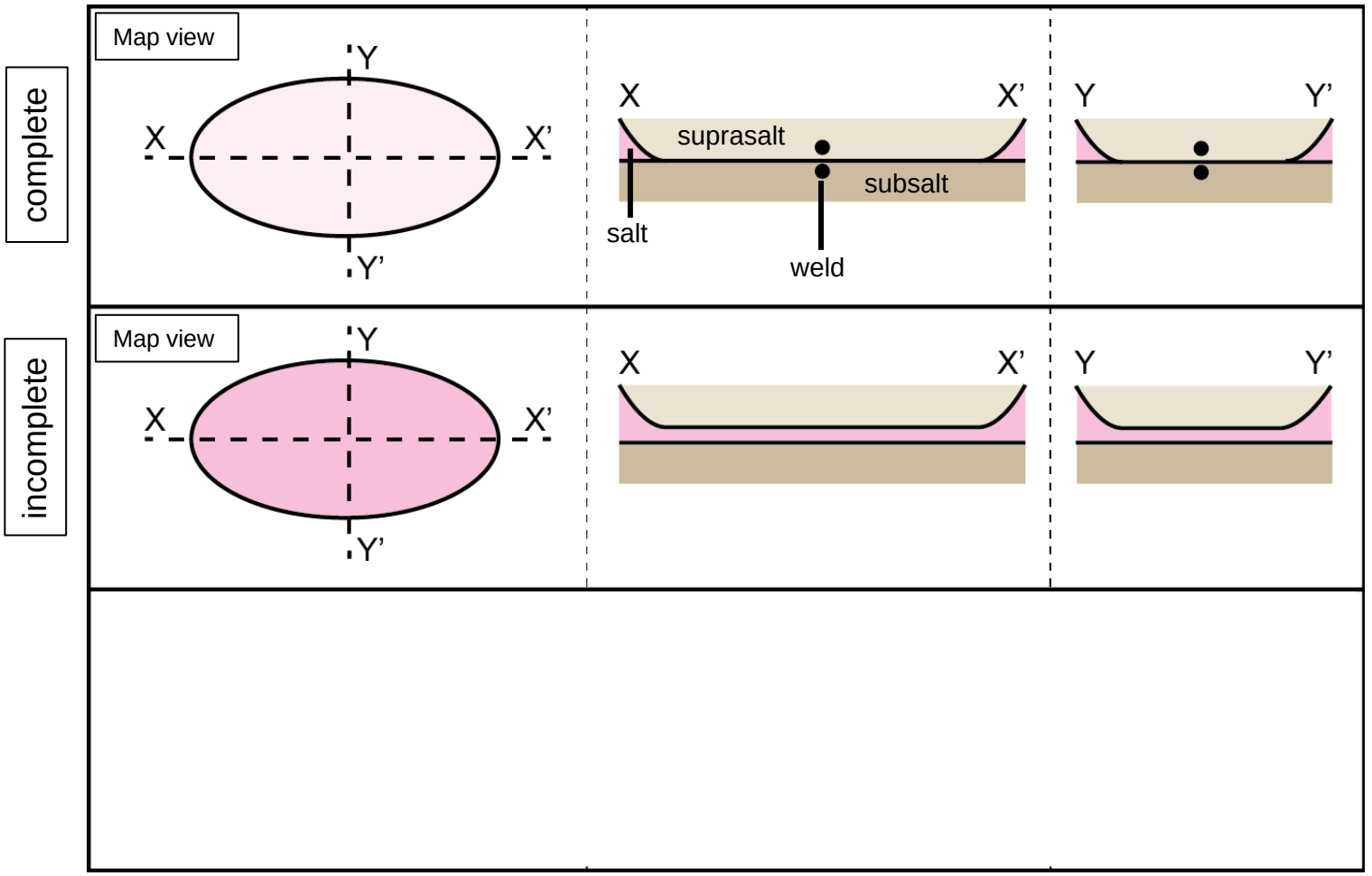

- **complete** - contains **no** remnant salt
- **incomplete** – contains **up to 50 m** of remnant salt

What's a Weld?

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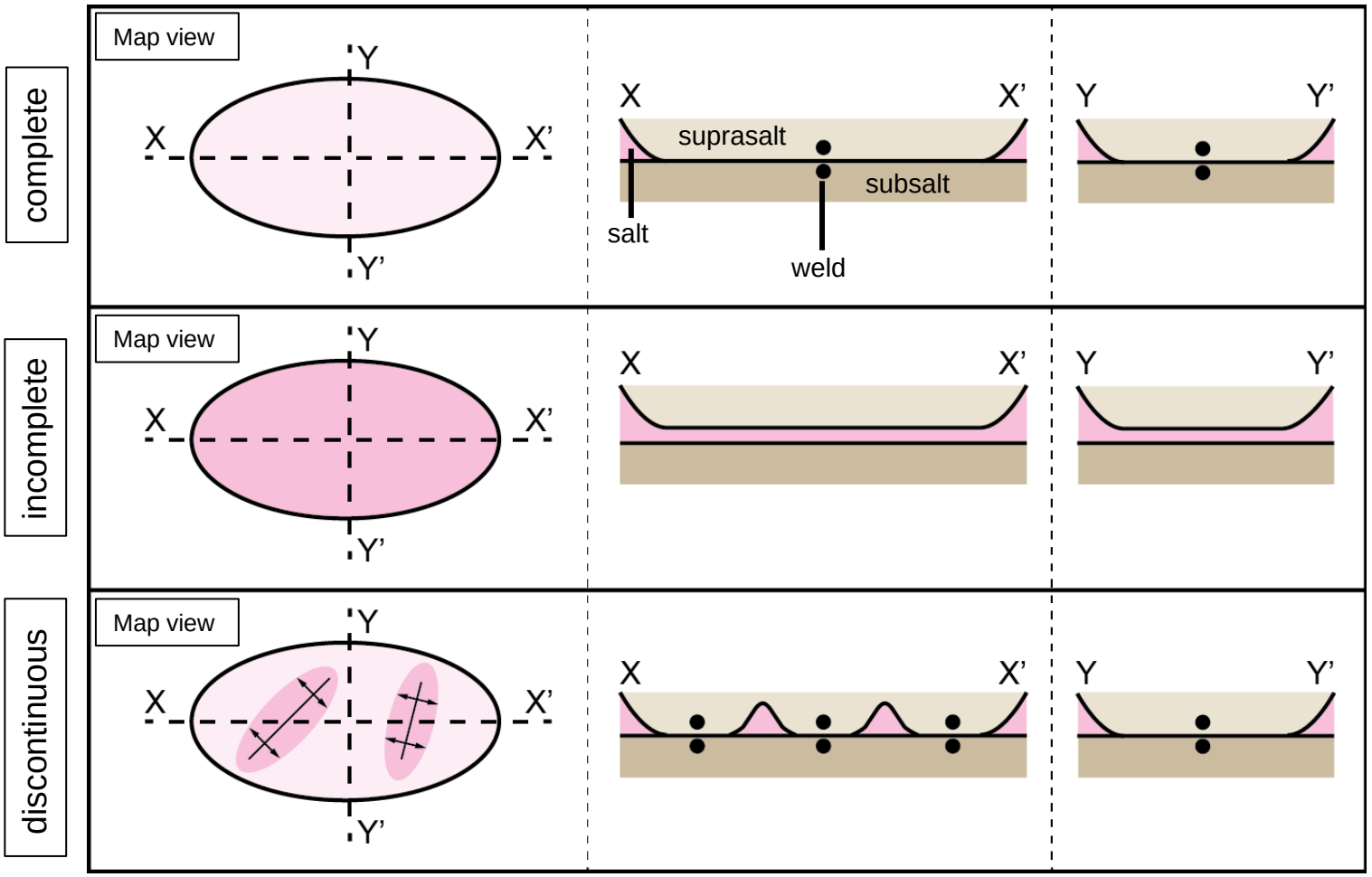

- **complete** - contains **no** remnant salt
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- **discontinuous** – contains **complete and incomplete** parts

What's a Weld?

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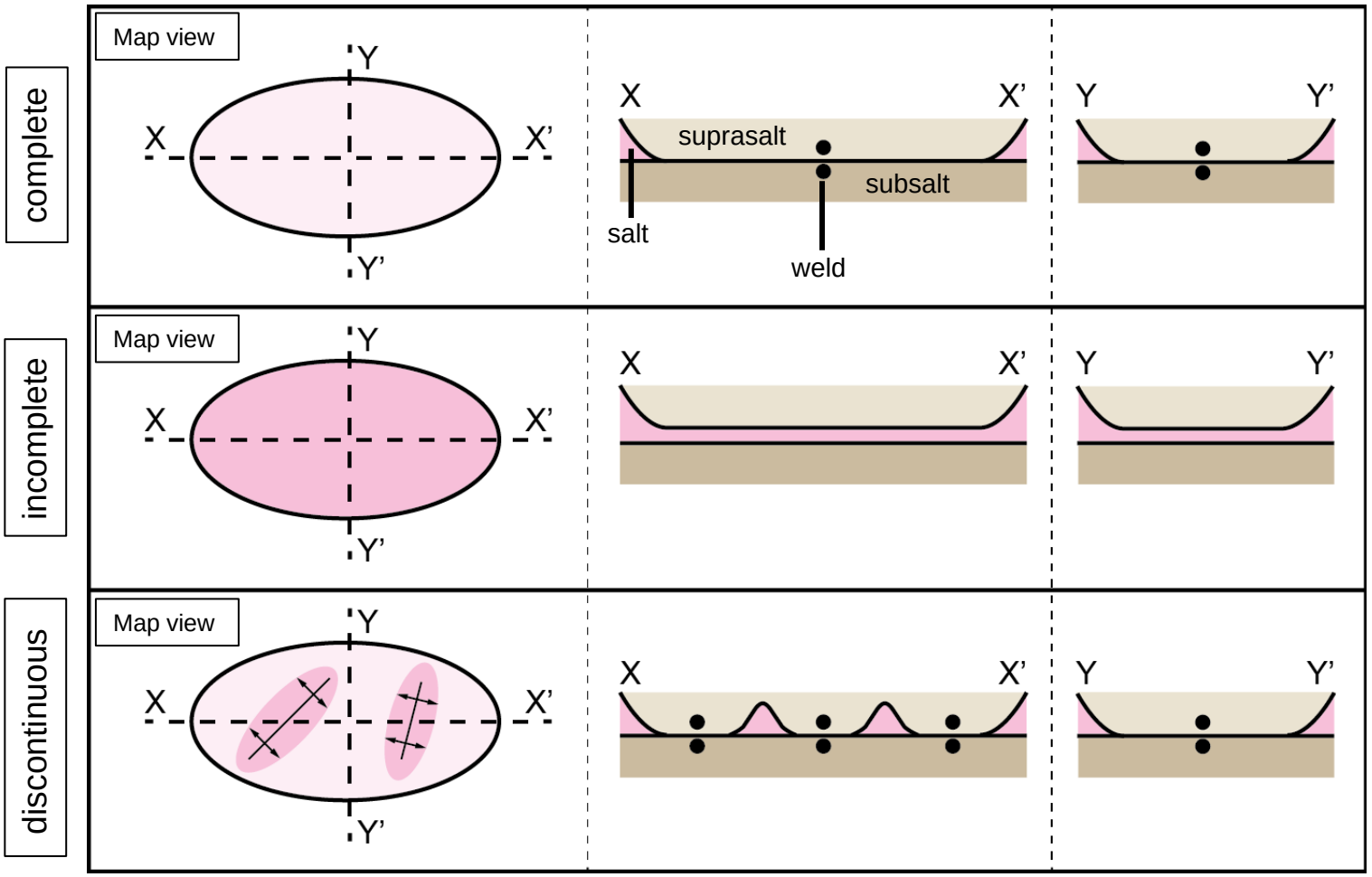

- **complete** - contains **no** remnant salt
- **incomplete** – contains **up to 50 m** of remnant salt
- **discontinuous** – contains **complete and incomplete** parts
- **apparent** – appears free of salt at scale of observation…

Why are Welds Important?

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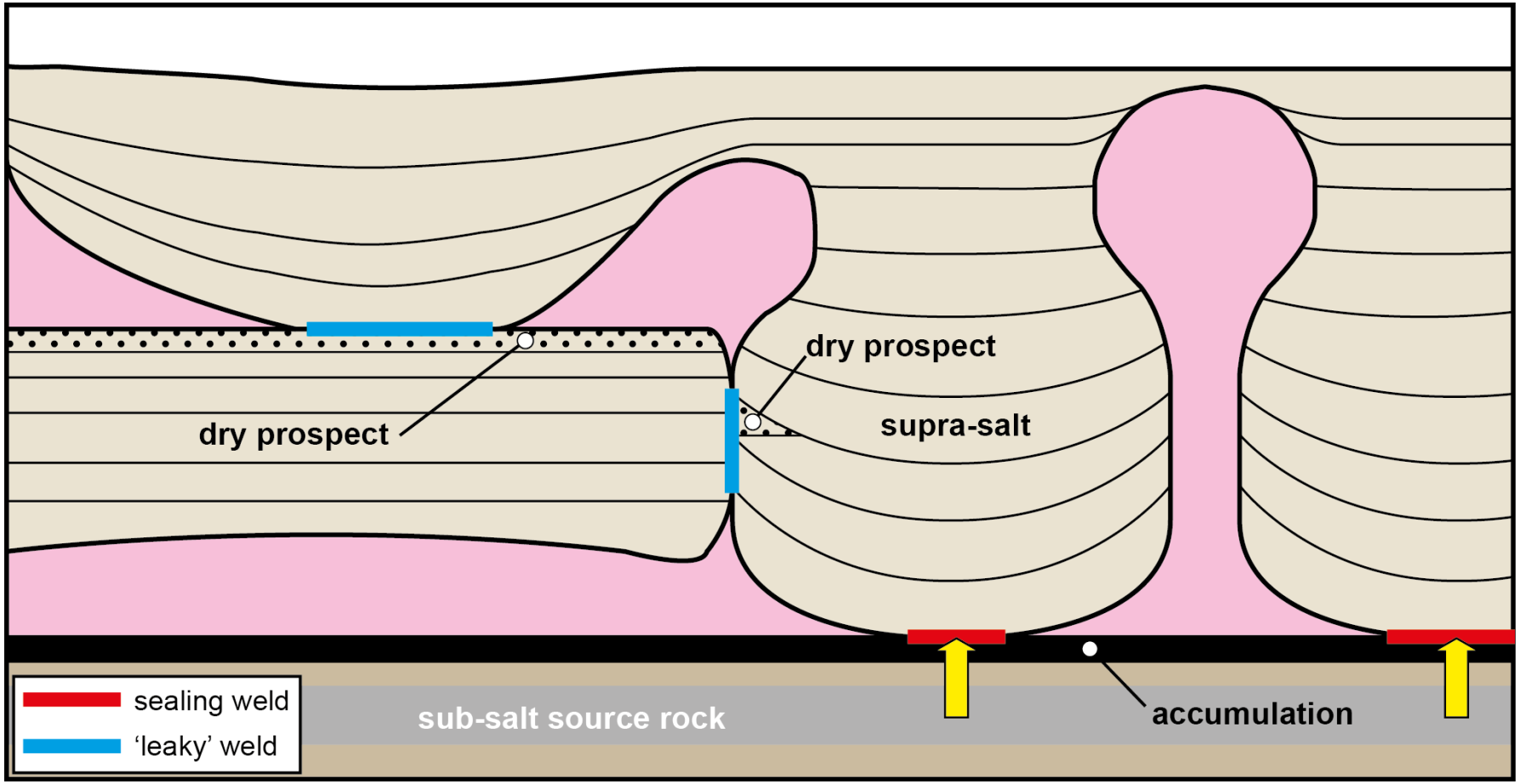

- Determining weld thickness and composition difficult using only seismic data
- Degree of welding and weld composition may impact prospectivity

Why are Welds Important?

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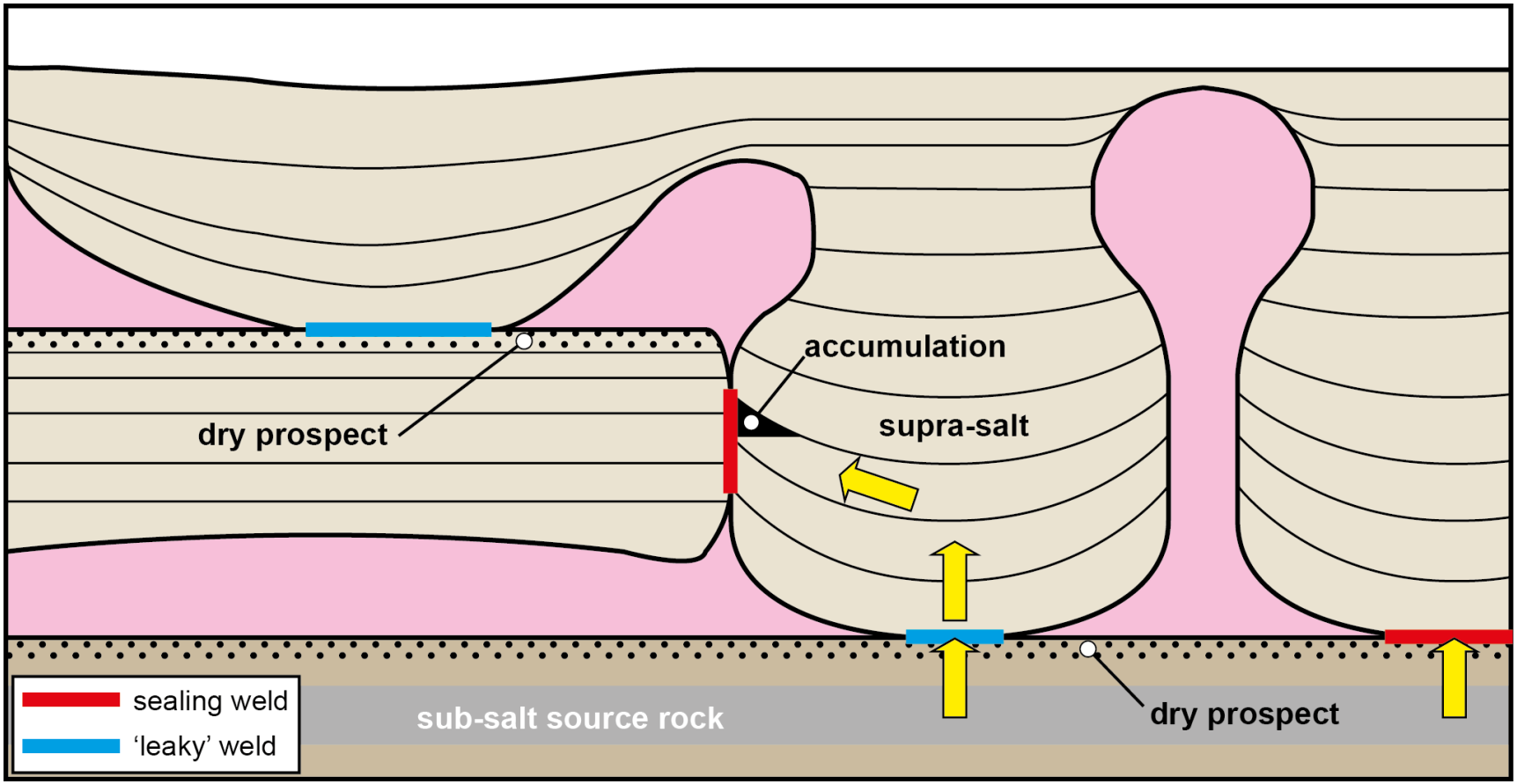

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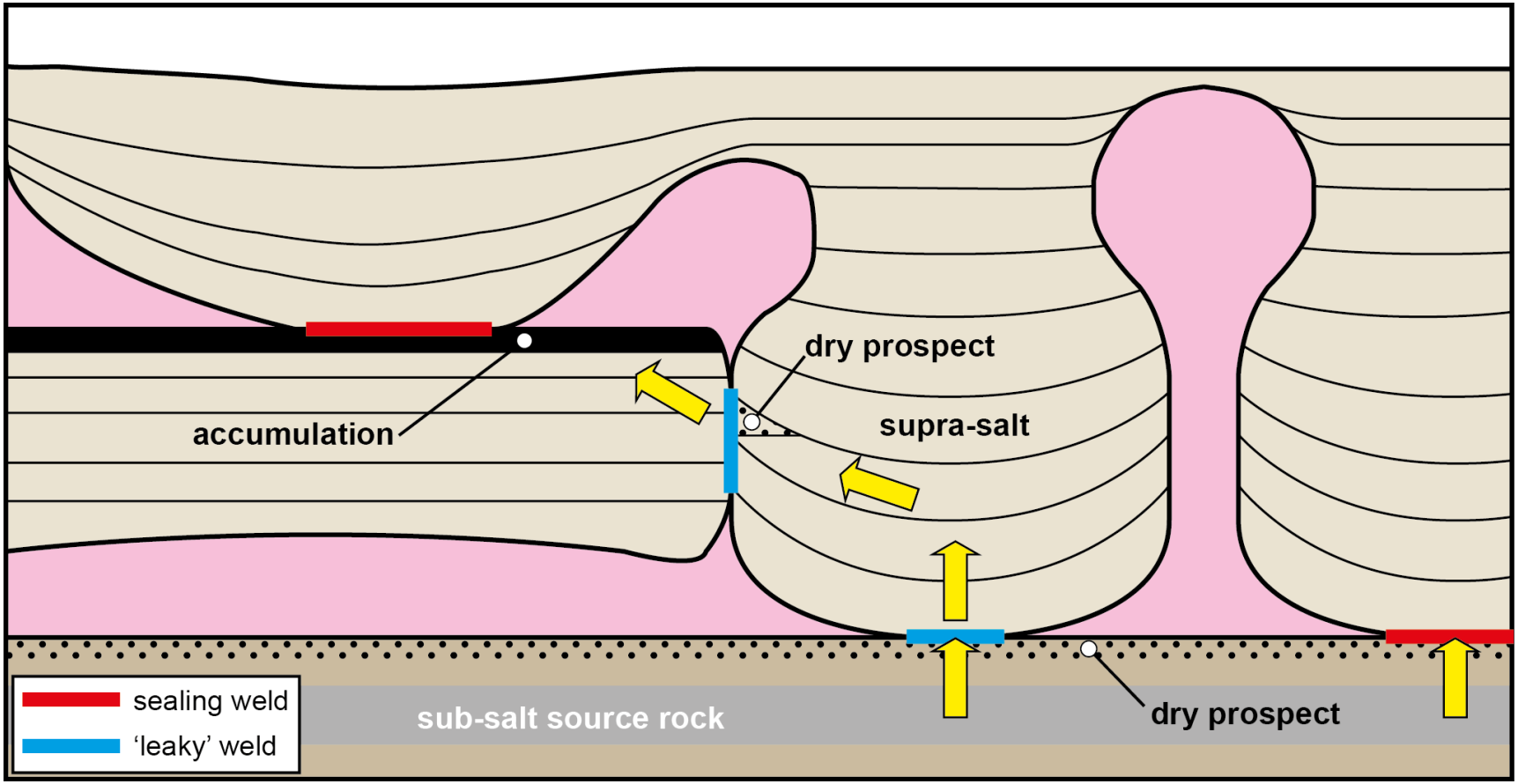

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Motivation and Talk Outline

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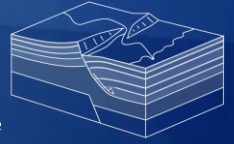
- How much salt remains in an incomplete/apparent weld?

Motivation and Talk Outline



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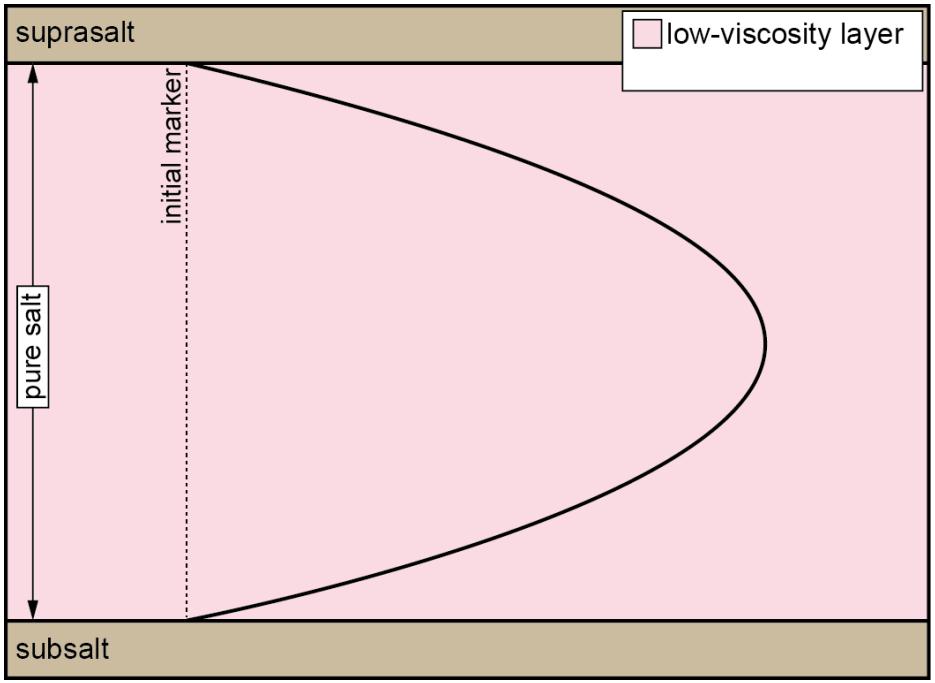

modified from Wagner & Jackson (2011)

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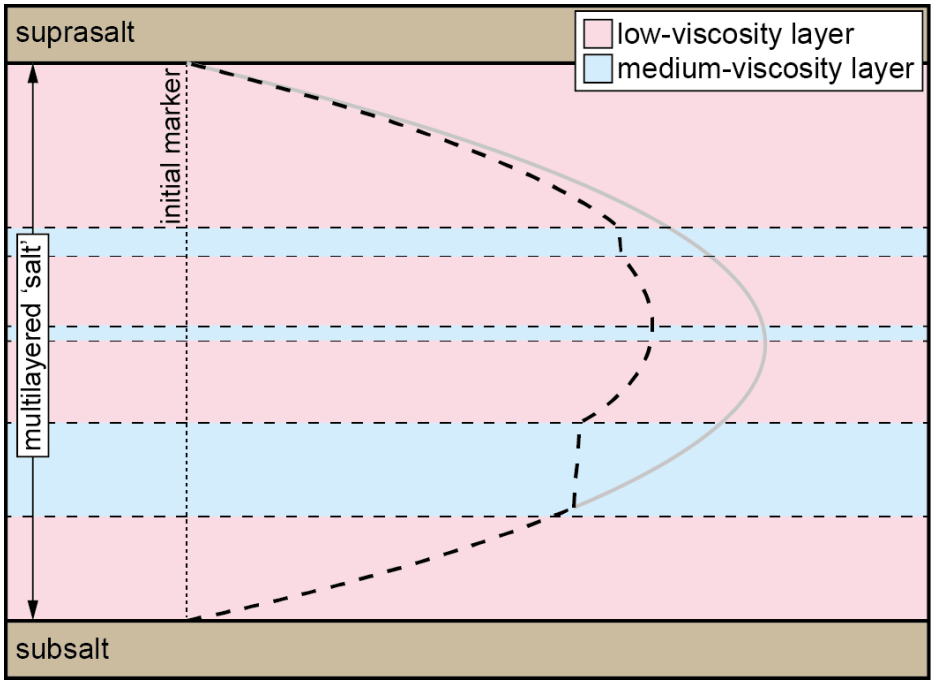

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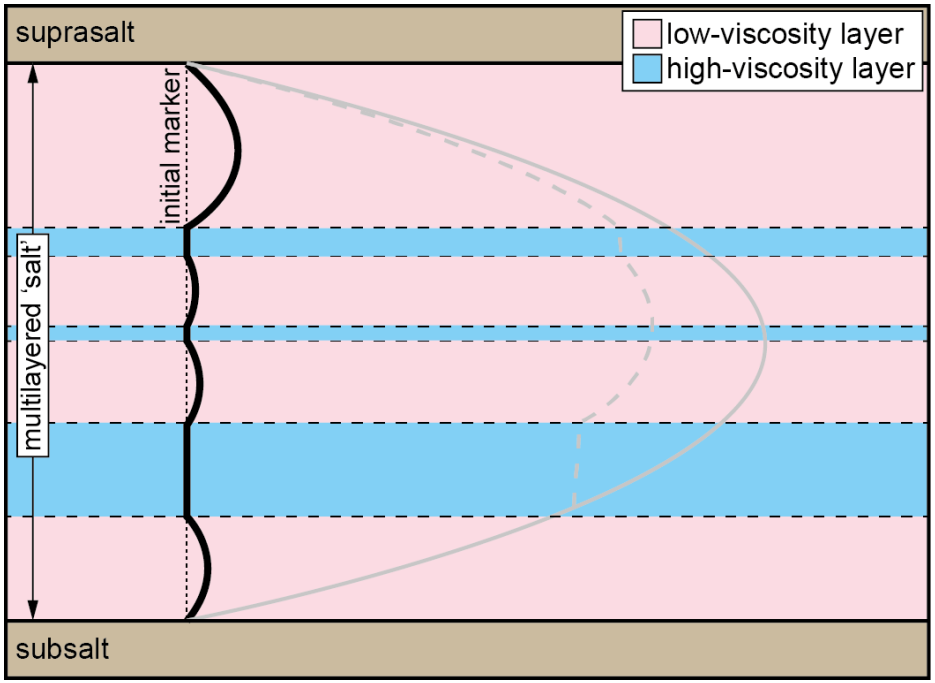

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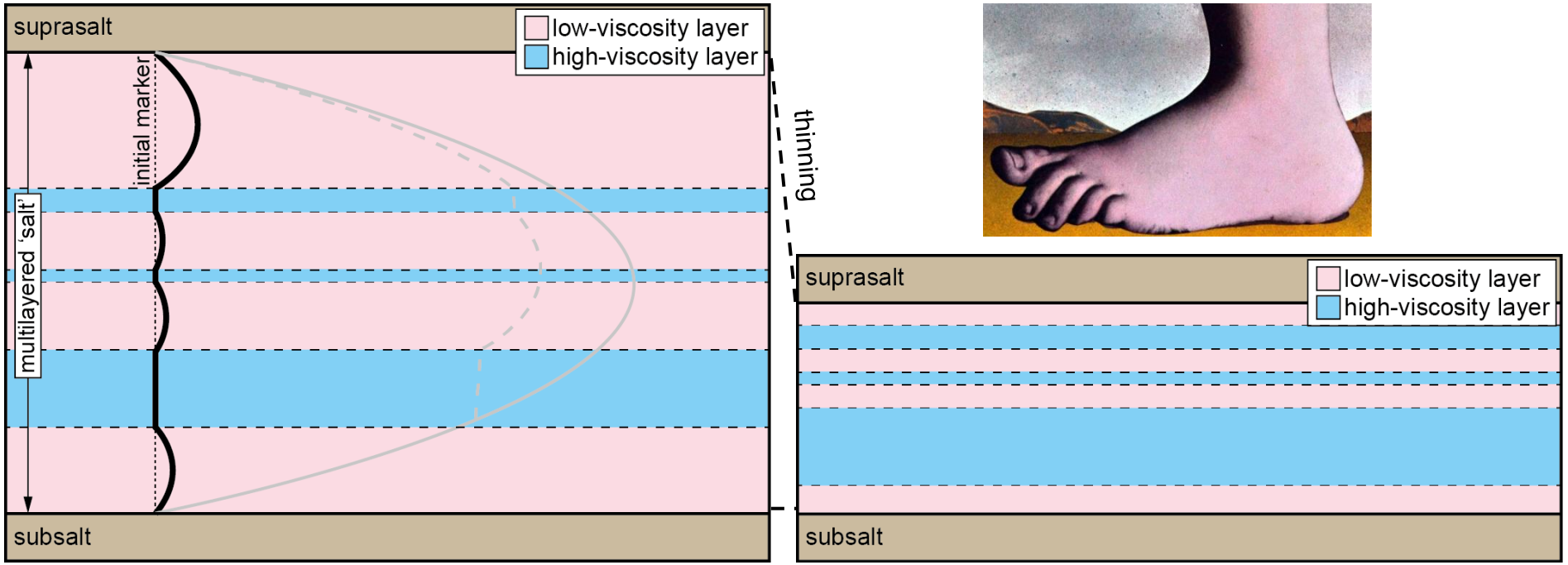

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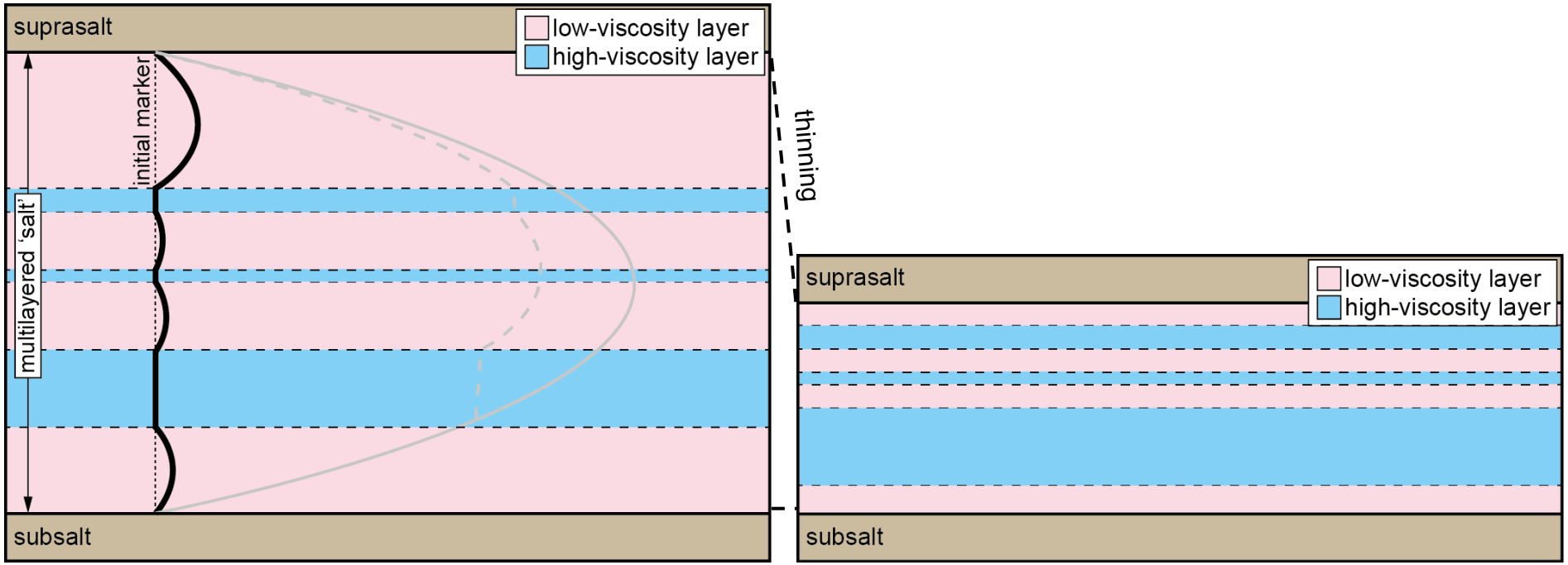

modified from Wagner & Jackson (2011)

- **Seismic and borehole data from Santos Basin, offshore SE Brazil**
- **Seismic and borehole expression of a weld**
- **Regional structural-stratigraphic context of the weld**
- **Genetic Model, future work and conclusions**

Santos Basin, offshore SE Brazil

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Santos Basin, offshore SE Brazil

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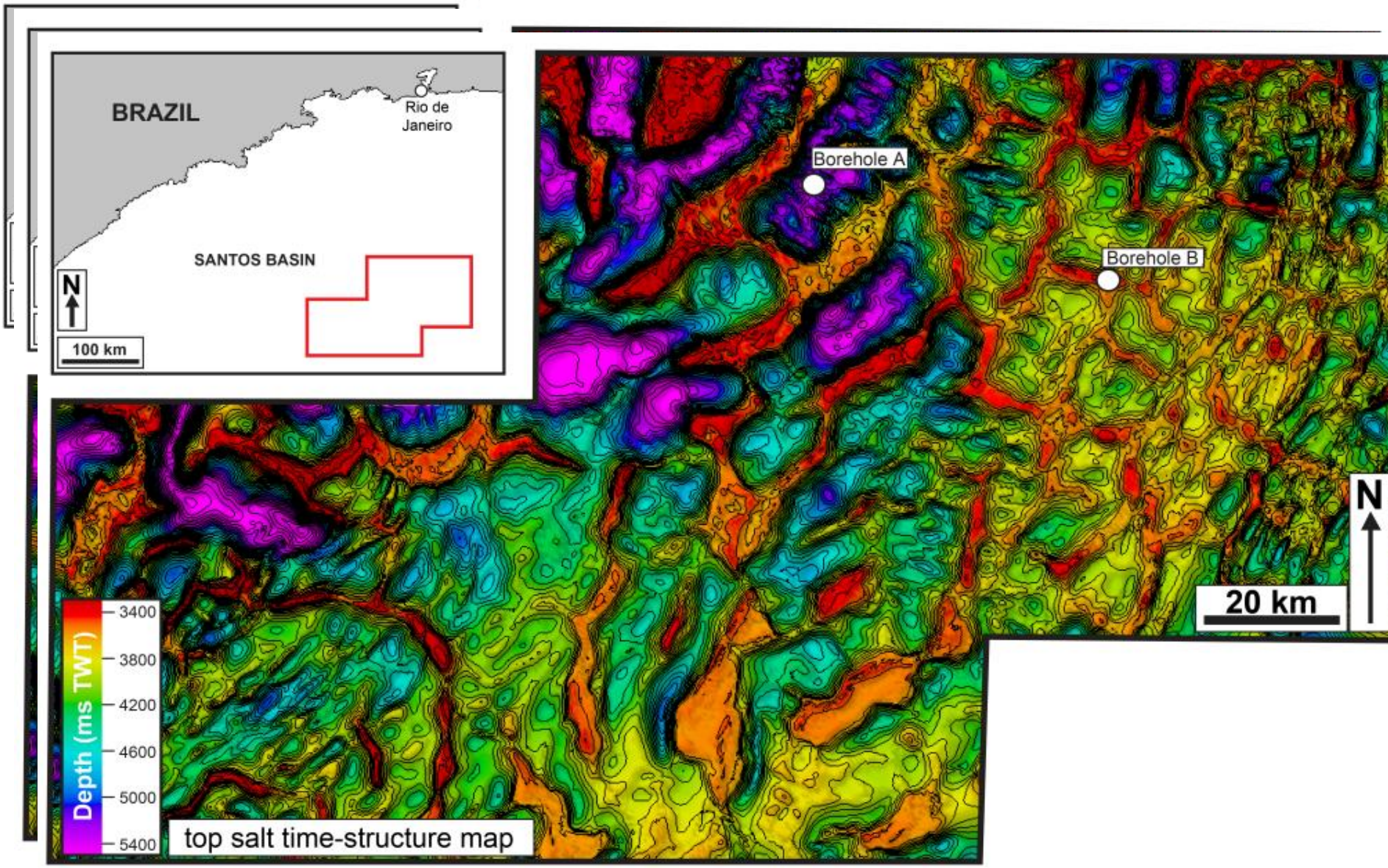

Salt-Related Structural Style

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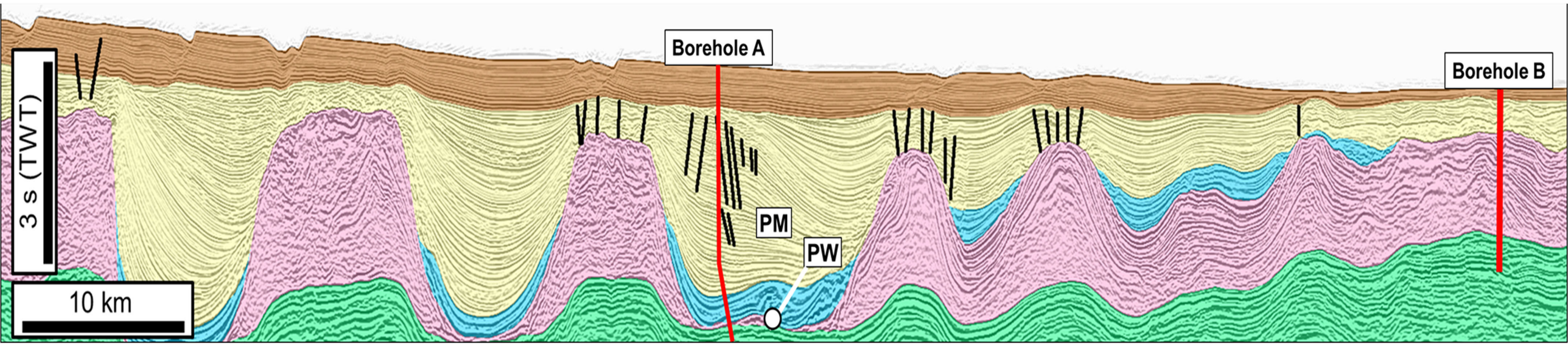

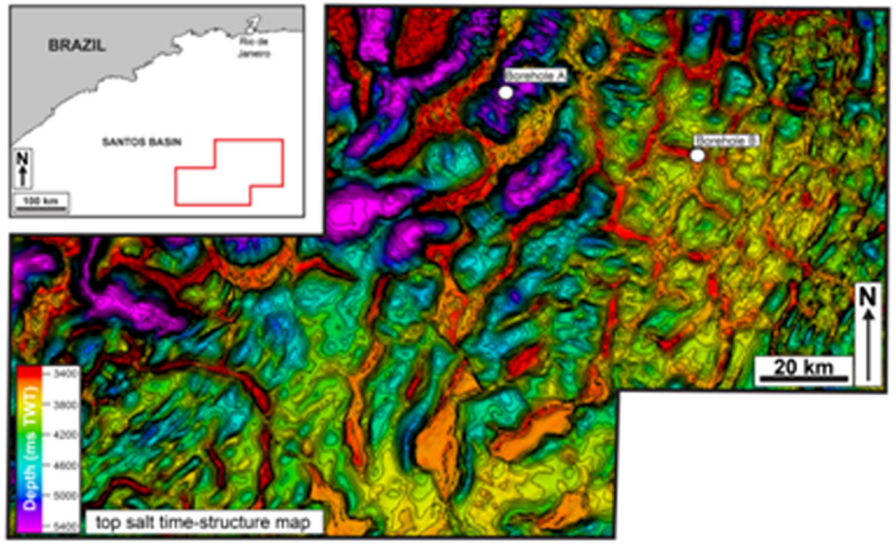

Key

- post-Oligocene
- Cenomanian-lower Oligocene
- Albian-Cenomanian
- Salt (uppermost Aptian)
- Presalt

Parati Minibasin and Weld

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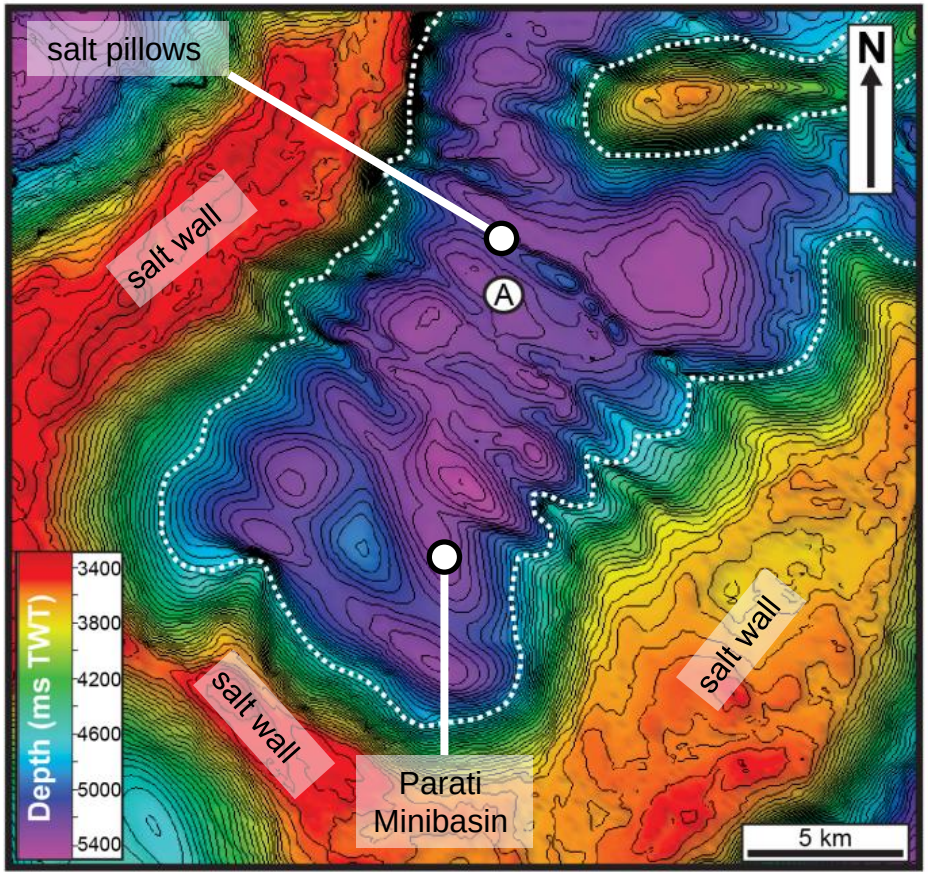
top salt time-structure map



- Parati Minibasin up to 5 km deep and 10 km wide
- Up to 600-m tall salt pillows at base

Parati Minibasin and Weld

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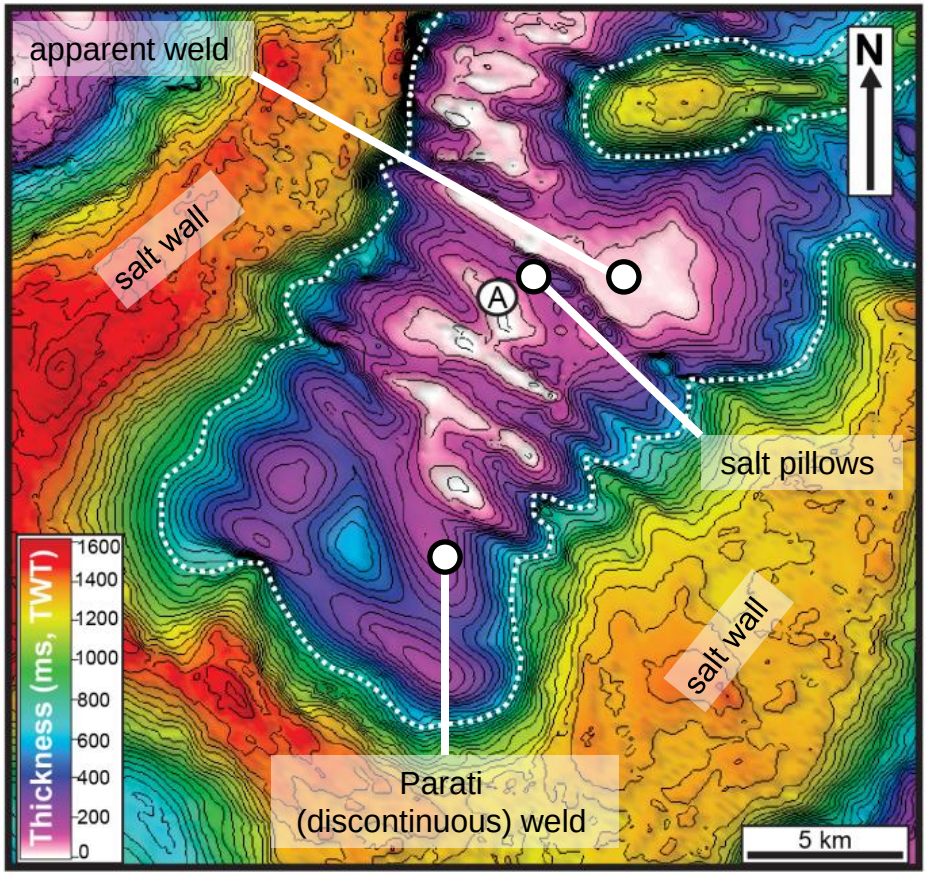
top salt time-structure map

salt isochron



- Parati Minibasin up to 5 km deep and 10 km wide
- Up to 600-m tall salt pillows at base
- Parati Weld is ‘discontinuous’
- Complete portions are ‘apparent’

Seismic Expression of Weld

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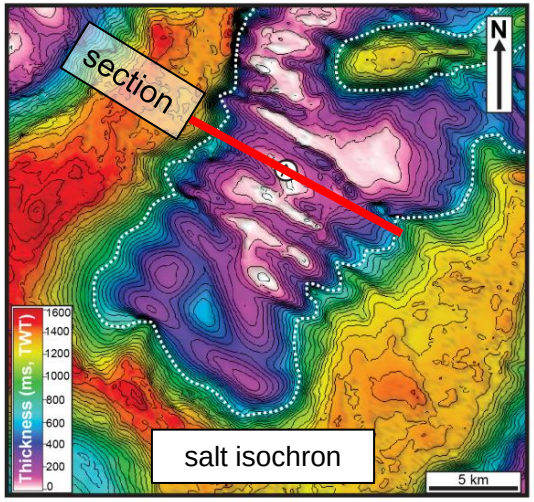
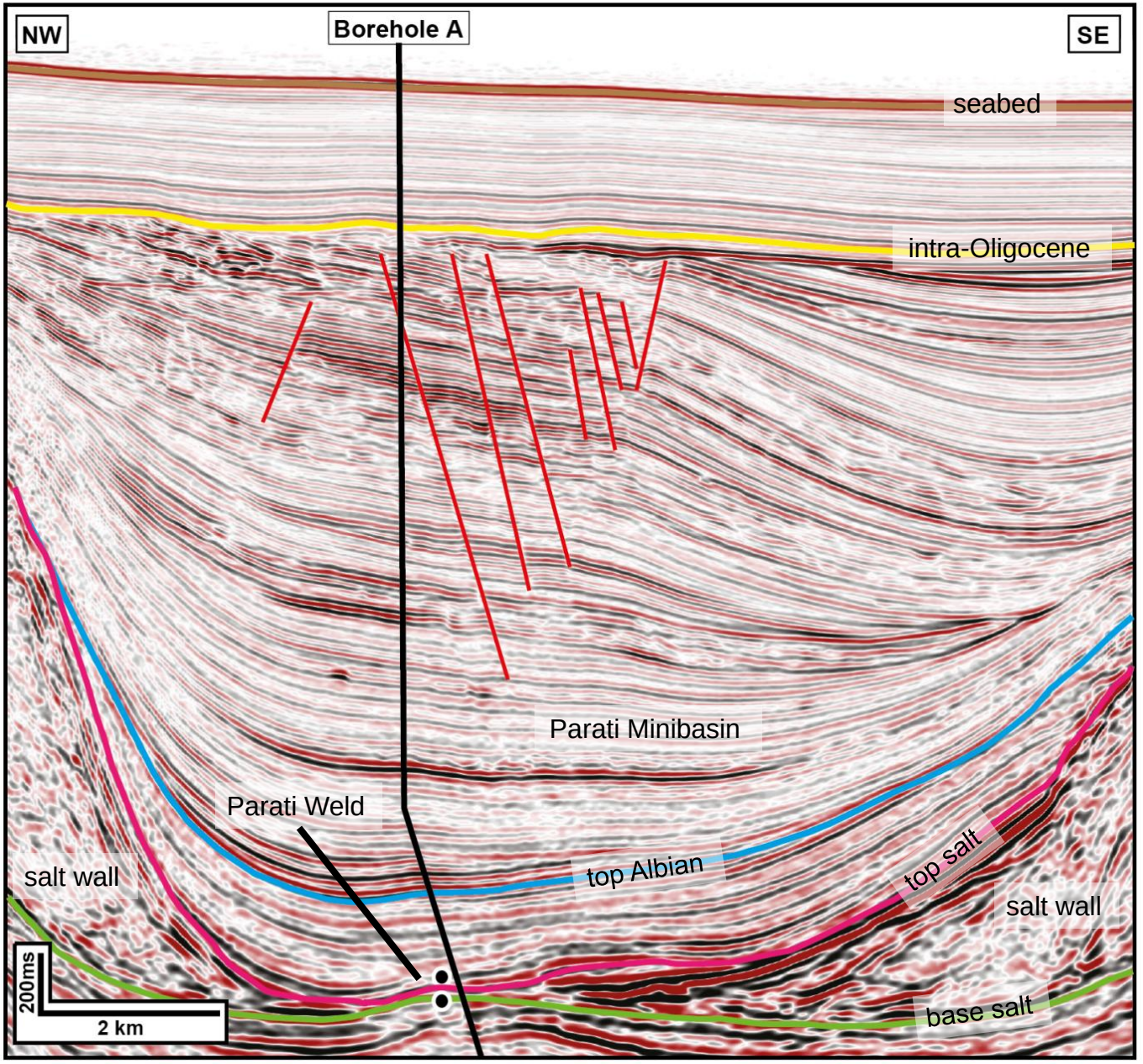


- Minibasin *c.* 10 km wide
- 5 km Cretaceous-lower Palaeogene strata
- Weld appears ‘complete’ in this orientation and at this scale of observation (i.e., an ‘apparent’ weld)



Seismic Expression of Weld

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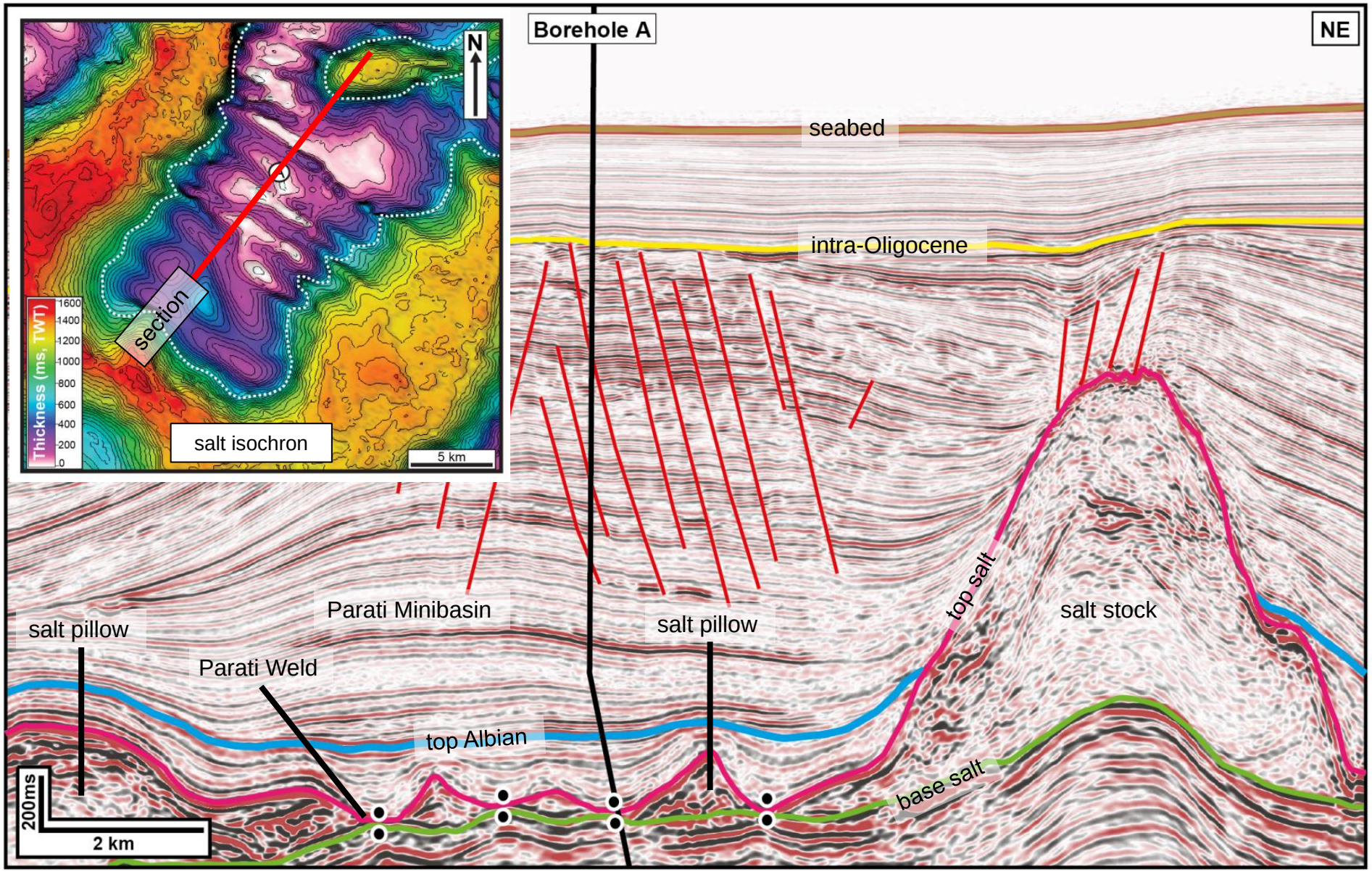

Borehole Expression of Weld

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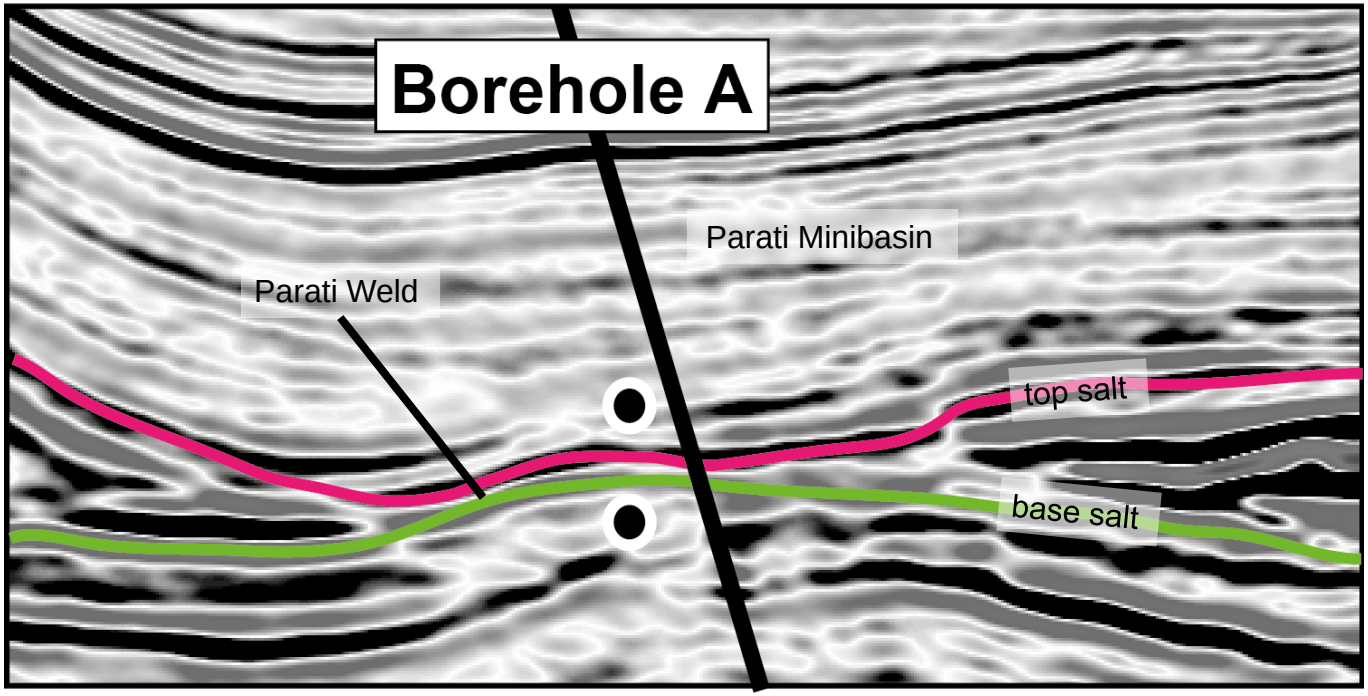

Borehole Expression of Weld

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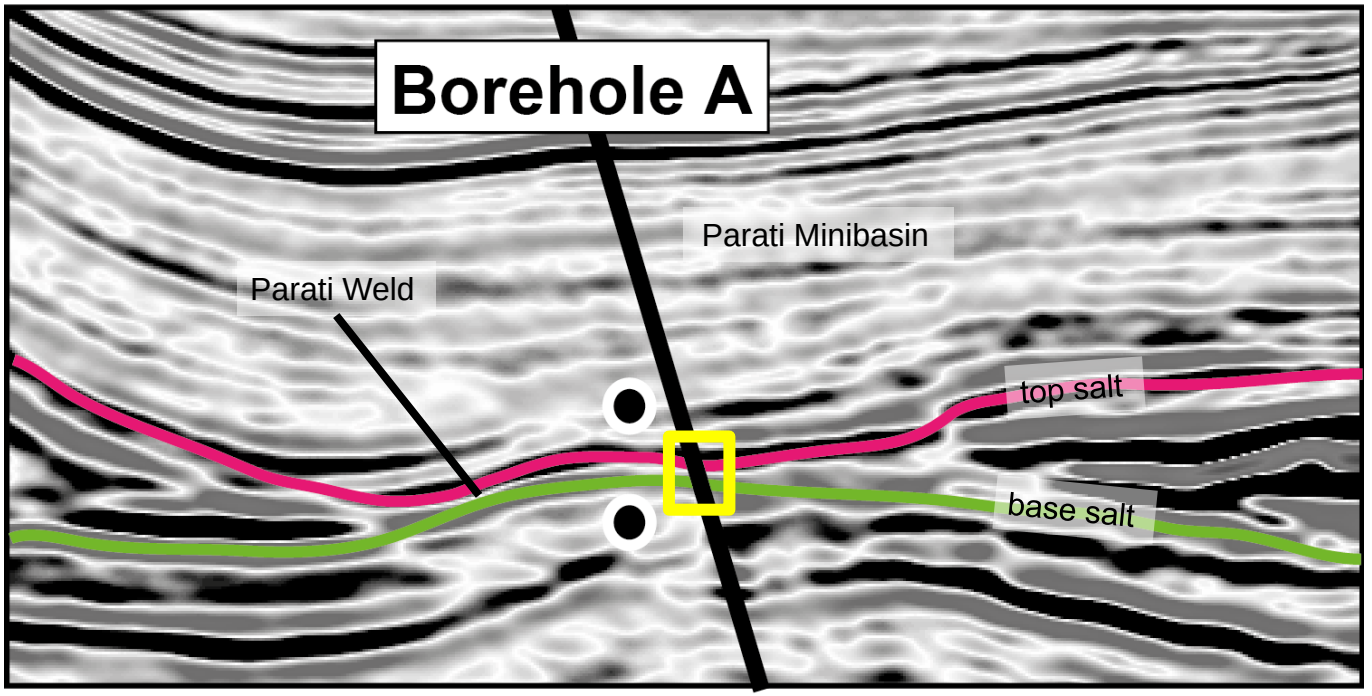

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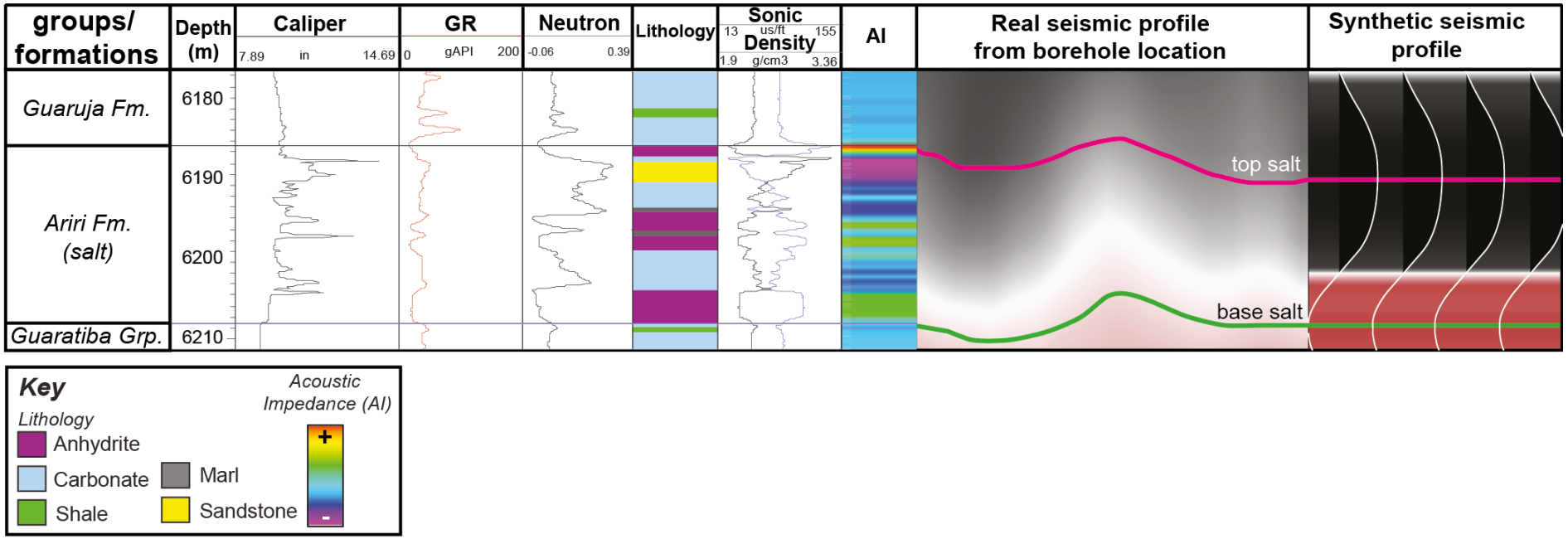

Borehole Expression of Weld

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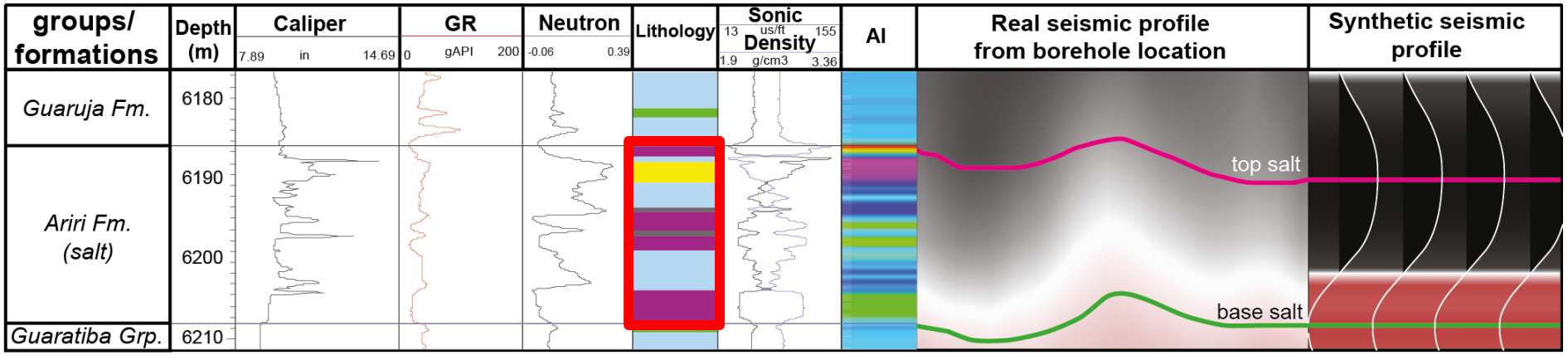

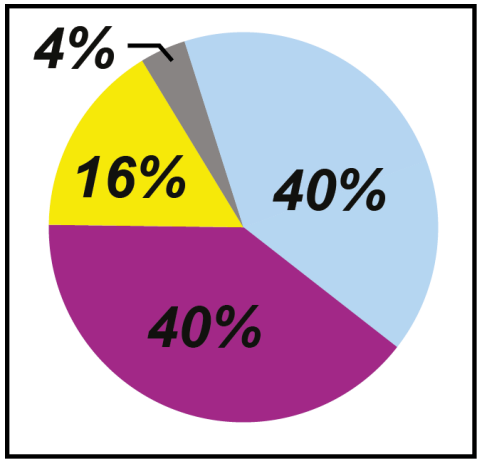

- Parati Weld 22 m thick
- No halite; carbonate- and anhydrite-dominated

Regional Stratigraphic Context

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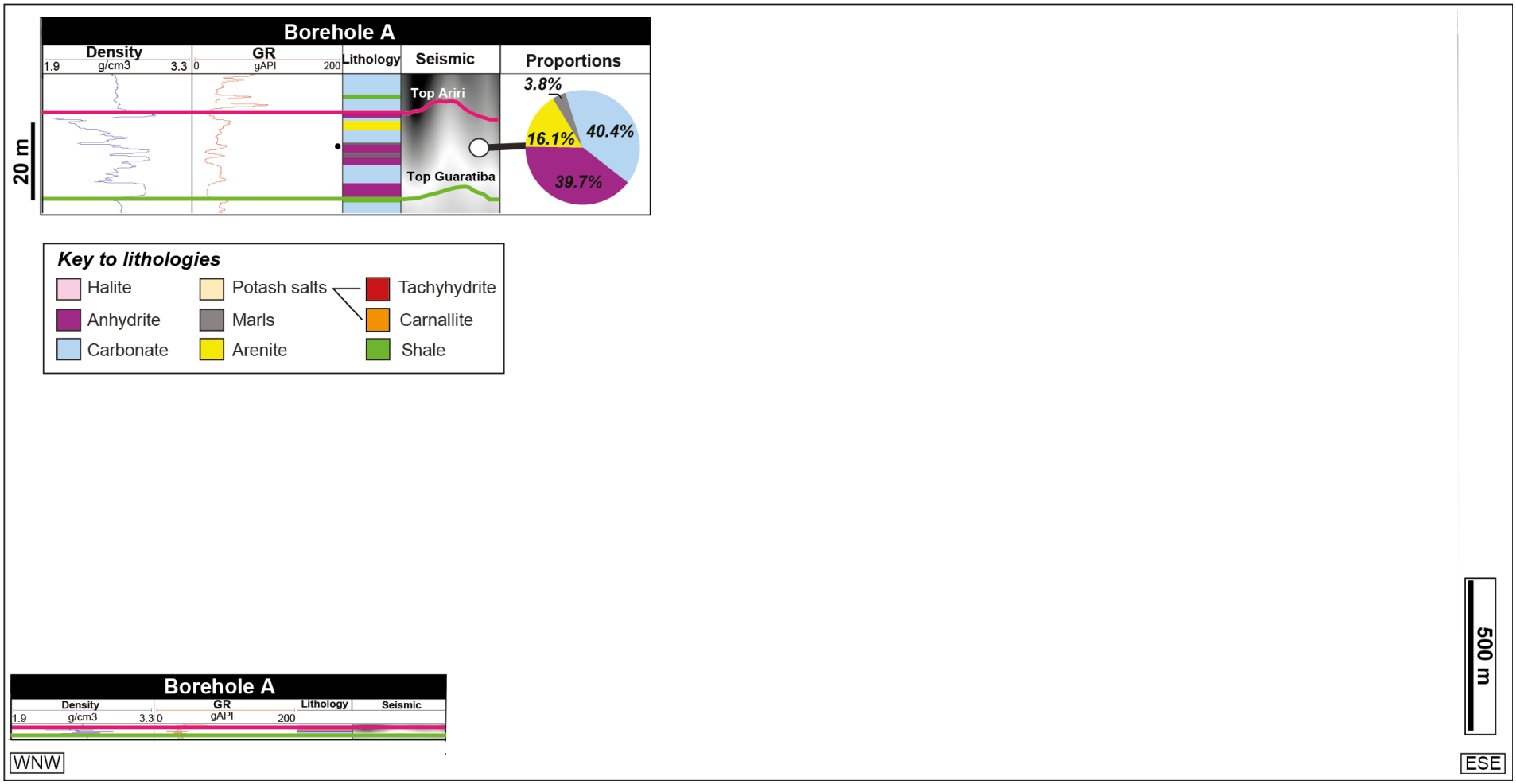

- Marked variations in salt thickness and lithology
- Areas of thick salt (Borehole B) halite-rich (86%); no carbonate, and minor carnallite (12%) and anhydrite (2%)

Regional Stratigraphic Context

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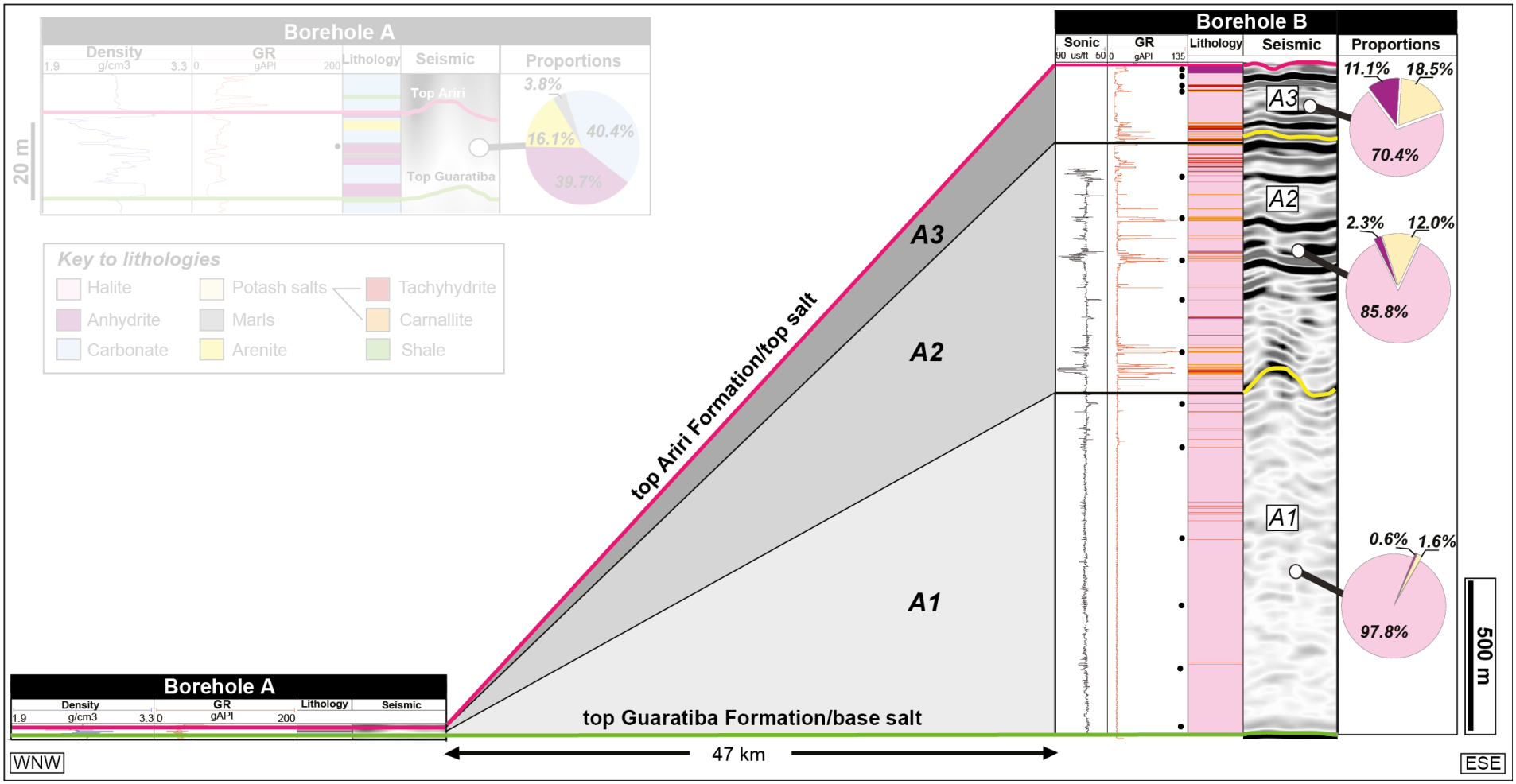

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Genetic Model for Weld Formation

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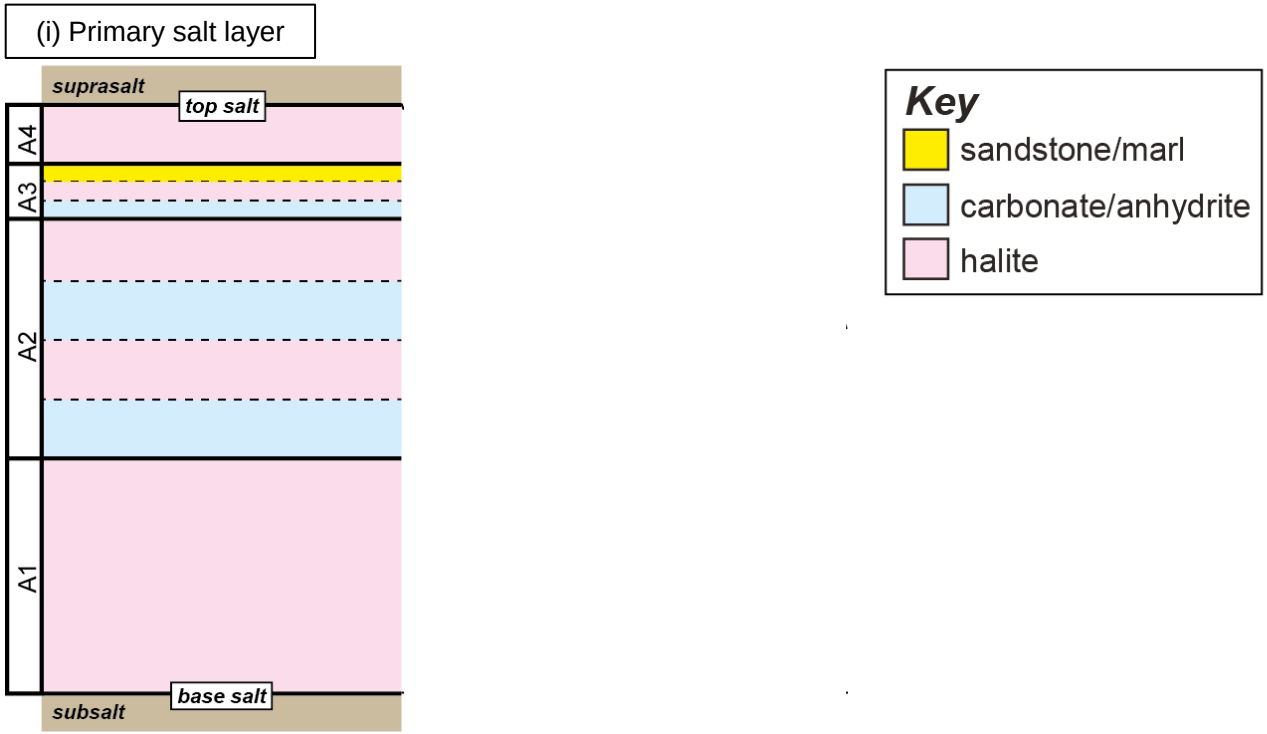
- **Stage (i)** – pre-thinning salt



Genetic Model for Weld Formation

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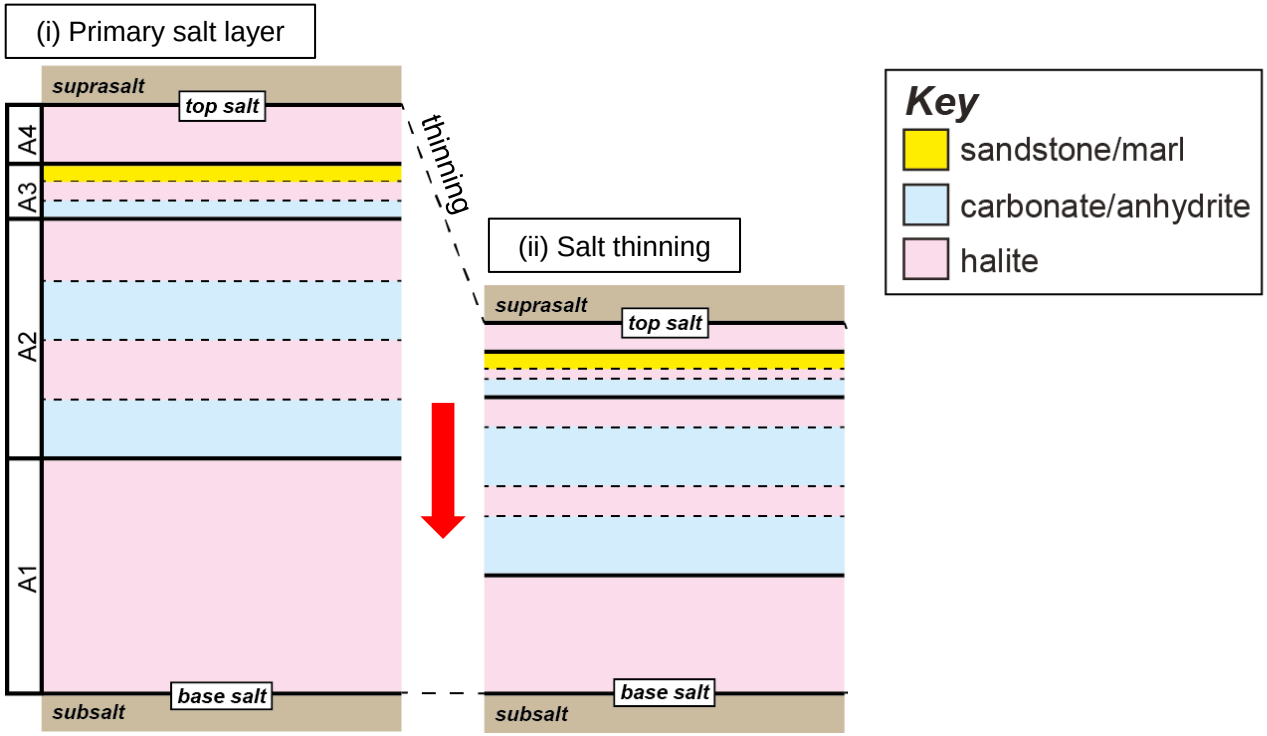
- **Stage (i)** – pre-thinning salt
- **Stage (ii)** – salt thinning; preferential expulsion of low-viscosity halite



Genetic Model for Weld Formation

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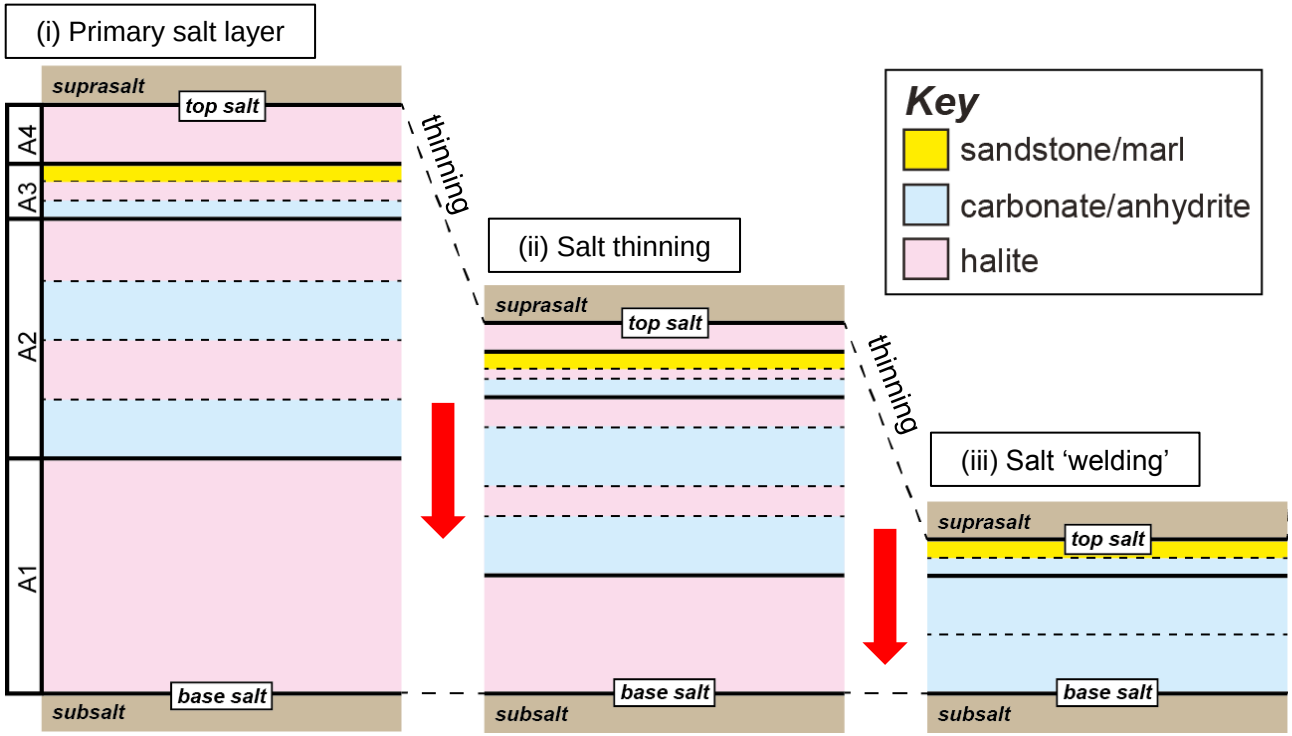
- **Stage (i)** – pre-thinning salt
- **Stage (ii)** – salt thinning; preferential expulsion of low-viscosity halite
- **Stage (iii)** - salt welding; complete evacuation of halite; remnant non-halite (high-viscosity) lithologies



Genetic Model for Weld Formation

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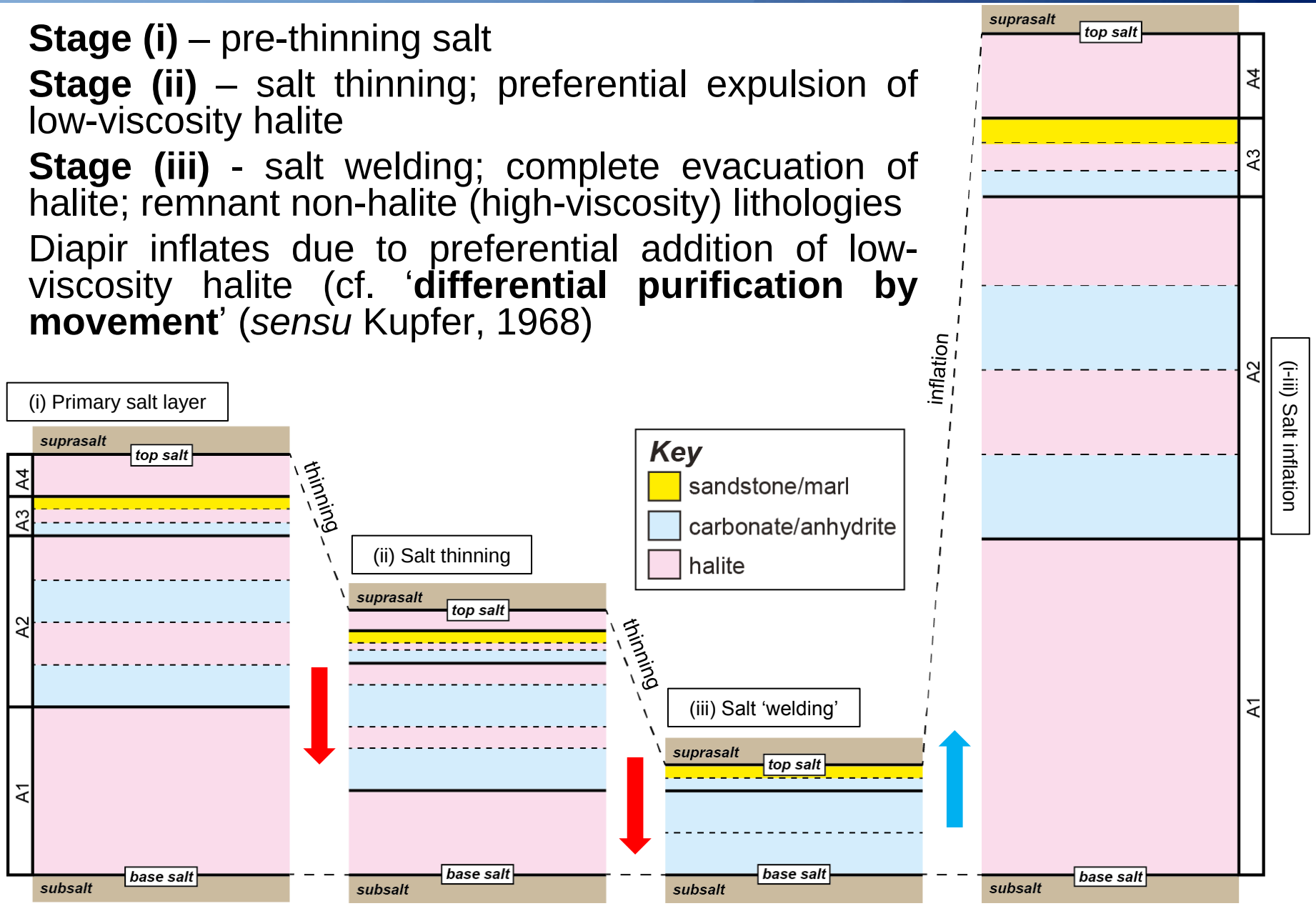
- **Stage (i)** – pre-thinning salt
- **Stage (ii)** – salt thinning; preferential expulsion of low-viscosity halite
- **Stage (iii)** - salt welding; complete evacuation of halite; remnant non-halite (high-viscosity) lithologies
- Diapir inflates due to preferential addition of low-viscosity halite (cf. '**differential purification by movement**' (*sensu* Kupfer, 1968)



Conclusions and Future Work

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- **How much salt remains in an incomplete/apparent weld?**
- Well proves a few tens of metres of (sub-seismic) salt remain in **apparent weld** - this term should be used until borehole data unequivocally prove absence of salt

- **What type of salt remains in an incomplete/apparent weld?**
- Halite-poor but **rich in 'evaporite-associated' lithologies** (e.g., carbonates and anhydrite) - autochthonous layer stratigraphy influences weld thickness and potential sealing properties

- **What might we infer about processes occurring during welding?**
- Observations **support analytical and numerical results** (few tens of metres left in weld due to drag along boundary layers) - 'differential purification by movement'

- Additional subsurface case studies required; well data are critical!

- Empirical database capturing link between weld type, thickness, composition, hydrocarbon column height, etc

- Seismic forward modelling; what can seismic attributes tell us about weld thickness and physical properties pre-drill?