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


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

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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)
• **primary** - joins strata originally above and below *autochthonous* salt
What’s a Weld?

- **primary** - joins strata originally above and below *autochthonous* salt
- **secondary** – joins minibasins originally situated either side of diapirs
What’s a Weld?

- **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
<table>
<thead>
<tr>
<th>What’s a Weld?</th>
</tr>
</thead>
<tbody>
<tr>
<td>subsalt</td>
</tr>
<tr>
<td>suprasalt</td>
</tr>
<tr>
<td>salt</td>
</tr>
<tr>
<td>weld</td>
</tr>
</tbody>
</table>

Map view

Map view

Map view
What’s a Weld?

- **complete** - contains **no** remnant salt
### What’s a Weld?

**Complete** - contains **no** remnant salt

**Incomplete** – contains **up to 50 m** of remnant salt
What’s a Weld?

- **complete** - contains **no** remnant salt
- **incomplete** – contains **up to 50 m** of remnant salt
- **discontinuous** – contains **complete and incomplete** parts
What’s a Weld?

- **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?

- Determining weld thickness and composition difficult using only seismic data
- Degree of welding and weld composition may impact prospectivity
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How much salt remains in an incomplete/apparent weld?
Motivation and Talk Outline

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• What type of salt in an incomplete/apparent weld?
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• What type of salt in an incomplete/apparent weld?
• What might we infer about processes occurring during welding?
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• 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
Salt-Related Structural Style

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

Borehole A
PM
PW
Borehole B
Parati Minibasin and Weld

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

- 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

- salt isochron
- intra-Oligocene
- Parati Minibasin
- Parati Weld
- seabed
- salt stock
- salt pillow
- Borehole A
- top salt
- base salt
- top Albian
Borehole Expression of Weld

Parati Minibasin

Parati Weld

Borehole A

top salt

base salt
Borehole Expression of Weld

Parati Minibasin

Parati Weld

Borehole A

top salt

base salt
## Borehole Expression of Weld

### Key

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Acoustic Impedance (AI)</th>
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<tbody>
<tr>
<td>Anhydrite</td>
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</tr>
<tr>
<td>Carbonate</td>
<td></td>
</tr>
<tr>
<td>Marl</td>
<td></td>
</tr>
<tr>
<td>Shale</td>
<td></td>
</tr>
<tr>
<td>Sandstone</td>
<td></td>
</tr>
</tbody>
</table>

### Groups/Formations

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Caliper</th>
<th>GR</th>
<th>Neutron</th>
<th>Lithology</th>
<th>Sonic Unit Density</th>
<th>AI</th>
<th>Real seismic profile from borehole location</th>
<th>Synthetic seismic profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guaruja Fm.</td>
<td>6180</td>
<td>7.89 in</td>
<td>14.69</td>
<td>0</td>
<td>0.06</td>
<td>6.30</td>
<td>1.13 g/cm³</td>
<td>155</td>
</tr>
<tr>
<td>Ariri Fm. (salt)</td>
<td>6190</td>
<td>7.89 in</td>
<td>14.69</td>
<td>0</td>
<td>0.06</td>
<td>6.30</td>
<td>1.13 g/cm³</td>
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<td>1.13 g/cm³</td>
<td>155</td>
<td><img src="image1" alt="Real seismic profile" /></td>
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<tr>
<td>Guaratiba Grp.</td>
<td>6210</td>
<td>7.89 in</td>
<td>14.69</td>
<td>0</td>
<td>0.06</td>
<td>6.30</td>
<td>1.13 g/cm³</td>
<td>155</td>
</tr>
</tbody>
</table>
Borehole Expression of Weld

- Parati Weld 22 m thick
- No halite; carbonate- and anhydrite-dominated
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%)
• 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%)
Genetic Model for Weld Formation

- **Stage (i) – pre-thinning salt**
Genetic Model for Weld Formation

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

(i) Primary salt layer

Key:
- Yellow: sandstone/marl
- Light blue: carbonate/anhydrite
- Pink: halite

Diagram showing the stages:
- (i) Primary salt layer
- (ii) Salt thinning
- (iii) Salt ‘welding’
Genetic Model for Weld Formation

- **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))

Key:
- **sandstone/marl**
- **carbonate/anhydrite**
- **halite**
Conclusions and Future Work

• 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?