Synextensional magmatism controlling the localization of epithermal mineralization in the Guazapares Mining District, northern Sierra Madre Occidental, Mexico

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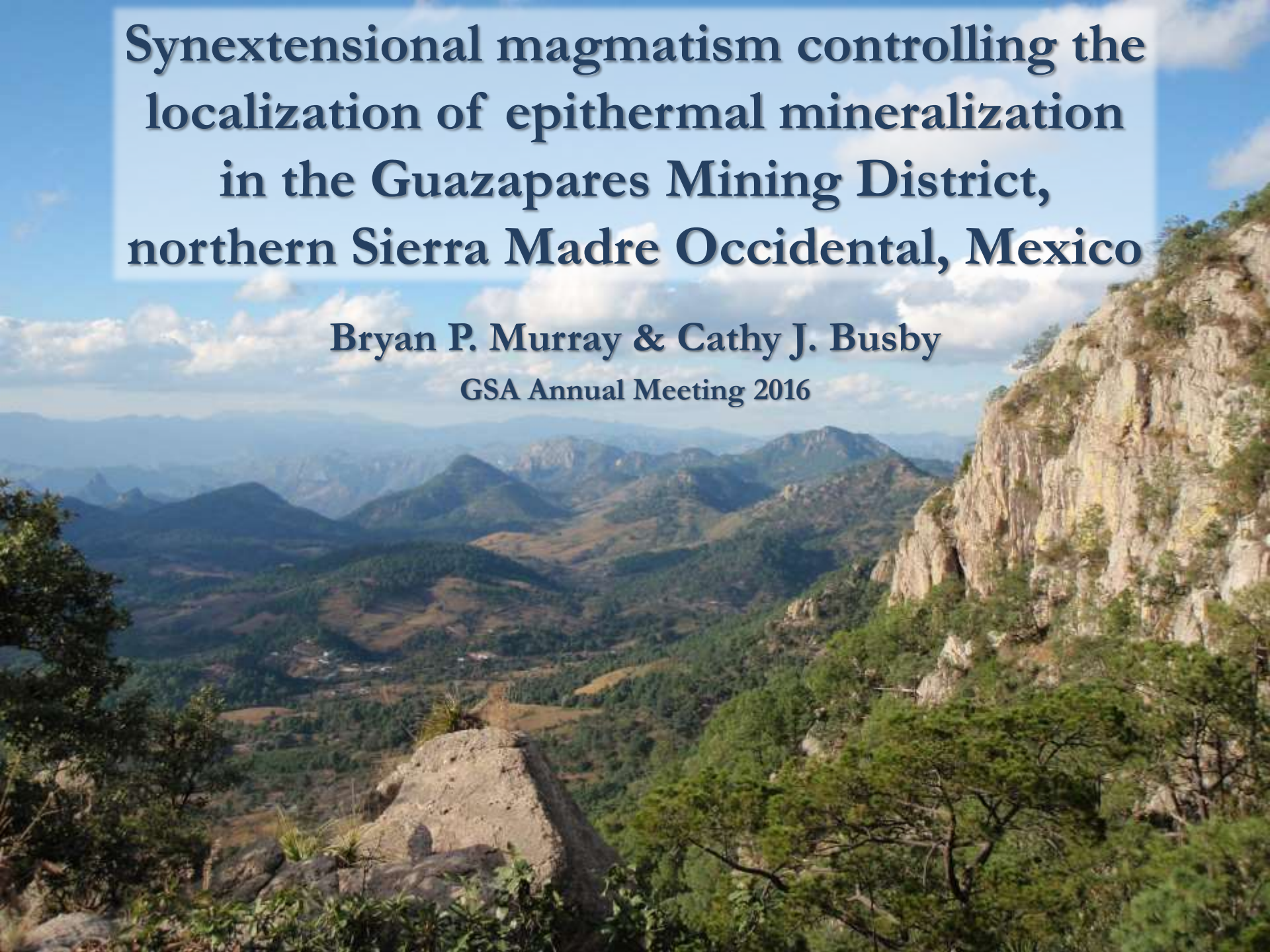
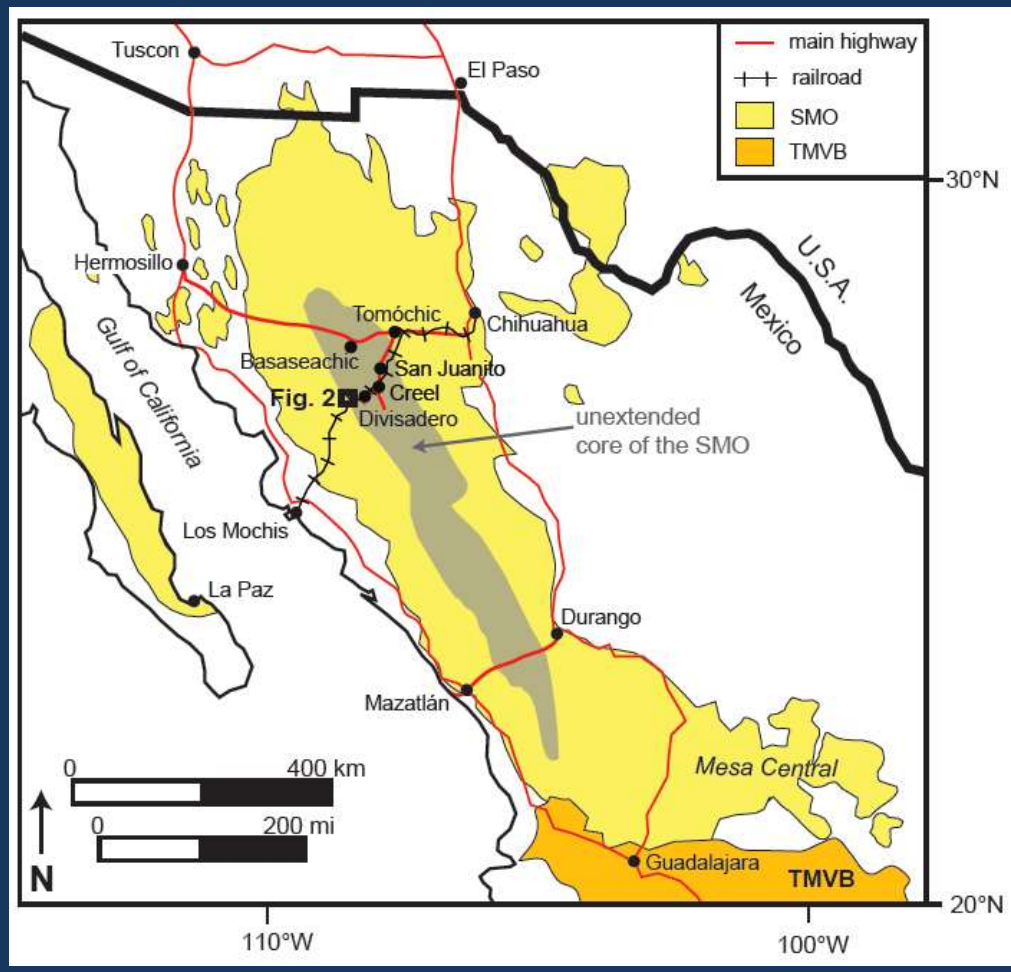


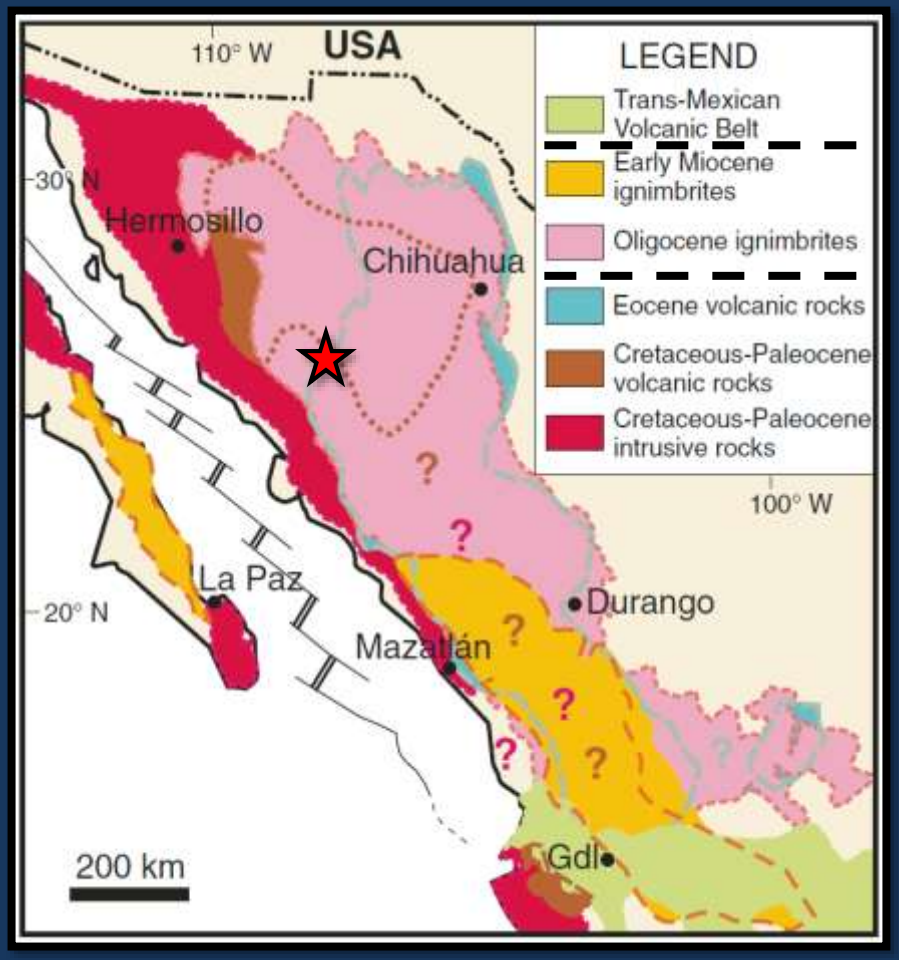
Sierra Madre Occidental (SMO)

- Biggest Tertiary silicic large igneous province
- Extends over 1,200 km from U.S.-Mexico border
- Covers 300,000–400,000 km^2, average thickness 1 km
- Unextended core surrounded by the Miocene-age extensional belts
- Erupted during the mid-Cenozoic ignimbrite flare-up of the western North America Cordillera



(after Henry and Aranda-Gomez, 2000; Ferrari et al., 2002, Bryan et al., 2013)

Regional stratigraphy



(Ferrari et al., 2007)

Subdivision of SMO volcanic rocks:
(after McDowell & Keizer, 1977)

1) Lower Volcanic Complex (LVC)
   - Late Cretaceous to Eocene
   - Andesitic arc magmatism

2) Upper Volcanic Supergroup (UVS)
   - Eocene to Early Miocene
   - Silicic ignimbrite flare-up
   - Two main ignimbrite pulses:
     - Early Oligocene (32 – 28 Ma)
     - Early Miocene (24 – 20 Ma)

3) Southern Cordillera basaltic andesite province (SCORBA)
   - Mostly Oligocene-age (33-17.6 Ma)
   - Erupted during the final stages and after each ignimbrite pulse

Guazapares Mining District

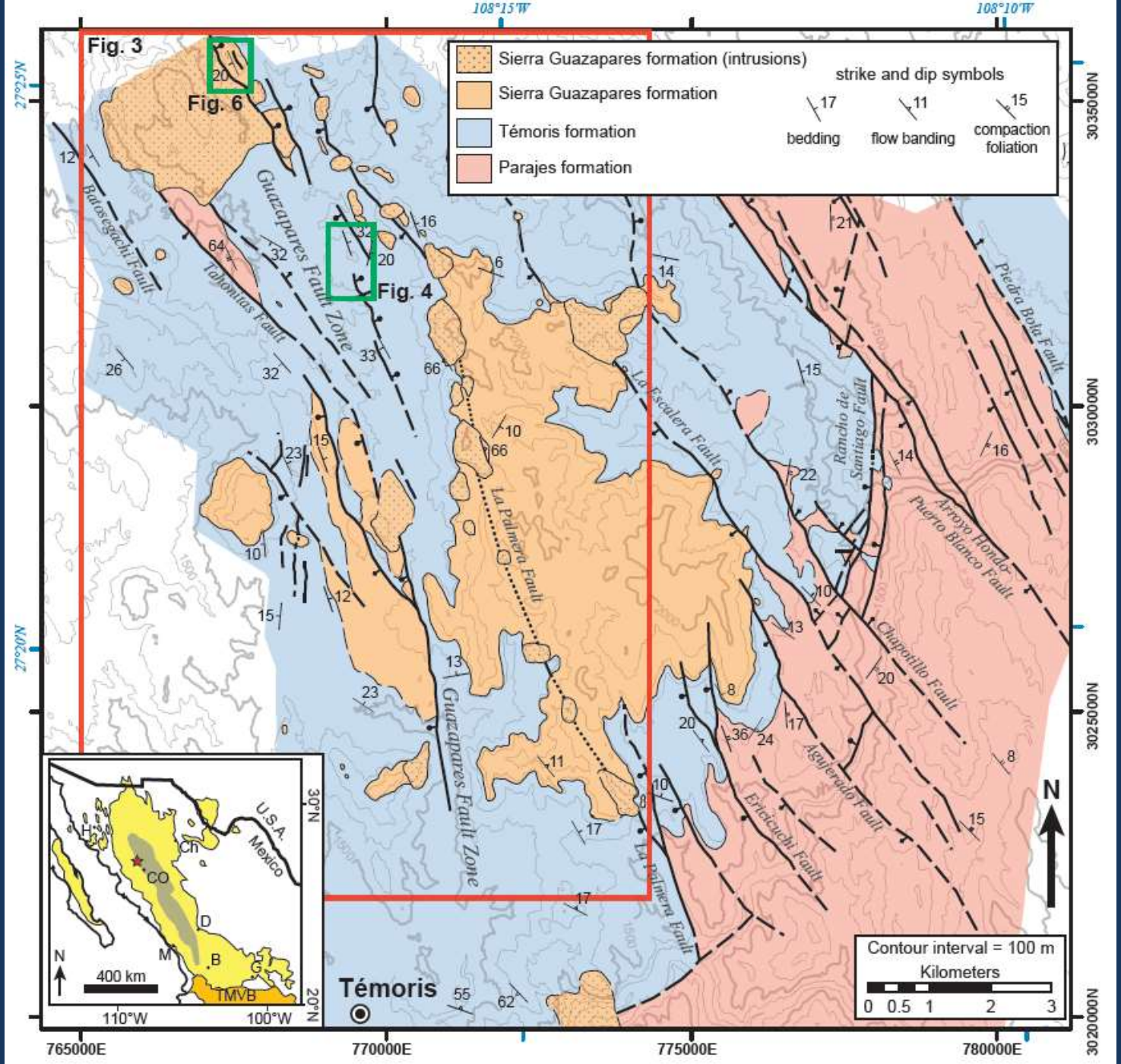
- Western edge of the "unextended" northern SMO in Copper Canyon region, within Sierra Madre Gold/Silver Belt (~250 km SW of Chihuahua)
- Detailed local economic geology studies by Paramount Gold, etc.
- Regional 1:50k geologic mapping by Mexican government (2004)
  - Lacks structural detail or age controls
  - Mapped as LVC Paleocene-Eocene andesites and UVS Oligocene rhyolite tuffs

(Roy et al., 2008)

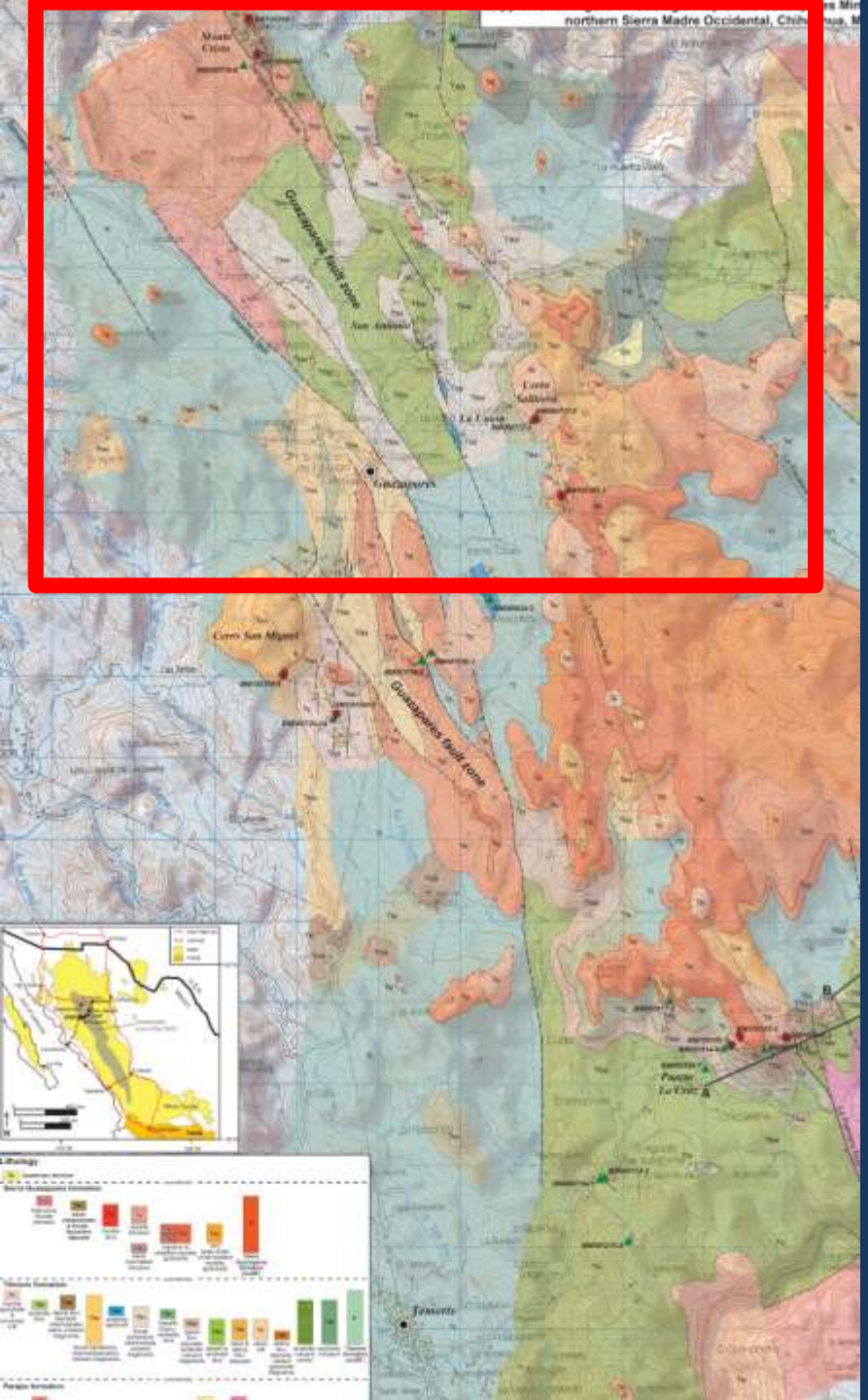
Guazapares Mining District

Recent geologic mapping, zircon U-Pb LA ICP-MS dating, modal analyses, and whole-rock geochemistry (Murray et al., 2013 *Geosphere*):

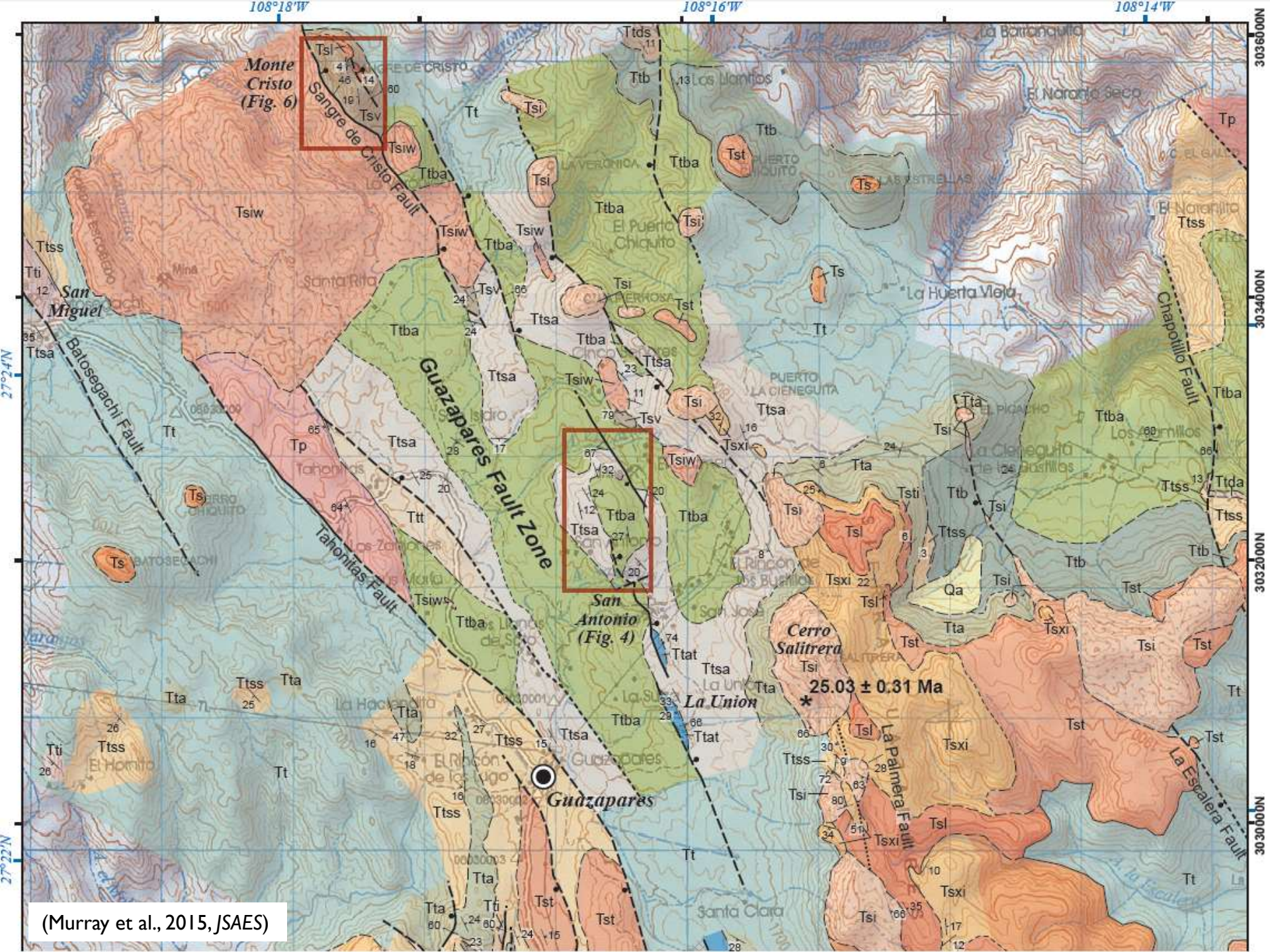
- Two UVS silicic volcanic formations, separated by a mafic-intermediate volcanic & sedimentary formation
  - Early Oligocene ignimbrite pulse (Parajes formation)
  - SCORBA (Témoris formation)
  - Early Miocene ignimbrite pulse(?) (Sierra Guazapares formation)
- Previously unmapped Late Oligocene half-graben basins bound by NW-trending syndepositional normal faults, extension preceding locally-derived mafic-intermediate and silicic volcanism
- **Direct relationship is inferred between the timing of silicic intrusions, extensional structures, and localization of epithermal mineralization**



(Murray et al., 2015, *JSAES*)



(Murray et al., 2013)



(Murray et al., 2015, *JSAES*)

Stratigraphy

Three synextensional UVS "formations" in the Guazapares Mining District:

1) Parajes formation:

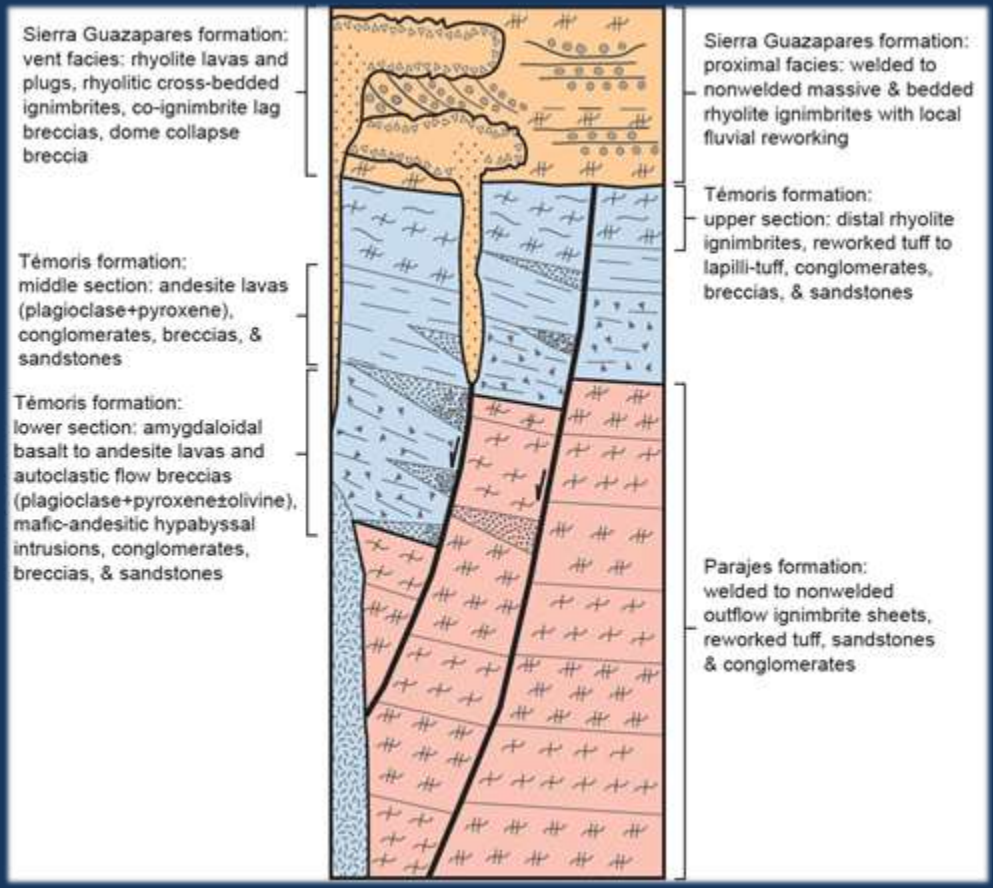
- ca. 27.5 Ma
- Silicic outflow ignimbrite sheets

2) Témoris formation:

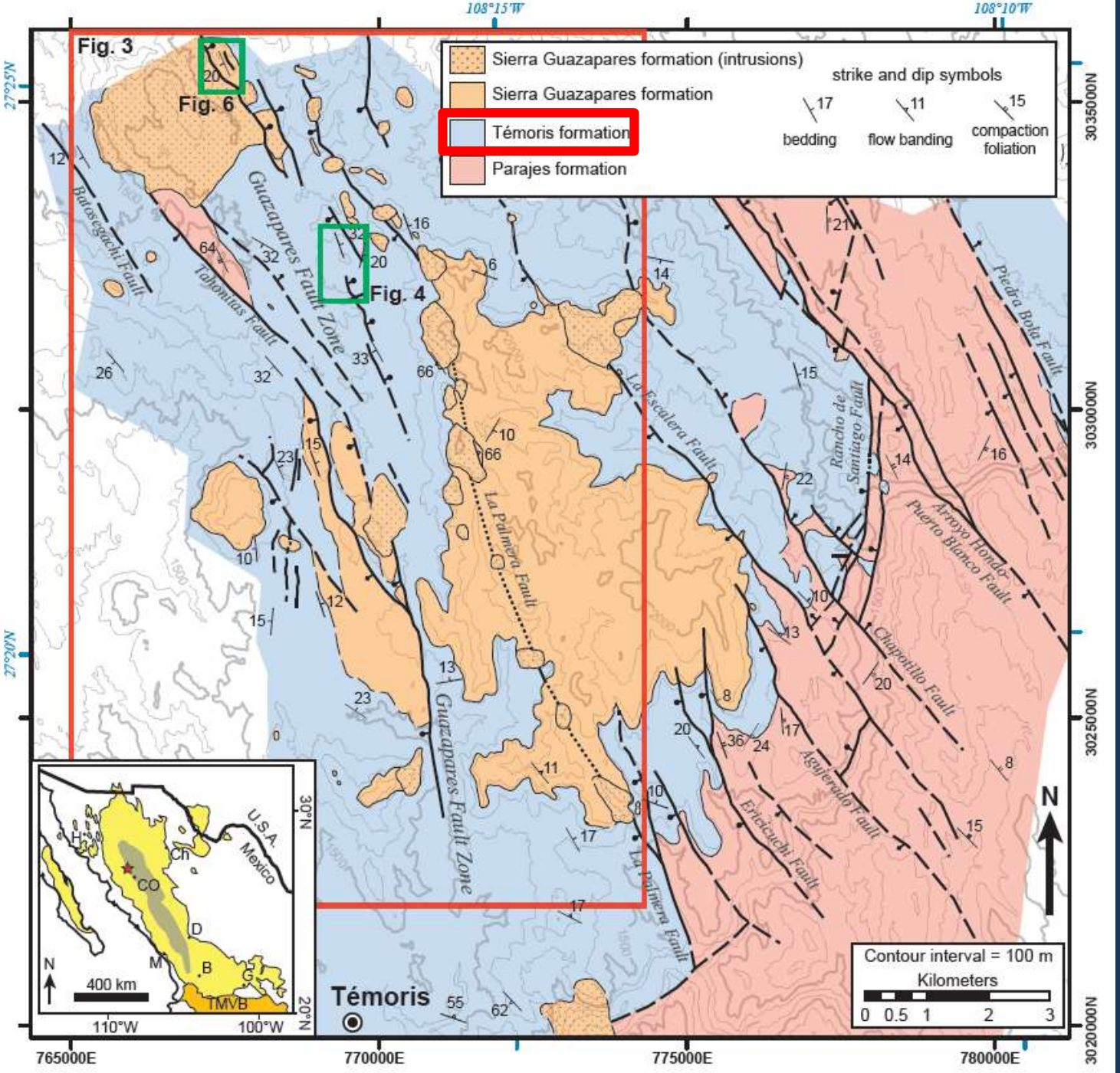
- ca. 27.5 – 24.5 Ma
- Mafic-intermediate volcanic rocks
- Alluvial deposits

3) Sierra Guazapares formation

- ca. 24.5 – 23 Ma
- Silicic fissure eruptive centers

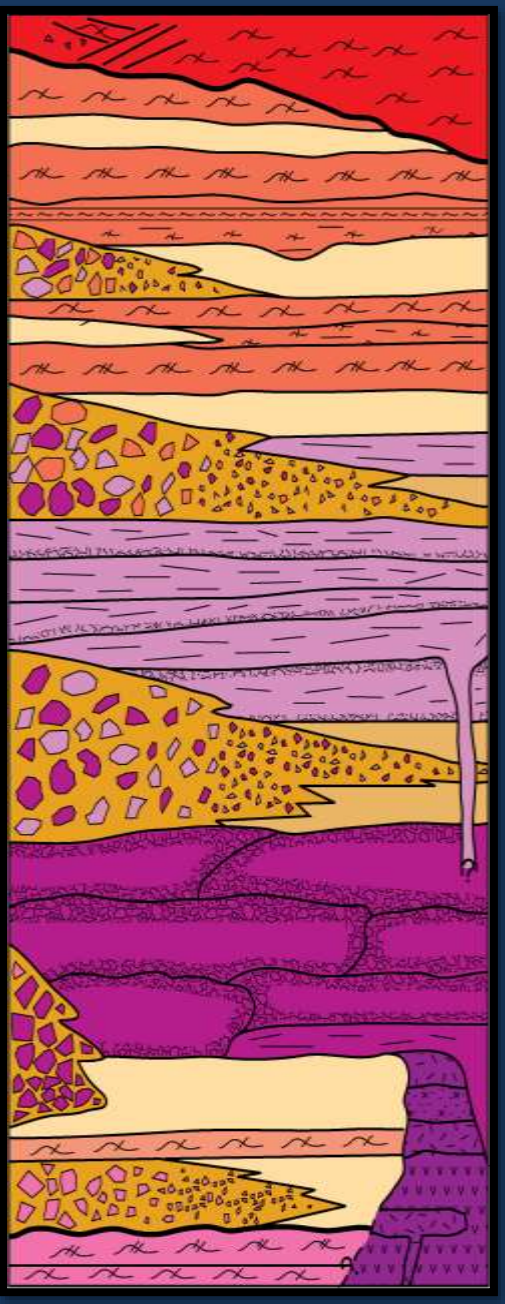


(Murray et al., 2013)



(Murray et al., 2015, *JSAES*)

Témoris formation (ca. 27.5 – 24.5 Ma)



Sierra Guazapares formation

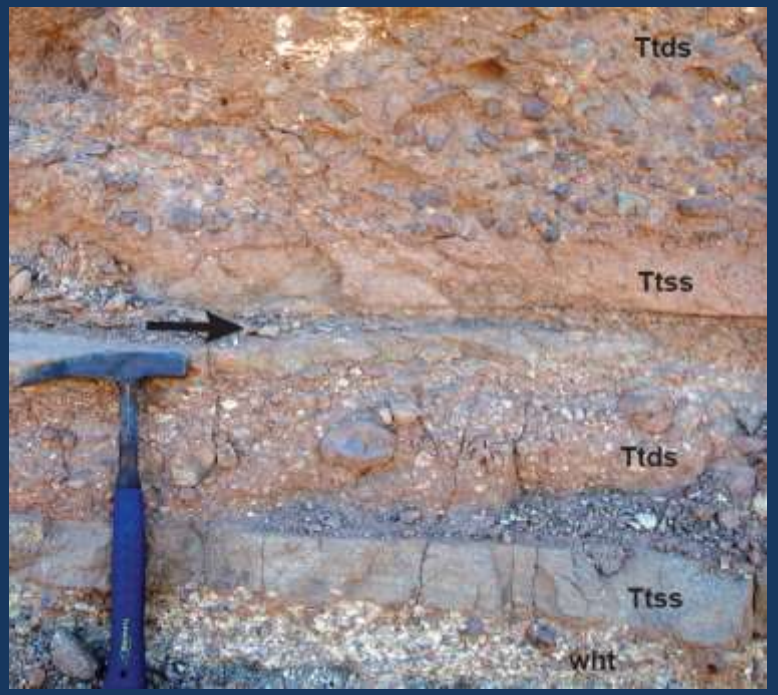
Upper section:
distal rhyolite ignimbrites, reworked tuff to lapilli-tuff; conglomerates, breccias, & sandstones **~24.5 Ma**

Middle section:
andesite lavas; conglomerates, breccias, & sandstone

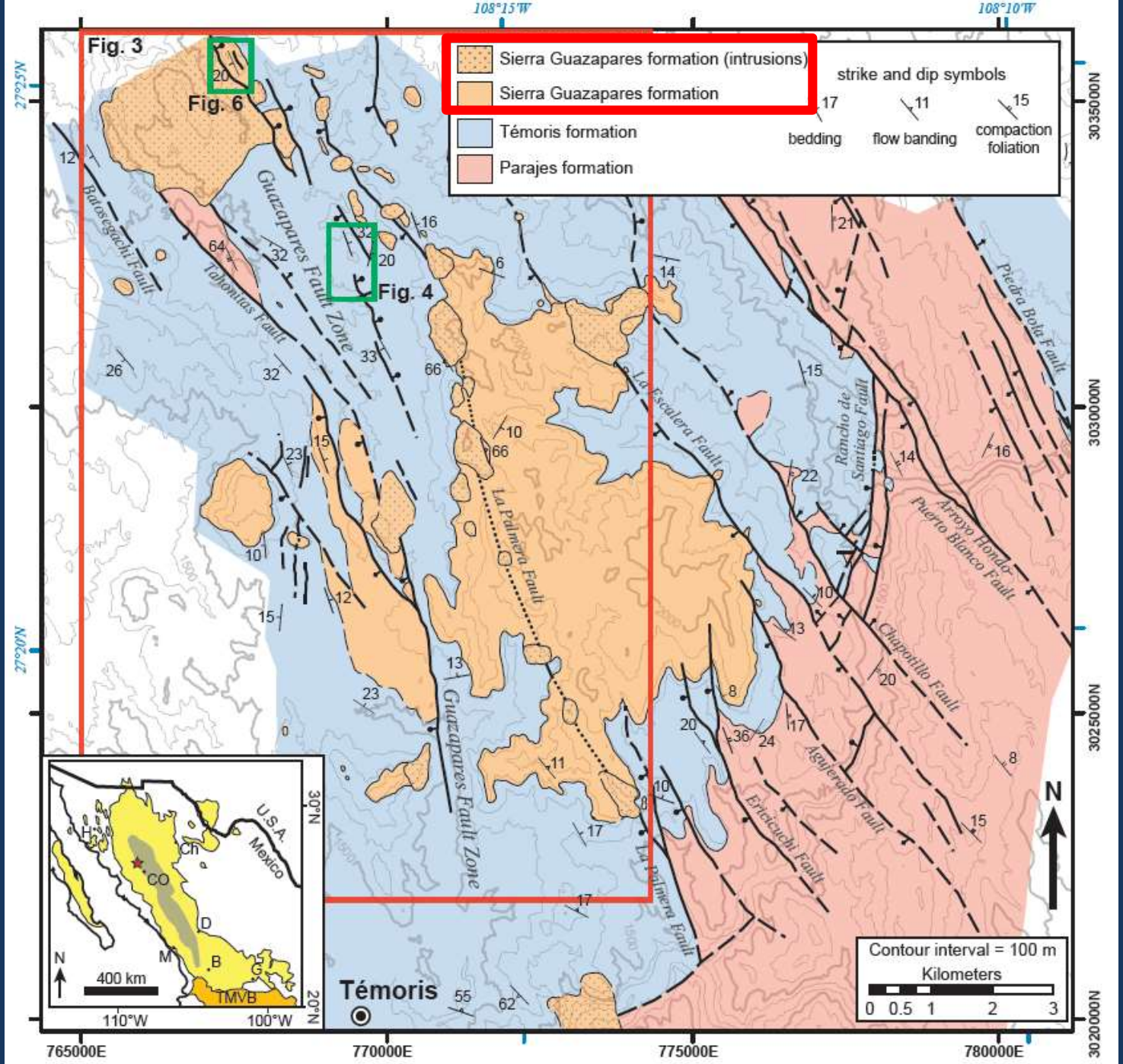
Lower section:
amygdaloidal basalt to andesite lavas and autoclastic flow breccias, mafic-andesitic hypabyssal intrusions; conglomerates, breccias, & sandstones **27.3 ± 0.3 Ma**

Basal deposits: debris flow w/ Parajes fm. clasts; distal silicic tuff

Parajes formation



Host most epithermal deposits

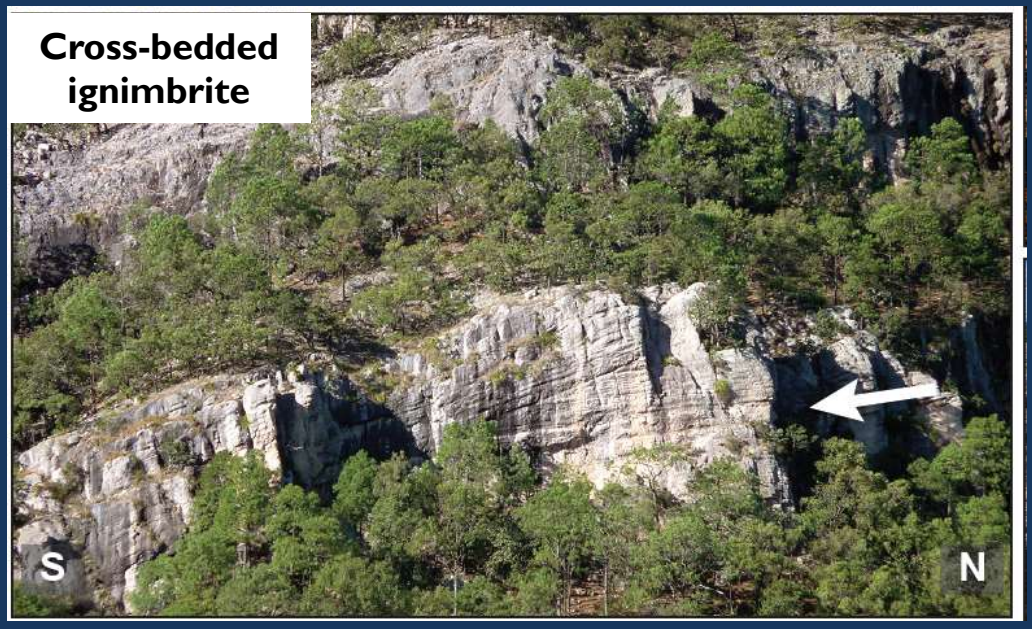


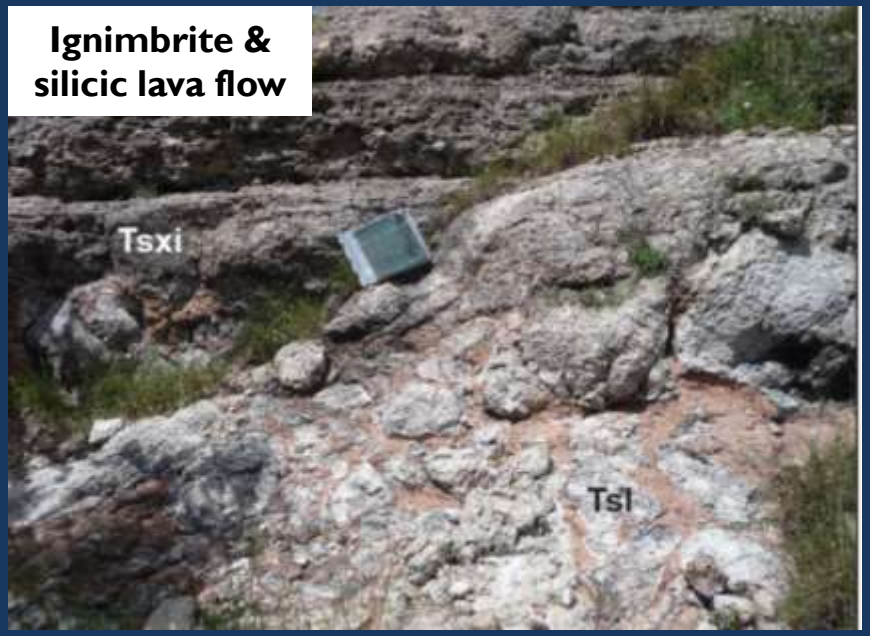
(Murray et al., 2015, *JSAES*)

Sierra Guazapares formation (ca. 24.5 – 23 Ma)

Silicic fissure magmatism:

- **Vent facies:** rhyolite lavas and plugs, rhyolitic cross-bedded ignimbrites, co-ignimbrite lag breccias
- **Proximal facies:** welded to nonwelded massive & bedded rhyolite ignimbrites with local fluvial reworking

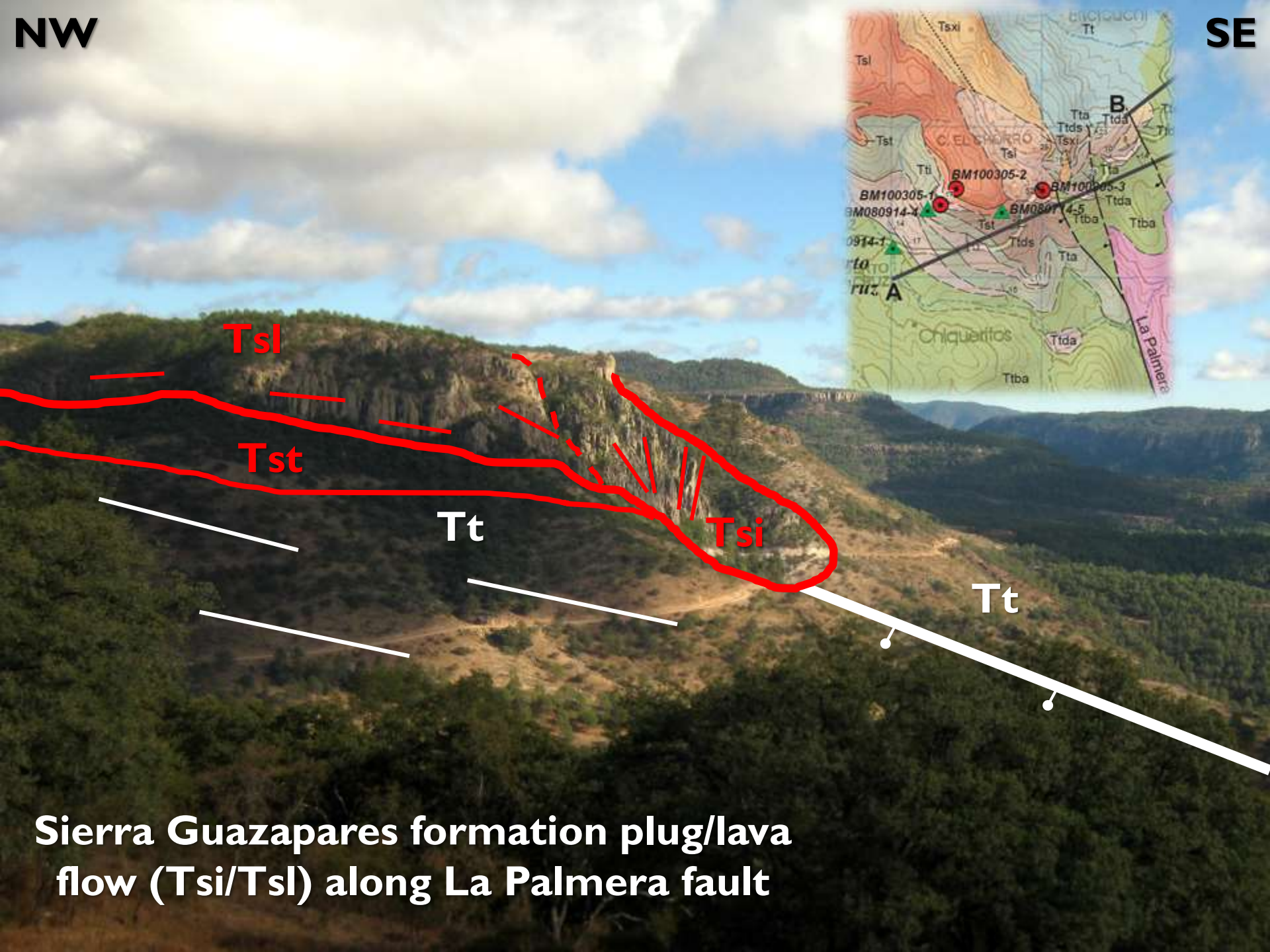




Sierra Guazapares formation fissure volcanism

Pre-existing normal faults controlled the location of Sierra Guazapares formation fissure volcanism

- Cross-bedded ignimbrites found in ~3 km-wide belt around La Palmera fault, laterally transition away to massive & bedded ignimbrites
- Rhyolite plugs and lava flows also restricted to La Palmera fault & other faults in region



Sierra Guazapares formation plug/lava flow (Tsi/Tsl) along La Palmera fault

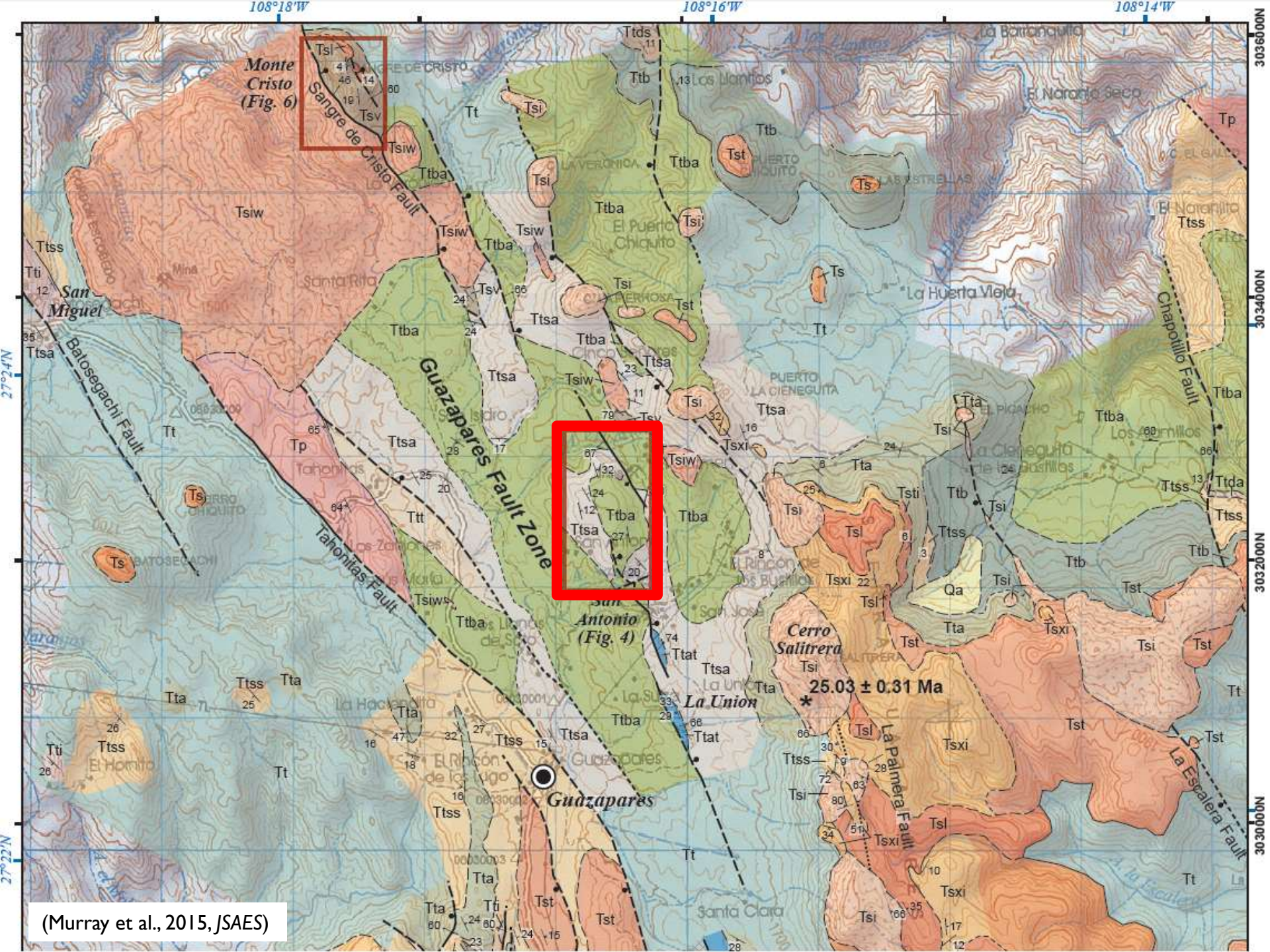
Implications for epithermal mineralization

Localization of epithermal mineralization favored where pre-existing extensional structures are spatially associated with Sierra Guazapares formation rhyolite plugs

- low-to-intermediate-sulfidation, gold-silver-lead-zinc vein and breccia deposits

Normal faults and accommodation zones provide conduits for intrusion-related hydrothermal fluids and localize epithermal mineralization

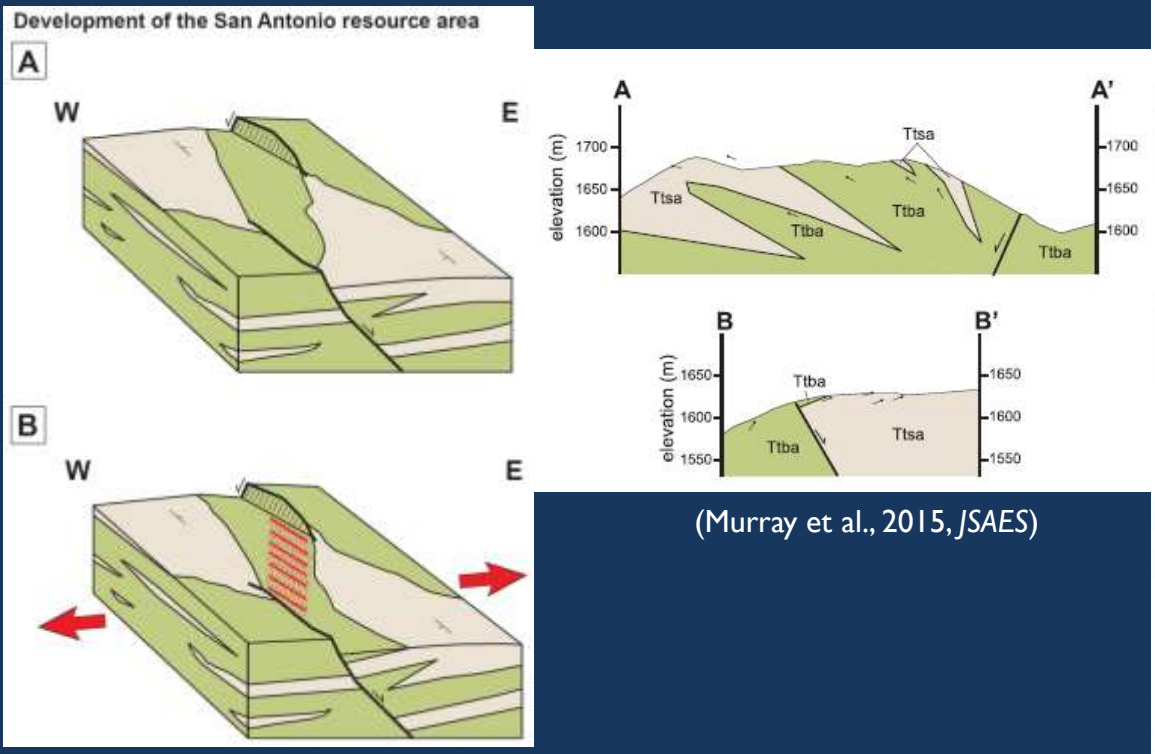
Resource areas of Guazapares Fault Zone



(Murray et al., 2015, *JSAES*)

San Antonio resource area

- Two en echelon NW-trending normal faults with opposing dip-directions
- Mineralization along subvertical structures in antithetic accommodation zone between faults
- Silicic intrusions crop out ~0.5 – 1 km east, ~120 m-depth below resource



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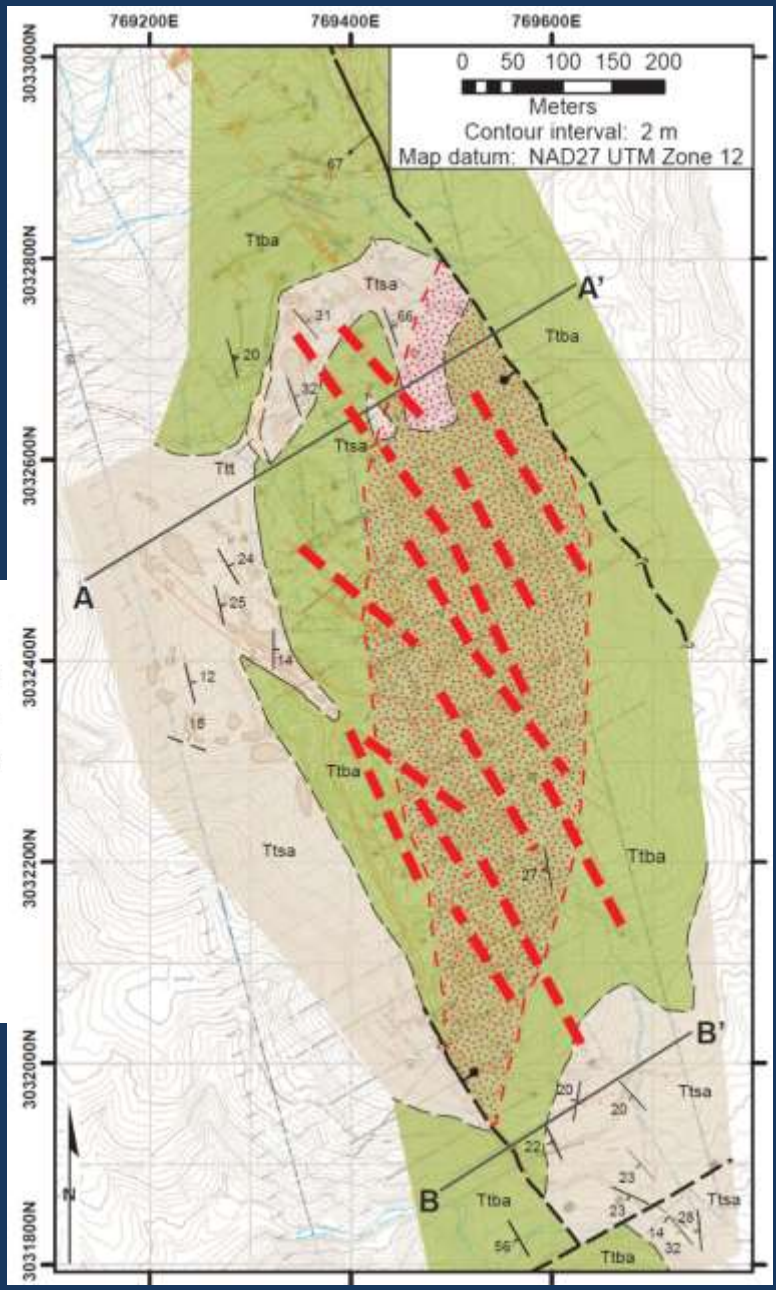
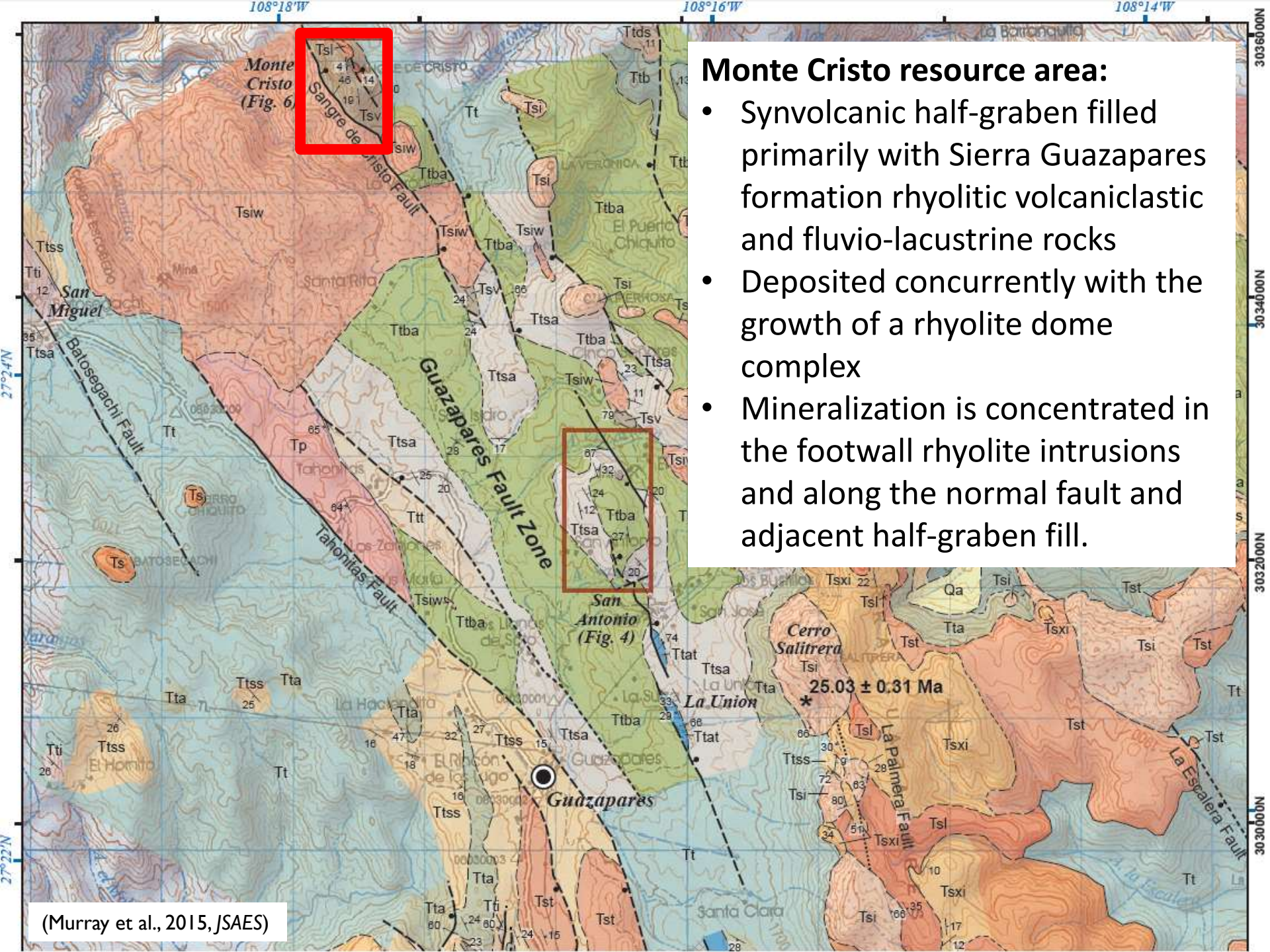
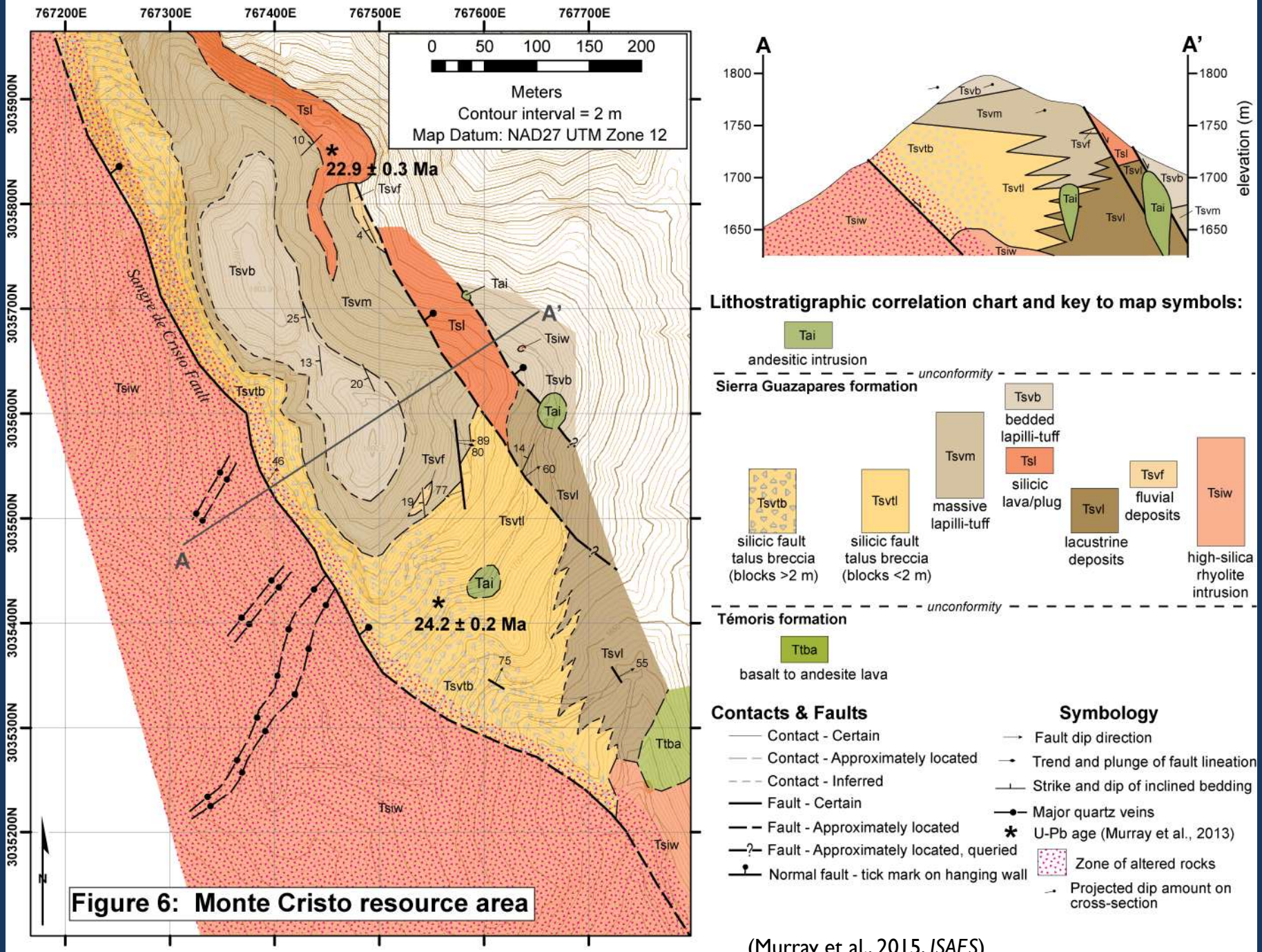
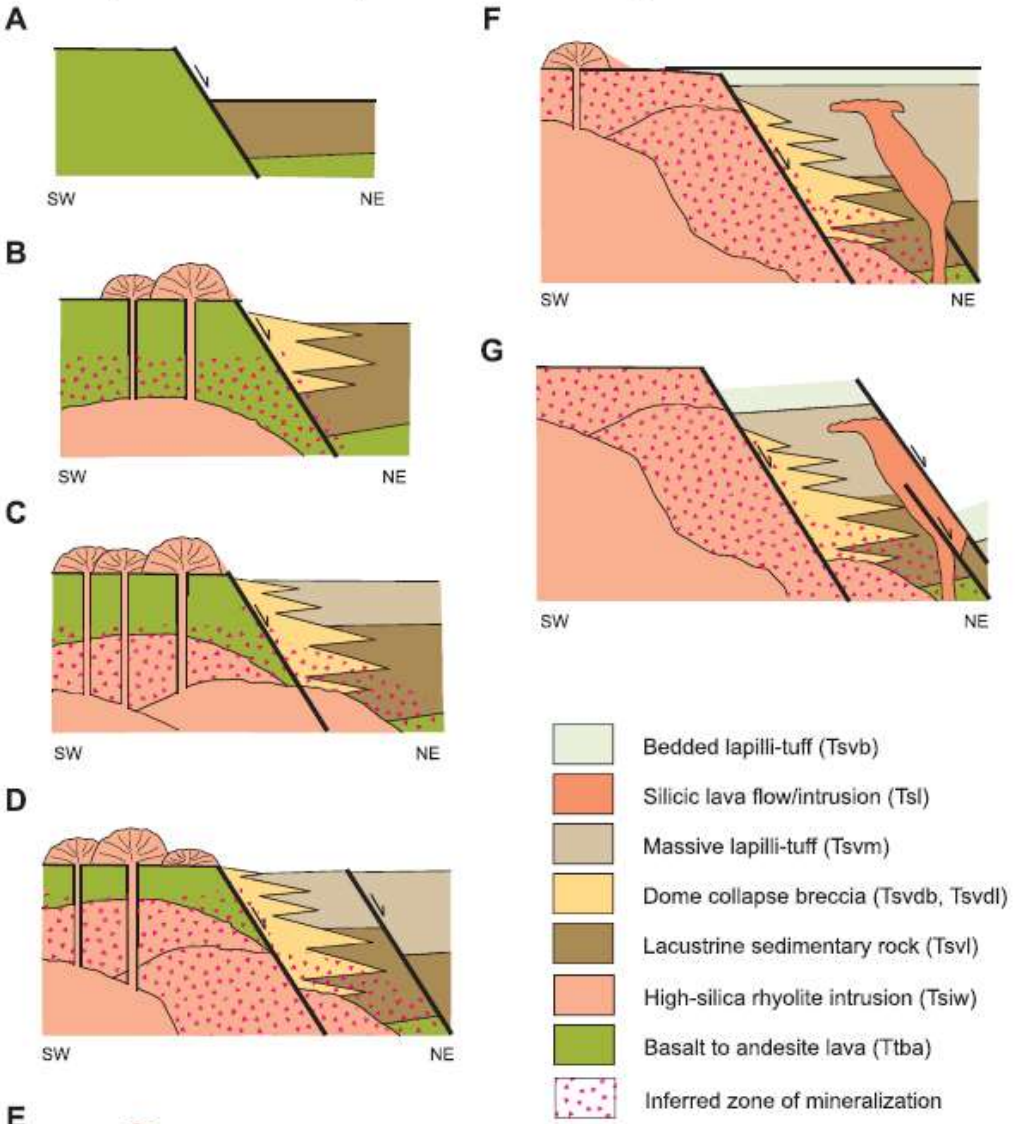


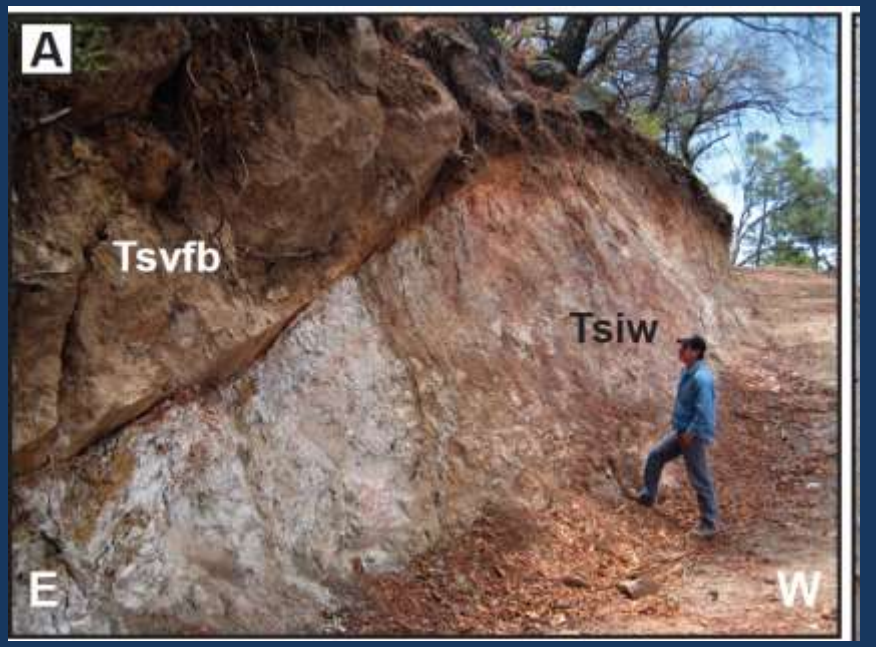

Monte Cristo (Fig. 6)
Sangre de Cristo Fault
Guazapares Fault Zone
Batosegachi Fault
Tahonitas Fault
San Antonio (Fig. 4)
Cerro Salitrera
25.03 ± 0.31 Ma
La Union
Guazapares
La Palmera Fault
La Escalera Fault
San Miguel
Monte Cristo resource area:
• Synvolcanic half-graben filled primarily with Sierra Guazapares formation rhyolitic volcaniclastic and fluvio-lacustrine rocks
• Deposited concurrently with the growth of a rhyolite dome complex
• Mineralization is concentrated in the footwall rhyolite intrusions and along the normal fault and adjacent half-graben fill.
(Murray et al., 2015, JSAES)

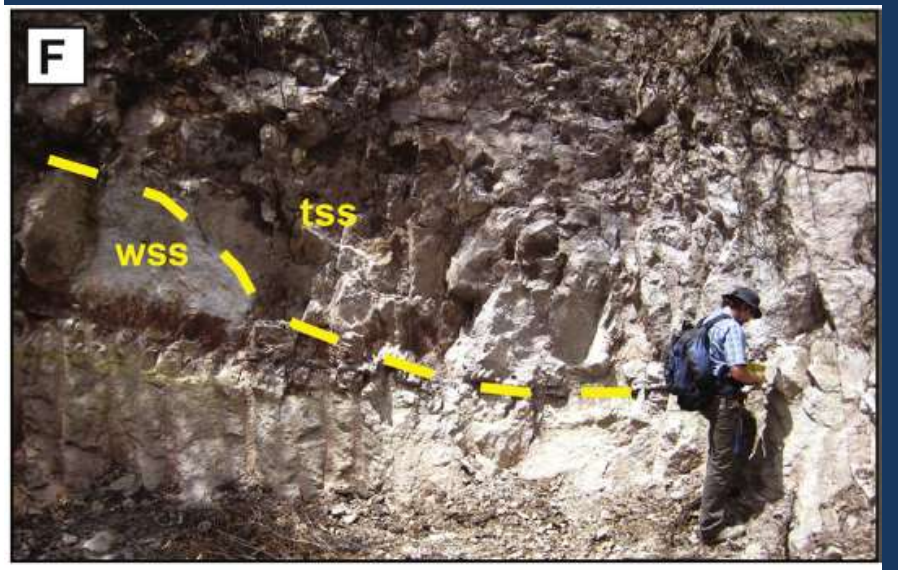


(Murray et al., 2015, *JSAES*)

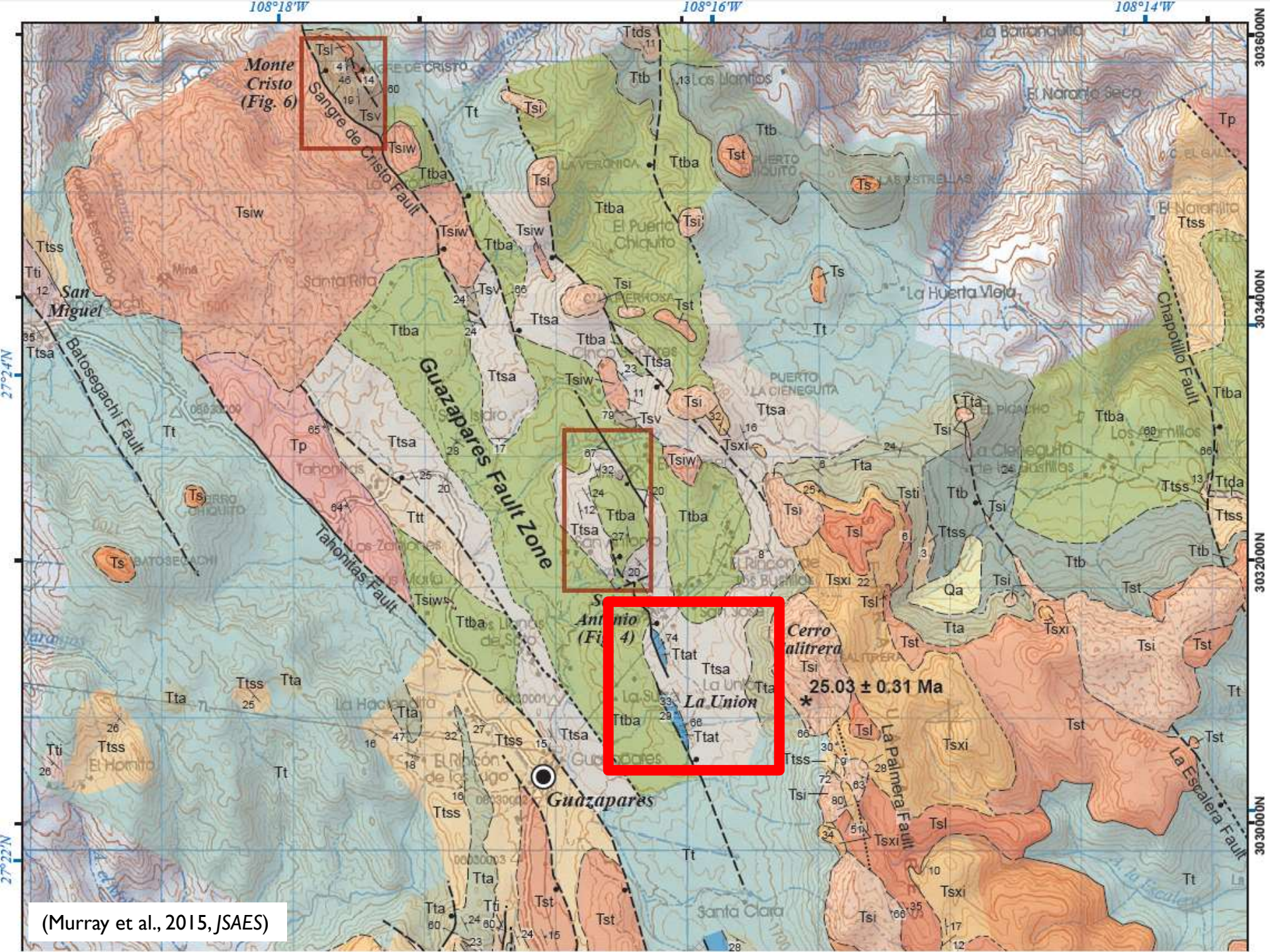
Development of the Sangre de Cristo half-graben basin







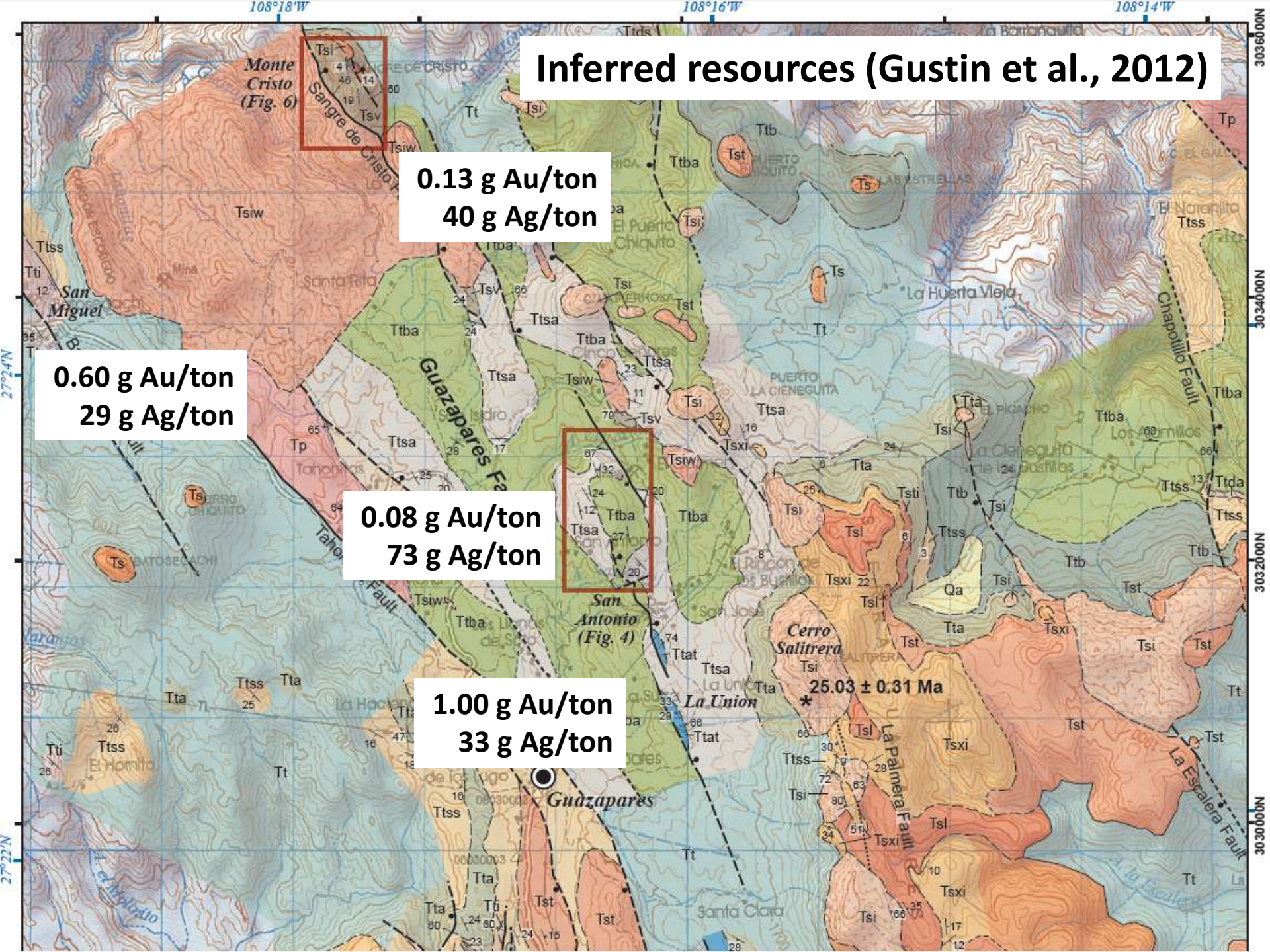
(Murray et al., 2015, *JSAES*)



(Murray et al., 2015, *JSAES*)

La Union resource area

- Mineralization is concentrated along a synthetic normal fault accommodation zone.
- Adjacent to the La Unión resource area (<1 km E) is Cerro Salitrera, one of the largest rhyolite plugs in the area.


Inferred resources (Gustin et al., 2012)
0.13 g Au/ton
40 g Ag/ton
0.60 g Au/ton
29 g Ag/ton
0.08 g Au/ton
73 g Ag/ton
1.00 g Au/ton
33 g Ag/ton
Monte Cristo (Fig. 6)
San Antonio (Fig. 4)
Cerro Salitrera
25.03 ± 0.31 Ma
La Union
Guazapares
Sangre de Cristo Fault
Guazapares Fault
Tahonitas Fault
La Palmera Fault
Chapotillo Fault
La Escalera Fault
108°18'W
108°16'W
108°14'W
27°24'N
27°22'N
3036000N
3034000N
3032000N
3030000N

Conclusions

- Three Late Oligocene-Early Miocene synextensional UVS formations are identified in Guazapares Mining District, younger than the previously inferred Eocene LVC age
- Majority of resource areas in district are found along "main Guazapares structure", adjacent to trend of Sierra Guazapares formation rhyolite plugs
- Mineralization in San Antonio and La Union resource areas concentrated in accommodation zones between normal faults
- Monte Cristo resource area consists of synvolcanic half-graben basin. Mineralization concentrated in footwall subvolcanic intrusions and fault-adjacent basin fill
- Mineralization likely related to emplacement of Sierra Guazapares formation rhyolite intrusions; normal faults and accommodation zones provide conduits for intrusion-related hydrothermal fluids and localize precious metal mineralization.

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