Testing Numerical Models of Subsalt Deformation through Field Observations: Case Studies from the Flinders Ranges, South Australia

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Motivation and Background

Drilling through salt sheets is dangerous because of the complex relationship between stress, fluid pressure and deformation in subsalt strata (Dusseault et al., 2004). This relationship evolves as deformation accumulates and the mechanical and hydrological properties of subsalt strata are progressively altered. Because even the best seismic data have difficulty resolving deformation beneath allochthonous salt sheets, researchers commonly turn to kinematical or numerical models of salt emplacement to predict the distribution and intensity of subsalt deformation. These models have not been rigorously tested against field and well data.

Nikolinakou et al. (2019) examined the evolution of a salt sheet and its adjacent minibasin and synkinematic sediments and predict a 1-2 km thick, ductile shear zone below salt (Figure 1a). Although "disturbed zones" up to a few hundred meters thick have been recognized beneath salt and are often attributed to halokinetic ductile shear, the origin and detailed characteristics of these zones are largely known from well logs (Saleh et al., 2013); physical studies of subsalt strata are rare. This study aims to fill that data gap by conducting detailed analyses of subsalt strata beneath two allochthonous salt sheets in the Flinders Ranges of South Australia. Additional studies of subsalt strata are presented elsewhere in this session by Lueck and Fischer (presentation EGU2020-21155).

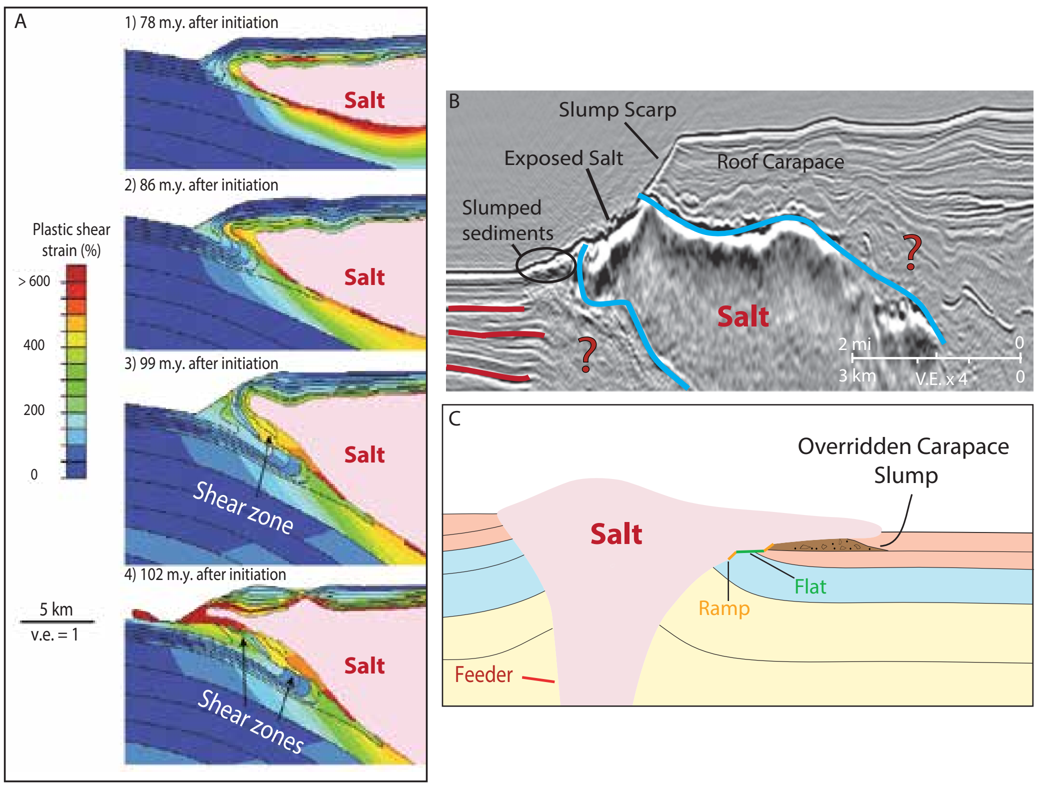


Figure 1. A) Geomechanical model by Nikolinakou et al. (2019) illustrating the evolution of plastic shear strain in roof sediments that are overturned in front of an advancing salt sheet. B) Seismic image modified from Hudec and Jackson (2006) illustrating roof carapace slumping. Note the poor resolution near the salt body. C) Schematic cross sectional diagram illustrating an allochthonous salt sheet overriding suprasalt carapace slumps.

Sheet-like allochthonous salt structures present in the Flinders Ranges have structural and stratal geometries analogous to those in the Gulf of Mexico (Rowan et al., 2019). Although these structures initiated in the Neoproterozoic, later regional-scale tilting and folding during the Delamerian Orogeny created an oblique, cross-sectional map view that allows for the detailed characterization of near-salt deformation at a scale of meters to hundreds of meters. Previous high-resolution mapping and mesoscopic structural analysis by Williams et al. (2018) established the pattern of deformation near a tertiary weld in the Willouran Ranges and provided a framework model in which to interpret the origin and timing of deformation near allochthonous salt. This study aims to apply, test and refine that framework using a methodology similar to that employed by Alsop et al. (2000) for diapirs in Nova Scotia.

In this study, we analyze deformation patterns present in the subsalt flats of two exposed allochthonous salt sheets (Figure 2). The thickness of the overlying salt sheet is >1 km at the Arkaroola field area and <1 km at the Arkaba field area. We use a combination of field mapping and 2-3 cm/pixel resolution drone imagery to conduct mesoscopic structural analysis that characterizes the deformation pattern in the strata adjacent to salt along transects at each field site.

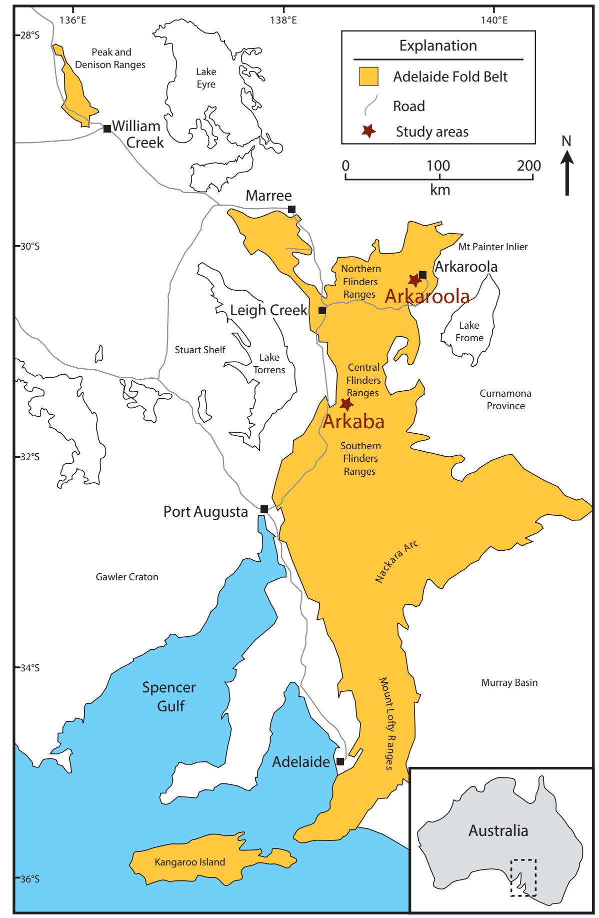


Figure 2. Generalized location map of the Adelaide Fold Belt modified from Hearon et al. (2015). Inset map shows the approximate location within Australia. Yellow shaded area represents the Adalaide Fold belt; red stars indicate the location of the two field areas. Arkaba is in the Central Flinders Ranges and Arkaroola is in the Northern Flinders Ranges.

Arkaba Field Area Map

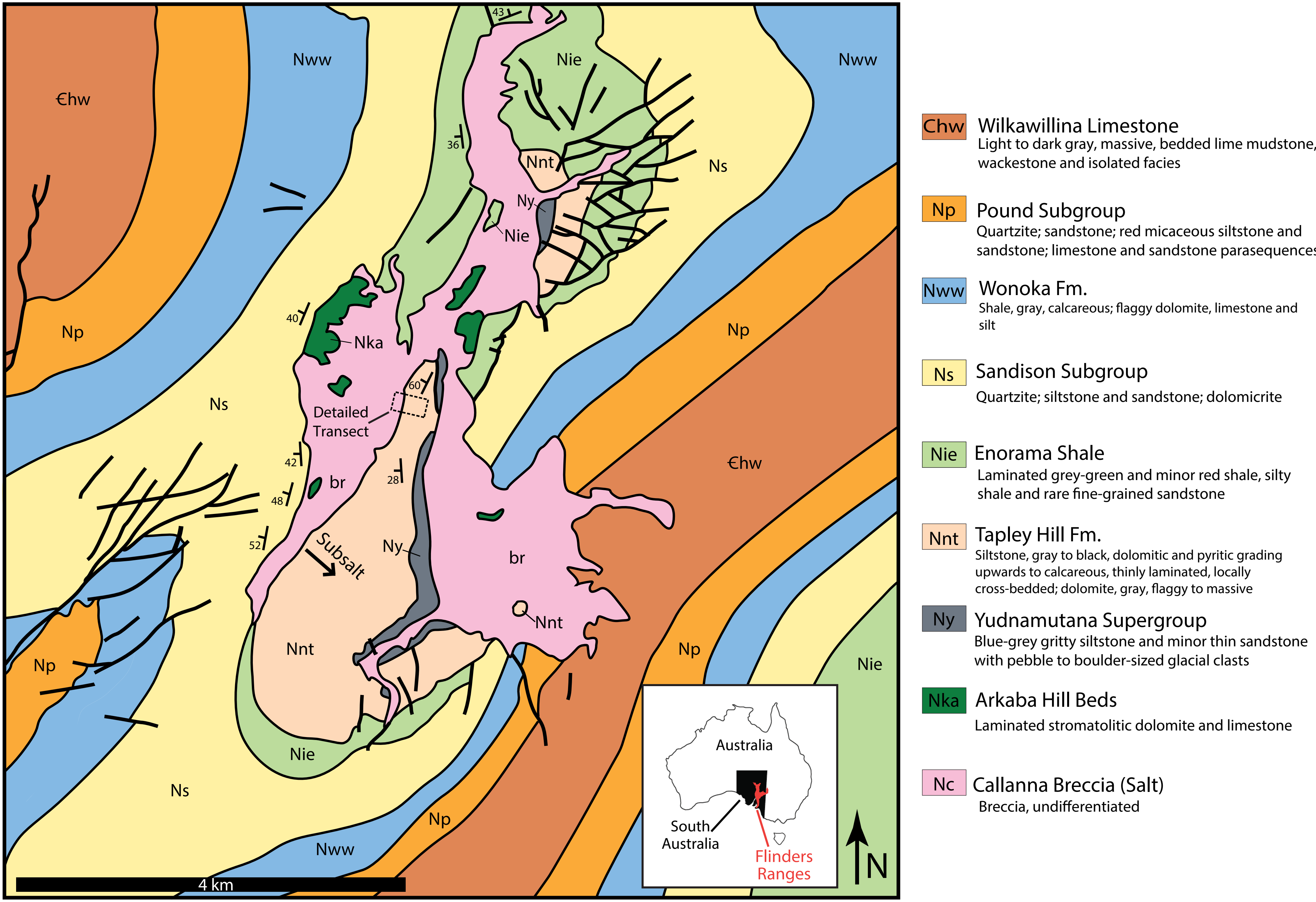
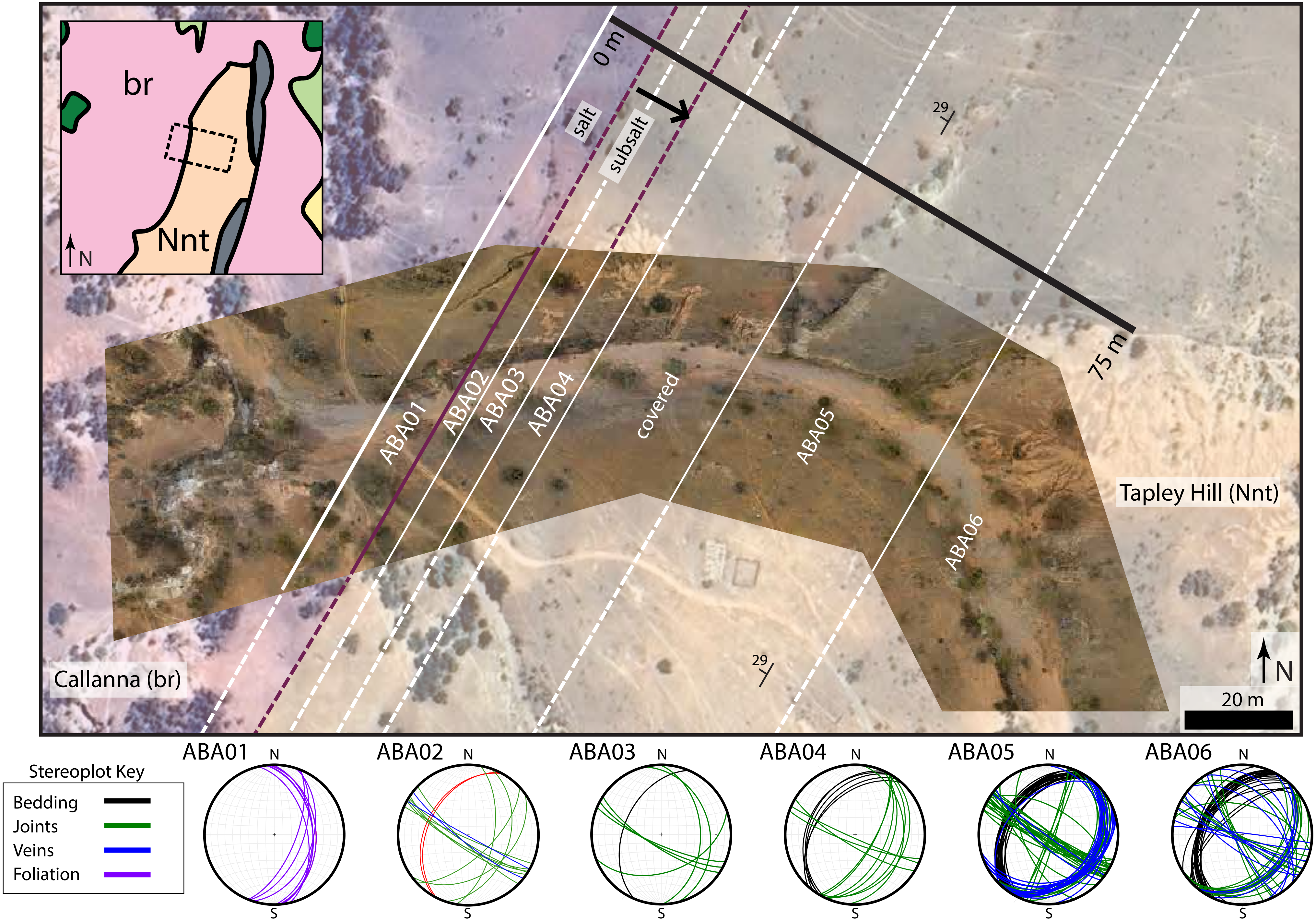


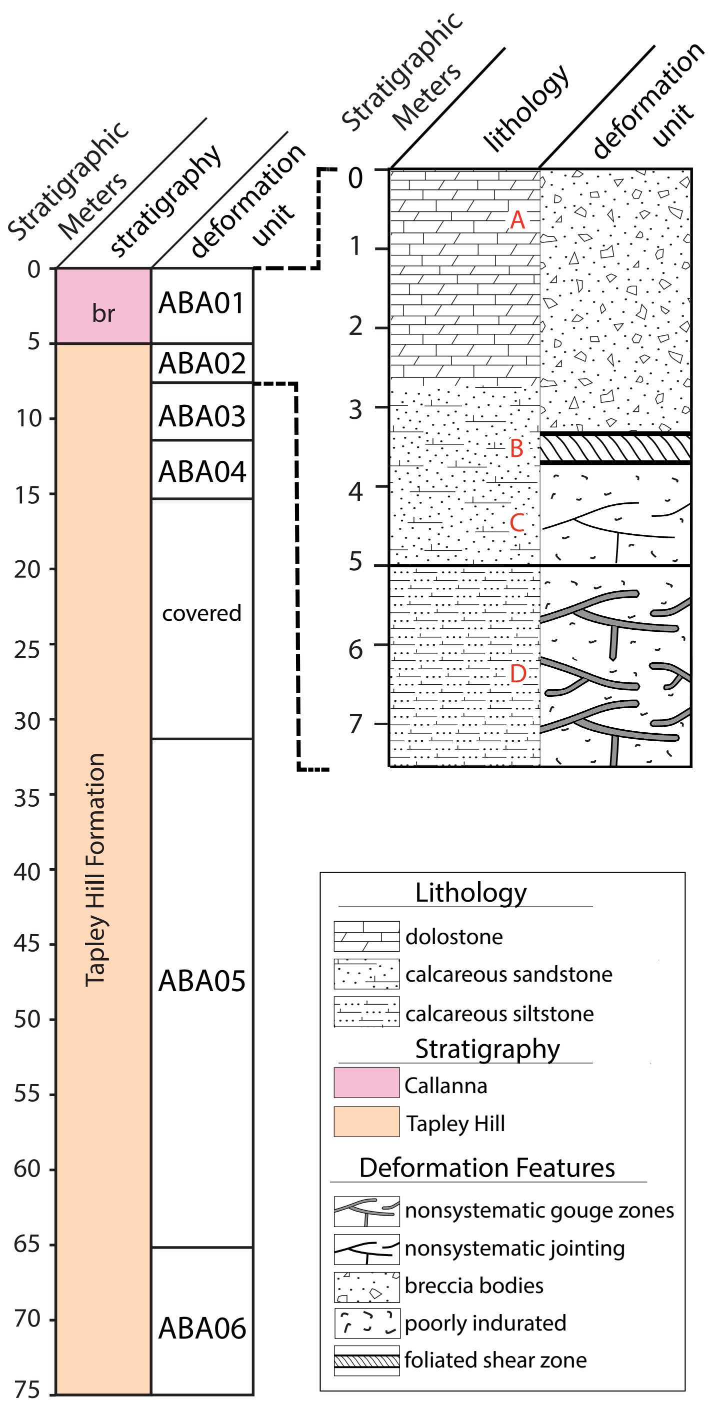
Figure 3. Regional geologic map and stratigraphic column of the Arkaba field area based on the Hawker and Wilpena Quadrangles. The black outline represents the detailed field area in Figure 3.

Arkaba Transect

Figure 4: Aerial photo of the Arkaba transect showing the extent of high resolution drone imagery. The transect line (heavy black) is oriented perpendicular to bedding. The transect starts in the Callanna and spans 75 stratigraphic meters into the subsalt flat across the Tapley Hill Formation. Local salt thickness above subsalt strata is >1 km.



Near Salt Deformation at Arkaba



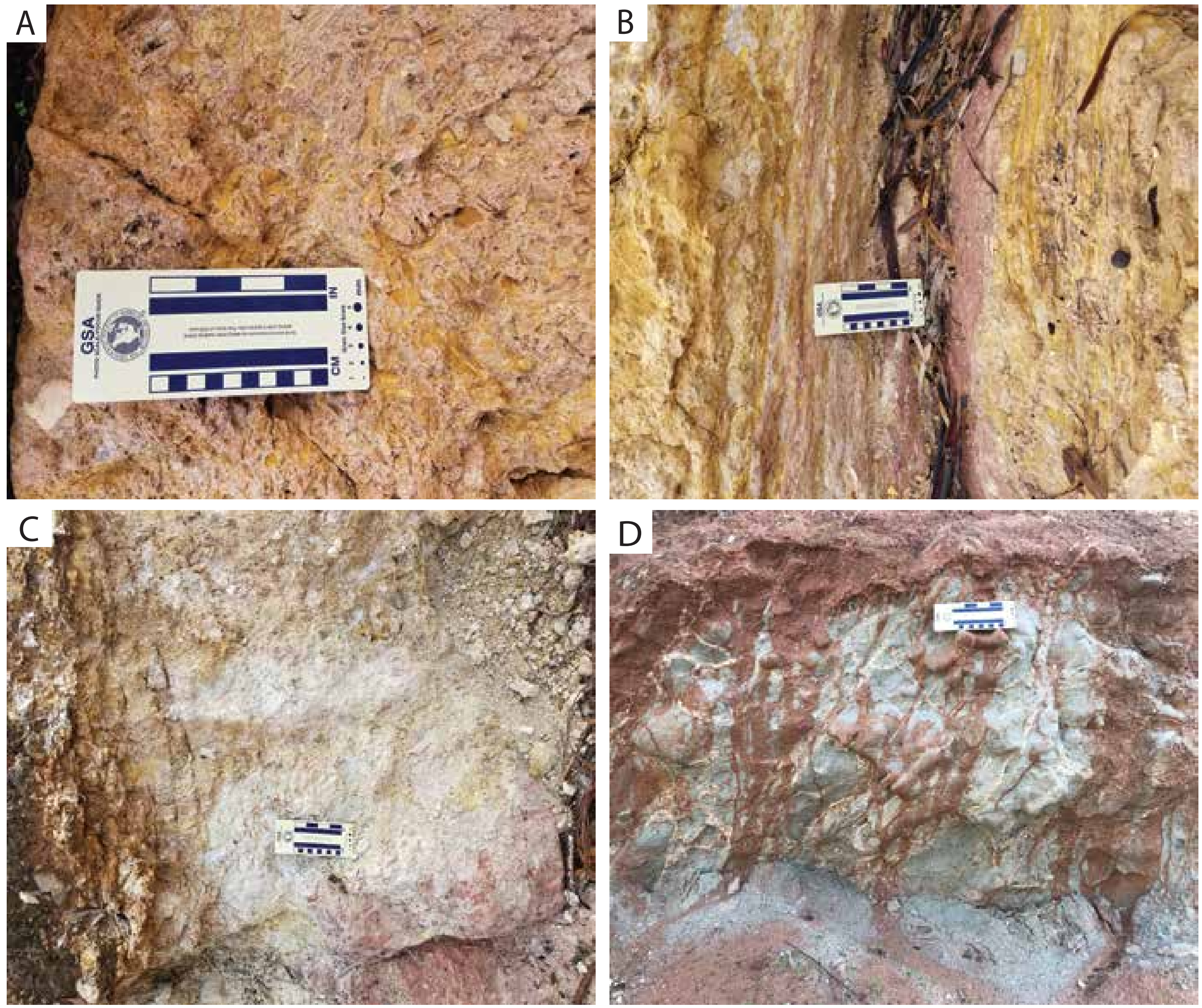


Figure 5. Lithostratigraphic and deformation details of stations ABA01 and ABA02 along the Arkaba transect. Station ABA01 is in the Callanna and station ABA02 is in the Tapley Hill Formation. A) Texture of Callanna dolomite breccia in ABA01. B) Strongly foliated zone in the Callanna. C) Poorly indurated calcareous sandstone at the base of ABA01. D) Thin, nonsystematic gouge zones characteristic of ABA02. Corresponding letters in column show position of photos.

Near Salt Deformation at Arkaba

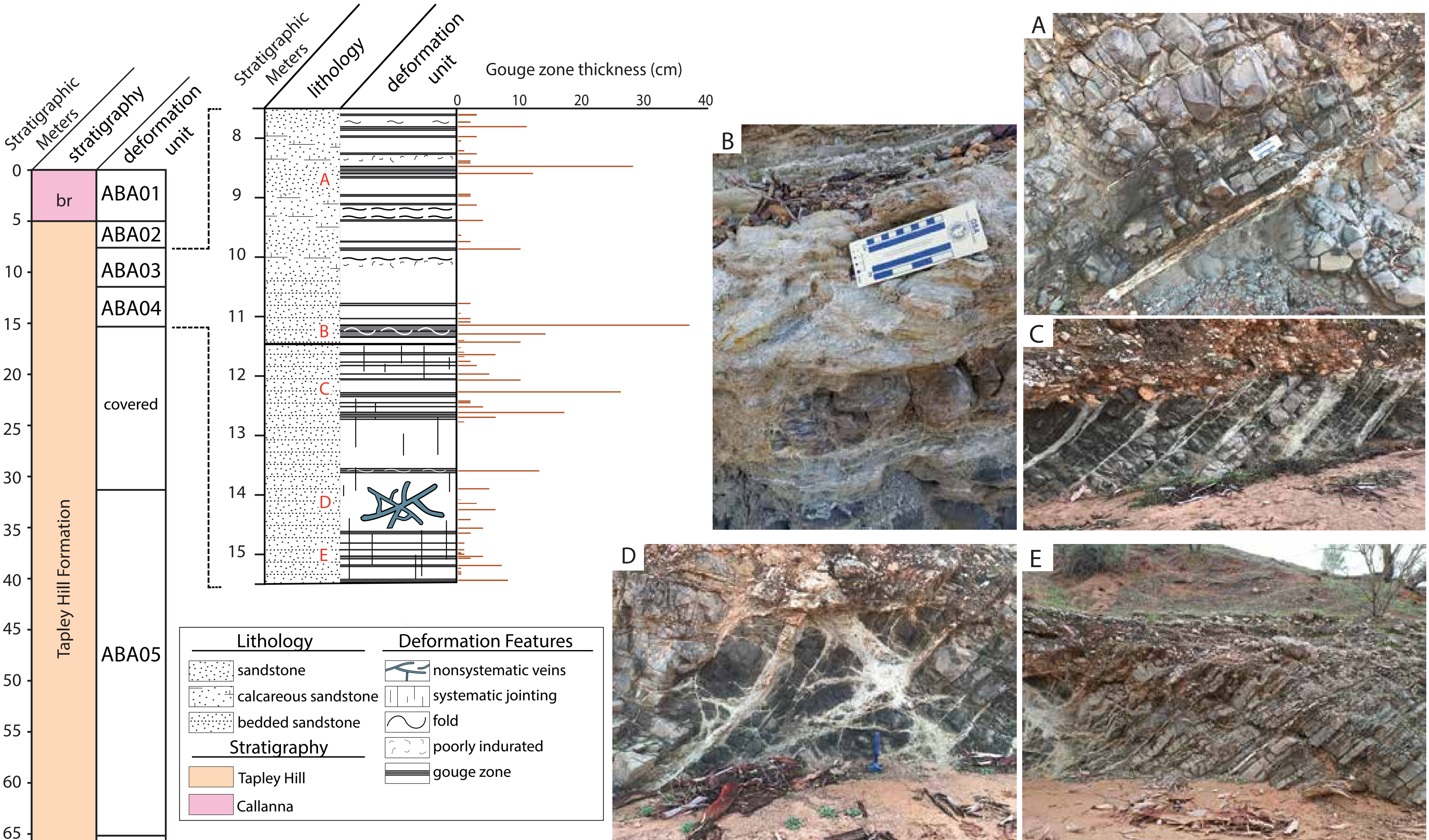


Figure 6. Lithostratigraphic and deformation details of stations ABA03 and ABA04 along the Arkaba transect. A) Along strike view of gouge zones in ABA03. B) Small folds within poorly indurated layer with calcareous mineralization. C) Along strike view of gouge zones in ABA04. D) Nonsystematic gouge zones near the base of ABA04. E) Fracture network at the base of ABA04. Corresponding letters in column show position of photos.

Near Salt Deformation at Arkaba

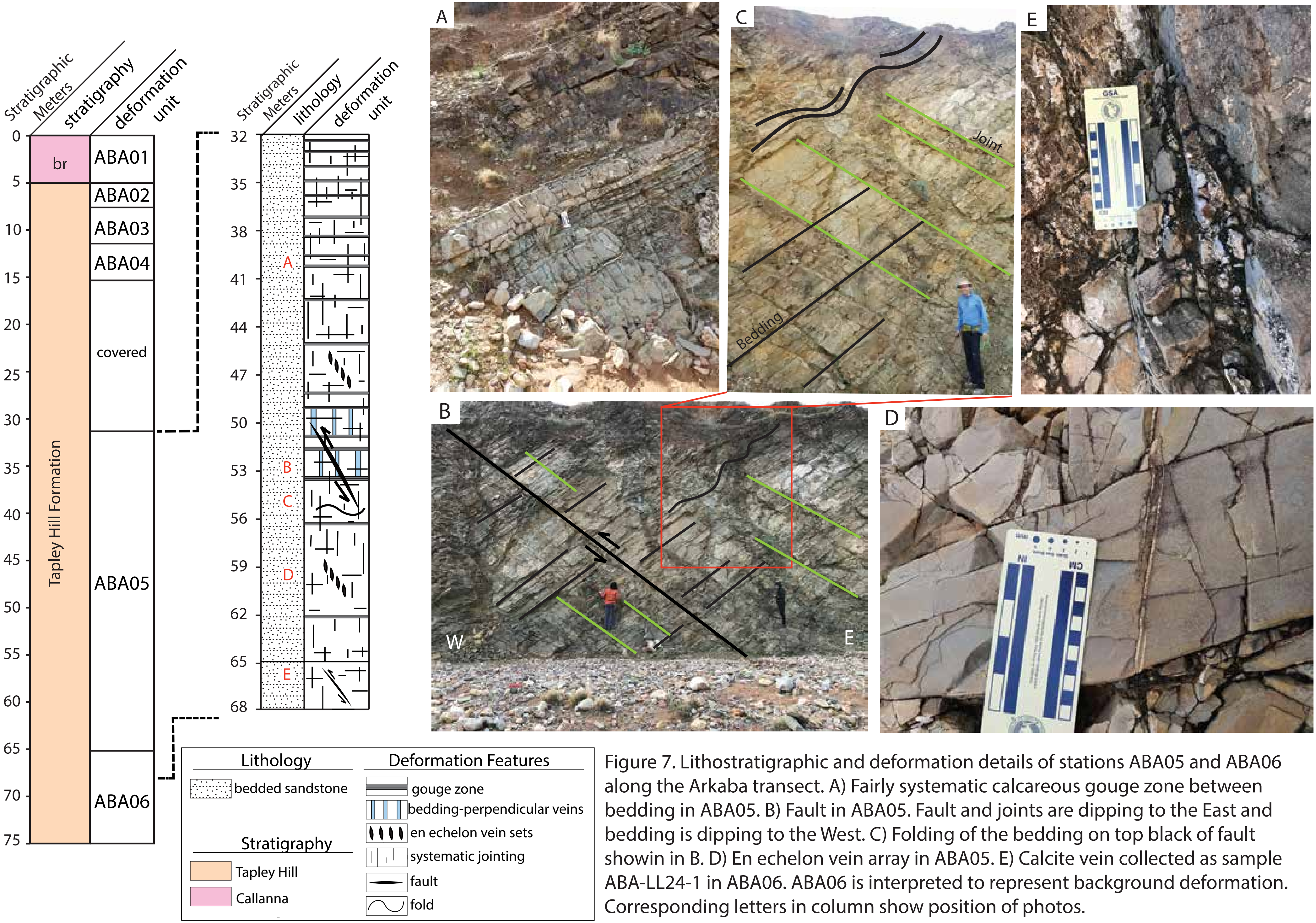


Figure 7. Lithostratigraphic and deformation details of stations ABA05 and ABA06 along the Arkaba transect. A) Fairly systematic calcareous gouge zone between bedding in ABA05. B) Fault in ABA05. Fault and joints are dipping to the East and bedding is dipping to the West. C) Folding of the bedding on top black of fault showin in B. D) En echelon vein array in ABA05. E) Calcite vein collected as sample ABA-LL24-1 in ABA06. ABA06 is interpreted to represent background deformation. Corresponding letters in column show position of photos.

Arkaroola Field Area Map

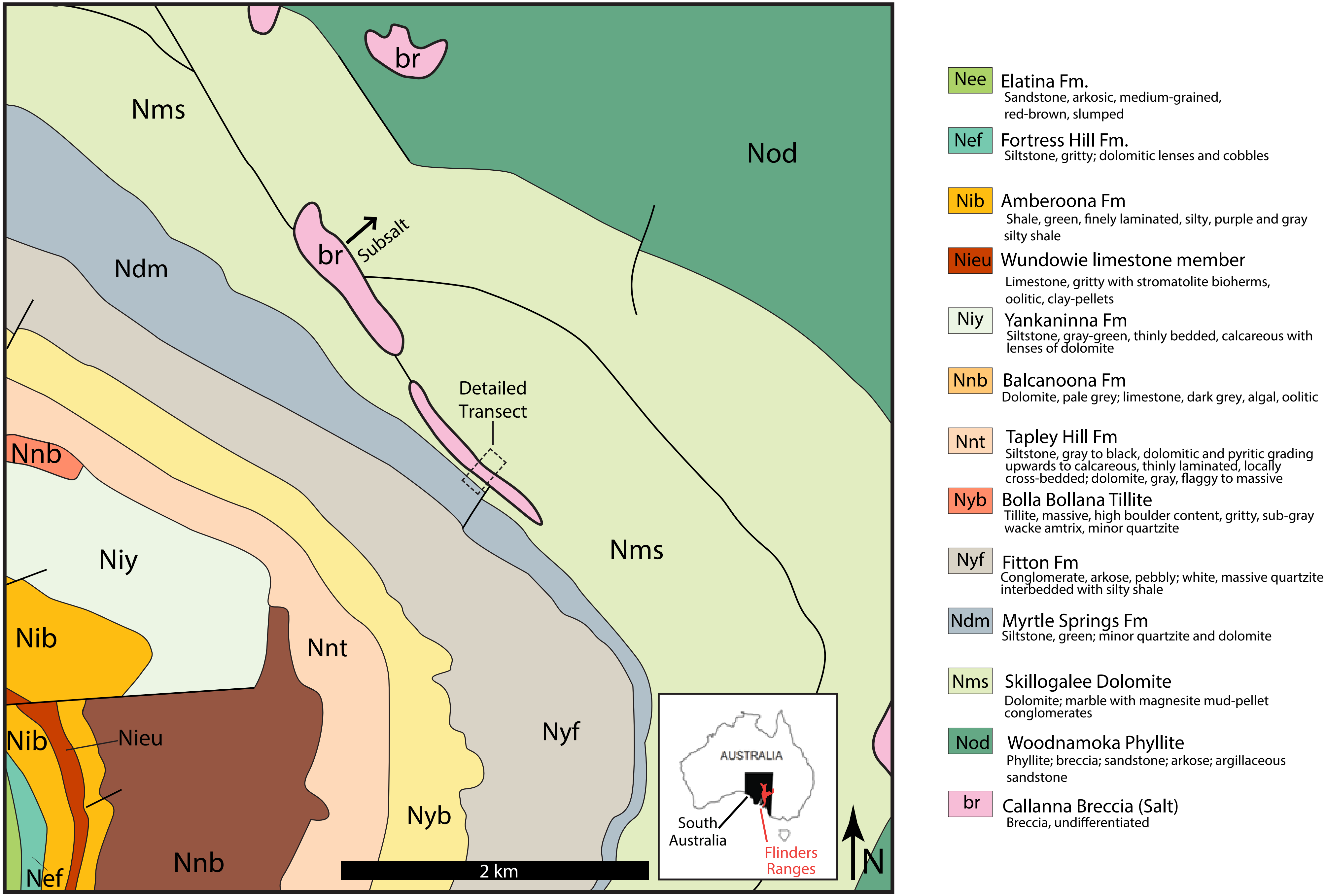
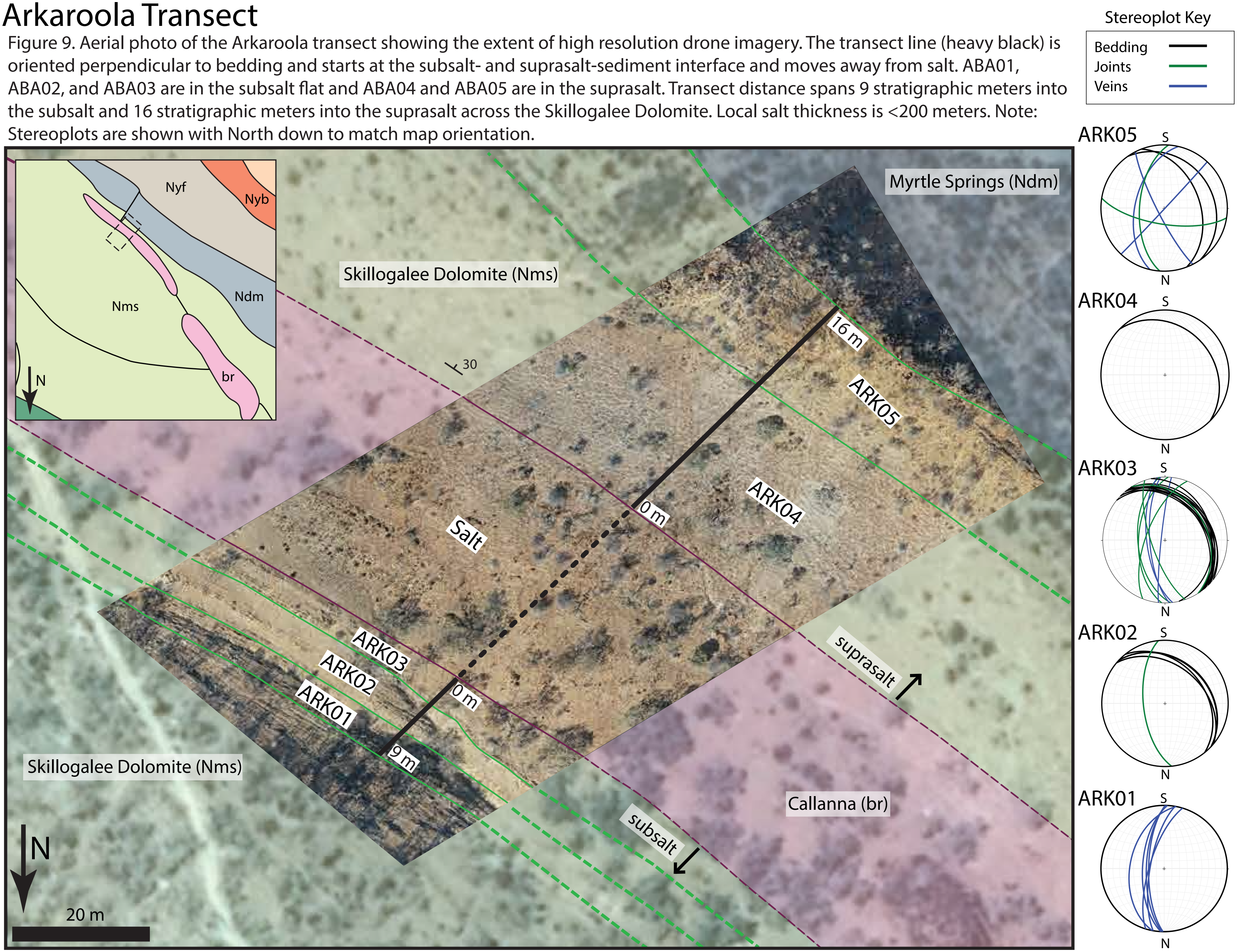


Figure 8. Regional geologic map and stratigraphic column of the Arkaba field area based on the Umberatana Quadrangle. The black outline represents the detailed field area in Figure 9.

Arkaroola Transect

Figure 9. Aerial photo of the Arkaroola transect showing the extent of high resolution drone imagery. The transect line (heavy black) is oriented perpendicular to bedding and starts at the subsalt- and suprasalt-sediment interface and moves away from salt. ABA01, ABA02, and ABA03 are in the subsalt flat and ABA04 and ABA05 are in the suprasalt. Transect distance spans 9 stratigraphic meters into the subsalt and 16 stratigraphic meters into the suprasalt across the Skillogalee Dolomite. Local salt thickness is <200 meters. Note: Stereoplots are shown with North down to match map orientation.



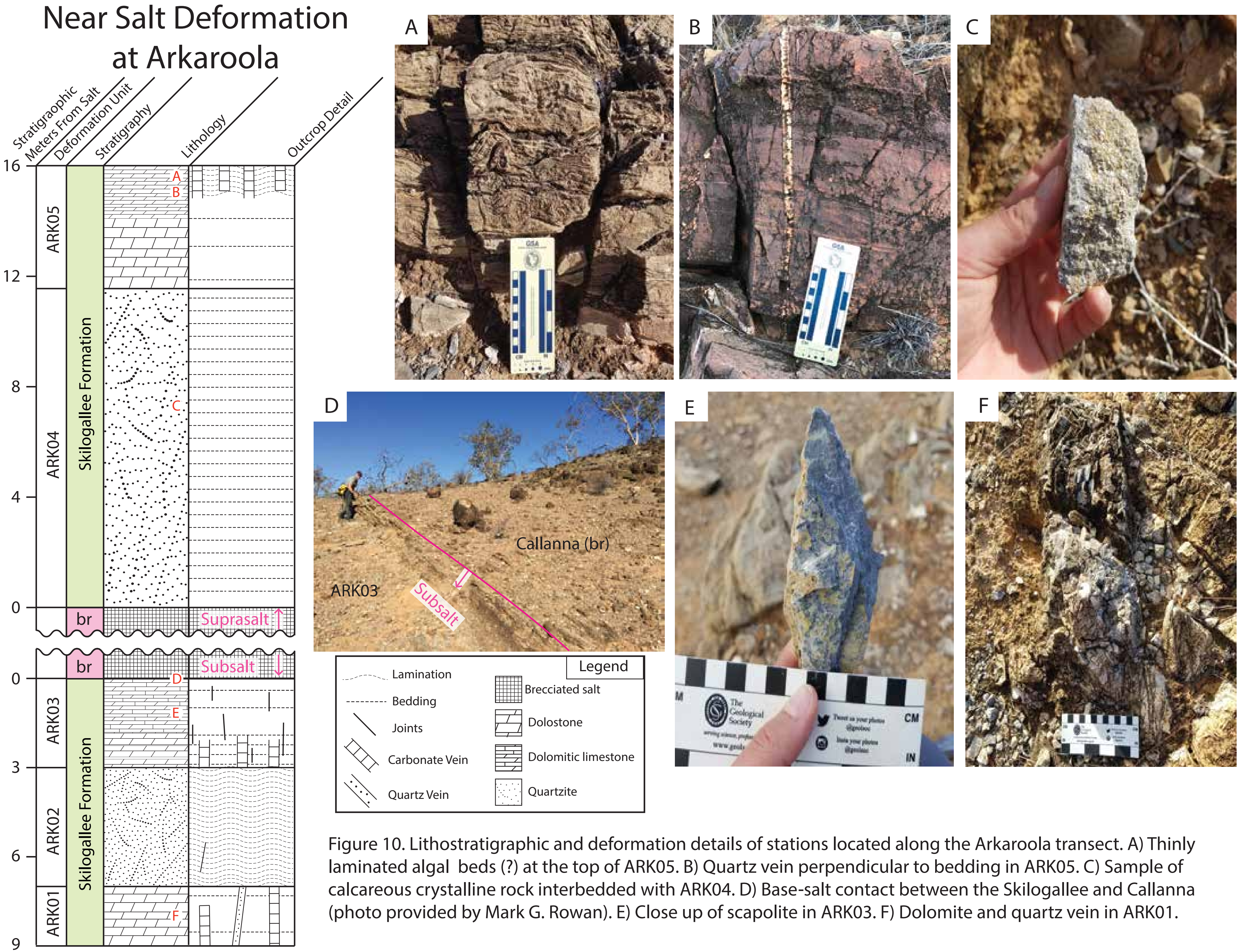


Figure 10. Lithostratigraphic and deformation details of stations located along the Arkaroola transect. A) Thinly laminated algal beds (?) at the top of ARK05. B) Quartz vein perpendicular to bedding in ARK05. C) Sample of calcareous crystalline rock interbedded with ARK04. D) Base-salt contact between the Skilogallee and Callanna (photo provided by Mark G. Rowan). E) Close up of scapolite in ARK03. F) Dolomite and quartz vein in ARK01.

Conclusions

Deformation beneath the subsalt flats appears to correlate to the thickness of the overlying salt sheet.

•Where the preserved salt sheet thickness is < 200 m there is little to no mesoscopic deformation.

•Where the salt sheet is > 1 km thick, strata are brecciated near the salt-sediment interface, brittle fractures are abundant, and layer-parallel shear zones and mineralized fractures decrease in abundance downward in the stratigraphic section.

Our results suggest that existing numerical models overestimate the amount and stratigraphic extent of deformation beneath allochthonous salt sheets. Continued field study of near salt deformation will help to constrain future models and provide criteria to distinguish halokinetic and soft sediment deformation.

Prompts for Discussion

What are the most important controlling variables that influence near-salt deformation?

What are the most important field observations that we can use to discriminate between salt tectonic and other types of deformation (e.g., carapace slumping, synsedimentary folding, etc.)?

What does the term “rubble zone” mean to you?

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