PS Geometries, Structures and Petrography of Tumey Injection Complex, California (USA)*

Gustavo Zvirtes¹, Andrew Hurst², Ruy Philipp³, Giuseppe Palladino², and Antonio Grippa²

Search and Discovery Article #51473 (2018)**
Posted April 9, 2018

*Adapted from poster presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, April 2-5, 2017

Abstract

The understanding of stratigraphic, structural, and petrographic features characterizing outcropping sandstone intrusions is fundamental for the study of sand injection complexes. Their mutual relationships may strongly help in the discovery and development of oil-bearing sandstone intrusions reservoirs. The Tumey Injection Complex (TIC) is a large sand injection complex intruding 350 meters of deep marine deposits of the Kreyenhagen Formation (Eocene) in Central California and extending laterally for over four kilometres. From the base to the top this formation consists of thin-bedded brown mudstones and shales alternating with two main levels of lithic sandstones. The sequence passes upward to biosiliceous mudstones which are erosively overlain by other level of sandstone with shales on the top. A detailed geological mapping supported by stratigraphic, structural, and petrographic analysis allowed understanding the relationships between the depositional units and injections along different measured logs. The TIC is made by (1) host hydrofractured mudstones and shales, (2) depositional, locally remobilized, lithic sandstones (parent units), (3) an interconnected network of sills and dykes, and (4) injection breccias developed in the base of the biosiliceous mudstones. The parent units consist of amalgamated channelized lithic sandstones bodies containing preserved sedimentary structures and mudstone clasts. These sandstones have been modified by liquefaction and fluidization processes promoted by overpressured fluids feeding the uppermost intrusions net. The sills are structurally controlled by bedding whereas the dykes by a NW-SE oriented fracture system probably driven by NE-SW stresses. The injection network shows a range of geometries like multi-layered sills, stepped dykes and saucer shape intrusions. The depositional and injected sandstones have the same composition (lithic) and a provenance signature of recycled orogeny. They differ from the sandstones of the underlying formations which show a different mineral assemblage and a provenance from a dissected magmatic arc. This data attests that the parent units of the TIC are the sandstones of the Kreyenhagen Formation. The TIC is a sand injection complex intruded in host mudstones producing a range of structures and features and it can be used as an analogous for subsurface intrusive traps containing oil and gas.

^{**}Datapages © 2018 Serial rights given by author. For all other rights contact author directly.

¹Geology and Petroleum Geology, University of Aberdeen, Aberdeen, Aberdeen Shire, United Kingdom (g.zvirtes@abdn.ac.uk)

²Geology and Petroleum Geology, University of Aberdeen, Aberdeen, Aberdeen Shire, United Kingdom

³Mineralogia e Petrologia, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

References Cited

Cartwright, J., D. James, M. Huuse, W. Vetel, and A. Hurst, 2008, The Geometry and Emplacement of Conical Sandstone Intrusions: Journal of Structural Geology, v. 30, p. 854-867.

Dickinson, W.R. 1985. Interpreting Provenance Relations from Detrital Modes of Sandstones, *in* G.G. Zuffa (ed.), Provenance of Arenites, NATO ASI Series, C: Mathematical and Physical Sciences. D. Reidel Publishing Company, Dordrecht-Boston, v. 148, p. 333-361.

Folk, R.L., 1974, Petrology of Sedimentary Rocks: Hemphill, Austin, Texas, 159 p.

Hurst, A., A. Scott, and M. Vigorito, 2011, Physical Characteristics of Sand Injectites: Earth-Science Reviews, v. 106/3, p. 215-246.

Hurst, A., J.A. Cartwright, M. Huuse, R. Jonk, D. Schwab, D. Duranti, and B. Cronin, 2003, Significance of Large-Scale Sand Injectites as Long Term Fluid Conduits: Evidence from Seismic Data: Geofluids, v. 3, p. 263-274.

Hurst, A., and J.A. Cartwright (eds.), 2007, Implications for Hydrocarbon Exploration and Production: American Association of Petroleum Geologists Memoir 87, 274 p.

Huuse, M.J., J.A. Cartwright, A. Hurst, and N. Steinsland, 2007, Seismic Characterization of Large-Scale Sandstone Intrusions, *in* A. Hurst and J. Cartwright (eds.), Sand Injectites: Implications for Hydrocarbon Exploration and Production: American Association of Petroleum Geologists Memoir 87, p. 21-35.

Jonk, R., J. Parnell, and A. Hurst, 2005, Aqueous and Petroleum Fluid Flow Associated with Sand Injectites: Basin Research, v. 17, p. 241-257.

Vigorito, M., and A. Hurst, 2010, Regional Sand Injectite Architecture as a Record of Pore Pressure Evolution and Sand Redistribution in the Shallow Crust: Insights from the Panoche Giant Injection Complex, California: Journal of the Geological Society, London, v. 167, p. 889-904.











Geometries, Structures and Petrography of Tumey Injection Complex, California (USA)

Gustavo Zvirtes¹, Andrew Hurst¹, Ruy Philipp², Giuseppe Palladino¹, Antonio Grippa¹

1. Geology and Petroleum Geology, University of Aberdeen, Aberdeen, United Kingdom.

2. Mineralogy and Petrology, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil.







Recent sediments

Tumey sandstone Lentil

White biosiliceous shale and diatomites

Domengine Formation (Eocene)

Lodo Formation (Paleocene)

Moreno formation

Grey medium lithic sandstone (turbidites) TGIC

Tumey Shale

LEGEND

STRUCTURES

Thrust and

Normal Faults

Injection breccias

(sills and dykes)

Sandstone Intrusion net

Back Thrusts

Introduction

Giant sand Injection complexes besides being special and intriguing geological phenomena play a very important role in the evolution of sedimentary basins and as hydrocarbon-bearing sandstone intrusion reservoirs (Jonk, et al. 2005; Hurst and Cartwright, 2007). They are typified by evidence of sand fluidization and injection in the shallow crust and are recognized extensively in outcrops (Vigorito and Hurst, 2010) and in the subsurface (Hurst et. al., 2003; Huuse, et. al., 2007).

The Tumey Giant Injection Complex (TGIC) is a large sand injection complex intruding at least 350-400 meters of Eocene deep marine deposits of Kreyenhagen Formation (**KF**) in the west portion of San Joaquin Basin in Central California, extending laterally for tens of kilometers. In order to better characterize this complex a key area localized in Tumey Hill has been analyzed where the TGIC has a lateral extension of over two kilometers (Fig. 1).

Method

tone (parent units), sandstone intrusions (sills, dykes and composite intrusions) and hydraulically-fractured host mudstone. Their mutual relationships studies at outcrop strongly support exploration and development of hydrocarbon-bearing sandstone intrusion reservoir in subsurface

Geological Setting

The Tumey Giant Injection Complex (TGIC) is a large interconected sand injection net of fine- to medium lithic sandstones intruding a mudstone int val of the deep marine Kreyenhagen Formation (Eocene) in fore arc basin system with excellent expousures at Tumey Hills area (Figs. 1 and 2)

The KF consists from the base to the top of thin-bedded brown mudstone with a lower channelized depositional lithic sandstone level. The sequence grades upward into pale biosiliceous mudstone that alternates with a upper deposits of channelized lithic sandstones representing turbidites as amalgamated channelized fine- to medium grained lithic sandstone in which primary sedimentary structures are preserved and commonly have mudstone clast and conglomeratic basal lags. The upper parts of the these sandstones are typically structureless by extensively liquefaction and fluidization processes promoted by fluid overpressure(Figs. 2, 3 and 4).

This interval of KF is compleately intruded by fine-to medium sandstones with similar composition of the turbidites. The sequenceis unconformable overlaid by the Tumey Sandstone Lentil which cut the biosiliceous mudstones and the sandstone intrusions, constraining the sand injection complex event to the Eocene (Fig. 4a).

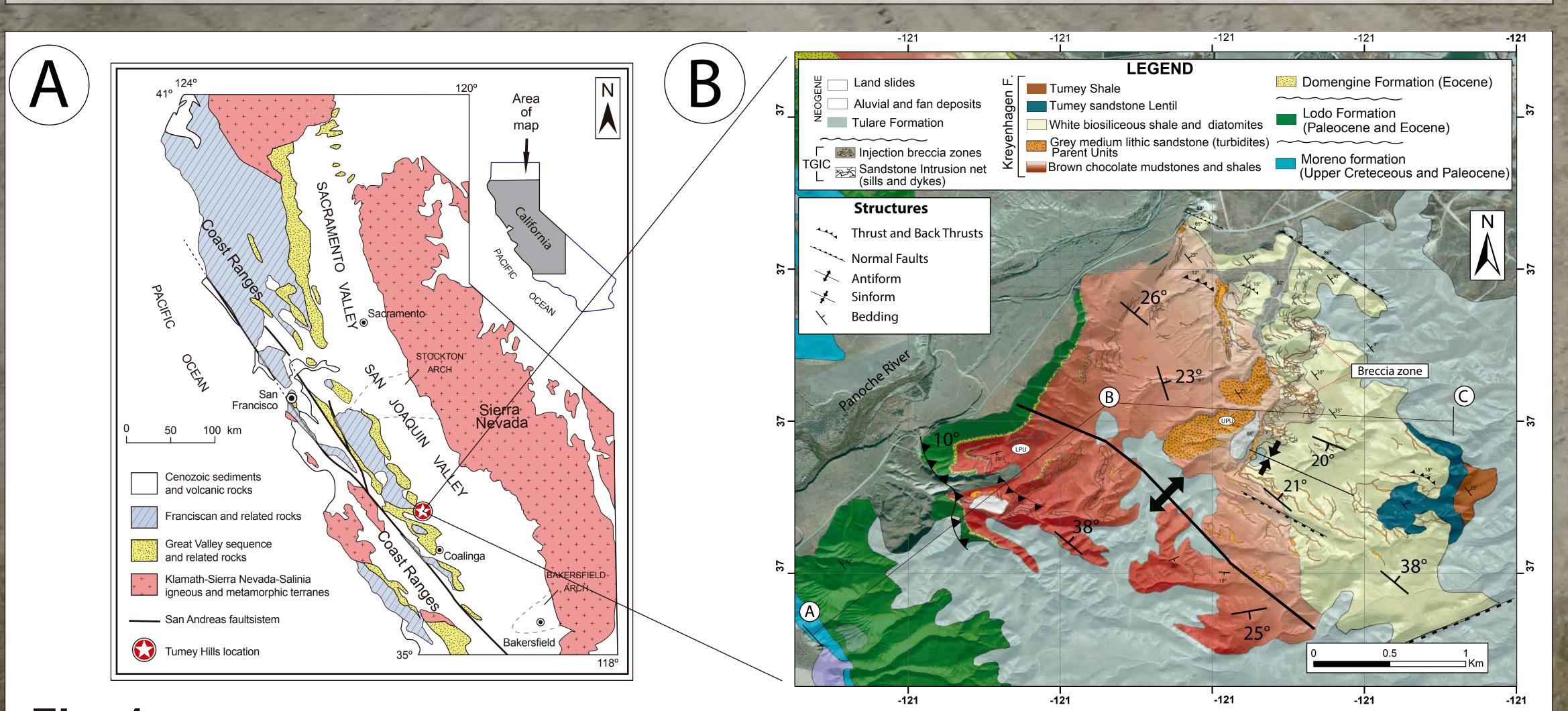


Fig. 1 - A) Geological map of Central California with the study area location. B) Geological map of Tumey Hills. IPU - Lower Parent Unit; UPU- Upper Parent Unit.

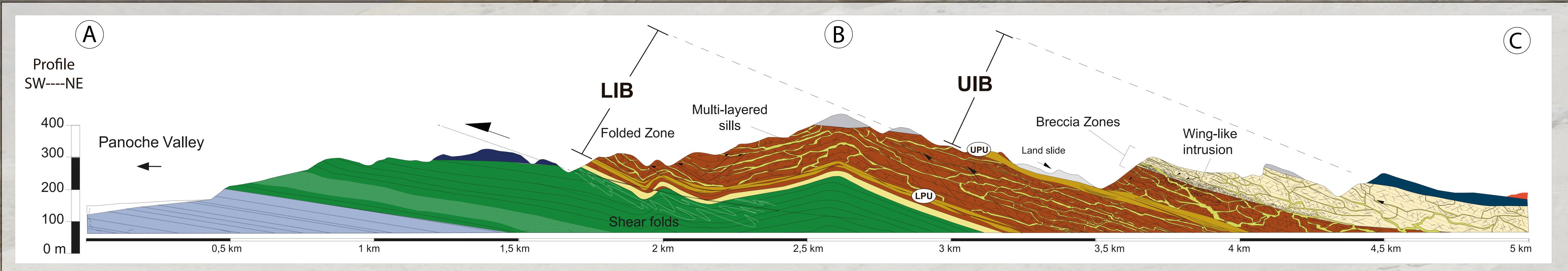


Fig. 2 - Geological section of Tumey Hills (location on Figure 2). LIB - Lower Intrusion Belt; UIB - Upper Intrusion Belt; LPU - Lower Parent Unit; UPU - Upper Parent Unit.

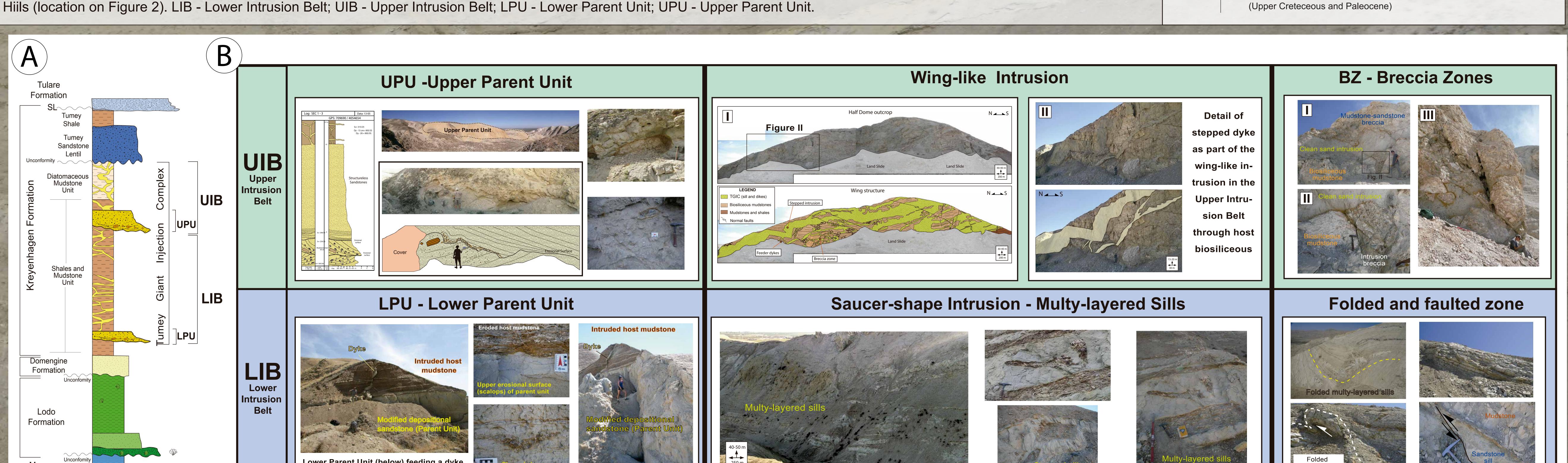


Fig. 3 - Architectural organization and features of TGIC. (A) Stratigraphic column of Tumey Hills area. (B) Main injectite units of TGIC with respective outcrops and field observations.

Architectural organization of TGIC

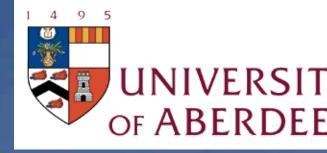
Through detailed mapping the TGIC is subdivide

- (1) Lower Intrusion Belt (LIB) and
- (2) Upper Intrusion Belt (UIB) (Figs. 2 and 3).

The LIB is made of (i) host hydraulically-fractured smectite mudstones and shales, (ii) depositional partially remobilized, lithic sandstones bodies with 5 to 12 m thick forming the Lower Parent Units (LPU), (iii) and interconnected network of sandstone intrusions, essentially as multy-layered sills connected by thin

The UIB is made of (i) Upper Parent Unit (UPU) comprised by highly modificated depositional channelized lithic sandstones (30-45 m thick), (ii) host hydraulic-fractured and brecciated biosiliceous mudstones, (iii) and interconnected network of sandstone development of stepped intrusions forming wing-like

the contact of biosiliceous and smectite mudstones





Conselho Nacional de Desenvo Científico e Tecnológico

Geometries, Structures and Petrography of Tumey Injection Complex, California (USA)

Gustavo Zvirtes, Andrew Hurst, Ruy Philipp, Giuseppe Palladino, Antonio Grippa

1. Geology and Petroleum Geology, University of Aberdeen, Aberdeen, United Kingdom.
2. Mineralogy and Petrology, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil.













Hurst Ruy P. Philipp Giuseppe Palladino Antonio Grippa

Petrographic analysis

The petrography of TGIC consisted analysis of all representative sandstones units that could be related to the sand injectition system (Fig. 4). The description and classification of sands from different strata allow the comparative analysis of composition, texture and provenance of each sandstone body from different units (Fig.5 and 6).



What is the composition, texture and provenance siganture of the sandstones bodies?

Which of these sandstones have similar characteristics?

Are the sandstone intrusions made of more than one composition?

Which are the parent units of the injection complex?

Method

To answer these questions geological mapping and sampling of the sedimentary and intrusive sandstone bodies throughout the area (Fig. 5 and 6) were proposed to describe and define the main petrofacies association of the sandstone intrusions and its potential parent units (Fig. 4).

Microscopic observations and estimation of the proportion of the principal grain types of the different sandstones bodies were made through the Gazzi-Dickinson method (counting of 300-500 points in each thin section) along with textural and diagenetic analysis (cement and porosity) (Figs. 6 and 7). The data aquired feed a dataset of a petrographic software (*Petroledge*) which produces a series of petrographic analisys as accurate ternary diagrams with siliciclastic classification of Folk (1974) and provenance of Dickinson (1985) (Fig. 8).

Results

The petrography of depositional and injected sandstones of KF reveals strong compositional and provenance similarities (Figs. 6, 7, 8). Both are lithic sandstone cemented by gypsum with very similar detritic composition (Figs. 6 and 7) being classified as litarenites (Fig. 8B) and with a provenance signature of a recycled orogen (Fig. 8D).

They strongly differ from the sandstones recognized in the underlying formations which have a completely distinct mineral assemblage with lithic arkose of Lodo Formation and feldspatic litarenite of Domengine sandstones (Figs. 7 and 8B). The provenance signatures of these formations is a dissected magmatic arc to transitional magmatic arc (Fig. 8D).

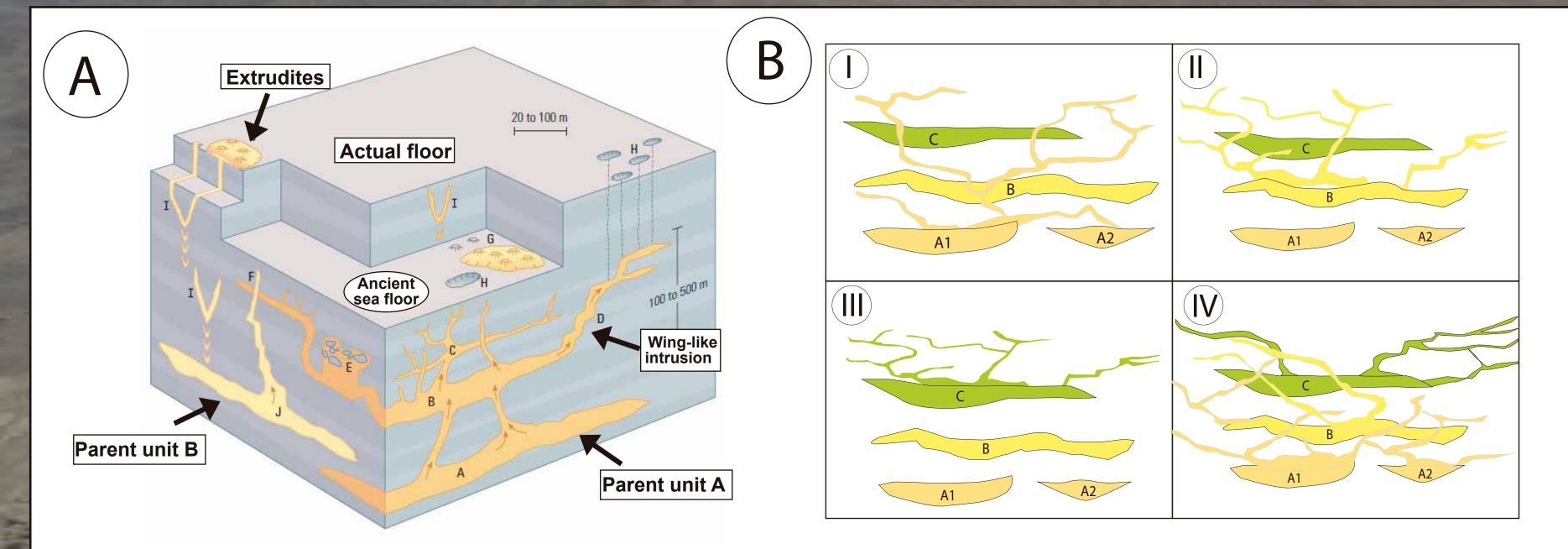


Figure 4-A) Block diagram of possible sand injection features and the relative relationship of two compositionaly different parent units. B) Hypothetical models with three different potential parent units in different cross cutting relationships.

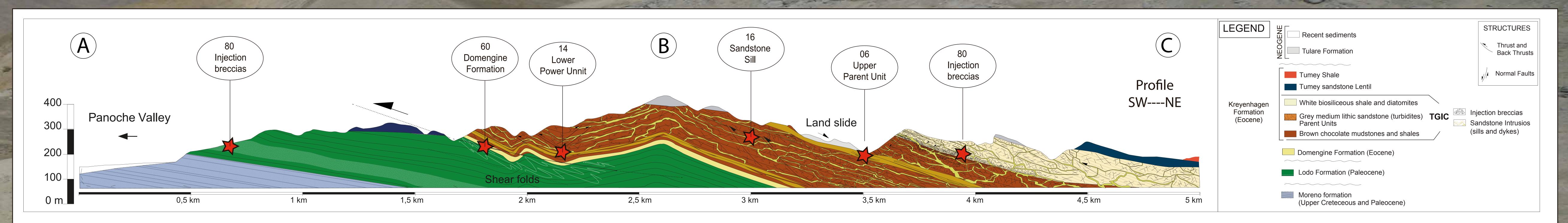


Fig. 5 - Geological cross section of Tumey Hills with the location of the main sandstone samples to thin section analysis showed in the figures 6 and 7.

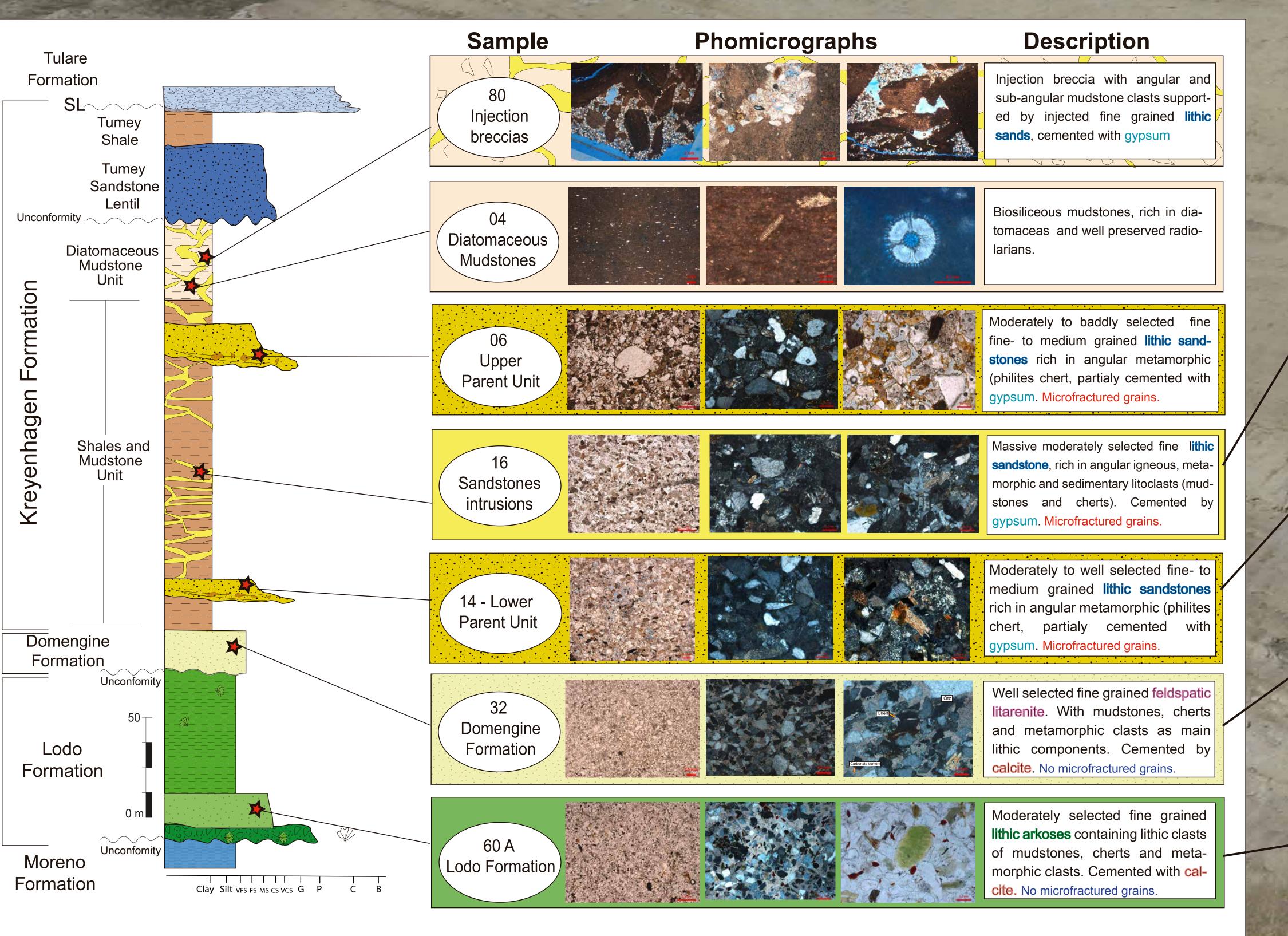


Fig. 6 - Stratigraphic column of Tumey Hills with the location of the samples to thin section analysis (left). On right, schematic table with the photomicrographs and description of the main units of Tumey Hills.

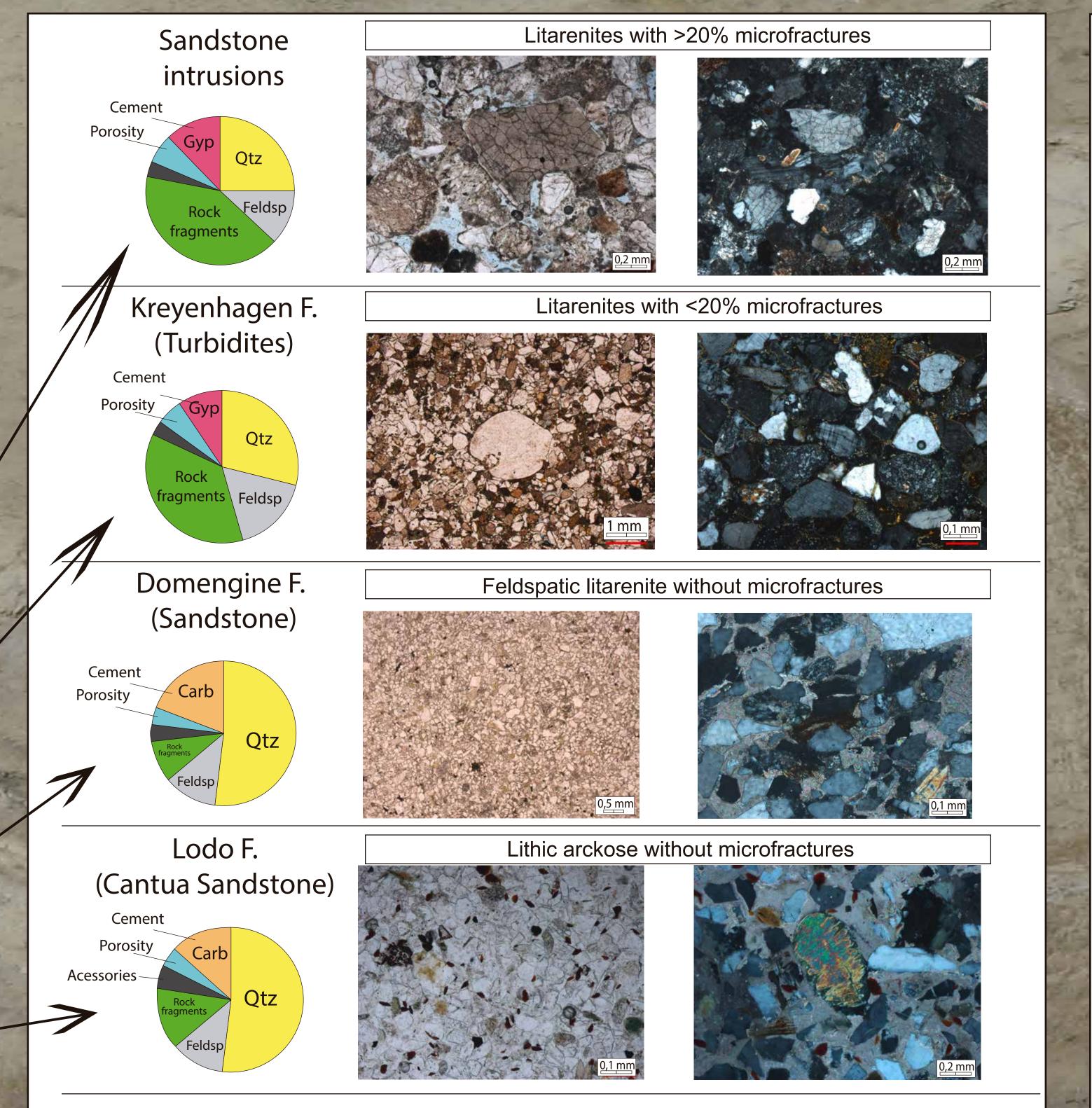


Fig. 7 - Detritic composition pie diagrams (left) of different sandstone units and repective photomicrographs (right).

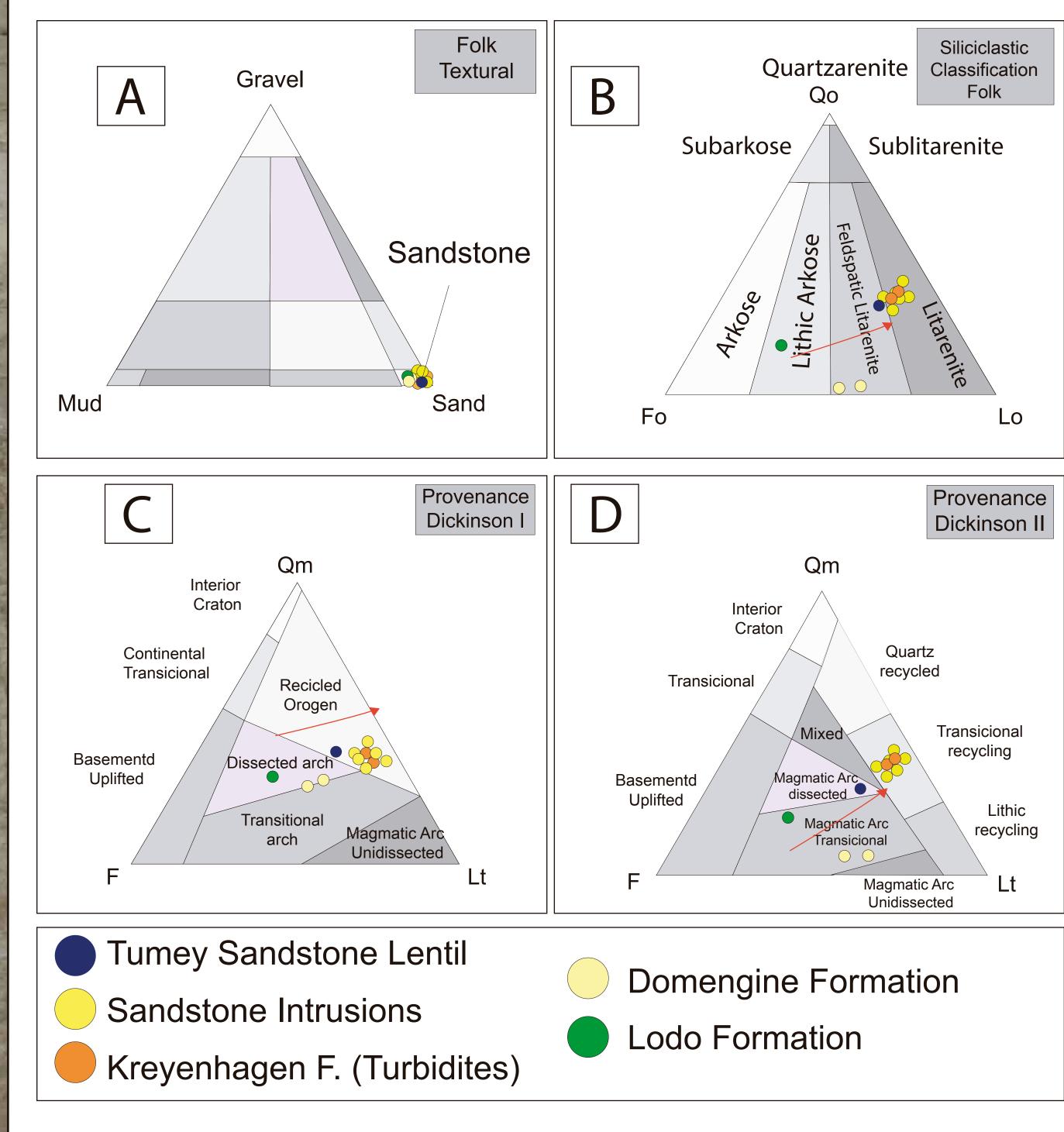
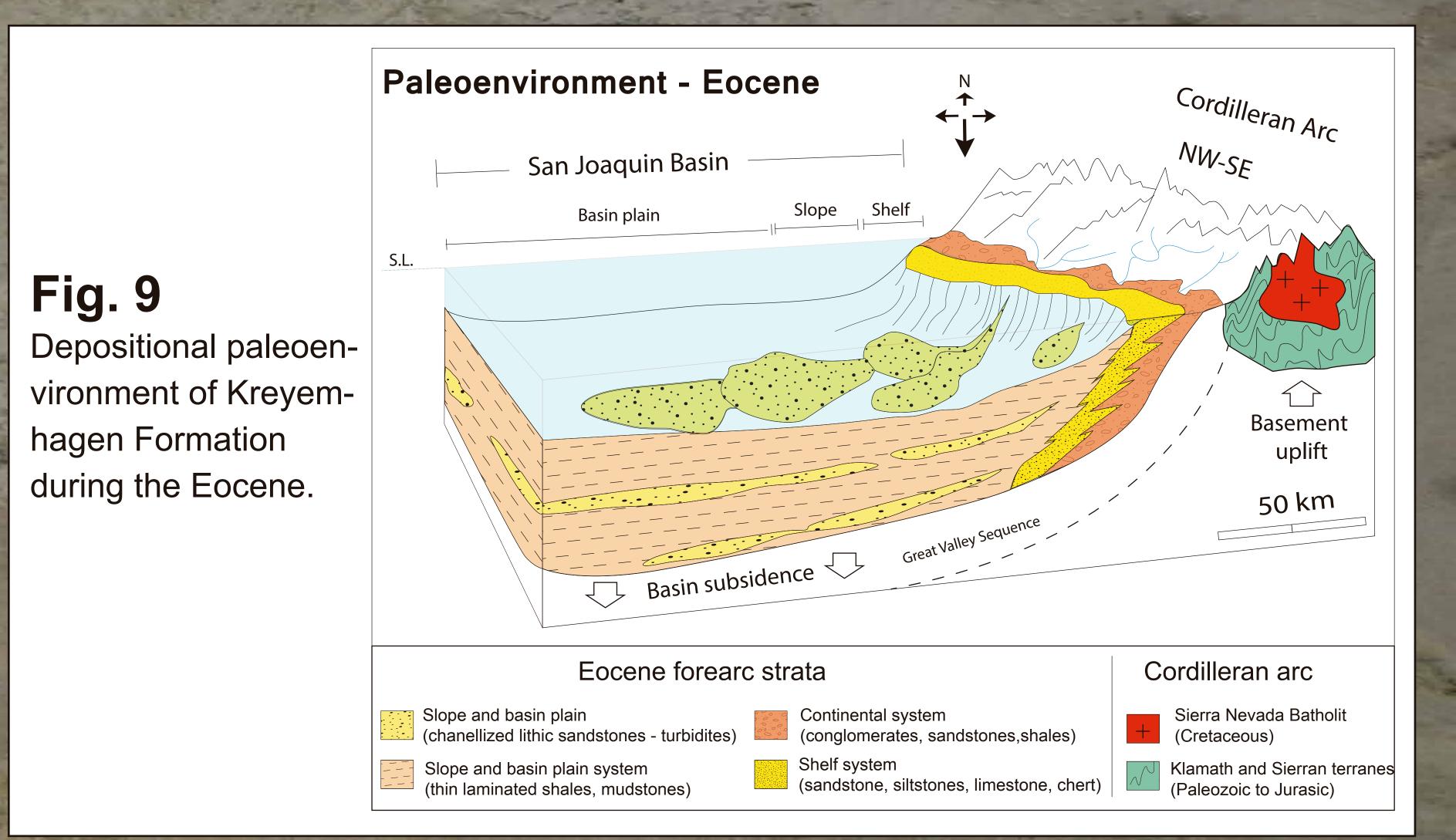


Fig. 8 - Compositional and textural diagrams of the sandstones of Tumey Hills. A) Textural Classification (Folk, 1974); B) Siliciclastic classification of Folk, 1974; C and D) Provenance ternary diagrams (Dickinson, 1985).

Conclusion remarks

Acording with the data aquired the main source area to the depositional sandstones was the Sierran Arc located to East during the Paleogene. A significative provenance signature changing ocurred from a **transitional arc** signature registered by Lodo and Domemgine formations during the Paleocene/Early Eocene, to a **recycled orogen** of the Kreyenhagen Formation in the Middle/Upper Eocene, suggesting the exumation of the Sierran arc during these epochs.

The detrital composition comparison and microtextures observation as the **presence of microfractures** in the sandstone intrusions and in the KF as well as the provenance signature confirm that the **parent units** of the TGIC are the tubiditic sandstones of the KF without contribution of sand of the underlying units.













Data Integration

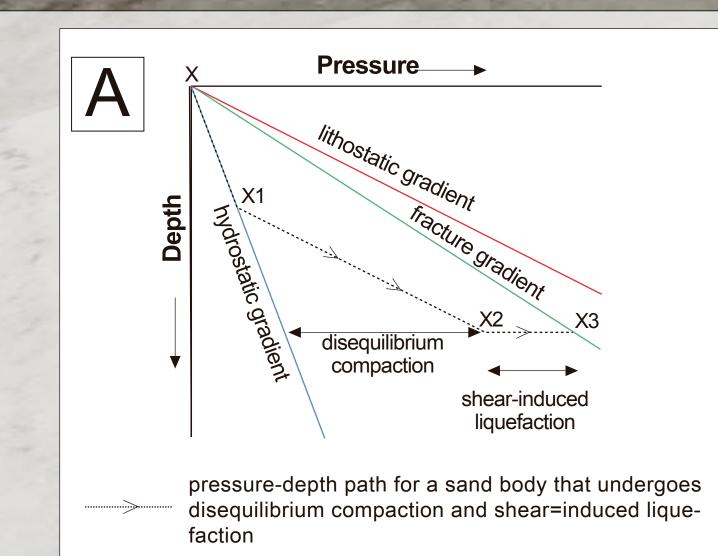
improvement of the understanding of how it was formed as well as the organization of the main architectural elements of the complex (Fig. 10). It also define the petrographic characterization of each element of the complex and its inter relationships.

The TGIC was formed by an overpreesured system that increased the pore fluid overpressure until reach and overcome the fracture-pressure gradient of the host mudstone and sands in the parent units (Fig. 11). This overcome generated the hydrofracture and brecciation through the fracture system.

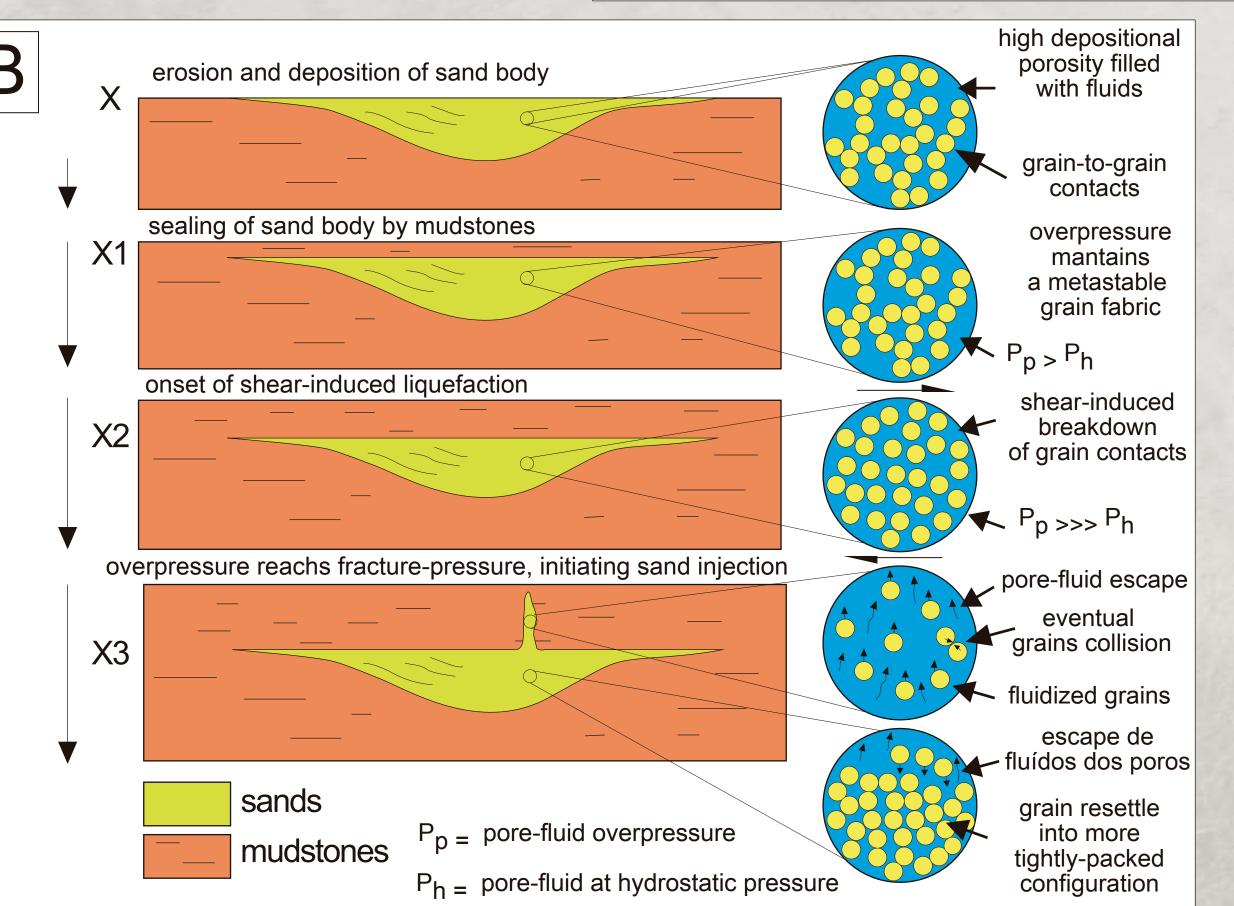
The intrusions created two main disticnt regional scale injection geometries. In the lower level (LIB) the saucer-shape intrusion with multy-layered sills connected by dykes (Figs. 10B and 10C). In the upper level (UIB) ocurred the predominance of stepped dykes and sills forming conical-shape intrusions with wing-like intrusions (Figs. 10, 12 and

The intrusive network comprises near to bedding-parallel sills and bedding-discordant dykes that are emplaced in a NW-SE oriented fracture system constrained by NE-SW stresses Figs. 10B).

Fig. 11 - A) Possible pressure-depth path (dashed black line) for a sand body enveloped in low-permeability strata. B) Grain fabric changes that accompany overpressuring in a sand body. Modified from Hurst et. al., (2011).



Belt (A) and the respective geological interpretation (B).



Geometries, Structures and Petrography of Tumey Injection Complex, California (USA)

Gustavo Zvirtes, Andrew Hurst, Ruy Philipp, Giuseppe Palladino, Antonio Grippa

1. Geology and Petroleum Geology, University of Aberdeen, Aberdeen, United Kingdom.
2. Mineralogy and Petrology, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil.











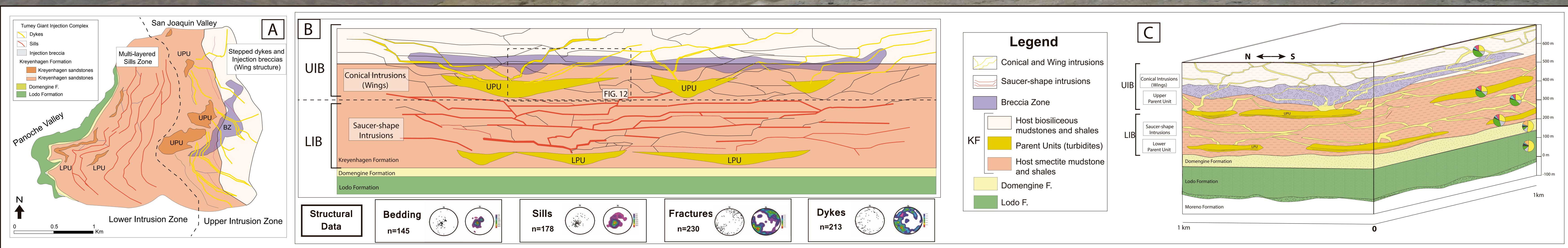
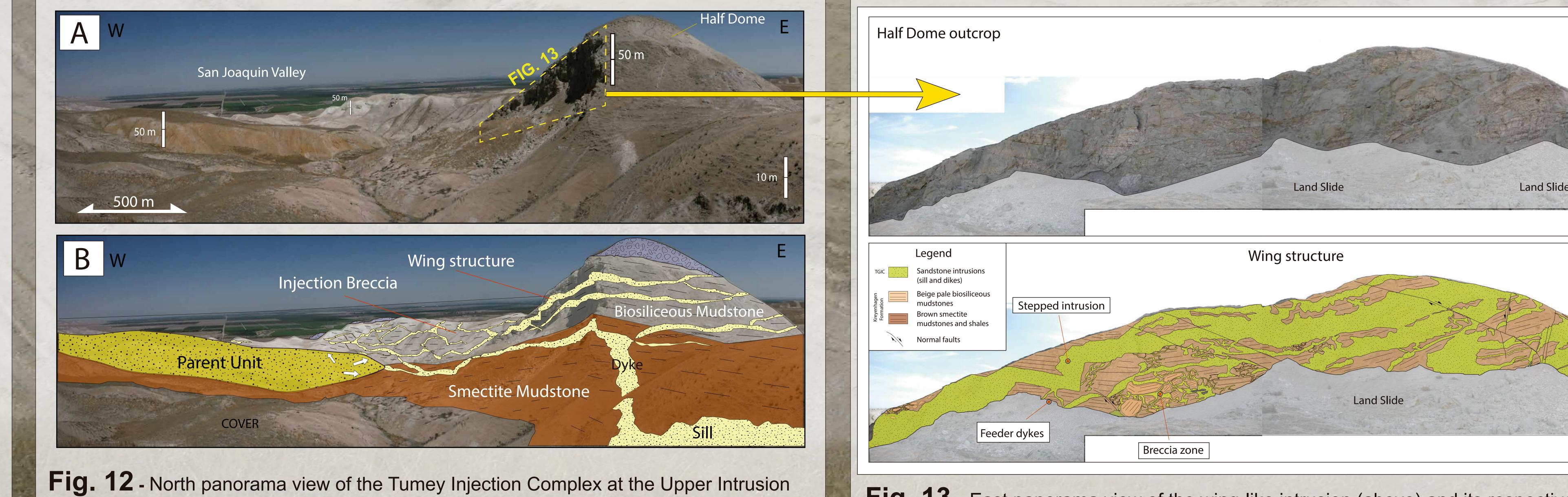
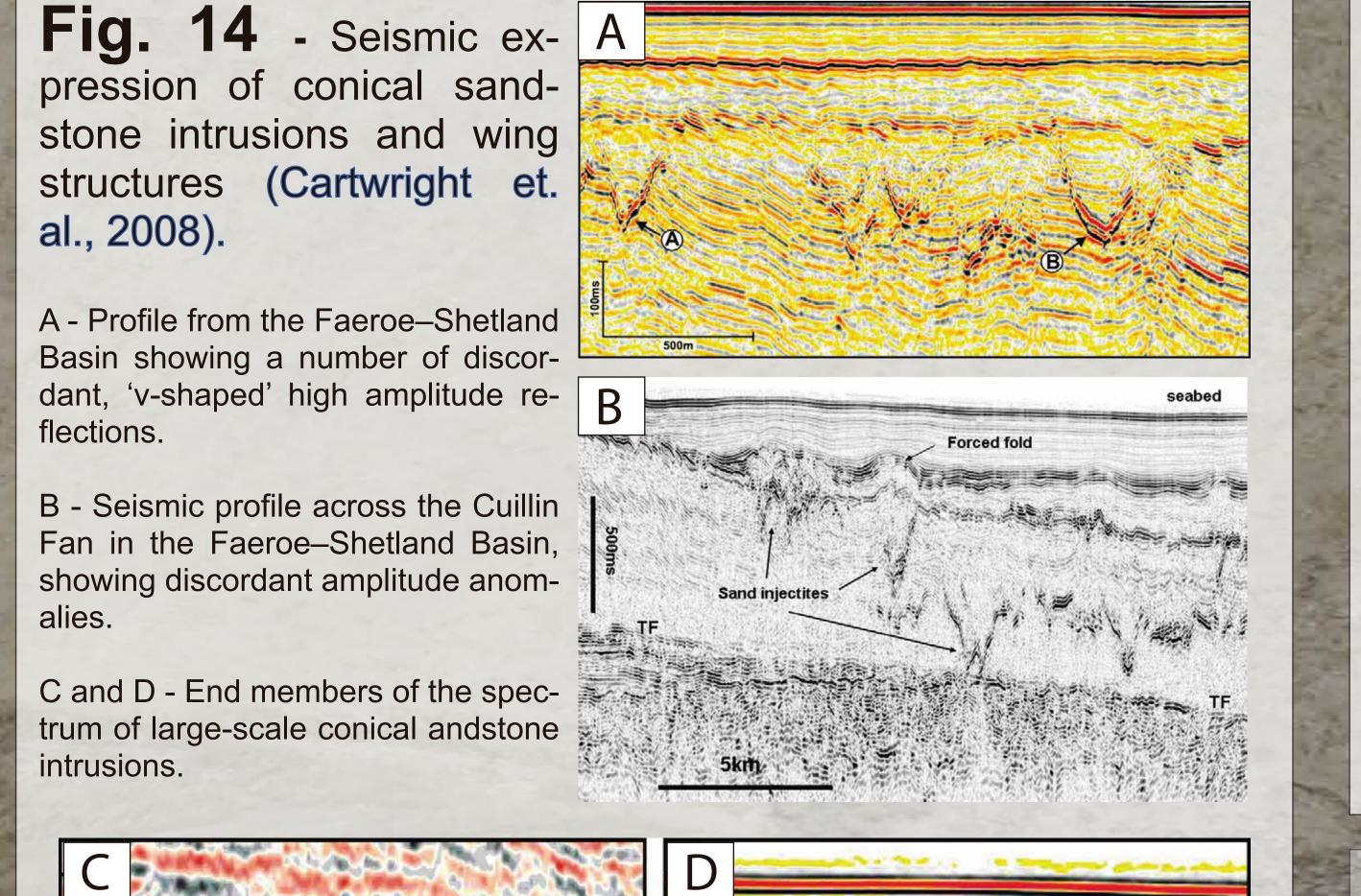


Fig. 10 - A) Simplified geological map of TGIC. B) Geological cross section model of the architectural data (below). C) Block diagram of the architectural organization and predominant intrusive geometries of TGIC (above) and the structural data (below). C) Block diagram of the TGIC with detrital composition pie diagrams showed in figure 7. LIB - Lower Intrusion Belt; UIB - Upper Intrusion Belt; LPU -Lower Parent Unit; UPU: Upper Parent Unit.

N₋S







Conclusions

- Petrographic studies of the sandstones give the information about textural and mineral composition, micro-structures, and source area (provenance) of each unit. These parameters were crucial on the definition and characterization of sand injection bodies and its respective parent units, improving the understanding of the evolution of the TGIC and the depositional sandstones of Pelocene and Eocene epoch in the San Joaquim basin.

- The mapping of TGIC revels an architectural organization of two distinctive intrusion belts with sill-dominated saucer-shape intrusions and the stepped-dykes dominated with the development of wing structures. These geometries are identified in subsurface seismic data and can be directly correlated as an outcrop analog (Fig. 14).
- The TGIC is a good example of a giant sand injection complex that is valuable analogue to support subsurface analysis of similar geological environments.

References

Dickinson, W.R. (1985) Interpreting provenance relations of arenites. (Ed. by G.G. Zuffa), pp. 333-361. Reidel Dordrecht. Folk, R.L., (1974) Petrology of sedimentary rocks. Hemphill, Austin, Texas, 159 pp.

Hurst, A., Cartwright, J.A., Huuse, M., Jonk, R., Schwab, D., Duranti, D., Cronin, B., (2003b) Significance of large-scale sand injectites as long term fluid con-Hurst, A., Cartwright, J.A. (Eds.), (2007) Implications for Hydrocarbon Exploration and Production: American Association of Petroleum Geologists Memoir, Tulsa