Geology of southern Mesa Central of Mexico: An example of three-dimensional deformation in the Oligocene

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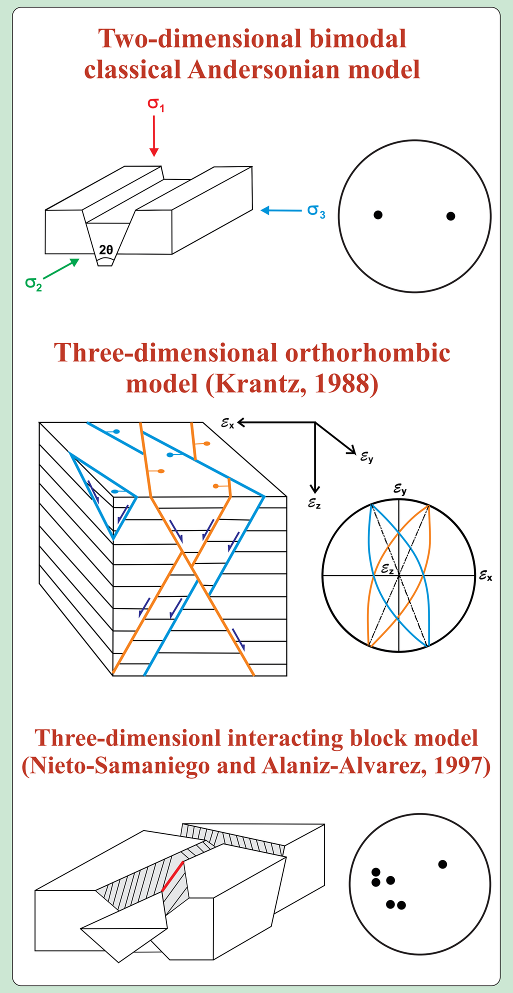
Abstract

Usually, the deformation in the upper crust is considered two-dimensional, that implies null deformation in one principal strain axes. A conspicuous feature of southern Mesa Central is that the Cenozoic deformation is three-dimensional, produced by early Oligocene tectono-thermal activity. We mapped a region in central Mexico, where the Cenozoic rocks are affected by a polymodal fault pattern. We identified six stratigraphic units: 1) Mesozoic mafic volcanic and sedimentary marine rocks. 2) Clast-bearing pre-Oligocene continental deposits. 3) Rupelian rhyolitic lavas, lava domes and ignimbrites, of ~32-30 Ma and ~28-27 Ma. 4) Chattian volcanic rocks of ~23.5 Ma. 5) Miocene basalt lava flows. 6) Poorly-consolidated conglomerate and sandstone with maximum depositional age ~16.5 Ma. The main fault systems are oriented NE-SW, NW-SE, N-S and E-W. Fault crosscutting relationships are not univocal. U-Pb zircon ages of lithological units allowed to stablish their peak of activity at 30-27 Ma, nearly contemporaneous with volcanism. The structural analysis shows a polymodal fault pattern with a wide dispersion of poles (n=478). We calculated the kinematic tensors (Linked Bingham). The relative strain values of individual grabens and faults (e_2/e_1 less than 0.15) suggest a two-dimensional deformation state. In contrast, the eigenvalues from all fault sets (e_2/e_1 = 0.79) indicate a three-dimensional deformation. The geological mapping allows a first quantitative approach about the origin of the polymodal fault pattern located in the southern Mesa Central, which could have been generated under the same state of stress with quasi-simultaneous activity of normal fault systems during the Oligocene, producing three-dimensional deformation.

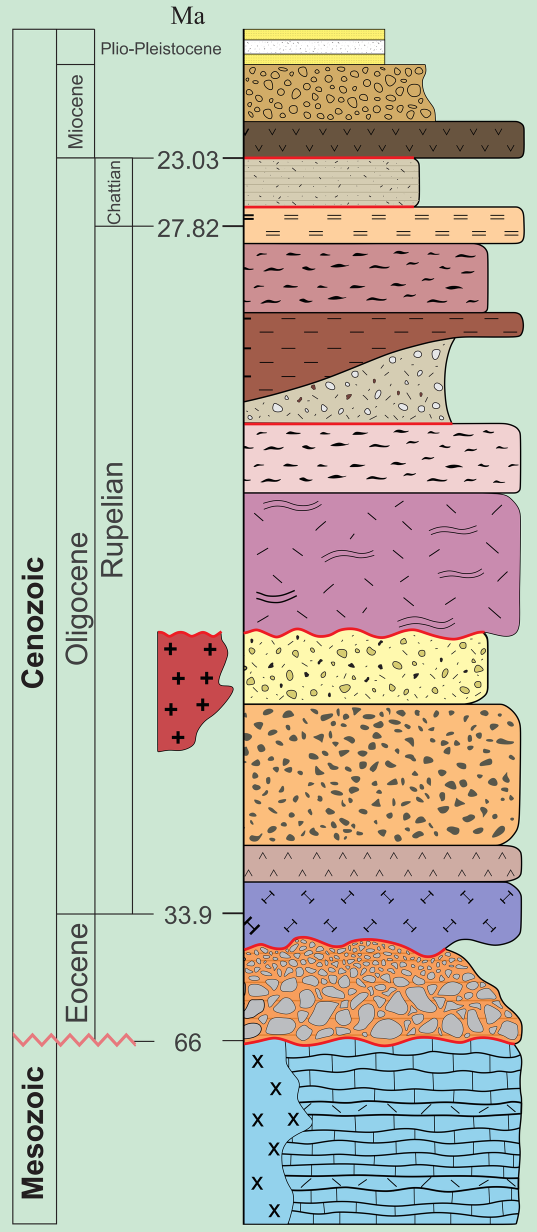
Introduction



The three-dimensional polymodal fault patterns have been widely documented in a wide range of scales, from experimental lab works to cases in nature (Donath, 1962; Oertel, 1965; Aydin and Reches, 1982; Krantz; 1988, 1989). Nevertheless, the prediction of polymodal faults respect eigenvectors of stress or deformation triaxial remains poor (Healy *et al.*, 2015). There are models that predict the formation of two-dimensional bimodal (Andersonian model) and three-dimensional orthorhombic fault patterns by rupture of rocks (Reches, 1978; Krantz, 1988). Other models establish that three-dimensional polymodal fault patterns that do not limit the number, symmetry and orientation of faults, are due to reactivation of pre-existing planes (Nieto-Samaniego and Alaniz-Alvarez, 1997).

In southern Mesa Central of Mexico there is a case of polymodal normal fault pattern, where converge several normal faults and grabens with different orientations (NW-SE, NE-SW, N-S, E-W). These faults were formed simultaneously, presumably under three-dimensional deformation (Nieto-Samaniego *et al.,* 1999, 2007). To try to explain the development of this polymodal pattern we carried out geologic mapping of a region between San Luis Potosí and León cities. We focused on the stratigraphy supported by detail petrography and U-Pb zircon ages. For the structural analysis, we used dynamic (Angelier, 1979; Delvaux and Sperner, 2003) and kinematic methods (Marret and Allmendinger, 1990).

Stratigraphy



Alluvium and Las Pilas tuff -- Non-consolidated fluvial deposits and very fine white-colored fall-air pyroclastic deposit

Poorly-consolidated sandstone and conglomerate ***~16.5 Ma***

Basalt and basaltic andesites -- Massive and pseudostratified lava flows

Tres Encinos ignimbrite -- Rhyolitic pseudostratified non-welded pumice-rich ligh brown-colored ignimbrites ***23.48±0.24 Ma***

Deseadilla ignimbrite -- Rhyolitic massive welded vitreous porphyritic orange-colored ignimbrites ***27.72±0.13 Ma***

Ibarra ignimbrite -- Rhyolitic pseudostratified welded devitrified light pink-colored ignimbrites ***27.83±0.37 Ma***

Salto del Ahogado ignimbrite -- Rhyolitic massive densely welded vitreous brown-colored ignimbrites ***28.34±0.5 Ma***

Cañada Grande ignimbrite -- Rhyolitic massive non-welded pumice and ash-rich light brown-colored ignimbrites ***28.72±0.27 Ma***

El Cóporo ignimbrite -- Rhyolitic porphyritic welded devitrified light pink-colored ignimbrites ***30.14±0.16 Ma***

Chichíndaro rhyolite/Portezuelo latite -- Porphyritic lava flows and domes associated with breccias, tuffs and dikes ***30.53±0.24 Ma***

Duraznillo intrusive -- Quartzmonzodioritic dark green-colored body intrusive ***30.82±0.52 Ma***

Los Juanes ignimbrite -- Rhyolitic non-welded light yellow colored ignimbrites and associated air-fall tuffs ***30.6 Ma***

Rincón de Ortega ignimbrite -- Rhyolitic densely welded massive lithic-rich orange-colored ignimbrites ***31.12±0.16 Ma***

Oligocenic andesites -- Subordinates porphyritic altered andesitic lava flows

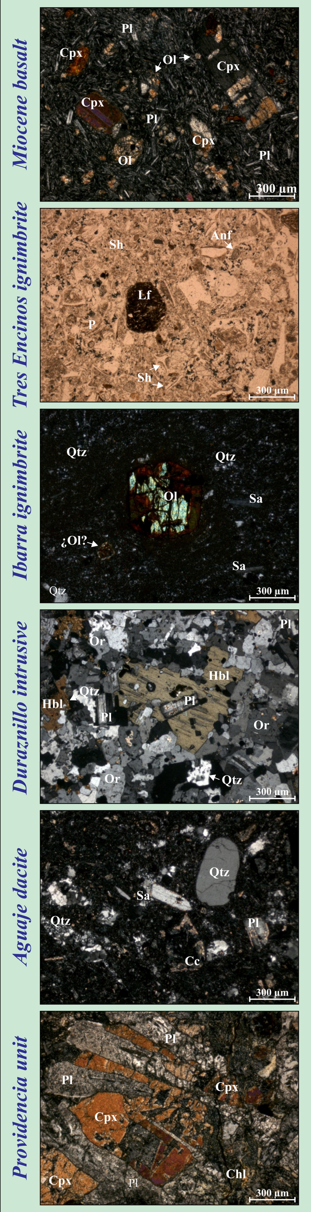
Aguaje dacite -- Dacitic light purple-colored lava flows with K-feldspar megacrysts more than 5 cm length ***34.36±0.26 Ma***

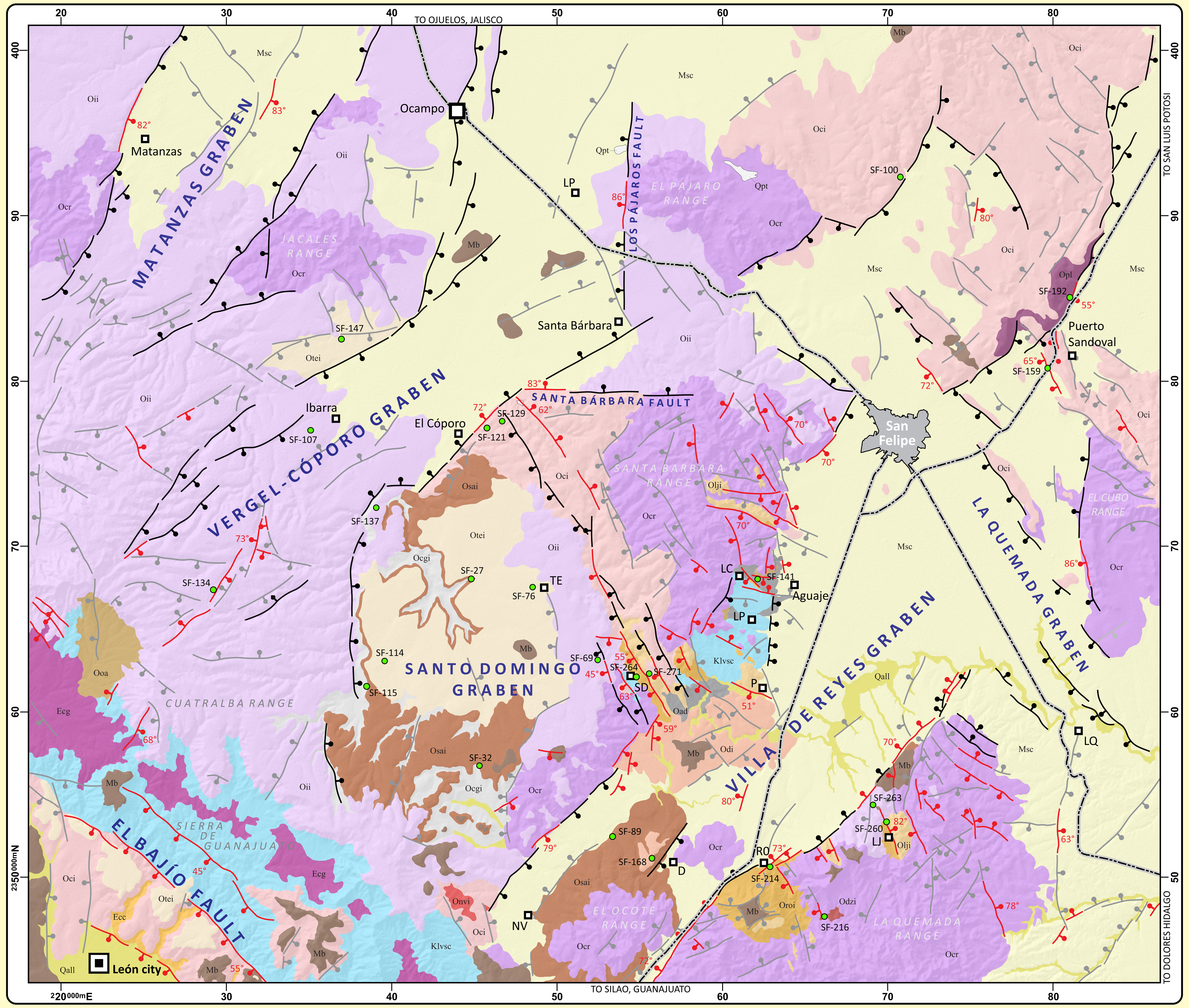
Los Cedros conglomerate -- Continental polymictic clast-bearing well-cemented light orange-colored conglomerate

Providencia unit -- Late Jurassic-early Cretaceous sedimentary and mafic igneous rock slightly folded and affected by greenschist facies metamorphism

Discordance

Petrography





Explanation

Normal fault; Normal fault with measured structural data; Inferred normal fault; City/town; U-Pb dated sample; Major road

Mesozoic: Klvsc — La Providencia unit & Sierra de Guanajuato Volcanosedimentary Complex

Eocene: Ecc — Los Cedros-Duarte conglomerates; Ecg — Comanja Granite

Rupelian: Oi — Ibarra ignimbrite; Osai — Salto del Ahogado ignimbrite; Ocgi — Cañada Grande ignimbrite; Oci — El Cóporo ignimbrite; Opl — Portezuelo latite; Ocr — Chichíndaro rhyolite; Olji — Los Juanes ignimbrite; Odi — Duraznillo intrusive; Onvi — Nuevo Valle intrusive; Oroi — Rincón de Ortega ignimbrite; Ooa — Oligocenic andesites; Oda — El Aguaje dacite

Chattian: Otei — Tres Encinos ignimbrite; Odi — Deseadilla ignimbrite

Miocene: Msc — Poorly-consolidated sandstone-conglomerate; Mb — Basalts-basaltic andesites

Plio-Pleistocene: Qall — Alluvium; Qpt — Las Pilas tuff

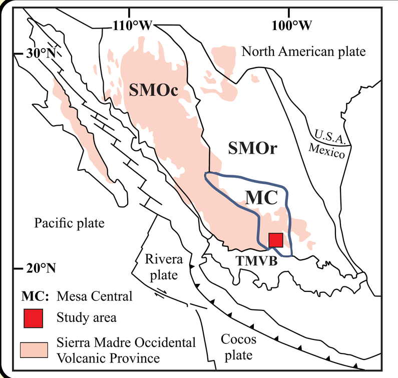
Geologic map of southern Mesa Central, Mexico

DATUM: 14Q UTM WGS84

Topographic base from INEGI

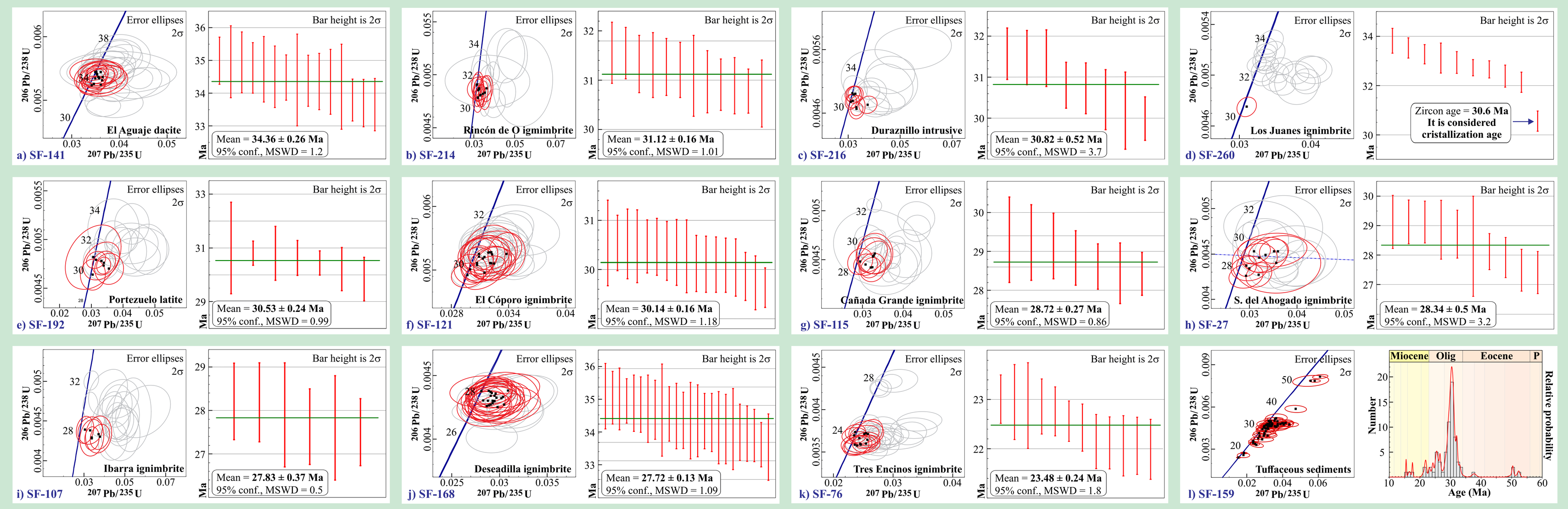
kilometers 0 10

NV: Nuevo Valle de Moreno; D: Deseadilla; P: El Payán; RO: Rincón de Ortega; SD: Santo Domingo; LP: La Providencia; LC: Los Cedros; LJ: Los Juanes; TE: Tres Encinos; LP: Los Pájaros; LQ: La Quemada

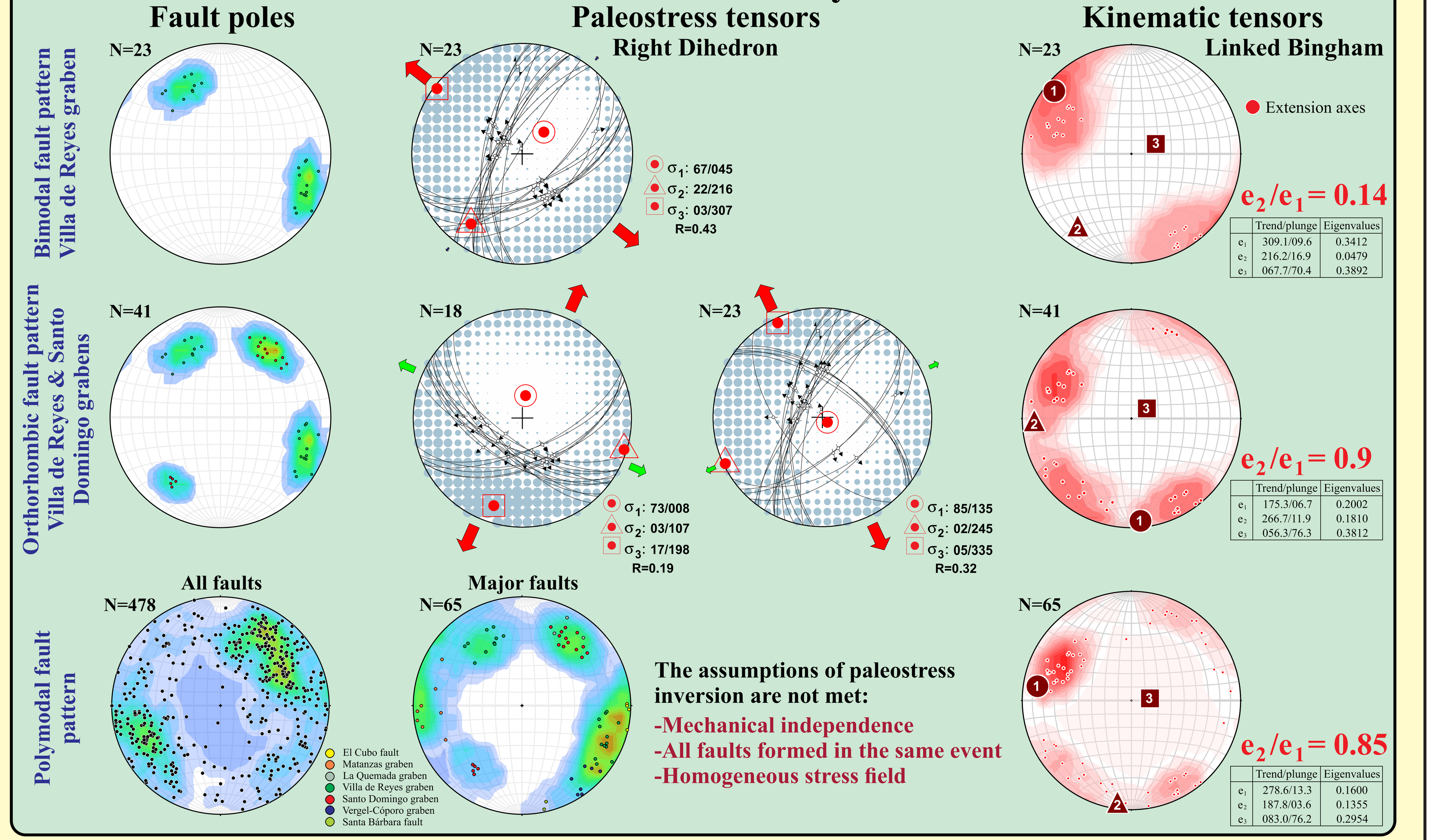


U-Pb zircon geochronology

Samples were analysed by LA-ICPMS at Laboratorio de Estudios Isotópicos of the Centro de Geociencias, UNAM, using the methodology of Solari *et al.* (2010)



Structural analysis



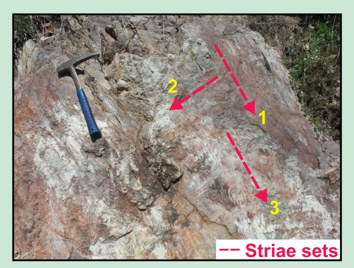
The assumptions of paleostress inversion are not met:
- Mechanical independence
- All faults formed in the same event
- Homogeneous stress field

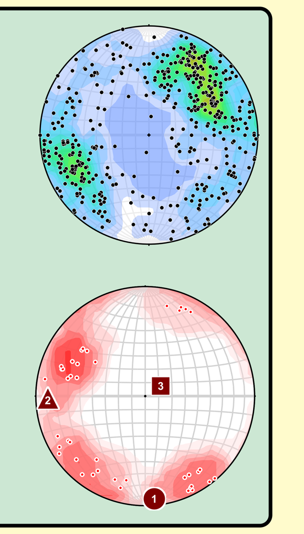
Evidences of three-dimensional deformation

Polymodal normal fault pattern identified from geological mapping

The closeness of faulting age (early Oligocene)

Ambiguity in crosscutting relationships among faults at regional and outcrop scales (quasi-simultaneous activity)





Relative strain values e_2/e_1 of ~0.9 indicate three-dimensional deformation

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