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STRUCTURE AND DEFORMATION HISTORY OF ASTYPALEA ISLAND, AEGEAN SEA

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ABSTRACT

Astypalea Island lies south of the Late Cretaceous to Eocene high-pressure belt of the Cyclades and north of the Miocene high-pressure belt of the External Hellenides. The rocks of the island belong to the Tripolitza unit. The latter unit occupies a critical tectonic position in Astypalea between the unmetamorphosed Tripolitza rocks in Crete and the high-pressure Basal unit, which is correlated to the Tripolitza unit, in the Cyclades. We have subdivided the deformation history of Astypalea Island into four events, D_1 through D_4. The problem with interpreting the structural data is that the D_1 and D_2 events cannot unequivocally be ascribed to horizontal crustal contraction or crustal shortening. In our interpretation, D_1 caused top-S internal imbrication within the Tripolitza unit as a result of crustal shortening. We envision that this event occurred when the Phyllite-Quartzite and Plattenkalk units were underthrust beneath the Tripolitza unit in the Oligocene. D_2 was probably associated with top-N extension and may be related to large-scale crustal extension across the Cretan detachment in the Early Miocene. D_3 caused high-angle faulting due to E-W contraction and D_4 was due to N-S extension.

KEY WORDS: Structure, Deformation, Tripolitza unit, Astypalea Island, Aegean, Greece.

1. INTRODUCTION

Astypalea Island is situated between the Late Cretaceous to Eocene high-pressure belt of the Cyclades and the Miocene high-pressure belt of the External Hellenides (Fig. 1). It is made up by apparently unmetamorphosed or weakly metamorphosed limestones and marls of the Tripolitza unit, which are overlain by Eocene to Oligocene flysch (IGME, 1986). The Tripolitza unit (Philippson, 1892) represents an external platform sequence which was flanked to the north by the Pindos basin and to the south by the Ionian basin (Jacobshagen, 1986; Papanikolaou, 1987). Platform-type carbonates range in age from Late Triassic through Late Cretaecous (Fleury, 1980). Bauxite deposits, soil horizons and intraformational breccias indicate periodical emergence of the platform. The Tripolitza platform subsided from the latest Cretaceous through the Eocene as indicated by deposition of nummulite-bearing marls on top of rudist-bearing platform carbonates.

The Tripolitza unit in Astypalea occupies a critical position between the unmetamorphosed Tripolitza unit in Crete and the high-pressure (350-400°C, 8-10 kbar) Basal unit in Evia, Tinos, Fourni and Samos in the Cycladic zone (Fig. 1). The Basal unit has been correlated to the Tripolitza unit by Avigad et al. (1997), Shaked et al. (2000) and Ring et al. (1999, 2001). On Amorgos Island to the northwest of Astypalea, rocks which belong to the Tripolitza unit (Fytrolakis et al., 1981) show a weak high-presssure overprint (<350°C, 5-8 kbar; Minoux, 1981).

The latest Cretacous through Eocene subsidence of the Tripolitza platform is interpreted to have resulted from thrust loading caused by the southward advancing internal thrust sheets. Widespread flysch deposition in the Late Eocene and Oligocene in the Pindos and Tripolitza units of the External Hellenides are also related to thrust propagation and the development of topography in the hinterland. In Evia, Katsikatos et al. (1986) and Shaked et al. (2000) proposed that the Tripolitza unit in the Almyropotamos window was overthrust by the Cycladic blueschist unit in the Oligocene. In the Early Miocene, the basal contact of the Tripolitza unit was reactivated as a large-scale extensional detachment, which facilitated rapid exhumation of the more external high-pressure Phyllite-Quarzite and Plattenkalk units in its footwall (Fassoulas et al., 1994; Thomson et al., 1999).

The aim of this contribution is to report the results of reconnaissance structural mapping on Astypalea Island. Our work shows that Tripolitza limestones were emplaced on top of Tripolitza flysch by top-S shearing during a first deformation event. This was followed by top-N movement, which was mainly localized within the flysch. A third deformation event led to faulting during E-W contraction followed by normal faulting due to N-S extension.

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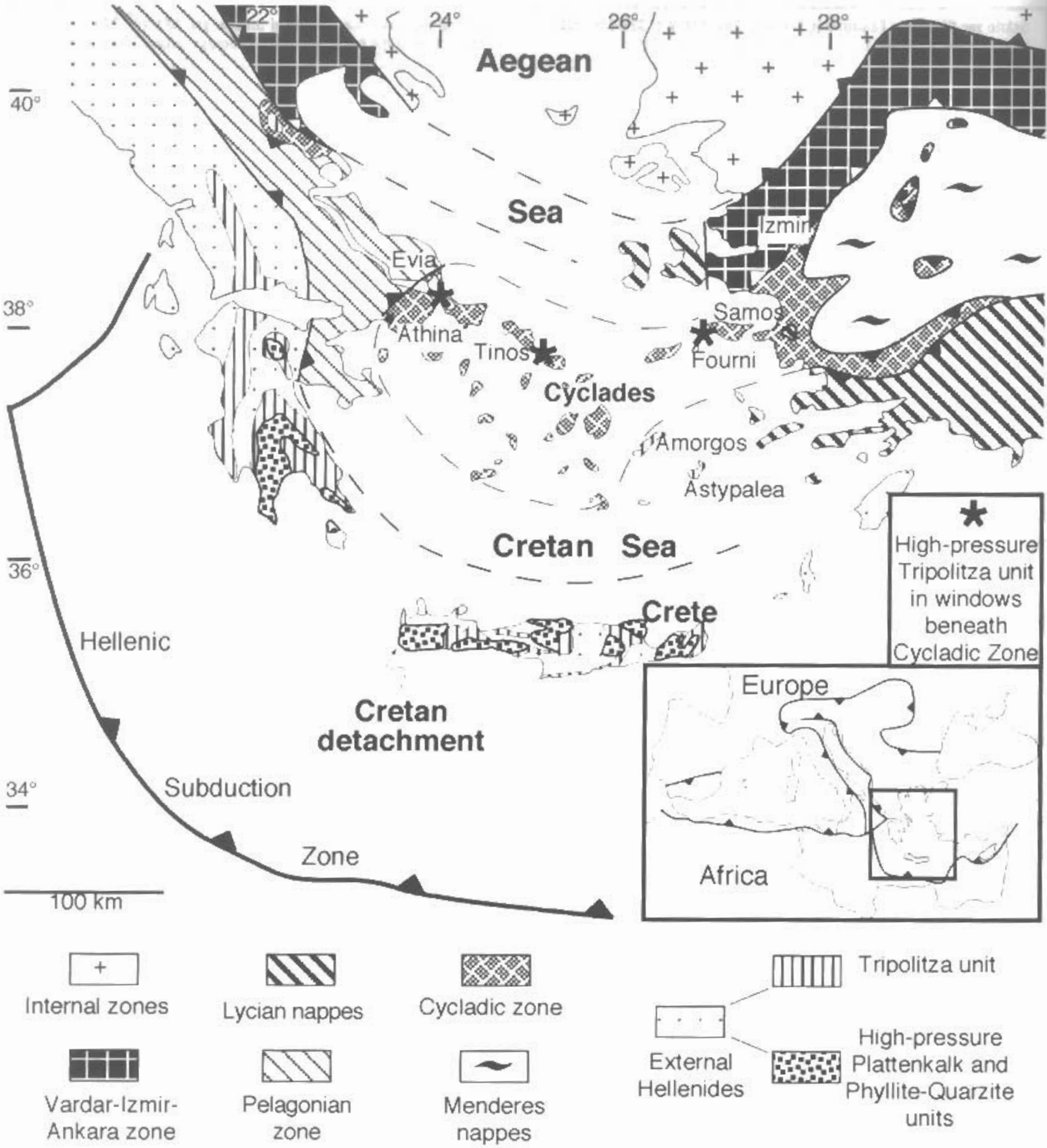

Fig.1: Generalized tectonic map of the Aegean showing position of Astypalea Island (modified from Jacobshagen, 1986). Insert: Miocene to Recent thrust fronts in Mediterranean region and location of main map.

2. LITHOLOGY AND STRUCTURE

The carbonates of the Tripolitza unit on Astypalea Island grade in their upper parts into 10-30 m thick marls, which are Paleocene to Early Eocene in age (IGME, 1986). On top of the marls follow flysch deposits. The flysch mainly consists of carbonate-free lithic sandstones with a few conglomerate layers. Bolders in these conglomerates are up to 40-60 cm in diameter and were derived from the Tripolitza and Pindos units. In addition, also peridotite clasts occur (IGME, 1986), which must have a source high up in the nappe stack above the Pindos unit. The occurrence of limestone blocks of more than 100 m in diameter in the upper parts of the flysch (Fig. 2) may either represent olistoliths or imbricated slices associated with the emplacement of the Tripolitza limestone sheet above the flysch.

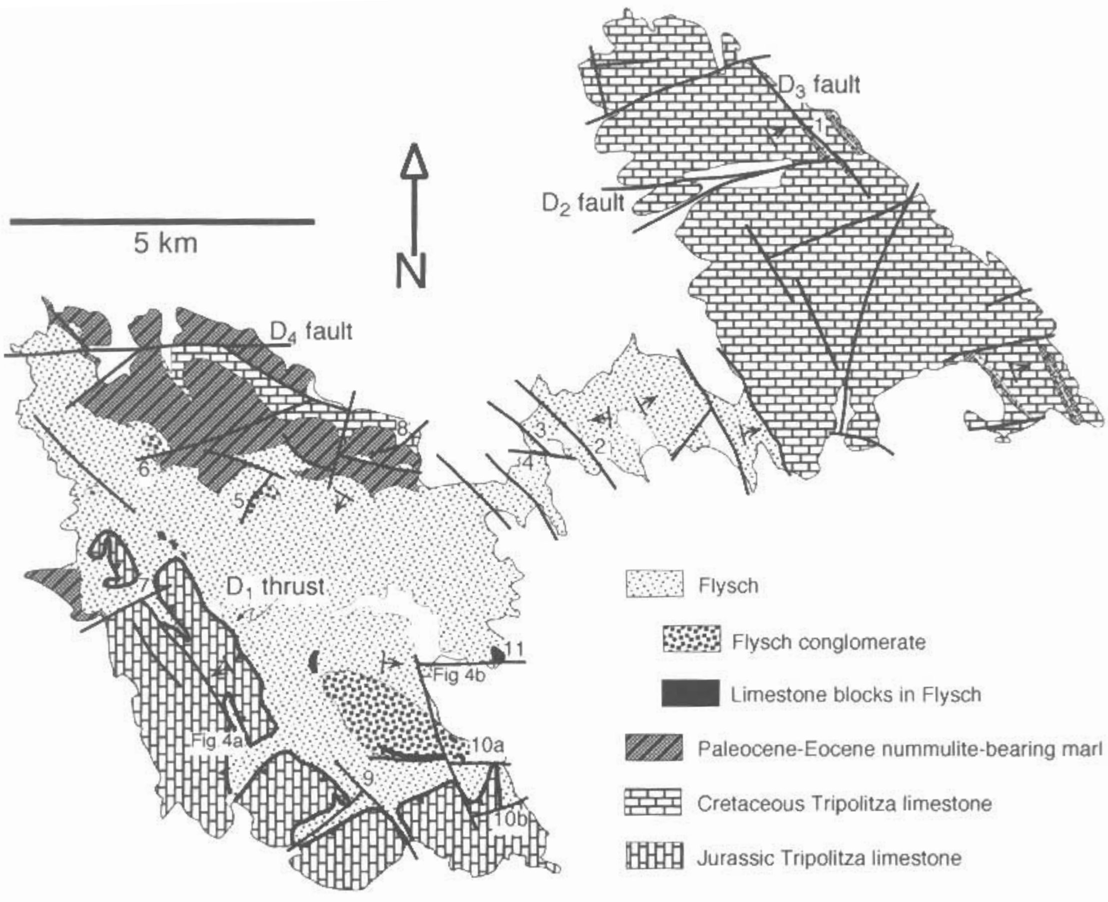

Fig.2: Tectonic map of Astypalea Island (modified from IGME, 1986). Note that W-striking D_2 faults are cut by NNW- to NNE-striking faults (D_3 faults), which are in turn cut by W-striking D_4 faults.

The general structure of Astypalea Island is relatively simple. The lower part of the island is made up of Cretaceous platform limestones, marls and flysch representing an undisturbed transition from shallow marine limestones via deeper marine marls to sub-CCD flysch. On top of the flysch rest with a tectonic contact Jurassic platform limestones (IGME, 1986) (Fig. 2). The foliation dips in general shallowly and depicts a weak great-circle distribution. The inferred large-scale fold axis plunges gently to the east-southeast (Fig. 3). The axial planes of inferred large-scale folds dip steeply to the north-northeast. Subsequent to foliation development, the island was cut by a number of faults (Fig. 2).

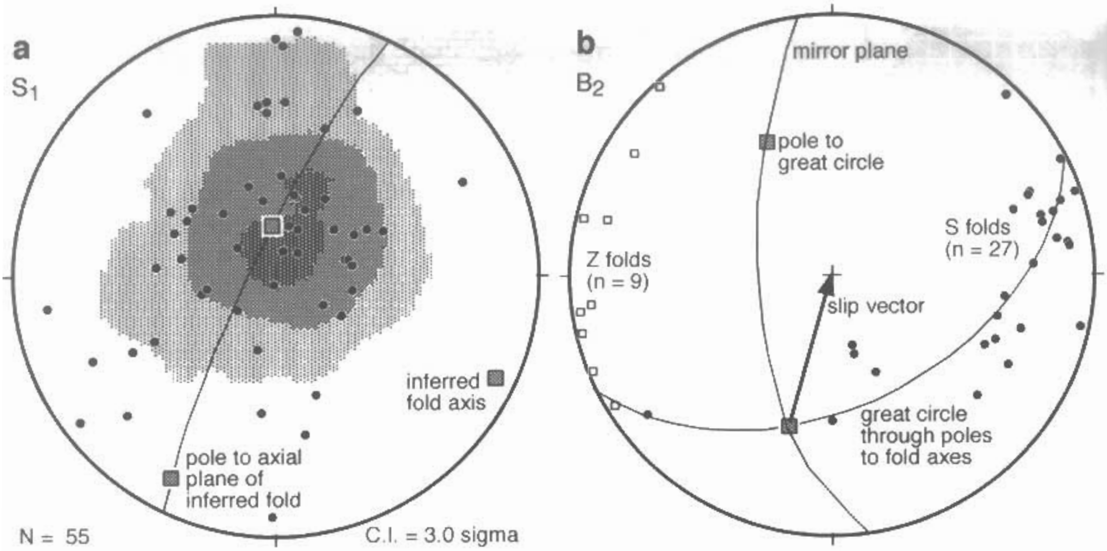

Fig.3: (a) S_1 foliation planes from Astypalea Island, deduced great circle and associated pole (inferred fold axis). The pole to the axial plane of the inferred fold, which is steeply dipping to the north is also shown (lower-hemisphere equal-area projection). (b) B_2 folds separated into S and Z folds. The sense of asymmetry is used to distinguish between clockwise and anticlockwise asymmetry, or a Z and S shape of the fold respectively, when viewed in the down-plunge direction of the fold axis. The method of Hansen (1971) (or internal-rotation-axis method of Cowan & Brandon 1994) was used to deduce the average direction and sense of shear from asymmetric folds, which occur in shear zones in flysch. The method is based on the fact that layers in sheared rocks may form asymmetric folds, which reflect the direction and sense of shear during deformation. The axes of the S and Z folds are expected to lie on a great circle representing the shear plane in which they formed, and are distributed in two groups, separated from each other by a mirror plane. The shear direction can be determined from the intersection of the shear plane (average girdle of S and Z axes) and the mirror plane. An important assumption is that the final deformational fabric has a monoclinic symmetry, defined by the mirror plane (Cowan & Brandon 1994). The slip vector is interpreted to indicate the average direction and sense of tectonic transport of the hanging wall relative to a fixed footwall.

3. DEFORMATION STRUCTURES

We have subdivided the deformation history of Astypalea Island into four deformation events, D_1 through D_4. The first event (D_1) was associated with the duplication of the limestone sequence (Fig. 4a) and large-scale upright to south-vergent folding. The limestone in the western part of the island was emplaced above the flysch along a sharp, ˜5 metre thick fault plane. The flysch in the footwall shows brittle-ductile shear bands indicating top-S tectonic transport. The limestone in the hanging wall depicts a N-S oriented stretching lineation expressed by stretched carbonate clasts. Small-scale asymmetric south-vergent folds also occur in limestone. Directly above the fault, a <1 metre thick zone of pronounced brecciation and chaotically arranged joints and small-scale veins occurs.

Structures of the second event (D_2) were only observed in distinct zones in the flysch. These zones are up to 50 metre thick and numerous north-verging B_2 folds occur in these zones (Fig. 3b). The folds are usually associated with small-scale top-N/NW faults (Fig. 4b). The oldest set of high-angle faults appears to be associated with D_2 (Fig. 2) and resulted from N-S extension (Fig. 5). Associated large faults strike preferentially E-W, whereas smaller faults also strike N-S.

The D_2 high-angle normal faults are cut by a younger set of faults (D_3). Faults belonging to D_3 include ˜N-striking reverse faults, ˜NW-striking sinistral and ˜NW-striking dextral strike-slip faults and formed during overall E-W contraction. The orientation of the X and Y axes (X>Y>Z, principal strain axes) scatter but both axes lie an a N-S oriented great circle (Fig. 5). A still younger set of high-angle faults (D_4) developed in response to normal faulting during N-S extension and mainly includes normal faults, which strike E-W.

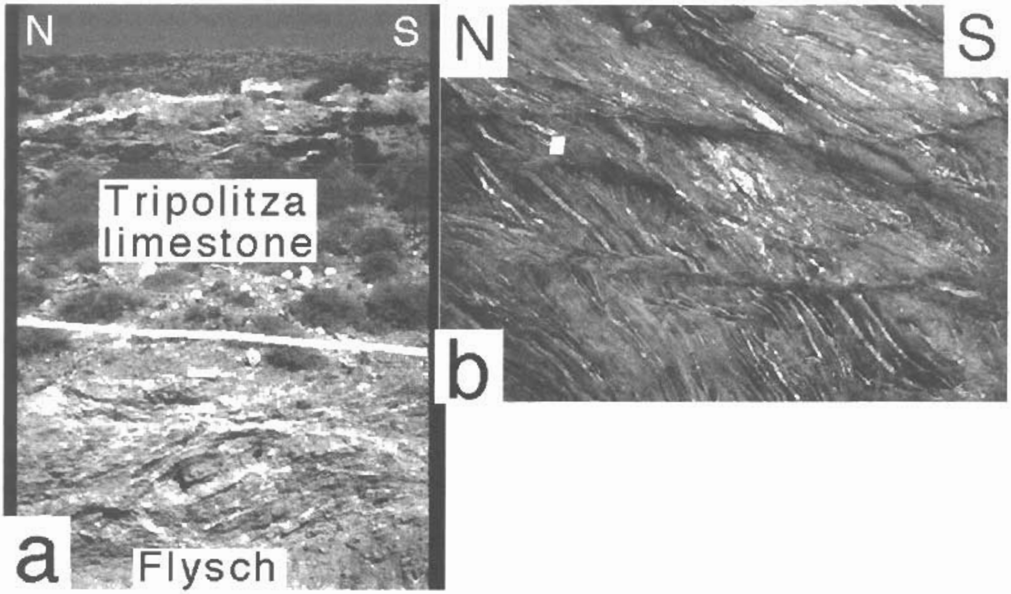

Fig.4: (a) D_1 contact between flysch and Tripolitza limestone. The shear bands in flysch indicate top-S movement. The limestones show pronounced brecciation at the contact but ductile stretching above the contact. (b) Top-N-displacing D_2 faults in flysch. A few asymmetric folds are associated with the faults and also indicate top-N sense of shear.

4. TECTONIC INTERPRETATION

The problem with interpreting the structural data from Astypalea Island is that the D_1 and D_2 events cannot unequivocally be ascribed to horizontal crustal contraction or crustal shortening. Our preferred interpretation is that D_1 resulted from top-S crustal imbrication as a result of crustal-scale shortening. The reasons for ascribing the D_1 event to N-S shortening are: (1) D_1 resulted in duplication of a stratigraphic sequence, which was apparently subhorizontally layered before thrusting. The inferred subhorizontal layering is critical because extensional faulting of a stratigraphic sequence which dipped steeper than the extensional fault would also cause stratigraphic repetition (cf. Wheeler and Butler, 1994). (2) The limestone in the hanging wall of the fault shows a progressive development from ductile to brittle structures. The brittle structures probably developed at the end of thrusting when deformation was localised along the thrust plane. The flysch in the footwall does not show this pronounced ductile-to-brittle transition in its structural development. The difference in the ductile-to-brittle behaviour in the hanging- and footwall would be compatible with thrusting because the hanging wall moves (faster) upward relative to the Earth's surface. For a normal fault a pronounced ductile-to-brittle development of structures would be expected for the footwall. (3) Evidence from Syros Island shows that early deformation in the Cyclades was associated with top-S thrusting (Ridley, 1984).

The D_1 event was probably associated with final flysch deposition and would therefore be Oligocene in age. Thomson et al. (1999) showed that underthrusting of the Phyllite-Quartzite and Plattenkalk units underneath the Tripolitza unit in Crete occurred in the Oligocene (36-32 Ma) and the ensuing high-pressure overprint of all three units occurred in the Early Miocene (Seidel et al., 1982; Thomson et al., 1999; Ring et al., 2001). At this time the Plattenkalk and Phyllite-Quartzite units now exposed in Crete were north relative to present Astypalea Island.

Top-N/NW transport during D_2 is even harder to interpret tectonically. If our interpretation that the early set of high-angle faults are associated with D_2 is correct, then it seems plausible to relate D_2 to N-S crustal extension. Such an interpretation would fit into the general regional tectonic syntheses, which show pronounced Miocene crustal extension in the Aegean (e.g. Lister et al., 1984; Avigad et al., 1997; Thomson et al., 1999; Forster and Lister, 1999). If this interpretation is accepted, the top-N extensional structures would probably be associated with the Cretan detachment, which underlies much of the Tripolitza unit.

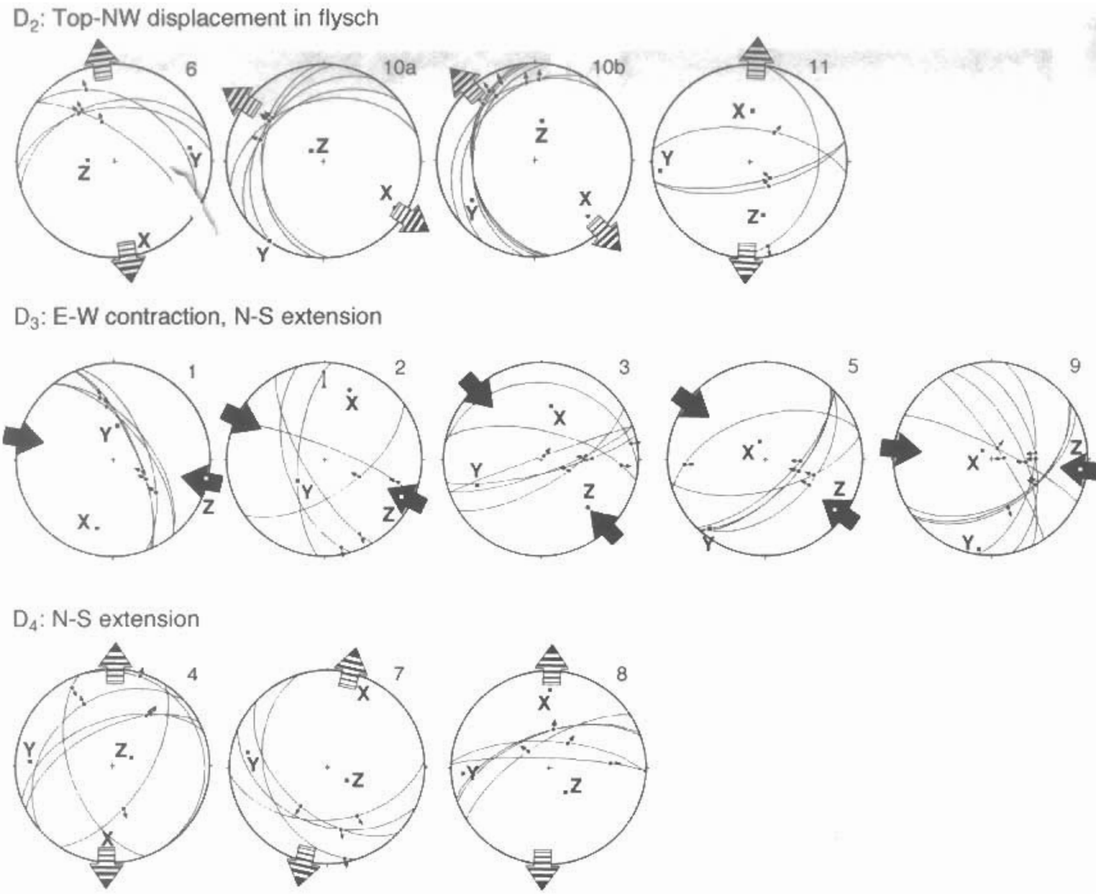

Fig.5: Kinematic data from faults exposed on Astypalea Island. The diagrams show great circles of fault planes and the projected trace of slickenside lineations in a lower-hemisphere equal-area projection; principal strain axes (X>Y>Z) are shown – the deduced extension directions (X) for D_2 and D_4 and contraction axes (Z) for D_3 are indicated by arrows; outcrop number is indicated on upper right and can be located in Fig.2. The subdivision into three phases of faulting is principally based on cross-cutting faults and cross-cutting striations at fault planes.

Because it can safely be assumed that the high-angle faults related to D_3 and D_4 were not rotated to any significant degree after their formation the D_3 event was due to E-W contraction and D_4 due to N-S extension. There is widespread evidence in the eastern Aegean for a short-lived phase of E-W contraction in the Tortonian (Ring et al., 1999, for Samos; Ring, unpublished data, for Patmos). The cause for this contractional event remains enigmatic; a relationship to westward escape of the Anatolian microplate might be envisioned. N-S extension during D_4 fits into the general pattern of young to Recent N-S-directed normal faulting in the Aegean.

5. CONCLUSIONS

We have subdivided the deformation history of Astypalea Island into four events. According to our interpretation, D_1 caused top-S contractional imbrication within the Tripolitza unit. We envision that this event occurred when the Phyllite-Quartzite and Plattenkalk units were underthrust beneath the Tripolitza unit in the Oligocene. D_2 was probably associated with top-N extension across the Cretan detachment in the Early Miocene. D_3 caused high-angle faulting due to E-W contraction and D_4 was due to N-S extension, which is probably still going on.

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