the south (S of Errachidia), thus lying at a higher regional elevation than in much of the interior of the range. Although mountain peaks near the section reach 3700 m, the mean altitude of the range is slightly above 1500 m. Refraction seismics showed crustal thicknesses between 35 and 38 km.

When considering a potential isostatic undercompensation, the following facts should be taken into account: 1) the relatively low mean altitude, 2) the regional elevation difference of the top of basement in the range and adjacent plateaux and its crustal density implications, and 3) the fact that the actual uplifted region exceeds the extent of the deformed belt (the plateaux are well above 1000 m – with crustal thickness of 33–35 km – and in other traverses the Atlas is flanked by prominent 100 km scale uplifts with very mild alpine reworking – Moroccan Meseta and Antiatlas).

A crustal origin for the relief difference between High Atlas and marginal plateaux can be accepted, but larger-scale dynamic topography is invoked for the entire region. Teleseismic P-wave investigations suggested a thinned lithosphere under the High Atlas mountains, consistently with abundant quaternary vulcanism. However, neotectonic features and fault-plane solutions of shallow earthquakes indicate a compressional (thrust and wrench) setting. In the light of these evidence we propose that lithosphere folding was a significant contributor to uplift in the North African foreland, sustaining high topography and balancing peripheral flexural subsidence during building of the High Atlas topographic loads.

Plio-Pleistocene oblique plate convergence and modes of transtensional deformation in the south–southeastern Hellenic Forearc (Greece)

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Southward migration of the Hellenic subduction zone (HSZ) and north–south (N–S) extension within the overthickened Hellenic orogenic wedge began as early as Late Oligocene and increased the curvature of the subduction zone from a nearly straight E–W plate margin to its present arcuate map pattern. The subduction front continued to migrate southward with N–S extension reaching Crete at ~19 Ma, and high-pressure/low-temperature assemblages (HP/LT) were rapidly exhumed along a top-to-the-north extensional detachment until they reached the surface to serve as Middle Miocene sediment sources. The first extensional basins formed in the earliest Late Miocene, when continued N-S extension formed rapidly deepening elongated half-graben basins, striking parallel to the arc. The increasing curvature of the HSZ imparts changing kinematics of fore-arc deformation due to arc-parallel gradients in obliquity of plate convergence. On Crete this is evidenced by a change towards radial extension that dominated during the remainder of the Late Miocene, forming a series of N–S and E–W trending half-graben basins.

Numerical modeling (Ten Veen & Meijer, 1998) have shown that from 11 Ma till 5 Ma arc-normal pull, acting on a curved arc geometry, seems to be the dominant force distribution responsible for radial extension in the overriding plate. This corroborates the observations on the style of extension/deformation for that period on Crete. Model results for the last 5 Ma predict an increased transform resistance along the eastern segment of the arc (Pliny and Strabo trenches) due to increased obliquity. This Pliocene change in fore-arc kinematics established the neotectonic strain regime of the southern Hellenic Arc, which is suggested to be than dominated by wrench tectonics.

Recent structural mapping/kinematic analyses, tectonostratigraphy, and chronostratigraphy on Crete and Rhodos addressed the changing kinematics along the strike of the Hellenic arc with increasing obliquity of convergence for the past 5 Myears. The Plio-Pleistocene Agia Galani Basin (Southern Crete) formed in response to faulting along a series of ENE trending strike-slip faults. An important part of the basin is made up of longitudinal syn-sedimentary dragfolds ("forced folds"), whereas older Miocene faults were reactivated as prominent normal faults. The NE trending Apolakkia Basin on Rhodos has an internal (syn-sedimentary) deformation that is characterized by forced folds, oblique normal faults and antithetic strike-slip faults. For both basins studied, the orientation of the main structures and kinematic analyses suggest that the basins formed due to sinistral wrench faulting where folds developed in response to either forced folding or contractional folding, but where the component of extension was equally important. In this way, by using the fill of Pliocene-Recent basins for temporal and paleogeographic control and documenting its syn- and post-depositional deformation as well as adjacent basement kinematics, the neotectonic deformation internal to the fore-arc uplift can be interpreted in terms of transtensional wrench faulting. Based on these results it is proposed that the Hellenic forearc is one of the few examples where oblique subduction resulted in transtensional rather than transpressional deformation. However, the mechanical coupling between the obliquely subducting lithosphere, the southward migrating subduction zone and deformation in the overriding plate is yet poorly understood. Future modeling, based on the new field data, may eventually help to solve these questions.

Coupling of lithospheric layers at wrenching plate boundaries: the clutch model

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Although geologists typically recognize that significant deformation at plate boundaries takes place in the mantle, the tie between mantle movement and crustal tectonics is not clear. Wrench settings are a particularly good place to evaluate this coupling. The critical tool to evaluate mantle flow is shear-wave splitting, which is thought to reflect strong crystallographic preferred orientation of olivine. Shear-wave splitting along most wrenching plate boundaries – including the San Andreas system, the Caribbean–South America plate margin, and the South Island of New Zealand – shows a delta t~1.0–2.0 s.

This large amount of splitting suggests the existence of a vertically-oriented shear zone extending downward to ~100–200 km. Using these data, we can qualitatively evaluate the interplay between these lithosphere-scale shear zones and the deformation of the crust. In the San Andreas region and the northern part of the South Island of New Zealand, the upper crust is broken into rigid slivers, typically 20 km wide, separated by strike-slip faults. However, the relationship between the structure of the upper crust and the lithospheric shear zone is unclear. Clues on the structure of the crust beneath the brittle layer can be found along the Caribbean-South America plate boundary. There, shear-wave splitting (delta t~2.0 s) has been interpreted as a mantle shear zone accommodating the westward translation of South America, relative to the relatively fixed Caribbean plate, over the last 50 million years. Deformation is concentrated on the northern lip of South America, from the eastern tip of Trinidad's Northern ranges to the Paría Peninsula in NE Venezuela. Here, metasediments of the South American paleo-margin were exhumed and display a cross section through the upper-mid crust, with metamorphic grade increasing westward (T~200 °C to ~400 °C). An EW cross section exposes several kilometers of crust, with subvertical foliations in the east, associated with upright folds, becoming subhorizontal eastward, through an interpreted brittle–ductile transition. In this zone, the lineations are east–west, subparallel to the plate margin.

Argon thermochronology suggests that these fabrics are Tertiary (20–30 Ma) and fission-track analysis has demonstrated that the metamorphic rocks were exhumed in the last 10 million years. Such fabrics may have formed to couple the plate-scale wrench zone in the mantle and lower crust to the overlying rigid upper crustal blocks. This coupling resulted in intense deformation within rheologically-controlled subhorizontal high-strain zones that transmitted deformation upward to the rigid blocks; this suggests that upper crustal deformation and mantle flow are connected. Subhorizontal reflectors recognized at ~10–20 km depth in the San Andreas region and most wrenching margins probably represent these coupling zones, which act as a clutch to connect the rigid upper crust to the lower part of the lithosphere.