Structural and petrologic analysis of the Vari Gneiss, a fault-bounded panel of quartzofeldspathic rock, Syros, Greece

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INTRODUCTION

The Greek Cyclades, located 300km north of the Hellenic Trench, have a metamorphic and tectonic history related to subduction. The Alpine Orogeny involved Cretaceous/Tertiary subduction followed by Miocene extension. The island of Syros consists mainly of semi-pelitic schist, marble, and metabasite that underwent blueschist-grade metamorphism (Ridley, 1984). The Vari Gneiss, however, is a fault-bounded quartzofeldspathic unit in southwestern-most Syros (Fig.1 insert) that is of lower grade. This study investigates the structural fabrics and metamorphic petrology of the Vari Gneiss in order to determine its relationship to the other rocks on Syros. Structural analysis reveals a three-stage deformational history for the Vari Gneiss. Petrologic work indicates a protolith of calcic arkose or granitoid and a metamorphic grade of upper greenschist/ epidote-amphibolite facies.

METHODS

Fieldwork consisted of structural mapping and observation of deformational features and their orientations. Samples were collected from across the unit and from surrounding rocks to encompass structural and compositional variations. Stereonet analysis in the lab used field measurements for geometric and kinematic interpretations of strain history. Thin section work, focused on mineral composition, textures, and microstructures, constrained the protolith, metamorphic grade, and sequence of deformational/metamorphic events.

DESCRIPTION

The Vari Gneiss is a homogeneous calcareous gneiss that crops out over 2km^2 between Azolimnos Point and Sandorinius Beach (Fig.1). The rock consists of 45-50% plagioclase ($Ab_{65\text{-}70}$ by Michel-Levy technique), 25-30% quartz, 10-15% muscovite, and 5-10% epidote. The Si to Al ratio for muscovite (3:2 by SEM analysis) indicates that white micas are poor in phengite, the high-P phase. A significant Fe component in epidote is suggested by its high birefringence. Chlorite locally makes up ≤30% of the Vari Gneiss in fractured zones. Mafic rocks crop out in a 200m^2 Fe/Mg-rich zone in the SW corner of the Vari Gneiss (Fig.1), where gneisses contain up to 15% amphibole and 10-50% chlorite.

Alternation of mm-scale plagioclase and quartz bands with muscovite and epidote layers defines the foliation. Amphibole and epidote exist as broken and fractured grains, while plagioclase and quartz form mosaics of euhedral or polygonal grains, reflecting recrystallization. Muscovite crystals make up distinct wavy bands. Retrograde chlorite commonly surrounds epidote and amphibole grains.

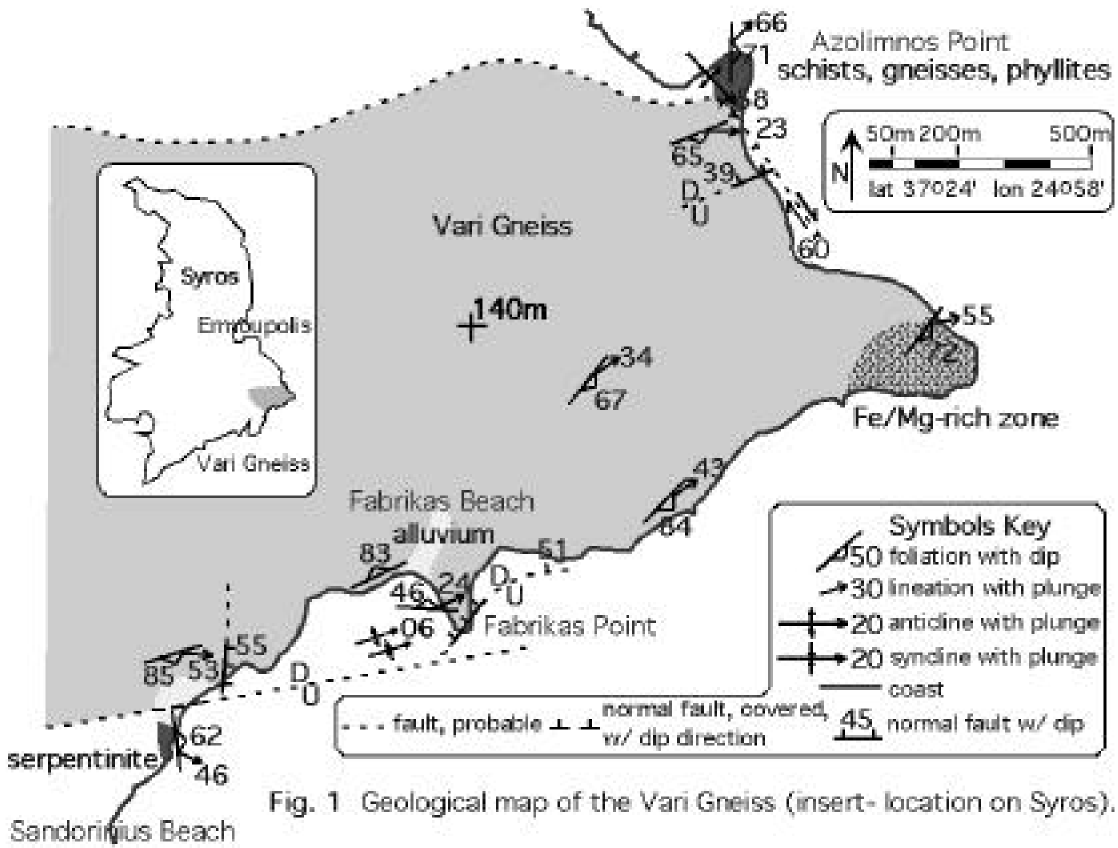


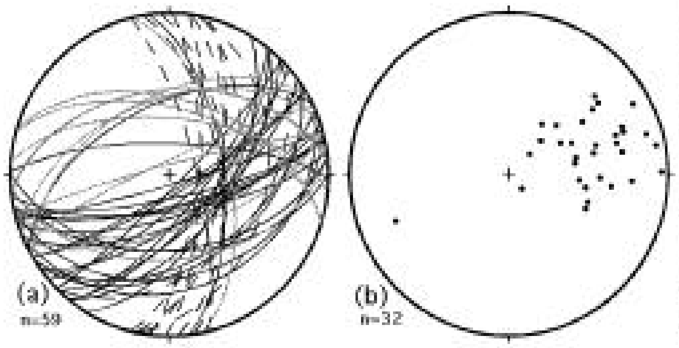
Fig. 1 Geological map of the Vari Gneiss (insert- location on Syros).

A strong but fine-textured mineral foliation and lineation exist throughout the Vari Gneiss. Plagioclase and quartz form subhedral, ~3mm-wide elongate grains that define the foliation as lenses and the lineation as rods. Muscovite grains are euhedral, 2-5mm-wide flakes that define the foliation. Epidote grains are granular-textured, generally ≤1mm in size, and therefore are not typically visible in hand sample. Foliation consistently strikes E-NE and dips moderately-steeply SE (Fig.2). Exceptions are near Fabrikas Beach, where foliation dips NW, and a group of rocks immediately outside the Vari Gneiss at Azolimnos Point that strikes N and dips steeply E. Lineation throughout the unit trends E-NE and generally has a moderate plunge (Fig.2).

Shear bands, or crenulation folds, are found throughout the Vari Gneiss, asymmetrically folding the foliation and lineation. Individual shear bands record ≤1cm offset. Striking NE with a shallow dip or SW with a moderate dip, most shear bands record reverse oblique movement. The asymmetric folds predominantly record NW vergence. Many microscopic ductile features exist in the Vari Gneiss, including asymmetric epidote porphyroclasts, muscovite tails (Fig.3), and S-C fabrics defined by muscovite packages. All of these deformational features dominantly record top-to-NW reverse movement.

A few map-scale folds exist within the Vari Gneiss. Around Fabrikas Beach (Fig.1) panels of NW-dipping foliation exist within regional SE-dipping foliation. Lineation orientation alternates between the panels, suggesting folding between them. A π-solution yields an E-NE striking fold axis with near-horizontal axial plane. Near Azolimnos Point (Fig.1) a SE-plunging fold explains the gradual shift in foliation orientation from a N strike at the point's tip to an E-NE strike 150m S of the point.

Truncating all ductile features, faults exist at each coastal boundary of the Vari Gneiss and within the unit. The boundary faults are recognized by zones of cataclasis, by discordance in foliation orientation, and by abrupt change in rock type. Brecciated zones that grade from cataclasite through fractured rock to fresh rock coincide with a coastal depression filled with alluvium (Fig.4). The SW coastal boundary near Sandorinius Beach (Fig.1) separates NE-striking Vari Gneiss from N-NW-striking serpentinite. The NE boundary separates Vari Gneiss from a suite of N-striking schistose rocks that contain garnet. The fault's N side consists of a highly sheared chlorite-rich phyllite. The Azolimnos Point rocks share many ductile features with the Vari Gneiss, but they record dominantly SW transport.



- - Azolimnos Pt group
— Fabrikas Pt (Vari)

Fig. 2 Vari Gneiss (a)foliation (b)lineation

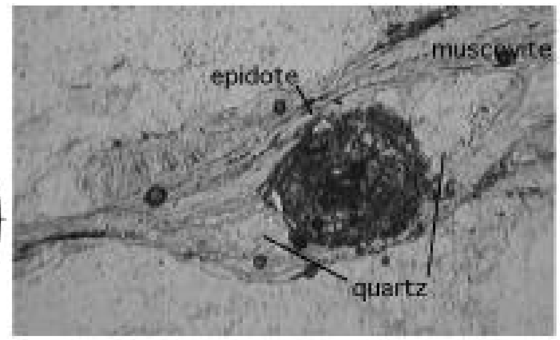


Fig. 3 Epidote porphyroclast with muscovite tails and pressure shadows infilled by quartz indicating dextral shear sense (top-to-NW).

The orientation and movement sense of both boundaries may be approximated by nearby distinct faults and fractures, since the boundaries themselves are wide brecciated zones. The NE boundary at Azolimnos Point (Fig.1) has an orientation defined by a distinct border between fractured and pristine Vari Gneiss that strikes NW and dips moderately SW. Two faults within the Vari Gneiss offset a green marker layer by 1m and lie 150m S of the NE boundary (Fig.1). The marker layer records normal displacement and probably represents the movement sense of the NE boundary fault.

The SW boundary fault's orientation is approximated by a fault that lies 100m to the N, striking N and dipping moderately W. This well-defined fault (Fig.4) has a 2m-thick layer of gouge. Also within the Vari Gneiss, two faults bound a semi-ductile zone that records normal displacement at Fabrikas Point (Fig.1). This fault pair is interpreted to be a continuation of the SW boundary fault zone. The normal offset may be indicative of the movement on the larger boundary fault.

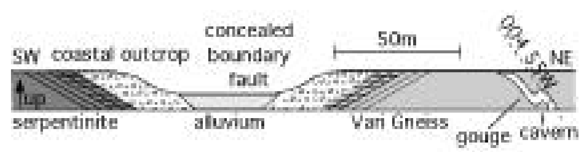


Fig. 4 SW Boundary near Sandorinius Beach

AN INTERPRETIVE HISTORY

The somewhat fine grain size and uniform distribution of minerals throughout the Vari Gneiss indicate either a sedimentary or granitoid protolith. The composition is Al-rich with a significant Ca component, and lesser amounts of Fe/Mg and Na, suggesting that the protolith was most likely a calcic arkose. Low occurrence of K-feldspar and abundance of plagioclase reflect either source rock composition or fluid alteration after deposition. Grain size and textural homogeneity are not diagnostic of a protolith since they could indicate a coarse sandstone or an intrusive rock.

Accretionary prism sediments are compositionally and texturally compatible with the Vari Gneiss. The Ca component suggests a marine environment, and calcite was consumed during prograde metamorphism and crystallization of epidote. The primary mechanism for burial of accretionary wedges is tectonic, with a contribution from tectonic sedimentation in a dynamic setting.

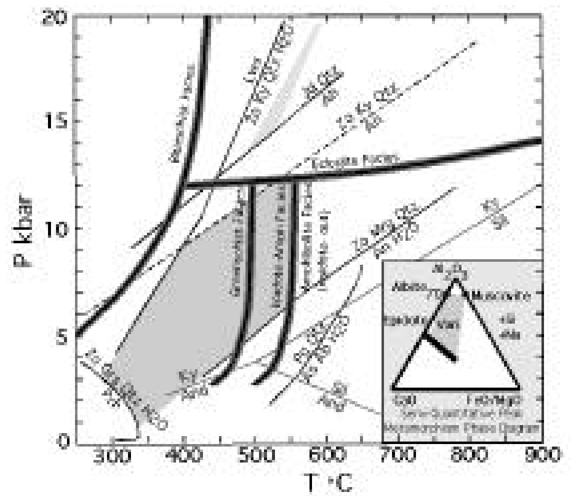


Fig. 5 ▭ Zone of Vari Gneiss peak metamorphism. Petrogenetic grid for the CKNASH system w/ excess Qtz and H_2O (based on Spear, 1993) ▭ Zone of metabasite high pressure metamorphism in northern Syros (from Ridley, 1984) (▬ Blatt & Tracy, 1996; --- Goldsmith, 1980)

The peak metamorphic assemblage consists of amphibole, epidote, plagioclase, and muscovite (Fig.5 insert). All were involved in deformation. The stability field for the assemblage is 5-12 kbar and ~500°C (Fig.5), which is the epidote-amphibolite (or upper greenschist) facies. Amphibole-producing conditions were achieved across the unit, although amphibole is found exclusively in the Fe/Mg-rich zone that had an appropriate composition for crystallization of amphibole (Fig.1). The Vari Gneiss composition outside this relatively mafic zone yielded little amphibole.

Foliation and lineation formed during or after peak metamorphism since all minerals in the peak assemblage align with foliation. The foliation and lineation orientations record WSW-ENE lengthening and NNW-SSE shortening. Shear bands developed after the foliation and lineation since they disrupt these features. Shearing records SW to NE stretching and NW to SE contraction, so it occurred during a late stage of the same event, or an event similar in orientation to the one that produced foliation and lineation. If so, the shear bands record a change in the shortening direction and convergence. Based on the recrystallization of plagioclase, shearing occurred at conditions >400°C (Weijermars, 1997).

Brittle faults and fractures formed later than the ductile features they cut. They formed at <3km depth based on their cataclastic deformation style. Retrograde metamorphism is spatially associated with brittle deformation, as illustrated by chalcopyrite and sericite concentrations near faults. Retrogression occurred where chlorite surrounds amphibole. The faults are extensional features that juxtapose lower grade upon higher grade rocks, through normal displacement, and generally record NW to SE lengthening.

The map-scale folds previously discussed probably relate to faulting since both fold sets occur adjacent to faults. The fold at Azolimnos Point (Fig.1) likely results from drag folding along the NE boundary fault zone. Drag folding of this orientation indicates a right-lateral component of offset on the fault zone.

REGIONAL COMPARISON

The protoliths of Syros rocks, including pelites, limestones, and mafic volcanics, may have coexisted with the Vari Gneiss protolith in a sea floor setting. The metamorphic grade of other Syros rocks strongly contrasts that of the Vari Gneiss. The Vari Gneiss has experienced pressures ~10kbar lower (Fig.5) than the blueschist and eclogite facies rocks that make up Syros (Ridley, 1984). However the fabric orientations within other Syros rocks match those in the Vari Gneiss, suggesting that both were involved in the same tectonic event(s). The blueschists 1.5 km SW of the Vari Gneiss SW boundary have E-NW striking and shallowly N dipping foliation, shallowly NE plunging lineation, and microscopic ductile features recording top-to-NW transport (Sable, this volume). Furthermore the entire W Cyclades structural domain exhibits a SW-NE stretching direction (Lister and Forster, 1996).

A scenario of subduction in an accretionary prism may be helpful in understanding the compatible protoliths, matching deformational fabrics, and contrasting metamorphic histories between the Vari Gneiss and its surrounding rocks. In this model (Fig.6), blueschist-grade rocks of Syros would have been underplated material within the subduction zone, and Vari Gneiss could have been tectonic sediments shed into the trench. This process of convergence and thickening across the accretionary wedge generates an instability that causes extension. During lateral spreading of the thickened crust, normal faults place lower-grade hanging wall rocks down against the higher-grade footwall. In this way, the Vari Gneiss from a higher structural level could be juxtaposed against the high-P sequence that comprises the rest of Syros. Rotation on listric faults could explain the steep foliation in the Vari Gneiss, which contrasts that of other Syros rocks.

The Vari Gneiss was subducted less deeply but developed in a setting similar to the other Syros rocks, as indicated by its lower grade but similar high-P, low-T track. The foliation and shear band fabrics probably developed during Alpine convergence. The rocks of contrasting grade were juxtaposed via normal faults, just as the accretionary prism model depicts. Further work to reconstruct the Vari Gneiss P-T path would involve a more quantitative petrologic analysis, with detailed thermobarometry to enhance our understanding of the Vari Gneiss in a tectonic context.

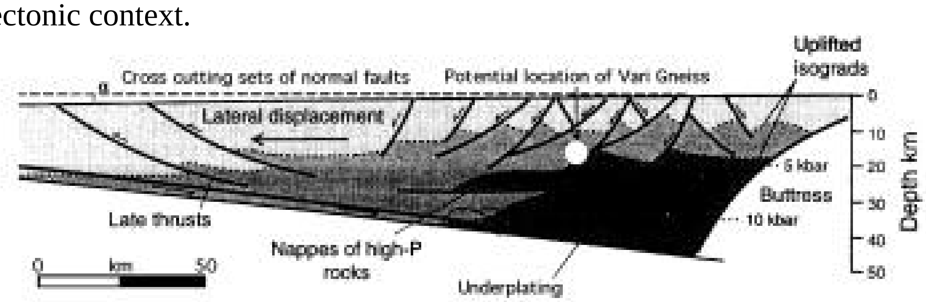


Fig. 6 Cross section of accretionary prism model illustrating extension of the upper crust and simultaneous underplating at depth. Blueschist material (black) metamorphosed in the base of the wedge is juxtaposed next to lower grade material (grey) via normal faults. (from Spear, 1993)

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