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POLYPHASE MESO- TO CENOZOIC STRUCTURAL DEVELOPMENT ON POROS ISLAND (GREECE)

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ABSTRACT

A polyphase structural edifice of Meso- to Cenozoic sedimentary and ophiolitic rocks is exposed on Poros Island (Argolis, Greece). Early to Middle Cretaceous platform carbonates (Akros Formation) and slumped calciturbiditic slope deposits (Poros Formation) (tectonic phase F1) show an upward transition to Upper Cretaceous siliciclastic carbonates and Maastrichtian-Eocene flysch (Ermioni Complex), indicating a convergent tectonic regime (F2). Cenomanian-Turonian ophiolite emplacement is documented by coarsening upward flyschoid serpentinite breccias intercalated with Akros limestones, being overthrusted by massive serpentinite (F2). Early to Middle Tertiary thrusting (F3) results into an imbricated nappe stack. Mélanges and Serpentinite lenses within the thrust planes absorb most of the strain. Pre-pliocene SE and SSW vergent folding (F4) and Neogene to present normal faulting and associated volcanism (F5) characterize the later phases of deformation. A new tectonic and a geological map are presented.

KEY WORDS: Argolis; Mesozoic; Poros Island; thrusting; serpentinite; detritus; Akros Formation; Poros Formation; Ermioni Complex; Greece.

1. INTRODUCTION

The alpidic orogen of the Hellenides is build of several SW to S vergent nappe zones, the West and Central Hellenic Nappes, the Median Crystalline Belt, and the Innerhellenic Nappes, thrusted over a southern vorland (Jacobshagen, 1979). Two parallel Tethyan ophiolite belts, the Vardar zone to the east and the Pindos zone to the west, border the Central Hellenic Pelagonian Nappe Group which is thought to represent an accreted microcontinent. Rifting from Gondwana took place in Mid-Tertiary times (Pe-Piper & Piper, 1984). Ophiolite emplacement and closure of the basin took place in the Late Jurassic to Early Cretaceous (Aubouin, et al. 1970) with latest obduction events in Turonian (Schwandner, 1997) to Early Tertiary times (Clift & Robertson, 1989). Several workers suggested that the Pindos basin remained open until the Eocene, as indicated by continuous deep water sedimentary successions in northwestern Peloponnesos (e.g., Degnan & Robertson, 1991).

The southwest facing Subpelagonian margin as exposed in the Argolis Peninsula (NE Peloponnesos) comprises Triassic to Tertiary sedimentary sequences, Jurassic ophiolites, and island arc volcanics (Dietrich, et al, 1987; Clift & Robertson, 1989). Due to the latter the Argolis Peninsula acquires an ambiguous position of a probably segmented platform/margin setting (Clift & Robertson, 1990b). Robertson et al. (1987) identified the Argolic Upper Cretaceous to Eocene calciturbiditic and flysch succession as an accretionary complex (Ermioni Complex), overthrusted onto the Argolis Platform to present NNW (Clift, 1996). It is build of an up to 8 km thick stack of Maastrichtian to Eocene terrigenous turbidites (Bachmann & Risch, 1979), slivers of MOR-Basalts (Clift & Robertson, 1989), and Cretaceous carbonate successions of the Ermioni, Akros and Poros Formations which are exposed near Ermioni and

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on Poros Island. The island of Poros is situated off the northeastern Argolis coast, in the Saronic Gulf. A geological overview is provided in Fig. 1.

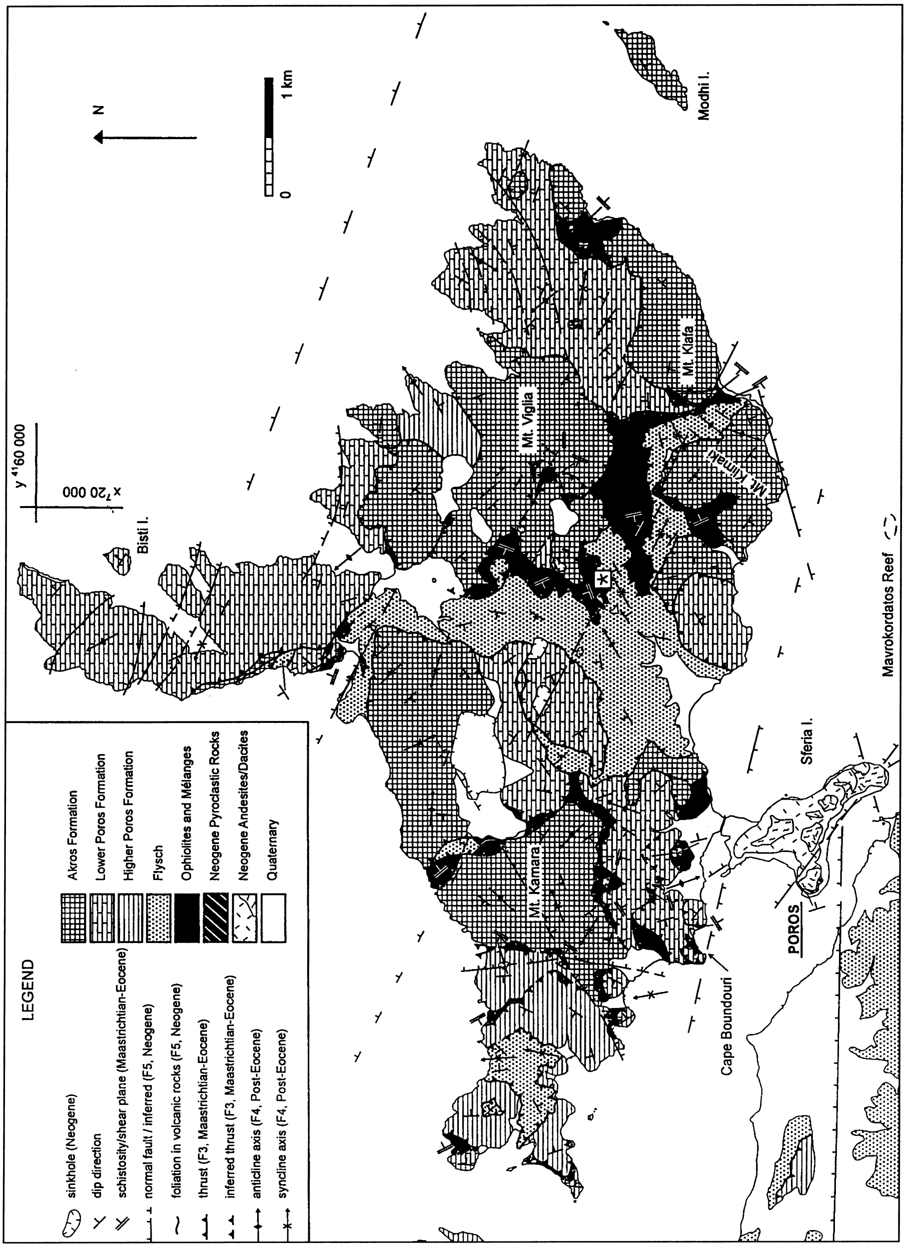

Fig. 1: Structural map of Poros Island with major lithological units, simplified from Schwandner (1997). The star shows the location of the section in Figure 2.

2. LITHOLOGIC UNITS EXPOSED ON POROS ISLAND

Akros Formation

(Aptian-Turonian)

The Akros Formation (Philip, et al., 1989; "Massenkalk" of Bachmann & Risch, 1979) is characterized by poorly bedded shallow water rudistid limestones (rudstones and packstones) alternating with density flow derived intraclastites. At the eastern flank of the Klafa Mountain, a representative section of three fining upward cycles is exposed with a minimum stratigraphic thickness of 310 m. The neritic facies forms the basis of each sequence and its frequent several meters thick banks assume a dominant position throughout the section. It has rudists in situ and poorly graded/banked intraclastic beds with rudist shell fragment clusters which are replaced by chert.

Furthermore, chert-replaced, cm-thick siliciclastic intercalations with current lamination and load casts indicate temporarily fast sedimentation, in dm- to m-sized banks. Coarse clastic tongues with a lateral dimension of up to 2-3 meters-within massive micritic limestone-point to at least sublitoral deposition. Due to shell fragments of nerinea, rudists, and other bivalves combined with rare corals and bryozoes found at Askeli and Kalami this facies resembles remarkably certain outcrops on Methana. In microfacies, subsparitic rudstones and packstones with ichnofossils, echinoderm and gastropod fragments, and the paired occurrence of peloids and micritized pellets/shell fragments indicate a platform environment depositional setting for the Akros Formation. Synsedimentary deformation and the clastic content increase upsection. Together with an average thinning of the banks this indicates a retrogradation or drowning of the platform.

In the Eastern part of the island, intercalations of flyschoid microbreccias occur within the Akros limestone, with chert and serpentinite as the major fragment lithologies. They increase upward in abundance, frequency and unit thickness to become an olive colored succession of chert bearing serpentinite microbreccias with only few marly limestone interbeds. Within 4-10 m stratigraphic thickness they culminate into an alternation of meter-sized graded coarse monomict serpentinite breccias and cm-thick flyschoid sepentinitic marly sands. A rapid increase in clast size with abundant metagabbro clasts, coarsening upward character, limestone matrix and a final clast accumulation to 95 % volume serpentinite with directly overthrusted massive serpentinite points to a submarine ophiolite emplacement, as shown in Figure 2. Near Nea Epidauros on the mainland, the lower boundary is transgressional (Philip, et al., 1989). The oldest banks date at least of the Lower Cretaceous on Poros (Schwandner, 1997). The youngest Akros limestones date from the Turonian on Poros, as indicated by the microfauna in culminating polymict serpentinite parabreccias with limestone matrix, beneath submarine overthrusted serpentinite (Figure 2; Schwandner, 1997).

Lower Poros Formation

(?Barreme-Cenomanian)

The Poros Formation (Clift & Robertson, 1990b; "Allodapische Kalke" of Bachmann & Risch, 1979) is a calciclastic flyschoid succession. It contains several meters thick, poorly graded, calcic intraclastite banks with fragments of Akros limestone and rudists/bivalves/bryozoes. These thick interbeds occur in a succession of typically dm-thick quartz-free calciturbidites with an upward increase of the siliciclastic content. Synsedimentary deformation is present by several tens of meters scaled slumps and intrafolial normal faulting towards the top. Cm-sized calcic arenites occur as interbeds every 0.5 to 4 m. Ribbon and nodular chert is typical for the whole section, the latter being boudin-like results of presumably postdiagenetic extension. Purely marly sections of up to 1.5 m beneath red colored, chert rich laminated sections with reduced Bouma cycles indicate a more distal depositional setting. Throughout the oldest beds of the Lower Poros Formation rudist fragments indicate a Cretaceous age but not Upper Jurassic as Clift & Robertson (1990a) suggested.

The upper boundary has been arbitrarily defined as the volumetric increase of the calciturbiditic beds to over 50 % by Clift & Robertson (1990b). This definition does not distinguish terrigenous from limestone detritus and bears the problem of cyclic repeated occurrence of calciturbidites through the section. However, the terrigenous fraction increases upsection. Taking only the terrigenous detritus content into account, the definition would point to an increasing sediment supply which can be explained in terms of source activation and relief steepening. Applying this modified definition, a seperation into the Lower Poros Formation being a slope facies, parallel to the Akros Formation (platform facies), and the purely calciturbiditic, distal Higher Poros Formation becomes useful. The boundary approximately equals that between the "Allodapische Kalke" and the "Kalk Mergel Serie" of Bachmann & Risch (1979) which is of

Turonian age. According to the interpretation of Clift (1996), the Higher Poros Formation would form the basis of the accreted Ermioni complex.

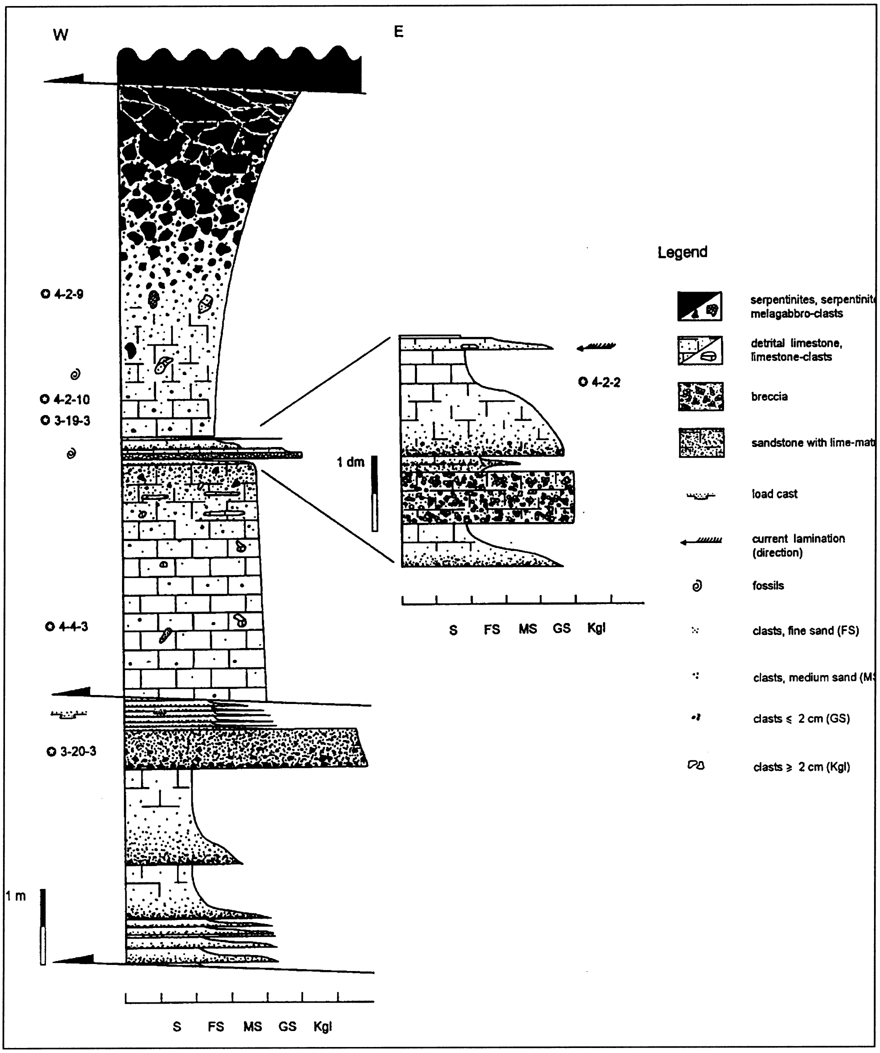

Fig. 2: Stratigraphic type section of flyschoid serpentinite breccias culminating into serpentinitic breccias (see discussion in the text). Road cut at the southern Viglia flank, UTM [x 719940; y 4155070], from Schwandner (1997).

Higher Poros Formation

(Turonian-Maastrichtian)

The Higher Poros Formation (Schwandner, 1997; “Kalk Mergel Serie” of Bachmann & Risch, 1979) forms a uniform succession of marly limestones and graded marls with abundant nodular chert towards the base. Calciturbidites alternate with marly limestones. To the top, red and green marls of up to 12 m thickness with first quartz grains mark the transition to quartzous turbiditic sedimentation of the Flysch. The color of the marls is postsedimentary, as it is visible by the obvious roll front character. Synsedimentary deformation is abundant throughout the whole section: 0.5 to 4 m slump bodies, slump delamination shoulders, olistholites, and meter-scaled syndepositional faults show the highly active character of the slope surface. Clasts in the coarse basal beds of in most cases complete Bouma cycles are mainly limestone, chert and in increasing abundance up to 20 % serpentinite. Following Bachmann & Risch (1979), the base of the Higher Poros Formation is of Turonian age. Pink nodular limestones typically below the transitional marls of the top of the section are of Maastrichtian age.

Flysch

(Maastrichtian-Eocene)

As set forth in the definition of Suesskoch (1976), the boundary to the Argolic flysch is drawn at the first occurrence of quartzous sandstone banks which typically occur within the transitional marls. Sandy to conglomeratic turbiditic quartzous sandstones, often with carbonaceous matrix, and sandy marls form the main body of the flysch. Complete Bouma cycles and bank thicknesses up to 5.5 m with short lateral extent reflect an affinity to type II turbidites of Mutti (1985). Convolute bedding and reworked flysch sandstone clasts within the beds indicate fast sedimentation and unstable slope conditions. These features combined with coarse channelized breccias at the base, and synsedimentary imbrication imply fast accretion and a proximal setting. This is supported by the observation of intercalated pillow lavas and flows on the mainland (Clift, 1996). Serpentinite phacoids, intense strata parallel shear, and imbrication demonstrate the intense tectonization. Towards the top of the section, the marlier and more conglomeratic character of the flysch shows a relative retrogradation of the depositional center. The total structural thickness is at least 120 m on Poros, on the Argolic mainland at Adheres Mountain it is up to 8 km (Clift, 1996).

Ophiolites: Serpentinites, Gabbros, and Basalts

(Upper Jurassic?)

The serpentinite bodies on Poros are almost exclusively in intensively sheared tectonic contact to their wall rocks. Three different phenotypes can be distinguished on the basis of their shear fabric and grade of alteration/metamorphosis. The *Massive serpentinites* are metaharzburgites with a rythmic banding. Bastite clusters after orthopyroxene and lizardite after olivine, as well as resorbed Cr-spinel with magnetite reaction rims make up their main constituents. Most of the smaller (< 100 m) serpentinite bodies are of *green, sheared serpentinite. Penetrative sheared and kakiritic serpentinites* occur as the main strain absorbing lithologies in shear zones. Grain rotation indicates quasiductile behaviour. The enrichment of secondary Magnetite, iron oxhydrates, and talc/calcite/lizardite characterize the mineralogy. Mineral reactions in order of occurrence through time are serpentinization, bastitization, magnetite growth on the expense of Cr-spinel, and carbonatization. The latter seems to be due to hydrothermal alteration, as indicated by carbonate growth on the expense of bastite and along cracks into the rock. Olivine and orthopyroxene are preserved in the bay between the Klafa and Klimaki Mountains.

Gabbros are only found as exotic fragments within serpentinitic breccias. *Basaltic lava* clasts are rare and often brecciated and/or sheared. Calcite veining and high Na_20 content document spillitization. Hyaloclastite fragments indicate subaquatic extrusion in considerable water depth. X-ray diffraction revealed the paragenesis albite-quartz-calcite-dolomite-prehnite which points to the lower greenschist facies. Analysis of leached and pure samples by XRF reveal altered trachybasalts with N-MORB-affinity which is obscured by alkali enrichment. Discrimination diagrams even on the basis of relatively immobile trace elements show an alteration-induced shift away from the MORB-field usually into intraplate volcanics. Main occurrences of those lavas are as fragments in serpentinitic and flyschoid mélanges.

Ophiolites: Serpentinite Breccias

(Turon-?Paleocene)

In association with serpentinite bodies, chaotic to poorly graded breccias with serpentinite as the major clast lithology are found on Poros. Two different facies groups can be distinguished on Poros. The one group as described above represents culminating monomict serpentinite breccias with directly overthrusted massive serpentinite, developing from the flyschoid chert/serpentinite breccias within the Akros Formation (Figure 2). Intercalated limestones contain Turonian Globotruncans (Schwandner, 1997). The other facies group is a poly- or monomict orthobreccia in limestone matrix. It occurs in the form of partly graded bands of approximately 10 m thickness around certain serpentinite bodies, indicating a submarine deposition, probably as thrust fronts sticking out of the shelf surface. Within the flysch serpentinite bearing chaotic polymict ortho-megabreccias as well as monomict parabreccias with pillow lava fragments occur.

Mélanges

(?Eocene)

At the base and within the larger thrust sheets of the flysch and the Higher Poros Formation, serpentinitic and flyschoid mélanges can be found on Poros Island. Purely flyschoid mélanges are found along the western coast, NW of Kamara Mountain, and in Variarnia Bay. Serpentinitic mélanges are found in the eastern monastery valley at 120 m altitude in the bay between Klafa and Klimaki and at the eastern flank of Cape Boundouri. Clasts are typically serpentinitic breccias, flysch sandstone, and serpentinite. Rare pillow lava and metagabbro clasts are abundant as well.

Neogene Volcanic Rocks

On Sferia Peninsula between Poros and the mainland and possibly at the Mavrokordatos Reef, andesitic to dacitic porphyric volcanics with hornblende, biotite, b-crystobalite, and plagioclase phenocrysts are common. Mingling textures with mafic xenoliths form a foliation of parallel plagioclase and hornblende rich bands. The extrusive geometry and the foliation are oriented along a NNW-SSE striking lineament. At the western tip, lavas overly east dipping base surge deposits which are topped by a few meters of epiclastic soil.

3. STRUCTURE

F1: The Passive Margin: Synsedimentary Deformation

(Aptian-Cenomanian)

Within the upper Akros and Poros Formations, synsedimentary extension is evident through slumping and syndepositional normal faulting in a meter- to cm-scale. Transport vectors are oriented towards the present SW (Clift & Robertson, 1990a). Taking the long wavelength (km-scale) folded character of their measured sections into account, the fold axes can be rotated back to yield a rather SSW orientation of transport, as seen on the mainland. Later thrusting and rotation on listric conjugate thrusts make a reconstruction of the original slope orientation rather dubious. The oldest beds deformed this way date of Aptian, the youngest of at least Cenomanian time.

F2: Transition from Passive to Active Margin Setting and Ophiolite Obduction

(Turonian-Maastrichtian)

The increase of siliciclastic detritus into the Higher Poros Formation, the increasing abundance and size of serpentinite clasts, and the parallel development of flyschoid serpentinitic breccias document advancing thrust sheets of serpentinite within the shelf body, indicating complementary accretion. More frequent slumping and the transition to flyschoid sedimentation require a steepened relief of the source area. In addition, synsedimentary high angle normal faults dissect the yet unconsolidated sediments. These phenomena all point to a now convergent tectonic environment leading to first submarine ophiolite emplacement in Turonian times (Figure 2).

F3: Orogenic Stage: Thrusting and Imbrication

(Maastrichtian-Eocene)

After primary ophiolite emplacement, flyschoid sedimentation starts in the Maastrichtian, which indicates an activated sediment source. Synsedimentary thrusting within the flysch and overthrusting of this accretionary pile on mélange horizons characterize the orogenic stage. Due to the limestone matrix of flyschoid sediments still documenting marine conditions, closure of the basin is considered to have occured no earlier than in Paleocene time. Serpentinite shear lenses absorb most of the strain whch becomes evident through the intense tectonization within those bodies relative to the sedimentary rocks. The thrusted nappe edifice is build of a base of Akros limestone, Poros Formation and Flysch as the next layer, Higher and Lower Poros Formation above this, and Poros Formation + Akros limestone with flyschoid serpentinitic breccias at the top. Those latter units show oblique tectonic folds indicating SW vergent transport. Serpentinite bodies of up to 1 km in size usually occur within the thrust planes. The uppermost Akros limestone forms several prominent klippes along the southern and eastern coast.

F4: Collisional Folding

(Pre-Pliocene)

SSW and SE vergent, long wavelength folding of the whole edifice documents the collisional stage. Jacobshagen & Skala (1977) have confirmed these directions for a majority of the Greek Hellenides. The serpentinitic thrust planes are folded in the same manner. This deformation predates F5.

F5: Normal Faulting and Volcanism

(Pliocene-recent)

Postorogenic Neogene extension in the Hellenides as a response to a changed stress field allowed the ascent of subduction related melts which underwent different stages of fractionation, mingling, and hybridization (Dietrich, et al., 1988; Papazachos & Comninakis, 1993). Onset of Neogene initial volcanism (dated on Poros 3.1 Ma) is typically with silicic melts by pyroclastic eruptive activity. This pattern is evident on Methana and Aegina (Dietrich, et.al., 1988) as well as on Poros (Schwandner, 1997). Major fault geometries are oriented ENE-WSW, NW-SE, & SSW-NNE on Methana (Dietrich, et al., 1995) and are two intersecting NW-SE striking/SW dipping and WNW-ESE (Graben of Trizinia) striking normal faults on Poros (Schwandner, 1997).

4. CONCLUSIONS

The main results of this study consist of the following: new geological mapping results of the island with the lithological units summarized in this paper; a structural and geological map (both simplified in Figure 1) and both presented on the 8th International Congress of the Geological Society of Greece, Patras, May 27-29, 1998; the detailed stratigraphic description which also yielded the Turonian age of the initial thrust emplacement of the ophiolites (Figure 2). The above as well as new and refined tectonic data on the nappe edifice on Poros Island indicate a SW vergent thrusting with multiple repetition of single units. SW vergent stacking with Akros limestone flyschoid serpentinite breccias on top allows for relative repositioning of this unit to the present NE.

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