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Selected case studies in the high and ultrahigh pressure terranes of Dabie Shan and Sulu (China)

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ABSTRACT. — A unique metamorphic terrane, the Dabie Shan and Sulu regions in east-central China, is well known worldwide for the widespread occurrence of rocks with ultrahigh pressure metamorphic (UHPM) overprint. Among the considered case studies, the Zhujiachong quartz-eclogites and related metamorphic veins followed a clockwise P-T path. The veins are considered to have formed before metamorphic peak by prograde breakdown of lawsonite. The eclogitic peak, estimated at ca. 2.4 GPa and 700 °C, is followed by a two-stage retrograde evolution. UHPM talc-kyanite quartzite with the mineral association typical of «whiteschist» has been found in Dabie Shan at Hualiangting. The geologic setting and trace element geochemistry suggest that the whiteschist derived from a felsic dyke. A minimum P of 2.6-2.7 GPa and a T of ca. 710 °C have been estimated for the metamorphic peak. The identification in Dabie Shan of a E-W trending narrow belt ca. 40 km long and 1-2 km wide, the Wuhe-Pailou Unit (WPU), supports the «in-situ» origin of the UHPM, and constrains the real size of the exhumed tectonic units. A clockwise P-T path was inferred for the WPU, which consists of an early prograde part up to P ~ 3.3 GPa and T ~ 720 °C and a two-stage retrograde evolution. In southern Sulu, at Donghai, kyanite-phengite-epidote eclogite and kyanite – OH-rich topaz quartzite were subjected to UHPM at P ~ 3.5 GPa and T ~ 850 °C. The growth of hydrous and/or zoned minerals under eclogite facies conditions is promoted by brines with variable salinity and type of dissolved cations ± CO_2. The presence of high-density brines at the coesite to quartz transition is also suggested by the primary fluid inclusions within OH-rich topaz and by the related isochore that indicates P = 2.8 GPa at 800 °C. Considerable differences in peak metamorphic P have been recorded by quartz- and coesite eclogites in Dabie Shan and Sulu, but the shape of post-peak P-T paths, characterized by a significant decompression coupled with minor cooling, seems to be peculiar of all studied units.

RIASSUNTO. — La catena orogenica del Dabie Shan e Sulu in Cina centro-orientale è famosa per la diffusione di rocce metamorfosate in condizioni di pressione molto alta (UHPM). In questo lavoro sono descritti litotipi il cui studio ha contribuito alla comprensione di importanti aspetti dei processi di collisione continentale, quali la dimensione delle unità geologiche subdotte ed esumate, l'origine locale o esotica del UHPM, la natura dei fluidi presenti al picco metamorfico. Nell'area di Zhujiachong (Dabie Shan), vene metamorfiche associate a eclogiti sono state interpretate come il prodotto di reazioni prograde di disidratazione vicino al picco metamorfico. La presenza di lawsonite tra i minerali della fase prograda ha permesso di ipotizzare la cessione, in condizioni

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eclogitiche, di significativi volumi di fluido acquoso. Nell'area di Hualiangting sono stati studiati «scisti bianchi», probabilmente derivati da originari filoni aplitici. In queste rocce il picco di UHPM è ben vincolato dai dati petrologici, che sono coerenti con quelli ottenuti nelle eclogiti associate. L'Unità di Wuhe-Pailou (WPU), cartografabile per oltre 40 km, è costituita dall'associazione di gneiss, marmi, eclogiti e quarziti a giadeite, con relitti di UHPM. Evidenze petrologiche suggeriscono l'estensione regionale del UHPM. A Donghai (Sulu), il picco di UHPM ottenuto dallo studio di eclogiti e quarziti è di T ~ 850 °C e P ~ 3,5 GPa. Tale studio ha evidenziato che la crescita, in condizioni eclogitiche, di minerali idrati e/o zonati è stata favorita dalla presenza di fluidi ad $H_2O \pm CO_2$ con salinità e tipi di ioni disciolti variabili. Le inclusioni fluide primarie in un topazio ricco in OH e la relativa isocora confermano che questo minerale è cresciuto in presenza di un fluido acquoso ad elevata salinità e densità, in condizioni P-T corrispondenti alla transizione tra coesite e quarzo. Il cammino P-T delle unità studiate è caratterizzato da condizioni di picco barico piuttosto diverse ma da traiettorie decompressionali molto simili, con una prima fase quasi adiabatica che suggerisce una comune evoluzione tettono-metamorfica nella fase esumativa.

KEY WORDS: *eclogite, coesite, ultrahigh pressure metamorphism, Dabie Shan, Sulu, China.*

INTRODUCTION

Coesite, the ultrahigh pressure polymorph of silica, was first described in continental crust twenty years ago in the Dora-Maira Massif of the Italian western Alps (Chopin, 1984). Since that time, evidences of ultrahigh pressure metamorphism (UHPM) have been found in several localities of the world (for a comprehensive review, see Carswell and Compagnoni, 2003). After two decades of UHPM studies, the Dabie Shan - Sulu belt is now universally recognized as the best UHPM area in the world, thanks to the widespread occurrence of rocks with UHPM overprint. Along this belt, several tectonic units preserve high pressure (HP) or ultrahigh pressure (UHP) mineral assemblages. The Dabie Shan - Sulu belt is a great natural laboratory to test important aspects of collision tectonics as for instance the «in-situ» or «exotic» origin of the UHPM rocks, the nature of metamorphic fluids at UHPM conditions, the size of the subducted tectonic units. The aim of this paper is to describe peculiar aspects of this metamorphic terrane, giving special emphasis to the scientific contribution of the Italian research groups.

The Dabie Shan – Sulu belt of east-central China belongs to the nearly 2000 km long orogenic belt produced by the Triassic collision between the Sino-Korean and the Yangtze plates. This belt, which extends from Qinling to Sulu, is displaced by the NE-SW trending left-lateral Tancheng-Lujiang (Tan-Lu) Fault, active since the Cretaceous (e.g. Wang *et al.*, 1995), with an offset of about 500 km between Dabie Shan and Sulu (Fig. 1). In the eastern Dabie Shan, tectonometamorphic zones include from north to south: the migmatitic North Dabie Complex (NDC), the UHP and HP Eclogite Complex (EC), and the epidote-amphibolite facies Susong Group (SG). The northern EC contains coesite-eclogite, while the southern EC is commonly regarded as containing only quartz-eclogite. In the Sulu belt, the Yantai-Qingdao-Wulian fault (YQWF) separates two sectors with strongly different geologic histories: NW of the YQWF, almost no eclogites have been found; SE of the YQWF, a complex mixture of UHP and HP rocks occur together with lower grade metamorphic rocks. A detailed description of Dabie Shan and Sulu geologic units is beyond the aim of this paper: for a comprehensive review of the regional geology, see e.g. Hirajima and Nakamura (2003).

HP METAMORPHIC VEINS IN DABIE SHAN QUARTZ ECLOGITE

Eclogite facies rocks have been extensively studied in the Dabie Shan - Sulu belt, but little importance has been given to the associated metamorphic veins. The presence of metamorphic veins in eclogites, usually

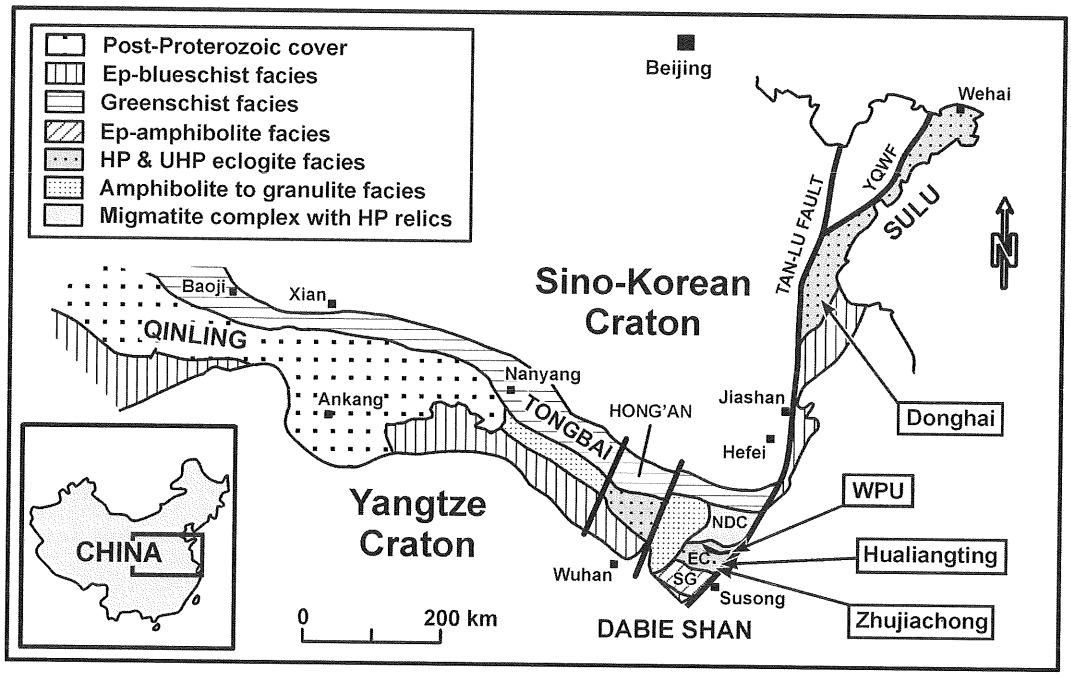

Fig. 1 – Simplified tectono-metamorphic sketch map of the Qinling – Dabie Shan - Sulu belt, eastern China. Arrows point to locations of the case studies presented in this paper.

considered as relatively «dry» rocks, is especially interesting since it may shed light on the nature and amount of fluid present during the HP and UHP metamorphism. Peculiar kyanite-zoisite-quartz veins and host eclogites, exposed in the Zhujiachong valley in the quartz-eclogite zone of the EC in Dabie Shan (Fig. 1), have been studied by Castelli *et al.* (1998).

The Zhujiachong quartz-eclogites and related veins occur within two micas - epidote - garnet - plagioclase gneiss as lenses up to 200 m thick and more than 1 km long. The metamorphic veins, up to 20 cm thick, show pegmatitic grain-size and consist of kyanite ± zoisite ± omphacite ± paragonite ± rutile ± apatite ± clinozoisite in a quartz matrix (Fig. 2a): kyanite and paragonite are partially replaced by a symplectite of corundum + oligoclase ± magnetite.

The eclogite is medium-grained and consists of omphacite [$(Na_{0.64}Ca_{0.33}Fe^{2}_{0.03})(Fe^{3}_{0.16}Mg_{0.34}Al_{0.50})Si_2O_6$], garnet (core: $Alm_{53}Prp_{21}Grs_{22}Sps_{03}Adr_{01}$; rim: $Alm_{54}Prp_{30}Grs_{11}Sps_{01}Adr_{04}$; Fig. 3a; mineral abbreviations after Kretz, 1983), clinozoisite, and minor kyanite and quartz, with accessory rutile, apatite, zircon and opaque ores. The garnet cores include clinozoisite, rutile, quartz, omphacite, glaucophane + Mg-taramite, paragonite and apatite. Locally, poikiloblastic zoned amphibole (core: glaucophane; rim: Mg-cummingtonite) occurs. Clinozoisite aggregates are interpreted as pseudomorphs after former porphyroblastic lawsonite. Garnet is rimmed or completely replaced by retrogression blue-green ferroan pargasite + plagioclase (An_{2-34}) + magnetite. Omphacite is partly replaced by early albite/oligoclase + diopside (X_{Jd} up to 0.13; Fig. 3a) and late albite + silicic edenite symplectites. Kyanite is often replaced by a hercynite + andesine ($X_{An} = 0.43$) symplectite.

Geothermobarometric calculations, mineral compatibilities of peak and retrograde minerals of both eclogite and veins and calculated phase

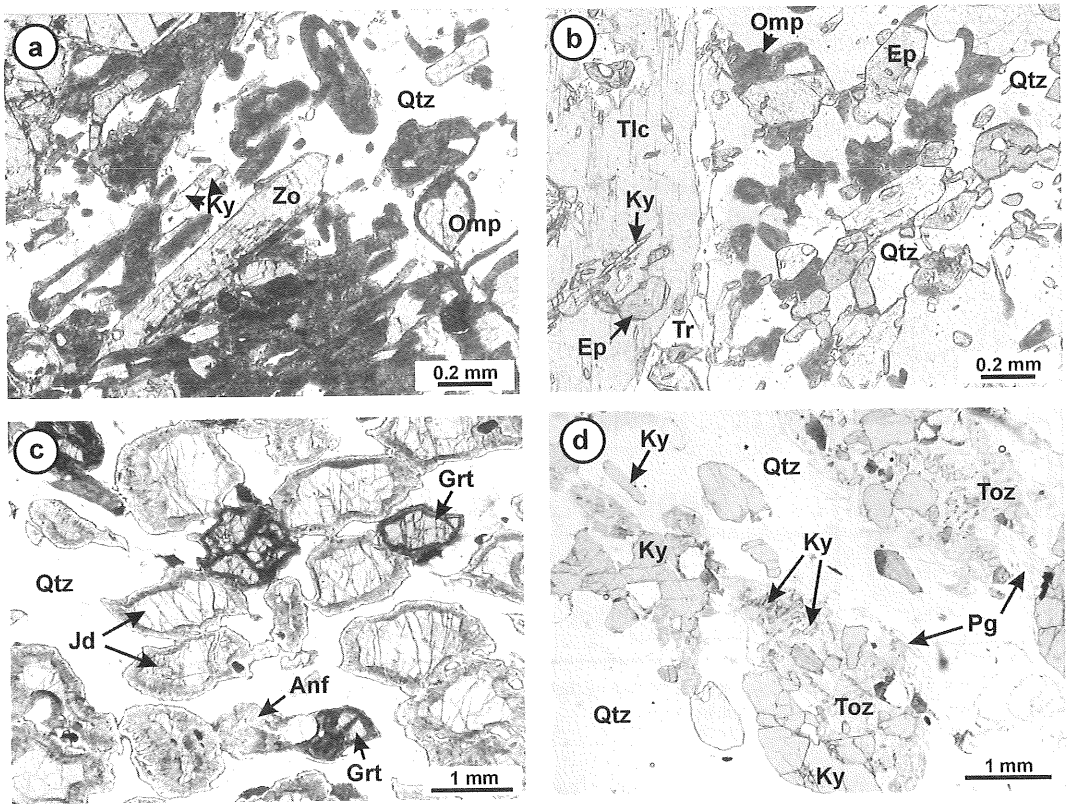

Fig. 2 – (a) Omphacite (Omp) - zoisite (Zo) - kyanite (Ky) - quartz (Qtz) vein from Zhujiachong (RPC106). Omphacite is replaced by a fine-grained symplectite of diopside and plagioclase. Plane polarized light (PPL). (b) Hualiangting whiteschist (RPC184), showing porphyroblastic talc (Tlc) in equilibrium with kyanite (Ky) and epidote (Ep). Former coesite was replaced by granoblastic quartz (Qtz). Note the retrograde tremolite (Tr) rim around talc and the symplectite after omphacite (Omp). PPL. (c) Jadeite-bearing granofels, Xinjian (RPC250), mainly consisting of quartz (Qtz) after coesite, jadeite (Jd) and garnet (Grt). Amphibole (Anf) grows at the expense of garnet. Polyphase coronitic retrogression around jadeite and garnet is evident. PPL. (f) Weakly foliated quartzite from Hushan, Donghai (RPC781), consisting of quartz (Qtz), kyanite (Ky), OH-rich topaz (Toz) and paragonite (Pg). OH-rich topaz contains kyanite relics and is rimmed by retrogression paragonite. PPL.

relationships suggest a clockwise P-T path (Fig. 4), characterized by initial eclogitic conditions from the lawsonite to the epidote stability field. The veins possibly formed before peak metamorphic conditions by prograde breakdown of lawsonite, the fluid released favoring the growth of coarse-grained vein minerals. The eclogitic peak, estimated at ca. 2.4 GPa and 700 °C, is followed by a two-stage retrograde evolution: the earlier stage, characterized by quasi-adiabatic decompression from eclogite- to amphibolite facies conditions, implies a rapid exhumation from depths of ca. 90 km to mid crust levels (P > 0.8 GPa and T=700 °C); the later stage, which occurs under greenschist facies conditions, is characterized by slower exhumation rates.

The widespread occurrence of veins and their pegmatitic grain-size requires the presence of abundant fluid which was probably stored in metamorphic mineral phases such as lawsonite. From the number and average size of

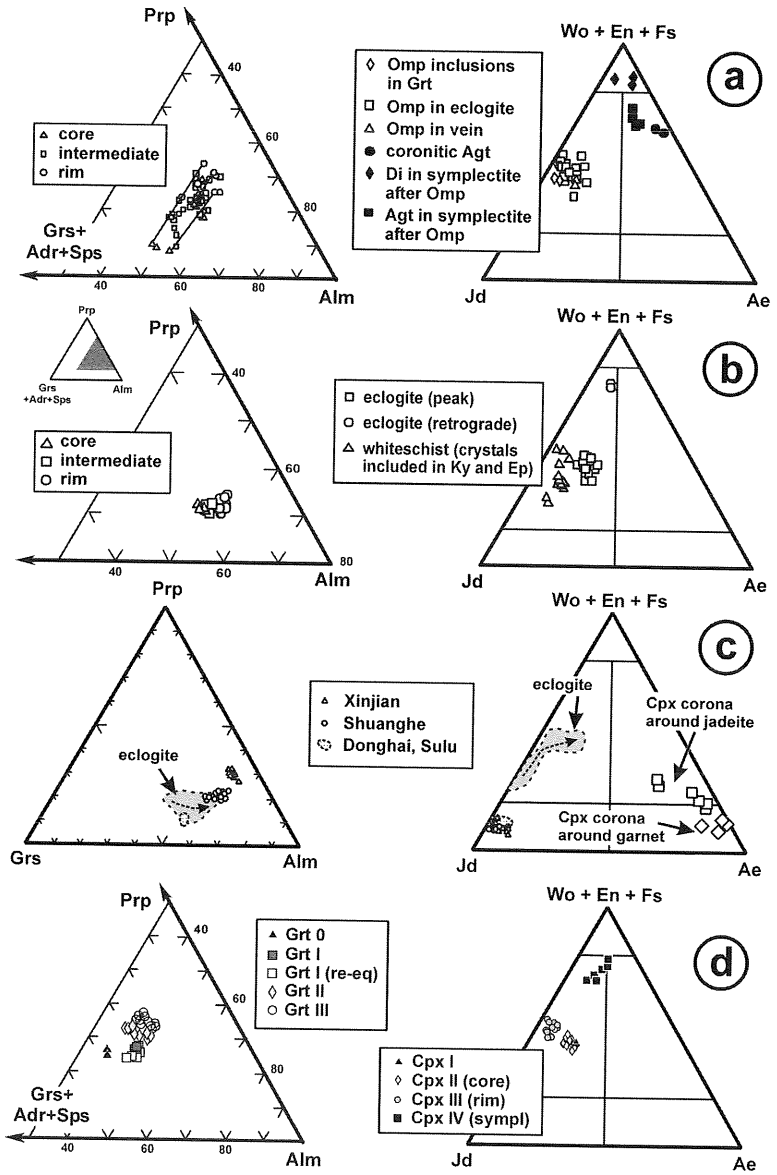

Fig. 3 - (a) Zhujiachong HP unit: garnet compositions from eclogite. Tie lines link core to rim compositions. Compositions of peak and retrograde clinopyroxenes from eclogite and veins (Rolfo, 1998). (b) UHP whiteschist and host eclogite at Hualiangting: compositions of garnets and of peak and retrograde clinopyroxenes (Rolfo *et al.*, 2000). (c) Wuhe-Pailou Unit (WPU): compositions of UHP peak garnet and clinopyroxene from jadeite-bearing granofels from Shuanghe (Cong *et al.*, 1995; Liou *et al.*, 1997) and Xinjian (Rolfo *et al.*, 2004), Dabie Shan, and from Donghai, Sulu (Zhang *et al.*, 1995). Compositions of garnet and clinopyroxene from different eclogites of the WPU are also plotted for comparison; dotted lines show the trend of chemical zoning, arrows pointing to rim compositions. (d) Hushan and Qinglongshan, Donghai: compositions of different garnet and clinopyroxene generations from eclogite (Ferrando, 2003).

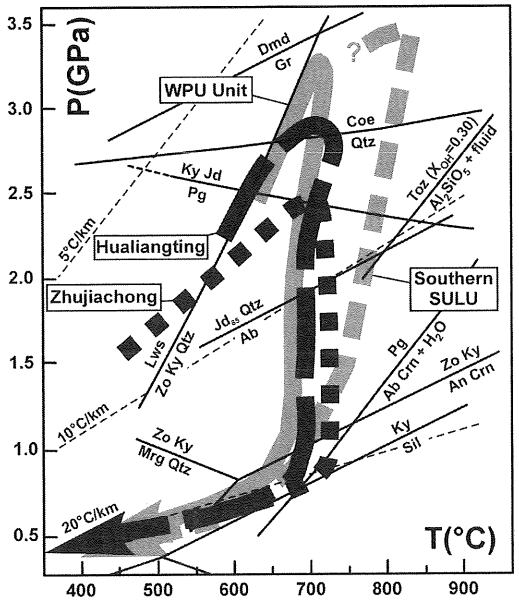

Fig. 4 - Petrogenetic grid showing the P-T paths recorded in different sectors of the Eclogite Complex in Dabie Shan: the WPU Unit (after Rolfo *et al.*, 2004), the Zhujiachong metamorphic veins and quartz-eclogite (after Castelli *et al.*, 1998), and the Hualiangting whiteschist and eclogite (after Rolfo *et al.*, 2000). The P-T path recorded by eclogite and kyanite-topaz quartzite from Donghai, southern Sulu (after Ferrando, 2003), is also shown for comparison. Mineral abbreviations after Kretz (1983).

clinozoisite pseudomorphs in the Zhujiachong quartz-eclogite, a maximum lawsonite content of about 20 vol.% was estimated by Castelli *et al.* (1998), which corresponds to a water content of ca. 2 wt.%. The relatively common presence of such clinozoisite aggregates in eclogites from a variety of metamorphic belts (e.g. Deer *et al.*, 1986) supports the idea that lawsonite may play an important role for recycling of water in subduction zones (Schmidt and Poli, 1994).

UHP WHITESCHIST IN DABIE SHAN

The first occurrence in Dabie Shan of the UHPM talc-kyanite assemblage typical of whiteschist was reported by Rolfo *et al.* (2000) at the Hualiangting reservoir in the coesite EC of Dabie Shan (Fig. 1), where the whiteschist assemblage occurs in a weakly deformed leucocratic layer, less than half a meter thick, crosscutting a coesite-bearing eclogite lens associated to white mica - garnet gneiss.

The whiteschist, really an omphacite-talc-kyanite-epidote quartzite, is fine-grained and consists of quartz (ca. 70 vol.%), minor kyanite, talc, epidote, omphacite, and accessory rutile, apatite, and zircon (Fig. 2b). Quartz has granoblastic texture and interlobate grain boundaries, suggesting its inversion from coesite during exhumation. REE-rich (up to 5 wt%, mostly Nd and Ce) epidote idioblasts include abundant polycrystalline aggregates of quartz after coesite and less abundant kyanite, omphacite, and rutile. Talc occurs as randomly oriented homogeneous porphyroblasts, rimmed by tremolite - cummingtonite, and includes kyanite + epidote. Fresh omphacite, commonly preserved only as inclusion in kyanite and epidote, is homogeneous with average composition Jd_{52} Aeg_{10} (Fig. 3b). In the matrix,

omphacite is replaced by aegirine-rich Na-pyroxene (Jd_{15} Aeg_{10}) + plagioclase symplectite. Kyanite occurs as both (I) millimeter-long idioblasts, including polycrystalline quartz aggregates after coesite, epidote and minor omphacite, or as (II) prismatic pseudomorphous aggregates of small crystals associated with quartz ± epidote. Kyanite, which includes fresh omphacite with the highest jadeite content (X_{Jd} up to 0.60), is commonly rimmed by a thin retrogression corona of oligoclase (An_{12-29}) ± epidote. Kyanite aggregates and idioblastic epidote define a rough foliation, parallel to the talc-kyanite quartzite selvages; talc flakes crosscut this foliation.

The host eclogite consists of zoned omphacite (X_{Jd} = 0.44 to 0.37 from core to rim), garnet (Fig. 3b), quartz, kyanite, epidote, phengite (Si up to 3.47 a.p.f.u.), amphibole, and accessory rutile, apatite, zircon and ilmenite. Coesite and its polycrystalline quartz pseudomorphs are included in epidote, omphacite and kyanite.

From field and petrographic observations, Rolfo *et al.* (2000) found that the whiteschist and the host eclogite share the same polyphase tectonometamorphic evolution. The resulting clockwise P-T path (Fig. 4) consists of prograde trajectory up to peak conditions (P > 2.6-2.7 GPa and T = 710 ± 20 °C), followed by a quasi-adiabatic decompression and a final almost isobaric cooling. The UHP stage was constrained in both the whiteschist and the host eclogite by the occurrence of coesite, the garnet-omphacite-phengite geobarometry, the Fe-Mg partitioning between garnet and clinopyroxene, the stability of talc + kyanite, and the lack of evidence for partial melting. The post-peak metamorphic conditions (P > 1.5-2.0 GPa and T = 650 ± 30 °C) were constrained by the rim compositions of garnet-clinopyroxene pairs, the lowest jadeite-content in Na-clinopyroxene, and the stability of Na- and Ca-amphiboles. A second stage of decompression (P = 0.7 GPa and T = 670 ± 40 °C) was constrained by the jadeite content of the aegirine-rich pyroxene in the symplectite after omphacite, the amphibole-plagioclase pairs, the Al content in the amphibole of the symplectites after omphacite.

Concerning the protolith of the Hualiangting whiteschist, minor and trace elements are consistent with a magmatic origin. Moreover, the REE pattern of the whiteschist fits quite well with the REE patterns of leucogranitic and trondhjemitic rocks from Dabie Shan (Rolfo *et al.*, 2000). All data suggest that the rock composition was modified, after emplacement, by a metasomatic process implying loss of some elements. This conclusion is supported by the occurrence of the kyanite + quartz aggregates, clearly pseudomorphs after a former Al-bearing mineral, possibly a feldspar, which lost alkalis during UHPM.

Summing up, the whiteschist derives from a felsic dyke intruded into the mafic rock prior to peak UHP metamorphism, probably coeval with the emplacement of the nearby granitic rocks metamorphosed to the white mica - garnet gneiss. Also this gneiss, which is widespread all over the Dabie Shan and Sulu and is devoid of UHP minerals, might have consequently suffered UHP conditions (Compagnoni and Rolfo, 1999).

A COHERENT UHPM UNIT IN DABIE SHAN

The discussion about the «in-situ» (formed in the present geologic setting) versus «exotic» (formed elsewhere and tectonically introduced into the present country rocks) origin of UHPM rocks rises by the common preservation of fresh eclogite boudins within large volumes of low pressure gneisses (e.g. Compagnoni and Rolfo, 1999; Nakamura and Hirajima, 2000). Moreover, very few data are available to estimate the real size of the subducted and exhumed tectonic units (e.g., Hacker *et al.*, 2000). The identification in Dabie Shan of a narrow UHPM belt ca. 40 km long and 1-2 km wide, the Wuhe-Pailou Unit (WPU), provides new evidence to the «in-situ» origin of the UHPM, and gives significant constraints to the exhumation of large coherent tectonic units (Rolfo *et al.*, 2004).

The WPU is exposed with NNW-SSE trend in the EC of Dabie Shan (Fig. 1), and typically consists of gneiss, marble with minor eclogite, and jadeite-bearing granofels with rare garnetite and eclogite nodules. The jadeite-bearing granofels is the most peculiar UHPM felsic lithology of Dabie Shan, and occurs as lens-like bodies, up to hundreds of meters long, medium-grained and isotropic. It consists of quartz, jadeite, garnet, and accessories (Fig. 2c). Fine-grained aggregates of quartz suggest its inversion from former coesite. The UHP peak assemblage was coesite + jadeite + garnet ± epidote ± phengite ± kyanite, with accessory rutile, apatite, and zircon. Fresh coesite inclusions are common in both jadeite and garnet. Garnet is homogeneous (Alm_{59-64} Prp_{27-32} Grs_{7-10} on average at Xinjiang; Alm_{59-62} Prp_{20-22} Grs_{17-19} Sps_{0-5} at Shuanghe; Fig. 3c) and includes in the core prograde Mg-taramite, quartz, rutile, and paragonite ± monazite, while jadeite and coesite are included only at the rim. Jadeite (Jd_{82-85} Aeg_{1-9} Di_{3-7} in Xinjian; Jd_{82-87} Aeg_{1-4} Di_{8-9} in Shuanghe; Fig. 3c) includes paragonite, garnet, quartz, rutile, apatite and zircon. Retrograde paragonite is locally found in the matrix. Amphibole porphyroblasts, zoned from glaucophane in the core through crossite to Mg-riebeckite in the rim, grew mainly at the expense of jadeite and garnet. Jadeite and garnet systematically show a coronitic reaction texture (Fig. 2c): garnet is surrounded by an inner thin rim consisting of barroisitic amphibole, bounded by a fine-grained intergrowth of albite + Mg-taramite + magnetite + white mica ± hercynite ± corundum, and by an outer continuous rim of aegirine-augite (Di_{28} Jd_2 Aeg_{70}) in contact with quartz. Jadeite is surrounded by an inner, relatively thick, rim consisting of albite/oligoclase + katophorite + magnetite ± hercynite, and by an outer, thinner corona of an aegirine-rich pyroxene (Di_{24} Jd_{10} Aeg_{60}, Fig. 3c).

Eclogite contains quartz when associated to the jadeite-bearing granofels, whereas contains carbonate when associated to marble and paragneiss. Eclogites are medium-grained and consist mainly of garnet, omphacite and quartz. Garnet is slightly zoned, its almandine and pyrope contents increasing and grossular content decreasing from core to rim, respectively (Fig. 3c). Omphacite shows a general decrease in jadeite and increase in aegirine contents from core to rim, respectively (Fig. 3c), and is partly replaced by symplectites of albite-oligoclase + pargasitic hornblende, or by albite + aegirine-rich clinopyroxene. Minor phases are paragonite, phengite (Si up to 3.53 a.p.f.u.), clinozoisite with a relict REE-rich core, carbonate, amphibole (from Mg-katophorite in the core to barroisite to hastingsitic hornblende at the rim), and accessory rutile or high-Al titanite (Al up to 0.26 a.p.f.u.), zircon, and apatite. Coesite and/or polycrystalline quartz aggregates occur both in garnet and omphacite.

For the WPU, a clockwise P-T path was estimated by Rolfo *et al.* (2004) and consists of an early prograde part up to coesite-eclogite facies conditions, an early decompression stage and a late part characterized by a near-adiabatic decompression down to low pressure amphibolite facies conditions, followed by a final cooling to greenschist facies conditions (Fig. 4). Geothermobarometric estimates performed on mineral assemblages of the jadeite-granofels and associated eclogites constrain the following P and T steps of the exhumation path: P ~ 3.3 GPa and T ~ 720 °C (UHP Stage), P ~ 1.9 GPa and T ~ 680 °C (first decompressional HP stage), P ~ 1.1 GPa and T ~ 670 °C (second decompressional «coronitic» stage), and P < 0.8 GPa and T < 600 °C (final cooling).

Detailed mapping of representative sectors of the WPU (Rolfo *et al.*, 2004) shows that all lithologies, excluding leucocratic granitic gneiss, are characterized by gradual contacts. Most WPU lithologies are usually retrogressed to amphibolite- or to greenschist facies conditions, but the jadeite-bearing granofels are usually still recognizable both in the field and under the microscope, so that the areal extent of the WPU may be easily defined. Thus, the WPU lithologic association is a coherent

UHPM slab surrounded by granitic orthogneiss. The inferred P-T path of the WPU, characterized by a post-climactic quasi-adiabatic decompression, is a strong argument in favor of a large coherent block of subducted continental crust that experienced fast exhumation.

UHP ECLOGITE AND QUARTZITE IN SOUTHERN SULU

A sector of the UHPM zone at Donghai in southern Sulu, close to Hushan and Qinglongshan (Fig. 1), has been recently studied by Ferrando (2003). Two peculiar lithologies hosted in granitoid gneiss were selected on the basis of mineral assemblage, mineral zoning, clear microstructural relationships, and abundance of fluid inclusions: kyanite – phengite – epidote eclogite and kyanite – topaz quartzite.

The eclogite consists of garnet, omphacite, porphyroblastic epidote and amphibole, paragonite, phengite, kyanite, quartz, and accessory rutile, apatite, zircon, and opaque ores. The occurrence of different generations of eclogite facies minerals suggests a polyphase metamorphic evolution (Ferrando *et al.*, 2002). At the UHP peak (T ~ 850 °C and P ~ 3.5 GPa) the inferred mineral assemblage was garnet ($Alm_{45}Prp_{27}Grs_{26}Sps_{02}$; Grt I in Fig. 3d) + «supersilicic» clinopyroxene ($Jd_{40}Di_{43}Aeg_{17}$; Cpx I in Fig. 3d) + kyanite + coesite. From UHP to HP conditions, the evolution is defined by the growth of garnet (from $Alm_{44}Prp_{30}Grs_{25}Sps_{01}$ to $Alm_{43}Prp_{35}Grs_{20}Sps_{02}$; Grt II and Grt III in Fig. 3d, respectively), omphacite (from $Jd_{43}Di_{42}Aeg_{15}$ to $Jd_{45}Di_{50}Aeg_{05}$; Cpx II and Cpx III in Fig. 3d, respectively), phengite (Si = 3.507 - 3.226 a.p.f.u. from core to rim), epidote, and amphibole (barroisite to Mg-katophorite from core to rim). The late metamorphic evolution is mainly characterized by the growth of amphibole (edenite to actinolite) + Na-plagioclase symplectites after omphacite. The resulting P-T path (Fig. 4) is characterized by an initial strong decompression coupled with a moderate cooling at eclogite facies conditions, and a final almost isobaric cooling up to greenschist facies conditions.

The quartzite consists of quartz, kyanite, paragonite, OH-rich topaz, accessory rutile, pyrite, zircon, apatite, and rare barite (Fig. 2d). Microstructural relationships suggest that OH-rich topaz developed at the expense of kyanite during early decompression (Ferrando *et al.*, 2003). The OH content in topaz (mean X_{OH} = 0.28), calculated from electron microprobe data, was confirmed by single-crystal X-ray diffraction data (Alberico *et al.*, 2003). OH-rich topaz crystals are crowded with primary fluid inclusions. Microthermometric measurements revealed that the original trapped fluid was a high-density (1.14 - 1.16 g/cm^3) Ca-dominated brine (2.5 wt.% NaCl and 15 wt.% $CaCl_2$) containing traces of CO_2 [$X(CO_2)$ = 0.04]. The isochore, calculated from the fluid inclusions with the highest densities, suggests a pressure of 2.8 GPa at the post-climactic temperature of 800 °C and confirm that the OH-rich topaz grew during an early decompression phase, at the coesite to quartz transition, in the presence of high-density brines. At the same P-T conditions, a fluid with similar composition promoted the growth of hydrous minerals also in the associated eclogites.

DISCUSSION AND CONCLUSIONS

In this paper, a number of selected areas and lithologies of the Dabie Shan - Sulu belt have been described in order to clarify some important aspects of continental collision tectonics, such as the size of the exhumed tectonic units from mantle depths, the «in-situ» or «exotic» origin of the UHPM rocks, the nature of metamorphic fluids at peak metamorphic conditions.

The metamorphic veins associated to the Zhujiachong quartz-eclogites (Castelli *et al.*, 1998) probably formed, before metamorphic peak, by prograde breakdown of lawsonite, which appears to play an important role as a fluid storage mineral in metabasites during

subduction. The whiteschist at Hualiangting (Rolfo *et al.*, 2000), derived from a felsic dyke, probably intruded into mafic rocks prior to peak UHP metamorphism, most likely at the same time as the emplacement of the granitic protoliths of the orthogneiss widespread all over the EC, but usually lacking UHPM minerals because of pervasive amphibolite facies overprinting. The identification in Dabie Shan of the Wuhe-Pailou Unit (WPU - Rolfo *et al.*, 2004) provides new support in favor of the «in-situ» origin of the UHPM, and gives new constraints to the size of the subducted and exhumed tectonic units. In southern Sulu, eclogite and quartzite containing hydrous and zoned minerals stable at eclogite facies conditions where studied by Ferrando (2003), which constrained their polyphase metamorphic history and characterized the nature of metamorphic fluids.

Significant differences in peak metamorphic P have been recorded by quartz- and coesite eclogites in Dabie Shan and southern Sulu (Fig. 4). However, all retrograde P-T paths, characterized by a significant post-climactic decompression coupled with minor cooling, are peculiar and suggest that these units reached different depths during metamorphism, and that their juxtaposition occurred during an earlier exhumation stage. During this stage, a very fast exhumation is suggested by the P-T paths and by preservation of coesite in UHPM rocks. These units were subsequently subjected to slower uplift and to a barrovian-type regional metamorphism and deformation, which are responsible for the widespread amphibolite facies metamorphic overprint. The near adiabatic decompression shown by mineral assemblages of coherent unit such as the WPU is a strong argument in favor of the existence of large blocks of subducted continental crust that experienced fast exhumation. In fact, an isothermal decompression is only possible if thick tectonic units undergo a fast exhumation, thus preventing thermal perturbation. The occurrence in Dabie Shan of such UHPM units suggests that the orogen consists of unusually large (and thick) slices of continental crust. The large size of these slices has been also inferred for other portions of the same orogen, e.g. the Hong'an area west of Dabie Shan (Hacker *et al.*, 2000) and northeastern Sulu (Nakamura and Hirajima, 2000).

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