ION MICROPROBE U-PB DATING OF ZIRCON FROM A MONVISO METAPLAGIOGRANITE: IMPLICATIONS FOR THE EVOLUTION OF THE PIEDMONT-LIGURIA TETHYS IN THE WESTERN ALPS

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ABSTRACT

The Monviso metamorphic ophiolite, one of the best preserved relics of oceanic crust in the Western Alps, was formed during the opening of the Mesozoic Western Alpine Tethys and underwent metamorphism to eclogitic conditions during Alpine subduction. The Monviso ophiolite encompasses the whole lithological spectrum of the Piedmont-Liguria ophiolite rocks, with a basal unit of serpentinized peridotite in tectonic contact with the overlying metagabbros, eclogites and pillowed metabasalts. Slivers of serpentinized peridotite hosting banded eclogites and metagabbros divide these units from the overlying Forciolline Unit. The latter (formerly called Costa Ticino Series) is an overturned sequence of gabbros with pods of cumulate troctolite and lenses of serpentinized peridotite, overlain by massive and pillow metabasalts. A unit of massive metabasalts tops the tectonic stack.

A body of jadeite-quartz bearing metaplagiogranite has been recently found in the Basal Serpentinite Unit near Vernè, northwest of Sampeyre, Val Varaita. Zircon crystals recovered from the Vernè metaplagiogranite have large domains with typical magmatic zoning with broad oscillatory bands. They have Th/U ratios in the range 0.3-0.7, as commonly observed in magmatic zircon. *In situ* ion microprobe (SHRIMP) U-Pb dating of the magmatic domains yielded a mean age of 152±2 Ma, which is interpreted as the crystallization age of the Monviso plagiogranite. Unzoned domains that crosscut magmatic zircon yielded younger, apparent ages which are most likely due to Pb loss during Alpine metamorphism.

In conjunction with previous works on ophiolites from the Western Alps, Northern Apennines, and Alpine Corsica, the new data from Monviso suggest that the plutonic activity in the Piedmont-Liguria domain of the western Tethys may have lasted only 15 to 20 Ma, between *ca*. 170 and *ca*. 150 Ma. As shown by Radiolarian biostratigraphy, this is approximately the same time span encompassed by the extrusion of tholeiite basalts which cap both the gabbro plutons and their peridotite country rocks.

The new data indicate that the plutonic activity recorded at Monviso was coeval with basalt extrusion and deep-sea sediment deposition in some Ligurian-type ophiolite bodies of the Cottian Alps. This suggests that the oceanic crust preserved in the Monviso ophiolite may have formed later, and in a more central position of the basin, than the oceanic crust preserved in such Ligurian-type ophiolite bodies.

INTRODUCTION

Dykes and irregular intrusive bodies of plagiogranite are a minor but widespread member of the Piedmont-Liguria ophiolite sequence in the Western Alps, northern Apennines and Alpine Corsica (Castelli et al., 2002, and references therein). Since the pioneering studies of Mattinson (1975), Tilton et al. (1981) and Ohnenstetter et al. (1981) the plagiogranites have been utilized for dating the last stages of the plutonic activity in ophiolites. This has been possible because they contain relatively large amounts of primary magmatic zircon, for which concordant U-Pb isotopic ages are believed to date the time of original magmatic crystallization.

In this paper we report the results of U-Pb dating by SHRIMP ion microprobe on a large metaplagiogranite body emplaced in the Basal Serpentinite Unit of the Monviso metamorphic ophiolite of the Western Alps (Castelli et al., 2002). In conjunction with previous data on eclogitic metaferrogabbros from the same Monviso ophiolite (Rubatto and Hermann, 2002), on the Montgenèvre ophiolite (Costa and Caby, 2001) and stratigraphic age data on other ophiolite bodies of the Cottian Alps (De Wever and Baumgartner, 1995), the new data tightly constrains the timing of the oceanic crust formation in this part of the Western Alps. The new data fit well in the age pattern emerging from recent studies, both isotopic and biostratigraphical, for the ocean crust generation in the Piedmont-Liguria basin, and allow speculating on the time relationships between the plutonic and volcanic activity in the western Tethys.

GEOLOGICAL SETTING

Ophiolites occur in the Western and Central Alps as a major component of the Piedmont Zone (Fig. 1). According to their geological setting, type of sedimentary cover and grade of metamorphism four types of ophiolite occurrence are distinguished in the Cottian Alps:

1) A large, composite nappe of ultramafics (serpentinized peridotites), gabbros and basalts with minor sediments, metamorphosed under eclogitic conditions in Eocene time. Late deformations and erosion have separated the ophiolite nappe of the Cottian Alps in two parts: the Monviso and the Rocciavré "massifs". The ophiolite nappe is thrust over the Dora-Maira basement nappes, where the Alpine metamorphism has been of high-pressure (eclogitic) to ultra-high-pressure type. Tiny relics of metasedimentary cover sequences are comprised of quartzite (metachert), quartz-rich micaschists and calcschists stratigraphically overlying metabasalts,

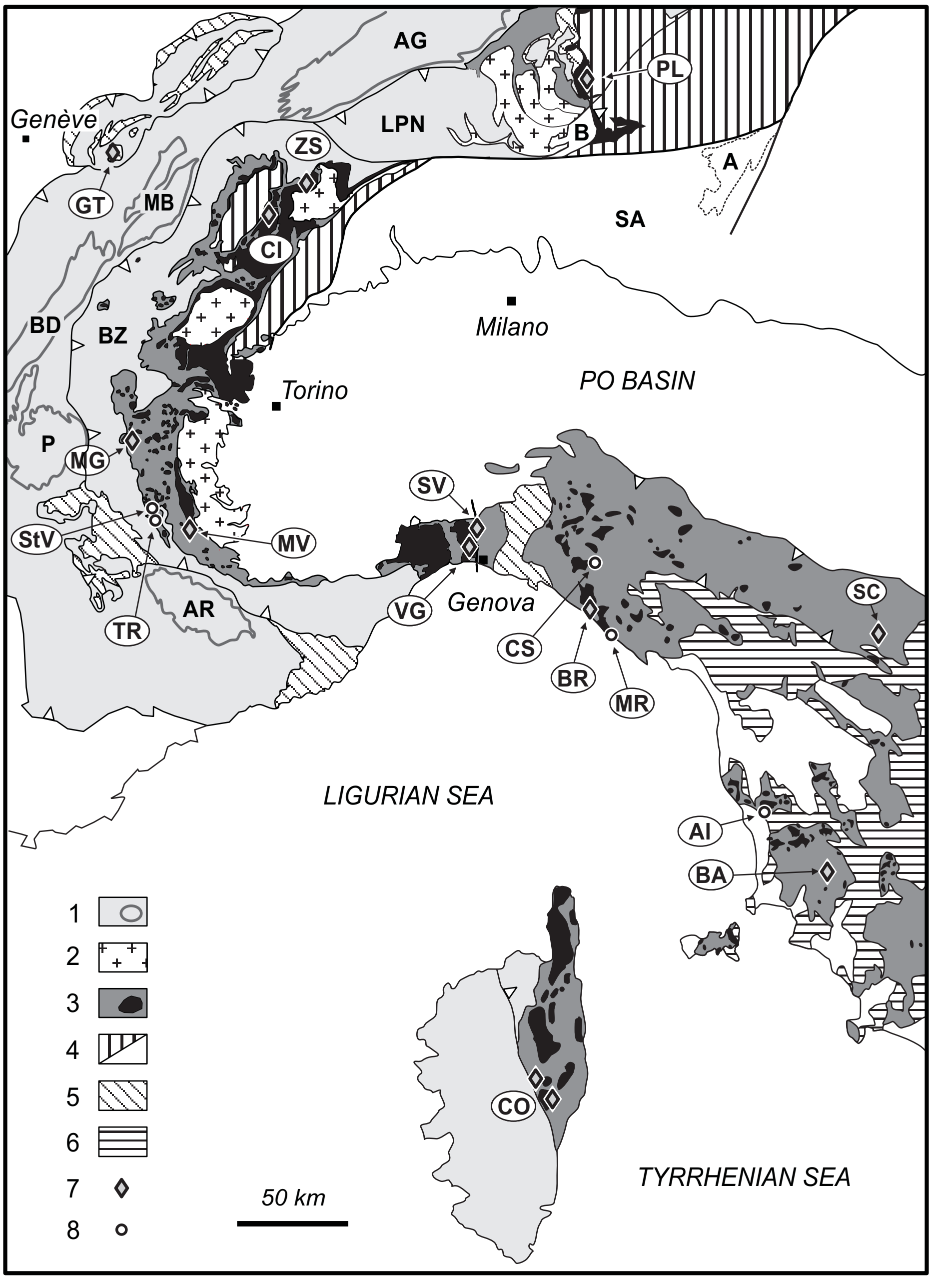

Fig. 1 - Simplified structural map of the Western Alps, northern Apennines and Corsica, showing the major ophiolite bodies derived from the Piedmont-Liguria Tethys (compiled after Beccaluva et al., 1977; Serri, 1980; Spicher, 1980; C.N.R., 1990; Bortolotti, 1992; Borsi et al., 1996; Rampone and Piccardo, 2000; Castelli et al., 2002; with modifications). 1: Helvetic-Dauphinois and External Penninic units. The thick grey line contours the External Crystalline Massifs (AR: Argentera, P: Pelvoux, BD: Belledonne, MB: Mont Blanc - Aiguilles-Rouges, AG: Aar-Gotthard). BZ: Briançonnais Zone, LPN: Lower Penninic Nappes. 2: Middle Penninic Nappes. 3: Piedmont-Liguria units, with ophiolite bodies shown in black. 4: Austroalpine units and Southern Alps (SA). 5: Tertiary Flysch nappes. 6: Tuscan Units. 7-8: Selected radiometric and stratigraphic ages in the Piedmont-Liguria units, respectively. A and B are the Adamello and Bregaglia Tertiary intrusions.
Location of radiometric data that are discussed in the text is: (BA) Bartolina (Bortolotti et al., 1990); (BR) Bracco (Borsi et al., 1996); (CI) Lago di Cignana (Rubatto et al., 1998); (CO) Corsica (Ohnenstetter et al., 1981); (GE) Gets nappe (Bill et al., 1997); (MG) Montgenèvre (Costa and Caby, 2001); (MV) Monviso (this work); (PL) Platta nappe (Schaltegger et al., 2002); (SC) Sasso di Castro (Bortolotti et al., 1995); (SV) Sestri-Voltaggio Zone and (VG) Voltri Group (Borsi et al., 1996); (ZS) Zermatt-Saas Zone (Allalin and Mellichen metagabbros, Sparrenflue Mn-rich metasediments: Rubatto et al., 1998).
Location of stratigraphic data that are discussed in the text is: (AI) Aiola, (CS) Costa Scandella and (MR) Monte Rossola (Chiari et al., 2000); (StV) Saint-Véran and (TR) Traversiera (De Wever and Baumgartner, 1995).

metagabbros and serpentinites (Lombardo and Pognante, 1982). Outside the Cottian Alps, Type 1 ophiolite bodies make up the Zermatt-Saas Zone of Valais and Val d'Aosta (Bearth, 1967; Elter, 1971; Dal Piaz, 1999, and refs. therein). South of Val d'Aosta, Type 1 ophiolite bodies are widespread in the Valli di Lanzo (Sandrone et al., 1986, with refs.) and make up the Voltri Group of western Liguria (Piccardo et al., 2001, with refs.).

2) Ophiolite bodies with blueschist facies metamorphism and a Ligurian-type sedimentary cover. Here ultramafics (serpentinized peridotites), gabbros and basalts occur as isolated bodies (tectonic slices and/or olistoliths), often within sedimentary sequences of Cretaceous age, like the "Formation du Col Agnel" (Lemoine and Tricart, 1979). Outside the Cottian Alps, Type 2 ophiolite bodies occur in the Montenotte nappe of the Ligurian Alps and in the Cravasco-Voltaggio Unit of the Sestri-Voltaggio Zone.
3) Ligurian-type ophiolite bodies which are lithologically identical to Type 2, but were not affected by the blueschist facies metamorphism. In the Cottian Alps these include only the Montgenèvre ophiolite. Outside the Cottian Alps, Type 3 ophiolite bodies are widespread in the Internal Liguride units of the Northern Apennines, (Decandia and Elter, 1972; Abbate et al., 1980) and in the Platta-Arosa nappes of the Central Alps (Dietrich, 1970; Desmurs et al., 2001).
4) Clasts of ophiolite lithologies (basalt, ophicalcite), which, together with clasts of sedimentary and crystalline lithologies, form polygenic breccia bodies. Such bodies are hosted in a sequence of calcareous shales occurring at the base of the Helminthoid Flysch in the Ubaye valley ("Schistes de Serenne": Kerchove, 1969). Outside the Cottian Alps, slide blocks of non-metamorphic ophiolite lithologies are found in the basal formation (wildflysch) of the Gets nappe (Elter G. et al., 1966) and are widespread in the External Liguride units, where they are associated with lower and upper crustal lithologies of continental origin (Marroni et al., 1998).

THE MONVISO OPHIOLITE

The Monviso ophiolite complex is a north-trending body, 35 km long and up to 8 km wide. The Monviso complex is sandwiched structurally between the underlying Dora-Maira thrust units and the tectonically higher, dominantly metasedimentary, units of the Piedmont Zone. A belt of carbonate schists (*calcescisti* of the Italian geological literature, *Schistes Lustrés* of the French geological literature) and of Triassic dolomite marbles divides the Monviso ophiolite complex from the underlying Sampeyre and Dronero units of the Dora-Maira Massif. The Monviso ophiolite complex is in contact with the external metasedimentary units along a steep west-dipping normal fault (Philippot, 1990; Ballèvre et al., 1990).

In its central and thickest part, the Monviso ophiolite is comprised of six units (Fig. 2). They are described here in some detail as earlier descriptions (Lombardo et al., 1978; MONVISO, 1980) require modification from more recent data (Philippot, 1990; Schwartz et al., 2000) and our unpublished observations:

– Basal Serpentinite Unit, 400m thick, of antigorite serpentinite, only rarely preserving relics of the pre-serpentinization mineralogy. The serpentinite derives from a dominantly lherzolitic protolith, with only minor harzburgite and dunite, and is cut by transposed dykes of rodingitized gabbro and, possibly, basalt. Particularly in its upper part, the basal serpentinite unit hosts bodies of foliated metagabbro, metaferrogabbro (eclogite) and metaplagiogranite. One of such eclogite bodies is associated to the Verné metaplagiogranite dated in this study.

Relics of a sedimentary cover were found in the upper Val Po south of Lago Fiorenza, at Lago dell'Alpetto (Lombardo et al., 1978), and east of Punta Rasciassa (M. Gattiglio, B. Lombardo, and F. Mondino, 2002, pers. comm.). The sedimentary cover is comprised of carbonate micaschists and quartz-rich micaschists south of Lago Fiorenza (ascribed to the Upper Jurassic-Lower Cretaceous on lithological ground by Lagabrielle and Lemoine, 1997), and of grey marbles overlying ophicalcite east of Punta Rasciassa.

– Lago Superiore Unit, a discontinuous belt of strongly deformed and recrystallized metagabbro typically with emerald-green spots of chromian omphacite ("smaragdite"). The metagabbro hosts small bodies of ultramafic cumulates transformed into chloritoid-bearing rocks, and pods, layers and lenses of eclogite, up to a few tens of meters across. In these pods eclogite may be interlayered with smaragdite metagabbro, and may show a gabbroic texture with relics of igneous clinopyroxene.

– Viso Mozzo Unit, consisting of greenschist and banded glaucophane-epidote metabasites of basaltic parentage. Small bodies of glaucophane- and epidote-rich pillow metabasalt are preserved in the Balze di Cesare section (south of Viso Mozzo). A breccia texture is common in the upper part of the unit, where thin layers of carbonate micaschists are interbedded (or folded) with the metabasite. Small bodies of eclogite occur on the southwestern slope of Viso Mozzo (Schwartz et al., 2000) and at its very top. Their relationships to the host metabasites are unclear and these eclogites could also belong to the Passo Gallarino Unit.

– Passo Gallarino Unit, comprised of a 100 m thick slab of interlayered eclogite and omphacite metagabbro ("Passo Gallarino Complex"), hosted in serpentinized peridotite ("Colle del Viso Serpentinite"). The serpentinite is overlain by a thin metabasalt sheet, capped by quartzite and quartz-rich micaschist. The metabasalt and overlying micaschist were previously included in the Costa Ticino Series, but, following Philippot (1990), they are here included in the Passo Gallarino Unit. The Passo Gallarino Complex is characterized by strong syn-eclogitic to high-temperature, blueschist deformation and by the compositional association of gabbronorite with ferrogabbro (ilmenite-magnetite gabbro) and very thin sheets of metaplagiogranite. The only relic of the igneous mineralogy is a red-brown augite ($Ca_{42}Mg_{36}Fe_{22}$).

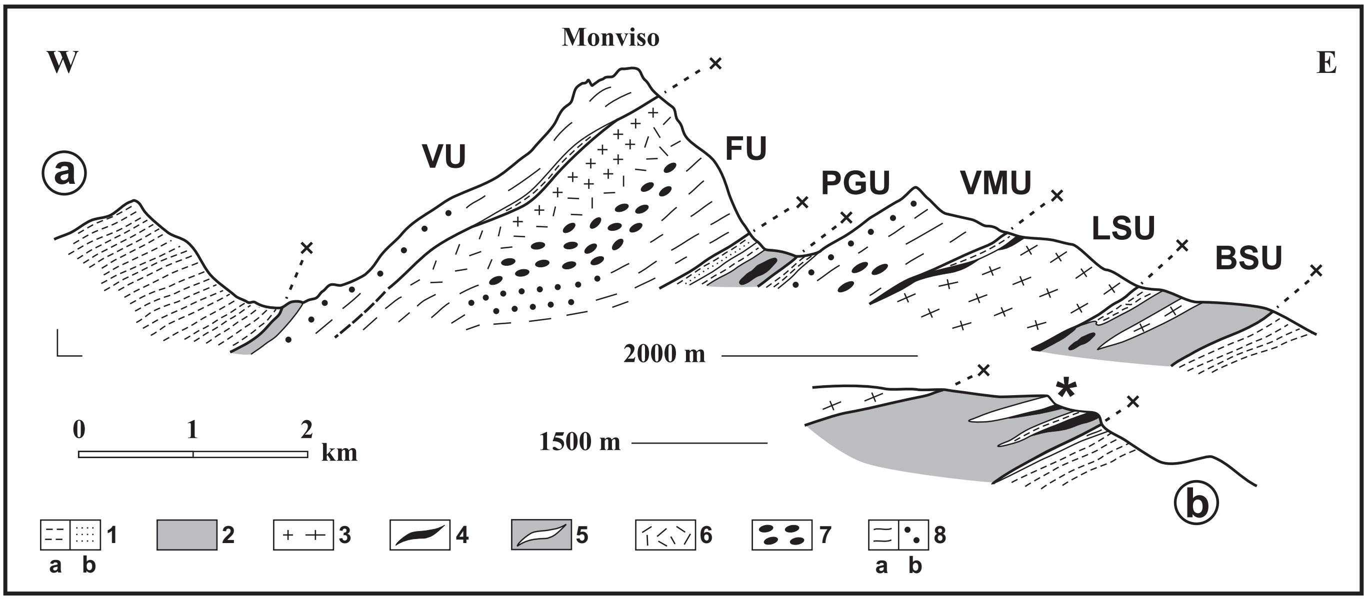

Fig. 2 - Cross sections through the Monviso meta-ophiolite in the upper Valle Po (a) and along the northern side of the middleVal Varaita (b). Keys to symbol are: 1a) carbonate micaschists; 1b) quartz-rich micaschists and metacherts; 2) serpentinites and antigorite schists; 3) isotropic and foliated metagabbros; 4) metaferrogabbros and eclogites; 5) metaplagiogranite; 6) massive metabasalts; 7) pillowed metabasalts; 8a) banded metabasites; 8b) metabasites with breccia texture. VU: Vallanta Unit, FU: Forciolline Unit, PGU: Passo Gallarino Unit, VMU: Viso Mozzo Unit, LSU: Lago Superiore Unit, BSU: Basal Serpentinite Unit. The asterisk locates the Verné metaplagiogranite body.

– *Forciolline Unit*, previously called Costa Ticino Series (Lombardo et al., 1978) whose complete sequence is best exposed in the Vallone delle Forciolline. This unit is an overturned sequence of metagabbros, massive and pillowed metabasalts, and of banded glaucophane-epidote metabasites derived from pillowed basalts and basalt breccias. The metagabbros show generally well preserved igneous textures and range from small bodies of layered cumulate meta-troctolite and anorthosite to isotropic, coarse-grained metagabbro with pods of metaferrogabbro. Composition of relict Cpx in isotropic metagabbro ranges from diopside ($Ca_{45}Mg_{48}Fe_7$) to augite ($Ca_{38}Mg_{50}Fe_{12}$). Rafts of serpentinized tectonite peridotite, up to a few hundred meters long were found in the metagabbros at Punta Corsica and Picco Ajaccio, and are believed to be derived from the country rocks of the gabbro pluton.

The basalt sequence rests stratigraphically on the metagabbros and comprises massive metabasalts, both aphyric and porphyritic, overlain by pillowed metabasalts and basalt metabreccias. As elsewhere in the Piedmont-Liguria ophiolites, a sheeted dyke complex between the gabbro section and the volcanics is lacking at all, but metabasalt dykes with chilled borders are common in the upper part of the gabbro section, and also occur in the pillow metabasalts. Major- and trace-element compositions indicate protoliths of ocean-floor tholeiite affinity, with a fractionation trend determined mainly by segregation of olivine and plagioclase (Piccardo and Fiora, in Lombardo et al., 1978). The Forciolline Unit is capped by a sedimentary cover of carbonate micaschists and, locally, of quartz-rich micaschists.

- *Vallanta Unit*, an overturned slab, up to 300m thick, of fine-grained eclogitic metabasalts, with small relics of a sedimentary cover of carbonate micaschists, and possibly of an ultramafic sole. This unit is topographically and tectonically the highest and caps the very top of Monte Viso and Viso di Vallanta.

Summarizing the field data presented above, it appears that two different types of lithological sequence are present in the Monviso ophiolite: 1) units, like the Forciolline Unit, where a relatively thick basalt sequence caps gabbros and serpentinized peridotites, 2) units, like the Basal Serpentinite Unit, where serpentinized peridotites are directly covered by a thin sedimentary sequence. These magma-rich- and magma-poor units show strong affinities with the oceanic lithosphere found respectively at the centers and tips of 20-100 km long segments which characterize the axis of the slow-spreading Mid Atlantic Ridge (Lagabrielle and Lemoine, 1997).

ANALYTICAL TECHNIQUES

Cathodoluminescence investigation of zircon was carried out at the Electron Microscope Unit, Australian National University, with an HITACHI S2250-N scanning electron microscope working at 15 kV, ~60 µA and ~20 mm working distance.

U-Th-Pb analyses were performed using a sensitive, high-resolution ion microprobe (SHRIMP II) at the Research School of Earth Sciences. Instrumental conditions and data acquisition were generally as described by Compston et al. (1992). The data were collected in sets of seven scans throughout the masses. The measured $^{206}Pb/^{238}U$ ratio was corrected using reference zircons from a gabbro of the Duluth Complex in Minnesota (AS3, 1099 Ma), whereas a zircon of known composition (SL 13) has been used to determine the U content of the target. The data were corrected for common Pb on the basis of the measured $^{207}Pb/^{206}Pb$ ratios. The common Pb composition was assumed to be that of Broken Hill, which approximates the laboratory common Pb background at the RSES. Age calculations were done using the software Isoplot/Ex.

GEOCHRONOLOGY

Sample description

The dated metaplagiogranite has been sampled in the Basal Serpentinite Unit, close to the locality of Verné (3 km NW of Sampeyre, Val Varaita) and belongs to an eclogite-metaplagiogranite body about 300 m long and 70-80 m thick within the serpentinites. A detailed description of the Alpine mineralogy and the chemical composition of the metaplagiogranite is given by Castelli et al. (2002), and only a synopsis will be given here. Primary texture and magmatic minerals in the metaplagiogranite are mostly obliterated by multistage Alpine re-equilibration, and the rock now consists of albite, quartz and relict jadeite, with minor green Na-pyroxene, zoned Na-amphibole, phengite, garnet, and accessory rutile, allanite and zircon. However, the presence of a primary hypidiomorphic fabric is locally suggested by the shape of some quartz domains, which were possibly interstitial to euhedral magmatic plagioclase. Anhedral allanite and zircon are interpreted as relics of the magmatic assemblage.

Major, trace, and REE data are typical of oceanic plagiogranite, and similar to those of metaplagiogranite from other meta-ophiolite units of the Western Alps, Northern Apennines and Corsica. Petrological and preliminary geochemical data suggest that the Monviso plagiogranite could have formed by fractional crystallization of ocean-floor tholeiite magmas in Late-Jurassic times, and likely represents late stages of the plutonic activity in the Piedmont-Liguria Tethys.

Zircon U-Pb data

The plagiogranite contains a significant amount of zircons (several hundreds grains from a few kilograms sample). The crystals are anhedral and they generally have an irregular surface. They are pale yellow and not transparent, in part because of the large number of inclusions they contain. The cathodoluminescence investigation reveals two different zoning patterns, which are often present within the same crystals (Fig. 3): i) domains with a very weak oscillatory zoning or uniform CL emission; ii) domains with cloudy or patchy zoning which often cross cut the oscillatory zoning. Inclusions are concentrated in the cloudy zoned areas, often along fractures. They mainly consist of quartz, albite and apatite, with minor Na-amphibole.

The oscillatory/uniform domains have low contents of Th and particularly U (30-70 ppm and 10-40 ppm, respectively, Table 1), as often observed in gabbroic zircons (e.g. Rubatto et al., 1998). The resulting Th/U ratio is similar in the 10 crystals analyzed (0.35-0.78). Three analyses on cloudy domains indicate higher U contents (40-190 ppm) and thus Th/U ratios at the lower end of the range observed in the oscillatory/uniform domains, or even lower. The U-Pb analyses of the oscillatory/uniform domains form a tight cluster in the total $^{238}U/^{206}Pb$ vs total $^{207}Pb/^{206}Pb$ diagram (Fig. 4)

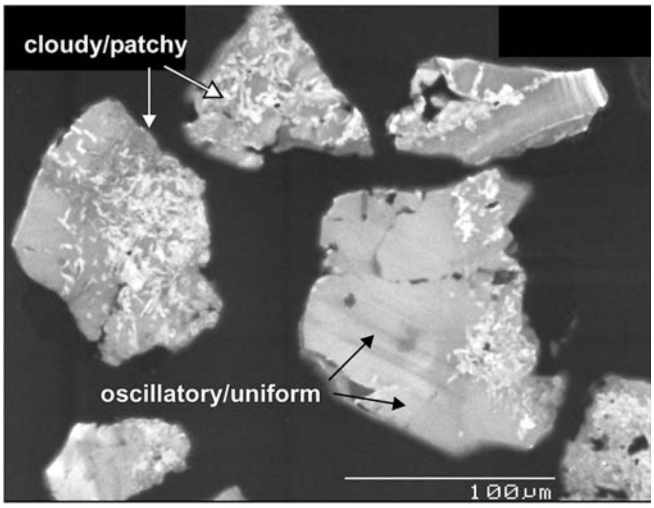

Fig. 3 - Cathodoluminescence image of zircon from the Verné metaplagiogranite. Uniform domains and domains with oscillatory zoning are of magmatic origin. The cloudy/patchy areas were affected by Pb loss, most likely during the Alpine metamorphism.

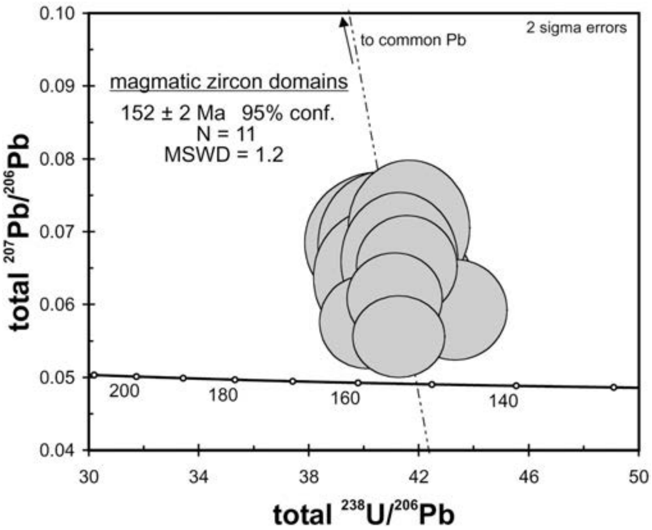

Fig. 4 - Total U-Pb diagram of analyses on magmatic zircon. The error ellipses indicate 2σ errors. The data form a tight cluster that, projected on the Concordia curve from common Pb, defines an age of 152±2 Ma.

Table 1 - SHRIMP U-Th-Pb analyses of zircon from the Verné metaplagiogranite (sample DB9).

	U (ppm)	Th (ppm)	Th/U	%Pb com	Total $^{238}U/^{206}Pb \pm 2\sigma$		Total $^{207}Pb/^{206}Pb \pm 2\sigma$		$^{206}Pb/^{238}U \pm 2\sigma$		Age $^{206}Pb/^{238}U \pm 2\sigma$	
uniform/oscillatory zoning domains												
#20.2	31	23	0.78	1.96	41.30	1.74	.06603	0.0077	0.0237	0.0010	151.3	6.5
#21.1	65	39	0.62	0.99	40.08	1.40	.05778	0.0052	0.0247	0.0009	157.3	5.5
#22.1	30	14	0.48	2.25	40.63	2.29	.06860	0.0078	0.0241	0.0014	153.3	8.7
#23.1	31	13	0.44	2.20	40.66	1.92	.06820	0.0082	0.0241	0.0012	153.2	7.3
#24.1	27	9	0.35	1.70	40.42	1.86	.06389	0.0075	0.0243	0.0011	154.9	7.2
#25.1	59	41	0.73	1.21	43.33	1.55	.05943	0.0056	0.0228	0.0008	145.3	5.2
#26.1	64	36	0.57	1.37	41.11	1.41	.06102	0.0051	0.0240	0.0008	152.8	5.3
#27.1	31	14	0.46	2.49	41.64	1.81	.07064	0.0075	0.0234	0.0010	149.2	6.6
#28.1	32	14	0.47	1.44	41.89	1.83	.06150	0.0076	0.0235	0.0011	149.9	6.6
#29.1	58	34	0.60	1.88	41.55	1.50	.06539	0.0057	0.0236	0.0009	150.5	5.5
#30.1	68	39	0.59	0.77	41.27	1.38	.05581	0.0045	0.0241	0.0008	153.2	5.2
cloudy/patchy domains												
#20.1	37	17	0.47	2.27	43.48	1.87	0.0686	0.0026	0.0225	0.0003	143.3	6.2
#5.2	84	11	0.14	15.40	99.73	4.24	0.1887	0.0129	0.0084	0.0004	53.9	2.5
#10.2	188	63	0.34	9.39	88.14	2.88	0.1208	0.0069	0.0104	0.0010	66.6	2.2

and plot close to the Concordia curve because of their low common Pb content. A regression line forced to Broken Hill common Pb defines an age of 152±2 Ma (95% confidence level). Three analyses on the cloudy domains yielded younger, scattering $^{206}Pb/^{238}U$ ages (143±6, 67±2 and 54±2 Ma, 2σ, Table 1).

Interpretation

The weak oscillatory zoning and the medium Th/U ratio (>0.1) indicate that the zircon domains dated at 152 Ma are magmatic. Inclusions of quartz and apatite are consistent with a magmatic origin. The U-Pb analyses on these domains do not show scattering and are interpreted as dating the crystallization of the plagiogranite at 152±2 Ma, during formation of the Western Tethys ocean crust.

The different ages obtained from the domains with cloudy/patchy zoning indicate that in these areas the U-Pb system has been affected by a later event, whose age is likely to be at least as young as 54 Ma. Given the geological and petrological history of the rock, it is likely that the perturbation of the isotopic composition of the zircons occurred during the Tertiary Alpine metamorphism, which elsewhere in the Monviso meta-ophiolite is dated at 45±1 Ma (Rubatto and Hermann, 2002). Inclusions of albite and rare Na-amphibole are in line with this hypothesis. Zircons with similar features have been also described in the Zermatt - Saas Fee ophiolites and interpreted as being affected Pb loss and recrystallisation during the Alpine metamorphism (Rubatto et. al., 1998).

DISCUSSION

Timing of the ophiolite plutonism in the Piedmont-Liguria Tethys

The data presented above indicates that in the Monviso ophiolite the last pulses of plutonic activity were emplaced at 152±2 Ma. An earlier stage in the formation of the oceanic crust preserved in the Monviso ophiolite sequence is documented by the intrusion age of the Lago Chiaretto metaferrogabbro (eclogite) on which Rubatto and Hermann (2002) obtained a mean age of 163±2 Ma by *in situ* U-Pb dating of magmatic zircon domains. The older radiometric age corresponds to the Callovian (164-159 Ma) in the time scale of Gradstein et al. (1995), and to the Bathonian (164-160 Ma) in the time scale of Odin (1994). The younger radiometric age corresponds to the Kimmeridgian (154-151 Ma; Gradstein et al. 1995) or the Oxfordian (154-146 Ma; Odin, 1994). From these data a minimum time span of 7-15 Ma can thus be assumed for the plutonic activity recorded in the Monviso ophiolite. However, as only two rocks were dated so far, the existence in the Monviso ophiolite of older, or younger gabbro bodies cannot be excluded.

Recently acquired radiometric data that provide direct age constraints on the formation of oceanic crust allow an assessment for the timing and duration of the plutonic activity at the scale of the whole Piedmont-Liguria basin. These radiometric data are located in Fig. 1 and summarized in Fig. 5.

In the eclogite-facies meta-ophiolites of the Western Alps, the Allalin olivine gabbro and the Mellichen leucogabbro, both from the Zermatt-Saas ophiolite zone, yielded a U/Pb zircon age of 163.5±1.8 Ma, and of 164.0±2.7 Ma, respectively (Rubatto et al., 1998). In the eclogite-facies Voltri Group a U/Pb zircon age of 150.1±0.7 Ma was obtained for a metatrondhjemite dyke within Mg-gabbro (Borsi et al., 1996), whereas eclogitized gabbros provided a less precise whole-rock Sm/Nd isochron age of 177±23 Ma (Borsi, 1995).

In the blueschist-facies meta-ophiolites of the Western Alps, a U/Pb zircon age of 153.3±1.0 Ma was obtained for a metadiorite dyke within a Fe-diorite from the Cravasco-Voltaggio Unit of the Sestri-Voltaggio Zone, whereas the host Fe-diorite gave an age of *ca*. 156 Ma (Borsi et al., 1996). In Corsica, two albitite samples from the Rospigliani series yielded zircon U/Pb ages of 161±3 Ma (Ohnenstetter et al., 1981).

In the Chenaillet unit of the Montgenèvre ophiolite, the largest ophiolite complex of the Western Alps which escaped the high-pressure metamorphism, several rocks were dated by Costa and Caby (2001). The more reliable ones are zircon ages: a leucodiorite vein within sheared gabbros yielded an age of 156±3 Ma, whereas an albitite lens within serpentinized peridotite yielded concordant ages at 148±2 Ma. In addition to these two ages, Costa and Caby (2001) also present Sm-Nd whole-rock data but, as the significance of such data is still debated in the literature, it appears premature to speculate about geological interpretations based on whole-rock isochrons.

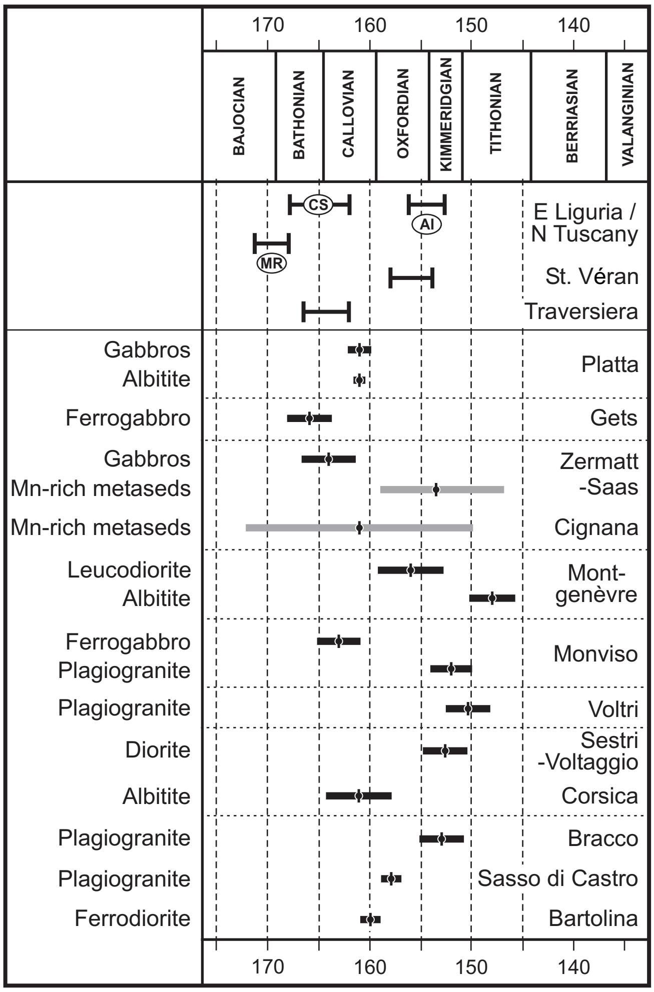

Fig. 5 - Representative U/Pb and $^{40}Ar/^{39}Ar$ ages of plutonic rocks and Mn-rich metasediments from ophiolites of the Alps, Northern Apennines and Corsica. The ages are shown as bars encompassing 2σ errors. Isotopic ages are compared: 1) to the stratigraphic ages of the first supra-ophiolitic radiolarian sediments in the western Alps (Saint-Véran: De Wever and Baumgartner, 1995) and in eastern Liguria - northern Tuscany (Monte Rossola: MR, Chiari et al., 2000), 2) to the stratigraphic age of supra-basaltic radiolarian sediments in the Cottian Alps (Traversiera: De Wever and Baumgartner, 1995). The stratigraphic ages of the oldest (Costa Scandella: CS) and youngest (Aiola: AI) supra-basaltic radiolarian sediments in eastern Liguria - northern Tuscany (Chiari et al., 2000) are shown for comparison. Source of isotopic ages as in Fig. 1. Time scale from Gradstein et al. (1995).

In the Platta nappe of the Central Alps, zircons from a coarse-grained Mg-gabbro, a ferrogabbro, a diorite dyke and an albitite clast in a pillow breccia have a statistical mean age of 160.9±0.4 Ma, suggesting that formation at 161±1 Ma is representative of the entire gabbro suite in this area (Schaltegger et al., 2002).

Lastly, pegmatitic gabbros occurring as olistoliths within the basal wildflysch of the Gets nappe (Préalpes) were dated using the U/Pb and Ar/Ar techniques (Bill et al., 1997). Zircons (U/Pb) and amphiboles (Ar/Ar) from two samples, a Mg-gabbro and a differentiated pargasite gabbro, provided identical values of 166±2 Ma, interpreted as the crystallization age of the gabbros.

In the Internal Ligurides of the Northern Apennines, a rodingitized dyke of plagiogranite hosted in serpentinized lherzolite of the Bracco area provided a U/Pb zircon age of 153.0±0.8 Ma (Borsi et al., 1996, sample RG-1). In the same area, an olivine gabbro gave a whole rock-pl-cpx Sm-Nd internal isochron of 164±14 Ma (Rampone et al., 1998). In the External Ligurides, Ar/Ar data on amphiboles from the Sasso di Castro plagiogranite (Bortolotti et al., 1995, sample DG 104), recalibrated against the new age of 523,1 Ma measured on age standard MMhb-1 give a precise age of 157.96±0.77 Ma (I.M. Villa, 2002, pers. comm.) for the crystallization of the plagiogranite. As noted by Bortolotti et al. (1995), this age is identical within experimental error to the Ar/Ar amphibole age measured on La Bartolina ferrodiorite of southern Tuscany (Bortolotti et al., 1990). Lastly, plagioclase-clinopyroxene pairs of spinel lherzolites from the External Ligurides yielded a Sm/Nd isochron age of *ca*. 165 Ma, which has been interpreted as the age of metamorphic re-equilibration from spinel- to plagioclase-facies conditions (Rampone et al., 1995), and linked to the early Jurassic decompressional evolution (Rampone and Piccardo, 2000).

In summary, available geochronological data of magmatic rocks from different Piedmont-Liguria ophiolites of the Western Alps, Corsica and Northern Apennines range from *ca*. 170 to *ca*. 150 Ma, with most ages clustering in the 165-160 and 155-150 Ma age brackets (Fig. 5).

From the synopsis of data given above it would be tempting to draw the conclusion that an overall time-lithology correlation exists in the plutonic rocks of Piedmont-Liguria basin, as advocated, for example by Costa and Caby (2001), with early emplacement of gabbroic melts into the mantle peridotites, followed much later by plagiogranite emplacement. While this interpretation is undoubtedly true in individual ophiolite segments, a closer look to the data indicates that it is not consistent with the age pattern at the scale of the whole Piedmont-Liguria basin. Actually, even if the data are still scarce, they seem sufficient to show that both differentiated and undifferentiated tholeiite melts were emplaced at the same time in different portions of the Piedmont-Ligurian oceanic crust. Strongly differentiated plagiogranites and Fe-Ti gabbros (or zircons derived thereof) occur throughout the whole time span from *ca*. 170 (Gets nappe: Bill et al., 1997) to *ca*.150 Ma (Fig. 5). This is the same time span in which much less differentiated gabbros (e.g. the Allalin body: Rubatto et al., 1998) crystallized. Nevertheless, as pointed out by Costa and Caby (2001), it is worth noting that plagiogranites intruded in the peridotites (e.g. Montgenèvre, Monviso, Voltri, Bracco) are the most recent intrusive rocks, ranging from 153 to 148 Ma.

Time relations between the plutonic and volcanic activity in the Piedmont-Liguria basin

The radiometric ages discussed above suggest that the plutonic activity recorded in Piedmont-Liguria ophiolites of the Western Alps, Corsica and Northern Apennines lasted from *ca*. 170 to *ca*. 150 Ma, with most ages clustering in the 165-160 and 155-150 Ma age brackets.

As elsewhere, the sediments are often the only possibility for obtaining age constraints for the extrusive basalts of the Piedmont-Liguria basin. Selected biostratigraphic data from the Northern Apennines and Western Alps ophiolites (Fig. 1) are discussed hereafter and summarized in Fig. 5.

The lower limit for the beginning of the volcanic activity is provided by the radiolarites of latest Bajocian-early Bathonian age (i.e. 169±1 Ma according to Gradstein et al., 1995) deposited at the base of massive basalts on top of ophicalcites covering serpentinites at Monte Rossola, Internal Ligurides (Chiari et al., 2000). The youngest age (latest Oxfordian-Early Kimmeridgian) for supra-basaltic cherts was found in several Tuscan localities, including Aiola (Chiari et al., 2000). These ages imply a 169±1 to 154±1 Ma age bracket for the duration of basalt extrusion in the Ligurian basin according to the time scale of Gradstein et al. (1995).

In the Piedmont ophiolite basin, the Alpine recrystallization has obfuscated beyond recognition any fossil record preserved in the metaradiolarites, the only exceptions being Gias Traversiera and Saint-Veran (De Wever and Baumgartner, 1995; and refs. therein), both Type 2 blueschist ophiolites of the Cottian Alps. Radiolarians preserved in phosphate nodules from red-coloured shales overlying pillow basalts and serpentinized peridotites in the ophiolite body of Gias Traversiera, Acceglio, Italy (Lagabrielle et al., 1982) are of Late Bathonian-Early Callovian age (corresponding to 167-162 Ma according to Gradstein et al., 1995), whereas Radiolarians preserved in rhodochrosite nodules from a metachert horizon overlying ultramafic breccia and ophicalcite at Pic Cascavelier, Saint-Véran, France (Caby et al., 1987) are of Middle-Late Oxfordian age (158-154 Ma). These data are consistent with the maximum depositional ages for Mn-rich metasediments overlying the mafic rocks in the eclogite-facies Zermatt-Saas ophiolites of the Pennine Alps, which are *ca*. 161±11 Ma at Lago di Cignana and 153-154 Ma at Sparrenflue (U/P ages on detrital zircon: Rubatto et al., 1998).

Summing up, the chronostratigraphic evidence preserved in the Piedmont-Liguria radiolarites and U/Pb zircon ages in Mn-rich metasediments suggest that, at the scale of the whole Piedmont-Liguria ophiolite basin, the duration of basalt extrusion was *ca*. 13-17 Ma, and it was approximately synchronous to the plutonic activity.

A discussion of possible genetic models for the whole Piedmont-Liguria Tethys in the light of radiometric ages and Radiolarian biostratigraphy is beyond the scope of this work. We note, however, that the short duration of synchronous plutonic and volcanic activity (from *ca*. 170 to *ca*. 150 Ma) suggests that the embryonic ocean model (eg. Abbate et al., 1994; Piccardo et al., 2001) rather than a mature, slow- to very-slow-spreading, Atlantic-type ocean model (eg. Lagabrielle, 1994; Lagabrielle and Cannat, 1990) may better fit the geological history recorded in the Piedmont-Liguria ophiolites.

PALEOGEOGRAPHICAL IMPLICATIONS OF THE AGE DATA

De Wever and Baumgartner (1995), who have recently re-assessed the age of supra-ophiolitic radiolarites in blueschist-facies Ligurian-type ophiolite bodies of the Western Alps, suggested that they may be diachronous, with an age difference of up to 10 Ma in two adjacent areas (Fig. 5). Specifically, they demonstrated that Radiolarians from Gias Traversiera (Acceglio, Italy) are of Late Bathonian-Early Callovian age (167-162 Ma, according to Gradstein et al., 1995), whereas Radiolarians from Pic Cascavelier (Saint-Véran, France) are of Middle-Late Oxfordian age (158-154 Ma). This age difference corresponds to *ca*.10 Ma in both the Gradstein et al. (1995) and in the Odin (1994) time scale. The same diachronicity is seen in the Northern Apennine ophiolites, where cherts lying above the basalts range in age from the late Bathonian-early Callovian (168-162 Ma) at Costa Scandella (Chiari et al., 2000) to the latest Oxfordian-early Kimmeridgian (156-152 Ma) in several Tuscan localities, including Aiola (Chiari et al., 2000). These ages correspond to an average time span of *ca*. 11 Ma in the Gradstein et al. (1995) time scale.

By considering both the chronostratigraphic and radiometric ages from the Cottian Alps, basalt extrusion and deep-sea sediment deposition at Gias Traversiera appear to be synchronous with the crystallization of Fe-Ti gabbros in the Monviso ophiolite complex (163±2 Ma: Rubatto and Hermann, 2002) and earlier by *ca*. 10 Ma than the emplacement of the Monviso plagiogranite (152±2 Ma: this work). That is, differentiated tholeiite gabbros were being emplaced at Monviso at the same time basalts were extruded above a peridotite floor at Traversiera (Fig. 5).

Taking the age data at face value it may be concluded that in different parts of the Piedmont-Liguria Tethys the formation of oceanic crust was achieved by the same sequence of processes: exhumation of mantle peridotites, emplacement and differentiation of tholeiite melts in shallow-level plutons, high-temperature ductile deformation, exposure on the ocean floor of peridotites and gabbros, followed by basalt extrusion and deep-sea sedimentation (see for example the comprehensive reviews by Lemoine et al., 2000 and Piccardo et al., 2001). However, this evolution was not synchronous in the different sectors. For example, from the age of the sediments and the crystallization ages of the plutonic rocks, a time polarity is evident in the development of the oceanic crust exposed in the ophiolite bodies of the Cottian Alps, with Gias Traversiera forming first, followed by Pic Cascavelier and then by Monviso and Montgenèvre. If we translate the time sequence into paleogeographic position of the ophiolite bodies, it can be speculated that the oceanic crust preserved at Gias Traversiera was formed nearer to the continental margin than Monviso, which formed later and hence in a more distal position, with Pic Cascavelier sitting in an intermediate position.

CONCLUSIONS

Zircon crystals recovered from a Monviso metaplagiogranite hosted in the Basal Serpentinite Unit record a crystallization age of 152±2 Ma, corresponding to the Kimmeridgian (154-151 Ma; Gradstein et al. 1995). In conjunction with the intrusion age of the Lago Chiaretto metaferrogabbro (163±2 Ma: Rubatto and Hermann, 2002), this age brackets the formation of the intrusive sequence preserved in the Monviso meta-ophiolite within a minimum time span of 7-15 Ma during Callovian to Kimmeridgian times.

The U-Pb ages from Monviso fit well in the time span defined by the whole data set of reliable crystallization ages for Western Alps and Northern Apennines ophiolites. Such ages suggest that the plutonic activity in the Piedmont-Liguria domain of the western Tethys may have lasted no more than 15 to 20 Ma, from *ca*. 170 to *ca*. 150 Ma (Bathonian-Kimmeridgian, according to Gradstein et al., 1995).

A comparison of these data with the age of volcanic activity in the Piedmont-Liguria ophiolite basin, deduced from Radiolarian biostratigraphy, demonstrates that the plutonic and volcanic activity were approximately coeval. This feature and the short duration of magmatic activity favour an embryonic ocean model relative to the model of a mature, slow-spreading, Atlantic-type ocean for the formation of the Piedmont-Liguria oceanic crust.

At the scale of the Cottian Alps ophiolites, the new data suggest that the plutonic activity recorded at Monviso was coeval with basalt extrusion and deep-sea sediment deposition in Ligurian-type ophiolite bodies (Gias Traversiera, Pic Cascavelier). This implies that the oceanic crust preserved in the Monviso ophiolite formed later, and in a more central position of the basin, than the oceanic crust preserved in such Ligurian-type ophiolite bodies.

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