Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 82 (1989)

Heft: 2

Artikel: K-Ar ages of ophiolites and arc volcanics of the Indus suture zone : clues on the early evolution of the Neo-Tethys

Autor: Reuber, Ingrid / Montigny, Raymond / Thuizat, Robert

DOI: https://doi.org/10.5169/seals-166398

Eclogae geol. Helv. 82/2: 699–715 (1989)

0012-9402/89/020699-17 $ 1.50 + 0.20/0

K-Ar ages of ophiolites and arc volcanics of the Indus suture zone: clues on the early evolution of the Neo-Tethys

INGRID REUBER[1], RAYMOND MONTIGNY[2], ROBERT THUIZAT[2] and ANNIE HEITZ[2])

ABSTRACT

K-Ar analyses on separated minerals are reported for different rocks from the Indus suture zone (Ladakh-Himalaya), including the Spongtang ophiolite, thrust approximately 30 km south of the suture and the Dras volcanic arc, which lies on an ophiolitic substratum.

Basic dikes intrusive into the ophiolitic assemblages yield two clusters of amphibole ages. The first, comprised between 140 and 125 Ma, mirrors both, a metamorphic event of amphibolite grade induced probably by an oceanic thrusting and intrusions of thin basic dikes. The second, at about 170 Ma, is tentatively interpreted as a minimum age of the ophiolite generation. Analytical uncertainties due to the low potassium content of the investigated minerals, preclude to interpret the rare intermediate ages.

Amphiboles extracted from rocks of the Dras arc yield ages falling in the 105–95 Ma range, which is in good agreement with the paleontological data. An age of 95±3 Ma is given by a biotite from a dioritic pluton that intruded the Dras volcanics. This result, given the size of the massif, is viewed in terms of cooling ages, which implies a pluton emplacement immediately following the volcanic activity and sedimentation dated in this area. An amphibole age of 78.5±2.9 Ma obtained on a small grain size fraction confirms the existence of a metamorphic episode at about 75 Ma in the arc terranes.

The data on ophiolites support previous suggestions concerning the evolution of the Neo-Tethys which called for the formation of an oceanic crust as far back as the end of Triassic or the beginning of Jurassic. On the other hand, our results on Dras volcanics and related rocks confirm earlier published age determinations on the arc series of Kohistan and Tibet.

RÉSUMÉ

Des analyses K/Ar sur minéraux séparés ont été effectués pour plusieurs roches provenant de la suture de L'Indus (Himalaya du Ladakh), notamment de l'ophiolite de Spongtang, qui se trouve charriée 30 km environ au sud de cette suture, et de l'arc de Dras, qui superpose un substratum ophiolitique.

Les dikes basiques qui intrudent ces assemblages ophiolitiques indiquent deux regroupements d'âges d'amphibole. Le premier, compris entre 140 et 125 Ma reflète à la fois un événement métamorphique en faciès amphibolite, lié probablement à un écaillage intra-océanique, et une intrusion de dikes basiques peu épaisses. Le deuxième, aux environs de 170 Ma, peut être interprété comme un âge minimal de la génération de l'ophiolite. Les incertitudes analytiques, liées à la faible teneur en potassium de ces roches, ne permet pas une interprétation des âges intermédiaires.

Les amphiboles extraites des roches reliées à l'arc volcanique de Dras indiquent des âges de l'ordre de 105 à 95 Ma, qui correspondent bien aux données paléontologiques. Un pluton dioritique intrudant ces séries volcaniques et sédimentaires indique un âge sur biotite de 95 ± 3 Ma. Compte tenu de la taille du pluton, cet âge correspond certainement à un âge de refroidissement, ce qui indique un emplacement du pluton immédiatement suivant l'activité

[1]) GRECO Himalaya, CNRS, Laboratoire de géologie stratigraphique et structurale, 40, avenue du Recteur-Pineau, 86022 Poitiers, France.

[2]) Ecole et observatoire de physique du Globe, 5, rue Descartes, 67084 Strasbourg, France.

volcanique et la sédimentation de cette région. L'âge de 78.5±2.9 Ma obtenu sur des amphiboles de taille plus petite, confirme l'existance d'un épisode métamorphique aux environs de 75 Ma dans les terrains d'arc.

Les données sur les ophiolites soutiennent des suggestions antérieures concernant la formation de la Néo-Téthys aussi tôt qu'à la fin du Trias ou le début du Jurassique. D'autre part, nos données sur l'arc de Dras sont en accord avec celles publiées sur le Kohistan et le Tibet.

Introduction

The indus suture zone, which constitutes one of the numerous sutures separating India from Eurasia, is bordered in the north by the Dras volcanics and the Ladakh batholith. The ophiolites outcrop in different tectonic environments: either as basement of arc volcanics or as thrust massifs south of the suture (Fig. 1).

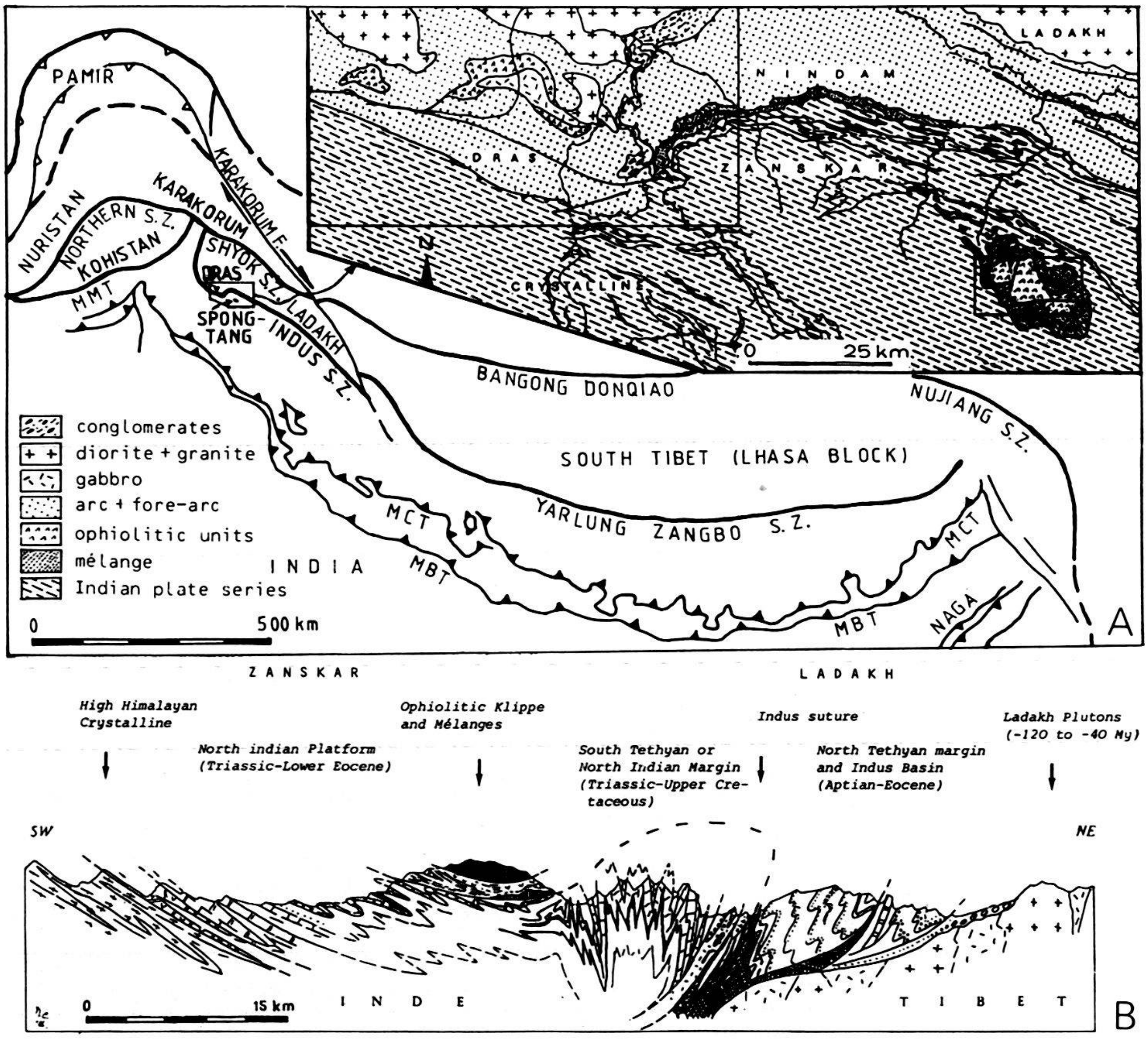

Fig. 1. Localisation of the two study areas on a simplified map of western Ladakh, located on a tectonic map of the Himalayas, simplified after GIRARDEAU et al. 1986 (A), and cross-section of Zanskar showing the relation of the Spongtang Klippe with the suture zone, from COLCHEN 1987 (B).

The various volcanic and plutonic rocks of the aforementioned area were subject to petrologic and geochronologic investigations (HONEGGER et al. 1982, SCHÄRER et al. 1984). In contrast, the ophiolite history still needs to be unravelled even though a Jurassic to early Cretaceous age is usually assumed for the accretion of ophiolites in this region (HONEGGER et al. 1982, CHANG 1984).

The main objective of this K-Ar study was, therefore, to decipher the sequence of events which affected the ophiolites in this area. Particularly crucial to a sound reconstruction of the Neo-Tethyan ocean are the crystallization time of the gabbroic rocks constituting the basic part of the sequence on one hand, and the time of intra-oceanic slicing and obduction on the other hand. Clues to the latter process can be gained by dating the metamorphic rocks associated with the ophiolites (THUIZAT et al. 1981, MONTIGNY et al. 1988). In order to avoid, as far as possible, the drawbacks caused by the low-K content and due to the complex tectonic history of ophiolites, we analysed amphibole solely because of its usually good argon retentivity (DALRYMPLE & LANPHERE 1969) and a potassium content that can be measured with flame photometry. A subsidiary aim was to establish the time relationships between the arc volcanics and ophiolites. A short time span between the crystallization of the two series would imply an origin in an arc environment for the ophiolites. Accordingly we completed the data base concerning the arc series of the region by dating amphiboles and a biotite from magmatic rocks spatially associated with the ophiolites.

Geological setting

The Ladakh area is located at the western end of the Indus-Tsangpo suture zone (Fig. 1). The Ladakh batholith and the volcanic series of Dras situated to the north of the suture testify a subductionrelated magmatic activity that affected the North-Tethyan active margin (HONEGGER et al. 1982, DIETRICH et al. 1983, THAKUR & MISRA 1984, SHARMA 1987, REUBER, in press). The South-Tethyan passive margin is represented by the Zanskar Mesozoic-Cenozoic sediments which are situated immediatly to the south of the suture. They overlie the High Himalayan crystalline (BASSOULLET et al. 1978, 1980, FUCHS 1977, 1979, 1982, BAUD et al. 1982, KELEMEN & SONNENFELD 1983). Remnants of oceanic material are preserved in the melanges of the Indus suture zone (GANSSER 1980a & b, SUTRE 1989), in the Spongtang Klippe (REUBER 1966) and in the basement of the Dras and Nindam series (REUBER, in press, SUTRE 1989).

1. The Spongtang Ophiolite

The Spongtang Klippe is mainly composed of peridotites. They were discovered at the end of the last century (LYDEKKER 1880, 1883, LA TOUCHE 1888, MCMAHON 1901) but mapped and studied in detail only during the last decade (BASSOULLET et al. 1980, KELEMEN & SONNENFELD 1983, REIBEL & REUBER 1982, REUBER et al. 1983, REUBER 1986). The ophiolite tectonically overlie a volcano-sedimentary melange of late Cretaceous to early Eocene age, which contains ophiolitic blocks, and a serpentinite base (COLCHEN & REUBER 1986, COLCHEN et al. 1987, REUBER et al. 1987). The complete assemblage was thrust over sedimentary series of the Zanskar unit (Figs. 1, 2), which

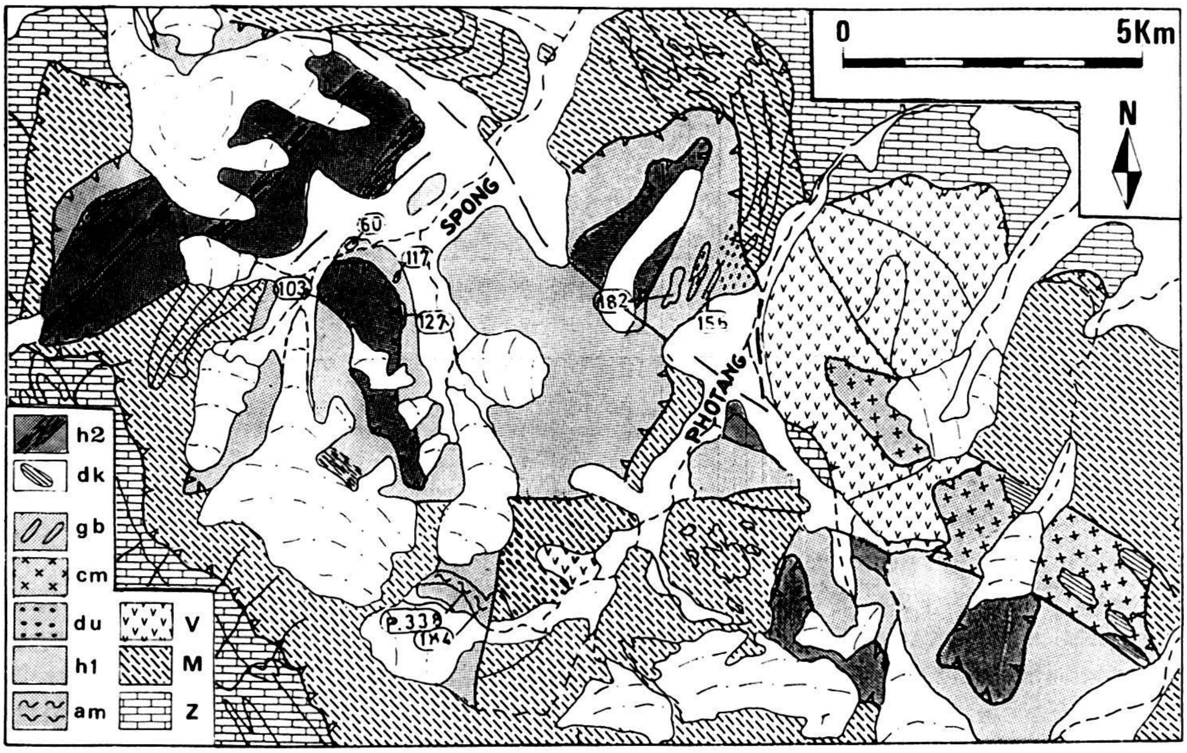

Fig. 2. Localisation of the samples from the Spongtang ophiolite. h2 = harzburgites of the upper unit; lower unit: dk = dike swarms, gb = gabbro dikes, cm = cumulates, du = dunites, h1 = harzburgites; am = amphibolites – metamorphic sole; V = massive volcanic rocks and pillow lavas, M = melange, Z = Zanskar series – "par-autochtonous".

includes lower Eocene or even younger strata. Accordingly the thrusts should postdate lower Eocene (Colchen & Reuber 1987, Kelemen et al. 1988).

The peridotites are harzburgitic tectonites affected by a high temperature plastic flow typical of the asthenospheric uprise below an oceanic spreading center. They are separated into two units by a flat mylonitic shear zone (Fig. 2). The upper unit is composed of a lherzolitic harzburgite (Ol≈60%, opx≈35%, cpx≤4%, Cr+) and the lower unit of a highly depleted harzburgite (Ol≥75%, opx≥25%, Cr+). This superposition is quite the reverse of what is found in a standard ophiolite. The near horizontal intra-peridotitic shear is viewed as the result of an intra-oceanic thrust (Reuber 1986, Mevel & Reuber 1987). In the western part, vertical shear zones are frequent. They may be related to oceanic transform zones and consequently to the accretionary environment. These vertical shear zones are, in some instances, intersected by the nearly horizontal intra-peridotitic shear (Spong) whereas in other places (Photang) those two types are a continuation of one another.

Scant cumulates are found in the eastern part of the lower unit. Ultramafic rocks, as wehrlites with pyroxenite layers, predominate over gabbros (Reuber 1986). Dikes of pyroxenite and pegmatitic gabbro intruded still hot harzburgites as no chilled margins are observed. Their width is decimetric to plurimetric. They are frequently deformed by shear zones of the two aforementioned types (Mevel & Reuber 1987). Their intrusion is thought to have taken place in the accretional environment and, at least in some places, the deformation appears to be in continuation with the intrusion.

Diabase dikes with chilled margins occur as swarms intruding the cumulates and as isolated dikes intruding the harzburgites of the lower unit. The latter type, where situated within the intra-peridotitic shear, are transformed into foliated amphibolite.

Layered amphibolites interbedded with chert represent a typical facies of an intra-peridotitic sole (Parrot & Whitechurch 1978), derived from volcanics and sedimentary deposits. They outcrop below the major harzburgite unit and are associated with other harzburgites and the melange.

2. The Dras volcanic arc of the Kargil area

The Dras volcanics and related Kargil intrusives located to the west and south of the Ladakh batholith (Fig. 1) have been extensively investigated (Wadia 1937, Frank et al. 1977, Honegger et al. 1982, Dietrich et al. 1983). Detailed mapping of the Kargil area (Reuber, in press) reveals three lithostructural units (Fig. 3):

1) The Dras I unit. In Dras I, the important sedimentary part includes Orbitolina limestones, similar to those of the facially equivalent Naktul nappe, dated Albian to Cenomanian (Fuchs 1979). Recently an ammonite has been found (by Paul Franck) in black slates of Dras I formation, confirming a middle Albian age (Thieulloy et al. 1988). In many places, Dras I is sheared under greenschist facies conditions, grading into amphibolite facies in the proximity of the plutons of gabbroic to granitic composition which intrude the Dras I series (Honegger et al. 1982, Rai & Pande 1982, Reibel 1984). Honegger et al. (1982) and Dietrich et al. (1983) propose the beginning of arc activity as early as late Jurassic based on dates from radiolarian chert intercalated with pillow lava. These strata are viewed as part of the oceanic substratum by Reuber (in press).

2) The Naktul nappe. The Naktul nappe (Fig. 3) is thrust over the Butum conglomerates (probable equivalent of the Miocene part of the Kargil formation), unconformably overlying Dras I and Dras II. It consists of several tectonic slices. Purely volcaniclastic material in the southeast may represent an equivalent of the Nindam fore arc facies. No penetrative deformation is observed in this formation with the exception of the black slates located at the base of the nappe.

3) The Dras II unit. The Dras II formation consists of a volcaniclastic unit containing predominantly volcanics of explosive origin. Well stratified tuff unconformably overlie the Dras I, grading into a coarser breccia in the central part of Stang and Dandalung mountains where they are hydrothermally "welded". Carbonates are absent in this formation, which contains no fossil. Heretofore no radiometric data is available.

3. The Dras ophiolite

The three arc related units, described in the preceding chapter, stratigraphically overlie serpentinized harzburgites and occasionally remarkably complete ophiolitic assemblages. Beside ultramafics, these include gabbros, diabase dikes and pillow lavas as in the area of Dras, between Thasgam and Saliskote, at the base of Dandaldung mountain, at Arju La and at the base of the southernmost slice of Naktul (Reuber, in press, Fig. 3). Isolated diabase dikes in the serpentinites are commonly foliated. At their largest outcrop between Thasgam and Saliskote the serpentinized harzburgites gradually

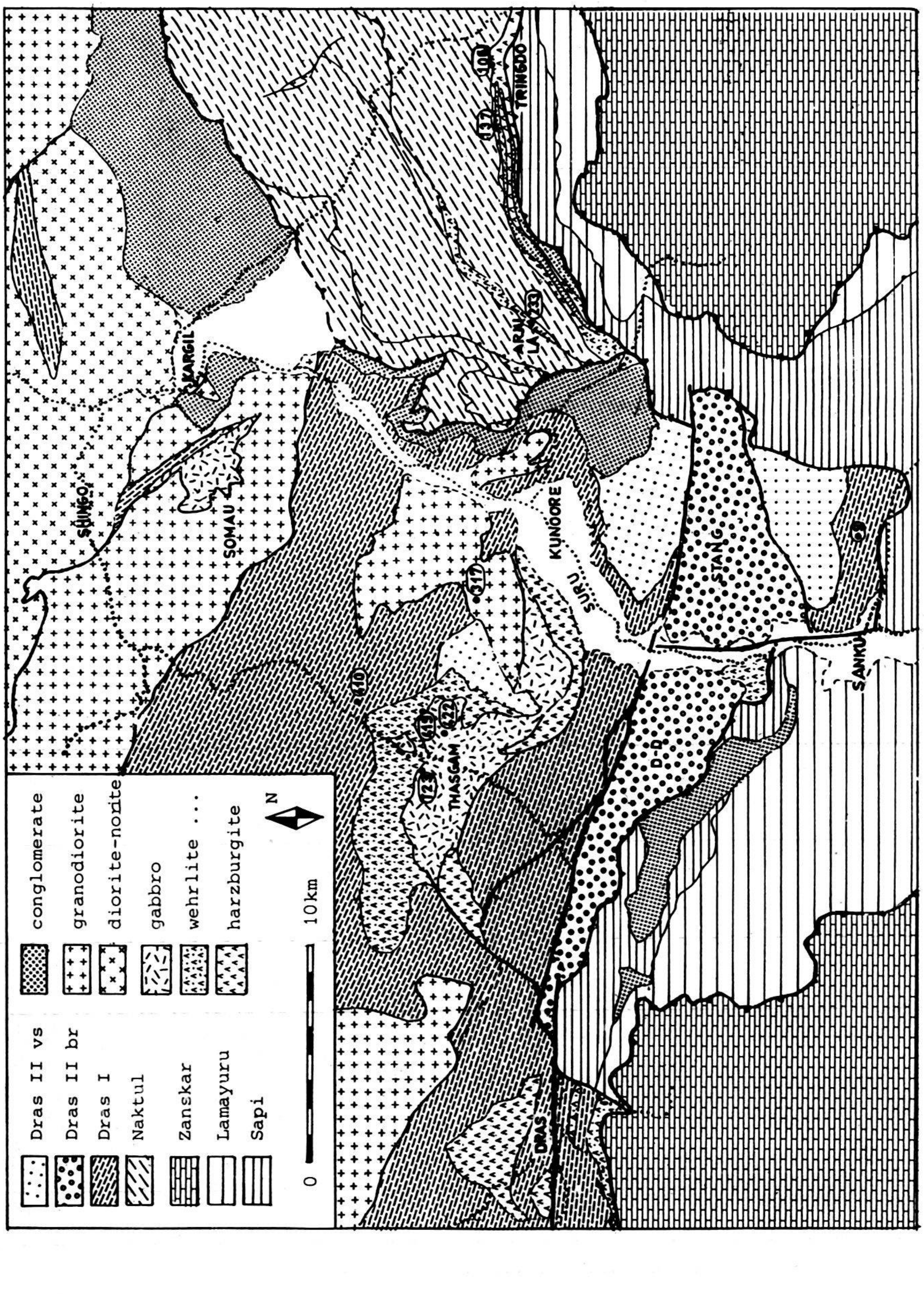

Fig. 3. Localisation of the samples from the Dras area; wehrlite ... stands for essentially ultramafic cumulates, but includes some gabbro and diabases, Dras II: vs = volcano-sedimentary strata, br = breccia, D–D = Dandaldung mountain.

give way to dunites and wehrlites; diabase dikes more or less foliated are frequent at the northern edge of this complex. In the south, the wehrlites are intruded by larger amounts of coarse grained to pegmatitic gabbro and undeformed diabase dikes. The ultramafics have previously been interpreted as intrusive into the arc series (Prasad et al. 1980, 1982, Reibel 1984), but also proposed to be oceanic on the ground of geochemical data (Radhakrishna et al. 1987).

Analytical techniques

All of the K-Ar determinations were performed on separated minerals, amphibole and exceptionally biotite. Both are known as reliable K-Ar clocks (Hart 1964, Hanson & Gast 1967). The closure temperature of amphibole is high, 530±40 °C after Harrison & McDougall 1980).

Unless otherwise stated, the 100–160 μm sieve fraction of the ground rock was selected for magnetic separation. Whenever necessary, heavy liquids were used for further refinement. The purity of the extracted minerals was usually better than 99%, although a few hornblendes may contain up to 3% of epidote. The analytical procedure, more extensively described elsewhere (Westphal et al. 1979) is as follows: potassium was measured by flame photometry with a lithium internal standard. Argon was extracted in a heat-resistant glass vacuum apparatus and determined by isotope dilution (^{38}Ar as a tracer) using a MS 105 mass spectrometer. All samples were measured using the static method.

The set of constants recommended by Steiger & Jäger (1977) was used for age calculation. Quoted age uncertainties represent the effect of the estimated analytical precision at one standard deviation on the calculated age. They were calculated using the procedure given by Cox & Dalrymple (1967).

Results and discussion

The analysed samples belong to six lithologies, four of which are related to oceanic events (Table 1):

- gabbros clearly related to oceanic accretion; they are frequently deformed;
- diabase dikes, possibly post-dating accretion;
- foliated diabase dikes, deformed within the intra-peridotitic shear zone;
- amphibolites from the metamorphic sole.

Two facies represent subduction-related magmatism (Table 1):

- pyroclastics and associated diabase dikes;
- dioritic plutons intrusive into the arc volcanics.

1. Spongtang

The difficulty in dating oceanic accretion with the conventional K-Ar method results from the low potassium content of most primary minerals of the crustal sequence. Accordingly the investigation is restricted to compositionally rock types which do not present clear genetic relationships with the cumulates.

No	Sample	Mineral	K_2O weight %	rad Ar 10^{-13} mole/g	%^{*40}Ar	calculated age	locality
81/60	leucogabbro dike	brown hornblende	0.028	0.5172	10	(124 ±75)	Spong
81/117	leucogabbro dike	brown hornblende	0.148	2.8146	52	127 ± 9	Spong
81/182	leucogabbro dike	green hornblende (non-magnetic)	0.158	3.2879	43	139 ± 8	Photang
81/182	leucogabbro dike	green hornblende (magnetic)	0.148	3.4671	39	156 ±11	Photang
81/156	diabase dike	green hornblende	0.133	2.6395	23	133 ±10	Photang
81/103	foliated diabase	green amphibolite	0.190	6.7402	7.2	231 ±23	Spong
81/127	foliated diabase	green amphibolite	0.155	3.953	33	169 ± 9.5	Spong
P 338	amphibolite	green amphibolite (+ epidote)	0.843	16.961	94	135 ± 4	Photang
81/184	meta-chert	green amphibolite	0.130	3.497	24	178 ±12	Photang
SD 419	hornblende wehrlite	green hornblende	0.153	4.072	70	176 ±10	Thasgam
T 23	hornblende gabbro	green hornblende	0.240	6.198	69	171 ± 8	Thasgam
SD 422	hornblende gabbro	green hornblende	0.270	6.3895	78	157 ± 7	Thasgam
SD 233	hornblende gabbro	brown hornblende (+ epidote)	0.151	3.1956	68	141 ± 8	Arju La
SD 137	foliated diabase	green amphibolite	0.164	3.144	54	128.5± 7	Tringdo
SD 106	diabase dike	green amphibolite	0.122	1.742	36	96.6± 6.5	Tringdo
SD 9	porphyric tuff	green hornblende	0.920	14.153	86	103.8± 2.8	Sanku
SD 410	porphyric tuff	green hornblende (>1 mm)	0.427	6.049	83	95.8± 2.8	N-Thasgam
SD 410	porphyric tuff	green hornblende (0.1–0.16 mm)	0.379	4.379	67.5	78.5± 2.9	N-Thasgam
SD 317	diorite	biotite	6.296	87.834	90	94.4± 2.7	>Thasgam

Table 1: Analytic data, for sample locations see fig. 2 and 3.

The cumulates of the Spongtang ophiolite are essentially wehrlites with subordinate amounts of gabbros, which do not contain amphibole. In contrast, well developed fresh amphiboles are abundant in some of the pegmatitic gabbro dikes. Diabase dikes from the dike swarms contain green interstitial amphibole along with primary clinopyroxene. The rare plagiogranites associated with the dike swarms have not delivered any zircon yet.

– *Gabbro dikes.* Pegmatitic gabbro dikes intrude harzburgite and coarse grained dunite. They contain fresh pyroxene and/or amphibole within a matrix of severely altered plagioclase. These dikes evolve in composition from pegmatitic pyroxenite to hornblende gabbro. The intensity of deformation increases parallel to that of magmatic evolution with the exception of the most evolved facies. Secondary amphibole develops on pyroxene but also on primary amphibole, even in moderately deformed samples.

The investigated samples follow the aforementioned evolution: samples 81/60 contains a brown hornblende with occasionally a core of clinopyroxene. Kink bands are rather scant; sample 81/117 displays a brown hornblende occasionally rimmed by

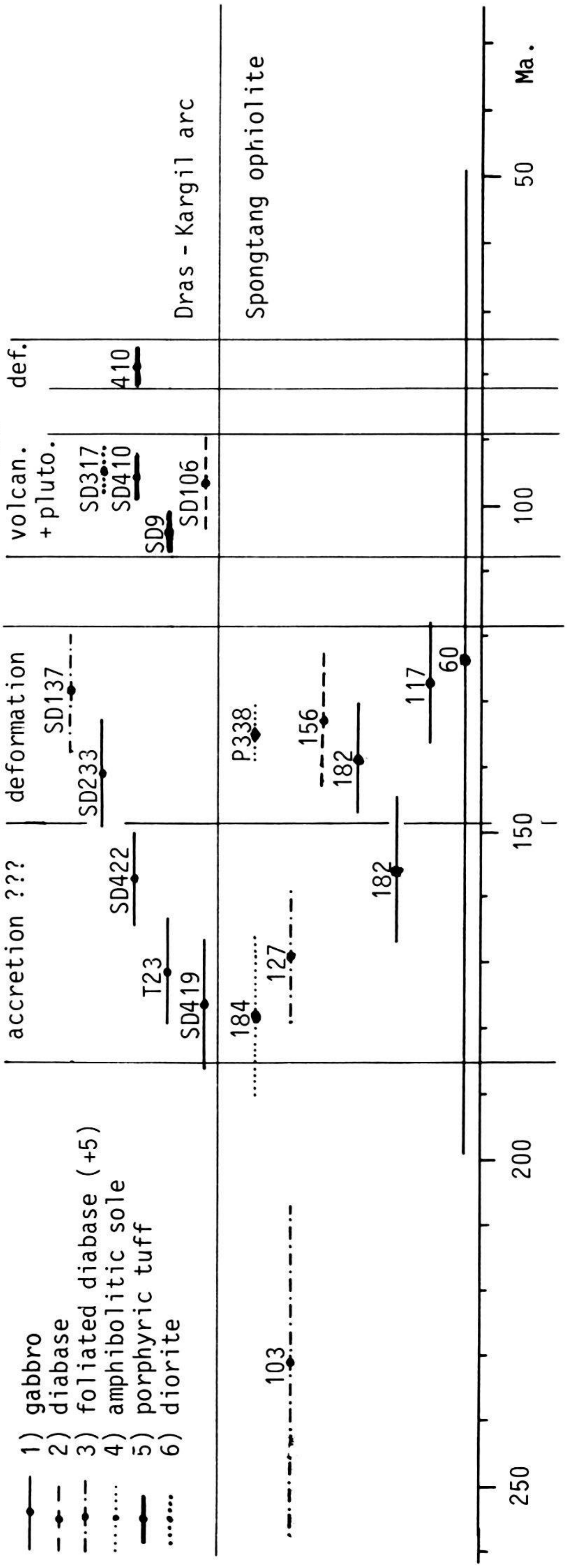

Fig. 4. Representation of the ages obtained, including their analytical error.

green hornblende and showing rare kink bands. Sample 81/182 presents a well-developed green hornblende of magmatic origin with acicular crystals of about 7×25 mm. Occasional cores of brown hornblende and secondary green amphibole can be observed.

The age of amphibole 81/60 cannot be taken into consideration because of the large analytical uncertainity, 124±75 Ma. A similar date was determined for amphibole 81/117, 127±9 Ma (Fig. 4, Table 1) which is not at variance with the age yielded by the less magnetic fraction of amphibole 81/182, 139±8 Ma. On the other hand, the magnetic fraction of amphibole 81/182 indicates an older age of 156±11 Ma (Fig. 4 and Table 1). The dispersion of the results taken into consideration may be real or due to analytical uncertainties.

– *Diabases.* The isolated diabase dikes intruded already cooled host rock as indicated by their chilled margins. The intrusion can take place at any time in the oceanic environment either right after the accretion or later, even subsequently to the intra-oceanic thrusting, as observed in Turkish ophiolites by Cakir et al. (1978). The doleritic diabase dikes contain more or less altered plagioclase, primary clinopyroxene and interstitial green hornblende. Sample 81/156 is located in the section of the gabbro dikes deformed in the amphibolite facies (Mevel & Reuber 1987). The green hornblende most probably is contemporaneous with the shear event that affected the gabbros, though the diabase itself appears little deformed. The age obtained on the green amphibole of sample 81/156 is 133±10 Ma, and thus coherent with those yielded by amphibole 81/117 and by the less magnetic fraction of amphibole 81/182 (Fig. 4 and Table 1).

– *foliated diabase dikes.* The intra-peridotitic shear also affects basic dikes. Isolated diabase dikes are then transformed into green amphibolite. Amphibole ages were expected to reflect the time of metamorphism and accordingly that of the shear event assumed to be caused by an intra-oceanic thrusting (Reuber 1986). Actually the two investigated samples yield amphibole dates higher than those of the gabbroic dikes. Amphibole 81/103 and amphibole 81/127 indicate ages of 231±23 Ma and 169±10 Ma respectively (Fig. 4 and Table 1).

– *Amphibolites from the metamorphic sole.* These layered and foliated amphibolites are represented by sample P 338 which contains green hornblende, plagioclase and epidote and 81/184 that is a green hornblende embedded in chert. They give ages of 135±4 Ma and 178±12 Ma respectively (Fig. 4 and Table 1).

In conclusion, the amphibole ages yielded by the various rocks of the Spongtang ophiolite display a definite cluster between 130–140 Ma. Older dates spread from 156±11 Ma to 231±23 Ma.

The most significant age is given by amphibole P 338. Due to a higher potasium content, the analytical uncertainty results in a moderate age error only, compared with the other samples, and also the possible inherited argon may not affect the calculated age considerably. Accordingly, the K-Ar age can approximately reflect the time of metamorphism in these rocks which have recrystallized in amphibolite facies. We, therefore, assign with confidence an age of 135±4 Ma to the metamorphism related to an important shear event which affected the Spongtang ophiolite. Reuber (1986) views the shearing as the consequence of an intra-oceanic thrusting similar to the one described by Parrot & Whitechurch (1978) in Turkish-Syrian ophiolites.

In contrast to amphibole P 338, the comparable results yielded by amphibole 81/117, 81/182 and 81/156 cannot be so straightforwardly interpreted, as all of those samples are moderately deformed, but the amphiboles appear to be essentially of magmatic origin. Accordingly, on one hand, it seems reasonable to envisage a magmatic event coeval with the deformation and metamorphism that affected P 338. As shown by relation of the horizontal shear zones with the vertical, transform-related ones, intra-oceanic thrusting should take place immediately following the magmatic activity of the accretionary ridge.

On the other hand, the observed ages may represent a complete or partial resetting of the K-Ar clocks linked to the metamorphism. The main argument for such a contention is the dispersion of ages yielded by two fractions of amphibole 81/182. The higher date might correspond to a partial resetting and the lower to a complete resetting of the K-Ar clock during the intra-oceanic metamorphism. The large analytical uncertainties preclude, however, to regard the two ages as significantly different.

The dispersed older ages of the metamorphic amphiboles 81/184, 81/127 and 81/103 are not easily interpretable (Fig. 4, Table 1). The ages of amphiboles 81/184 and 81/127 (178±12 Ma and 169±10 Ma respectively) may point to an older magmatic origin of these dikes, of which the amphiboles preserved memory due to very reduced resetting of the K/Ar clock in a possibly confined environment during metamorphism, though even the idea of an ancient metamorphic event cannot be ruled out. The similarities with ages obtained for the Dras ophiolite in Thasgam area support the idea of initial accretion as old as Middle Jurassic.

The isolated age data of the deformed dike 81/103 only (231±23 Ma), appears poorly documented and geologically meaningless. It possibly has to be explained by excess argon due to incomplete degassing already during magmatic dike injection. In fact, the problem of excess argon (Roddick & Farar 1983) becomes significant for the age calculation where radiogenic argon is extremely low, due to low potassium content, as in many ophiolitic samples. Incorporation of excess argon into the amphibole lattice during magmatic or metamorphic (re)crystallization requires an elevated gas pressure due to a "sealed" environment, such that the gas cannot "escape". Such conditions are observed for example in the glassy rims of oceanic pillow lavas, but no more in their microcrystalline central part, or in highly silicious metamorphic cherts (cf. sample 81/184) etc. No data is available to discuss whether such special conditions could equally be attained in isolated diabase dikes injected into peridotites at deeper levels. The data presented here might be interpreted in that direction, i.e. that the relatively small volumes of basic magma within the ultramafic mantle cannot degas completely and thus juvenile argon was trapped already during magmatic crystallization and was maintained during metamorphic recrystallization. Consequently the calculated age may be even older than the true age of magmatic injection of the basic magma.

2. Dras

In this area oceanic events similar to those of the Spongtang domain are followed by volcanic and plutonic activity typical of arc volcanism. The ophiolite pile is represented by gabbros and deformed diabases associated with serpentinized harzburgite and wehrlite.

1. Ophiolites

– *Gabbros.* Two sites of gabbro were investigated: a pegmatitic hornblende gabbro, located around Thasgam (Dras I unit), which intrudes wehrlites and displays cumulate textures and a deformed gabbro of probable cumulate origin, contained in the harzburgite-wehrlite-gabbro assemblage of Aryu La at the base of a slice in the Naktul nappe.

– The gabbros of the Thasgam area are featured by a large grain size and show an intrusive contact into the wehrlites including transformation of pyroxenes within wehrlites into amphiboles in the vicinity of the contact. The absence of pyroxene and the pegmatitic texture are not typical of ophiolitic gabbros. As intrusives, their age represents a minimum age for the peridotite.

The ages are older than those obtained for the Spongtang area and those of the arc related rocks, which clearly indicates that the peridotites cannot be intrusive into the arc volcanics: amphibole SD 419 of secondary origin in a wehrlite and amphibole T 23 extracted from a gabbro yield similar age values, 176±10 Ma and 171±8 Ma respectively. Amphibole SD 422 from a gabbro of the same area yields a slightly lower age, 157±7 Ma.

– The gabbros of Arju La, by contrast, are quite typical of an ophiolite sequence. Occurrence of amphibole is restricted to deformed samples. Amphibole SD 233 gives an age of 141±8 Ma, definitely younger than those indicated by the Thasgam gabbros, and reflects the age of the deformation event.

– *Diabases.* Isolated diabase dikes intrude serpentinized harzburgite. They also occur in the volcanic and volcaniclastic series. Occasionally they intersect the contact between ultramafics and volcanics, and therefore many of them are related to the arc system and not of oceanic origin. For this reason, only a foliated diabase dike, similar to those observed in Spongtang was investigated concerning the oceanic events.

– *Foliated diabase dikes.* Isolated diabase dikes transformed into foliated amphibolites like those of Spongtang are common in the serpentinites above Tringdo. Green amphiboles are well orientated within the foliation, together with altered plagioclase and rare quartz. Amphibole SD 137 indicates an age of 128.5±7 Ma, which is well comparable to the cluster of ages yielded by the Spongtang ophiolite.

– *Amphibolites from the metamorphic sole.* No amphibolite which might be attributed to an ophiolitic metamorphic sole has been found in the Dras area.

In conclusion, the Dras ophiolite displays the same age pattern as the Spongtang ophiolite. Strongly to moderately deformed amphiboles yield ages comprised between 130 and 140 Ma while undeformed samples indicate dates at about 170–180 Ma. One amphibole gives an intermediate age of 157±7 Ma.

The similarity of age patterns for the Spongtang and Dras massifs leads us to propose the following scheme for the evolution of the ophiolites in this region:

– Ages comprised between 130 and 140 Ma reflect both a time of metamorphism as in amphibolite P 338 and a time of deformation accompanied by dike intrusion. Particularly in the Spongtang ophiolite, part of the amphiboles giving 140–130 Ma ages are essentially magmatic. If the ages corresponded to a resetting event induced by the metamorphism affecting the infra ophiolitic soles, the mineralogy of the gabbro would probably not have kept its pristine magmatic features, considering the temperature of the order of 530±40 °C necessary to reset the K-Ar clock of hornblende (Harrison & McDougall 1980).

– Ages at 170–180 Ma reflect a possible time of intrusion of a previous dike generation in Spongtang. The same range of ages is obtained for doubtlessly magmatic hornblende of gabbros intrusive into the ultramafics of Thasgam. Since in both cases the 170–180 Ma dates pertain to facies intrusive into wehrlites and peridotites, they represent minimum estimates for the ophiolite formation.

2. Volcanics and arc related rocks

– *Volcanics of Dras I.* Porphyric lavas and tuffs contain phenocrystals of green hornblende, SD 9, SD 410, embedded in a microcrystalline matrix, often rich in epidote. Doleritic dikes intersecting the volcanics and occasionally the serpentinitic substratum as SD 106 represent the feeder dikes of the overlying volcanics. Ages cluster between 105 and 95 Ma with the exception of fine grained amphibole SD 410, which indicates a date of 78.5±2.9 Ma (Fig. 4, Table 1). This fine grained amphibole is considered secondary and related to the deformation affecting the northern part of Dras I (Reuber, in press) dated by Sharma et al. (1978) at 77.5±1 Ma. Sample SD 410 was indeed taken near to a shear zone and shows a tenuous schistosity.

– Diorite plutons intrusive into the Dras I volcanics. Sample SD 317 was sampled in a pluton south of Somau in the same antiformal zone as the gabbros of Thasgam. It is a diorite containing biotite and green hornblende with occasional relic pyroxenes (Schulthess 1986). The biotite yields an age of 94.4±2.7 Ma, definitely distinct from that of the Thasgam gabbros with which it is in close spacial relation. Given the size of the pluton, the age must be viewed as a cooling age, which means that the crystallization age is probably a few million years older, similar to those determined by Honegger et al. (1982) and Schärer et al. (1984) elsewhere in the same area: 103±3 and 101±2 Ma with U/Pb zircon method on the dark grey diorites of the northern Kargil intrusives and the diorites near to Kunoore respectively.

The diorite, represented by SD 317, intrudes Orbitolina and Rudist bearing limestones of Dras I exposed in the Suru-Dras ridge which corresponds to an Aptian/Albian age, a situation similar to the one of the Kunoore diorite dated by Schärer et al. (1984). This implies a short time span between deposition of the volcano-sedimentary series and the emplacement of the pluton.

Geodynamic implications

As already underlined, our data on arc related rocks of the Ladakh area concorde with those obtained in Kohistan and Tibet by previous studies (Table 2) and confirms the mid-Cretaceous age of the Dras I series and their intrusives (Honegger et al. 1982, Reuber, in press). Middle Jurassic radiolarites (Honegger et al. 1982, Frank et al. 1977, Dietrich et al. 1983) are viewed as normal oceanic cover of the Dras ophiolite dated here as middle Jurassic. This interpretation is in concordance with the repeated observation of mid-Cretaceous strata at the base of the fore-arc series, overlying or not serpentinites in primary contact (Sutre & Reuber 1988, Sutre 1989).

We view our results on ophiolites of a particular interest concerning the early evolution of the Neo-Tethys. The two investigated ophiolites display two salient features: (1) the volume of basic rocks, prominently represented by gabbro and diabase dikes,

unit	documented ages (Ma)		
Kohistan	105–90	77–65	55–25
Dras	**107–90**	**80–60**	**Dras II?**
Ladakh	–	70–60	55–25
Shyok	–	–	45–35
Tibet	110–90	60	(40), 15–10
Karakorum	120–95	85–10	
blueschists	105–95 (Dras oceanic volcanics)		
	90–80 (Kohistan)		

Table 2: Summary of the data from the arc related series according to Honegger et al. (1982), Reynolds et al. (1983), Petterson et al. (1985), Schärer et al. (1984), Sharma et al. (1978), Maluski et al. (1983), Göpel et al. (1984), Honegger et al. (in press), Rex et al. (1987), Coulon et al. (1986).

are extremely subordinate with respect to ultramafics; (2) they are polygenetic; 40 Ma, at least, separate two generations of basic magma. A similar hypothesis was proposed for the Xigaze ophiolite (Tibet) which outcrops in the vicinity of the Yarlung Tsang-po suture zone (Göpel et al. 1984, Girardeau et al. 1984, 1985) They envisage an episode of basic dike intrusions at 120±10 Ma preceded by an earlier event of late Paleozoic to early Mesozoic age.

The first characteristic is suggestive of an accretion at a slow spreading ridge. The second can indicate that either the spreading in the Neo-Tethys was discontinuous or an early compressive event was accompanied by magma generation. A ridge jump does not appear necessary to explain the small volumes of magma observed associated with the tectonometamorphic event.

Slow and intermittent spreading is frequently taken as indicative of a back arc location. In the studied area, however no remnants of a Jurassic arc, located south of the well documented Cretaceous Dras arc/Ladakh batholite are known.

The Dras ophiolite doubtlessly is found actually as substratum of the arc and forearc, whereas the Spongtang Klippe may never have seen any arc environment. Both appear to have been generated in the Neotethyan oceanic realm of yet disputed size.

Conclusions

The data obtained on ophiolitic rocks display two clusters of ages, 180–170 Ma and 140–125 Ma. The arc related rocks show dates comprised between 104 and 95 Ma with the exception of one fine grained amphibole (77 Ma).

The well documented group of data between 140 and 125 Ma for oceanic rocks corresponds to deformed ones. These ages probably reflect episodes of oceanic magmatism which preceded or accompanied an intra-oceanic thrusting event. The latter occurs prior to the marginal reopening observed in the ophiolites of southern Tibet (Marcoux et al. 1982, Girardeau et al. 1985). The interpretation of the first group of ages, at 180–170 Ma, is more tentative. In our opinion, they represent an ancient oceanic episode, featured by dike intrusions, possibly reflecting the age of the early Neotethyan crust.

The ages yielded by the Dras arc magmatics correspond to an early volcano-plutonic event comprised between 105 and 90 Ma, absent in the Ladakh pluton but evidenced in Kohistan and Tibet (references cited Table 2). Additional investigations are necessary to document the recent thermal history of this area.

Acknowledgements

We thank M. Colchen, J. Girardeau, C. Mevel, E. Sutre for very helpful suggestions and comments, and J. Hunziker for his constructive review. Financial support from CNRS-GRECO Himalaya Karakorum is gratefully acknowledged by I.R. and A.H.

REFERENCES

Bassoullet, J.P., Colchen, M., Marcoux, J., & Mascle, G. 1978: Une transversale de la zone de l'Indus de Khalsi à Photaskar, Himalaya du Ladakh. C.R. Acad. Sc. Paris 286, 563–566.

Bassoullet, J.P., Colchen, M., Juteau, T., Marcoux, J., Mascle, G., & Reibel, G. 1980: Geological studies in the Indus suture zone of Ladakh (Himalayas). Contrib. Him. Geol. 2, 96–124.

Baud, A., Arn, B., Bugnon, P., Crisinel, A., Dolivo, E., Escher, A., Hammerschlag, J.G., Marthaler, M., Masson, H., Steck, A., & Tièche, J.C. 1982: Le contact Gondwana-péri-Gondwana dans le Zanskar oriental (Ladakh, Himalaya). Bull. Soc. géol. France 24/2, 341–361.

Chang, C. 1984: Les caractéristiques tectoniques de l'évolution de la zone de suture du Yarlung Zangpo. In: Etude géologique et géophysique de la croûte terrestre et du manteau supérieur du Tibet et de l'Himalaya. (Ed. by Mercier, J.L., & Li Ganguen), 341–350.

Cakir, U., Juteau, T., & Whitechurch, H. 1978: Nouvelles preuves de l'écaillage intra-océaniques précoces des ophiolites téthysiennes: les roches métamorphiques infra-péridotitiques du massif de Pozanti-Karsanti (Turquie), Bull. Soc. géol. France 20/1, 61–70.

Colchen, M. 1987: La zone de l'Indus en Himalaya du Ladakh (excursion géologique, août 1987). Géochronique 21, 3.

Colchen, M., & Reuber, I. 1986: Les mélanges ophiolitiques du Zanskar, Himalaya du Ladakh. C.R. Acad. Sc. Paris, 303/II, 719–724.

— 1987: Obduction of the Spongtang klippe traced by the stratigraphic data of the underlying melange, Ladakh-Himalaya. Terra Cognita 7/2–3, 111 (abstract).

Colchen, M., Reuber, I., Bassoullet, J.P., Bellier, J.P., Blondeau, A., Lys, M., & Wever, P. de 1987: Données biostratigraphiques sur les mélanges ophiolitiques du Zanskar, Himalaya du Ladakh. C.R. Acad. Sc. Paris 305/II, 403–406.

Coulon, C., Maluski, H., Bollinger, C., & Wang,S. 1986: Mesozoic and Cenozoic volcanic rocks from central and southern Tibet: Ar^{39}-Ar^{40} dating, petrological characteristics and geochemical signification. Earth Planet. Sci. Lett. 79, 281–302.

Cox, A., & Dalrymple, G.B. 1967: Statistical analysis of geomagnetic reversal data and the precision of potassium-argon dating. J. Geophys. Res. 72, 2603–2614.

Dalrymple, G.B., & Lanphere, M. 1969: Potassium-Argon Dating. Freeman and Co. San Francisco.

Dietrich, V.J., Frank, W., & Honegger, K. 1983: A Jurassic-Cretaceous Island arc in the Ladakh-Himalayas. J. Volc. Geotherm. Res. 18, 405–433.

Frank, W., Gansser, A., & Trommsdorff, V. 1977: Geological observations in the Ladakh area (Himalayas). A preliminary report. Schweiz. min. petr. Mitt. 57, 89–113.

Fuchs, G. 1977: Traverse of Zanskar, from the Indus to the valley of Kashmir. Jb. Geol. B-A Wien 120, 219–229.

— 1979: On the geology of western Ladakh. Jb. Geol. B-A Wien 122, 513–540.

— 1982: The geology of western Zanskar. Jb. Geol. B-A Wien 125, 1-50.

Gansser, A. 1980a: The significance of the Himalayan suture zone. Tectonophysics, 62, 37–52.

— 1980b: The ophiolite suture zone of the Ladakh and the Kailas region – A comparison. Journ. Geol. Soc. India 20, 277–281.

Girardeau, J., Marcoux, J., & Zao Yougong 1984: Lithologic and tectonic characteristics of the Xigaze ophiolite (Yarlung Zangbo suture zone, southern Tibet, China): kinematics of its emplacement. Eclogae geol. Helv. 77/1, 153–170.

Girardeau, J., Mercier, J.C.C., & Zao Yougong 1985: Origin of the Xigaze ophiolite, Yarlung Zangbo suture zone, southern Tibet, China. Tectonophysics 119, 407–433.

Girardeau, J., Marcoux, J., & Montenat, C. 1986: The neo-cimmerian ophiolite belt in Afghanistan and Tibet: comparison and evolution. Proceed. Intern. Symp. Istanbul/Turkey.

Göpel, C., Allegre, C.J., & Rong Huaxu 1984: Lead isotopic study of the Xigaze ophiolite (Tibet). The problem of the relationship between magmatites (gabbros, dolerites, lavas) and tectonites (harzburgites). Earth Planet. Sci. Letters 69, 301–310.

Hart, S.R. 1964: Petrology and isotopic mineral age relations of a contact zone in the Front Range, Colorado. J. of Geology 72, 493-525.

Hanson, G.M., & Gast, P.W. 1967: Kinetic studies in contact metamorphic zones. Geochim. Cosmochim. Acta 31, 1119–1153.

Harrison, T.M., & McDougall, I. 1980: Investigation of an intrusive contact, northwest Nelson, New-Zealand I. Thermal, chronological and Isotopic constraints. Geochim. Cosmochim. Acta 44, 1985–2004.

Honegger, K., Dietrich, V., Frank, W., Gansser, A., Thöni, M., & Trommsdorff, K. 1982: Magmatism and metamorphism in the Ladakh Himalayas, Earth Planet. Sci. Let. 60, 253–292.

Honegger, K., Le Fort, P., Mascle, G., & Zimmermann, J.L. (in press) The blueschists along the Indus suture zone in Ladakh, NW-Himalaya (sousmis...)

Kelemen, P.B., & Sonnenfeld, M.D. 1983: Stratigraphy, structure, petrology and local tectonics, Central Ladakh, NW-Himalaya. Schweiz. min. petr. Mitt. 63, 267–287.

Kelemen, P.B., Reuber, I., & Fuchs, G. 1988: Structural evolution and sequence of thrusting in the High Himalayan, Tibetan-Tethys and Indus Suture zones of Zanskar and Ladakh, Western Himalaya: Discussion. J. Struct. Geol. 10, 129–130.

La Touche, D. 1988: Rediscovery of Nummulites in Zanskar. Rec. Geol. Surv. India 21, 160–162.

Lydekker, R. 1980: Geology of Ladakh and neighbouring Districts. Rec. Geol. Surv. India 13/1, 26–59.

— 1983: The geology of the Kashmir and Chamba Territories and the Britisch District of Khagan. Mem. Geol. Surv. India 22, 1–344.

McMahon, C.A. 1901: Petrological notes on some peridotites, serpentines gabbros and associated rocks, from Ladakh, North-Western Himalayas. Mem. Geol. Surv. India 31/3, 303–329.

Maluski, H., Proust, F., & Xiao X. 1983: Age du magmatisme calco-alcalin trans-himalayen du Tibet méridional: premiers résultats obtenus par la méthode ^{39}Ar-^{40}Ar. Mission franco-chinoise au Tibet. CNRS, Paris, 335–339.

Marcoux, J., De Wever, P., Nicolas, A., Girardeau, J., Xiao Xuchang, Chang Chengfa, Wang Naiwen, Zao Yougong, Bassoullet, J.P., Colchen, M., & Mascle, G. 1982: Preliminary report on depositional sediments on top of the volcanic member: the Xigaze ophiolite (Yarlung Zangbo suture zone). Ofioliti 2/3, 395–396.

Mevel, C., & Reuber, I. 1987: Pyroxenite and Mafic dykes in the Spongtang ophiolitic peridotite, Ladakh, Himalaya. Terra Cognita 7/2-3, 111 (abstracts).

Montigny, R., Whitechurch, H., Reuber, I., Thuizat, R., & Juteau, T. 1983: K-Ar ages of the Antalya ophiolites (Turkey); geological implications. Sci. Géol. Bull. 36/1, 61–72, Strasbourg.

Montigny, R., Le Mer, O., Thuizat, R., & Whitechurch, H. 1988: K/Ar and $^{40}Ar/^{39}Ar$ study of metamorphic rocks associated with the Oman ophiolite: tectonic implications. Tectonophysics 151, 345–362.

Parrot, J.F., & Whitechurch, H. 1978: Subductions antérieures au charriage nord-sud de la croûte téthysienne: facteur de métamorphisme de séries sédimentaires et volcaniques liées aux assemblages ophiolitiques syro-turc, en schistes verts et amphibolites, Rev. Géol. Dyn. Géogr. Phys. 20/2, 153–170.

Prasad, U., Singh, B., & Venkataraman, K. 1982: Ultramafites of Dras – Kargil area, Kargil District, J+K state. Contemp. Scientif. Res. In: Himalaya 2. (Ed. by A.K. Sinha), Dehra Dun, 25–31.

Prasad, U., Singh, B., Venkataraman, K., & Gosh, D.B. 1980: Petrochemical characteristics of basic and ultrabasic rocks of Dras area, "Indus ophiolite belt", Ladakh-India. Proceed. ophiol. Symp. Cyprus 1979, 444–453.

Radhakrishna, T., Divakara Rao, V., & Murali, A.V. 1987: Geochemistry and petrogenesis of ultramafic and mafic plutonic rocks of the Dras ophiolitic melange. Indus suture (northwest Himalaya). Earth and Planetary Science Letters 82, 135–144.

Rai, H., & Pande, I.C. 1982: Study of Norite from the Kargil Igneous complex. Indus suture zone, Ladakh-India. Contemp. Scientif. Res. In: Himalaya 2. (Ed by A.K. Sinha), Dehra Dun, 32–42.

Reibel, G. 1984: L'association pluto-volcanique de Dras (Suture de l'Indus – Himalaya du Ladakh). Pétrologie d'un fragment de croûte d'arc insulaire. Thesis ULP Strasbourg.

Reibel, G., & Reuber, I. 1982: La klippe ophiolitique de Spongtang-Photaksar (Himalaya du Ladakh); une ophiolite sans cumulats. C.R. Acad. Sc. Paris 294/II, 557–562.

Reuber, I. 1986: Geometry of accretion and oceanic thrusting of the Spongtang Ophiolite, Ladakh-Himalaya. Nature, 321, No. 6070, 592-596.
— 1987: Tectogenesis of the Dras Volcanic Arc, Ladakh - Himalaya. Terra Cognita 7, 111-112 (EUG IV abstracts).
— (in press): The Dras arc - two successive volcanic events on eroded oceanic crust. Tectonophysics, spec. vol. on Himalayan tectonics.
Reuber, I., Colchen, M., & Mevel, C. 1988: The geodynamic evolution of the south-Tethyan margin in Zanskar, NW-Himalaya, as revealed by the Spongtang ophiolitic melanges. Geodynamica Acta 1, 283-296.
Reuber, I., Nehlig, P., & Reibel, G. 1983: Ductile shearing in the peridotites of the Spongtang Nappe, Ladakh, NW-Himalaya. In: Himalayan Shears, (Ed. by Saklani, P.S.), New Dehli, 10-32.
Rex, A.J., Tirrul, R., Searle, M.P., Barnicoat, A., Rex, D.C., Crawford, M.B., & Windley, B.F. 1987: Geological and tectonic evolution of the central Karakoram Range. The Royal Soc. Meeting Nov. 1987.
Reynolds, P.H., Brookfield, M.E., & McNutt, R.H. 1983: The size and nature of Mesozoic Tertiary magmatism across the Indus Suture Zone in Kashmir and Ladakh (NW India and Pakistan). Geol. Rdsch. 72/3, 981-1004.
Roddick, J.C., & Farrar, E. 1971: High initial argon ratios in hornblende, Earth Planet. Sci. Lett. 12, 208-214.
Schärer, U., Hamet, J., & Allegre, J.C. 1984: The Transhimalaya (Gangdese) plutonism in the Ladakh region: a U-PB and Rb-Sr study, Earth Planet. Sci. Lett. 67, 327-339.
Schulthess, C. 1986: Contribution à l'étude pétrographique et géochimique de roches intrusives du Ladakh ouest. Report M.Sc. Strasbourg.
Sharma, K.K. 1987: Crustal growth and 2 stage India-Eurasia collision in Ladakh. Technophysics 134, 17-28.
Sharma K.K., Sinha, A.K., Bagdasarian, G.P., & Gukasian, R.Ch. 1978: Potassium-Argon dating of Dras Volcanics, Shyok Volcanics and Ladakh Granite, Ladakh, Northwest Himalaya. Himalayan Geol. 8, 288-295.
Steiger, R.H., & Jaeger, E. 1977: Subcommission on Geochronology: Convention on the use of decay constants in geo- and cosmochronology. Earth Planet. Sci. Letters 36, 359-362.
Sutre, E. 1989: La zone de l'Indus en Himalaya du Ladakh: stratigraphie et tectonique, évolution géodynamique. Thèse Univ. Poitiers, en prép.
Thakur, V.C., & Misra, D.K. 1984: Tectonic framework of the Indus and Shyok suture zones in eastern Ladakh, northwest Himalaya. Tectonophysics 101, 207-220.
Thieulloy, J.P., Reuber, I., Mascle, G., & Colchen, M. 1988: L'âge des séries volcano-plutonique d'arc de Dras au Ladakh. Himalayan Workshop III, Lausanne, 32 (abstract).
Thuizat, R., Whitechurch, H., Montigny, R., & Juteau, T. 1981: K-Ar dating of some infraophiolitic metamorphic soles from the eastern Mediterranean: New evidence for oceanic thrustings before obduction. Earth Planet Sci. Letters 52, 302-310.
Wadia, D.N. 1937: The Cretaceous volcanic series of Astor-Deosai, Kashmir, and its intrusions. Rec. Geol. Surv. India 72 (2), 151-161.
Westphal, M., Montigny, R., Thuizat, R., Bardon, C., Bossert, A., Hamzeh, R., & Rolley, J.P. 1979: Paleomagnétisme et datation du volcanisme permien, triasique et crétacé du Maroc. Can. J. Earth Sci. 16, 2150-2164.

Manuscript received 30 November 1988
Revision accepted 24 April 1989