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The Yarlung–Zangbo paleo-ophiolite, southern Tibet: implications for the dynamic evolution of the Yarlung–Zangbo Suture Zone

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Abstract

The Yarlung–Zangbo Suture Zone, a major geological structure in Tibet, is well known as the locus of tectonic emplacement of the Tethyan ophiolites. Current models propose that most of the East Tethyan oceanic lithosphere was subducted within a single subduction zone, active during the Middle or Late Cretaceous, which was completed during the Paleogene collision between India and Asia. The Early Cretaceous sedimentary Giabulin Formation in southern Tibet, includes conglomeratic members that contain ultramafic and mafic plutonic pebbles, as well as radiolarian chert clasts, that record the erosion of oceanic lithosphere involved in a subduction event which occurred earlier than previously believed. Geochemical analyses, mineral chemistry, stratigraphic chronology, and sedimentary analysis, including source provenance, suggest that the pebbly conglomerate was formed through erosion of an unknown ophiolitic source that was geochemically distinguishable from the Xigaze ophiolites within the Yarlung–Zangbo Suture Zone, southern Tibet. We infer the existence of an older ophiolitic source, termed the Yarlung–Zangbo paleo-ophiolite, that was dismembered and eroded during an earlier subduction stage not taken into account in current models.

1. Introduction

The Yarlung–Zangbo Suture Zone (YZSZ), a major lineament in Tibet that is accepted as the collision zone between India and Asia (e.g. Allègre et al., 1984; Burg and Chen, 1984; Xiao, 1984; Coulon et al., 1986; Dewey et al., 1990; Yin et al., 1994), is an extremely complex tectonic zone (Fig. 1). It includes seven different tectonic-sedimentary units. From north to south these are (Fig. 1a, b): Gangdese arc complex (including the Sangri Group), the Qiuwu Formation, the Giabulin Formation, the Xigaze Group, ophiolitic massifs, the Liuqu Group, and mélange zones. The forearc sedimentary Xigaze Group is divided into three units (from base to top): the Chongdui Formation, the Sangzugang Formation, and the Angren Formation (Fig. 1b) (BGMRT, 1993; Wang et al., 1996). The ophiolitic massifs including Xigaze ophiolites, which form the basement of the Xigaze Group (Xiao, 1984; Girardeau et al., 1985; Wang and Yu, 1988; Einsele et al., 1994), comprise the main part of the YZSZ. Current models suggest that most of the East Tethyan oceanic lithosphere was subducted within a single subduction zone during the Middle (Coulon et al., 1986) or Late Cretaceous (Allègre et al., 1984; Dewey et al., 1990; Yin et al., 1994) and closed during Paleogene continental collision (Molnar and Tapponnier, 1975; Patriat and Achache, 1984; Rowley, 1998). However, this study of the Early Cretaceous Giabulin Formation implies more complicated Tethyan subduction processes than previous models. In addition, the Late Jurassic to Early Cretaceous Sangri Group (BGMRT, 1993) indicates that the volcanic-sedimentary continental margin of the southern Lhasa Terrane was active earlier than generally acknowledged.

Field investigations over four years, stratigraphic chronology (Liu et al., 1996; Liu, 1996), geochemical analysis, mineral chemistry, and provenance analysis have been conducted on the Giabulin Formation and the nearby Xigaze ophiolites. The conglomeratic part of the Giabulin Formation contains ultramafic and mafic plutonic pebbles, as well as radiolarian chert clasts, that record the erosion of a disappeared oceanic lithosphere, believed to have been involved in an earlier subduction event than that previously recognised. The occurrence of ultramafic pebbles indicates the existence of a Yarlung–Zangbo paleo-ophiolite as the source of the conglomeratic unit within the Giabulin Formation. This paper is devoted to the discussion of this hypothesis and its implications for a five-stage evolution of the

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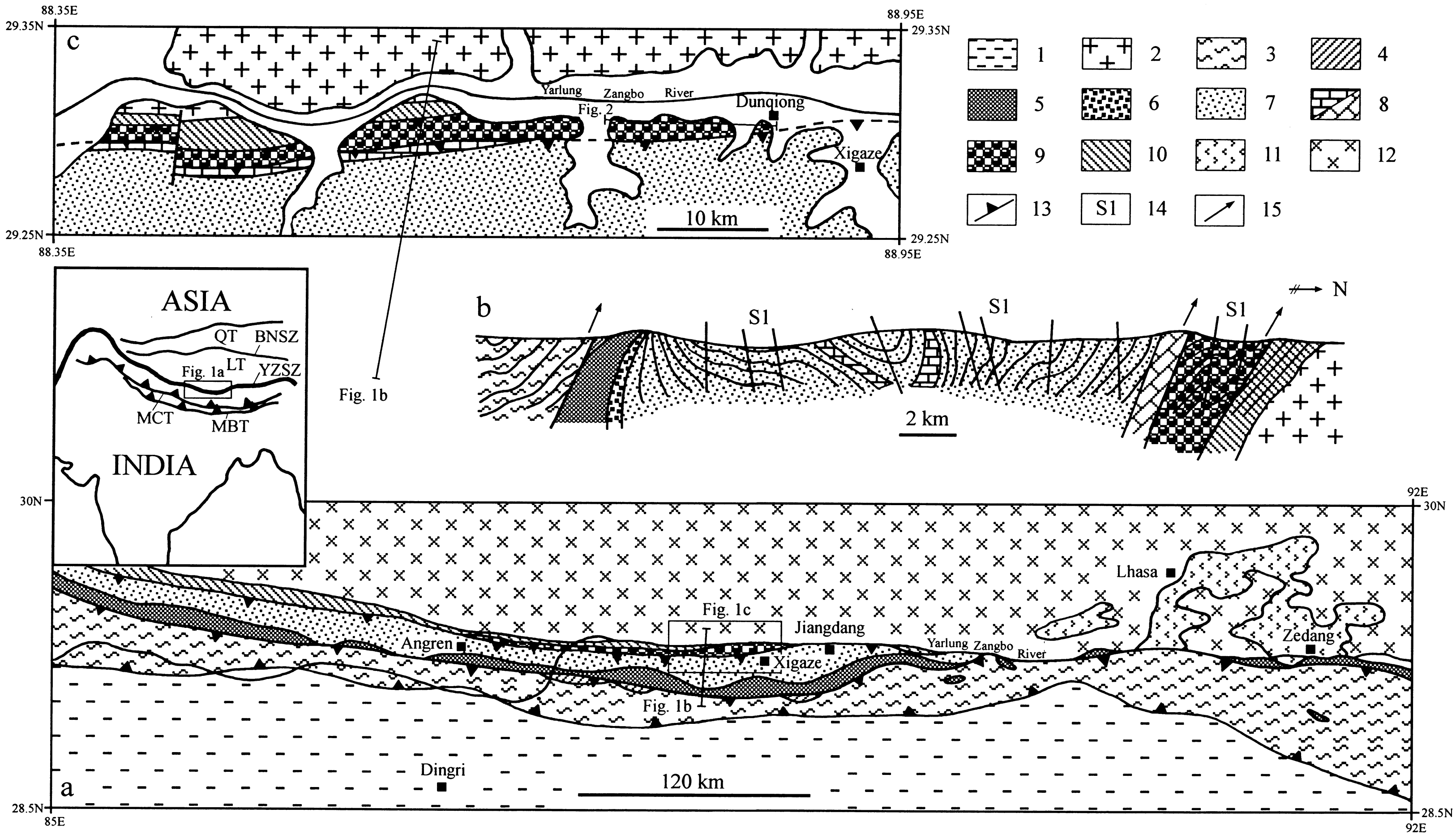

Fig. 1. (a) Geologic map of the Yarlung–Zangbo Suture Zone, southern Tibet, modified after BGMRT (1993), and the distribution of the Giabulin Formation, showing continental sutured characters between the Lhasa Terrane (Asia) and the Himalaya Terrane (India). (b) Profile of the Yarlung–Zangbo Suture Zone, modified after Burg and Chen (1984), showing the contact relationship among the seven tectonic–sedimentary units. From north to south, they are Gangdese Arc Complex (including the Sangri Group), the Qiuwu Formation, the Giabulin Formation, the Xigaze Group (including the Sangzugang Formation, the Angren Formation, and the Chongdui Formation), ophiolitic massifs, the Liuqu Group, and mélange zones. (c) Geologic map of the Xigaze region, modified from Liu et al. (1996), showing tectonic characteristics of the Giabulin Formation. 1, Himalaya Terrane (Tethys sediments); 2, Gangdese Arc Complex; 3, mélange zones; 4, the Liuqu Group; 5, ophiolitic massifs; 6, the Chongdui Formation; 7, the Angren Formation; 8, the Sangzugang Formation; 9, the Giabulin Formation; 10, the Qiuwu Formation; 11, the Sangri Group; 12, Lhasa Terrane, 13, thrust; 14, cleavage; 15, thrust direction; MCT, main central thrust; MBT, Main Boundary Thrust; YZSZ, Yarlung–Zangbo Suture Zone; BNSZ, Banggong–Lujiang Suture Zone; LT, Lhasa Terrane; QT, Qiangtang Terrane.

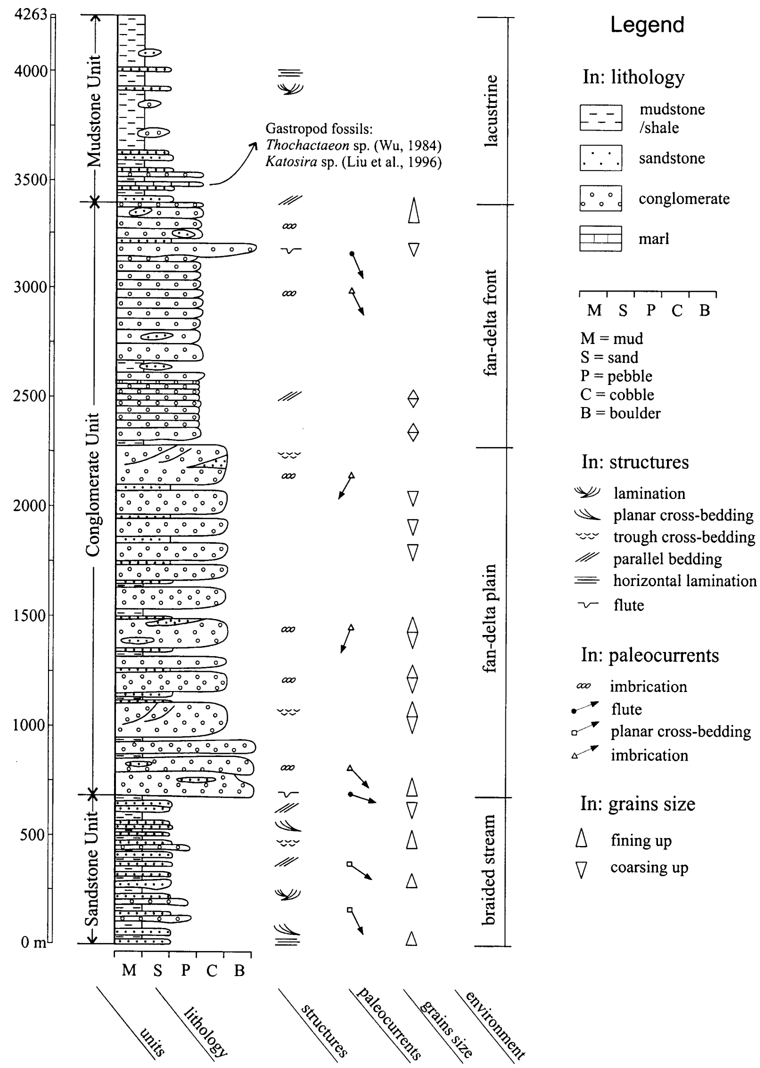

Fig. 2. Sedimentary column of the Giabulin Formation showing characteristics of lithology, structures, paleocurrents, grain size changes, and distribution of lithologic units and environments. See Fig. 1c for the location of the site where the section was measured.

Yarlung–Zangbo Suture Zone with two Tethyan subduction events between the Late Jurassic and Paleogene.

2. Sedimentary and stratigraphical analyses

The Giabulin Formation, paralleling the northern margin of the Yarlung–Zangbo ophiolite, is characterized by a sequence of varicoloured sandstones and conglomerates (Liu et al., 1996; Liu, 1996). The 3.5 km wide by 200 km long, 4263 m thick sedimentary sequence extends from Jiangdang in the east to Angren in the west (Fig. 1a). Previously, it was included within the Tertiary Qiuwu Formation and interpreted as Tertiary molasse eroded and deposited during India–Asia continental collision (Yin et al., 1988; Liu et al., 1990; Ratschbacher et al., 1992; Yin et al., 1994; Einsele et al., 1994) as few geochronologic constraints were available. The Qiuwu Formation consists of grey and red granite and intermediate to felsic volcanic–pebble conglomerate interlayered with thin strata of coal (Yin et al., 1988; Liu, 1996). The Giabulin Formation was produced as a tectonic slice between the Tertiary Qiuwu Formation molasse (Wu, 1984) to the north and the Middle Cretaceous Sangzugang Formation limestone (west) (Bassoulet et al., 1984) or the Middle–Late Cretaceous Angren Formation flysch (east) (Wan et al., 1998) to the south (Fig. 1b, c). The style of deformation exhibited by the Giabulin Formation is very similar to that observed in the Middle–Late Cretaceous Xigaze Group (Burg and Chen, 1984; Ratschbacher et al., 1992; Einsele et al., 1994).

Three lithological units contained within the Giabulin Formation are (from the base to the top): sandstone, conglomerate, and mudstone (Fig. 2) (Liu, 1996). The sandstone unit, 692 m thick, displays trough and tabular cross-bedding and parallel bedding, interpreted as braided stream deposits (Liu, 1996). The sandstone clasts consist of 37–70% siliceous material, mainly radiolarian chert, and some ultramafic–mafic clastics (Liu, 1996). Clast analysis of the

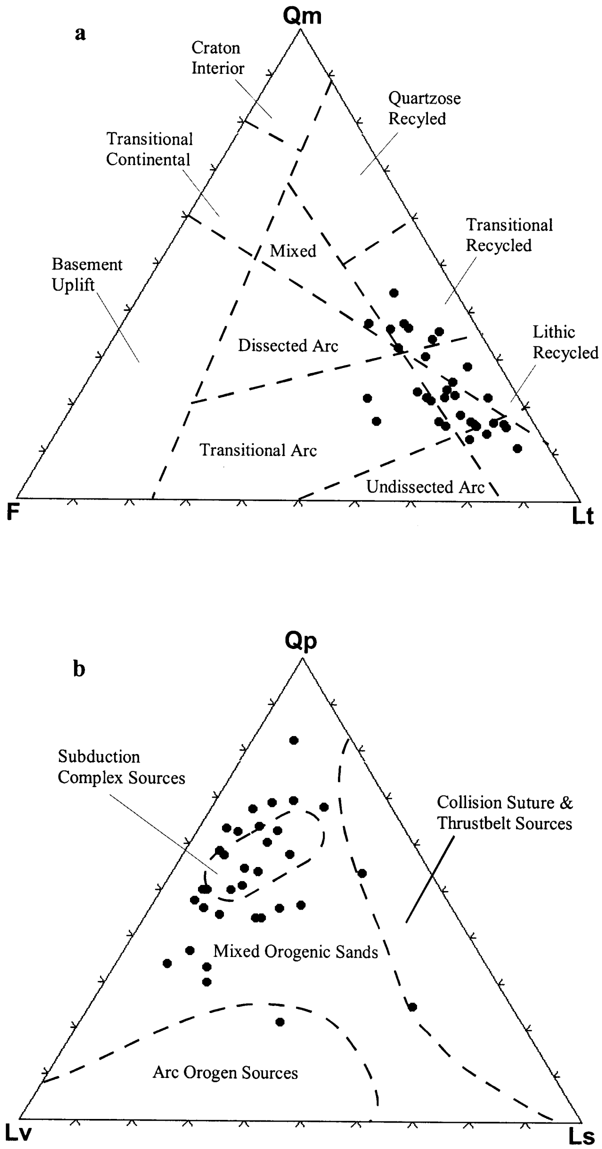

Fig. 3. Framework-grain QmFLt and QpLvLs composition (after Dickinson, 1985) of the Giabulin Formation sandstones, mainly showing transitional-lithic recycled and subduction complex sources. In (a): Qm, monocrystalline quartz grains; F, total feldspar; Lt, total polycrystalline; in (b): Qp, polycrystalline; Lv, total volcanic–metavolcanic rock fragments; Ls, unstable sedimentary–metasedimentary rock fragments.

sandstone, plotted on a QmFLt diagram (Dickinson, 1985), shows the source is consistent with a transitional-lithic recycled and transitional arc orogen (Fig. 3a). Almost all sandstones plot in the mixed orogen and mainly subduction complex source fields on a QpLvLs diagram (Fig. 3b).

The conglomerate unit, 2679 m thick, contains rounded pebbles and interstitial sands (e.g. Fig. 4a) and is interpreted to represent a braided stream-fan delta sedimentary environment (Fig. 2) (Liu, 1996). The pebbles consist of a variety of lithologies. Statistical analysis shows that for a reference group of 100 pebbles studied in 13 sites, there is a gradual increase in the proportion of radiolarian chert pebbles from 46% to 64% to 88% (with a decrease at some sites) with stratigraphic height (Fig. 5). Meanwhile, the proportion of ultramafic pebbles increases from 2% to 16% to 17% (also with a decrease at some sites), while the abundance of intermediate and mafic clasts decreases. The ultramafic–mafic suite and metamorphic rock pebbles are composed of peridotite, gabbro, plagiogranite, and mafic schist. Most of the ultramafic clastic materials are spinel peridotite (Fig. 4a, b). The Early Cretaceous radiolarian fossil assemblage in the chert pebbles of the Giabulin Formation conglomerate unit, have the characteristics of the *Costata* sub-zone (Wang, 1997), quite different from the radiolarian assemblage of the Xigaze ophiolites, with the composition of the *Cecrops septemporata* sub-zone (Wu, 1988).

The mudstone unit, 892 m thick, consists mainly of violet mudstone and siltstone with layers of sandstone, marl, and conglomerate at the bottom (Fig. 2). Autochthonous gastropod fossils of *Thochactaeon* sp. (Wu, 1984) and *Katosira* sp. found in the marl at Dunqiong, 10 km west of Xigaze (Fig. 1c) (Liu et al., 1996), constrain the biostratigraphic age as Early Cretaceous.

The orientation of 68 palaeocurrent indicators, such as imbricated pebbles (Fig. 4a), groove casts, and tabular cross-bedding of the sandstone, indicate predominant sediment transport from north to south (Figs. 2 and 6). The clastic fraction ranges from 37–70% quartzose material in the sandstone unit to 46–64% chert pebbles in the conglomerate unit. Therefore, sedimentary analysis supports the hypothesis that an ophiolite contributed material to the Giabulin Formation from the north.

3. Mineral chemistry

Spinels are accessory mineral phases that are excellent indicators of partial melting and percolation processes commonly occurring in the upper mantle, as well as of original geodynamic genetic settings (Hisada and Arai, 1999). In addition they are resistant to alteration, being the last minerals to be replaced in peridotites undergoing serpentinization. These properties make spinels good candidates as discriminant minerals (Hisada and Arai, 1999). Therefore, we analysed spinels in both peridotitic clasts from the Giabulin Formation and samples collected from the nearby Xigaze ophiolites in order to compare their respective mineral compositions. Microprobe analyses of spinels and clinopyroxene were performed on a Cameca SX-100 at Université Laval (Québec, Canada).

Our conclusions are based on analysis of 45 Cr-spinels from seven sites of the Giabulin Formation conglomeratic unit and 271 analyses from 40 samples of Xigaze ophiolites. Spinels from the Giabulin Formation fall into two groups. One group is made of secondary Cr-magnetites resulting from replacement of primary Cr-spinels (Group 1a, Fig. 7). Alteration processes caused selective removal of Al and Mg from initial mineral framework. Even though the

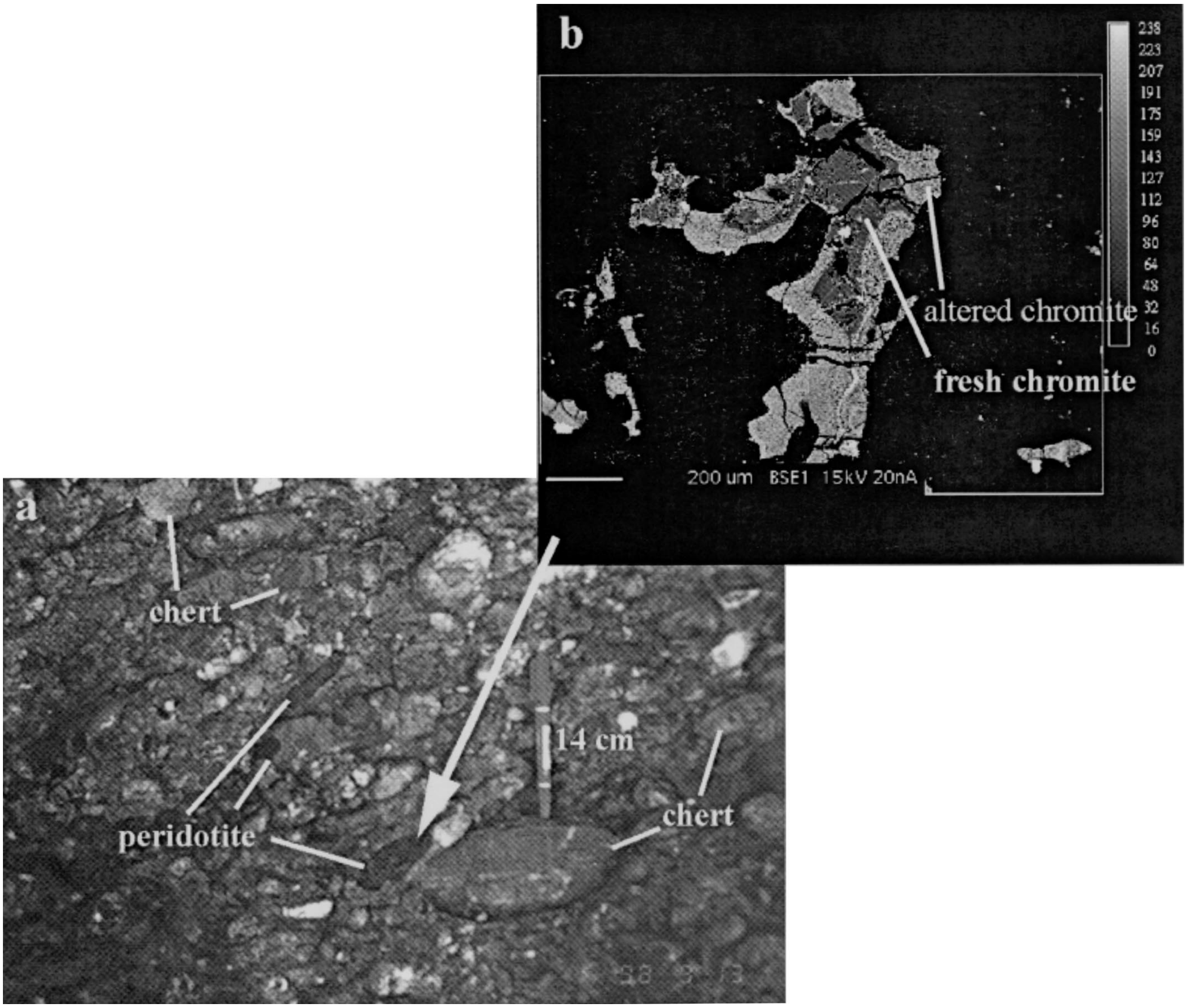

Fig. 4. (a) Field photograph of the conglomerate within the Giabulin Formation showing rounded peridotite pebbles, and (b) back scattered electron photomicrograph of chromite in peridotite clast.

Cr-magnetites cannot be used as magmatic indicators, they nevertheless indicate a probable ophiolitic parentage. The second group consists of fresh aluminous spinels showing very low Cr♯ (Cr/(Cr + Al)) ranging from 0.17 to 0.31 (Group 1b, Fig. 7). These compositions contrast with Xigaze spinels having a wide range of Cr♯ values spanning the interval of 0.13–0.77, but mostly greater than 0.40 (Group 2, Fig. 7). The Giabulin Formation Al-spinels are most likely derived from relatively less depleted upper mantle material, compared to the Xigaze ophiolite peridotites that have a more depleted composition, based on the abundance of Cr-spinels. Preliminary microprobe analyses of clinopyroxene in the Giabulin Formation is in agreement with this interpretation. The clinopyroxene from the Giabulin Formation has higher TiO_2 and lower Cr_2O_3 contents than those from Xigaze ophiolite.

The occurrence of Al-spinels among the Giabulin Formation clasts supports the hypothesis that they were derived from an ophiolitic source and precludes Xigaze ophiolites as a potential source (Hébert et al., 1999). Furthermore, the prominence of Cr-spinels over Al-spinels in Xigaze ophiolites would be reflected in the resulting erosion-derived sediments; this is not the case for the Giabulin Formation.

4. Geochemistry

In order to provide more information concerning the affinity of the ophiolitic pebbles, seven representative samples of the Giabulin Formation were analyzed for rare earth element (REE) content. They are compared to analyses of 11 corresponding rock types from the Yarlung–Zangbo ophiolite (Bao and Wang, 1984) (Fig. 8). The Giabulin Formation clasts display flat REE patterns with La/Yb ratios close to 1.1 (Fig. 8a). The patterns are not fractionated during magmatic evolution and recall T-MORB patterns (Jacobsen and Wasserburg, 1979). All the Yarlung–Zangbo ophiolitic samples have relatively fractionated REE patterns (except samples 4 and 5 with flat patterns) and very low absolute REE content (Fig. 8b). Sample 14 has a strongly

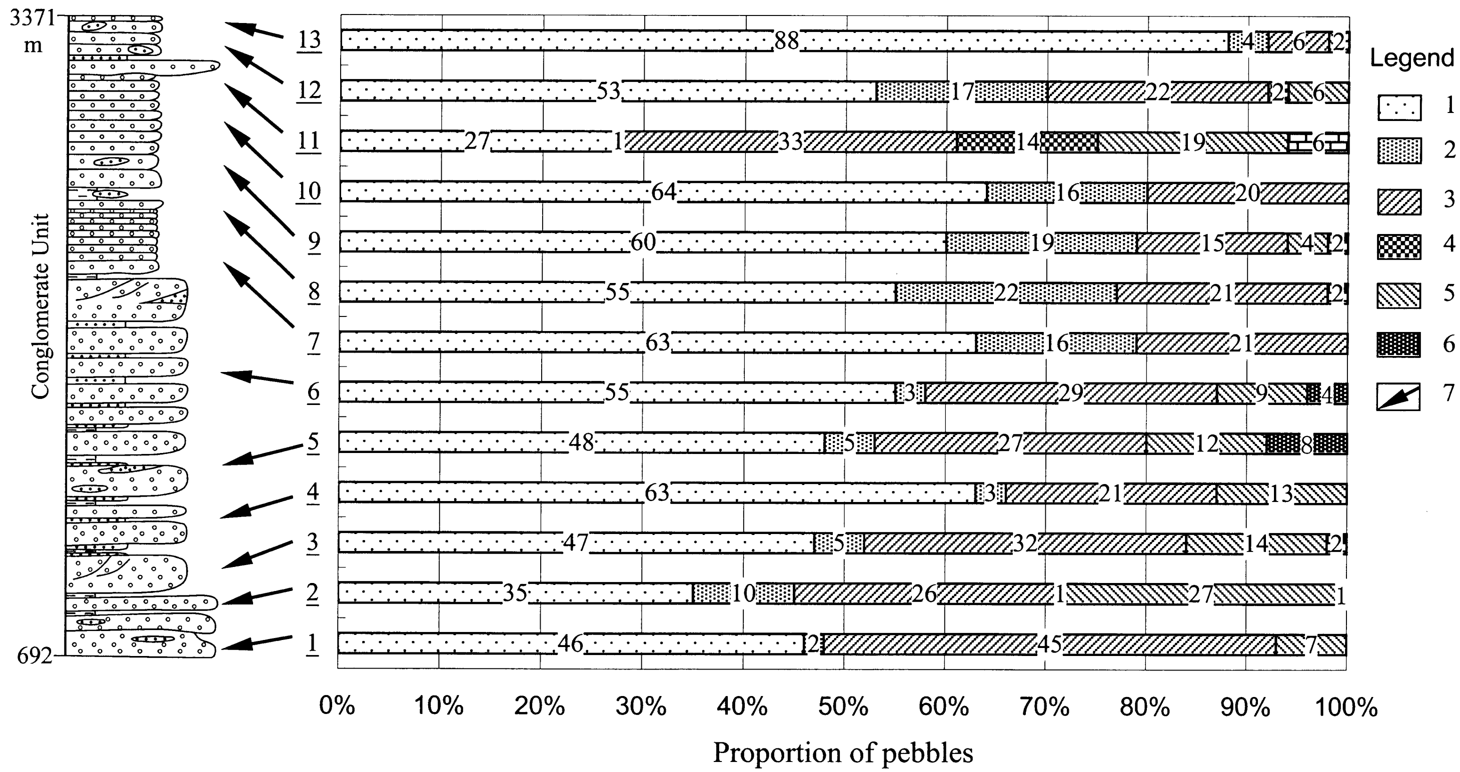

Fig. 5. Pebble compositions for the conglomeratic unit of the Giabulin Formation, Xigaze region, showing main pebble component changes with column height. 1, ultramafics; 2, cherts; 3, intermediate-mafics; 4, granites; 5, sandstones and conglomerates; 6, metamorphic rocks; 7, sample sites. See Fig. 2 for patterns used for lithologies in the left hand column.

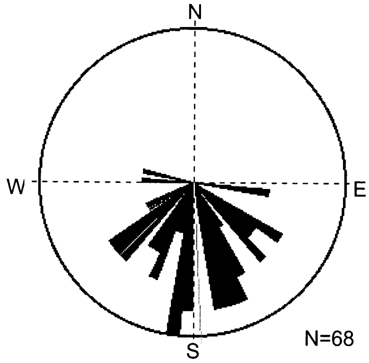

Fig. 6. Paleocurrent rose diagram of the Giabulin Formation sediments, measured from imbricated pebbles and groove casts in the conglomerate unit and tabular cross-bedding in the sandstone unit. N is the number of the paleocurrent measurements.

positively fractionated pattern with a high La/Yb of 3.5, compatible with alkaline series. Samples 6 to 13 show LREE depleted patterns with La/Yb ratios of 0.5. The latter patterns are similar to N-MORB occurring along certain segments of the mid-Atlantic Ridge (Le Roex et al., 1998). We conclude from the geochemical data that the Giabulin Formation pebbles could not be derived from the same source as the Yarlung–Zangbo–Xigaze ophiolite. In addition, even though all the igneous rocks have a composition compatible with a formation within a ridge environment, they are not derived from the same source.

5. Discussion

The stratigraphic chronology constrains the depositional age of the Giabulin Formation to Early Cretaceous (Liu et al., 1996). Sedimentary provenance, inferred from paleocurrent analysis, indicates that the source that contributed the clasts lay to the north. The mineral and whole rock geochemical data suggest that the source of the Giabulin Formation ultramafic pebbles and the Yarlung–Zangbo ophiolite were formed in different genetic environments.

The composition of the Giabulin Formation spinels and clinopyroxenes suggests the host peridotites were fertile, implying they had undergone a very low degree of partial melting. In comparison, the mineral chemistry of spinels and clinopyroxene, and geochemistry of Yarlung–Zangbo peridotites, are characteristic of a more refractory upper mantle. The possible initial geodynamic settings for the Yarlung–Zangbo Ophiolite are within a spreading ridge over depleted mantle and a suprasubduction zone including back-arc basin and arc environment (Hébert et al., 2000). The sedimentary analysis indicates that the clastic fraction of the Giabulin Formation sandstone and conglomeratic units could come from somewhere off the southern margin of the Lhasa Terrane, rather than from the Gangdese Arc Complex distributed at the southern margin of the Lhasa terrane.

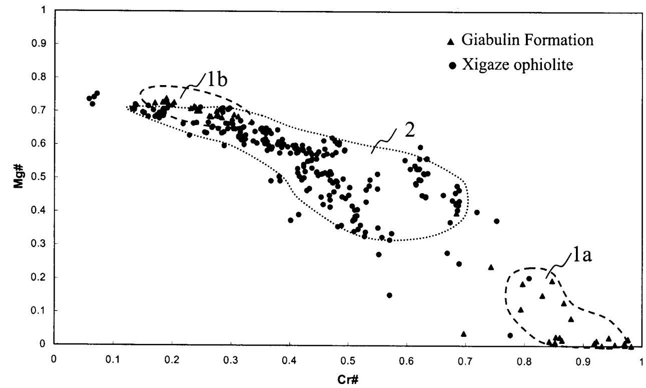

Fig. 7. Compositional characteristics Cr♯ vs Mg♯ of Cr-spinels from peridotitic clasts of the Giabulin Formation and Xigaze ophiolite. Spinel from the Giabulin Formation defines two group fields (see text for details). Cr♯ = Cr/(Cr + Al), Mg♯ = Mg/(Mg + Fe^{2+}).

Based on the mineral chemistry and the geochemistry of the Yarlung–Zangbo Ophiolite and the Giabulin Formation, and sedimentary provenance analysis of the Giabulin Formation, it is clear that the inferred source for the pebbles forming the Giabulin Formation conglomerate, is different from ophiolites now outcropping to the south. No known exposed ophiolite fits the data presented in this paper. We propose the term 'Yarlung–Zangbo paleo-ophiolite' (YZPO) to designate the cryptic source terrane to account for the particular compositional attributes presented here. According to age relationships, the YZPO could correspond to the early subduction of the Tethys, constrained to the Late Jurassic or Early Cretaceous.

The hypothesis of the existence of a paleo-ophiolite is consistent with the sedimentary component of the Xigaze Group, and magmatism and volcanism on the Lhasa terrane. Metamorphic sand-sized rock fragments and rutile and chromite grains, which are found in the Angren Formation of the Xigaze Group deposits, were considered to originate from ophiolitic and metamorphic rocks to the north (Dürr, 1996). The current Yarlung–Zangbo Ophiolite was not tectonically emplaced until the closure of the Tethys, during Paleogene continental collision (Molnar and Tapponnier, 1975; Patriat and Achache, 1984; Rowley, 1998). Therefore, the YZPO or the Giabulin Formation could provide the ophiolitic clastic fraction to the Angren Formation. The oldest known intrusives, formed at 128 Ma on the southern Lhasa Terrane (Schärer et al., 1984) and at 175–180 Ma on the northern Lhasa Terrane (Zhou et al., 1997), and pre-Aptian/Albian volcanic activity on the northern Lhasa Terrane (Coulon et al., 1986) could be related to the early destruction of the Tethyan basin.

In addition, the 4878 m thick volcanic–sedimentary rock series of Late Jurassic to Early Cretaceous age, recorded as the Sangri Group (BGMRT, 1993; Wang et al., 1996) on the southern margin of the Lhasa Terrane (Fig. 1a) were ignored, because they are partly covered by Tertiary volcanism. The group is composed of andesitic lava, andesitic

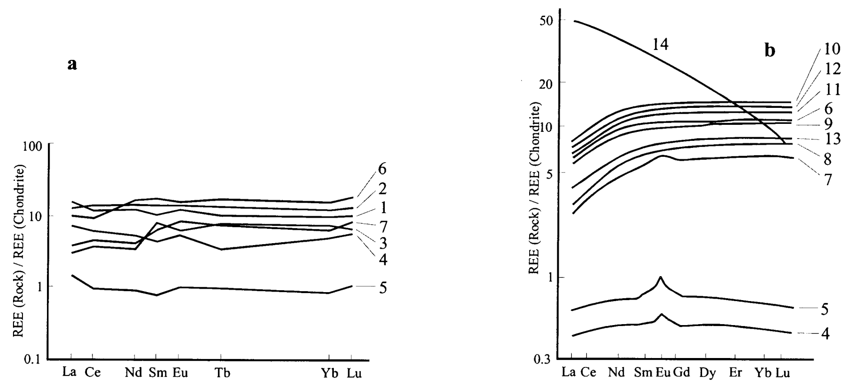

Fig. 8. Rare earth element (REE) patterns for two ophiolite compositions from southern Tibet: ophiolitic pebbles of the Giabulin Formation (a) and the Yarlung–Zangbo ophiolite (b) (Bao and Wang, 1984). (a): 1, zoisite plagio-amphibole schist; 2, gabbro; 3,4, amphibole gabbro; 5, carbonated pyroxene-peridotite; 6, diopside; 7, pyroxene diorite; (b): 4, dunite; 5, layered gabbro; 6, isotropic gabbro; 7,8, diabase; 9, dolerite; 10, diabase; 11, spilite; 12, massive basalts; 13, pillow basalts; 14, Jurassic–Cretaceous lavas.

clastic lava, andesitic volcanic breccia, and dacite, and has calc-alkaline island arc affinities (BGMRT, 1993; Wang et al., 1996). It could represent an active continental arc on the southern margin of the Lhasa Terrane, driven by the early subduction of the Tethys.

A possible meta-ophiolitic suite (gabbros, dolerites, basalts, green and grey cherts), discovered within the southern part of the Gangdese Belt (Burg et al., 1983; Allègre et al., 1984), could correspond to the relic YZPO. But the confirmation needs further work. The YZPO could be correlated to the Shyok paleo-ophiolite situated between the Karakoram Batholith to the north and the Ladakh Arc Complex to the south in the Ladakh Himalayas. The Shyok paleo-ophiolite represents the earlier Tethyan subduction during pre-Cretaceous (e.g. Frank et al., 1977), though some authorities argued against the existence of the paleo-ophiolite (e.g. Rai, 1982).

6. Implications

The implications of the existence of the YZPO for the dynamic evolution of the Yarlung–Zangbo Suture Zone are an addition to previous models of an earlier Tethyan subduction event in the Late Jurassic to Early Cretaceous, and on the modification of such models (Fig. 9). The model proposes that the Yarlung–Zangbo Suture Zone and Tethyan oceanic crust experienced two periods of subduction. This proposition is based on: (1) the existence of YZPO and the Sangri Group volcanic–sedimentary rock series, which could be the source of the Early Cretaceous Giabulin Formation; (2) the ages of the oldest magmatic and volcanic rocks on the Lhasa Terrane; (3) the ages of components of the Xigaze Group; and (4) the geochemical and petrologic characteristics of the Yarlung–Zangbo Ophiolite.

Coulon et al. (1986) deduced that the Tethyan oceanic crust began to underthrust the Lhasa Terrane at approximately 120–115 Ma. We suggest that the age of northward Tethyan subduction is earlier, possibly during the Late Jurassic, based on the existence of the Late Jurassic to Early Cretaceous YZPO and the Early Cretaceous Giabulin Formation, as well as the age of the oldest plutonism (Schärer et al., 1984; Zhou et al., 1997) and volcanism (Coulon et al., 1986; BGMRT, 1993) on the Lhasa Terrane. At that time, the Lhasa Terrane had already been sutured to the Qiangtang Terrane along the Banggong–Nujiang Suture Zone (Fig. 1a—index map) (Girardeau et al., 1984; Dewey et al., 1990; Zhou et al., 1997), and the subduction zone jumped southwards. The Tethyan oceanic ridge was characterized by abnormal lithosphere at the junction between the oceanic ridge and transform faults (Pozzi et al., 1984; Yu and Wang, 1990; Deng and Pearce, 1990). The northern ultramafic–mafic oceanic crust of Tethys was scraped off and made up the subduction complex of the early Tethyan subduction zone (Fig. 9a).

The emplacement of the YZPO Complex may have occurred in the interval from ~125 to 114 Ma (Fig. 9b). The lower limit of ~125 Ma is based on the Early Cretaceous age of the Giabulin Formation (Liu et al., 1996). The ophiolitic materials, represented by clasts in the sandstone and conglomeratic units of the Giabulin Formation, could be derived from the ultramafic–mafic accretion of the Late Jurassic to Early Cretaceous paleo-ophiolitic complex.

The late subduction of the Tethyan oceanic crust started at about 114 Ma, according to the M2 magnetic anomaly (Patriat and Achache, 1984). Tethyan ocean crust between the two subduction zones made up the basement of the Xigaze forearc basin. The Middle Cretaceous breccia of the Chongdui Formation (Wu, 1984), the lower-most unit of the Xigaze Group, formed along the southern margin of the basin. The Aptian/Albian limestone of the Sangzugang Formation (Bassoulet et al., 1984), the lower unit of the Xigaze Group, was deposited on the northern margin of the forearc basin (Fig. 9c). Middle Cretaceous volcanism

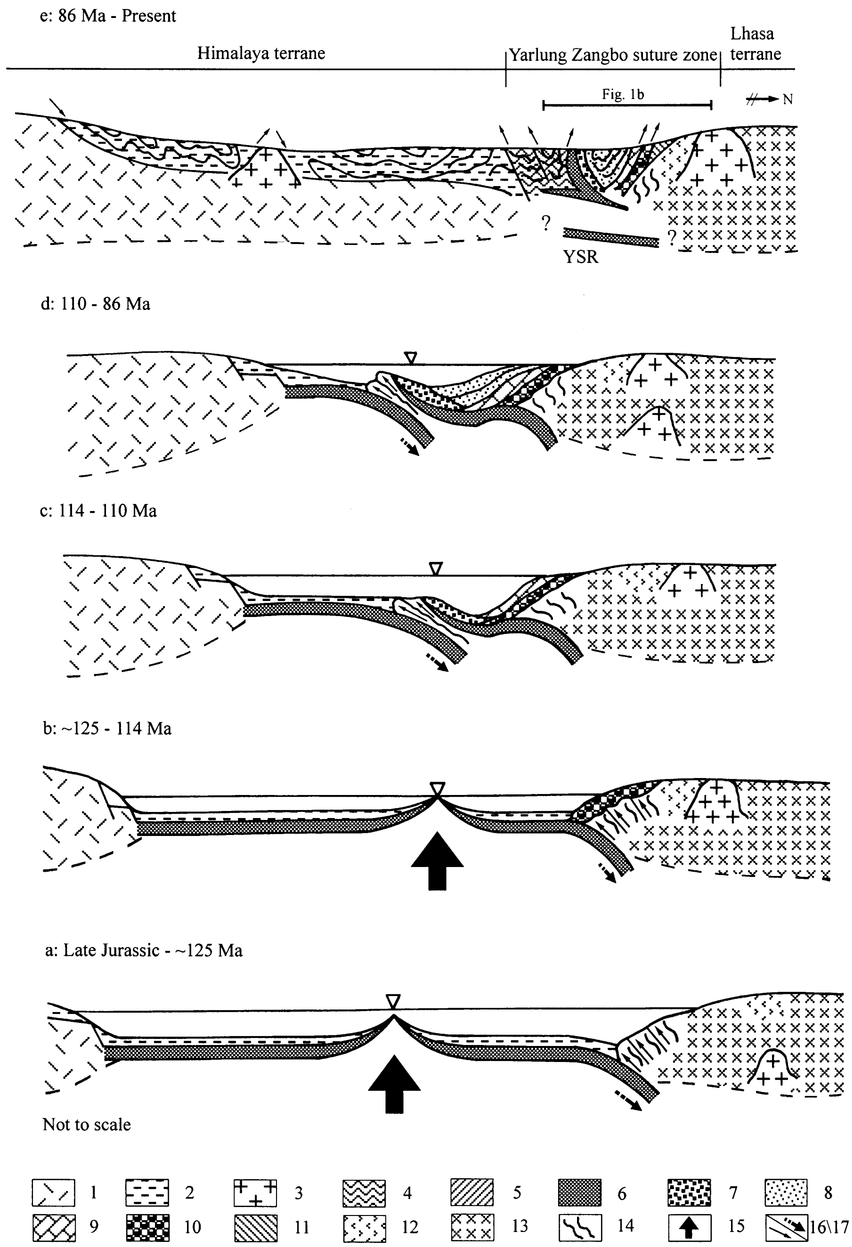

Fig. 9. Dynamic evolution of the Yarlung–Zangbo Suture Zone, showing five stages of evolution, with two Tethyan subduction events from the Late Jurassic to present, modified after Allègre et al. (1984), Coulon et al. (1986), and Yin et al. (1994). 1, Himalaya Terrane (northern India crust); 2, Tethys sediments; 3, granite; 4, mélange zones; 5, the Liuqu Group; 6, ophiolitic massifs; 7, the Chongdui Formation; 8, the Angren Formation; 9, the Sangzugang Formation; 10, the Giabulin Formation; 11, the Qiuwu Formation; 12, the Sangri Group; 13, Lhasa Terrane (with the Gangdese Arc Complex on southern margin); 14, deformation; 15, spreading ocean ridge; 16, 17, directions of thrust and subduction; YSR, Yarlung Suture Reflection (Makovsky et al., 1996; Zhao et al., 1996).

also formed in the North Lhasa Terrane during this period (Coulon et al., 1986).

The flysch deposits of the Angren Formation, the main component of the Xigaze Group, developed during the late Albian to late Coniacian (110–86 Ma) (Wan et al., 1998) (Fig. 9d). The provenance of the Angren Formation could either be the Gangdese Arc Complex (Dürr, 1996) including the Sangri Group, or the Giabulin Formation and the YZPO.

The emplacement of the Yarlung–Zangbo Ophiolite could have occurred during Paleogene continental collision (Molnar and Tapponnier, 1975; Patriat and Achache, 1984; Rowley, 1998) (Fig. 8e). The mélange zones on the southern margin of the Yarlung–Zangbo Ophiolite could represent the complex scraped from the northern Tethyan oceanic crust at the later subduction zone. The Tertiary molasse of the Liuqu Group and Qiuwu Formation formed during and after the collision, representing the main orogenic stage (e.g.

Yin et al., 1988; Liu et al., 1990). The homoclinal northward-dipping Yarlung Suture Reflection (YSR) (Makovsky et al., 1996; Zhao et al., 1996), found by the INternational DEep Profiling of Tibet and the Himalaya (INDEPTH) project, has been suggested to be the Tethyan ophiolitic slab (Fig. 9e).

7. Conclusions

The conglomeratic unit of the Giabulin Formation contains ultramafic and mafic plutonic pebbles, as well as radiolarian chert clasts, that records the erosion of oceanic lithosphere involved in a subduction event earlier than previously believed. Geochemical analyses, mineral chemistry, stratigraphic chronology, and sedimentary analysis, including source provenance, suggest that the conglomerate was formed through erosion of ophiolitic material unlike the Xigaze ophiolites. We propose the existence of an older ophiolitic source, termed the Yarlung–Zangbo paleo-ophiolite, which was dismembered and eroded during an earlier subduction stage which is not taken into account by current models. We present a modified model of the five-stage dynamic evolution of the Yarlung–Zangbo Suture Zone, with two Tethyan subduction events from the Late Jurassic to present. This early subduction stage of East Tethys, from the Late Jurassic to the Early Cretaceous, never recognized before in Tibetan geological studies, is herein proposed for the first time.

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