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A transform margin in the Mesozoic Tethys: evidence from the Swiss Alps

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With 12 figures

Zusammenfassung

Überreste des Ligurisch-Piemontesischen Ozeans mit seiner ophiolitischen Unterlage sind in den südpenninischen Decken Graubündens (E-Schweiz) erhalten. Auf Grund einer Analyse der südpenninischen Stratigraphie und einem Vergleich mit Serien aus ophiolithführenden Decken der Westalpen und Apenninen interpretieren wir die südpenninischen Decken als Relikte eines ozeanischen Transform-Bruch-Systems. Diese Interpretation beruht auf drei Argumenten: (1) Die stark zerrissene Ophiolitabfolge ist von pelagischen Sedimenten des ?mittleren und oberen Jura überlagert, wobei diese sowohl mit Basalten als auch mit Serpentiniten in stratigraphischem Kontakt sind. Wir vergleichen die südpenninischen Serpentinite mit Serpentinit-Protrusionen entlang von ozeanischen Bruchzonen. (2) Ophiolith-Breccien (»Ophicalcite«), die entlang bestimmter Zonen innerhalb des Serpentinitmuttergesteins auftreten, sind mit Breccien, wie sie in heutigen Transform-Brüchen gefunden werden, vergleichbar. Tektonische und sedimentäre Prozesse waren an der Bildung dieser Breccien beteiligt. Serpentinite zerbrachen in tektonisch aktiven Zonen und die entstehenden Risse und Gräben wurden mit pelagischem Sediment und mit Kollapsbreccien gefüllt. Hydrothermale Prozesse überprägten viele der Ophicalcite. (3) In den oberjurassischen Radiolariten findet man wiederholt Einschaltungen von Konglomeraten, in denen Ophiolith-Komponenten dominieren, in denen aber auch Komponenten von granitischen Gesteinen und von Flachwasserkarbonaten (?Triasische Oolite) an verschiedenen Orten beigemischt sind. Daraus schließen wir auf eine enge Nachbarschaft von ozeanischer und kontinentaler Kruste im Bereich des südpenninischen Ozeans. Ähnlich wie heute im Golf von Kalifornien dürfte die mesozoische kontinentale Kruste entlang des Ligurisch-Piemontesischen Ozeans durch Bruchzonen segmentiert worden sein. Über dieses ausgeprägte Relief lagern sich in der unteren Kreide pelagische Kalke, Mergel und schwarze Kieselschiefer, die Hinweise auf die Ozeanographie der Tethys geben.

Abstract

Remnants of the Liguria-Piemont Ocean with its Jurassic ophiolitic basement are preserved in the South Pennine thrust nappes of eastern Switzerland. Analysis of South Pennine stratigraphy and comparison with sequences from the adjacent continental margin units suggest that South Pennine nappes are relics of a transform fault system. This interpretation is based on three arguments: (1) In the highly dismembered ophiolite suite preserved, Middle to Late Jurassic pelagic sediments are found in stratigraphic contact not only with pillow basalts but also with serpentinites indicating the occurrence of serpentinite protrusions along fracture zones. (2) Ophiolite breccias (»ophicalcites«) occurring along distinct zones within peridotite-serpentinite host rocks are comparable with breccias from present-day oceanic fracture zones. They originated from a combination of tectonic and sedimentary processes: i.e. the fragmentation of oceanic basement on the seafloor and the filling of a network of neptunian dikes by pelagic sediment with locally superimposed hydrothermal activity and gravitational collapse. (3) The overlying Middle to Late Jurassic radiolarian chert contains repeated intercalations of mass-flow conglomerates mainly comprising components of oceanic basement but clasts of acidic basement rocks and oolitic limestone also exist. This indicates a close proximity between continental and oceanic basement. The rugged morphology manifested in the mass-flow deposits intercalated with the radiolarites is draped by pelagic sediments of Early Cretaceous age.

Résumé

Des restes de l'océan liguro-piémontais avec son socle ophiolitique jurassique sont préservées dans les nappes du Pennique méridional de Suisse orientale. L'analyse de la stratigraphie sud-pennique et la comparaison avec les séquences d'unités de marge continentale adjacentes, suggèrent que les nappes penniques méridionales sont les restes d'un système de failles transformantes. Cette interprétation se base sur 3 arguments: (1) dans la séquence ophiolitique fortement disloquée, des sédiments pélagiques du Jurassique moyen à supérieur préservent des contacts stratigraphiques non seulement avec des basalts en coussins, mais aussi avec des serpentinites, indiquant l'occurence de protrusions ultramafiques le long de zones de fractures. (2) Des brèches ophiolitiques (»ophicalcites«) qui apparaissent dans des zones distinctes à l'intérieur de masses de péridotite-serpentinite sont comparables aux brèches des zones de fractures actuelles. Ces roches sont issues de la combinaison de processus tectoniques et sédimentaires, notamment la

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fragmentation du socle océanique au fond de la mer et le remplissage d'un réseau de filons néptuniens par du matérial sédimentaire pélagique, suivi localement d'une activité hydrothermale et d'un effondrement gravitationel. (3) Les radiolarites sur-jacentes du Jurassique supérieur recèlent des intercalations répétées de conglomerats d'écoulements de masse, comprenant principalement des constituants du socle océanique, mais aussi des clastes de roches acides et de calcaires oolithiques, indiquant ainsi la contiguité du socle continental et océanique. La morphologie mouvementée traduite par des dépôts d'écoulements de masse intercalés dans les radiolarites, est recouverte par des sédiments pélagiques d'âge crétacé inférieur.

Краткое содержание

Остатки лигурийско-пьемонтского океана с его офиолитной подстилкой находят в южно-пенниских покровах Граубюндена (восточная Швейцария). На основании анализа южно-пеннинской стратиграфии и сравнения с сериями офиолитных покровов западных Альп и Апеннин, авторы рассматривают южно-пеннинские покровы, как реликты некой океанической системы разломов. Такая интерпретация основана на трех аргументах: 1) Сильно разорванная свита офиолитов перекрыта пелагическими отложениями средней и верхней юры, причем эти отложения оказываются в стратиграфическом контакте, как с базальтами, так и с серпентинитами. Авторы сопоставляют южно-пеннинские серпентиниты с протрузиями серпентинитов вдоль океанической зоны разломов. 2) Офиолитовые брекчии – "офикальциты" –, залегающие вдоль известных зон внутри материнских пород серпентинитов, можно сравнить с брекчиями, найденными в сегодняшних трансформных разломаных структурах. Тектонические и осадочные процессы принимали участие в создании этих брекчий. Серпентиниты разломались в тектонически активных зонах, а образовавшиеся трещины и грабены заполнились пелагическии отложениями и коллапсбрекчиями. Гидротермальные процессы изменили многие офикальциты. 3) В верхне-юрских радиоляритах находят всегда включения конгломератов, в которых хотя и господствует офиолитовая компонента, но на некоторых местах примешиваются гранитные породы и карбонаты мелководья (триасовые оолиты?). На основании этого авторы предполагают близкое соседство океанической и материковой коры в регионе южно-пеннинского океана. Как сегодня в калифорнийском заливе, так и мезозойская материковая кора вдоль лигурийско-пьемонтского океана разделена на сегменты зонами разрывов. Над этим рельефом залегают нижние горизонты мела из пелагических известняков, мергеля и черного кремнистого сланца, что указывает на океанографию Тетиса.

Introduction

Ophiolites and associated pelagic sediments, preserved in the South Pennine nappes in Eastern Switzerland, are interpreted as remnants of the Mesozoic central Tethys defined earlier as the »géosynclinal piémontais« (Haug 1909). Steinmann (1905, 1925) regarded radiolarian chert overlying the ophiolites as deposits formed in the abyssal part of the Mesozoic Tethys and he traced the basin facies throughout the Alps into the Ligurian Apennines. Before the advent of plate-tectonics ophiolites were considered as preorogenic intrusive or extrusive rocks, formed preferentially along fractures within the Piemont geosyncline (Argand 1916). De Roever (1956) questioned the intrusive or extrusive character of part of the ophiolite suite. He suggested to interpret the Alpine peridotites as tectonically emplaced slabs originating from deeper levels (»Peridotitschale«) accompanied by basaltic volcanism during the Jurassic. With his model of peridotite emplacement, De Roever could best explain the absence of contact metamorphism around peridotite lenses. Later, when the new global framework of plate-tectonics was established, Alpine ophiolites first were reinterpreted as documents of a Jurassic mid-ocean ridge system (Laubscher 1969, Dewey & Bird 1970) cut by a series of transform faults (Dietrich 1976). Plate-kinematic reconstructions of the Jurassic Atlantic-Tethys system, however, suggested important relative motions between Africa and Europe resulting in a sinistral transcurrent boundary between these continents (e.g. Biju-Duval et al. 1977, Laubscher and Bernoulli 1977). Minor ophiolites and oceanic sediments along the Maghrebide chains are preserved as documents of this transform boundary (Bouillin et al. 1977). Along the Adriatic promontory (Channell and Horvath 1977) or microcontinent (Biju Duval et al. 1977), ophiolite occurrences can be traced from Southern Italy (Lanzafame et al. 1979) across the Northern Apennines, the Western and Central Alps into the Tauern window of the Austrian Alps (Hoeck 1983). Ophiolites and associated pelagic sediments of Late Jurassic to Early Cretaceous age outcropping in the Ligurian Apennines are compared with mid ocean-ridge formations, which were highly fragmented by oceanic fracture zones (Cortesogno et al. 1981; Barrett 1982). Evidence for a transform domain origin of ophiolites on Corsica and in the Western Alps is given by various authors (e.g. Ohnenstetter 1979; Lemoine 1980). The Piemont Ocean, defined by these ophiolites, can be traced into the complex and highly metamorphic Zermatt-Saas Zone (e.g. Bearth 1967). In eastern Switzerland, ophiolites and associated pelagic sediments are the major lithologic elements of the South Pennine nappes. These oceanic sequences record the tectono-sedimentary evolution of a transform domain along the northern margin of the Adriatic promontory as we will document in the present study. Based on stratigraphic and sedimentological information we will argue that within the highly dismembered ophiolite suite signs of Jurassic oceanic tectonics are preserved. Ophicalcites, often in close association with serpentinites and peridotites, are described as tectono-sedimentary breccias. In the Upper Jurassic sediments numerous talus and gravity flow breccias are taken as evidence for a rugged morphology and a close neighbourhood of continental crust with oceanic basement. The decreasing imprint of oceanic tectonics on the sedimentary record of the Early Cretaceous allows to use these pelagic deposits as a record of paleoceanography.

The South Pennine nappes in Eastern Switzerland

The South Pennine Arosa Zone and Platta nappe in Eastern Switzerland form a complex zone of imbricated slices of oceanic and distal continental margin origin (Fig. 1). These units, outcropping from north of Klosters to the Engadine are sandwiched between Austroalpine and Middle Pennine nappes. The Austroalpine nappes long have been recognized as elements of the southern continental margin of the Mesozoic Tethys (e.g. Trümpy 1975), while the Middle Pennine nappes originate from the distal part of the northern continental margin (Laubscher and Bernoulli 1977). Imbricates with lithologies of continental margin origin occur preferentially along the upper and lower boundaries of the South Pennine nappe complex. These imbricates, often embedded in a shaly or serpentinitic matrix, form, together with lenses of ophiolites, oceanic sediments and flysch sequences tectonic melanges (Lüdin, in prep.). Of interest for us in the present study are the tectonic elements, where ophiolites and oceanic sediments are preserved in their original stratigraphic context. We may further compare the oceanic sequences preserved in the low grade metamorphic Arosa and Platta nappes with sequences from the Fex and Forno valleys south of the Engadine (Peretti 1985). DeCapitani et al. (1981) link the Forno ophiolites with the large ophiolite complex in the Val Malenco. The Margna nappe, separating the Malenco-Forno zone from the Fex valley (Finger et al. 1982), may be interpreted as a continental margin relic within the Jurassic Piemont Ocean (Trümpy 1985), or it may have

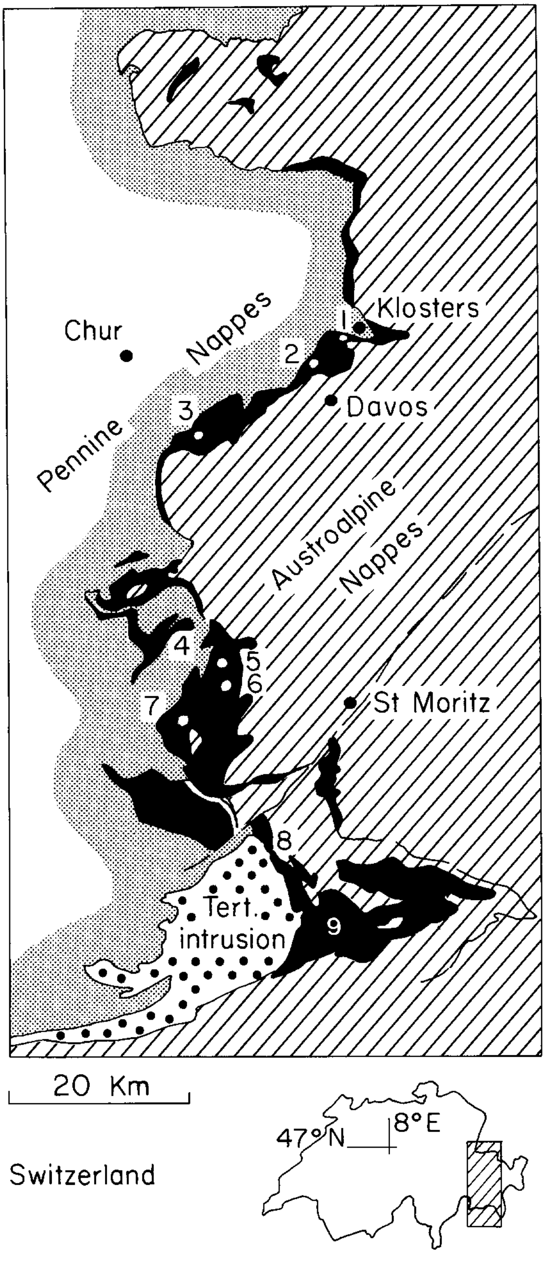

Fig. 1. Tectonic sketch map of southeastern Switzerland, showing the occurrence of ophiolite-bearing units in black. Information for this study was gained at the following localities: (1) Klosters-Gotschna, (2) Totalp-Parsenn, (3) Arosa-Hörnli, (4) Crap Farreras-Savognin, (5) Alp Flix-Falotta, (6) Val Savriez, (7) Val Bercla, (8) Monte del Forno, (9) Val Malenco.

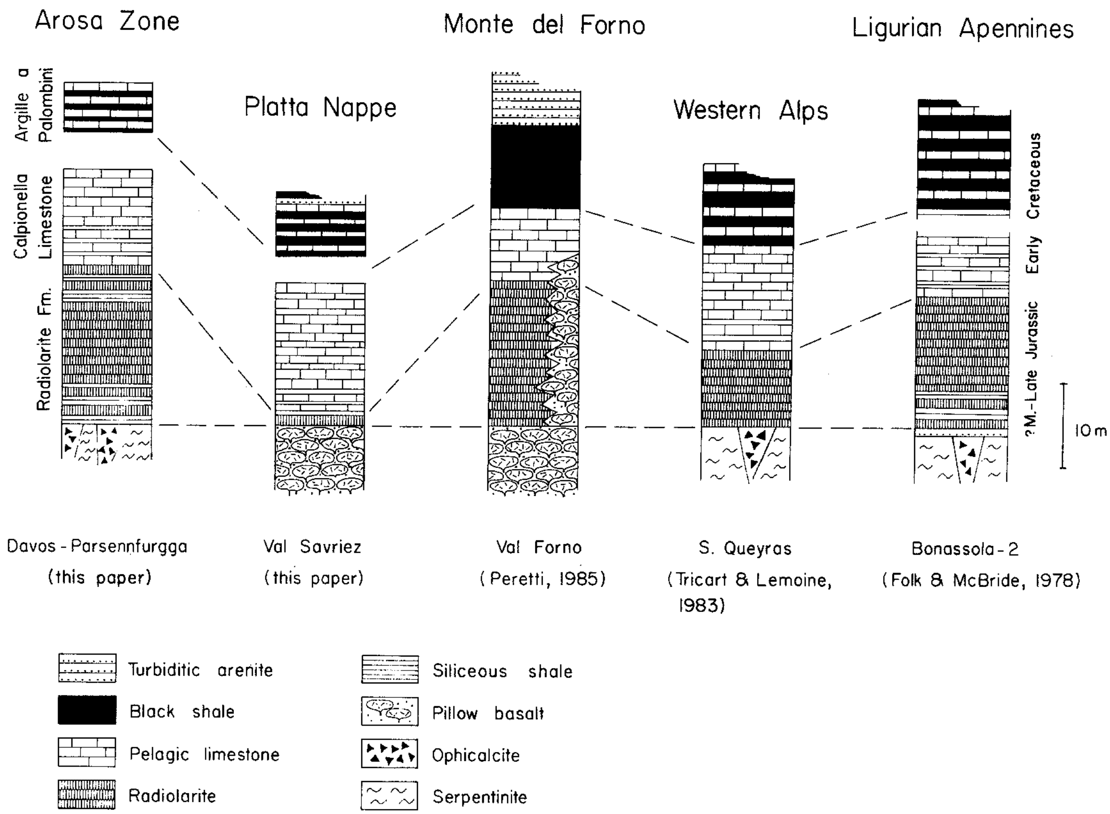

Fig. 2. Stratigraphy of the South Pennine Arosa and Platta nappes in comparison with the stratigraphy of the Monte del Forno and the ophiolite bearing units of the Western Alps and Ligurian Apennines.

been emplaced inbetween ophiolite nappes by early Alpine tectonic thrusts (LAUBSCHER 1970).

In all the imbricates originating from the Piemont Ocean, dismembered Jurassic ophiolites form the base of the Late Jurassic to Early Cretaceous oceanic sequences (Fig. 2). Radiolarian chert and pelagic limestones, known as Calpionella or Aptychus Limestone, form the pelagic cover of the oceanic basement rocks. Dark siliceous shales and marls, alternating with pelagic limestones, deposited during the Early Cretaceous are known as Argille a Palombini Formation in the Ligurian Apennines (DECANDIA and ELTER 1972). Dark siliceous shales, formed under poorly oxygenated bottom water conditions during the Aptian and Early Albian (DIETRICH 1970, WEISSERT et al. 1985) mark the end of pelagic sedimentation in the South Pennine Piemont Ocean. Flysch deposits of Albian to Cenomanian age signal beginning subduction and obduction in the Alpine Tethys (WINKLER et al., in prep.).

The oceanic sequences from the northern areas of the south Pennine nappes were altered under weak Alpine metamorphic conditions. The degree of metamorphism increases towards the south reaching greenschist facies conditions near the Engadine valley (DIETRICH et al. 1974).

A fragmented oceanic crust

Although the major lithologies of an ophiolite suite are present in the South Pennine nappes, no complete section through oceanic crust and lithosphere has been preserved. It appears, that the ophiolite suite was highly dismembered during Alpine orogeny. In contrast, however, to areas such as the Oman mountains, where a complete ophiolite sequence has been preserved, south Pennine pelagic sediments stratigraphically overlay peridotites and serpentinites as well as mafic rocks. Near Davos, a large complex of serpentinized lherzolites occurs in stratigraphic contact with ophiolitic breccias, known as ophicalcites, and is stratigraphically overlain by radiolarites (Fig. 2 and 3, BERNOULLI and WEISSERT 1985). Pillow basalts, with a mineralogy and bulk

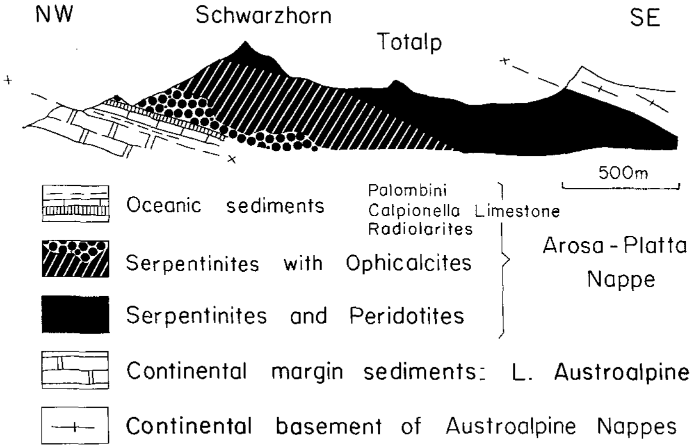

Fig. 3. Cross-section across Totalp imbricate north of Davos showing the tectonically overturned oceanic stratigraphy. Modified after Peters (1963).

chemistry comparable with tholeiitic basalts are covered by pelagic sediments at various localities within the Arosa Zone and the Platta nappe (Dietrich 1969, Green 1982). Best preserved are contacts between metavolcanics and sediments at the localities Val Savriez (Fig. 2 and 4) and Crap Farreras near Savognin (Eiermann 1984). At both of these localities stratigraphic sections are overturned and the thickness of the radiolarites is only a few meters. At the locality Falotta (Alp Flix, Fig. 1) metabasalts alternate with pillow breccias, hyaloclastites and pelagic limestones, probably of Early Cretaceous age. From south of the Engadine Valley (Monte del Forno, Fig. 2) Ferrario and Montrasio (1976) and Peretti (1985) document stratigraphic contacts between metavolcanics and radiolarian chert. No oceanic sediments are known to be in contact with the Malenco serpentinite. Highly sheared ophicalcite zones within the Malenco serpentinite still are of debatable origin. DeCapitani et al. (1981) describe the brecciated appearance of these ophicalcites. They further mention questionable graded bedding structures in ophicalcites from the Val Sassera (Malenco) and they conclude that a possible tectono-sedimentary origin of these breccias could be envisaged. Likewise, in the ophiolite zones of the Western Alps and in the Ligurian Apennines pelagic sediments overlay peridotites and serpentinites, gabbros and pillow basalts (Decandia and Elter 1972, La Gabrielle et al. 1982). Pelagic sediments of Late Jurassic and Early Cretaceous age draping indiscriminately various lithologies of the ophiolite suite are taken as evidence for an early fragmentation of the oceanic crust in this part of the Tethys. Oceanic tectonic processes causing serpentinite protrusions and basalt extrusions lasted from Middle to Late Jurassic times at least into the Early Cretaceous.

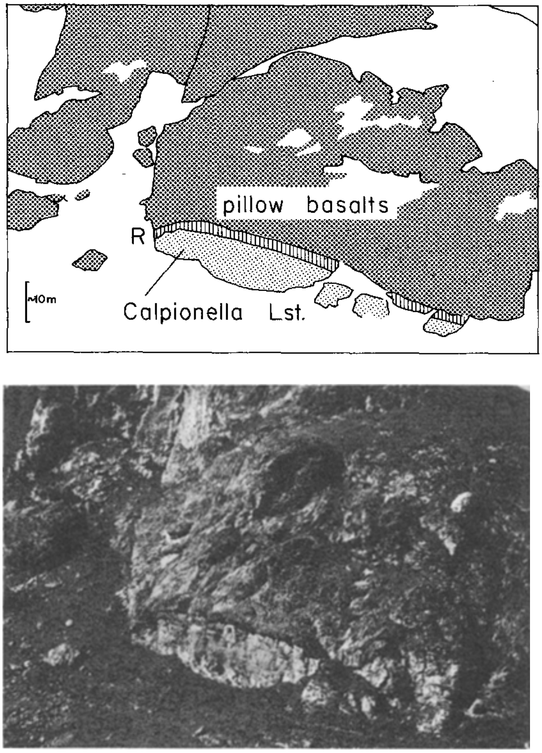

Fig. 4. Tectonically overturned oceanic stratigraphy at locality Val Savriez where pillow basalts are in stratigraphic contact with radiolarites (R).

In modern oceans outcrops of serpentinized ultramafics are found along spreading ridges (AUMENTO and LOUBAT 1971) within transform domains (BONATTI et al. 1974, FOX et al. 1976) and along compressional ridges as the Gorringe Bank in the North Atlantic (LA GABRIELLE and AUZENDE 1982). Yet, most common are serpentinite occurrences along transform faults, where a topography with deep basins bound by transverse ridges allows the exposure of thick oceanic crust and lithosphere. Uplift of peridotites in these tectonically active environments is accompanied by extensive serpentinisation affecting between 20% and 80% of the peridotite volume (BONATTI and HAMLYN 1981). The source of the solution causing the hydration and serpentinisation of the peridotites may have been seawater heated in a hydrothermally active regime, as discussed by WENNER and TAYLOR (1971) in an oxygen and hydrogen isotope study of Jurassic peridotites from the Ligurian Apennines.

Ophicalcites: breccias of tectono-sedimentary origin

Serpentinites in the South Pennine nappes of Eastern Switzerland are frequently seen in close association with ophiolite breccias, widely known as ophicalcites (e.g. CORNELIUS 1935). In an earlier paper on the ophicalcites of the Davos area (BERNOULLI & WEISSERT 1985), we argued that many of the Alpine ophicalcites were formed by tectono-sedimentary processes. We interpreted the polyphase breccias, occurring in graben-like structures up to several tens of meters wide, as lithologies resulting from the tectonic fragmentation of ultramafic rocks on the deep sea floor of the evolving Tethys Ocean (Fig. 5). Clasts of serpentinites of mm- to dm-size are embedded in a red or gray carbonate matrix and/or cemented by sparry calcite. Clear indications of a sedimentary infill of the red, recrystallized carbonate is seen in sedimentary structures preserved in the recrystallized carbonate. Parallel-laminations, graded bedding of ophiolite detritus and geopetal infill structures are best documenting sedimentary processes involved in the formation of these breccias (Fig. 6). The ophicalcites occuring within the serpentinites have to be distinguished from ophiolite breccias overlaying the basement lithologies and alternating with radiolarian chert. These breccias, interpreted as talus breccias or gravity flow deposits, will be described in a later paragraph.

Fig. 5. Lateral passage from serpentinite host rock with calcite veins into ophicalcite breccia. Locality: Totalp-Parsenn, north of Davos.

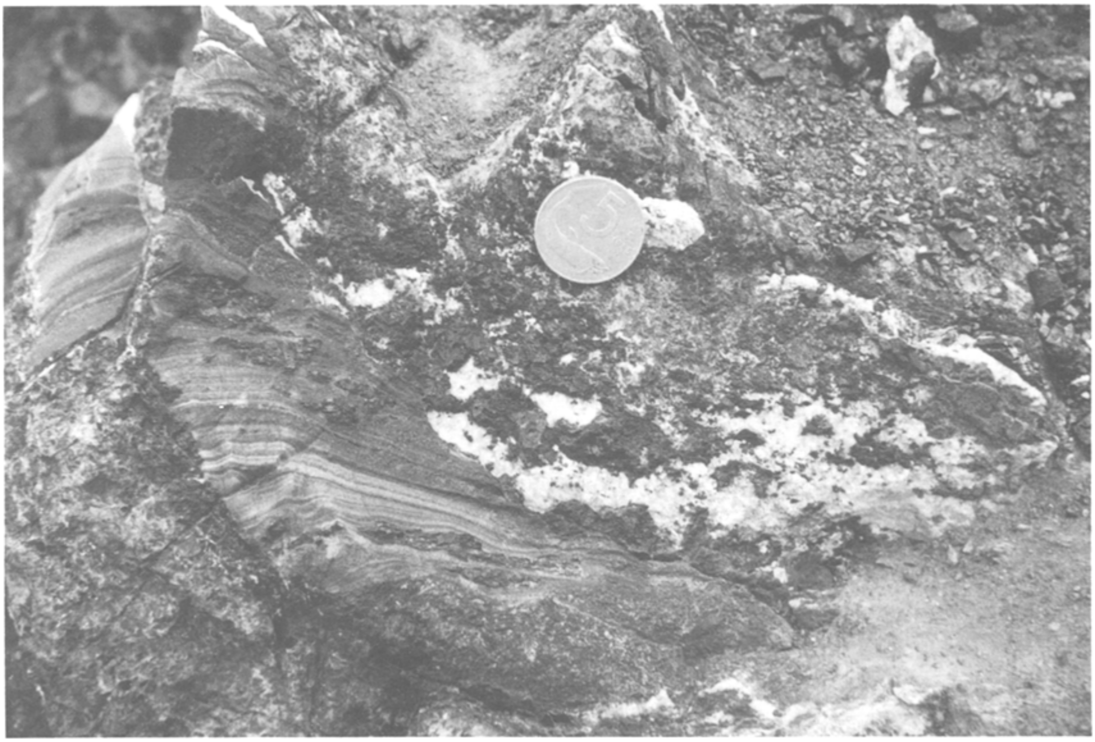

Fig. 6. Pocket in serpentinite host rock filled by laminated internal sediment. Layers and laminae of serpentinitic arenite show distinct size-grading. Diameter of coin is two cm. Locality: Totalp-Parsenn, north of Davos.

With increasing metamorphism difficulties arise when structures related to the sedimentary processes should be recognized. However, GREEN (1982) found evidence for a sedimentary origin of the carbonate in ophicalcites from the Arosa area, and, based on own observations we interpret some of the ophicalcites from the Platta nappe (Alp Flix-Falotta) in an analogous way. The ophicalcites from the Malenco-Serpentinite are affected by greenschist metamorphism. Here, the high degree of metamorphism and deformation makes an unraveling of early history exceedingly difficult. If tectono-sedimentary processes along Jurassic strike-slip faults were involved in the formation of these ophicalcites, or, if they are the product of metamorphic and metasomatic processes (e.g. TROMMSDORFF et al. 1980) remains open for debate.

Breccias, which are similar in fabric and composition to the ophicalcites from the Alps and Apennines have been dredged from trenches associated with fracture zones in the Atlantic Ocean (BONATTI et al. 1974, BONATTI et al. 1980). FOX and GALLO (1985) document how along ridge-transform-ridge plate boundaries strike-slip movements are confined to a very narrow zone of a few km. A surrounding transform domain of up to 10 km width is affected to a variable degree by strike-slip movements and by block faulting leading to extreme topographic variations within this zone. Formation of graben-like structures within the serpentinite host rock, filled with ophiolite collapse breccias, could either be caused by strike-slip movements or by the tectonic fragmentation along local fault zones. BERNOULLI and WEISSERT (1983) emphasize the analogies between ophicalcites and neptunian dikes, associated with the foundering of carbonate platforms in the Jurassic Tethys. During tectonic fragmentation of the rifted continental margin, polyphase breccias were formed within grabens along the margins of submarine highs (WIEDENMAYER 1963).

Hydrothermal activity

Our argument, that the red and grey carbonate in ophicalcite veins and fractures is of sedimentary origin, is based entirely on the observed sedimentary structures. Even in the low grade metamorphic envi-

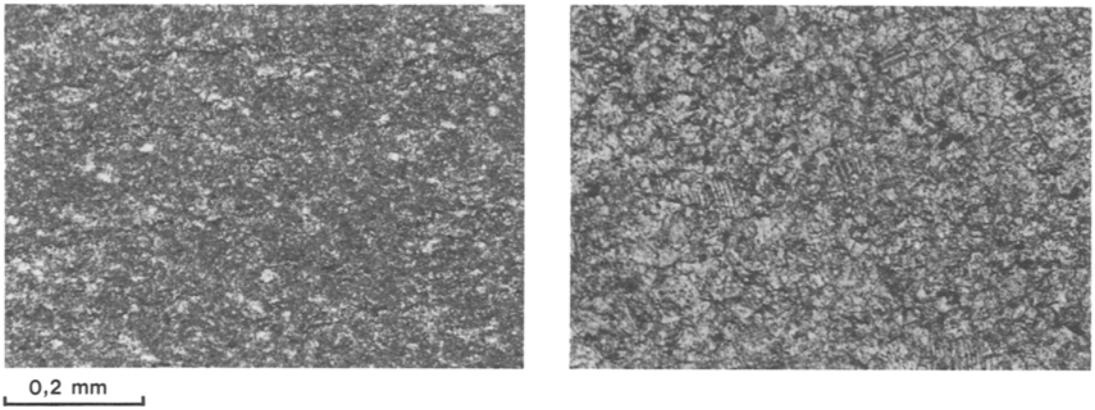

Fig. 7. Micrite of anchimetamorphic Calpionella Limestone (left) in comparison with equigranular texture of sparitic carbonate in sediment pockets of ophicalcite. Locality: Klosters-Gotschna.

ronment near Davos no indication of pelagic organisms as coccoliths or calcispheres was found in these carbonates. Under the microscope we observe a coarse, equigranular and hypidiotopic texture of the sparitic carbonate, which, at least in the anchimetamorphic terranes, contrasts with the equigranular micritic carbonate of the associated pelagic limestones of the Calpionella Limestone formation (Fig. 7). In the weakly recrystallized Calpionella Limestone, calpionellids indicating a Berriasian age still are preserved (WEISSERT 1975). The coarsely recrystallized carbonates of the ophicalcites sometimes contain aggregates of a garnet, recognized already by CORNELIUS (1935) in a regional study. PETERS (1963), in his petrographical analysis of the Totalp serpentinite and ophicalcites identified this mineral as hydroandradite. The hydroandratide or, at other localities, hydrogrossular (CORTESOGNO et al. 1981), is only a few microns in size and it typically can be traced along calcite-veins in fractured serpentinite and ophicalcite. It also may impregnate ophiolitic sandstones or ophiolite breccias as seen in samples from the Ligurian Apennines.

All of the observed hydrogarnet occurrences are not restricted to a specific Alpine metamorphic facies (DIETRICH 1969), and they may originate from an early phase of hydrothermal activity related to the emplacement of oceanic crust during the Jurassic. EASTON et al. (1977, 1982) studied semilithified micrite, identified as recrystallized nannofossil ooze of Miocene age, overlying oceanic crust along the Indian Ocean Ridge (Deep Sea Drilling Project Site 251). They related the formation of andradite-hydrogrossular, which is common in these micrites, to hydrothermal activity introducing Si, Al and Fe into a pore water-rich pelagic carbonate ooze. The oxygen isotope composition of the micrite indicates recrystallisation temperatures of about 170 °C. EASTON et al. (1982) mention how nannofossils only rarely were preserved in these Miocene pelagic carbonates. In analogy with these garnet impregnated micrites from the Indian Ocean we envisage a hydrothermal origin of the hydrogarnets in the Alpine ophicalcites. In addition to garnet formation, extensive recrystallisation and early, near seafloor lithification of the ophicarbonates may have been favoured by elevated temperatures. These early diagenetic alteration processes of an originally pelagic carbonate contrast with the normal diagenetic pathway of the Early Cretaceous pelagic sediments. Absence of any microfossils and a coarse recrystallisation texture therefore might find its explanation in a peculiar early diagenetic environment in a regime of high heat flow. Further evidence for a hydrothermally induced subseafloor metamorphism was presented by SPOONER et al. (1977) in a study of ophiolites from the Ligurian Apennines. They observed how Jurassic basalts were hydrated and enriched in the O-18 isotope due to alteration processes linked to hydrothermal fluids. We may regard the common Mn-ore deposits found within radiolarites overlying the oceanic crust (BONATTI et al. 1976, DE CAPITANI et al. 1981, SUANA 1984) as additional evidence for Jurassic hydrothermal systems altering ophiolites and, in part also, associated pelagic sediments.

In an oxygen and carbon isotope study of different carbonate cements and sediment infills of ophicalcites in the South Pennine nappes (WEISSERT & BERNOULLI 1984), we did not find any isotope signals related to early seafloor hydrothermal activity. Our studied carbonates all were reequilibrated with fluids present during Alpine metamorphism.

A rugged morphology

South Pennine ophiolites and ophicalcites are, in most cases, overlain by radiolarites of probable Mid- to Late-Jurassic age. De Wever and Caby (1981) and Baumgartner (1984), applying radiolarian stratigraphy, assigned an Oxfordian-Kimmeridgian age to analogous radiolarites from the Western Alps and the Ligurian Apennines. The Radiolarite Formation, as it is preserved in the Arosa and Platta nappes, is highly variable in thickness. At the locality Val Savriez, for example, we measured only one meter of radiolarian chert, while near Davos up to a few tens of meters of radiolarites and siliceous mudstones are preserved (Fig. 2). The base of the Davos section is formed by a few meters of siliceous mudstones. These pass into a sequence of red and green ribbon chert with variable chert-shale ratios (Fig. 8). The ribbon chert sequence, up to 20 m thick, is overlain by an alternating sequence of white pelagic limestones and red or purple siliceous shales, forming the base of the Early Cretaceous Calpionella Limestone Formation. Mineralogically, the radiolarites consist of quartz, illite, hematite or chlorite. Ophiolite detritus concentrated in some shale intervals has been identified by Gees (1954). Texturally the siliceous mudstones with only rare radiolaria contrast with the layered radiolarian cherts, which show wackestone and packstone textures. In these up to 15 cm thick chert layers, we observed frequent size-grading of the radiolarian tests and parallel and ripple lamination.

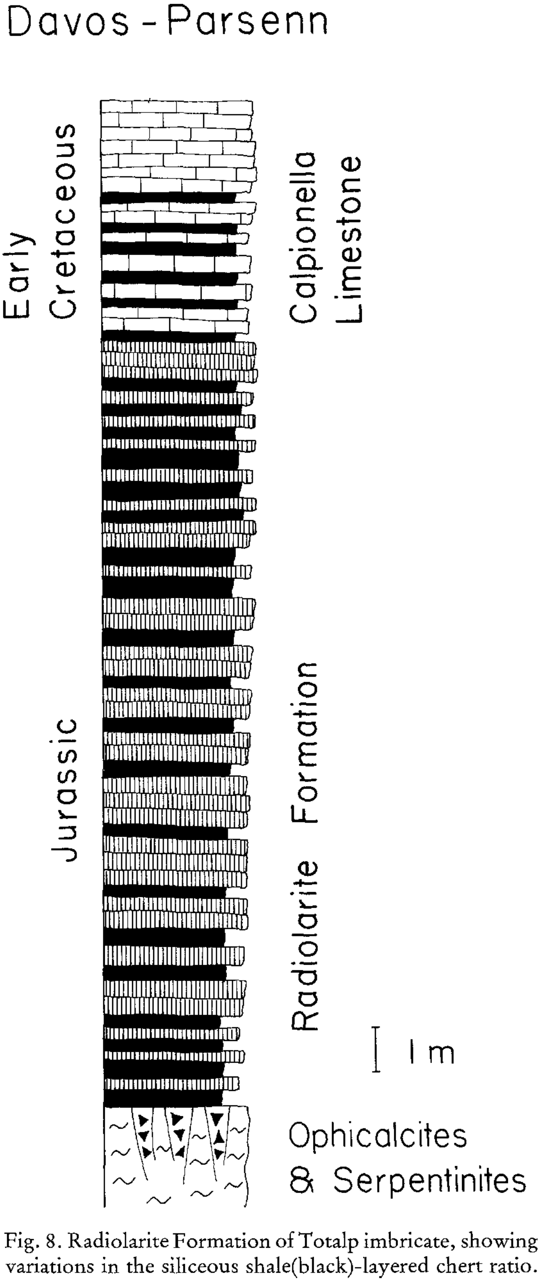

Fig. 8. Radiolarite Formation of Totalp imbricate, showing variations in the siliceous shale(black)-layered chert ratio. Locality of the section: Parsennfurgga, north of Davos.

In some of the more extensive radiolarite sequences ophiolite breccias and sandstones, a few cm up to several m in thickness, are intercalated with siliceous shale and chert. The size range of the clasts in the dominantely matrix-supported coarse breccias ranges from sand to pebble fraction and any organisation of the rounded or subangular clasts in the red shale matrix is lacking. While the majority of the clasts originate from the ophiolite sequence, admixtures of lithologies with a continental margin source were positively identified at different localities. Pebbles of a dolomitic oolite (Fig. 9) and of a grey micritic limestone are admixed to an ophiolite breccia near Parsennhütte (Davos). Gneiss clasts occur together with basalt fragments in a breccia located in the South Pennine units north of Weissfluh-Davos (Fig. 10). From units of the Platta nappe we further report findings of granitic clasts in ophiolite breccias near Alp Flix. In his description of an ophiolite sandstone from the Davos area Weissert (1975) mentioned debris of micaschist and carbonate cooccurring with the ophiolite detritus. A detailed description of the breccias and their composition will be given in a study by Bernoulli et al. (in prep.).

The radiolarites draping the ophiolite sequence are known as common pelagic lithology of Middle to Late Jurassic age in wide parts of the Alpine Tethys (Bernoulli and Jenkyns 1974, Jenkyns and Winterer 1982, Baumgartner 1984). The radiolarites represent a period of an elevated Calcium Carbonate

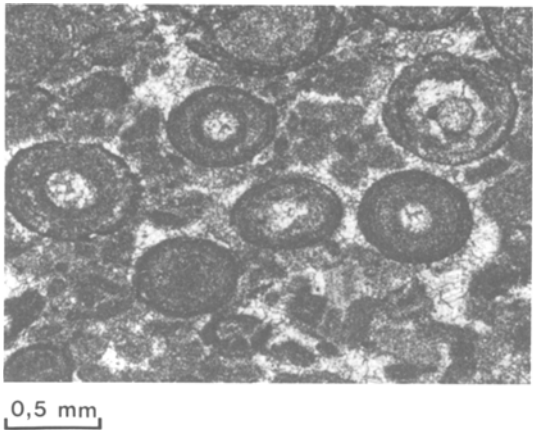

Fig. 9. Thin section photography of oolite clast from an ophiolite breccia at locality Parsenn, north of Davos.

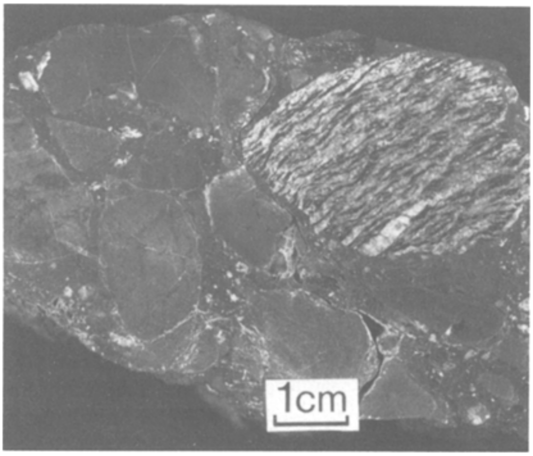

Fig. 10. Upper Jurassic basaltic breccia with a gneiss clast. Locality: Northwest of Weissfluh-Davos.

Compensation Depth (CCD), probably linked to heightened organic productivity in Tethyan surface water (Hsü 1976, Weissert 1979, Jenkyns and Winterer 1982). An increase in nutrient concentration facilitated the growth of a radiolarian population which is strongly dependent on nutrient limiting silica. With an increase of productivity the transfer of organic matter was enhanced and the degree of carbonate undersaturation was intensified due to oxidation of organic matter. Dissolution of carbonate particles and a shift in the CCD was the consequence of the proposed disturbance in the oceanic nutrient cycle. The radiolarian ooze deposits, formed under specific paleoceanographic conditions, were strongly modified by sedimentary gravity flows and turbidity currents, linked to a rapidly changing topography, as shown in earlier studies of the Alpine Tethys realm (e.g. Folk and McBride 1978, Kälin et al. 1979). In our area of study we take the high variability of the thickness in the Radiolarite Formation as a first indication of a complex and changing morphology with basins acting as sediment traps separated by sills and rises. In areas of sediment accumulation, a variety of sedimentary structures give direct evidence for redeposition and reworking of radiolarian ooze. The matrix-dominated breccias, with their chaotic internal structure were formed by subaqueous gravity flow processes. Talus breccias may have formed along steep submarine cliffs where granite and ophiolite lithologies were present for erosion.

Ophiolite breccias forming today at the talus of submarine cliffs were dredged along Gorringe Bank in the North Atlantic (La Gabrielle and Auzende 1982). The Gorringe Bank is interpreted as a Late Cretaceous and Tertiary compressional intraoceanic ridge superimposed on a transform-fault of Early Jurassic age (Cyagor Group 1984). Submarine cliffs along the distal continental margin with granitic rock walls open for erosion are described from the present day Bay of Biscaye (Pautot et al. 1976). In the case of the South Pennine units the situation is most complex because granitic and ophiolitic clasts occur together in various subaqueous gravity flow deposits. Similar observations were made in sequences from the Piemont ocean in the Western Alps (Polino and Lemoine 1984). A close neighbourhood of continental margin sources and ophiolite sources for the breccias described has to be postulated. Kelts (1981) proposed to use the Gulf of California as an actualistic example for the Alpine part of the Jurassic Tethys. He envisaged that an east-west trending transform-fault was located within the North Pennine Valais trough. However, we compare the Gulf of California, where a thinned continental crust is intersected by the projections of oceanic transform zones bringing ophiolites and continental margin sequences in close vicinity, with the South Pennine Piemont Ocean. Repeated reworking of talus breccias along ophiolite and granite cliffs in a tectonically active regime, where the basin and rise morphology is controlled by shearing and faulting, could result in the described polygenic mass-flow deposits found within the South Pennine radiolarite sequence.

Pelagic drape in the Early Cretaceous

The radiolarites, accumulated during the ?Middle and Late Jurassic in the Liguria-Piemont Ocean, are overlain by pelagic limestones passing into a se-

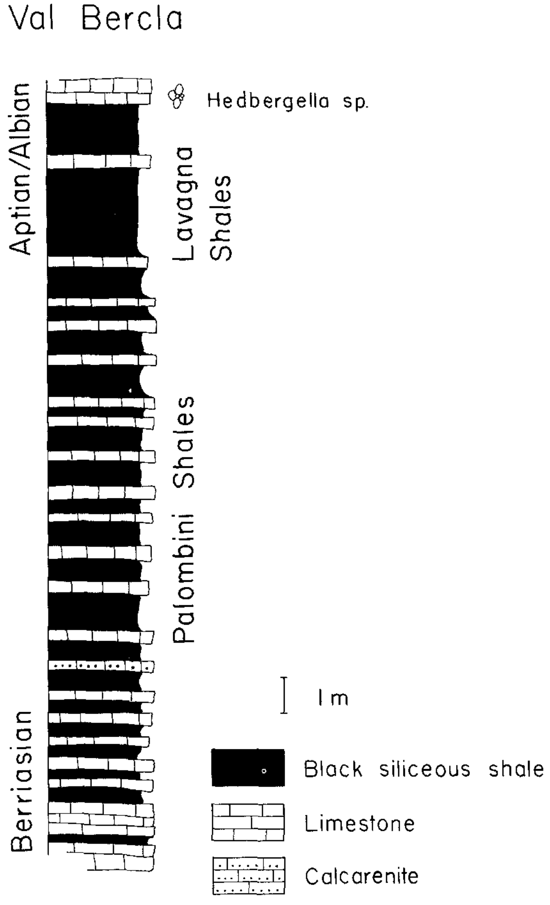

Fig. 11. Lower Cretaceous stratigraphy of Platta nappe with Argille a Palombini and Scisti di Val Lavagna overlaying Calpionella Limestone. Locality: Val Bercla.

quence of dark marls and shales with intercalated pelagic limestones. These two formations, the Calpionella Limestone Formation and the Argille a Palombini Formation, are covered by a sequence of black siliceous shales or slates, resembling the Scisti di Val Lavagna in the Ligurian Apennines (Decandia and Elter 1972). Hemipelagic marls, overlying these shales are dated as Aptian-Albian (Dietrich 1970).

The Calpionella Limestone Formation, a few meters up to a few tens of meters thick, shows at its base a sequence of grey micritic limestones alternating with red and purple siliceous marls. The pelagic limestones and shale beds are up to 20 cm in thickness. In the recrystallized texture of the limestones only calcite filled moulds of radiolaria and rare calpionellids are preserved. Weissert (1975) identified *Calpionella alpina*, *Tintinopsella longa* and *Tintinopsella carpathica* in basal limestones of the formation and consequently assigned a Berriasian age to this part of the formation. The coloured siliceous intervals are limited to the lower part of the limestone sequence. In the middle and upper part up to 20 cm thick beds of grey limestone alternate with carbonate layers displaying a distinct parallel lamination, with mm-laminae enriched in quartz and sericite. The Calpionella Limestone is gradually replaced by the black marl and shale–limestone sequence of the Argille a Palombini Formation. Dietrich (1970) described the best preserved sequence from the south Pennine nappes outcropping in the Val Bercla (Fig. 11). There, in tectonic contact with the underlying pillow basalts, a few meters of dark marls and limestones pass up-section into a carbonate poor section of shales or slates and rare intercalations of dark pelagic limestone. The dark micritic limestone beds, up to 20 cm thick, show silicification features along the upper and lower bedding plane. The dark chert rims are up to a few cm thick and they seem characteristic for the limestone beds in the Argille a Palombini Formation throughout the Liguria-Piemont Ocean. The black shales, with a highly variable organic carbon content of 0.05 to 1% according to a few preliminary analyses by Green (1982), consist mineralogically of quartz, illite-muscovite and chlorite. Mineralogically indistinguishable from these shales are the few meters of black shales with no carbonate intercalations forming the top of the Early Cretaceous pelagic sequence.

The onset of carbonate deposition in the Liguria-Piemont Ocean near the Jurassic-Cretaceous boundary, coincides with widespread nannofossil ooze sedimentation in the Atlantic and Tethys Ocean (Bernoulli 1972). The micritic texture and the preservation of the calpionellids allows the conclusion that these limestones originally were nannofossil limestones comparable to the unmetamorphosed Maiolica limestones of the southern margin of the Tethys. The Early Cretaceous is regarded as a period of low organic productivity in the oceanic surface water linked to decreased nutrient contents. A decrease in nutrient availability not only diminished the radiolarian population but facilitated the rapid expansion of a nannofossil assemblage which obviously was more adapted to low nutrient conditions (Berger 1976, Hsü 1976, Weissert 1979). While nannofossil limestones along the southern continental margin of the Tethys were deposited throughout the Early Cretaceous, a change in facies from a limestone sequence to a limestone-black shale sequence in the central and deepest part of the Tethys signals a change in bottom water conditions. The black shales

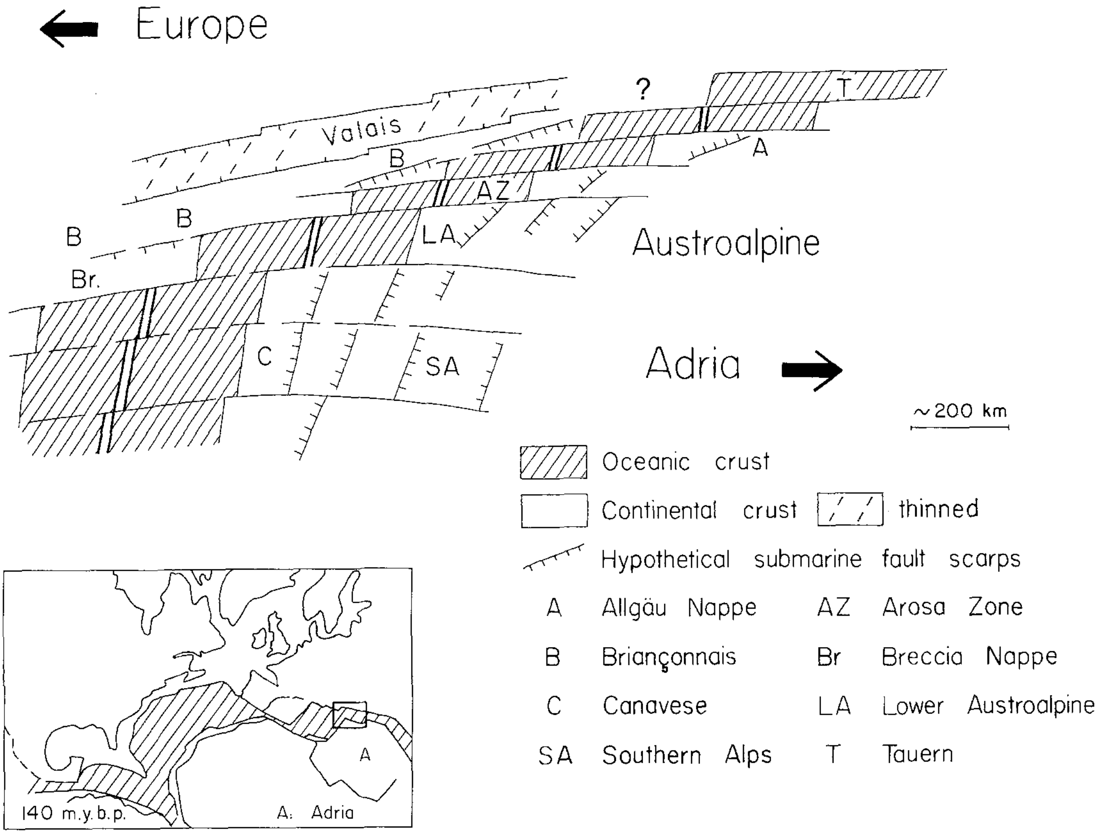

Fig. 12. Tentative paleotectonic reconstruction of the northern margin of the Ligurian Piemont Tethys in the Jurassic. The pattern of submarine fault scarps along southern continental margin was drawn in analogy to patterns found on modern continental margins (Montadert et al. 1979).

were deposited in oxygen depleted bottom water near or below the Early Cretaceous CCD. A periodic rise in the CCD is best explained by a repeated enrichment of bottom water in CO_2 due to oxidation of organic matter and restricted renewal of deep water (Weissert et al. 1985). The Late Aptian and Early Albian is known as the time period of most widespread anoxic deposits in the world oceans. A limited renewal of bottom water combined with an increased organic productivity best explains these anoxic sediments linked to a positive $\delta^{13}C$ spike in the global C-isotope record according to a model by Weissert et al. (1985). The expression of these anoxic events in the South Pennine nappes is seen in the few meters of black siliceous shales underlying the hemipelagic marls of the Albian. These hemipelagic marls mark the beginning of the convergence history between the European and African continents.

Conclusions

In the South Pennine nappes of Eastern Switzerland, a sequence of ophiolites and associated pelagic sediments of Jurassic and Early Cretaceous age records the tectono-sedimentary evolution of the Alpine part of the central Tethys. Our postulate, that the studied sequences represent relics of a Mesozoic transform-fault domain (Fig. 12), is based on the following arguments: (1) The pelagic sediments of Late Jurassic age are covering indiscriminately serpentinites, gabbros and basalts documenting a preceeding fragmentation of the oceanic crust. (2) Serpentinites, comparable to mantle protrusions in present day oceanic fracture zones, are intersected by a series of ophicarbonates. Sedimentary structures preserved in fractures, dikes and cracks within the ophicarbonates are arguments for a tectono-sedimentary origin of these breccias. The breccias formed along graben-like structures or neptunian dikes and they are comparable with ophiolite breccias dredged from oceanic transform faults. (3) A rugged morphology and steep cliffs caused the formation of subaqueous gravity flows and talus breccias with dominantely ophiolitic clasts. An additional continental margin source, possibly given by submarine granitic cliffs in close neighbourhood to the oceanic crust, is indicated by findings of granitic and shallow water limestone clasts in some of the ophiolite breccias intercalated with the Late Jurassic radiolarites. In the Gulf of California, suggested as an actualistic example for the tectonic pattern of the Liguria-Piemont Ocean, fragments of continental crust and oceanic basement are found in close vicinity due to strike-slip movements along fracture zones. By the end of the Jurassic, pelagic carbonates, draping the rugged morphology of the transform domain show a decrease in resedimentation features reflecting a decrease in tectonic activity in this part of the Liguria-Piemont Ocean. The pelagic sediments preserved mirror the paleoceanographic evolution of the central Tethys where, under poorly oxygenated conditions and under variable surface water productivity predominantely black shales were deposited during the second part of the Early Cretaceous.

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