Journal of the Geological Society, London, Vol. **147**, 1990, pp. 1009–1022, 9 figs. Printed in Northern Ireland

Geodynamic evolution of the northern and central Andes during early to middle Mesozoic times: a Tethyan model

ETIENNE JAILLARD[1,3], PIERRE SOLER[1], GABRIEL CARLIER[1] & THOMAS MOURIER[2]

[1]*ORSTOM, UR 1H, 213 rue La Fayette, 75480 Paris Cedex 10, France*

[2]*42 rue Richer, 75009 Paris, France*

[3]*Formerly at: Institut Français d'Etudes Andines, Lima, Peru and Laboratoire de géologie alpine, UA CNRS 69, Grenoble, France*

Abstract: The early to middle Mesozoic sedimentary and magmatic history of the northern and central Andes (i.e. the NNE-trending Colombian–Ecuadorian segment, and the NW-trending Peruvian segment) exhibits a spatially contrasted evolution involving several successive tectonic and geodynamic settings.

The late Triassic to late Liassic period began with a widespread marine transgression. From the latest Triassic, the Colombian marine shelf was progressively destroyed by southward propagating extensional tectonic activity but marine sedimentation continued in Peru. During this time, no significant magmatic activity is recorded except in the emerging Colombian area. This period is interpreted as the result of rifting of a Tethyan oceanic arm which separated the Colombian and palaeo-Mexican margins.

From latest Liassic, an important calc-alkaline magmatic arc developed along the emergent Colombian segment. Further south, the north-Peruvian shelf probably emerged, but marine sedimentation continued in southern Peru. During middle and early Late Jurassic times, the Colombian segment was characterized by important magmatic activity and by coarse clastic continental sedimentation. Along the Peruvian segment, a turbiditic trough, emergent areas, and continental basins were created, and the scarcity of calc-alkaline magmatism suggests that only very local subduction took place. This period is regarded as one of the southeastward subduction beneath the Colombian segment, and of Tethyan oceanic crust originating in the newly formed 'Colombian' oceanic arm. This pattern would have induced a chiefly left-lateral transform motion along the Peruvian segment.

By Kimmeridgian–Tithonian times, the palaeogeographic framework had drastically changed. Along the Colombian segment, magmatic activity ceased, and continental accretions occurred along dextral strike-slip sutures. In Peru, tectonic activity was recorded by the creation of a new turbiditic trough and by the resumption of detrital sedimentation. In the coastal area, arc-related volcanism indicated that subduction took place beneath this segment. This geodynamic change is interpreted as the result of a sharp decrease in the spreading activity of the Tethyan ridges and replacement by Pacific spreading centres inducing a roughly northeastward convergence direction.

The central Andes are considered a typical example of an orogenic belt related to the subduction of an oceanic plate beneath a continental margin. Many authors consider that subduction beneath the South American continent has taken place continuously since either late Palaeozoic or Liassic times (James 1971; Audebaud *et al.* 1973; Mégard 1978, 1987; Dalziel 1985). Nevertheless, others (Dalmayrac *et al.* 1980; Martinez 1980; McCourt *et al.* 1984; Aspden *et al.* 1987) have suggested that the Andean margin may have acted as a transform zone during part of Mesozoic times. This latter option is supported by new data relating to the sedimentary, tectonic, and magmatic evolution of the northern and central Andes during Jurassic times (see Aspden *et al.* 1987; Mojica & Dorado 1987; Mourier *et al.* 1988*a*; Jaillard & Jacay 1989). The aim of this paper is to synthetize the stratigraphical, sedimentological, tectonic and magmatic data, in order to propose an integrated, although probably oversimplified, model of the geodynamic evolution of the central and northern Andes during Triassic and Jurassic times.

The Huancabamba deflexion, situated at *c.* 5°S (Fig. 1) roughly separates the Andes into: (1) a northern, NE-to NNE-trending, 'Colombian' segment whose western part is made up of allochtonous terranes accreted during Mesozoic and Tertiary times (Feininger & Bristow 1980; McCourt *et al.* 1984; Aspden & McCourt 1986; Aspden *et al.* 1987; Bourgois *et al.* 1987; Feininger 1987; Mourier *et al.* 1988*b*); and (2) a southern, NW- to NNW-trending, 'Peruvian' segment, where no exotic blocks have been recognized (Mégard 1987; Beck 1988).

This paper is concerned only with the evolution of the 'integral', non-allochtonous South American continental plate which can be conveniently divided into several palaeogeographic domains (Fig. 1): (1) the eastern sedimentary basins, now exposed in the subandean zone and Oriente, which were bounded eastward by the Brazilian and Guianese Precambrian shields; (2) the axial Cordilleras (Central Cordillera of Colombia and Eastern Cordilleras of Peru and Ecuador) which acted as swells during part of Mesozoic times; (3) the western Andean basin (or west-Peruvian Trough) which is now exposed along the Peruvian western Cordillera; and (4) the Altiplano which

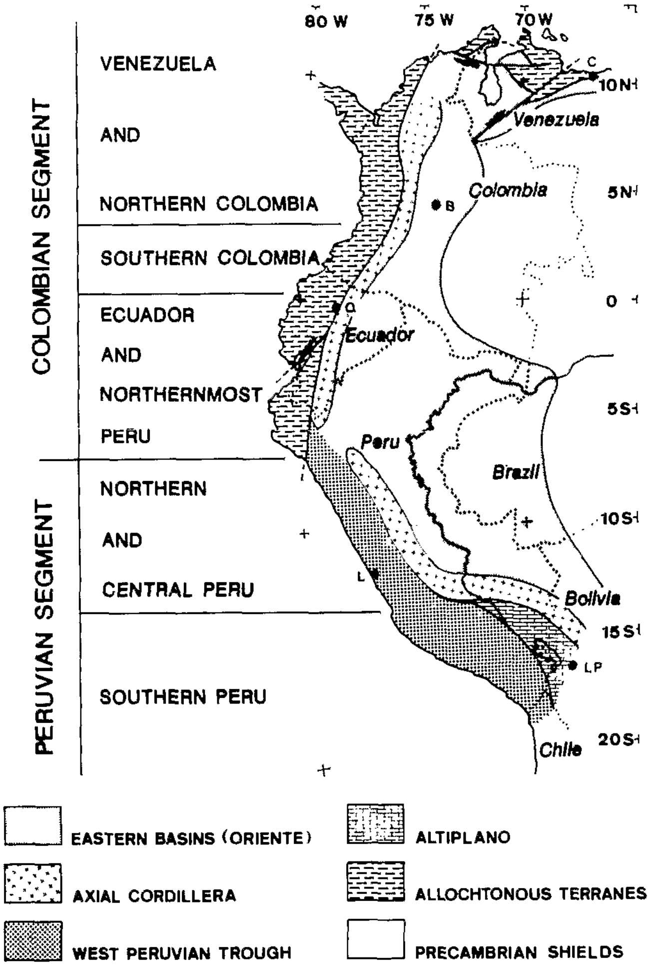

Fig. 1. Major tectono-stratigraphic units of the northern and central Andes (mainly after Cretaceous outcrops).
The present paper only deals with the evolution of the integral South American margin, i.e. the non-allochtonous units.

constitutes a distinct, southern structural zone, and develops southward into Bolivia.

In this paper, the time-scale of Haq *et al.* (1987) is used.

Evolution of the northern and central Andes during Early to middle Mesozoic times

The middle Triassic (240 to 220 Ma)

The Hercynian cycle ended with the deposition of continental red beds of late Permian to middle Triassic age (Pre-Payandé, El Sudan and Luisa Formations of Colombia: Geyer 1973; Macia *et al.* 1985; Mitu Group of Peru: Mégard 1978; Dalmayrac *et al.* 1980) (Fig. 2).

In Colombia, a few synkinematic plutons of this age are recorded and they have been related to subduction processes, to extensional tectonics (Macia & Mojica 1981), or to sinistral wrenching (McCourt *et al.* 1984, Aspden *et al.* 1987). In Ecuador, no intrusions of this age are recorded (Kennerley 1980; Baldock 1982).

In the Eastern Cordillera of Peru, calc-alkaline granodiorites and granites (Carlier *et al.* 1982), and alkaline to peralkaline comendites, basalts and syenites (Carlier *et al.* 1982; Mégard 1987) are present. These rocks are interpreted as not directly related to subduction processes; rather they would be associated to intracontinental, rifting-type extension (Kontak *et al.* 1985), associated with the offset of NW-trending normal faults (Dalmayrac *et al.* 1980).

In southwestern Peru, a thick sequence of undated andesitic flows (Chocolate and Junerata Fms, Fig. 2) overlie early Permian rocks and is capped by early Sinemurian limestones (Benavides 1962; Vicente 1981; Vicente *et al.* 1982). It exhibits the characteristics of a continental volcanic arc (James *et al.* 1975; Boily *et al.* 1984). We regard these formations as pre-Norian.

Norian to Hettangian (220 to 200 Ma)

In Colombia, Norian massive platform limestones (Payandé Fm, Fig. 2) are restricted to the southern areas (Fig. 3; Kummel & Fuchs 1953; Geyer 1973; Mojica & Dorado 1987), and these locally grade upward into black-coloured breccias and olistolith-bearing limestones and shales of Rhaetian age (Mojica & Llinas 1984). Then most of the area emerged and continental red beds intercalated with andesitic to acidic volcanic rocks were deposited along NNE–SSW trending grabens, indicating an extensional tectonic activity (Macia *et al.* 1985; Mojica & Dorado 1987). Plutons of this age are known only in the central part of Colombia (Aspden *et al.* 1987).

In Ecuador, though the Norian stage has not been recognized, its presence is assumed (Geyer 1982) at the base of the thick Santiago Formation which is partly of Sinemurian age (Tschopp 1953; Geyer 1974; Bristow & Hoffstetter 1977). No coeval intrusions are known within the continental margin (Baldock 1982, Hall & Calle 1982).

In northern and central Peru (Fig. 3), a first transgression took place during the Norian (Mégard 1968; Geyer 1982; Pardo & Sanz 1979; Prinz 1985), and is recorded by massive, cherty, dark-coloured platform limestones and dolostones of late Triassic age, which form the basal part of the Pucara Group (Chambara Fm: Mégard 1968; Loughmann & Hallam 1982, Fig. 2). The second, early Liassic transgression led to the deposition of bituminous, sandy and cherty, black-coloured limestones of Hettangian to Sinemurian age (Aramachay Fm: Mégard 1968; Palacios 1980; Prinz 1985), deposited in a deep shelf environment (Pardo & Sanz 1979; Loughman & Hallam 1982). Differential subsidence was controlled by NW-trending normal faults (Szekely & Grose 1972; Mégard 1978).

In southwestern Peru (Fig. 3), no late Triassic to early Liassic marine sediments are known.

Sinemurian to uppermost Liassic (200 to 180 Ma)

In Colombia (Fig. 4), the limestones of the Sinemurian marine transgression are restricted to NW-trending (fault-controlled?) troughs (Bata and Morrocoyal Fms: Geyer 1973; Maresch 1983; Mojica & Dorado 1987; Fig. 2). The other parts of Colombia remained emergent and received red, continental sedimentation (Saldaña and La Quinta Fms: Mojica & Dorado 1987). Throughout Colombia, post-Sinemurian deposits are essentially of volcanic or detrital continental origin; however, poorly dated, paralic sediments are reported locally (Fig. 2, Bata, El Indio, and Montebel Fms: Geyer 1973; Mojica & Dorado 1987).

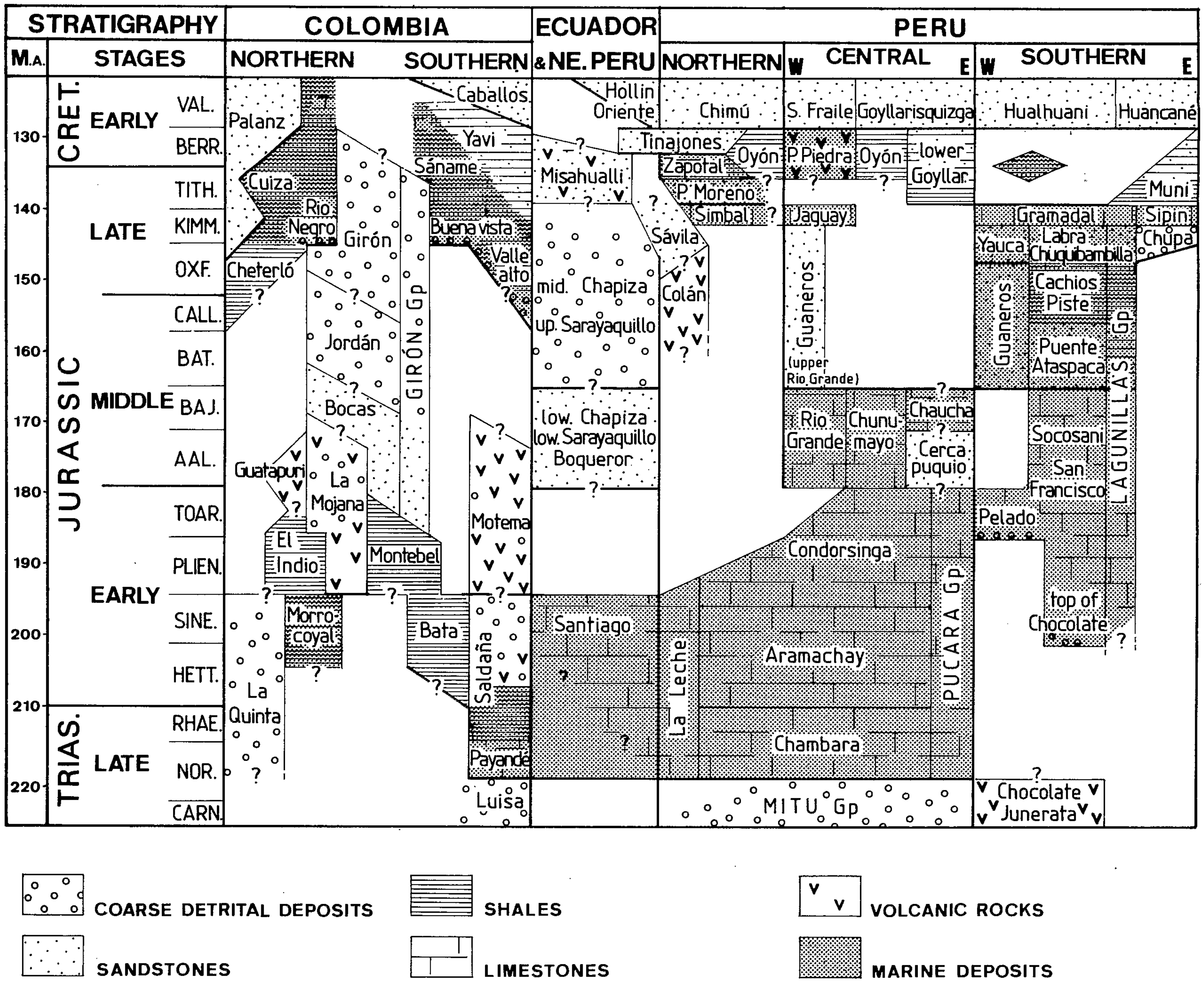

Fig. 2. Stratigraphic framework of the early to middle Mesozoic deposits of the northern and central Andes.

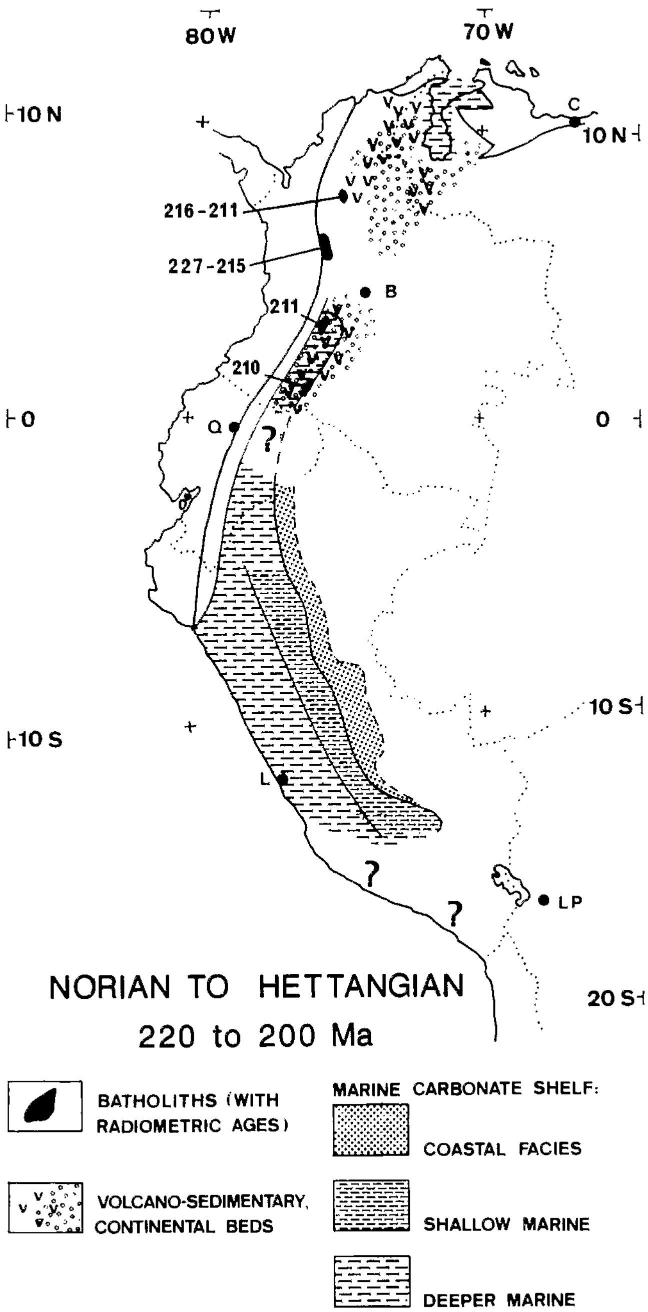

Fig. 3. Palaeogeographic reconstruction of the northern and central Andean margin during Norian to Hettangian times.

The northern areas (Colombia) progressively emerged whereas quiet shelf sedimentation continued in the south.

Some 198 to 192 Ma monzonites, granodiorites and granites of poorly known composition occur in the northern part of Colombia, principally in the Santander massif (Fig. 4), and have been related either to a peculiar subduction process, or to ensialic rifting (Aspden *et al.* 1987). These intrusions seem to cease after Sinemurian times. Nevertheless, these ages could represent older ages reset by subsequent intrusions (Aspden *et al.* 1987).

In Ecuador, the Sinemurian horizons in the Santiago Formation exhibit flysch-like facies (Geyer 1974). Toward the west, intercalations of volcanic breccias and tuffs are present (Tschopp 1953; Bristow & Hoffstetter 1977), but Liassic intrusions have so far not been reported in Ecuador (Hall & Calle 1982; Baldock 1982).

In northern and central Peru (Fig. 4), Sinemurian deposits consist of bituminous, cherty limestones representing a relatively deep marine environment (Aramachay Fm: Mégard 1968; Fig. 2). They locally disconformably overlie the Hettangian sediments (Wilson & Reyes 1964) and often contain significant amounts of sandy material (Mégard 1968; Palacios 1980). Calciturbidites have been

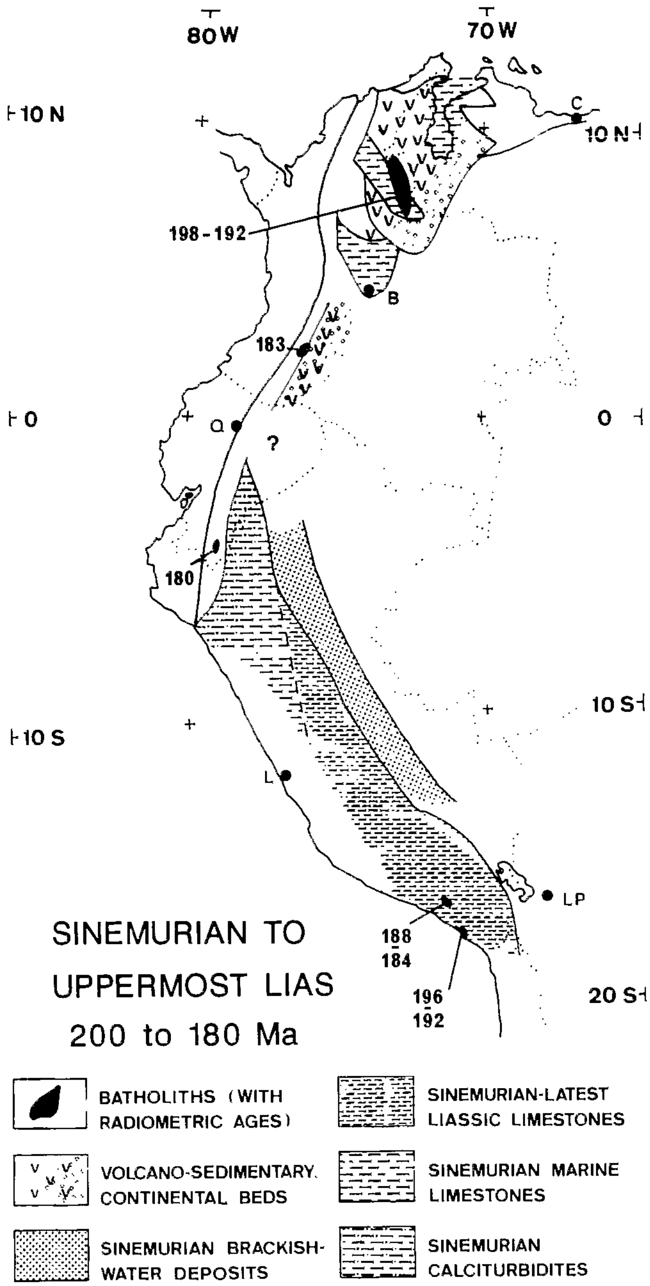

Fig. 4. Palaeogeographic reconstruction of the northern and central Andean margin during Sinemurian to latest Liassic times.

Extensional tectonic activity occurred in the northern areas (emergent in Colombia), and progressed southward (Sinemurian turbidites, and post-Sinemurian probable emergence in Ecuador and northern Peru). In southern Peru, the Liassic transgression covered a wide area.

reported in northern Peru (Pardo & Sanz 1979). The upper part of the Pucara Group comprises massive dolostones of late Liassic age (Condorsinga Fm: Mégard 1968; Fig. 2), which were deposited on a shallow platform (Loughman & Hallam 1982). The top of the sequence, which is of Toarcian age, is locally sandy (Szekely & Grose 1972; Mégard 1978; Palacios 1980). During Liassic times, sedimentation is thought to have been controlled by NW-trending normal faults (Szekely & Grose 1972; Mégard 1978).

Either because of subsequent erosion, or owing to non-deposition, the uppermost preserved sediments young toward the southeast: Sinemurian in northwestern Peru (Wilson & Reyes 1964; Pardo & Sanz 1979; Prinz 1985), Pliensbachian to Toarcian in northeastern Peru (Prinz 1985), and probably early Aalenian in central Peru (Mégard 1968, 1978; Westermann *et al.* 1980) (Fig. 2).

In southern Peru (Fig. 4), the andesitic flows of the Chocolate Formation are capped by shallow marine volcaniclastic rocks and limestones of early Sinemurian age (top of the Chocolate Fm: Benavides 1962; Vicente 1981; Vicente *et al.* 1982), which locally exhibit a thick basal conglomerate (Pelado Fm: Vicente 1981; Fig. 2). Farther east, adjacent to the Altiplano, the Sinemurian sediments are represented by dark-coloured limestones deposited in a deep marine platform environment; the base of the limestones is unknown (Lower Lagunillas Gp: Portugal 1974; Vicente 1981). In the whole area, late Liassic shelf limestones (Socosani and San Francisco Fms, part of the Lagunillas Gp, Fig. 2) locally overlying the Chocolate Formation through a basal conglomerate, indicate a new transgressive stage of Toarcian age (Vicente *et al.* 1982). They are commonly associated with extensional synsedimentary tectonic processes. (Vicente *et al.* 1982).

In southern Peru, radiometric ages of 196 to 182 Ma have been obtained for tonalitic plutons in the coastal area and in the Arequipa region (Beckinsale *et al.* 1985; Mukasa & Tilton 1985; Mukasa 1986) (Fig. 4). In the south Peruvian Axial Cordillera, 175 to 185 Ma radiometric ages have been obtained from syenitic and granodioritic intrusions (Stewart *et al.* 1974; Kontak *et al.* 1985). However, these ages can be interpreted as having been reset (Laubacher 1978; Kontak 1984).

Aalenian and Bajocian (180 to 165 Ma)

This period is generally poorly understood because of the widespread occurrence of undated continental sedimentation.

In Colombia, the post-Sinemurian deposits consist firstly of subaerial volcanic rocks (Motema, La Mojana and Guatapuri Fms, Fig. 2) and then of detrital continental deposits (Girón Gp, Bocas and Jordán Fms), deposited in fault-controlled grabens (Mojica & Dorado 1987). However, post-Sinemurian deposits are often absent, owing to subsequent erosion or to non-deposition (see Geyer 1973; Maresch 1983; Mojica & Dorado 1987 for reviews). During this period, and especially between 176 and 166 Ma, numerous tonalites and granodiorites were emplaced along the eastern edge of the Axial Cordillera (McCourt *et al.* 1984; Aspden *et al.* 1987) (Fig. 5). These plutons host copper mineralization of mid-Jurassic age (Sillitoe 1988). This magmatic belt extends southward into Ecuador and northernmost Peru (Hall & Calle 1982; Baldock 1982; Mourier *et al.* 1988*a*).

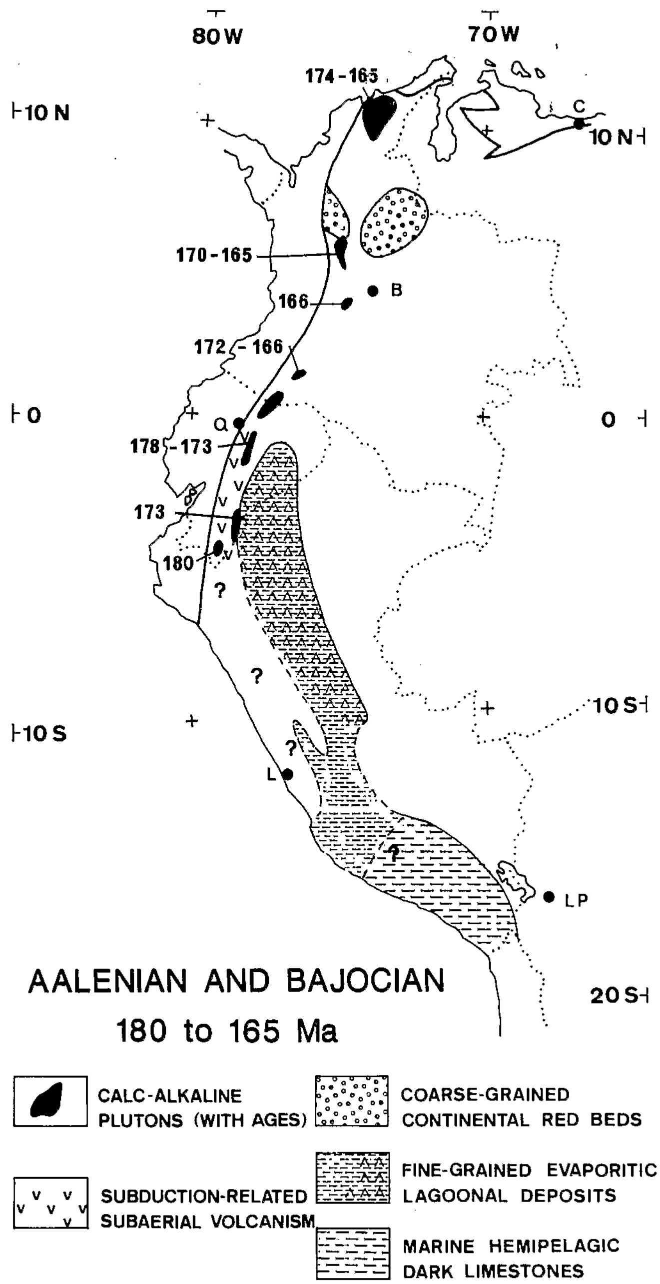

Fig. 5. Palaeogeographic reconstruction of the northern and central Andean margin during Aalenian and Bajocian times. (Subaerial volcanism and continental deposits are poorly dated).

A NNE-trending magmatic arc developed along the Colombian segment, together with local continental detrital sedimentation. Along the Peruvian segment, palaeogeographic zonation occurred with northwestern, subcontinental detrital sedimentation, and southeastern, hemipelagic calcareous sedimentation.

In the Oriente of Ecuador and Peru (Fig. 5), a thick, undated, terrigenous/lagoonal sequence of sandstones, shales, dolostones and gypsum (Lower Chapiza, Lower Sarayaquillo and Boqueron Fms, Fig. 2) disconformably overlies the Liassic limestones (Kummel 1948; Tschopp 1953; Faucher & Savoyat 1973; Pardo & Zuniga 1976; Laurent 1985). These formations are generally thought to be Middle Jurassic (Bristow & Hoffstetter 1977; Mégard 1978), but their lower parts could be locally equivalent to the top of the Pucara Group (Mégard 1978).

In northern Peru, outcrops of mid-Jurassic rocks are unknown.

In the central Peruvian Andes (Fig. 5), Aalenian to Bajocian shallow marine limestones and sandstones (Chunumayo Fm: Mégard 1968, 1978; Westermann *et al.* 1980) conformably overlie the Pucara Group, but Bathonian deposits are lacking (Fig. 2). Further north, fluvial plant-bearing red shales and sandstones (Cercapuquio Fm) are overlain by lagoonal limestones and silts (Chaucha Fm) and have been tentatively ascribed to the Aalenian and Bajocian respectively (Mégard 1968; Moulin 1989). However, a late Jurassic age is also possible (Mégard 1978).

Similar Aalenian to Bajocian deposits are known along the coast (Rio Grande Fm: Rüegg 1956; Mégard 1978; Westermann *et al.* 1980).

In southern Peru (Fig. 5), the calcareous hemipelagic sedimentation continued until Bajocian times (upper part of the Socosani Fm, San Francisco Fm, part of the Lagunillas Gp, Fig. 2) indicating a marked increase of water depth between Toarcian and Bajocian times related to extensional tectonic subsidence (Vicente *et al.* 1982).

No mid-Jurassic deposits are known in the Axial Cordillera and the Altiplano (Fig. 5), probably because of subsequent erosion, rather than to non-deposition, since the facies of the eastern areas are very similar to those of the western and coastal areas.

Bathonian to Kimmeridgian (165 to 140/145 Ma)

In Colombia, the lack of fauna precludes precise reconstructions, nevertheless, both erosion and fault-controlled red bed sedimentation continue (Jordan and Giron Fms: Geyer 1973; Mojica & Dorado 1987). Volcanic activity seems to decrease during late mid-Jurassic times. Locally, a poorly dated transgression began during the late Jurassic (Valle Alto and Cheterló Fms: Geyer 1973; Mojica & Dorado 1987) (Fig. 2).

Following a period of apparent magmatic quiescence (160–151 Ma), a new calc-alkaline plutonic pulse occurred along the Colombian segment (151–142 Ma, Baldock 1982; Hall & Calle 1982; McCourt *et al.* 1984; Aspden *et al.* 1987) (Fig. 6) accompanied in Colombia by porphyry-copper mineralization (Sillitoe 1988).

In Ecuador and northeastern Peru (Fig. 6), a thick, eastward tapering wedge of shaly, sandy and conglomeratic, continental red beds (middle Chapiza, upper Sarayaquillo Fms, Fig. 2) disconformably overlies the lagoonal deposits (Kummel 1948; Tschopp 1953; Pardo & Zuñiga 1976; Bristow & Hoffstetter 1977). Plant remains indicate a Jurassic age (Seminario & Guizado 1976). Sedimentation thickness indicates a westerly source for detritus supply (Portugal & Gordon 1976; Laurent 1985), suggesting that the Axial Cordillera was undergoing erosion (Tschopp 1953; Audebaud *et al.* 1973; Pardo & Zuñiga 1976).

In northernmost Peru, thick andesitic flows and volcanoclastic rocks were deposited (Colán Fm: Pardo & Sanz 1979; Fig. 2), partly during Callovian–Oxfordian times (Mourier *et al.* 1988*a*), and they are considered to represent the southern extension of the Colombian-Ecuadorian magmatic belt (Fig. 6). In the northern and central Peruvian Andes, south of 7°S, no deposits of late Middle Jurassic to early Late Jurassic age are known.

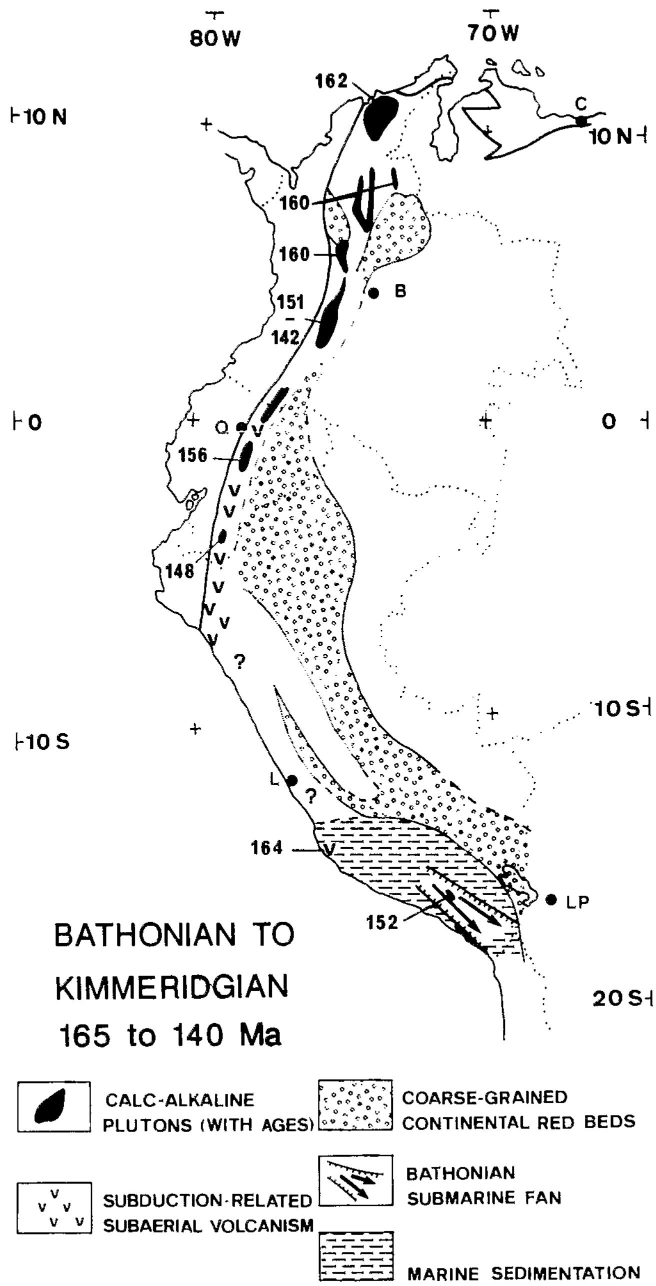

Fig. 6. Palaeogeographic reconstruction of the northern and central Andean margin during Bathonian to Kimmeridgian times.

In Colombia, magmatic activity continued, and the poorly dated, coarse, detrital continental sedimentation extended southward. In Peru, NW-trending emergent areas and troughs were created.

In the southern coastal area, a thick series of volcanogenic sandstones and black shales of Callovian and probably early Late Jurassic age were deposited (Guaneros Fm: Olchauski 1980; Vicente 1981; Fig. 2). Our field observations show that the volcanic rocks formerly considered as part of this formation, actually correspond to younger sills and dykes.

In southern Peru (Fig. 6), the Bajocian hemipelagic limestones are overlain by thick, southeastward prograding turbiditic fans (Puente and Ataspaca Fms: Vicente 1981;

Vicente *et al.* 1982) of Bathonian to Callovian age (Benavides 1962; Westermann *et al.* 1980; Vicente 1985). They pass northeastwards into hemipelagic slope deposits (part of the Lagunillas Gp, Fig. 2). Callovian–Oxfordian times are characterized by widespread pelagic black shales (Cachios Fm: Vicente 1985; part of Lagunillas Gp: Portugal 1974; Piste Fm: Pecho 1981), part of which exhibit synsedimentary normal faulting, slumping (Vicente *et al.* 1982), olistoliths and clastic dykes (Santander, pers. comm. 1988). The inferred extensional tectonic phase took place at the Middle to Late Jurassic boundary. In the Altiplano, no deposits of this age have been recognized.

During this period, magmatic activity along the Peruvian segment is very restricted (Fig. 6). Along the coast, a calc-alkaline, subduction-related andesitic flow of the upper Rio Grande Fm (Caldas 1978; Fig. 2) yielded a mid-Jurassic age (164 Ma, Aguirre & Offler 1985). On the other hand, some ages in the range 155–152 Ma were obtained by McBride (1977) and Mukasa (1986) from a few granitoids in southern Peru.

Kimmeridgian-Tithonian to Berriasian (140/145 to 125 Ma)

In parts of eastern Colombia, the sedimentation resumed with disconformable, undated conglomerates (Buena Vista breccias, Rio Negro Fm, Fig. 2), followed by undated red beds (Yavi Fm?) or plant-bearing dark shales and volcanogenic sandstones (Sáname Fm), locally and partly dated by a Kimmeridgian to Tithonian fauna (Cuiza Fm: Geyer 1973; Wiedmann 1981; Maresch 1983; Mojica & Dorado 1987). In other places, red bed sedimentation continues (Girón Fm, Boinet *et al.* 1985).

In Colombia, a significant gap in plutonism occurred during latest Jurassic to earliest Cretaceous times (142–124 Ma, Aspden & McCourt 1986; Aspden *et al.* 1987).

In Ecuador (Fig. 7), the upper part of the Chapiza Formation (Misahualli Mbr, Fig. 2) is composed of red shales, sandstones and conglomerates associated with basaltic and trachytic lavas, and then with rhyolitic tuffs (Baldock 1982; Hall & Calle 1982). It disconformably overlies the middle part of the Chapiza Formation (Tschopp 1953), and is considered as latest Jurassic to earliest Cretaceous according to both palynological (Bristow & Hoffstetter 1977; Canfield *et al.* 1982) and radiometric data (132 Ma, Canfield, *in* Feininger & Bristow 1980; Espin, *in* Hall & Calle 1982). It could be coeval with the intrusion of numerous basic, porphyritic bodies which cross-cut the latest Jurassic rocks and are capped by the Neocomian sandstones (Kummel 1948; Tschopp 1953; Bristow & Hoffstetter 1977). In the westernmost areas, volcanogenic quartzites very similar to the Neocomian quartzites are reported (Tschopp 1953), and may be correlated with the Berriasian Tinajones Formation (see below).

In northernmost and eastern Peru, there is no definitive report of deposits of this age. However they may exist as part of some late Jurassic deposits (e.g. the Sávila Fm: Reyes & Caldas 1987; Mourier *et al.* 1988*a*) (Fig. 2).

In northern Peru (Fig. 7), a lagoonal sequence of limestones and sandstones (Simbal Fm: Jaillard & Jacay 1989; Fig. 2) is sharply overlain by a thick sequence of proximal, southward-flowing turbidites in early Late Tithonian, followed by slumped, block-bearing, hemipelagic slope deposits, indicating notable tectonic activity (Punta Moreno Fm). These are overlain by black shales of late Tithonian to Berriasian age (Stappenbeck 1929; Geyer 1983; Zapotal Fm: Jaillard & Jacay 1989), and then by a fining-upward sequence of plant-bearing volcanogenic sandstones and shales with subordinate conglomerates (Tinajones Fm: Cobbing *et al.* 1981; Reyes & Caldas 1987; Mourier *et al.* 1988*a*; Fig 2). The latter detrital sequence disconformably overlies Liassic to Berriasian rocks, and

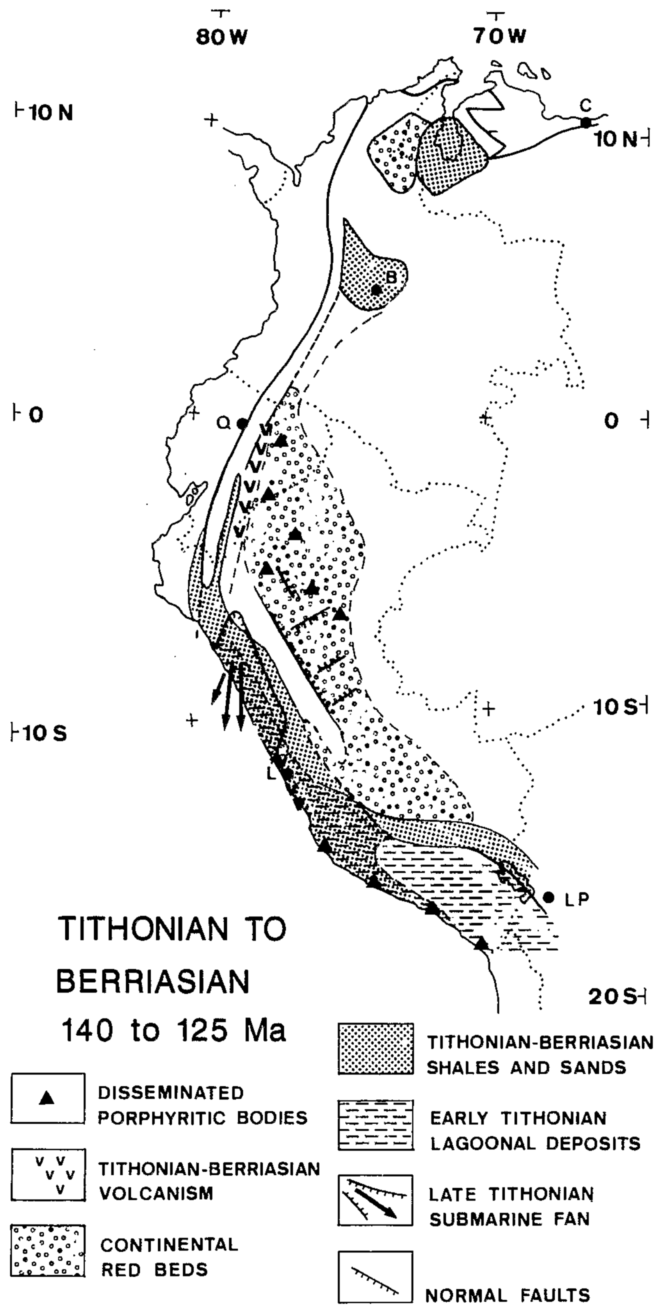

Fig. 7. Palaeogeographic reconstruction of the northern and central Andean margin during Tithonian to Berriasian times.

Except in Ecuador, magmatism ceased in the Colombian segment, and oblique collisions took place, which probably triggered the opening of the north-Peruvian turbiditic trough. Along the Peruvian segment, an extensional regime is recorded, while volcanic activity resumed along the coast (Lima).

exhibits numerous extensional synsedimentary tectonic features (Jaillard & Jacay 1989).

In central Peru, south of 11°S, no equivalent of the late Tithonian turbiditic sequence of northern Peru is known. The late Tithonian to Berriasian coal-bearing dark shales and sandstones (Oyón Fm: Wilson 1963; Mégard 1978; Cobbing *et al.* 1981) would be the southern equivalent of the Tinajones Fm (Fig. 2). Further east, red shales and sandstones were deposited during Tithonian–Berriasian times in fluvial to estuarine environments (lower Goyllarisquizga Fm: Moulin 1989), and disconformably overlie Liassic rocks or the Cercapuquio and Chaucha Formations. As mentioned above, these latter formations could be of Kimmeridgian–Tithonian age. At this time, sedimentation was controlled by NE–SW and NW–SE-trending normal faults (Arthaud *et al.* 1977; Moulin 1989).

In the coastal area of central Peru (Fig. 7), undated porphyritic andesites intercalated with greywackes and shales are overlain by basaltic flows and volcaniclastic deposits (Puente Piedra Fm: Rivera *et al.* 1975; Mégard 1978) of latest Berriasian age (Wiedmann 1981; Fig. 2). They have been interpreted as subduction-related, volcanic arc flows (Atherton *et al.* 1983, 1985). Further south, the Jaguay Formation of early Tithonian age (Rüegg 1961; Caldas 1978) comprises brecciated and siliceous limestones deposited in a shallow marine environment. Porphyritic dykes, sills and small stocks cross-cut the pre-Valanginian rocks along the southern Peruvian coast.

In southern Peru (Fig. 7), siliciclastic shelf deposits partly of Kimmeridgian age (Labra Fm: Benavides 1962; Vicente 1985; Vicente *et al.* 1982; Chuquibambilla Fm: Pecho 1981; Chachacumane Fm: Vicente 1981, 1985; Fig. 2) overlie the late Jurassic black shales, with a local unconformity (Yauca Fm: Olchauski 1980). They are overlain by limestones and sandstones representing a lagoon-barrier environment (Gramadal Fm: Benavides 1962; Vicente *et al.* 1982). The limestones have been locally dated as early Tithonian (Vicente 1985; Batty & Jaillard 1989). In some areas, late Tithonian fine-grained quartzites (Geyer 1983) or Berriasian black shales (Bellido 1956) are known, but emergence seems to have occurred elsewhere during late Tithonian-Berriasian times (Batty & Jaillard 1989; Fig 2).

In the Altiplano area, coarse conglomerates (Laubacher 1978; Chupa Fm: Klinck *et al.* 1986) disconformably overlie Palaeozoic rocks. They are followed by lagoonal limestones, shales and sandstones (Sipin Fm), which grade upward into tidal red shales and sandstones (Muni Fm: Newell 1949; Audebaud *et al.* 1976; Fig. 2). These formations exhibit a strong synsedimentary ENE–WSW-trending extension (Batty & Jaillard 1989).

Near the Berriasian–Valanginian boundary, a major disconformity occurred and led to the deposition, in most of the central and northern Andes, of a westward propagating sequence of clean and mature quartzites, which disconformably overlies Palaeozoic to Berriasian rocks (Kummel 1948; Tschopp 1953; Benavides 1956; Pardo & Zuñiga 1976; Laurent 1985; Jaillard & Jacay 1989; Batty & Jaillard 1989) (Fig. 2).

Synthesis of tectonic, magmatic, and sedimentary feaures

The evolution of the northern and central Andes during the early and middle Mesozoic can be divided into three main periods, each one showing distinctive sedimentary, tectonic and magmatic features (Fig. 8).

Middle Triassic to late Liassic (240 to 180 Ma)

Continental red bed sedimentation of Permo-Triassic age is followed by platform sedimentation which began with the widespread Norian transgression. During early Sinemurian and early Toarcian times, new transgressive stages are recorded. The marine carbonate shelf is diachronously destroyed by a southward migrating extensional tectonic activity which induced the immersion of the northern areas between the Rhaetian (Colombia), and the late Liassic (Ecuador and northern Peru). This tectonic activity is recorded in central Peru by local unconformities and by partly detrital sedimentation, and in southern Peru by extension-related subsidence (Fig. 8).

During this period, magmatic activity is mainly restricted to Colombia, and to southern Peru (Fig. 8). In the former area, most of the intrusions seem to be related to extensional or strike-slip processes, whereas in southern Peru, plutons intrude subduction-related volcanic rocks (Chocolate Fm). This poorly dated volcanic arc is the only preserved evidence that subduction occurred along the study area during an undetermined time-span between early Permian and middle Liassic times.

As a whole, this period is dominated by a southward propagating extensional tectonic regime. No clear evidence of subduction processes is preserved, except perhaps in southern Peru.

Aalenian to Kimmeridgian (180 to 140/145 Ma)

This time-span begins with a palaeogeographic change marked by widespread disconformable detrital deposits and local tectonic subsidence. A Bathonian tectonic phase resulted in the formation of the south Peruvian turbiditic trough, the probable emergence of the Axial Cordillera and the deposition of coarse continental beds in the eastern basins (Fig. 8). By Callovian–Oxfordian times, tectonic instability occurred and was contemporaneous with local black shale deposits.

The NNE-trending calc-alkaline, locally Cu-mineralized magmatic belt which extends all along Colombia and Ecuador (Fig. 8), unambiguously indicates that subduction took place beneath this segment (Aspden *et al.* 1987). The beginning of the subduction, as expressed by the 180 Ma intrusions roughly coincides with detrital sedimentation in Ecuador and in northern and central Peru, and with the tectonic subsidence of southern Peru.

In contrast, the scarcity of the intrusions along the Peruvian segment (Fig. 8) suggests that only local and/or episodic subduction occurred at this time. On the other hand, the creation of the south Peruvian turbiditic trough indicates an extensional tectonic regime.

In agreement with Aspden *et al.* (1987), we interpret this pattern as the result of a very oblique, southeastward convergence direction which would have induced a strong, sinistral strike-slip component along the Peruvian segment (Fig. 8). The southern turbiditic trough may be interpreted as a pull-apart basin. Nevertheless, the Bathonian, subduction-related andesites of the upper Rio Grande Formation (Aguirre & Offler 1985) suggest that oblique subduction may have taken place locally and sporadically along the Peruvian margin.

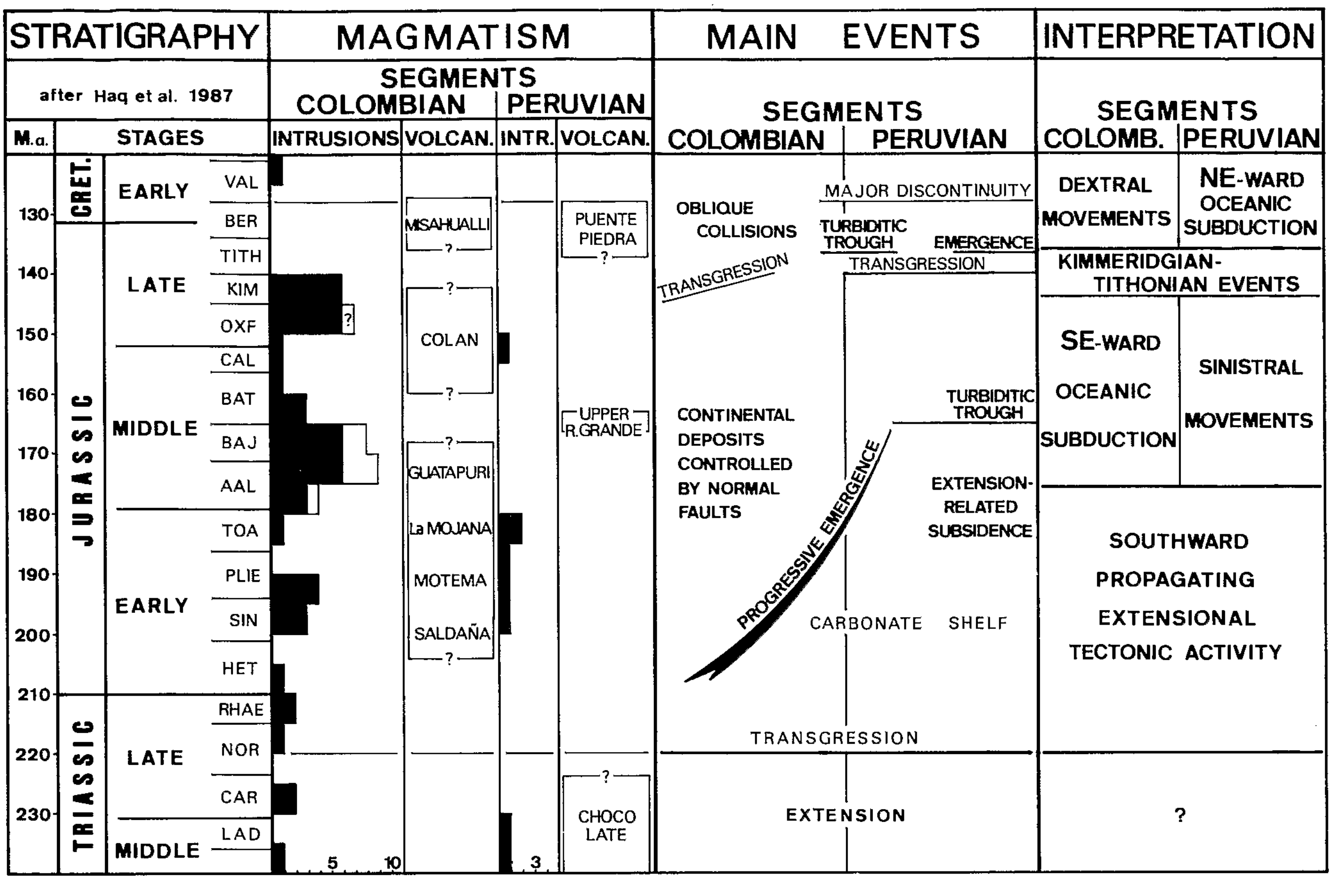

Fig. 8. A synthesis of the evolution of the Colombian and Peruvian segments. Intrusions are represented according to the number of known radiometric ages (Ecuadorian plutons in white). Volcanic formations illustrate the volcanic activity.

Between Norian and latest Liassic times, the magmatic activity remained low and the southward shift of the rifting-related tectonic activity progressively destroyed the Norian-Liassic carbonate shelf.

During middle and early–late Jurassic, an important magmatic arc developed in the Colombian segment, indicating roughly southeastward subduction beneath this segment, whereas ridges and detritus-filled trough were created in the Peruvian segment, as the result of sinistral wrenching tectonics.

From Kimmeridgian–Tithonian to Berriasian times, magmatism ceased abruptly along the Colombian segment which underwent dextral, oblique collisions. Along the Peruvian segment, new troughs and ridges were created, and the creation of the Lima marginal basin indicates that a grossly northeastward subduction took place beneath this segment.

Kimmeridgian to Berriasian (140/145 to 125 Ma)

This period begins with a widespread basal conglomerate, and with extensive shallow marine siliciclastic deposits which pass upwards into shallow marine limestones. In northern Peru, a turbiditic trough was created by late Tithonian times (Fig. 8). This period usually ends with the deposition of fluvial to coastal sands and shales which are frequently eroded and occur beneath the disconformably overlying Neocomian quartzites.

Along the Colombian segment, accretions of allochtonous terranes occurred during latest Jurassic to early Neocomian times (McCourt *et al.* 1984; Roperch *et al.* 1987; Mourier *et al.* 1988*b*; Restrepo & Toussaint 1988) (Fig. 8). These accretions are associated with a blueschist metamorphic belt with ages of 132 to 125 Ma (Feininger 1982; Bourgois *et al.* 1987), and are related to the 142 to 124 Ma gap in plutonism in Colombia (McCourt *et al.* 1984; Aspden & McCourt 1986; Aspden *et al.* 1987). These events could have triggered the opening of the north Peruvian trough (Jaillard & Jacay 1989).

The Peruvian segment recorded both an extensional tectonic regime, and a renewal of the volcanic activity in the coastal area (Puente Piedra Fm, Fig. 8). The andesitic flows of this formation show both subduction-related arc, and back-arc chemical affinities (Atherton *et al.* 1983, 1985).

Hence, the geodynamic pattern drastically changed during Kimmeridgian–Tithonian times. The NW-trending Peruvian segment records subduction processes while the NNE-trending Colombian segment was subjected to a strong dextral transform component (McCourt *et al.* 1984; Aspden *et al.* 1987), which can be related to the accretion of terranes originating to the south (Mourier *et al.* 1988*b*). These observations would therefore suggest a roughly northeastward convergence direction of the oceanic Phoenix plate relative to continental South America (Aspden *et al.* 1987) (Fig. 8).

The major pre-Valanginian erosional disconformity could represent either a sedimentary response to the Colombian and Ecuadorian accretions (Mourier *et al.* 1988*a*) or the effects of the incipient South Atlantic rifting (Jaillard & Jacay 1989).

The early to middle Mesozoic history of the northern and central Andes: a Tethys-controlled evolution

Recently published Mesozoic geodynamic reconstructions of the Caribbean region (Pindell & Dewey 1982; Klitgord & Schouten 1986; Ross & Scotese 1988) assume a continuous western margin for the Americas which united the western margin of northern Mexico with the western margin of northern Peru by the means of various continental microplates, remnants of which constitute present-day Central America (Fig. 9a). If accepted, important deductions may be inferred from these reconstructions.

During Early to Middle Jurassic times, the Tethyan rifting affected the Caribbean region, which acted as a complex sinistral transform zone. The central Atlantic opening induced the separation between the North and South American plates (Pindell & Dewey 1982; Anderson & Schmidt 1983). Therefore, the northwestward shift of North America can be correlated with the creation of a Tethyan oceanic arm along the Colombian segment. This Tethyan ridge extended southwestward through the Palaeopacific realm (Mooney 1980), and separated the northern Farallon oceanic plate from the southern Phoenix oceanic plate. As a consequence, subduction beneath Colombia cannot have started before the beginning of the spreading in the Tethyan–Colombian rift.

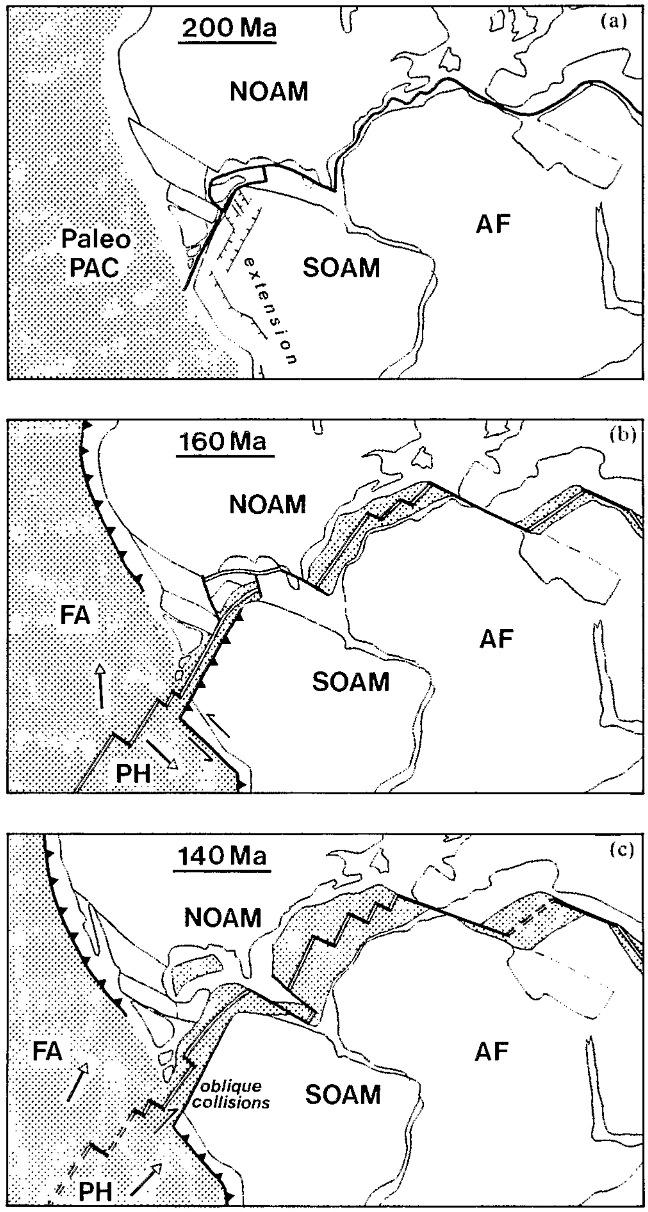

Fig. 9. Geodynamic model for the evolution of the northern and central Andes related to the early to middle Mesozoic Tethyan evolution. White areas, continental plates: AF, Africa; NOAM, North America; SOAM, South America. Shaded areas, oceanic plates: FA, Farallon; PH, Phoenix; PaleoPAC, Palaeopacific.
(a) During late Triassic–Liassic times, the Tethyan rifting passed between the Colombian and the palaeo-Mexican margins and produced an extensional regime throughout the northern and central Andean margin, probably associated with some strike-slip movements.
(b) During middle and early Late Jurassic, the southeastward subduction of the newly created Tethyan–Colombian oceanic crust beneath Colombia gave way to the sinistral transform offset of the Peruvian margin.
(c) During latest Jurassic and earliest Cretaceous times, spreading along the Tethyan ridges sharply decreased (or even ceased), and was replaced by the Pacific spreading centres. As a result, a northeastward subduction commenced beneath the northern part of the South American plate, and oblique, dextral collisions of continental blocks and oceanic ridges occurred along the Colombian segment.

The rifting phase

In western Gondwana, the Tethyan rifting began during late Triassic times and continued throughout Liassic times (Bernoulli & Lemoine 1980; Emery & Uchupi 1984; Olivet *et al.* 1984; Savostin *et al.* 1986; Lemoine *et al.* 1986). It induced an extensional regime in the Caribbean region (Pindell & Dewey 1982; Anderson & Schmidt 1983; Klitgord & Schouten 1986; Ross & Scotese 1988). During middle to late Liassic times, the Caribbean–Colombian rift was deep enough to allow exchanges of pelagic faunas between the Tethyan and Caribbean realms (Hillebrandt 1981; Thierry 1982).

The rifting-related extensional and possibly transcurrent stress is clearly recorded by the geological evolution of the Colombian segment (Mojica & Dorado 1987). It is proposed that the destruction of the Norian carbonate platform during Liassic times in Ecuador and Peru is also related to the evolving rifting process, the effects of which progressed diachronously southward (Fig. 9a).

The Tethyan subduction phase

The beginning of the spreading in the Western Tethys is of late Middle Jurassic age in the Western Alps (Lemoine *et al.* 1986); of latest Liassic (180 Ma, Olivet *et al.* 1984; Savostin *et al.* 1986) to early Bajocian age in central Atlantic (170–175 Ma, Emery & Uchupi 1984; Klitgord & Schouten 1986; Ziegler 1988); and of Aalenian to Bajocian age in the Caribbean region (175–165 Ma, Stephan *et al.* 1980; Pindell & Dewey 1982; Anderson & Schmidt 1983; Ross & Scotese 1988). Initial spreading rate in Central Atlantic seems to have been first very low (Olivet *et al.* 1984).

In Colombia, the calc-alkaline arc magmas were emplaced partly during the Toarcian (183 Ma) and mainly during the Aalenian and Bajocian (176–166 Ma, Aspden *et al.* 1987) (Fig. 8). This magmatic pulse may be regarded as being related to the subduction of the newly created Tethyan crust, formed in the Colombian oceanic arm (Fig. 9b). It probably coincides with the beginning of the detrital sedimentation throughout Ecuador and Peru.

According to the classical model of Uyeda & Kanamori (1979; see also Cross & Pilger 1982; Soler & Bonhomme, 1989), the strong tectonic stress (uplift and erosion), the voluminous intrusions and the Cu-mineralization recorded by the Colombian segment suggest fast, low-angle subduction of a young oceanic crust, which is in good agreement with the Tethyan interpretation (Fig. 9b).

The Bathonian tectonic phase (165–160 Ma) does not show clear correlations with global geodynamic events. Nevertheless, this diastrophic phase is widely known throughout South America (Zambrano 1978; Riccardi 1983), and has been recently reported in the western margin of North America (169–161 Ma, Dilles & Wright 1988; Wright & Fahan 1988).

In the Tethyan system, the Callovo-Oxfordian (155–150 Ma) is marked by a sharp increase in the spreading rate (Olivet *et al.* 1984; Savostin *et al.* 1986) and by tectonic events in the Western Alps (Lemoine *et al.* 1986) and Caribbean region (Anderson & Schmidt 1983). They can be regarded as coeval with part of the Nevadan orogeny (154 Ma: Schweickert *et al.* 1984; Ingersoll & Schweickert 1986). The tectonic instability recorded in the Central and Northern Andes could be related to these events.

The Bathonian and Callovo-Oxfordian Andean phases roughly coincide with a decrease of the magmatic activity along the Colombian segment, but the regional subduction pattern did not change significantly, since a new plutonic maximum occurred between 151 and 142 Ma in the Colombian segment (Aspden *et al.* 1987).

The Pacific subduction phase

Kimmeridgian–Tithonian times (140–145 Ma) are marked by drastic geodynamic changes. In the central Atlantic, the spreading rate sharply decreased (Olivet *et al.* 1984; Klitgord & Schouten 1986), as well as in the Western Alps (Savostin *et al.* 1986). Moreover, in the Caribbean region, southward ophiolite obductions are concealed by Neocomian deposits in Venezuela (Stephan *et al.* 1980). On the other hand, the beginning of the south Atlantic rifting is of late Oxfordian to early Tithonian age (147–136 Ma, Herz 1977; Ojeda 1982; Sibuet *et al.* 1985). The geodynamic change along the South American margins can be regarded as a result of this kinematic reorganization.

Duncan & Hargraves (1984) showed the convergence vector of the Phoenix plate to be the sum of the expansion vectors of the NE-trending Tethyan ridge and the Pacific spreading system located farther southwest (Hilde *et al.* 1977; Handschumacher *et al.* 1988). As a result, a fast spreading rate along the Tethyan ridge associated with a low spreading rate in the Pacific ridges would have induced a southeastward motion of the Phoenix oceanic plate (Duncan & Hargraves 1984). These conditions seem to have occurred between 180 and 145 Ma (Fig. 9b). In contrast, a slow spreading rate in the Tethyan Colombian ridge would have induced a northeastward motion of the Phoenix plate (Duncan & Hargraves 1984). We propose that the above mentioned sharp decrease of the spreading rate in the Tethyan ridges led to this situation after Kimmeridgian times (Fig. 9c).

Following Uyeda & Kanamori (1979), Cross & Pilger (1982) and Soler & Bonhomme (1989), the dominant extensional regime, together with the lack of any uplift indicated by the widespread Kimmeridgian–Tithonian transgression along the Peruvian margin, suggest a steep-dipping subduction of a slow-converging, possibly old oceanic slab.

Concluding remarks

The analysis of the evolution of the Andes north of the Arica elbow shows that the subduction was not uniform during early Mesozoic times. However, the proposed model is speculative and several uncertainties remain.

The early volcanic arc in southern Peru (Chocolate Fm) suggests that active subduction took place sometime between early Permian and Sinemurian times. In this paper, we assume that subduction ceased before late Norian times. Actually it is quite difficult at the moment to state whether subduction took place during the late Norian or not, and this problem needs further investigation.

In this paper, we use present-day maps to draw the palaeogeographic features. However, various tectonic and palaeomagnetic studies suggest that at least parts of the Andean margin have undergone significant tectonic rotation and shortening from early Mesozoic times. Further studies are needed in order to determine the palaeogeometry of the northern and central Andean margin.

We have considered the Kimmeridgian–Tithonian events of the central Andes to represent an unique and well-defined boundary for geodynamic regimes. Actually, field data from Peru suggest that the whole Kimmeridgian–Berriasian time-span represents a transitional period. However, the model proposed is in good agreement with the available geological data which clearly indicate that the various segments of the Andes underwent different evolutions.

From the late Triassic to the late Jurassic, Tethyan rifting dominated the evolution of northern South America. It is expressed by a palaeogeographic zonation perpendicular to the proposed convergence direction, with coarse continental sedimentation toward the northwest, shallow marine, fine detrital sedimentation in northern and central Peru, and deep marine carbonate sedimentation in southern Peru.

The late Jurassic events are related to a geodynamic revolution which is marked by the end of the roughly E–W-trending Tethyan break-up, and by the beginning of the roughly N–S-trending Atlantic rifting. In the study area, the palaeogeographic framework drastically changed into a NE–SW to E–W orientation, with eastern red beds, central emergent areas, and western shallow marine sedimentation. This displays the reaction of the South American margin to the new, northeastward convergence direction.

The Tethyan realm between Colombia and palaeo-Mexico may explain the Tethyan affinities of some Pacific provinces during early Mesozoic times (e.g. Marcoux *et al.* 1982). The disruption of the Tethyan realm during the Liassic rifting, followed by the shift of some of these continental microplates owing to the Tethyan and then Pacific spreading ridges during middle and late Jurassic times, could explain the subsequent accretion of Tethyan terranes of southern origin along the western North

American margin (Alvarez *et al.* 1980; Jones *et al.* 1982; Debiche *et al.* 1987).

Field work was financially supported by the Institut Français d'Etudes Andines (Lima & Paris) and by the Institut Français de Recherche Scientifique pour le Développement en Coopération-ORSTOM (Lima & Paris). We thank L. Aguirre, J. A. Aspden and H. Colley for their careful and fruitful reviews and for having considerably improved the English of the text.

References

AGUIRRE, L. & OFFLER, R. 1985. Burial metamorphism in the Western Peruvian Trough, its relation to Andean magmatism and tectonics. *In*: PITCHER, W. S., ATHERTON, M. P., COBBING, E. J. & BECKINSALE, R. D. (eds) *Magmatism at a Plate Edge, the Peruvian Andes*. Blackie, Glasgow and Halsted Press, New York, 59–71.

ALVAREZ, W., KENT, D. V., PREMOLI SILVA, I., SCHWEICKERT, R. A. & LARSON, R. A. 1980. Franciscan Complex limestones deposited at 17° South paleolatitude. *Geological Society of America Bulletin*, **91**, 476–484.

ANDERSON, T. H. & SCHMIDT, V. A. 1983. The evolution of middle America and the Gulf of Mexico–Caribbean region during Mesozoic times. *Geological Society of America Bulletin*, **94**, 941–965.

ASPDEN, J. A. & MCCOURT, W. J. 1986. Mesozoic oceanic terrane in the Central Andes of Colombia. *Geology*, **14**, 415–418.

——, —— & BROOK, M. 1987. Geometrical control of subduction-related magmatism: the Mesozoic and Cenozoic plutonic history of Western Colombia. *Journal of the Geological Society, London*, **144**, 893–905.

ARTHAUD, F., MÉGARD, F. & SÉGURET, M. 1977. Cadre tectonique de quelques bassins sédimentaires. *Bulletin du Centre de Recherche, d'Exploration et de Production, Elf-Aquitaine*, **1**, 147–188, Pau.

ATHERTON, M. P., PITCHER, W. S. & WARDEN, V. 1983. The Mesozoic marginal basin of Central Peru. *Nature*, **305**, 303–306.

——, WARDEN, V & SANDERSON, L. M. 1985. The Mesozoic marginal basin of Central Peru: a geochemical study of within-plate-edge volcanism. *In*: PITCHER, W. S., ATHERTON, M. P., COBBING, E. J. & BECKINSALE, R. D. (eds) *Magmatism at a Plate Edge, the Peruvian Andes*. Blackie, Glasgow and Halsted Press, New York, 47–58.

AUDEBAUD, E., CAPDEVILA, R., DALMAYRAC, B., DEBELMAS, J., LAUBACHER, G., LEFÈVRE, C., MAROCCO, R., MARTINEZ, C., MATTAUER, M., MÉGARD, F., PAREDES, J. & TOMASI, P. 1973. Les traits géologiques essentiels des Andes centrales (Pérou, Bolivie). *Revue de géographie physique et de géologie dynamique*, (2), **15**, 73–113.

——, LAUBACHER, G. & MAROCCO, R. 1976. Coupe géologique des Andes du Sud du Pérou de l'Océan Pacifique au Bouclier Brésilien. *Geologische Rundschau*, **65**, 223–264.

BALDOCK, J. W. 1982. *Geologia del Ecuador*. Direccion General de Geologia y Minas, Quito.

BATTY, M. & JAILLARD, E. 1989. La sedimentación neocomiana (Jurásico terminal – Aptiano) en el Sur del Perú. *Contribuciones de los simposios sobre el Cretácico de América latina*, Buenos-Aires 1989, Part A.

BECK, M. E. JR 1988. Analysis of Late Jurassic-Recent paleomagnetic data from active plate margins of South America. *Journal of South American Earth Sciences*, **1**, 39–52.

BECKINSALE, R. D., SANCHEZ-FERNANDEZ, A. W., BROOK, M., COBBING, E. J., TAYLOR, W. P. & MOORE, N. D. 1985. Rb-Sr whole-rock isochron and K-Ar age determinations for the Coastal Batholith of Peru. *In*: PITCHER, W. S., ATHERTON, M. P., COBBING, E. J. & BECKINSALE, R. D. (eds) *Magmatism at a Plate Edge, the Peruvian Andes*. Blackie, Glasgow and Halsted Press, New York, 177–202.

BELLIDO, E., 1956. Geología del curso medio del rio Huaytara, Huancavelica. *Boletín de la Sociedad geológica del Perú*, **30**, 33–47.

BENAVIDES, V. 1956. Cretaceous system in Northern Peru. *Bulletin of the American Museum of Natural History*, **108**, 352–494.

—— 1962. Estratigrafía pre-Terciaria de la región de Arequipa. *Boletín de la Sociedad geológica del Perú*, **38**, 5–63.

BERNOULLI, D. & LEMOINE, M. 1980. Birth and evolution of the Tethys: the overall situation *26th International Geological Congress*, Paris, Colloquy **C5**, 167–179.

BOILY, M., BROOKS, C. & JAMES, D. E. 1984. Geochemical characteristics of the late Mesozoic Andean volcanics. *In*: HARMON, R. S. & BARREIRO, B. A. (eds) *Andean magmatism: Chemical and isotopic constraints*. Shiva Press, Nantwich, England, 190–202.

BOINET, T., BOURGOIS, J., MENDOZA, H. & VARGAS, R. 1985. Le poinçon de Pamplona (Colombie): un jalon de la frontière méridionale de la plaque caraïbe. *Bulletin de la société géologique de France*, (8), I, **3**, 403–413.

BOURGOIS, J., TOUSSAINT, J. F., GONZALEZ, H., AZEMA, J., CALLE, B., DESMET, A., MURCIA, L. A., ACEVEDO, A. P., PARRA, E. & TOURNON, J. 1987. Geological history of the Cretaceous ophiolitic complexes of Northwestern South America (Colombian Andes). *Tectonophysics*, **143**, 307–327.

BRISTOW, C. R. & HOFFSTETTER, R. 1977. *Ecuador*. Lexique stratigraphique international, **5 a2**, C.N.R.S. Paris, 410 p.

CALDAS, J. 1978. *Geología de los cuadrángulos de San Juan, Acari y Yauca*. Instituto de Geología Minería y Metalurgía, Lima, Boletín **30 (A)**.

CANFIELD, R. W., BONILLA, G. & ROBBINS, R. K. 1982. Sacha oil field of Ecuadorian Oriente. *American Association of Petroleum Geologists Bulletin*, **66**, 1076–1090.

CARLIER, G., GRANDIN, G., LAUBACHER, G., MAROCCO, R. & MÉGARD, F. 1982. Present knowledge of the magmatic evolution of the Eastern Cordillera of Peru. *Earth Sciences Review*, **18**, 253–283.

COBBING, E. J., PITCHER, W. S., WILSON, J. J., BALDOCK, J. W., TAYLOR, W. P., MCCOURT, W. & SNELLING, N. J. 1981. *The geology of the Western Cordillera of Northern Peru*. Institute of Geological Sciences, Overseas Memoir, **5**, London.

CROSS, T. A. & PILGER, R. H. 1982. Controls of subduction, location of magmatic arcs, and tectonics of arc and back-arc regions. *Geological Society of America Bulletin*, **93**, 545–562.

DALMAYRAC, B., LAUBACHER, G. & MAROCCO, R. 1980. *Géologie des Andes péruviennes*. Travaux et Documents de l'ORSTOM, 122, Paris.

DALZIEL, I. W. D. 1985. Collision and Cordilleran orogenesis: an Andean perspective. *In*: COWARD, M. P. & RIES, A. (eds) *Collision Tectonics*. Geological Society, London Special Publication, **19**, 389–404.

DEBICHE, H., COX, A. & ENGEBRETSON, D. 1987. *The motion of allochtonous terranes across the North Pacific Basin*. Special paper of the Geological Society of America **207**.

DILLES, J. H. & WRIGHT, J. E. 1988. The chronology of early Mesozoic arc magmatism in the Yerington district of Western Nevada and its regional implications. *Geological Society of America Bulletin*, **100**, 644–652.

DUNCAN, R. A. & HARGRAVES, R. B. 1984. Plate tectonic evolution of the Caribbean region in the mantle reference frame. *Memoir of the Geological Society of America*, **162**, 81–93.

EMERY, K. O. & UCHUPI, E. 1984. *The geology of the Atlantic Ocean*. Springer Verlag, New York.

FAUCHER, B. & SAVOYAT, E. 1973. Esquisse géologique des Andes de l'Equateur. *Revue de géographie physique et de géologie dynamique*, (2), **15**, 115–142.

FEININGER, T. 1982. The metamorphic 'basement' of Ecuador. *Geological Society of America Bulletin*, **93**, 87–92.

—— 1987. Allochtonous terranes in the Andes of Ecuador and Northern Peru. *Canadian Journal of Earth Sciences*, **24**, 266–278.

—— & BRISTOW, C. R. 1980. Cretaceous and Paleogene history of coastal Ecuador. *Geologische Rundschau*, **69**, 849–874.

GEYER, O. F. 1973. Das präkretazische Mesozoikim von Kolumbien. *Geologisches Jahrbuch*, **5**, 1–156.

—— 1974. Der Unterjura (Santiago Formation) von Ekuador. *Neues Jahrbuch für Geologie und Paläontologie*, **9**, 525–541.

——1982. Comparaciones estratigráficas y faciales en el Triásico norandino. *Geologia Norandina*, Bogotá, **5**, 27–31.

—— 1983. Obertithonische Ammoniten-Faunen von Peru. *Zeitblatt für Geologie und Paläontologie*, **1**, **(3/4)**, 335–350.

HALL, M. L. & CALLE, J. 1982. Geochronological control for the main tectonic-magmatic events of Ecuador. *Earth Sciences Review*, **18**, 215–239.

HANDSCHUMACHER, D. W., SAGER, W. W., HILDE, T. W. C & BRACEY, D. R. 1988. Pre-Cretaceous tectonic evolution of the Pacific Plate and extension of the geomagnetic polarity reversal time scale with implications for the origin of the Jurassic "Quiet zone". *In*: SCOTESE, C. R. & SAGER, W. W. (eds) Mesozoic and Cenozoic Plate reconstructions. *Tectonophysics*, **155**, 365–380.

HAO, B. U., HARDENBOL, J. & VAIL, P. R. 1987. Chronology of fluctuating sea levels since the Triassic. *Science*, **235**, 1156–1167.

HERZ, N. 1977. Timing of spreading in the South Atlantic: information from the Brazilian alkalic rocks. *Geological Society of America Bulletin*, **88**, 101–112.

HILDE, T. W. C., UYEDA, S. & KROENKE, L. 1977. Evolution of the Western Pacific margins. *Tectonophysics*, **38**, 145–165.

HILLEBRANDT, A. von 1981. Kontinentalverschiebung und die paläozoogeographischen Beziehungen des Südamerikanischen Lias. *Geologische Rundschau*, **70**, 570–582.

INGERSOLL, R. V. & SCHWEICKERT, R. A. 1986. A plate tectonic model for the late Jurassic ophiolite genesis. Nevadan orogeny and forearc initiation, Northern California. *Tectonics*, **5**, 901–912.

JAILLARD, E. & JACAY, J. 1989. Les "couches Chicama" du Nord du Pérou: Colmatage d'un bassin né d'une collision oblique au Tithonique.

Comptes rendus hebdomadaire des séances de l'Académie des Sciences de Paris, (II), **308**, 1459–1465.

JAMES, D. E. 1971. Plate tectonic model for the evolution of the Central Andes. *Geological Society of America Bulletin*, **82**, 3325–3346.

——, BROOKS, C. & CUYUBAMBA, A. 1975. Early evolution of the Central Andean tectonic arc. *Carnegie Institution Yearbook*, **74**, 247–250.

JONES, D. E., SILBERLING, N. J., WYATT, G. & CONEY, P. 1982. Charactér, distribution, and tectonic significance of accretionary terranes in the Central Alaska Range. *Journal of Geophysical Research*, **87**, B5, 3709–3717.

KENNERLEY, J. B. 1980. Outline of the geology of Ecuador. *Overseas Geological and Mineral Resources*, **55**, 1–16, London.

KLINCK, B. A., ELLISON, R. A. & HAWKINS, M. P. 1986. *The geology of the Cordillera occidental and Altiplano, West of the Lake Titicaca, Southern Peru.* Instituto de Geologia, Minería y Metalurgía, Lima, preliminary Report.

KLITGORD, K. D. & SCHOUTEN, H. 1986. Plate kinematics of the Central Atlantic. *In*: VOGT, P. R. & TUCHOLKE, B. E. (eds) *The Geology of North America, The Western North Atlantic regions.* Memoir of the Geological Society of America, 351–378.

KONTAK, D. J. 1984. *The magmatic and metallogenic evolution of a Craton-Orogen interface: The Cordillera of Carabaya, Central Andes, SE Peru.* PhD thesis Queen's University of Kingston, Ontario.

——, CLARCK, A. H., FARRAR, E. & STRONG, D. F. 1985. The rift-associated Permo-Triassic magmatism of the Eastern Cordillera: a precursor of the Andean orogeny. *In*: PITCHER, W. S., ATHERTON, M. P., COBBING, E. J. & BECKINSALE, R. D. (eds) *Magmatism at a Plate Edge, the Peruvian Andes.* Blackie, Glasgow, and Halsted Press, New York, 36–44.

KUMMEL, B. 1948. Geological reconnaissance of the Contamana region, Peru. *Geological Society of America Bulletin*, **59**, 1217–1226.

—— & FUCHS, R. L. 1953. The Triassic of South America. *Boletin de la Sociedad geologica del Peru*, **26**, 95–120.

LAUBACHER, G. 1978. *Géologie de la Cordillère orientale et de l'Altiplano au Nord et Nord-Ouest du Lac Titicaca (Pérou).* Travaux et Documents de l'ORSTOM **95**, Paris

LAURENT, H. 1985. El Pre-Cretáceo en el Oriente peruano: su distribución y sus rasgos estructurales. *Boletín de la Sociedad geológica del Perú*, **74**, 33–59.

LEMOINE, M., BAS, T., ARNAUD-VANNEAU, A., ARNAUD, H., DUMONT, T., GIDON, M., BOURBON, M., de GRACIANSKY, P. C., RUDKIEWICZ, J. L., MÉGARD-GALLI, J. & TRICART, P. 1986. The continental margin of the Mesozoic Tethys in the Western Alps. *Marine and Petroleum Geology*, **3**, 179–200.

LOUGHMAN, D. L. & HALLAM, A. 1982. A facies analysis of the Pucara group (Norian to Toarcian carbonates, organic-rich shales and phosphates) of Central and Northern Peru. *Sedimentary Geology*, **32**, 161–194.

MACIA, C. & MOJICA, J. 1981. Nuevos Puntos de vista sobre el magmatismo Triásico superior (Fm Saldaña), Valle superior del Magdalena, Colombia. *Zeitblatt für Geologie und Paläontologie*, **1**, 243–251.

——, —— & COLMENARES, F. 1985. Consideraciones sobre la importancia de la paleogeografía y las áreas de aporte precretácicas en la prospección de hidrocárburos en el Valle superior del Magdalena, Colombia. *Geología Colombiana*, **14**, 49–70.

MARCOUX, J., MASCLE, G. & CUIF, J. P. 1982. Existence de marqueurs bio-sédimentaires et structuraux téthysiens issus de la marge Gondwanienne à la bordure ouest-américaine: implications paléogéographiques et paléobiologiques. *Bulletin de la sociéte géologique de France*, (7), **24**, 971–980.

MARESCH, W. V. 1983. The Northern Andes. *In*: MOULLADE, M. & NAIRN, A. E. M. (eds) *The Phanerozoic geology of the world, II. The Mesozoic, B.*, Elsevier, Amsterdam, 121–149.

MARTINEZ, C. 1980. *Structure et évolution de la chaine hercynienne et de la chaine andine dans le Nord de la Cordillère des Andes de Bolivie.* Travaux et Documents de l'ORSTOM, **119**, Paris.

MCBRIDE, S. L. 1977. *A K–Ar study of the Cordillera Real, Bolivia, and its regional setting.* PhD thesis, Queen's University of Kingston, Ontario.

MCCOURT, W. J., ASPDEN, J. A. & BROOK, M. 1984. New geological and geochronological data from the Colombian Andes: continental growth by multiple accretion. *Journal of the Geological Society, London*, **141**, 831–845.

MÉGARD, F. 1968. *Geología del cuadrángulo de Huancayo.* Boletín del Servicio de Geología y Minería, **18**, Lima.

—— 1978. *Etude géologique des Andes du Pérou Central.* Mémoire de l'ORSTOM, **86**, Paris.

—— 1987. Cordilleran and marginal Andes: a review of Andean geology North of the Arica elbow (18°S). *In*: MONGER, J. W. H. & FRANCHETEAU, J. (eds) *Circum-Pacific belts and evolution of the Pacific ocean basin.* American Geophysical Union, Geodynamic series, **18**, 71–95.

MOJICA, J. & LLINAS, R. 1984. Observaciones recientes sobre las características del basamento económico del Valle superior del Magdalena en la región de Payandé-Rovira (Tolima, Colombia), y en especial sobre la estratigrafía y petrografía del miembro Chicala. *Geología Colombiana*, **13**, 81–128.

—— & DORADO, J. 1987. El Jurásico anterior a los movimientos intermálmicos en los Andes Colombianos. *In*: VOLKHEIMER, W. & MUSACCHIO, E. (eds) *Bioestratigrafía de los sistemas Regionales del Jurásico y Cretácico de América del Sur.* 1: *El Jurásico anterior a los movimientos intermálmicos*, 49–110, Mendoza.

MOONEY, W. D. 1980. An East-Caribbean ridge during the Jurassic and the Cretaceous, and the Western Colombia. *In*: PILGER, R. J. (ed.) *The origin of the Gulf of Mexico and the opening of the Central North Atlantic Ocean.* Louisiana State University, Baton Rouge, 55–73.

MOULIN, N. 1989. *Faciès et séquences de dépôt de la plate-forme du Jurassique moyen à l'Albien, et une coupe structurale des Andes du Pérou central.* Thesis of the Montpellier University.

MOURIER, T., MÉGARD, F., PARDO, A. & REYES, L. 1988a. L'évolution méosozoïque des Andes de Huancabamba (3°–8°S) et l'hypothèse de l'accrétion du microcontinent Amotape-Tahuin. *Bulletin de la Société géologique de France*, (8), **4**, 69–79.

——, LAJ, C., MÉGARD, F., ROPERC'H, P., MITOUARD, P. & FARFAN-MEDRANO, A. 1988b. An accreted continental terrane in Northwestern Peru. *Earth and Planetary Science letters*, **88**, 182–192.

MUKASA, S. B. 1986. Zircon U–Pb ages of super-units in the coastal Batholith, Peru. *Geological Society of America Bulletin*, **58**, 241–254.

—— & TILTON, G. R. 1985. Zircon U–Pb ages of super-units in the Coastal Batholith, Peru. *In*: PITCHER, W. S., ATHERTON, M. P., COBBING, E. J. & BECKINSALE, R. D. (eds) *Magmatism at a Plate Edge, the Peruvian Andes.* Blackie, Glasgow and Halsted Press, New York, 203–205.

NEWELL, N. D. 1949. Geology of the lake Titicaca region, Peru and Bolivia. *Memoir of the Geological Society of America*, **36**, 111 pp.

OJEDA, H. A. O. 1982. Structural framework, stratigraphy, and evolution of the Brazilian marginal basins. *American Association of Petroleum Geologists Bulletin*, **66**, 732–749.

OLCHAUSKI, L. E. 1980. *Geología de los cuadrángulos de Jaqui, Coracora, Chala y Chaparra.* Boletín del Instituto de Geología, Minería y Metalurgía, **34 (A)**, Lima.

OLIVET, J. L., BONNIN, J., BEUZAT, P. & AUZENDE, J. M. 1984. *Cinématique de l'Atlantique Nord et Central.* Rapport scientifique du Centre National d'Exploration des Océans, **54**, Brest.

PALACIOS, O. 1980. El grupo Pucara en la región subandina (Perú Central). *Boletín de la Sociedad geológica del Perú*, **67**, 153–162.

PARDO, A. & SANZ, V. 1979. Estratigrafía del curso medio del rio la Leche. *Boletín de la Sociedad geológica del Perú*, **60**, 251–266.

—— & ZUÑIGA, F. 1976. Estratigrafía y evolución tectónica de la región de la Selva del Perú. *2ndo Congreso Latinoamericano de Geología*, Caracas 1973, **2**, 569–608.

PECHO, V. 1981. *Geología de los cuadrángulos de Chalhuanca, Antabamba y Santo Tomas.* Boletín del Instituto de Geología, Minería y Metalurgía, **35 (A)**, Lima.

PINDELL, J. & DEWEY, J. F. 1982. Permo-Triassic reconstruction of Western Pangea and the evolution of the Gulf of Mexico-Caribbean region. *Tectonics*, **1**, 179–211.

PORTUGAL, J. 1974. Mesozoic and Cenozoic stratigraphy and tectonic events of Puno- Santa Lucia Area, Department of Puno, Peru. *American Association of Petroleum Geologists Bulletin*, **58**, 982–999.

—— & GORDON, L. 1976. Geologic history of Southern Peru. *2ndo Congreso Latinoamericano de Geología*, Caracas 1973, **2**, 789–819.

PRINZ, P. 1985. Stratigraphie und Ammonitenfauna der Pucara-Gruppe (Obertrias-Unterjura) von Nord-Peru. *Palaeontographica A*, **188**, 153–197.

RESTREPO, J. J & TOUSSAINT, J. F. 1988. Terrane and continental accretion in the Colombian Andes. *Episodes*, **11**, 189–193.

REYES, L. & CALDAS, J. 1987. *Geología de los cuadrángulos de Las Playas, La Tina, Las Lomas, Ayabaca, San Antonio, Chulucanas, Morropón, Huancabamba, Olmos y Pomahuaca.* Boletín del Instituto de Geología, Minería y Metalurgía, **39 (A)**, Lima.

RICCARDI, A. C. 1983. *The Jurassic of Argentina and Chile. In*: MOULLADE, M. & NAIRN, A. E. (eds) *The Phanerozoic geology of the World, II; The Mesozoic, B.* Elsevier, Amsterdam, 201–263.

RIVERA, R., PETERSEN, G. & RIVERA, M. 1975. Estratigrafía de la Costa de Lima. *Boletín de la Sociedad geológica del Perú*, **45**, 159–196.

ROPERC'H, P., MÉGARD, F., LAJ, C., MOURIER, T., CLUBE, T. & NOBLET, C. 1987. Rotated oceanic blocks in Western Ecuador. *Geophysical Research Letters*, **14**, 558–561.

ROSS, M. I. & SCOTESE, C. R. 1988. A hierarchical tectonic model of the Gulf of Mexico and Caribbean region. *In*: SCOTESE, C. R. & SAGER, W. W.

(eds) Mesozoic and Cenozoic Plate reconstructions. *Tectonophysics*, **155**, 139–169.
RÜEGG, W. 1956. Geologie zwischen Cañete-San Juan, 13°00′–15°24′, SüdPeru. *Geologische Rundschau*, **45**, 775–858.
—— 1961. Hallazgo y posición estratigráfico-tectónica del Titoniano en la costa sur del Perú. *Boletín de la Sociedad geológica del Perú*. **36**, 203–208.
SAVOSTIN, L. A., SIBUET, J. C., ZONENSHAIN, L. P., LE PICHON, X. & ROULET, M. J. 1986. Kinematic evolution of the Tethys belt from the Atlantic ocean to the Pamirs since the Triassic. *Tectonophysics*, **123**, 1–35.
SCHWEICKERT, R. A., BOGEN, N. L., GIRTY, G. H., HANSON, R. E. & MERGUERIAN, C. 1984. Timing and structural expression of the Nevadan orogeny, Sierra Nevada, California. *Geological Society of America Bulletin*, **95**, 967–979.
SEMINARIO, F. & GUIZADO, J. 1976. Sintesis bioestratigráfica de la región de la Selva del Perú. *2ndo Congreso Latinoamericano de Geología*, Caracas 1973, **2**, 881–898.
SIBUET, J. C., HAY, W. V., PRUNIER, A., MONTADERT, L., HINZ, K. & FRITSCH, J. 1985. Early evolution of the South Atlantic Ocean: role of the rifting episode. *Initial Report of Deep Sea Drilling Project*. Washington DC, US government Printing Office, **75**, 469–481.
SILLITOE, R. H. 1988. Epochs of intrusion-related copper mineralization in the Andes. *Journal of South American Earth Sciences*, **1**, 89–108.
SOLER, P. & BONHOMME, M. 1989. Relations of magmatic activity to plate dynamics in Central Peru from late Cretaceous to present. *In*: KAY, S. & RAPELA, C. (eds) *Plutonism from Antarctica to Alaska*, Special Paper of the Geological Society of America, **241**, in press.
STAPPENBECK, R. 1929. Geologie des Chicamatales in NordPeru und seine Anthrazitlagerstätten. *Geologie und Paläontologie Abhandlungen*, **16**, (4), 1–51.
STEPHAN, J. F., BECK, C., BELLIZIA, A. & BLANCHET, R. 1980. La Chaîne Caraïbe du Pacifique à l'Atlantique. *26th International Geological Congress*, Paris 1980, Colloquy **C5**, 38–59.
STEWART, J. W., EVERNDEN, J. F. & SNELLING, N. J. 1974. Age determinations from Andean Peru: a reconnaissance survey. *The Geological Society of America Bulletin*. **85**, 1107–1116.
SZEKELY, T. S. & GROSE, L. T. 1972. Stratigraphy of the carbonate, black shale, and phosphate of the Pucara group (Upper Triassic-Lower Jurassic), Central Andes, Peru. *Geological Society of America Bulletin*. **83**, 407–428.
THIERRY, J. 1982. Téthys, Mésogée et Atlantique au Jurassique: quelques réflexions basées sur les faunes d'Ammonites. *Bulletin de la Société géologique de France*, (7), **24**, 1053–1067.
TSCHOPP, H. J. 1953. Oil explorations in the Oriente of Ecuador. *American Association of Petroleum Geologists Bulletin*, **37**, 2302–2347.
UYEDA, S. & KANAMORI, H. 1979. Back-arc opening and the mode of subduction. *Journal of Geophysical Research*, **84**, B3, 1049–1061.
VICENTE, J. C. 1981. Elementos de la estratigrafía mesozóica surperuana. *In*: VOLKHEIMER, W. & MUSACCHIO, E. A. (eds) *Cuencas sedimentarias del Jurásico y Cretácico de América del Sur*, **1**, 319–351, Buenos-Aires.
VICENTE, J. C. 1985. Early late Cretaceous overthrusting in the Western Cordillera of Peru. *In*: Symposium *Geology of the Andes and its relations to energy and mineral deposits*, Santiago 1985. *Memoir of the American Association of Petroleum Geologists* (in press).
——, BEAUDOUIN, B., CHÁVEZ, A. & LEÓN, I. 1982. La cuenca de Arequipa (Sur Perú) durante el Jurásico-Cretácico inferior. *5to Congreso Latinoamericano de Geología*, Buenos-Aires 1981, **1**, 121–153.
WESTERMANN, G. E. G., RICCARDI, A. C., PALACIOS, O. & RANGEL, C. 1980 *Jurásico medio en el Perú*. Boletín del Instituto de Geología, Minería y Metalurgía, **9 (D)**, Lima.
WIEDMANN, J. 1981. El limite Jurásico-Cretácico: Problemas y soluciones. *1ero Congreso Latinoamericano de Paleontología*, Buenos-Aires 1978, Colloquio: Limite Jurásico-Cretácico, **5**, 103–119.
WILSON, J. J. 1963. Cretaceous stratigraphy of Central Andes of Peru. *American Association of Petroleum Geologists Bulletin*, **47**, 1–34.
WILSON, J. J. & REYES, L. 1964. *Geología del cuadrángulo de Pataz*. Boletín del Instituto de Geología, Minería y Metalurgía, **9 (A)**, Lima.
WRIGHT, J. E. & FAHAN, M. R. 1988. An expanded view of Jurassic orogenesis in the Western United States Cordillera: Middle Jurassic (pre-Nevadan) regional metamorphism and thrust faulting within an active arc environment, Klamath mountains, California. *Geological Society of America Bulletin*, **100**, 859–876.
ZAMBRANO, J. J. 1978. Cuencas sedimentarias de la parte austral del Continente Sudamericano: Esquema preliminar de su evolución a fines del Jurásico y comienzons del Cretácico. *2ndo Congreso argentino de Paleontología y Biostratigrafía*, Buenos-Aires, **5**, 15–40.
ZIEGLER, P. A. 1988. *Evolution of the Arctic-North Atlantic and the Western Tethys*. Memoir of the American Association of Petroleum Geologists, **43**.

Received 16 June 1989; revised typescript accepted 31 January 1990.