Journal of Structural Geology, Vol. 3, No. 4, pp. 459 to 465, 1981.
Printed in Great Britain

0191-8141/81/040459-07 $02.00/0
Pergamon Press Ltd.

Reactivated Tibetan block in a Tethyan context

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(*Received* 19 *September* 1980; *accepted in revised form* 4 *April* 1981)

Abstract—The Tibetan block originated during the late Palaeozoic-early Mesozoic by separation from Gondwanic India and the opening of Neo-Tethys. The event, which was responsible for reactivating the Tibetan basement, closed Palaeo-Tethys, lying to the north of it, and created the Kun Lun fold system as a consequence of the collision of the north-moving Tibetan block with the Tarim–Tsaidam block.

During the late Cretaceous, South Tibet developed into an Andean-type foldbelt (Nyenchen Thangla) by subduction of Neo-Tethyan lithosphere beneath Tibet which had begun in the late Triassic. Mesozoic sedimentary sequences in Tibet are the response to an extensional regime behind an active margin. A Neo-Tethys island arc system at this margin was crushed during the early Eocene with the development of the Transhimalayan ophiolite and plutonic belts. Final collision during mid-Eocene times between the Himalayan microcontinent, a fragment of India and reworked Tibet in the Mid-Eocene produced the Indus–Tsangpo suture zone. A large part of the microcontinent, with an unconsumed segment of Neo-Tethys oceanic crust attached to it, presumably underthrust Tibet prior to the Himalayan orogeny. This feature is responsible for the double thickness of Tibetan crust and its young volcanism.

INTRODUCTION

TIBET is one of the most complex and little understood regions of Central Asia. Two especially significant features of the plateau are its average elevation (5 km) and the 70–80 km thickness of its continental crust which is double the normal thickness (Cummings & Schiller 1971). The high plateau region has traditionally been considered as the median mass between the Himalayas and the Central Asian fold belts (Holmes 1965). In recent years, with the availability of some, but inadequate, geological and geophysical data on Tibet, and with models of continental convergence zones (e.g. Dewey & Burke 1973, Toksöz & Bird 1977), several ideas about the origin of the Tibetan plateau have been proposed (e.g. Powell & Conaghan 1975). The complexity of Tibetan geology and tectonics, including its young volcanism, and the drawbacks of several models were discussed during the Penrose Conference on Tibet (Molnar & Burke 1977).

Tibet forms an integral part of the Asian geotectonic domain with a mainly south-directed polarity (Sinha-Roy 1978). The events which shaped the domain are linked with the evolution of Tibet because they reactivated it and significantly modified its margins. The purpose of this paper is to propose a tectonic evolutionary model for Tibet and surrounding regions.

REGIONAL GEOTECTONIC FRAMEWORK

In many discussions of Tethys, emphasis has been placed on the Mesozoic Period, but it is now generally believed that all the Palaeozoic orogenic systems of Eurasia display a Tethyan-related episode (Kamen-Kaye 1972). The eastward-widening Tethys in reconstructed Pangea (Bullard *et al.* 1965) is thought to comprise two oceans that are mutually exclusive, that is, a northern Palaeozoic Tethys and a southern Mesozoic Tethys called Palaeo-Tethys and Neo-Tethys respectively (Sinha-Roy 1978). Asian fold belts are the response to closure of these oceans at different times. The closure was not simply due to the existence of a number of continental blocks (Sinha-Roy 1978). Although most of these blocks are considerably reworked, the identifiable ones include Dzungaria (connected southeast with the Alashan–Inner Mongolia–Ordos block), Tarim–Tsaidam, Kang Tien, Nuristan–South Pamir (connected southwest with the Central Iran block), Tibet and Shan. The presence of blocks controlled sedimentary facies in adjacent troughs, oceans and subduction zones from the early Palaeozoic to the Early Cenozoic.

The geotectonic units surrounding Tibet are shown in Fig. 1. The Tarim–Tsaidam block, bounded by the prominent Altyn Tagh fault, was a stable landmass in Early Palaeozoic time (Chang 1963), and supplied sediments to the Tien Shan trough in the north and the Kun Lun trough in the south. The Tarim–Tsaidam block represents a possible fragment of the North China platform.

The Tarim block tapers out in the west as the western Kun Lun is superposed on the Atlai ranges of western Tien Shan. The arcuate south western margin of the Tarim block is partly enveloped by the Kun Lun fold belt. The Kara Kun Lun, forming the southern ranges of west central Kun Lun is the northern segment of western and central Tibet. The northeastern margin of Tibet merges with Bayan Kala which is the east-central segment of Kun Lun. Through a bifurcation of the Kun Lun fold belt to

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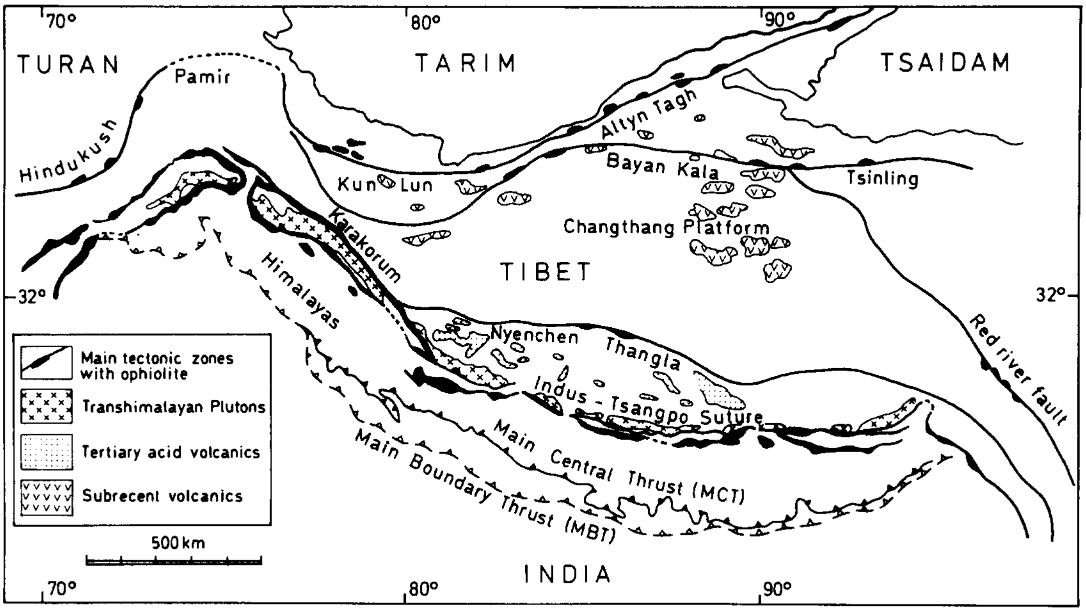

Fig. 1. Generalised geotectonic setting of the Tibetan plateau (modified after Gansser 1980 and the Geological Map of Asia, Chinese Academy of Geological Sciences 1976).

the west of the Kang Tien block and the Szechwan basin, the Tsinling fold belt extends eastwards and marks the collision junction between the North and South China platforms. The southern branch turns southeast around Kang Tien, and joins with the Mekong–Songma fold belt, whose major tectonic zone is the Red River fault.

The southern fold belt of the Tibetan plateau is the Nyenchen Thangla, which merges with the Karakorum in the west. The Bhamo–Myitkyinia fold belt of northeast Burma continues into the Nyenchen Thangla through Nu Shan. The eastern part of the Tibetan plateau is thus bounded by the eastern Kun Lun–Mekong–Songma fold belt and the Nyenchen Thangla–Nu Shan fold belt. The Karakorum–Nyenchen Thangla fold belt is flanked to the south by the Indus–Tsangpo suture zone, and is followed by the Himalayan fold belt.

GEOLOGICAL AND TECTONIC SETTING OF TIBET

Apart from the central Changthang platform (Fig. 1), much of the Tibetan plateau, especially its margins, comprises fold belts with ophiolitic zones. The generalised geological maps (Fig. 2) of Asia indicate that during Early Palaeozoic time a large part of Tibet was either a positive area or a shallow platform in the east and west where Cambro-Ordovician shallow-water sequences are preserved (Chinese Academy of Geological Sciences 1976). This changed during the Late Palaeozoic, when linear sedimentary basins developed with extensive volcanism, especially in the southern and eastern areas. Huang (1960) reported thick Devonian and Carboniferous deposits with submarine volcanics from the Lhasa–Bomi fold belt, and

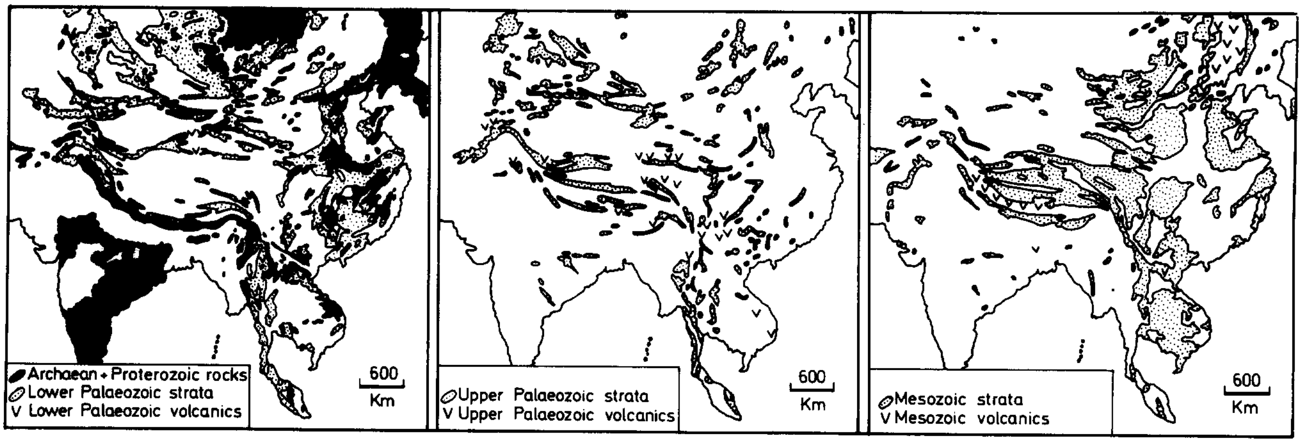

Fig. 2. Generalised distribution of Archaean to Mesozoic rocks in Asia (after the Geological Map of Asia, Chinese Academy of Geological Sciences 1976 and Geological Map of Asia and the Far East, ECAFE 1971).

suggested a Hercynian core for the Tibetan plateau.

The Mesozoic geology of central Tibet is dominated by widespread shallow-marine sediments. The eastern part of the plateau contains well developed Middle and Upper Triassic 'flyschoid' sequences intercalated with mafic, intermediate and silicic volcanics (Chinese Academy of Geological Sciences 1976). In general, Jurassic and Cretaceous sequences comprise shallow-marine sandstones and limestones. Post-Cretaceous uplift of the plateau was accompanied by Cenozoic and Subrecent volcanism over extensive areas (90,000 km^2, Gansser 1980) of the Changthang platform.

A complex of plutonic activity is recognised in Tibet, the eastern part of the Chinhai–Tibet plateau comprising granite and diorite plutons (230–190 Ma, K-Ar) intruding Triassic rocks. The early Yenshanian (190–150 Ma, K-Ar) biotite-granites, granodiorites and diorites are intruded into Jurassic sequences, and these are transgressively overlain by Cretaceous strata. Late Yenshanian (130–80 Ma, K-Ar) biotite-granite, granodiorite and monzonite plutons intruding Jurassic and Lower-Middle Cretaceous strata are common in the east and south of Tibet. Some of the ultramafic rocks of north Tibet could belong to the Late Yenshanian reactivation phase.

The Changthang platform is cut by a number of fault zones containing ultramafic bodies (Gansser 1980), mainly serpentinites. These bodies occur within Palaeozoic and Mesozoic sequences, and are considered to represent ophiolite complexes (Chang & Cheng 1973).

The northern margin of Tibet merges, through the Sungpan–Kantze and the Sinkiang fold belts, with the Kun Lun system. Late Triassic (Indosinian, Chinese Academy of Geological Sciences 1976) tectonic units in northern Tibet correspond with and continue into the comparable tectonic zones in the Yunnan and the Mekong–Songma belt of Southeast Asia. Stöcklin (1980) indicated the continuity of this belt through the northern Pamir, western Hindukush and northern Afghanistan into Kopet Dagh, and suggested a tectonic correlation between Central Iran and Tibet. The southern fold belt of Tibet, that is the Nyenchen Thangla (32°N fold belt, Molnar & Tapponnier 1978), located to the north of the Transhimalayan plutonic belt is characterised by widely distributed (900 km^2) Palaeogene and younger calc-alkaline volcanics (Gansser 1980), which include liparites, dacites, latites, andesites and granophyres with ignimbrites (Hedin 1916). Late Mesozoic ophiolites containing serpentinites and blueschists are reported from this fold belt (Chang & Cheng 1973).

Post-Cretaceous deformation is restricted to narrow zones. Although the Mesozoic cover sequences are flat-lying and little deformed in central and northern Tibet (Burke *et al.* 1974, Norin 1946), the Cretaceous limestones of southern Tibet are tightly folded (Molnar & Burke 1977). Old structural trends are mainly E–W and the deformation seems to be particularly strong in the western and eastern parts of the plateau. The folding of the Mesozoic strata pre-dates the young volcanic sequences (Sengör & Kidd 1979). The most recent structures are normal faults that trend approximately north-south. In contrast to Late Cenozoic to Recent extensional graben structures in the high plateau region, thrust faults dominate at lower elevations on the flanks of the plateau (Ni & York 1978). The large-scale strike–slip faults, characteristic features of Central Asian tectonics, do not affect Tibet (Molnar & Tapponnier 1978). Of these strike–slip faults, the Altyn Tagh fault borders Tibet in the north, while the Kun Lun and the Kang Tien faults branch from the plateau.

EVOLUTION OF TIBET

Although various models have been proposed for the tectonic evolution of the Tibetan plateau, the paucity of geologic information and the complexity of development are responsible for a lack of consensus among workers. Despite this, the models aim at explaining the principal features, namely the high elevation of the plateau, its thick crust, the young volcanism and the Late Cenozoic to Recent tectonic features. It is generally accepted that the tectonic characteristics of Tibet and its uplift are linked with convergence between India and Asia. Dewey & Burke (1973) suggested a basement reactivation model in which an Andean-type Asian margin collided with India. To accommodate further plate convergence, a hot Tibet shortened with resultant crustal thickening and partial melting of the lower crust. At a later time, active convergence between India and Eurasia did not apparently cause crustal shortening in Tibet, but instead resulted in strike–slip faulting along its margin (Molnar & Tapponnier 1978). Sengör (1979) and Sengör & Kidd (1979) interpreted the entire pre-Jurassic basement of Tibet as a giant accretionary mélange prism that was hit by India during the Himalayan collision. Based on ophiolite and granodiorite occurrences and on south-younging isotopic events, Chang & Cheng (1973) suggested sequential subduction and Phanerozoic collisional tectonics in Tibet. Following the concept of underthrusting of India beneath Asia (Holmes 1965), Powell & Conaghan (1975) suggested post-collisional (post-Oligocene) large-scale continental underthrusting of Greater India (Veevers *et al.* 1975), resulting in the double thickness of the Tibetan crust.

It appears that the evolution of Tibet is linked with the sequence of events leading to the opening and closing of the Tethys ocean. The episodic closure of Palaeo-Tethys through interactions between the blocks of Dzungaria, Tarim–Tsaidam and the major Eurasian plate gave rise to the Altai–Khingan and the Tien Shan fold belts (Sinha-Roy 1978). The final closure of Palaeo-Tethys took place along the southern Kun Lun through interactions between the blocks of Tarim–Tsaidam and Tibet. During the Late Cenozoic, the orogenic deformation reached the Himalayas across Tibet by the consumption of Neo-Tethys, and the reactivation of Tibet. The model of Tibetan evolution which follows takes into account these inferences and the known geologic/tectonic features of the plateau and adjoining areas (Fig. 3).

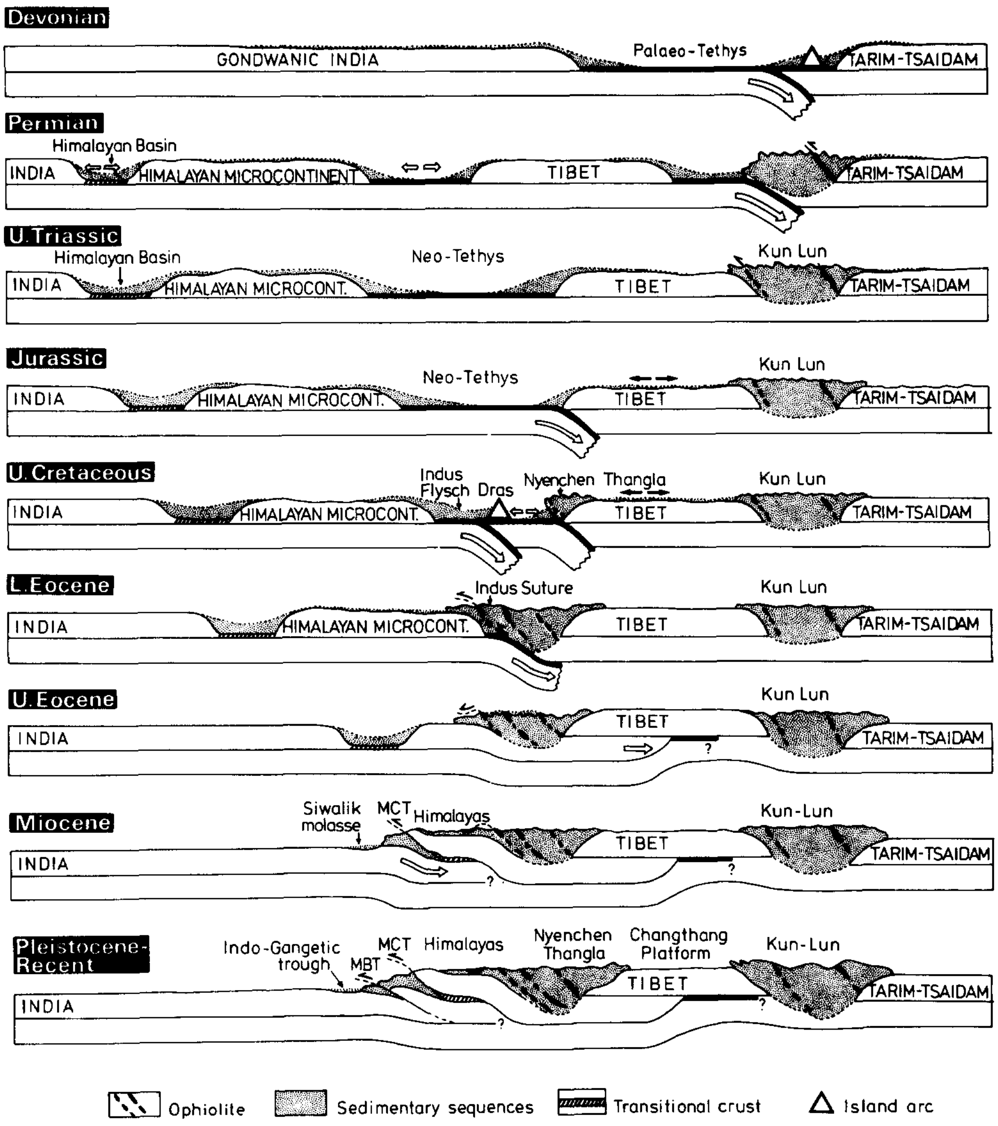

Fig. 3. Cartoon showing the evolution of Tibet and adjoining fold belts.

Most of the existing models consider Tibet as being underlain by continental basement and as part of Eurasia. Alternatively it has been suggested that Tibet is a fragment of Gondwanic India (Crawford 1974, Stoneley 1974, Sinha-Roy 1976a). Thus Tibet may be correlated with Central Iran which is a rifted segment of the Arabian plate (Stöcklin 1977), and with the Shan plateau, possibly another fragment of India (Sinha-Roy 1978). In these interpretations the continental fragments represent microcontinents, located between Neo-Tethys and the remnants of Palaeo-Tethys, and they comprised parts of the Cimmerian continent (Sengör 1979). Middle-Upper Palaeozoic floral and faunal (especially tetrapods) distributions in the Tethyan domain and Gondwana continents indicate a former continuity of these continental fragments with the Indo-Arabian shield. These, together with the platform facies of the sedimentary sequences, suggest that Neo-Tethys was shallow during the Middle and Late Palaeozoic (Konno 1963, Simpson 1970, Sun 1972).

The closing of southern Palaeo-Tethys commenced in Late Ordovician to Early Silurian times. Judging from the flysch prism in north Kun Lun, Altyn Tagh and Tsinling, and from the widespread rhyolite, keratophyre and spilitic volcanism in Altyn Tagh, Bayan Kala and Tsilling (Sung 1963), an Early Palaeozoic island arc system appears to have developed to the south of the Tarim–Tsaidam block. Granite and granodiorite plutons within the interior parts of the fold belt, and Middle Devonian basalts of possible marginal basins are consistent with a north-dipping subduction of Palaeo-Tethys. A strong deformation in the Late Devonian to Early Carboniferous, associated with volcanism and ophiolite emplacement (Markovski 1972) may have been caused by crushing of the island arc and its back-arc basins against Tarim–Tsaidam. The Lower Palaeozoic island-arc setting of the Kun Lun can be traced to the west of Kang Tien and Szechuan where extensive Permian basalts and andesites are probably related to Palaeo-Tethys subduction and back-arc spreading (Fan 1978).

Middle Palaeozoic tectonics in the Palaeo-Tethys domain are linked with an extensive Devonian regression in the shallow marine areas that covered the Transhimalayan regions, and with deformation and volcanism in Tibet. This deformation was possibly responsible for the initiation of the Hercynian consolidation of Tibet. A submarine mafic volcanic suite, associated with the thick arenaceous and argillaceous sedimentary sequences of west Yunnan, indicate that opening of Neo-Tethys and accretion of oceanic crust in the east began during the Late Devonian. Extension at the northern margin of Gondwanic India began during the Late Carboniferous with the extrusion of mafic and intermediate volcanics which are associated with the conglomerate and sandstone sequences of Nyenchen Thangla (Chang 1963) and Karakorum (Norin 1946, Desio 1964). This volcanic activity was related to the opening of Neo-Tethys, a process that continued through the Permian into the Triassic. As a result of the generation of Neo-Tethys, Tibet assumed the status of a separate continental block that moved northwards as Palaeo-Tethys closed. By Late Triassic time, Paleo-Tethys disappeared with the development of the Kun Lun fold belt; the final closure is marked by the southern ophiolite belt of the Kun Lun and the Red River suture. The northern and eastern parts of Tibet were involved in Early Mesozoic tectonism (e.g. the Chinshakiang fault zone, Stöcklin 1980) that affected the basement rocks in which deformation and metamorphism are pre-Devonian and, in places, Precambrian (Sengör & Kidd 1979).

The geology of the Himalayan and Transhimalayan regions indicates that Neo-Tethys was separated from an elongate Palaeozoic to Mesozoic Himalayan sedimentary basin by a crystalline barrier (Saxena 1971). The development of the Himalayan basin is contemporaneous with, and probably linked to, the opening of Neo-Tethys, and is one consequence of the rifting of India. These processes led to the generation of transitional crust in the Himalayan rift basin (Sinha-Roy & Furnes 1978, 1980), and to the creation of a Himalayan microcontinent (Sinha-Roy 1976b) which was a part of the Indian plate.

The spreading of Neo-Tethys ceased in Late Triassic time when Tibet was welded with Tarim-Tsaidam along the Kun Lun. By the Late Triassic to Early Jurassic a convergent plate boundary was established at the southern margin of Tibet. Thick (3 km) Late Triassic clastic sequences and andesite volcanics in southern Tibet, the folding of Upper Palaeozoic and Lower Triassic rocks in Nu Shan (SE Tibet) (Chang 1963), the deposition of the Upper Triassic Urdok Conglomerate in Karakorum (Desio 1974), and an abrupt sediment facies reversal from shelf-carbonates to continental clastics in south Pamir, were the initial responses to the formation of an Andean-type southern margin in Tibet. Neo-Tethys subduction beneath Tibet in the Jurassic caused silicic magmatism and extensional tectonics beneath a major part of Tibet, where fault-bounded Jurassic continental basins developed. The subduction continued through the Cretaceous when flysch wedges developed in south Karakorum, profuse rhyolitic, andesitic and basaltic volcanism (the Lin Tzung volcanics) and granite–granodioritic plutonism took place in Tibet. These events culminated in Late Cretaceous times in the creation of an Andean-type fold belt (Nyenchen Thangla) in southern Tibet. This fold belt, containing the northern ophiolite-mélange sequences of southern Tethys (Stoneley 1974), extends from the Makran through Chaman, Chitral, Skardu–Shigar and Nyenchen Thangla into the Bhamo–Myitkyina of Burma (Sinha-Roy 1979). Cretaceous sedimentation in the interior parts of Tibet took place over a wide area north of the evolving Andean-type fold belt.

Neo-Tethys subduction stepped to the south in the Late Cretaceous and, as a result, a new subduction system developed. This system is represented by the sedimentary sequences of the Indus flysch and the volcanic suite of the Dras (Frank *et al.* 1977) and Kohistan (Coward *et al.* 1980). Late Cretaceous oceanic crust generated in the back-arc basins was obducted when, in Early Eocene time, the island arc system was crushed against the Andean-type Tibetan margin. The ophiolite suite of Dras and Kohistan is the northern belt of the paired ophiolite belt of the Transhimalayas (Gansser 1980). The reworking of the Tibetan margin was responsible for the strong deformation exhibited by the Cretaceous sequences of southern Tibet. By Early-Middle Eocene times the remaining part of the Neo-Tethys crust had been subducted and collision of the Himalayan microcontinent with the marginal fold belt of Tibet had occurred. During the same episode the Indus–Tsangpo ophiolite-mélange (Gansser 1964) was formed, ophiolite nappes were thrust to the south, and the plutonic belt of Swat, Ladakh and Tsangpo had developed.

Although significant underthrusting of continental lithosphere may normally be constrained by buoyancy (McKenzie 1969) it seems, at least in the case of convergence between India and Tibet, that continued northwards movement of the Indian plate after collision resulted in dragging of the Himalayan microcontinent along a pre-existing subduction zone beneath southern Tibet in Middle-Upper Eocene times. This caused uplift of the Transhimalayas and southern Tibet. This event was associated with widespread transgressive molasse (Kailas) deposition. By Late Eocene to Early Oligocene times, a large segment of the Himalayan microcontinent with possible remanents of unconsumed Neo-Tethys oceanic crust attached to it, was underthrust beneath Tibet as a flat-lying slab. This caused widespread volcanism over Tibet and regional uplift of the plateau.

The underthrusting of the Himalayan microcontinent and Neo-Tethys crust beneath Tibet slowed down, possibly as a consequence of Middle Oligocene jamming of the lithosphere at the northern end against the lower crust of the Kun Lun. This event coincided with a change in the direction of spreading in the Indian ocean from N–S to NE–SW at the time of anomaly 11 (Sclater & Fisher 1974). Continued movement of the Indian plate led to intracontinental underthrusting (Le Fort 1975, Bird 1978) which, during the Miocene, deformed the Himalayan basin and produced the Main Central Thrust (MCT Fig. 1) (Sinha-Roy 1980). This main phase of the Himalayan orogeny was responsible for the onset of Siwalik molasse deposition. The last phase of deformation in the Pleistocene generated the Main Boundary Thrust (MBT Fig. 1) as an additional intracontinental thrust which deforms the Neogene sediments including the molasse of the foreland. Clearly, the Himalayan orogeny *sensu stricto* and the uplift of the Himalayas post-date the uplift of the Tibetan plateau, as, for example, is reflected by the antecedent drainage pattern.

The present day high-heat flow regime of the Tibetan plateau is one of its poorly-understood features. It may be related to the thickening of the crust consequential upon Andean-type orogeny and to doubling of the continental crust through underplating. The restriction of recent volcanics to the central and northern parts of the plateau (Fig. 1) is a feature presumably related to the occurrence of unconsumed Neo-Tethys oceanic crust beneath the northern part of the Changthang platform.

CONCLUSIONS

Tibet is a part of Gondwanic India that rifted in Late Palaeozoic to Early Mesozoic times to create the Neo-Tethys ocean between Tibet and the Himalayan microcontinent, the latter being another rifted fragment of India. The Middle Palaeozoic tectonism preceding and accompanying the major extensional phase caused the Hercynian reactivation of Tibet. Northward drift of Tibet progressively closed the pre-existing Palaeo-Tethys ocean and produced the Kun Lun fold belt between the Tibet and Tarim–Tsaidam blocks. The last closure event in Late Triassic time was the emergence of the southern Kun Lun fold belt which forms the northern reactivated margin of Tibet.

Neo-Tethys closure began after fusion of Tibet with Kun Lun and proceeded in stages from the Late Triassic to the Early Eocene. As a response the southern margin of Tibet was reworked into the Late Cretaceous Andean-type Nyenchen Thangla fold belt, while the major part of the block was the site of deposition of continental to shallow-marine Mesozoic sedimentary sequences in fault-bounded basins. An island-arc system was crushed against the Andean-type margin prior to collision at the Indus–Tsangpo suture between the Himalayan microcontinent and the reworked Tibetan margin. Continued movement of the Indian plate during the Eocene and Oligocene caused large-scale underthrusting of the Himalayan microcontinent with remanents of unconsumed Neo-Tethys crust remaining attached to it beneath Tibet. The uplift of Tibet thus preceded the uplift of the Himalayas, the latter being a Miocene to Pleistocene event caused by at least two phases of intracontinental underthrusting.

Acknowledgements—The presentation of this paper was considerably improved by J. F. Dewey, P. L. Hancock and B. A. Sturt. NTNF is thanked for a Fellowship.

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