Deformation phases and tectonic evolution
of the Lhasa block
(southern Tibet, China)

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ABSTRACT

We describe the deformations which affected the Lhasa block, north of the Tsangpo suture zone (southern Tibet, China). Two subzones with different paleogeographic, tectonic and metamorphic histories can be separated. Their evolutions and the implications for the development of the Himalayas are discussed.

RÉSUMÉ

Peu d'informations ont été jusqu'à présent publiées sur la géologie des régions situées au nord de la suture du Tsangpo, au Sud Tibet (République populaire de Chine). Nous décrivons rapidement les séries que l'on y rencontre et surtout les déformations qu'elles ont subi. Deux domaines diffèrent par leurs caractères paléogéographiques, tectoniques et métamorphiques. Leurs évolutions respectives et les implications qu'elles ont sur l'évolution de la chaîne Himalayenne sont discutées.

Introduction

The 2500 km long Indus-Tsangpo suture zone, which lies north of the High Himalayas, has been widely recognized as the trace of an ocean which separated the Indian continent from Asia in pre-Cenozoic times (Gansser 1977, 1980; Chang et al. 1977). Only in the northwestern Himalaya of India and Pakistan are the suture zone and the continental margins on either sides exposed outside China. Also the series north of the suture, which are rather critical for understanding the development of the Himalayas have been hitherto poorly known to the western geologists. In the summers of 1980, 1981 and 1982 geological studies have been carried out north of the Tsangpo suture zone by a French-Chinese team in southern Tibet. We report the observations collected between 89°30′ and 91°30′ E up to 150 km north of Lhasa. This study is based upon structural sketch mapping of the area, concentrat-

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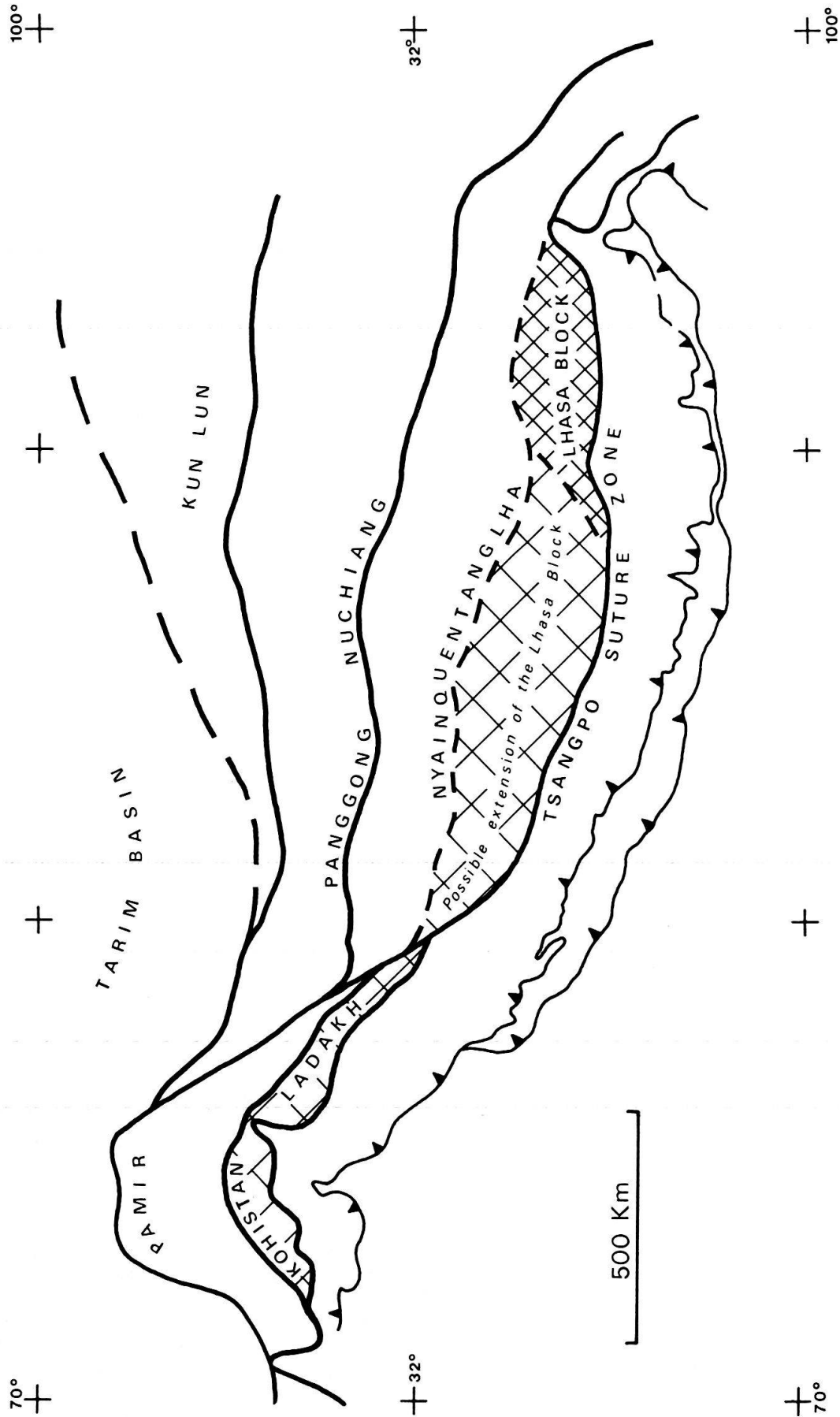
Fig. 1. Sketch map of the suture zones of Himalayas and Tibet. Situation of the Lhasa block.

ing on recording and analyzing the small scale structures along detailed cross sections. Pioneer work has been presented by HAYDEN (1907) and, since then, numerous informations have been obtained by the Chinese geologists.

The Lhasa block could be represented mainly in the eastern part of southern Tibet (Fig. 1) between about 89° and 95° E or may extend to the west up to the Ladakh area (Fig. 1); it is intruded at its southern edge by the Transhimalayan calc-alkaline plutonic belt (GANSSER 1981). The contact between the Lhasa block and the northern part of South Tibet is a major vertical east-west dextral strike slip fault perhaps running along an other suture zone. A simplified geological map of the area

Quaternary terraces	Jurassic and Triassic limestones of the northern domain
Unconformable conglomerates (Eocene?)	Triassic - Liassic flysch
Palaeocene series essentially ignimbritic lavas	Paleozoic
Cretaceous	Granitoids
Jurassic	Amphibolites
Triassic containing volcanics (v)	Gneisses
Southward thrusts	Recent normal faults

Fig. 2. Tentative geological map of the studied area.

discussed here is presented on Figure 2 and an attempt of the upper Paleozoic to Cenozoic stratigraphy is schematically summarized on Figure 3.

The region can be conveniently divided into two major zones:
— the Lhasa block sensu stricto,
— the magmatic arc (Transhimalaya or Gangdise belt).

1. The Lhasa block sensu stricto

This block can be devided into two lithostratigraphic and tectonic domains. To the north a sequence of Paleozoic to Cenozoic sediments deposited on a continental crust whereas to the south an oceanic crust could be the basement of a part of the mesozoic series and the calc-alkaline arc.
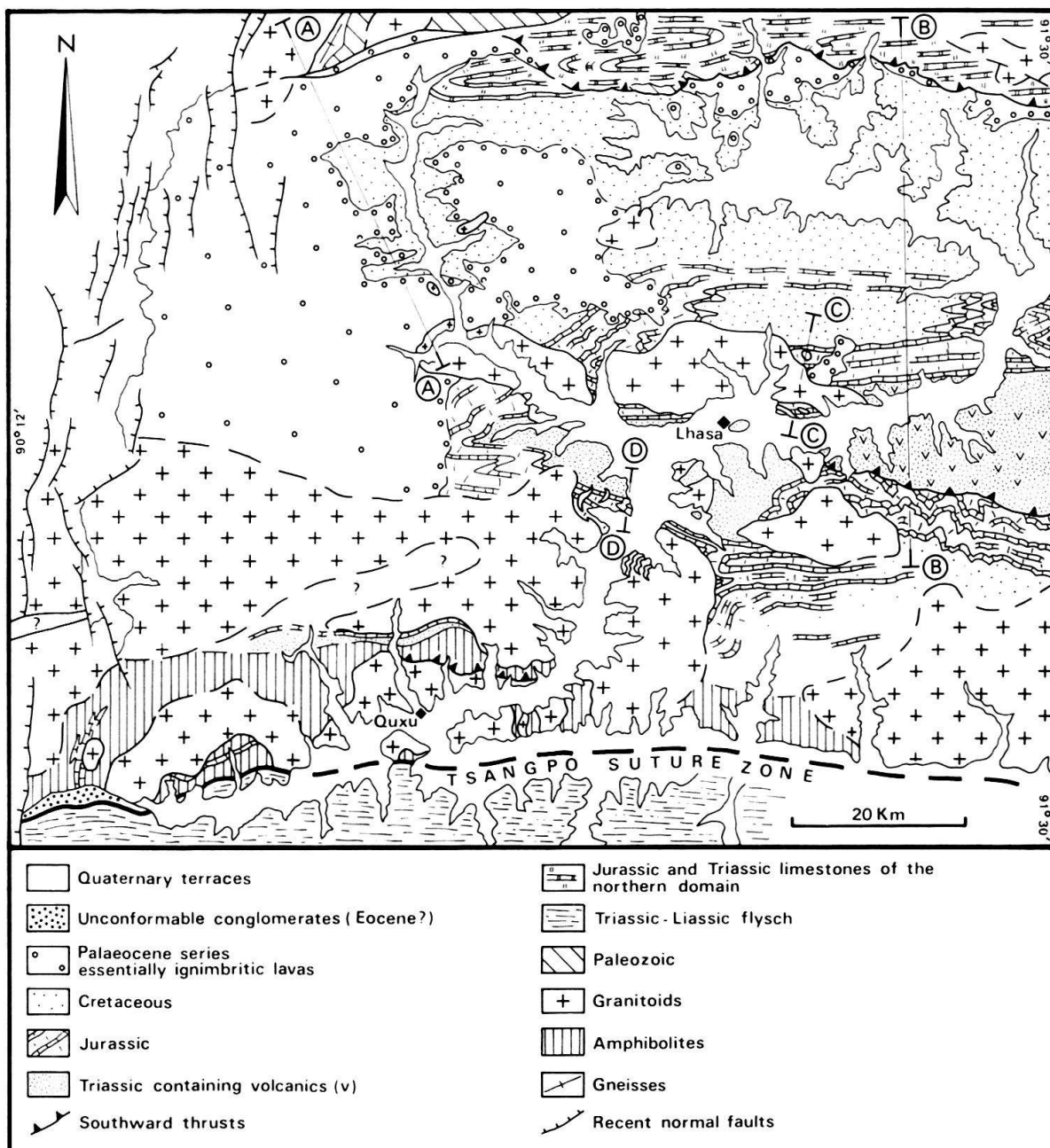
1.1 *Principal lithostratigraphic features* (Fig. 3)

1.1.1 *Northern domain*

The oldest terranes outcrop in the so-called Nyainquentanglha range and are represented by a tectonized metamorphic sequence in which coarse grained ortho-gneisses are dominant over high grade metasediments anatexites and two micas-garnet-sillimanite gneisses. They have not been dated precisely but are considered of probable Precambrian age (Academia Sinica 1980) and unconformably overlain by fossiliferous Carboniferous and Permian slates, quartz schists, conglomerates, and carbonates of Cathaysian affinities (JAEGER et al. 1982). These gneisses attest the continental nature of the pre-Mesozoic crust of this domain. Above the Permian, up to 1300 m of fine bedded limestones and dolomites at the base, interbedded with slates and some basaltic volcanics to the top are attributed to the Triassic (Academia Sinica 1980). The Jurassic is represented by a sequence about 1000 m thick of massive limestones intercalated in the upper part with black slates, quartzitic sandstones and coal lenses which include the lower Cretaceous (TUAN et al. 1977; BASSOULLET et al. 1983). The 1500 m thick Cretaceous (Takena) series appear more and more continental upwards. These clastic and some tuffaceous sediments are locally intruded by subvertical north-south undeformed doleritic dykes and include a thin layer of limestone with Aptian and Albian Orbitolinae (JAEGER et al. 1982, BASSOULLET et al. 1983). Interlayered red and green marls constitute the upper part of this sequence. There is a major unconformity between those Cretaceous and older sediments and the overlying "Linzizong series" (Fig. 4). The unconformable terranes are red sediments, conglomerates and sandstones associated with voluminous andesitic and ignimbritic series and volcanic clastics. At the base, the Linzizong rocks are upper Cretaceous-Paleocene in age (MALUSKI et al. 1982).

1.1.2 *Southern domain*

The deepest part of this domain seems to be exposed in the south. There, the lowermost unit consists of a sequence of amphibolites in which several terms of a possible meta-ophiolite suite can be recognized (gabbros, dolerites, basalts, green and grey cherts). White and light-grey marbles are locally found to the top of the

basic series. A sequence up to 1600 m thick of black shales, calcschists, siltstones and metagreywackes apparently barren of determinable fossils but of probable Triassic age (BASSOULLET et al. 1983) could lie over the amphibolites. However the contact between both units has not yet been clearly observed. In the "Triassic" sequence the volcanic component is important and consists mainly of calc-alkaline volcanic
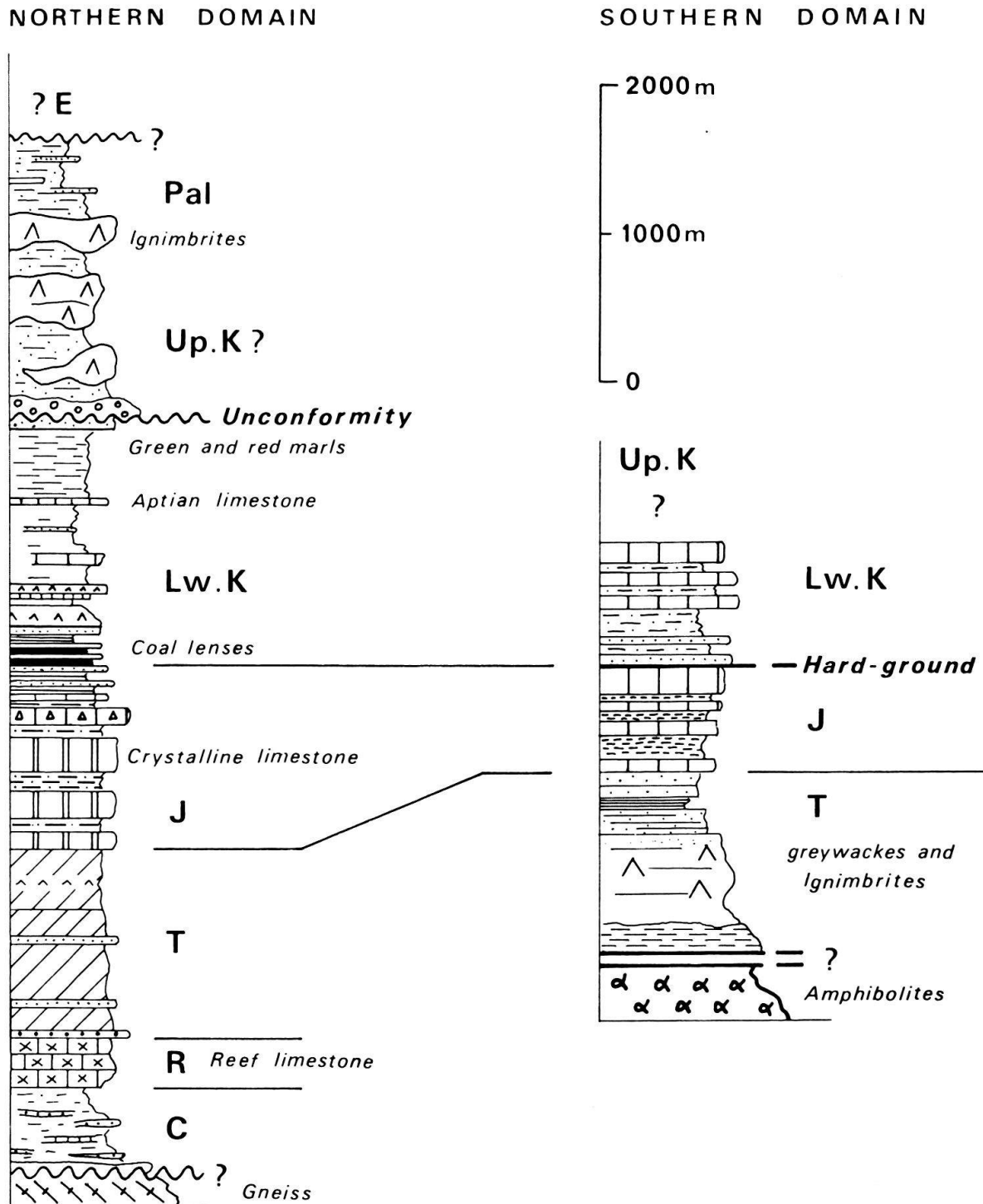
Fig. 3. Tentative lithostratigraphic log of the Lhasa block.

association (andesites s.l. and voluminous acid ignimbrites, Coulon, pers. comm.). In the upper 200 m, minor limestones are interbedded with shales and argillaceous interlayers. The crystalline limestones have provided upper Triassic Megalodonti-dae (BASSOULLET et al. 1983) and present a hard ground on the top. Above, a 200 m thick sequence of quartzitic sandstones and schists are Jurassic and lower Cre-

Fig. 4. Unconformity of the Paleocene on the Cretaceous red sediments of the northern domain. Road from Lhasa to Yangbajain (about 40 km northeast of Lhasa).
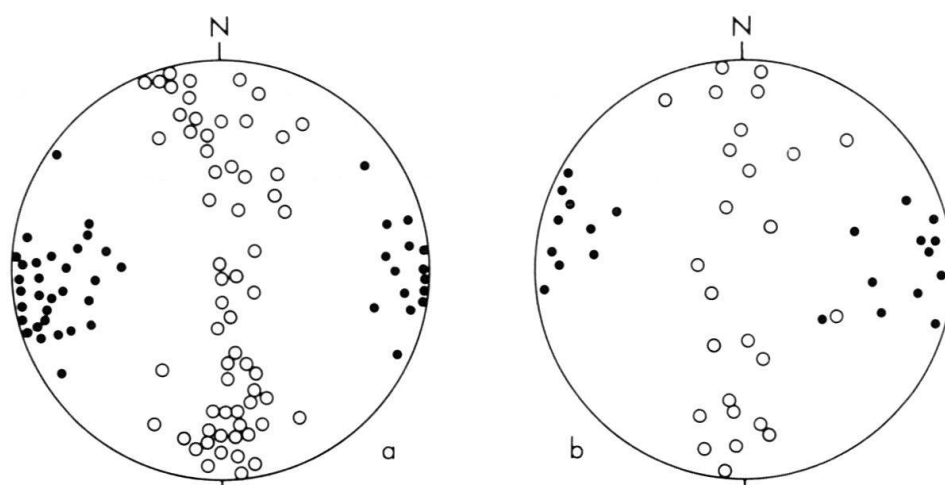
Fig. 5. Stereographic projection of F_2 fold axes (points) and poles of bedding S_0 (circles). a: southern domain; b: northern domain. Equal area, lower hemisphere.

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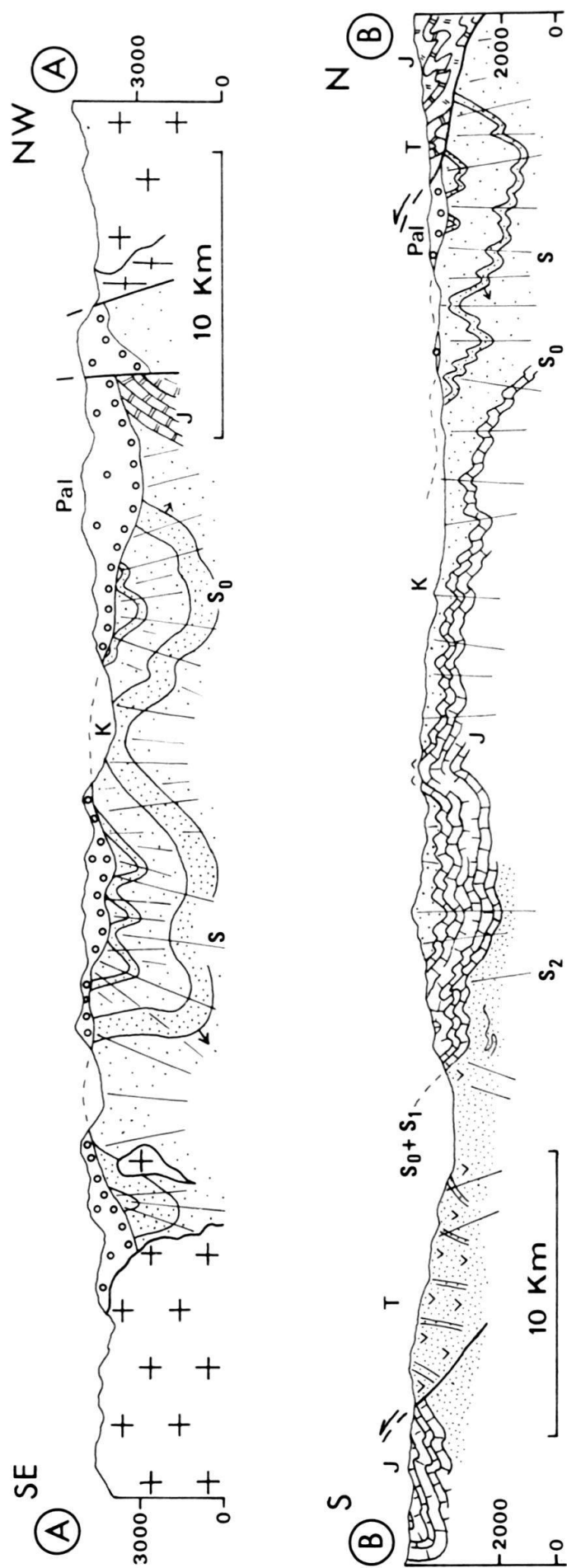
Fig. 6. Detailed cross section in the Lhasa block (situation on Fig. 2). Pal = Paleocene, K = Cretaceous, J = Jurassic, T = Triassic. Arrows indicate bottom of layers.

taceous in age (BASSOULLET et al. 1983). These shallow marine deposits grade upwards to a succession of limestones, calcareous sandstones and shales with some Orbitolinae bearing beds.

Metamorphism of the Triassic and Jurassic rocks is generally low grade (sericite, chlorite, muscovite, epidote). Contact metamorphism around the plutons may give rise to superimposed hornblende-hornfels facies of metamorphism (epidote-ido-crase-calcite-quartz-dipyre-garnet-hornblende-chloritoid).
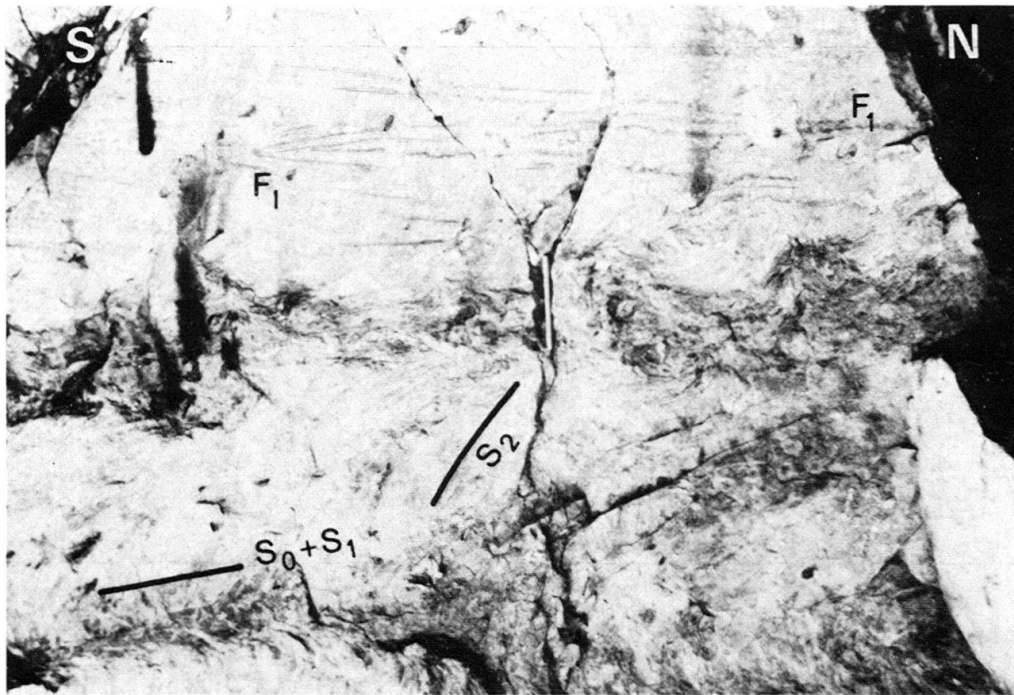
Fig. 7. F_1 isoclinal folds cut by the S_2 cleavage. S_0; bedding. Left bank of the Lhasa river, east of Lhasa.
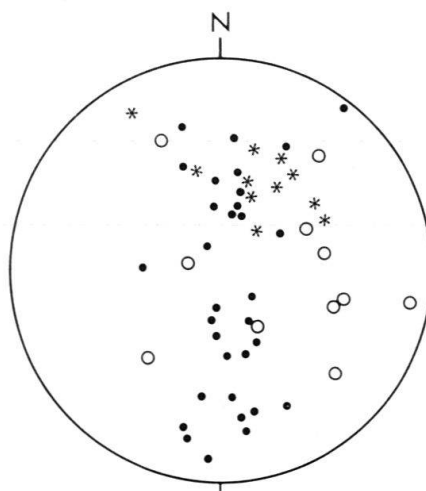
Fig. 8. Stereographic projection of D_1 structures, southern domain. Points = stretching lineation in the sedimentary rocks; asterisks = stretching lineation in the amphibolites; circles = bedding-cleavage intersection lineation in the sedimentary rocks. Equal area, lower hemisphere.

1.2 *Deformation*

1.2.1 *North*

The sedimentary rocks of the northern subzone have been folded about axes with east–west trends (Fig. 5, b). The disharmonic periodic folds appear symmetrical or verge slightly either to the north or to the south (Fig. 6). Their wavelength and amplitude are generally hectometric. Small scale second order folds are not common. A weak, nearly vertical axial plane spaced cleavage is formed at structurally deeper levels. These upright folds are truncated by the unconformity of the Linzi-

Fig. 9. Evidence of superposed D_1 and D_2 deformations. Inverted limb of F_2 fold indicated by S_0–S_2 relationships with right side out of bedding shown by ripple marks. Left bank of the Lhasa river, southwest of Lhasa.

zong terrains (Fig. 4) which are only affected by a several kilometers wavelength undulation and some late faults. Thrusts along which little horizontal southward displacement took place (no more than some kilometers) have been recognized (Fig. 2 and 6, B). 30% shortening by folding has been estimated along sections in the Cretaceous series.
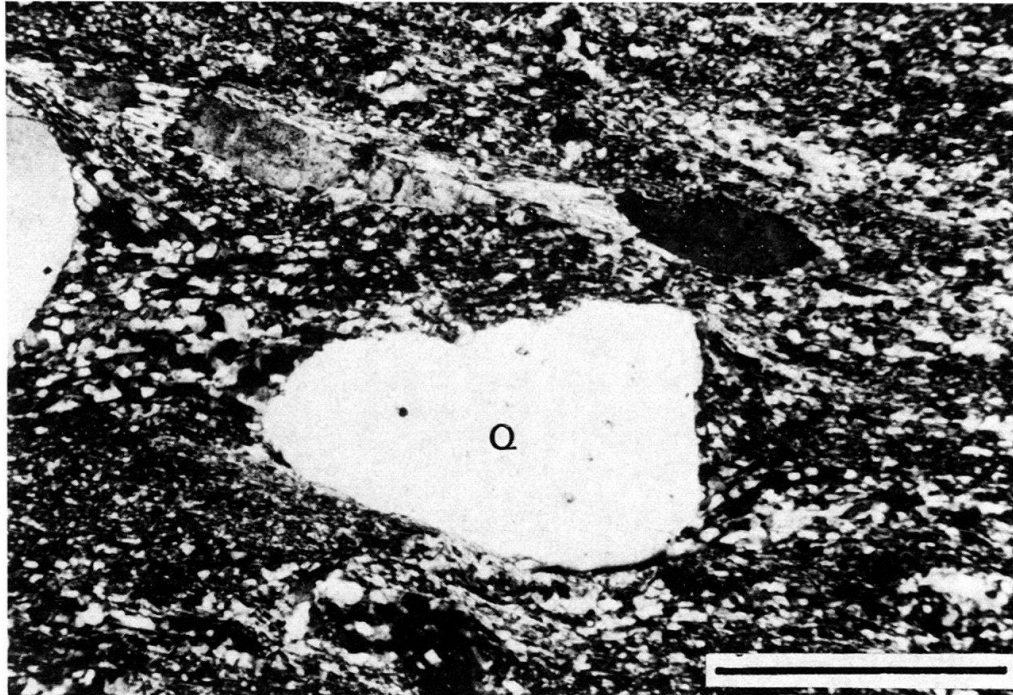
Fig. 10. S₁ cleavage and quartz pressure shadow on rhyolitic quartz phenocrysts in the XT 69 sample. XZ section of the rock. See the quartz c axis fabric in Figure 11. Bar = 1 mm.

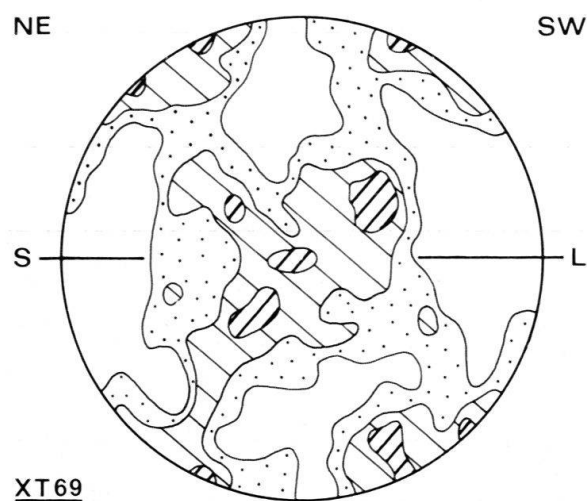Fig. 11. Quartz c axis orientations of 240 grains. Contours 1, 2, 4% per 1% area, Schmidt net lower hemisphere. Reference frame defined by S₁ axial cleavage (S) and L₁ stretching lineation (L). (X; Y; Z) = (1.33; 1; 0.5). Triassic metarhyolite, east of Lhasa.

1.2.2 *South*

Around and south of Lhasa, the rocks (mainly Triassic pelites and volcanoclastics) have suffered more intense and polyphase deformation.

First generation structures: A few isoclinal decimetric to decametric F_1 folds have been identified on the basis of their style (tightly appressed hinges) and superimposition upon them of structures of both F_2 and F_3 age (Fig. 7 and 9). Their axial plane surface is parallel to a spaced and locally slaty cleavage S_1 (Fig. 10). S_1 formed at a small angle to bedding S_0 and was probably more or less horizontal before refolding. This cleavage is more developed in pelitic metasediments and preserved within psammitic layers. Some rare intersection lineations S_0-S_1 are originally dispersed in orientation between N040 and N150 E (Fig. 8). The folds are overturned to the south as indicated by sedimentary structures (graded-bedding, ripple marks) and bedding-cleavage relation. A southward tectonic transport is also supported by the north-south stretching lineation L_S defined by elongated quartz grains locally visible on S_1. The intensity of this phase of deformation seems to increase southwards towards the suture zone: In the amphibolites the orientation of metamorphic minerals defines a prominent north-south lineation referred to as contemporaneous with L_S although it has not been possible to establish an absolute equivalence. This lineation is parallel to the axes of sheath folds in the marbles which indicate very intense shearing in this region. It is then assumed, in view of the strain associated with folding and fabric development, that the F_1 fold axes tend to be rotated towards parallelism with the principal extension direction during deformation represented by L_S (COBBOLD & QUINQUIS 1981). This could explain the dispersion

Fig. 12. F_2 fold hinges with S_2 axial plane cleavage $S_0 + S_1 =$ bedding + first cleavage. Left bank of the Lhasa river, east of Lhasa.
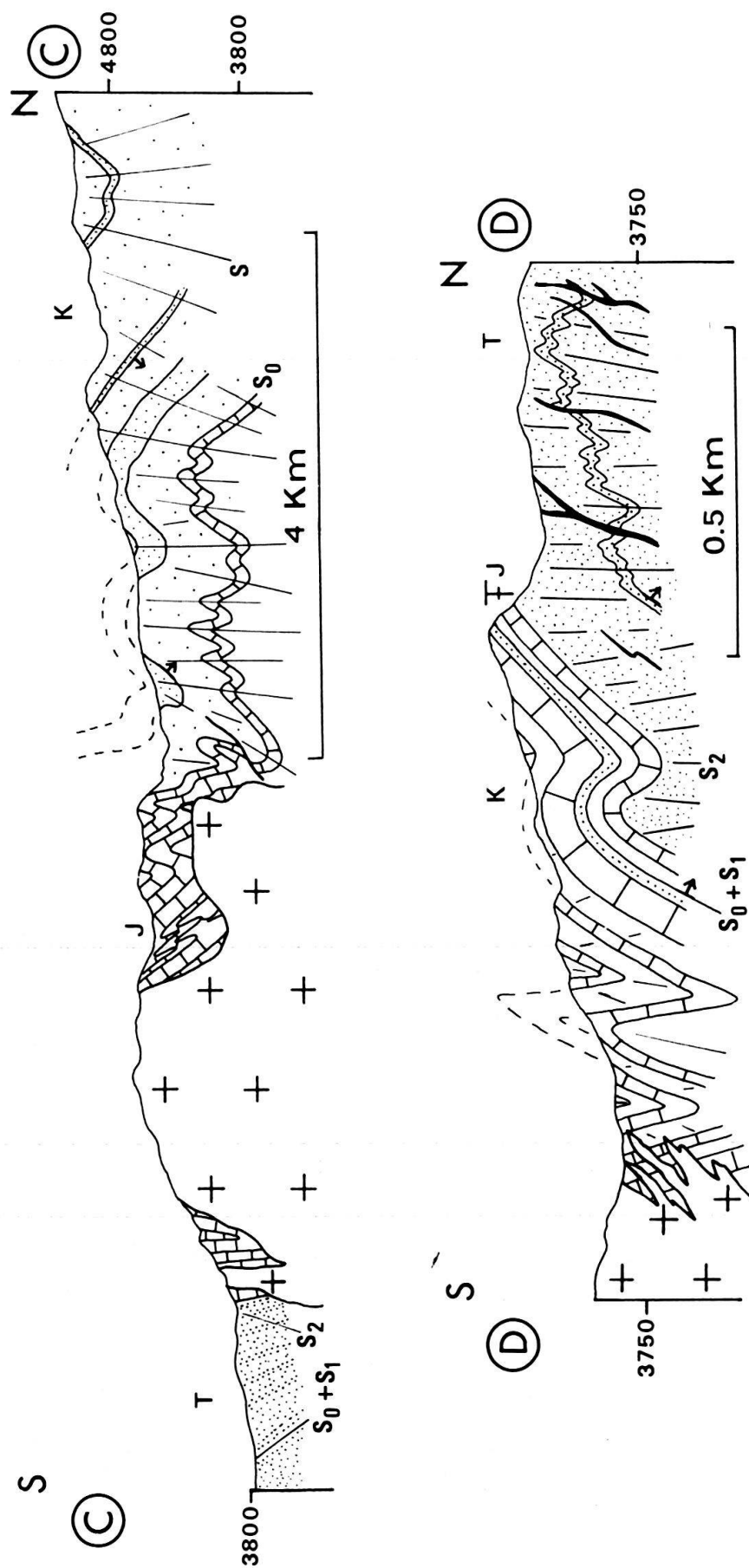
Fig. 13. Detailed cross sections in the Lhasa block (situation on Fig. 2). K = Cretaceous, J = Jurassic, T = Triassic. Arrows indicate bottom of layers.

in orientation of the F_1 axes and we suggest that one should find curved hinge lines F_1. West of Lhasa, FRY's method (1979) has been used to determine the finite strain of a metarhyolite for which S_1 and L_S are well marked. Measurements are made on magmatic blue quartz grains 1 to 3 mm in diameter whose centres dispersion defines an oblate finite strain ellipsoid: $K = 0.33$ with $(X; Y; Z) = (1.33; 1; 0.5)$. This type of deformation is consistent with the crossed girdles type c axis fabric of the quartz grains which form fine grained polycrystalline ribbons parallel to the S_1 cleavage of the rock (Fig. 11). Not enough markers are available to depict a possible zonation of the strain in the Lhasa block. At regional scale, mesoscopic F_1 with S_1 axial plane cleavage are rare. However there is good evidence, from sedimentary structures that the F_2 macroscopic folds are superimposed on pre-existing inverted stratigraphy which is ascribed to first deformation folding (Fig. 9). The consistency in style and orientation of the F_1 structures precludes the possibility that they could be related to the emplacement of the nearby plutons.

Second generation structures: All the major visible folds of the region are upright folds F_2 trending east–west (Fig. 5a) and refolding the earlier structures. In some places flexural slip folding is suggested by crystallization of calcite fibers along the layer boundaries. The style of the second order mesoscopic folds ranges from tight to moderately open hinges depending upon the layering. A well-developed fan like cleavage S_2 is roughly parallel to the mean attitude of the axial planes with unde-cided vergence (Fig. 12 and 13). An intersection lineation L_2 parallels the fold axes. S_2 is generally a typical cleavage showing pervasive alignment of mineral grains in the cleavage plane accompanied by development of subparallel pressure solution seams (Fig. 14). At some localities S_2 clearly deforms S_1 and then appears as as
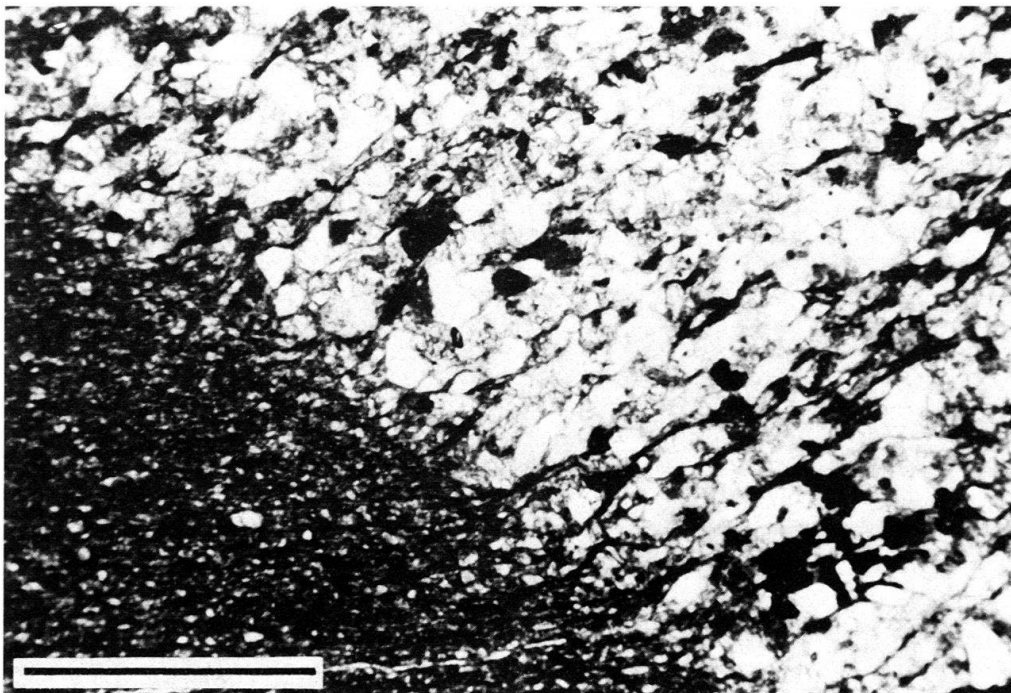

Fig. 14. Aspect of S_2 cleavage in thin section. Triassic sediments southwest of Lhasa. Bar = 1 mm.

crenulation cleavage. However we have generally noticed that the second generation structures are by far more visible than the first ones; in most cases penetrative S_2 has completely obliterated S_1. On the contrary, and probably for mechanical reasons, S_2 is ill represented in the southern amphibolites for which the most prominent fabric is due to the first phase. Nevertheless the second phase structures are developed with consistent orientation throughout the southern domain and clearly imply a north–south compression after formation of S_1. From detailed cross sections 50% of shortening mainly by buckling folds but partly by cleavage flattening can be estimated. By analogy, the upright folds described in the northern subzone could be the correlatives of the F_2 folds in the Lhasa region.

Third generation structures: Third generation structures can be identified by their superposition relationships with structures of the first and second deformational events. They are mesoscopic kink bands (Fig. 15) which locally deform S_2 with a dominant east–west orientation (Fig. 16). Their axial planes have a variety of attitudes.

Lately, different sets of "en échelon" tension gashes indicate that the fracturation in the area is polyphase.

1.3 *Discussion*

From both lithological and tectonic data, two domains can be separated in the Lhasa block s.s. The structural and age relationships between the two domains are not well understood. Two explanations can be considered to explain their differences:
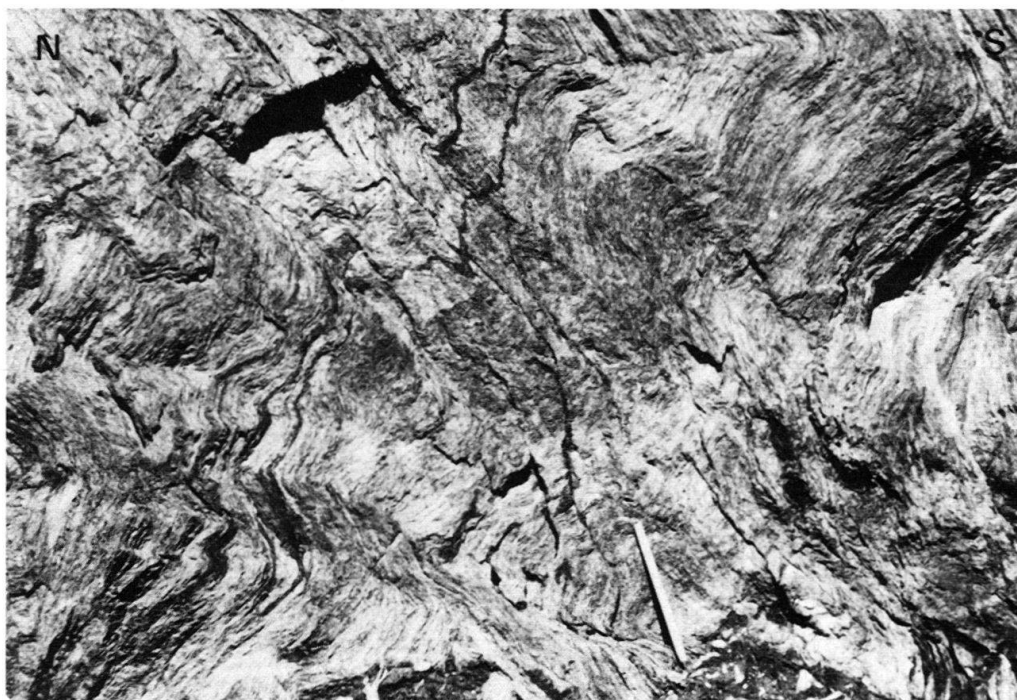

Fig. 15. D_3 folds (about 30 km east of Lhasa, right bank of the Lhasa river).

— An effect of structural level: The F_1 deformation developed only to the south in the Triassic and Jurassic deeper levels because they were situated close to a subduction zone. There is a front of deformation between the northern and southern subzones. The difference in lithostratigraphy could be accounted for by deeper marine deposits on an oceanic crust (the amphibolites) in the south than in the north where continuous shallow marine sedimentation occurred on a continental crust. As far as the oldest dated sediments in the south are triassic, the oceanic crust of the southern subzones should be of triassic age.

— A lower Cretaceous unconformity could exist between the series which show evidence of two main generations of folding in the Lhasa region and the northern series where only the second generation can be recognized. The unconformity plane has not been observed but the contact between the two subzones is not clear (generally faulted). Such an unconformity would be consistent with the amphibolites being deformed and metamorphosed before intrusion of the granodiorites of middle Cretaceous age (90 to 110 My, MALUSKI et al. 1982).

2. The transhimalayan magmatic belt and associated sedimentaries

2.1 Principal lithostratigraphic and petrological features

There appear to be three units in this zone which farther west continues all along southern Tibet up to Ladakh and Kohistan (FRANCK et al. 1977, KHAN TAHIRKHELI et al. 1978, HONEGGER et al. 1982). From north to south they are

— a thick calc-alkaline volcanism,
— an extensive plutonic belt,
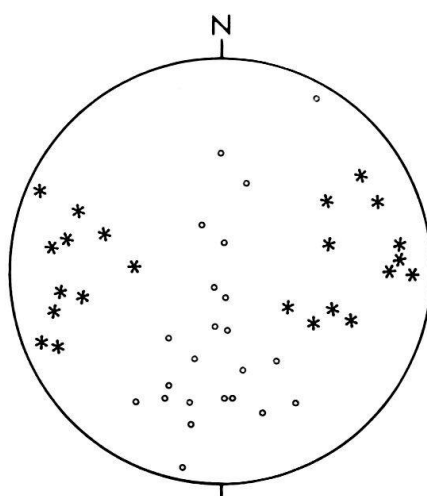— a sedimentary succession of conglomerates.

Fig. 16. Lower hemisphere, equal area plots of F_3 fold axes and L_3 lineations (asterisks). Circles = poles of axial planes of F_3 folds.

2.1.1 *The thick calc-alkaline volcanism*

Andesitic lava flows, acid ignimbrites and associated tuffs include most of the Linzizong formation (i.e. uppermost Cretaceous and younger series) as well as a more or less important part of the lower Cretaceous series previously described in the Lhasa block s.s. This volcanic unit is then widespread on the northern side of the Transhimalayan Range, but some outcrops are indicated in the plutonic belt itself on the 1:1,500,000 geological map of Tibet. We do not know yet if there the volcanics are unconformable onto the plutonic rocks or if they are intruded as both situations occur. MALUSKI et al. (1982) have dated a 59 ± 2 My andesite which outcrops south of Linzhu ($^{39}Ar/^{40}Ar$ method).

2.1.2 *An extensive plutonic belt*

It constitutes the magmatic axis of this 2500 km long zone from west to east and known as the Transhimalayan plutons (GANSSER 1980). Most of the intrusives in the batholith range in composition from tonalites to granodiorites with earlier bodies of noritic gabbros, hypersthene diorites, diorites and quartz diorites. This association of magma types is mostly pre-upper Cretaceous in age and has been intruded by late stage granites with radiometric Eocene ages (ZHANG et al. 1981, ALLÈGRE et al. 1982). The calc-alkaline plutonism is intrusive to the north in gneisses of the Nyainquentanglha belt and to the south in the amphibolites and mesozoic sediments of the southern Lhasa block. Numerous radiometric data have been published by the Chinese and have given ages which range between 120 and 40 My.
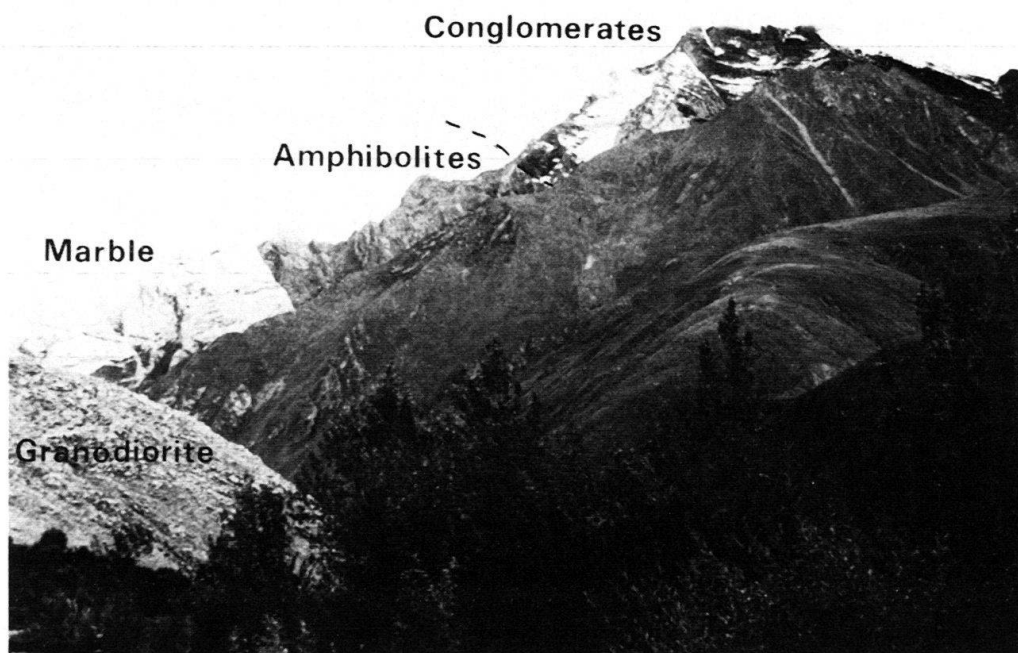

Fig. 17. Unconformity of the conglomerates on the amphibolites and marbles. Tsangpo valley, about 30 km west of Quxu.

MALUSKI et al. (1982) have dated hypersthene diorites at 93 ± 2 to 113 ± 2 My ($^{39}Ar/^{40}Ar$ method on biotites and hornblendes). As the pluton have the same bulk chemical composition as the calc-alkaline volcanism, we admit the same origin for these two magmatic units: They are related to a northward dipping subduction of the oceanic crust which separated India from the Lhasa block in Cretaceous (and earlier?) times.

2.1.3 *The sedimentary succession of conglomerates*

South of the crystalline axis, coarse conglomerates are intercalated in red shales and sandstones, and locally with ignimbritic flows. They are transgressive onto the Transhimalayan pluton and the amphibolites of the southern Lhasa block (Fig. 17). The coarse layers are up to 5 m thick, almost unstratified, crudely but distinctly graded. Pebbles are mostly of ignimbritic, andesitic and other volcanic pyroclastic and plutonic rocks derived from the magmatic belt to the north. Some pebbles of limestones and metamorphic rocks are present. These conglomerates belong to the Qiuwu formation as defined by WU et al. (1977) and were considered to appear at the base of the Cretaceous Fore Arc basin (the so-called Xigaze series, MU et al. 1973, SHACKLETON 1981). In fact the conglomerates are probably Cenozoic in age (KAUFFMAN 1981) and are separated from the Xigaze series to the south by a major fault. They compare remarkably well with the Indus Molasse of Eocene age in Ladakh (FRANK et al. 1977) and with the Kailas conglomerates (HEIM & GANSSER 1939) which are also transgressing Transhimalayan intrusives and contain pebbles of volcanics yielding Eocene ages (HONEGGER et al. 1982).

Fig. 18. Magmatic foliation indicated by long axes of xenoliths in a granodiorite. Road from Lhasa to Quxu.

2.2 Deformations

The division in different lithological units corresponds to a similar division in tectonic subzones.

2.2.1 The calc-alkaline volcanism

Most part of this subzone is very weakly deformed: large wavelength undulations and faulting. The commoner set of faults strikes east–west; related drag folds, slickensides and offset strata clearly establish right lateral or reverse relative movements. The older volcanites which belong to the Cretaceous of the northern subzone in the Lhasa block (see above) have suffered the F_2 event already described.

2.2.2 The plutonic complex

Most of the plutonic rocks are intrusive in the series of the southern Lhasa block and appear undeformed. The fabric of the granitoids is generally a magmatic feature: The lineation is defined by the distribution and shapes of mineral grains noticeably elongated blebs of mica and the long axis of xenoliths (e.g. road from Lhasa to Quxu, Fig. 18); the plunge is governed by the dip of the foliation defined by parallelism of the xenoliths. In thin section the minerals show no evidence of plastic deformation like undulose extinction, subgrain boundaries or deformation lamellae. Commonly an equilibrated magmatic association can be observed. When mapped in detail, the foliation describes blisters; at their borders, small scale shear zones due to ductile normal faulting can occur (Fig. 19). The lineation marked by

Fig. 19. Shear zones at the border of a pluton. Road from Lhasa to Quxu.

lenses of quartz and alignment of other minerals fragments in the shear zones is parallel to the magmatic lineation of the rock. These shear zones can be related to the intrusion of the granitoids.

Evidence of shearing or tectonic deformation is rare in the common facies, suggesting that if any, such deformation was healed by static recrystallization during cooling after emplacement. However, between Lhasa and Quxu, a ductile thrust zone is a prominent tectonic feature of the plutonic belt. This northward dipping shear zone is about 10–20 m thick and separates amphibolites of the Lhasa block from underlying granitoids. Its lateral extents have not been completely investigated. The top and bottom contacts of the deformed zone differ markedly. The amphibolites are much affected by late stage brittle failure giving rise to ultramylonites and phyllonites about 10 m in thickness; rocks of the mylonite series and rare cataclasites are developed in the plutonic rocks over 10 m from the contact to the rocks with a magmatic fabric. The east–west tectonic foliation S is superimposed onto the magmatic foliation and is more and more penetrative approaching the amphibolites. A north–south extension lineation L marked by a streaking of felsic mafic minerals and by preferred orientation of the long axes of quartz lenses is developed within S. In the XZ planes of the rock (orthogonal to S and parallel to L), shear planes, sigmoidal micas or polycrystalline aggregates, rotated porphyroclasts and asymmetrical pressure shadows comparable to those described in orthogneisses which have suffered shear deformation (BERTHE et al. 1979) give evidence for southward thrusting. Quartz c axes have been measured at the universal stage on fine-grained polycrystalline ribbons in the XZ planes of the rocks. A well-marked maximum that includes more than 10% of the measurements appears at the center of the diagram (lower hemisphere, Schmidt net) near the Y axis of the finite strain ellipsoid of the less deformed granitoids (Fig. 20, XT 39). In the most deformed mylonites the fabric is a crossed girdle with a defined outline and a set of discrete maxima at the center and at the border of the diagram (Fig. 20, XMT 25). The girdle
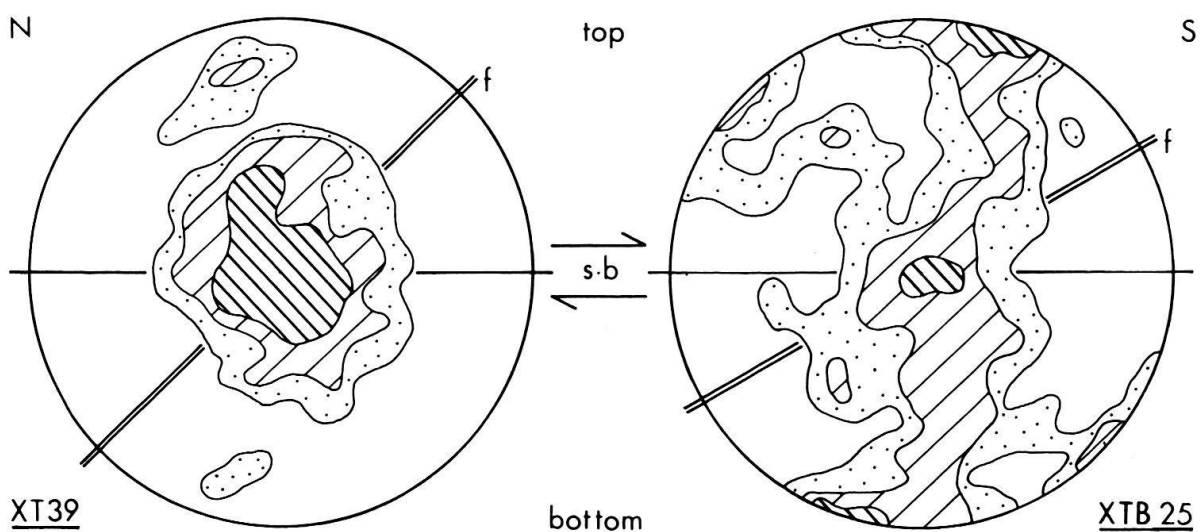

Fig. 20. Quartz c axis fabrics in the mylonitic thrust zone. 240 measurements for each diagram. The reference frame is defined by the mylonitic foliation (f) and the shear bands (s.b.). XZ section of the rocks. Contours at 1, 2, 4% per 1% area, Schmidt net lower hemisphere.

which contains the maxima is oblique to the foliation; this asymmetry indicates a sense of shear towards the south (BOUCHEZ 1977, BURG & LAURENT 1978). These fabrics of quartz c axes show that prismatic glide in a ⟨a⟩ direction is dominant during deformation of quartz; basal glide inferred from the maximum at the border of the diagram is a minor component. Referring to the data known from theoretical, experimental or natural deformation of quartz, this is consistent with conditions of deformation of $400° \leq T \leq 500 °C$ and $P \simeq 5$ kb (see e.g. WHITE 1976).

The time relationship between this thrust development and the regional folding phases has not been established.

2.2.3 *The conglomerates*

They show the same deformation features as the Xigaze series to the south. They have suffered only one phase of east-west folding with a dominant northward vergence (open to tight folds, box folds and chevron folds). A weak steeply dipping fan-like cleavage formed in the more pelitic layers.

These structures are similar (though different in age) to those in the series of the northern subzone of the Lhasa block. Shortening by folding is approximately 30%.

The faulted contact to the south with the Xigaze series is nearly vertical or dips south. Slickensides on the fault planes and related fractures indicate northward thrusting prior to dextral wrench faulting. Based upon information collected in other parts of the suture zone, this faulting is probably recent (Oligocene to Miocene).

Conclusions

The Lhasa block shows evidence of polyphase deformational events. Of these the first is by far the most intense to the south, producing low grade metamorphism and isoclinal folds in the lower mesozoic rocks and the dominant medium grade metamorphic fabric of the amphibolites if their deformation is contemporaneous with the F_1 event. Taking into account the similarities in style and orientation of the microstructures observed in both rock units, this is an assumption which appears reasonable to us. This first folding and metamorphic event is not recorded to the north.

Later deformations modified the first recognizable tectonic structures to the south and in the Lhasa block the fundamental tectonic framework is the result of a penetrative F_2 event due to north-south compression. The folding and fabrics associated with the subsequent deformations are of lesser intensity and their effects less ubiquitous. An angular unconformity surface between the middle Cretaceous rocks and the Linzizong series indicate that the sequence of deformational events was achieved by late Cretaceous times. No evidence of Quaternary compression (DEWEY & BURKE 1973) has been found.

The plutons are interpreted as having been to the north of a subduction zone due to the Cretaceous closing of an ocean of unknown width which separated India from the Lhasa block (e.g. POWELL & CONAGHAN 1973, 1975; MOLNAR & TAPPONNIER 1975, SINHA-ROY 1981). The magmatic calc-alkaline arc could be intrusive within the oceanic part (if the amphibolites in the south do represent a meta-ophiolite

suite) and partly on the margin of the northern continent (the xenoliths of acidic gneisses): The Lhasa block s.s.

At the present stage of knowledge, the deformation history of the Lhasa block can be tentatively summarized as follows:

— Metamorphism accompanied F_1 isoclinal folding (lower Cretaceous in age?) and may be related to northward subduction of an oceanic crust while calc-alkaline volcanism and plutonism take place. Intrusions postdate F_1 and develop contact metamorphism. This deformation event occurs only to the south close to the subduction zone.

— A period of continuing crustal shortening associated with further intrusions and slight metamorphism gave rise to F_2 folding and steepened the shallowly dipping S_1 cleavage. D_2 deformation event could be related to an Andine type belt.

   F_1 and F_2 seem to be separated from each other by a time interval. However, as the orientation of the principal stress axes remained approximately the same for both events, F_1 and F_2 represent probably pulses of a single orogeny.

— Emersion and erosion truncated all the structures by uppermost Cretaceous or lower Cenozoic times. The unconformable Paleocene series shows that volcanism was maximum at these times. No penetrative deformation took place after the Paleocene in the Lhasa block. This does not fit the continental and oceanic magnetic data which strongly suggest that the magmatic arc had collided with the northern margin of the Indian continent by late Paleocene-early Eocene times (e.g. DEWEY & BIRD 1970, POWELL & CONAGHAN 1973, MOLNAR & TAPPONNIER 1975, POWELL 1979, KLOOTWIJK et al. 1979, KLOOTWIJK & BINGHAM 1980). Two solutions can be put forward:

— The collision is not Eocene in age as claimed by these authors.

— The collision is Eocene in age but did not develop important tectonics on the northern side of the Tsangpo suture zone. We think that this is the best hypothesis.

Late expression of crustal shortening includes widespread strike slip and thrust faulting in the Lhasa block and in Central Asia (MOLNAR & TAPPONNIER 1975).

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