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MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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Sedimentology, palaeoecology and palaeoenvironmental evolution of the 1985 Lhasa to Golmud Geotraverse

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Vertical and horizontal measurements of almost 30 km of sections were made along the Geotraverse route at 113 localities ranging in age from Ordovician to Tertiary. Over 280 palaeocurrent measurements were taken and 200 thin sections were studied. Ordovician strata occur only in the Kunlun Terrane, where thick metamorphosed sequences of clastics and carbonates occur. These are tentatively interpreted as platform margin and slope deposits. During Carboniferous times in the Kunlun Terrane transgressive late-Dinantian marine limestones with tropical to subtropical Eurasian reefoidal faunas overlie fluviatile redbeds derived from an unroofed orogenic belt. The Lhasa Terrane contains shelf basin clastics with low-diversity faunas succeeded by thick late Carboniferous/early Permian glacio-marine mixtites deposited by iceberg meltout. Permian carbonate ramp and shelf facies with reefoidal developments occur over both the Lhasa and Qiangtang Terranes, with coal-bearing clastics and fluviatile redbeds also occurring in the latter. Permian sequences in the Kunlun Terrane comprise resedimented tuffaceous shelf basin clastics overlain by shelf carbonates. Triassic rocks are widely distributed. Those of the Lhasa Terrane are predominantly carbonate ramp and platform margin/slope facies showing evidence for shelf breakup due to extensional tectonics. Qiangtang sequences occur below and above a thick andesite lava development. Those below are mature fluviatile gravels derived from the north. The strata above the arc-related volcanics are typical shoaling-upwards carbonate ramp facies. Thick sequences in the southern Kunlun Terrane are tentatively ascribed to passive continental rise deposits of countourite drift aspects. Those in the northern areas are highly immature coarse clastics derived as alluvial fans from an Anisian–Carnian granitoid intrusive belt to the north. Jurassic sequences are unknown in the Kunlun Terrane. In the Qiangtang Terrane very thick (c. 5 km) sequences of clastic redbeds are interpreted as fluviatile and coastal plain molasse derived from the newly formed Kunlun orogen to the north. These intertongue southwards with marine shelf carbonates and clastics. The northern Lhasa Terrane contains thick clastic mudrocks and turbiditic sandstones of shelf basin aspects. Pelagic cherts and clastics overly oceanic pillow lavas, with ophiolitic ultrabasics capped by ferrosiallitic duricrusts and overlain by late Jurassic marine limestones. Cretaceous rocks are only known in the Lhasa Terrane. North of Lhasa they comprise northerly-derived fluviatile redbeds of molassic aspects which record the formation and uplift of the Jinsha/Banggong orogen. 300 km NW of Lhasa probable Neocomian fluviatile clastics are overlain by Lower Cretaceous marine carbonate buildup and lagoonal facies. Tertiary successions are almost entirely continental and record fluvio-lacustrine deposition in a number of basins which are thought to have originated as thrust-related features during major crustal shortening of the Tibetan Plateau in the Palaeogene and Neogene.

Introduction and methodology

Once sedimentary rocks have been dated palaeontologically (see Smith & Xu, this volume), they can yield much information of value to the tectonic interpretation of displaced terranes and collision orogenic belts like the Himalaya/Tibet Plateau. With the aid of palaeoecological data, facies analysis of the stratigraphic record of individual terranes enables the evolution of depositional environments to be deduced throughout time. This evolution can then be linked with other geological data to retrieve the basin and plate tectonic history. Critical to this approach is the accurate vertical and horizontal measurement of sedimentary sequences, with field records made of lithology, grain size, grain size trends, bed contacts, sedimentary structures, faunas and floras. During the Tibetan Geotraverse, almost 30 km of sections at 113 localities were logged in this way, albeit many at a rapid reconnaissance pace.

The evolution of a multiple-accreted terrane is usually accompanied by the periodic shedding of fluviatile molasse wedges into the subsiding continental margin or foreland basin of the youngest accreted terrane. Vital information concerning palaeoslope, orogenic vergence and unroofing trends is contained within such sequences and, once the fluviatile nature of the rocks is established, this data can be released by the complementary study of both palaeocurrents and petrography. Over 280 palaeocurrent measurements were taken. They are subdivided according to locality, age and the hierarchy of the measured structure in figure 17, see microfiche. In addition, over 200 thin sections were cut from sedimentary rocks and subjected to qualitative modal analysis, selected Carboniferous fluviatile sandstones being point-counted for 10 constituents. Field observations on pebble and boulder compositions are a more valuable indication of provenance than the sand-sized fraction and data of this kind are used wherever possible.

There are several kinds of evidence that the study of fossils can provide about palaeoenvironments. Trace fossils are rarely reworked and can therefore provide direct evidence of depositional setting, e.g. degree of sediment lithification, rates of sedimentation, environment of deposition. Taphonomic studies focus on the various processes that take place between death and discovery of the fossil assemblage. Critical information on the degree of reworking of an originally *in situ* community is essential for environmental analysis. Mode of life of individual species within a community structure can be deduced by a combination of functional morphology studies and comparison with extant communities. Valuable environmental constraints emerge from such studies

In the sections which follow, we discuss the sedimentary evolution of the Tibetan Geotraverse segment for successive geological periods, dividing each period between the Lhasa, Qiangtang and Kunlun Terranes. The emphasis is placed upon the factual record in each Terrane, followed by environmental and palaeogeographical deductions and hypotheses. In a later section we summarize the palaeogeographical evolution of the Tibetan Plateau (figure 16). The major sections of strata examined in each Terrane for the various geological periods are summarized in figures 1, 2, 6, 8, 9, and 11. For exact localities, see Kidd *et al.*, (this volume, field maps; see microfiche).

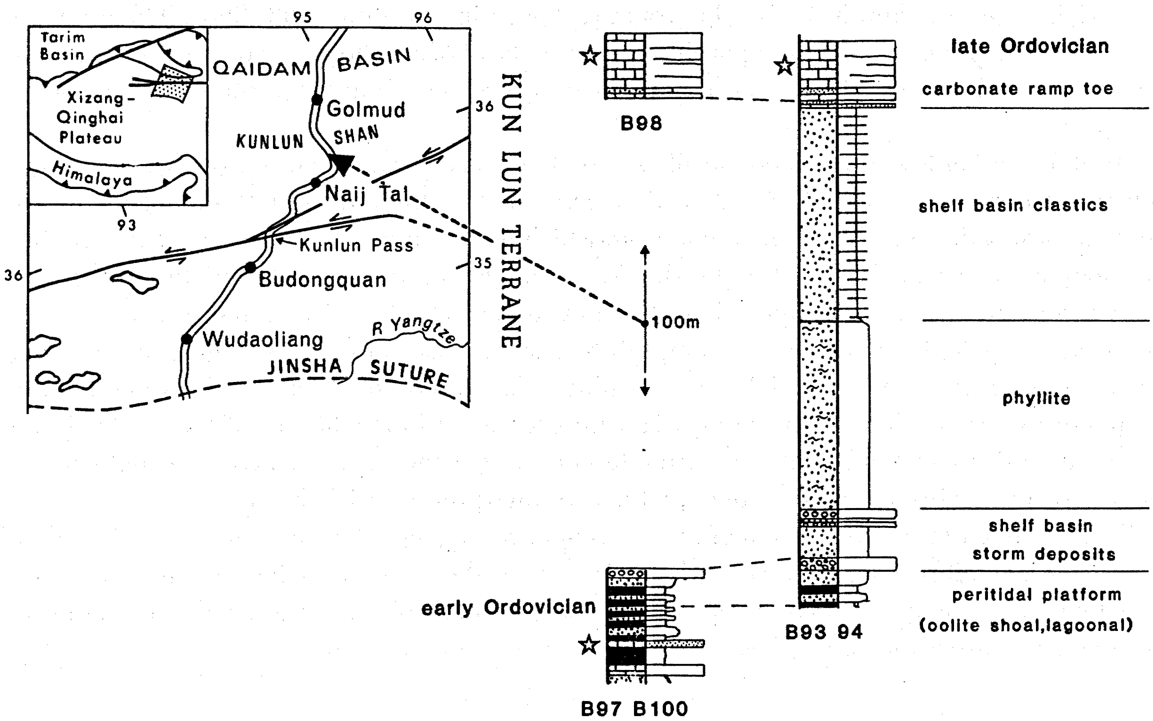

FIGURE 1. Ordovician lithofacies and tentative proposed correlations in the northern Kunlun Shan. B97, B98 etc. refer to localities.

ORDOVICIAN

Ordovician strata were encountered by us only in the Kunlun Shan where thick low-grade metamorphic sequences of clastics and carbonates were logged (figure 1). The considerable tectonic overprinting in this region has unfortunately destroyed almost all primary sedimentary features and much of the fossil content, making interpretation of these sequences difficult.

The best exposures were studied in the northern Kunlun Shan, close to Shuinichang just to the northeast of Naij Tal (localities B93, B101, figure 1). Here the oldest beds, dated as late Cambrian or early Ordovician on the strength of a unique trilobite fragment (locality B100, see Smith & Xu, this volume, Appendix), are dark blue or black graphitic phyllites interbedded with green quartz phyllites and three limestone beds, several metres in thickness, one of which is oolitic. The presence of organic-rich shales and oolitic limestones with trilobites suggests a platform margin origin for some of these facies. Above this comes quartz mica phyllite with two or three major (up to 60 cm thick) matrix-supported conglomerates. The highly-strained clasts, which are coarse and reach 30 cm diameter, are predominantly of white limestone and quartz, with subsidiary green and purplish sandy phyllite clasts. No igneous clasts were seen. The conglomerates may be debris flow deposits formed in a shelf-basin or on a platform slope. Next comes a thick succession of poorly bedded pale-green quartz mica phyllites, with no primary structures from which to interpret their facies. These grade up into well-bedded dark grey fine quartz wackes and slates which also lack primary sedimentary structures but which may be turbidites.

The topmost strata in the sequence are thick-bedded fossiliferous micritic limestones of late

Ordovician age (see Smith & Xu, this volume, Appendix, localities B93, B98). The fauna of shallow water corals and stromatoporoids appears to be allochthonous and restricted to possible storm deposit horizons; the sequence may have formed on the distal portion of a carbonate ramp.

Another belt of low grade metamorphosed sediments is found in the central Kunlun Shan. These were studied along the road section between the Xidatan and Wanbaogou, to the southwest of Naij Tal. There is no fauna from which to determine the age of this sequence, but the presence of spectacular quartz/white limestone conglomerates, identical with those described above from the northern Kunlun Shan, leads us to suspect a broadly similar age for the two successions. Near the base there are amphibole garnet schists of igneous origin; but whether intrusive or extrusive is impossible to determine. Most of this thick succession is made up of metamorphosed sandstones and mudrocks with occasional intercalations of thin-bedded and predominantly calcareous strata. Near the top of the sequence is a thick coarse conglomerate of quartz and white limestone pebbles, which we interpret as a debris flow.

The highly tentative correlation of the two sequences suggests that the central Kunlun Shan succession is Cambro-Ordovician in age. This is based on the assumption that the white limestone conglomerates are approximately equivalent and that most of the central Kunlun Shan succession lies stratigraphically below that seen to the east of Naij Tal.

Carboniferous (figure 2)

Carboniferous sedimentary rocks are known from the Lhasa and Kunlun Terranes along the Traverse route (figure 2). No exposure of Carboniferous in the Qiangtang Terrane was studied by us but sequences with facies and faunas similar to those of the Lhasa Terrane are known far to the west in the southern Karakoram Mountains (Norin 1946; Liang *et al.* 1983). In addition facies and faunas of Kunlun aspect are reported to the east around Qamdo (Dong & Mu 1984) as well as just to the west of our traverse route in Zhado County (Dong & Mu 1984).

(*a*) *Lhasa Terrane*

Stratigraphic sequences, comprising parts of the Pondo Group, were logged in detail at three localities; the columns in figure 2 summarize the major characters of the successions. The predominating mudrocks and siltstones are generally deformed and strongly cleaved, features preventing an accurate estimate of thickness. The whole Carboniferous section may exceed 1 km in thickness.

The lithofacies of the Pondo Group are dominated by dark grey mudrocks of shelf-basin origins. These contain abundant late Carboniferous fenestellid bryozoans, bivalves, brachiopods and crinoid debris, as at localities B19/B20 near Damxung. The crinoidal debris occurs in thin, sharp-based and sometimes graded laminae and is clearly allochthonous, probably of storm origins. The well-preserved bryozoan fronds are almost certainly preserved *in situ* and are indicative of a low energy environment, probably below all but storm wave base. Shallower shelf-basin facies, deposited above wave base, are represented by mudrocks with interlaminated siltstones and lenticular siltstone and fine sandstones with wave-ripple formsets and sparse-to-common bioturbation.

These fine-grained sequences are succeeded by a spectacular mixtite horizon which may be

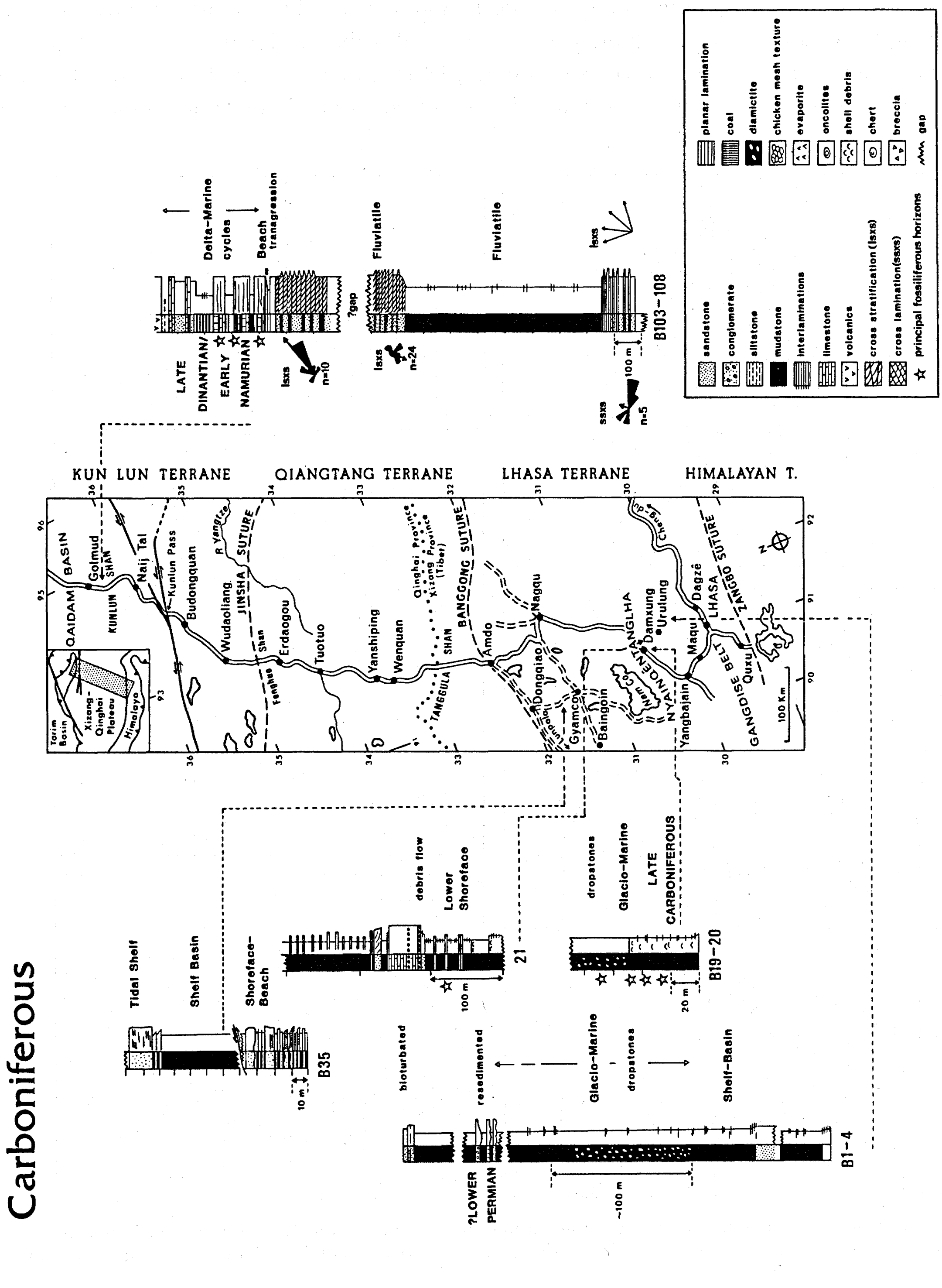

FIGURE 2. Distribution of Carboniferous measured sections, their lithofacies, environmental interpretations, age determinations and palaeocurrent distributions. See text for discussion and further data. Inset provides general key for this and subsequent diagrams.

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up to 100 m thick, although given the poor degree of exposure and correlation there may be several such horizons. Fossils place the age of the mixtite close to the Carboniferous–Permian boundary (Smith & Xu, this volume). The mixtite lithofacies comprises silty mudrocks, sometimes with siltstone and fine sandstone interlaminations in which occur scattered angular to subrounded granules, small to large pebbles and small cobbles (figure 3A,C,D). Clasts are of diverse origins and comprise various granitoids, felsites, quartzites and gabbros. They are never graded or sorted and are always matrix-supported. Several elongate pebbles lay with

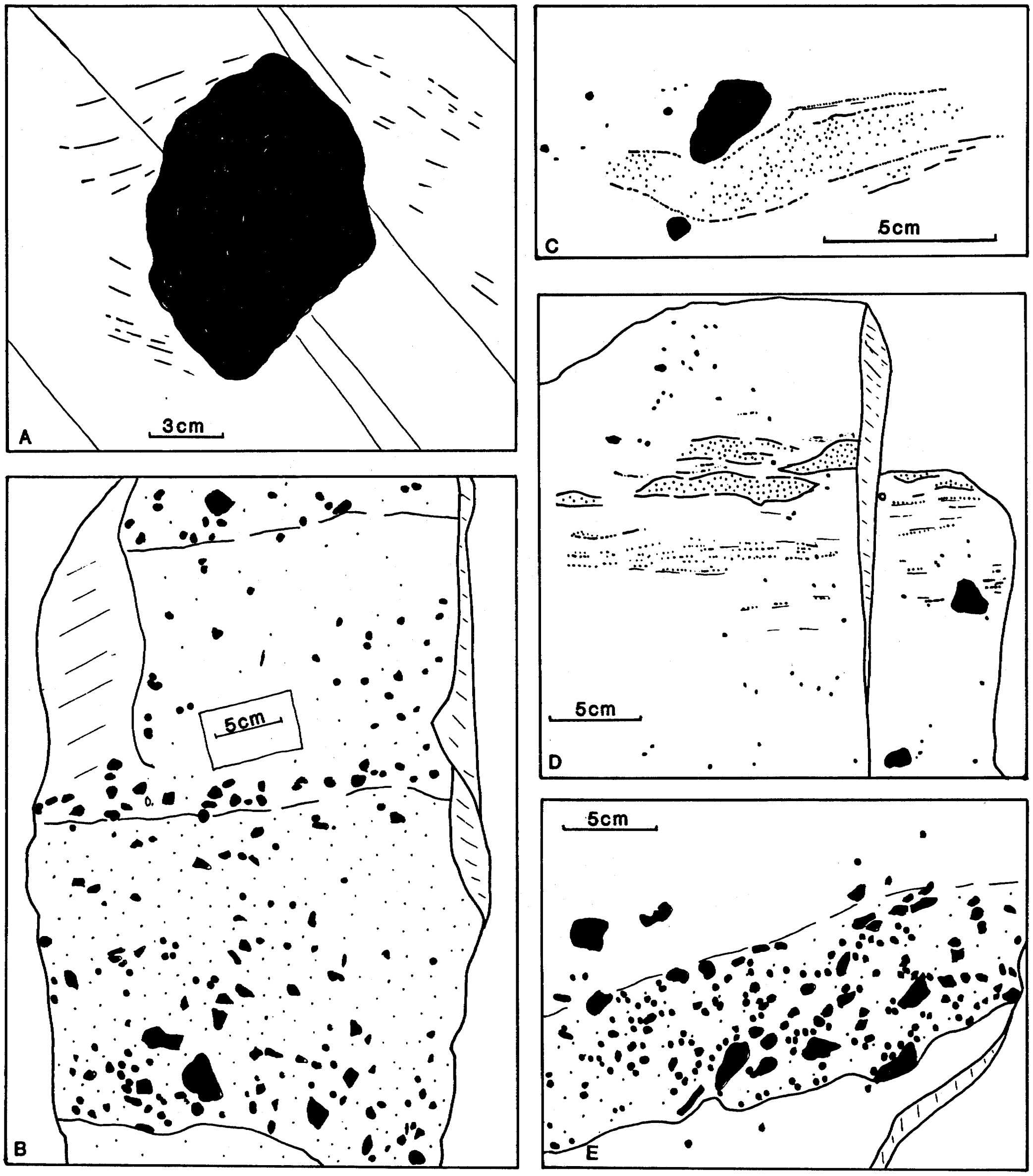

FIGURE 3. Sketches from photographs and field observations to show various late Carboniferous glacio-marine facies in the Lhasa Terrane. 3A – Large andesitic dropstone observed to cut faint lamination traces in cleaved mudrock. NW–SE lines represent cleavage planes. Locality B34, 3B – Resedimented pebbly sandstones showing crude grading and well defined internal bedding contacts. Locality B1, 3C, D – Small dropstone clasts in laminated mudrocks. Locality B1, 3E – Channelized pebbly sandstone lens with sharp basal contact overlying mudrock, possibly a resedimented product of turbidity flow. Locality B1.

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their long axes at a high angle to the bedding. Three examples were seen where pebbles had apparently cut across pre-existing siltstone interlaminations (figure 3A). Two showed fine multiple striations on their surfaces. At localities B19/B20 the lower contact between the clasts defining the mixtite and the underlying mudrocks is sharp, with the clasts occurring in close proximity to an *in situ* community of brachiopods, bivalves and fenestellid bryozoans. There are noticeably more siltstone interlaminations and fewer bryozoa at the base of the mixtite.

These various features are best explained on the basis of a glacio-marine dropstone origin for the clasts, the finer laminations perhaps representing the distal deposits of density currents and/or storm underflows. Our more detailed observations support previous diagnoses of glaciogenic origins (Tapponnier *et al.* 1981) but lend no support to alternative theories (Allègre *et al.* 1984).

In Section B1 at Urulung the glacio-marine mixtite is succeeded by a sequence of interlaminated lithofacies as described above, followed by pebbly coarse-grained sandstones and conglomerates showing grain-supported clasts, well-developed bed boundaries, internal normal grading, sharp erosional bases and rare channel-like forms (figures 3B, 3E). Clearly not of dropstone origins, they are interpreted as glaciogenic sediment from subaqueous moraines, redeposited by gravity flow processes down the proglacial depositional slope (see Edwards 1986, figure 13.6 for a generalized facies model). Successions above these units probably extend into the Lower Permian. They gradually coarsen upwards through wave-generated lenticular-laminated sandy siltstones of presumed storm origin into highly bioturbated muddy sandstones containing abundant *Teichichnus*. Section B21 also contains a limestone development (20 m thick) including a spectacular debris flow bed (1.5 m) with cobble-sized clasts of quartz, mudrock and limestone. This is taken as evidence for the gradual progradation of a clastic slope followed by construction of a carbonate platform bypass margin in a nearby area. Eventually a carbonate platform was established in the area north of Lhasa during Permo–Triassic times. Eruption of the Dagze basalt–andesite suite (1500 m; see Pearce & Mei, this volume) probably began in the late Carboniferous or early Permian (Smith & Xu, this volume).

A tidal and wave-influenced clastic facies of shoreface and tidal flat origin, the latter facies with *Diplocraterion* burrows, also occurs at Jang Co (Section B35). We have no direct evidence for the age of these beds but suspect that they may be Carboniferous from their structural position, location and general appearance. They are succeeded by 50 m of mudrocks and a prominent 12 m thick medium to coarse sandstone exhibiting multidirectional cross-stratification reminiscent of tidal sand facies.

(*b*) *Kunlun Terrane*

Carboniferous sequences outcrop in the northern foothills of the Kunlun Shan, where they define the Dagangou, Teqosu and Sijiaoyanggou Formations, all probably Carboniferous in age. Field evidence indicates that more than 1500 m of Carboniferous is present in the area, possibly much more.

Most Carboniferous strata comprise red-coloured siltstones, sandstones and pebbly sandstones. Above a basal conglomerate (not shown on figure 2) there is overall coarsening-upwards from siltstone to pebbly sandstones. Beds of coarser clastics, from 0.5–10 m thick, usually show sharp erosional lower contacts with either sandstone or siltstone. In the lower half of the succession fine-grained lithologies predominate (figure 2), comprising dull red silty mudrocks and thin (0.5–1.0 m), sharp-based, lithic and feldspathic sandstones with upper phase plane-bed laminations, climbing ripple cross-laminations and rare wave-modified current ripple formsets. Palaeocurrent measurements indicate a northwest vector mean transport direction, the sediment probably having been deposited by sheet floods on low gradient alluvial cones. The red pigment is assumed to be early diagenetic.

The upper half of the sequence (figure 2, B103–108) is first dominated by thick red multistorey lithic and feldspar-rich sandstones and pebbly sandstones which show well-developed trough cross-stratification and variable palaeocurrents with a SSW vector mean. They are interpreted as of fluviatile channel origin. Clasts include feldspars, basic volcanics, marbles and quartz. One marble clast resembling nearby Ordovician lithologies has well-developed foliation. The topmost clastics show marked changes in facies and petrography. White pebbly sandstones contain more abundant quartz clasts, usually well-rounded, and only rare feldspar sand grains. Other structures resemble those of the pebbly sandstones beneath and are again attributed to fluvial channel activity. Palaeocurrents from the southwest support the deduction that a different dispersal system has now developed. Sandstone storeys are separated by up to 13 m of red mudrocks with thin horizons of calcite nodules resembling the 'cornstone' nodules of pedogenic calcrete common in the Upper Palaeozoic fluviatile redbed sequences of NW Europe and Appalachia.

The red mudrocks of the Kunlun Carboniferous are succeeded by a rapidly coarsening-upwards sequence culminating in grain-supported, imbricated quartz conglomerate. The clasts, up to 10 cm diameter, are well-rounded to sub-rounded and clearly record major reworking, probably on a marine shoreface. This is strongly supported by the overlying grey mudrocks which contain a marine fauna and a 6 m dark lime wackestone rich in crinoidal debris at the top. Succeeding strata comprise 20 m of alternating grey mudrocks and limestones before a prominent shaly coal appears. Then comes a high diversity shallow water community of brachiopods, compound rugose and large solitary rugose corals with extensive dissepimentation, broad-spreading stromatoporoids and bryozoans, all *in situ*. Compound corals are predominantly massive and tabulate. Further up the succession, in the more massive limestones, erect fasciculate coral colonies dominate, suggesting slightly deeper water. The fauna is latest Visean or early Namurian in age. The succeeding strata ($>$ 200 m) comprise numerous cyclical alternations of marine limestones and clastics, the latter including facies of delta front and on-delta types (figure 4). These include coarsening-upwards cycles similar to modern inter-distributary bay fills; sharp-based, erosive, cross-stratified sandstones resembling crevasse or minor distributary channel deposits and thin coals and carbonaceous mudrocks of on-delta affinities. The fauna in the limestone beds is more restricted, but occasional echinoid and crinoid fragments and, less often, rugose corals confirm that fully marine conditions were periodically established from time to time throughout the entire succession.

The marine limestone/deltaic clastic cycles are remarkably similar to the late Dinantian/early Namurian 'Yoredale-cycles' that dominate the north British and North American (Kansas to Texas) successions of the Laurasian continental margins of Hercynia–Appalachia.

(c) *Carboniferous palaeogeography*

(i) *Lhasa Terrane*

The thick dropstone facies indicates that the Terrane lay on a continental margin within the iceberg fringe (perhaps extending to about 50° S by comparison with the Pleistocene) that

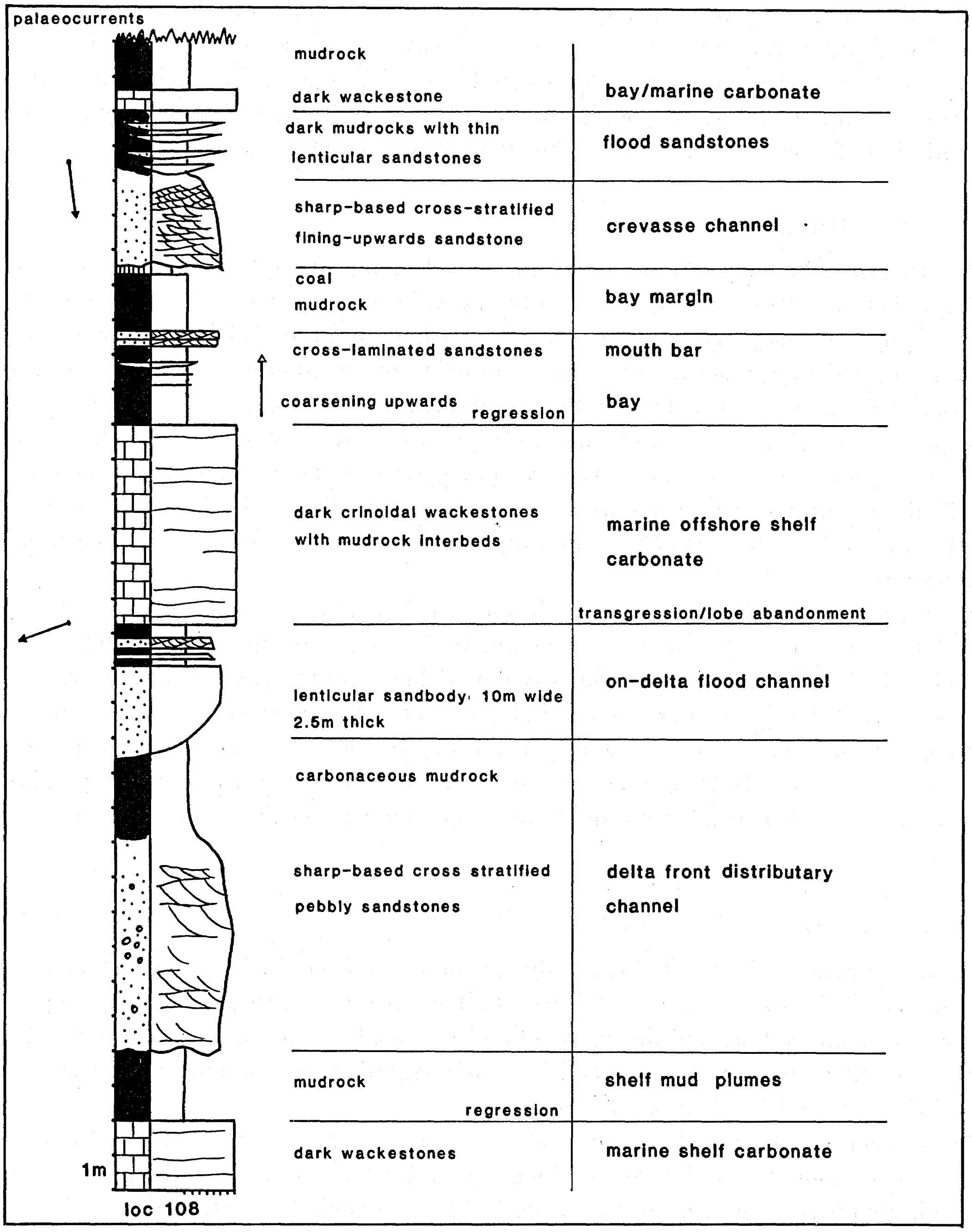

FIGURE 4. Log to show delta/marine cycles of Euro–North American 'Yoredale' aspect in the late Dinantian/early Namurian of the northern Kunlun Shan. Locality B108.

must have surrounded the icecap responsible for Permo–Carboniferous tillite deposition in South America, South Africa, North Arabia (Oman), North India and Australia (see Frakes 1979; Braakman *et al.* 1982; Powell & Veevers 1987). Our observations on clast compositions suggest a hinterland rich in granitoids and metamorphics but we have no directional structures indicating where these lay in terms of present day co-ordinates.

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Our sedimentary evidence thus supports the suggested location of this Terrane at the fringes of the Gondwanan superplate during late Carboniferous times (see Audley-Charles 1984; figure 16). The revised late-Carboniferous/early-Permian age for the thick Dagze volcanics, based on palaeontological dating of intercalated sediments (Smith & Xu, this volume), suggests the initiation of back-arc extension at this time (Pearce & Mei, this volume).

(ii) *Qiangtang Terrane*

Our traverse did not encounter rocks of Carboniferous age in this terrane. Published accounts of Carboniferous strata in its supposed continuation in the Karakoram Mountains of Western Tibet (Liang *et al.* 1983) record dropstone facies with many striated clasts. This leaves no room for doubt that the far western part of the terrane lay in the Gondwana iceberg fringe during Carboniferous times. Judging from published photographs (Liang *et al.* 1983), the clasts in the Cameng Formation are an order of magnitude larger than those of the Lhasa Terrane, perhaps indicating a more proximal position along a contemporary iceberg dispersal route. The mixtites described by Norin (1946) from the Herpatso Series of the Tashlig-kol in Western Tibet (34° 40′/80° 40′) are more closely comparable with the Lhasa examples in both grain size and composition.

In striking contrast with the successions in Western Tibet, those near to and east of the traverse route (Qamdo) contain fluviatile, coastal plain and marine sediments with a rich fauna closely related to the Kunlun Lower Carboniferous fauna. These contrasting Carboniferous sequences at either end of the Qiangtang Terrane indicate that the far western portion was part of the Gondwana facies belt whilst the eastern portion was part of the Eurasian facies belt. Either the elongate terrane straddled the intermediate latitudes between the two major 'superplates' or the correlation of structural boundaries from eastern and central Tibet to the Karakoram needs revision.

(iii) *Kunlun Terrane*

Palaeomagnetic data (Lin & Watts, this volume) from the fluviatile redbed facies yield a computed palaeolatitude of around 20° S ± 20°. This savannah latitude is strongly supported by semi-arid calcrete nodules and the nature of the associated marine faunas of Eurasian affinities. Also consistent with a low latitude is the red pigmentation, a common product of semi-arid early diagenesis in floodplain facies.

Reconstructions of basin style and tectonics are hampered by lack of regional information but it seems reasonable to regard the thick Lower Carboniferous fluviatile redbed sequence as a molassic phase derived from the unroofing of an orogenic belt to the north. Variability of the palaeocurrents may indicate deposition in extensional or strike-slip basins. Petrographic data suggests derivation of the detritus from basic to intermediate volcanics (possibly Devonian in age) of island arc type and from granitoid/gneiss terranes (figure 5). A major marine transgression, possibly eustatic, during the late Dinantian was accompanied by a radical change of drainage system and establishment of a mature quartz-rich hinterland in the southwest.

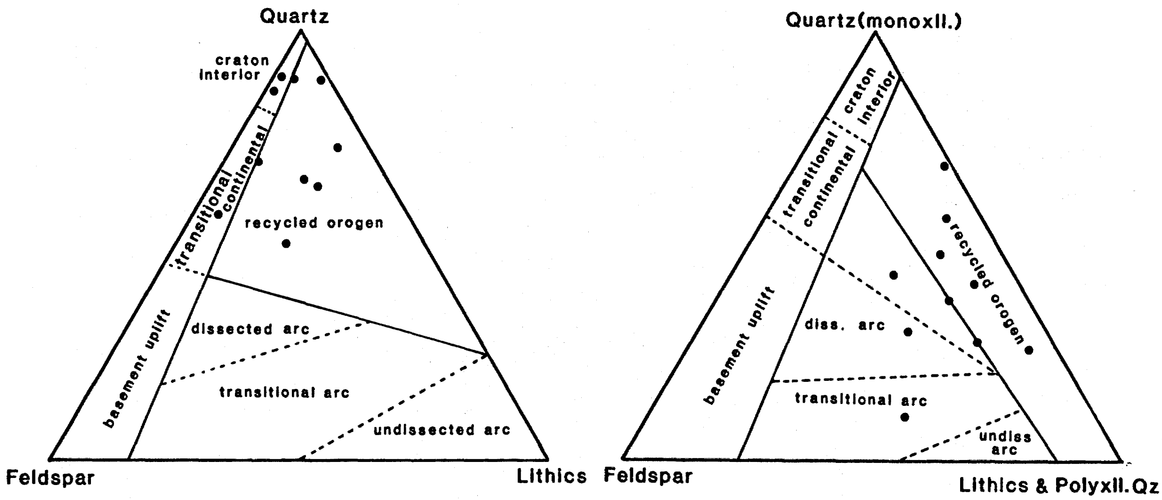

FIGURE 5. Ternary diagrams (after Dickinson & Suczek 1979) to show that the compositions of fine to coarse sandstones from the late Dinantian/early Namurian of the northern Kunlun Shan indicate a recycled orogen and volcanic arc provenance. Lithic components include common volcanic grains. Compositions based upon point counting 200 grains per slide. See text for discussion.

PERMIAN (figure 6)

(*a*) *Lhasa Terrane*

Permian sedimentary rocks (> 1 km thick) outcrop extensively north of Lhasa and are included in the Pondo Group (pars), and the Urulung, Lobadoi and Lielonggou Formations. Eruption of the Dhagze volcanics continued at least into the early Permian to the northeast of Lhasa.

The Lielonggou Formation around Doilungdeqen (Sections B11, B12) begins with well-sorted, fine to very fine fossiliferous sandstones showing parallel and low-angle laminations, wave-formed ripples and possible hummocky cross-stratification. Evidently subtidal mid- to upper-shoreface in origin, these were submerged by a relative sea level rise and thereafter acted as a nucleus for the accretion of a carbonate ramp now represented by well-bedded, dark and sparsely crinoidal wackestones (> 50 m). Low-energy ramp-toe conditions are postulated because of the occurrence of crinoid stems up to 2 cm long set in a carbon-rich wackestone matrix.

A similar, but finer-grained clastic-to-carbonate transition is documented in the Urulung area (Sections B1 and B2). Sandy siltstones and fine sandstones with occasional transported shell beds of possible storm origin are overlain by unfossiliferous, black, carbonaceous mudrocks. Higher in the sequence come occasional thin (0.5–1.0 cm) grainstones composed of bryozoan fragments. These are also probably storm deposits. The mudrocks are followed by a thick carbonate sequence which was not examined in detail. The carbonates are sparsely fossiliferous wackestones (with fusulinids and corals) and are interpreted as low-energy ramp-toe and offshore shelf facies.

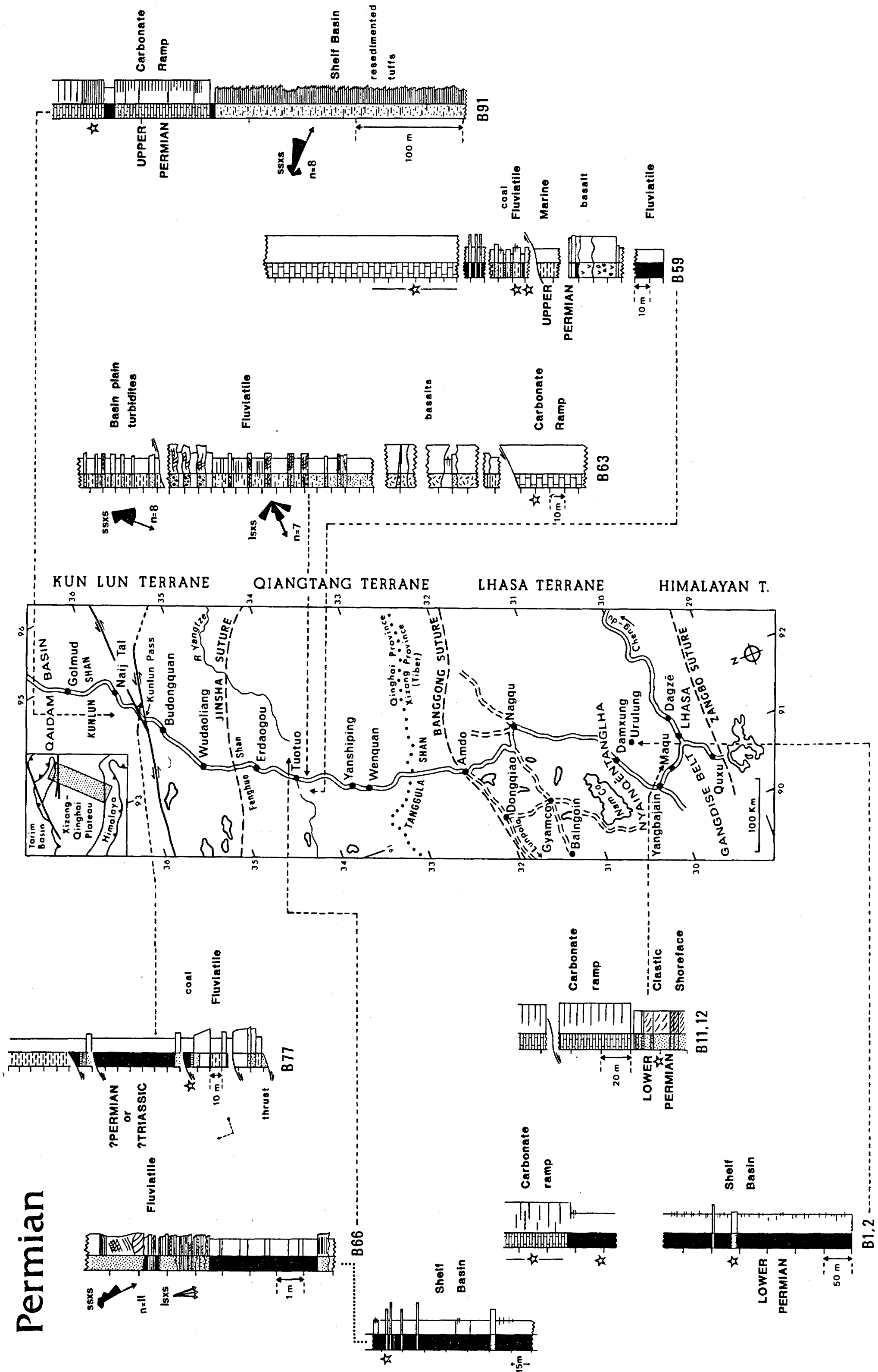

Figure 6. Distribution of Permian measured sections, their lithofacies, environmental interpretations, age determinations and palaeocurrent distributions. See text for discussion and further data. Key in figure 2.

(*b*) *Qiangtang Terrane*

Very thick sequences of Permian deposits crop out in the northern part of the Qiangtang Terrane around the Tuotuo River. They are included in the Kaixinling and Wuli Groups which may total over 6 km in thickness.

Section B59, south of the Tuotuo River, begins with undated variegated red/green mudrocks and thin purple sandstones of presumed continental (possibly well-drained floodplain) origin. These are succeeded by about 40 m of possibly subaerially erupted agglomerates, tuffs and basalt flows. The thick middle basalt flow shows fine vertical to subvertical tufa veins, perhaps recording a lengthy period of weathering prior to the eruption of the overlying tuffs. The volcanics are succeeded by 40 m of coal-bearing clastics with marine bands near the base dated as Longtanian (Upper Permian). The clastic lithofacies include dark grey carbonaceous mudrocks, a pale grey mudrock with well-defined vertical rootlets, 10–80 cm coals, finely interlaminated, silty-streaked mudrocks and 5–20 cm sharp-based possibly tuffaceous medium/coarse lithic-rich sandstones. This facies assemblage is inferred to have evolved from marginal marine to a sheltered bay/lake complex bounded by vegetated wetlands. The periodic sandy influxes are probably products of floods originating from distant distributary channels. A major transgression evidenced in Section B59 is recorded by a rapid upward transition via shoal-water algal packstones to thinly interbedded mudrocks and lapilli-bearing limestones. Finally a continuous spread of carbonate developed, now represented by dark, irregularly bedded fusulinid wackestones (> 200 m) with frequent horizons of chert nodules. The carbonates, dated as early Upper Permian (Smith & Xu, this volume, Appendix, Locality B59), indicate the construction of a carbonate ramp.

In an adjacent section, (B60, B61), similar fusulinid/crinoidal wackestones with abundant chert nodules are seen in faulted contact with four andesitic volcanic flows (> 60 m) of extensional rift affinities (Pearce & Mei, this volume). The lavas are interbedded with continental clastics (up to 8 m) showing southwest-directed, small-scale cross-stratification. One flow shows an irregular and highly vesiculated top capped with finely laminated chert. Succeeding thick fluviatile red beds are of uncertain age but the occurrence of possibly Permian limestone pebbles in them suggests a Triassic (or younger) age. Sedimentary structures record a palaeoflow towards the southwest. These redbeds are faulted in turn against turbiditic sandstones and grey mudrocks of uncertain age (section B62).

Section B66 exposes the Upper Permian Wuli Group where fossiliferous shelf-basin mudrocks and thin limestones coarsen upwards into a thick sequence (> 150 m) of rapidly alternating unfossiliferous fine sandstones and muddy siltstones. The sheet-like sandstones show sharp, often erosional, bases and internal upper phase plane-bed lamination, climbing ripple cross-lamination and rare large-scale cross-stratification (sets up to 65 cm thick). Grading is commonplace and convolute laminae and overturned foresets are occasionally seen. We interpret these lithofacies as sheet flood deposits on a low-gradient alluvial cone. Palaeocurrent data indicate a persistent flow to the southeast.

(*c*) *Kunlun Terrane*

Permian sections in the northern Kunlun Terrane around Naij Tal contrast dramatically with those described above. Around Wanbaogou Shan (Locality B91) the Hongshuichan Formation (Upper Permian) includes a thick lava sequence at the base, overlain by > 200 m

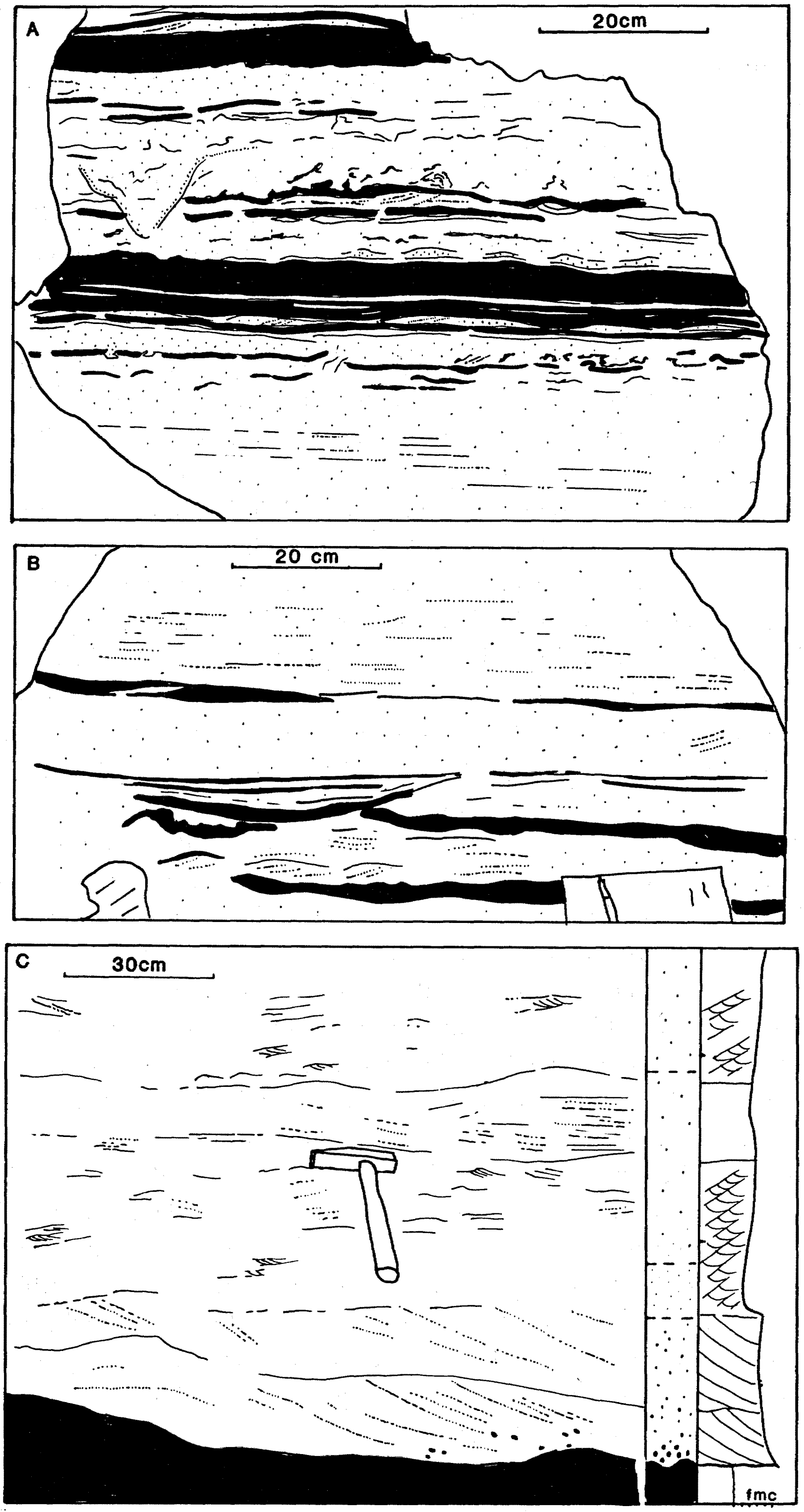

FIGURE 7. 7A/7B – Sketches from photographs and field observations of Permian resedimented tuffaceous fine sandstones and muddy siltstones (black shading). Note sharp-based sandstones with scoured basal contacts, wave-modified current ripple formsets and frequent lenticular muddy drapes. Locality B91. 7C – Field sketch and summary log to show possibly Permian fluviatile facies of sheet flood origin. Wuli Group, Lower Permian. Locality B66.

of chloritic fine to medium tuffaceous sandstones and siltstones. The sandstones are thinly bedded (5–25 cm) and frequently show grading, parallel lamination, cross-lamination and current-ripple formsets (figure 7). Scoured basal contacts, sometimes channelised, are typical. These features indicate that the sandstone and siltstone units probably consist of resedimented tuffs and other detritus, possibly representing the distal portion of a shelf-basin storm deposit or shelf-basin fan. Current structures prove flow to the ESE in the resedimented units. The clastic sequence is overlain by a thick (> 800 m) limestone succession. This includes skeletal wackestones, pseudobreccias and thin calcitised chicken-mesh anhydrites, and is interbedded with tuffaceous sands at the base. Cross-stratified grainstones with crinoidal debris follow quickly, interpreted as shallow, shore-face facies. Cross-stratification indicates transport to the southeast. Higher beds are thin-bedded fine calcareous silts and limestones, often with regular centimetre banding disrupted periodically by bioturbation. They are completely unfossiliferous and represent deposition either on shallow mud-flats or in a distal shelf-basin. The succession continues with unfossiliferous massive-bedded white limestones and then thinner-bedded limestones, often red. The whole succession is in excess of 200 m thick. The red limestones are fossiliferous, with layers of brachiopod shells and crinoid debris. The brachiopods prove a late Permian age for the sequence.

(*d*) *Permian palaeogeography* (figure 16)

(i) *Lhasa Terrane*

Permian sequences record the major progradation and development of a carbonate ramp over much of the southern part of the Lhasa Terrane (and indeed over much of Tibet), in an area that was previously shelf-basinal in character. No evidence was seen during our expedition of contemporaneous shelf-break or oceanic facies, but some extensional tectonic effects upon basin evolution are suspected because of the continued eruption of the possible back-arc Dhagze volcanics (see Pearce & Mei, this volume).

(ii) *Qiangtang Terrane*

As for the Carboniferous, we have no palaeomagnetic control on the palaeolatitudes of this terrane. The Wuli Group represents a Lower Permian shelf-basin which was filled by fluviatile clastics derived from the northwest. Following the coastal plain wetland facies of the Kaixinling coal basin, carbonate ramps developed in mid-Permian times, succeeded by an interval of basaltic/andesitic volcanism of extensional rift affinities.

(iii) *Kunlun Terrane*

Resedimented tuffaceous sandstones of the Wanbaogou Shan are interpreted as storm deposits in a shelf basin. Cessation of volcanism was followed by carbonate ramp development.

Triassic (figure 8)

Triassic rocks are widely distributed over Tibet, being present on all three terranes.

(*a*) *Lhasa Terrane*

Sequences at Doilungdeqen northwest of Lhasa define the Chaqupu Group (300 m). Ammonites above an internal disconformity date them as Upper Anisian (Middle Triassic, see

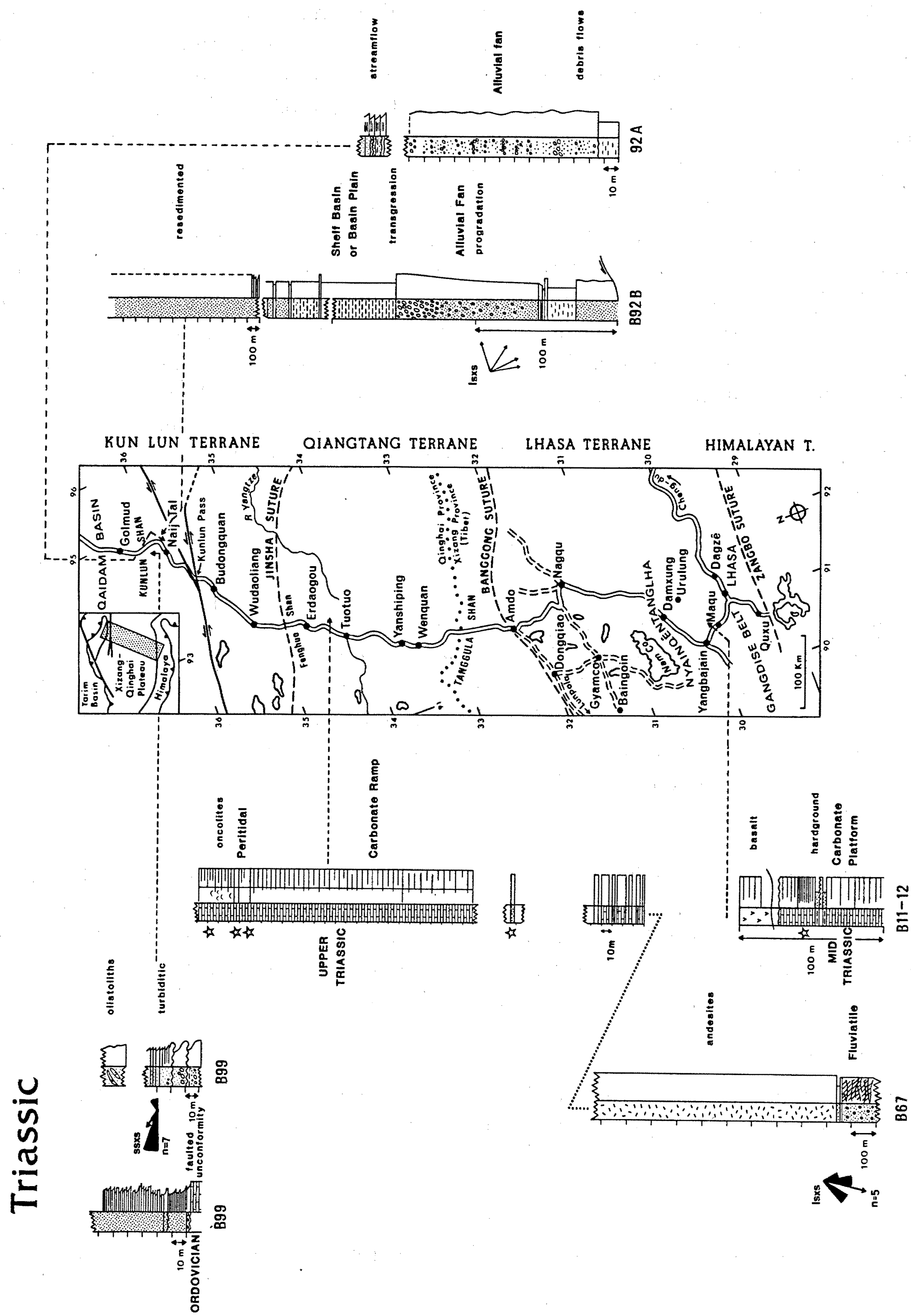

Figure 8. Distribution of Triassic measured sections, their lithofacies, environmental interpretations, age determinations and palaeocurrent distributions. See text for discussion and further data. Key in figure 2.

Smith & Xu, this volume, Appendix, locality B12). The Chaqupu Group is predominantly dark lime wackestone deposited on the lower slopes of a carbonate ramp. About halfway up the logged sequence there is a prominent bed with fissures (up to 40 cm deep) coated by 20 cm of dark ferruginous crust. Overlying chlorite-rich spherulitic mudrocks rest with slight angular discordance on the fissured horizon and pass upwards into ammonoid-bearing Upper Anisian limestones with occasional haematitic crusts on bedding planes. The topmost (6 m) limestone horizon is a grainstone with molluscan fragments and deep fissures and encrustations as before. The encrusted and fissured horizons are interpreted as products of periodic carbonate ramp fragmentation, probably caused by extensional faulting which generated local unconformities due to differential tilting. It is interesting to note that rapid water deepening, fracturing and exhalative mineralisation are characteristic features of Tethyan carbonate platform break-up in European Triassic sequences (Bernoulli & Jenkyns 1974). The sequence is overlain by 300–1000 m of basalt and andesitic lavas (Pearce & Mei, this volume).

Exposures of late-Triassic rocks are seen in the Qibulung area southeast of Urulung (Localities B3, B4) in a series of thrust-related folds. Wackestones with scattered bivalve and crinoid fragments occur in one thrust slice. A section to the north reveals thinly-bedded (15–30 cm) skeletal grainstones alternating with silty clastic mudrocks. The grainstones show faint internal parallel laminations and are interpreted as resedimented limestone turbidites of basin-plain origin. They provide additional evidence for carbonate platform break-up in late Triassic times, with the development of marked platform margins, perhaps fault-bounded. Other outcrops of limestone turbidites occur, as at locality B23, approximately 50 km northwest of Damxung (see Kidd *et al.*, this volume, field slips; Microfiche, in pocket), but have not been dated palaeontologically.

(*b*) *Qiangtang Terrane*

As described below, the central and southern parts of the Qiangtang Terrane are dominated by an extraordinary thickness of Jurassic strata. In the north, extensive and important outcrops of Triassic rocks occur in the Zhakongjian Mountains (Locality B67). Here, > 150 m of pebbly, cross-stratified coarse sandstones make up the lowest strata exposed. The sandstones are apparently multistorey with frequent erosion surfaces separating trough cross-stratified units up to 5 m thick. Cross-stratification azimuths indicate flow to the south. The 0.5–3 cm sub-rounded granules and pebbles are predominantly of quartz and black/green chert. Modal analyses prove mature quartz arenite compositions with high proportions of metamorphic polycrystalline quartz and sedimentary chert in the sand-size fraction. A thin possibly marine limestone caps the sequence and underlies a series of thick (> 800 m) porphyritic andesite flows of island arc affinities (Pearce & Mei, this volume).

The andesites are overlain by at least 200 m of limestones, but the contact is not exposed. These limestones are well bedded (30–40 cm), pale, sparsely skeletal wackestones of carbonate ramp aspect. The lowermost are rich in chert nodules. Ammonoids occur in the topmost units. Conodonts date the sequence as Norian (Upper Triassic; Smith & Xu, this volume, Appendix, locality B67). Several horizons in the upper part of the sequence show well developed algal oncolites and other stromatolitic laminations. Sometimes algal laminae coat the brachiopod valves. The upper part of the sequence thus records gradual shallowing-upwards into peritidal environments as the carbonate ramp prograded seawards.

(c) *Kunlun Terrane*

A highly deformed sequence of clastic strata, the Bayan Har Group, outcrops from the Jinsha Suture northwards to the Kunlun Pass. No faunas were discovered during the present expedition but fossils from areas to the east indicate a Triassic age (Smith & Xu, this volume). The deformation makes a thickness estimation extremely difficult but it may total several kilometres. Exposures are predominantly siltstone and mudrock, now deformed into slates. Some show rare thin (5–20 cm) very fine sandstone/coarse siltstone beds with sharp tops and bases. One example of small-scale cross-lamination indicated a palaeoflow to the west, similar to that deduced from microflute casts (*fide* J. F. Dewey). Most of these lithofacies are tentatively interpreted as continental rise deposits, possibly originating as contourites and accreted on to the southern margin of the Kunlun Terrane as an accretionary prism during the Triassic, an interpretation supported by structural data (Coward *et al.*, this volume).

Between the two strands of the Kunlun Fault along the southern margin of the Xidatan Valley, there are sections through a poorly dated succession which appears to be Permo–Triassic (the section, B77, is shown graphically with the Permian sections of figure 6). They occur at the junction between the low metamorphic grade slates of the Bayan Har Group to the south and the high grade rocks (garnet schists, phyllites and phyllenites) to the north. The rocks are highly thrust and intruded by sheared porphyritic granitoids dated (Rb/Sr) at 195 Ma (Lower Jurassic; Harris *et al.*, this volume). Section B77 (figure 6) is highly schematic and details of the true succession remain obscure. Undoubtedly, however, several sedimentary lithofacies occur in the various thrust slices. They include graded coarse wackes, dark mudrocks, carbonaceous mudrocks and at least one coal seam. The coarser clastic units contain angular acidic volcanic detritus. A mature quartzite unit (5 m thick) is also present. The variety of lithofacies is remarkable and it seems clear elsewhere (Localities M253, M245, M248; data of W. S. F. Kidd & J. F. Dewey) that individual thrust slices may represent olistolithic masses.

Sections of suspected Triassic age occur (B99) north of Naij Tal and show faulted and possibly erosive relationships with the underlying Ordovician. They must be younger than Anisian–Carnian because of the 240–224 Ma ages obtained from the Golmud batholith to the northeast (Harris *et al.*, this volume, Isotope Geochemistry, Locality G273), clasts of which are common in the sections. A late Triassic or early Jurassic age is therefore likely. Thick (> 200 m) polymict conglomerates and granule grade sandstones contain a large variety of clasts, some up to 1.5 m in apparent maximum diameter. Sedimentary structures are absent from the conglomerates, the large clasts of which are frequently matrix-supported. We interpret them as debris flows. The granule-grade units and sandstones occasionally show normal grading, cluster bedforms and parallel laminations, indicating streamflow origins. An upward trend to finer grain sizes is seen in section B92A, but B92B shows part of a coarsening-upwards sequence overlying an unfossiliferous limestone bed. Cross-stratification is seen in finer-grained sandstones in both sections, giving a flow direction towards the southeast. Crude imbrications of the larger boulders confirms this. The many types of clast in the conglomerates include various granitoids, microgranite, quartz porphyry, rhyolite, basic volcanics, gabbro, micaceous wackes, white limestone, dolomitic marble, purple-brown sandstone and quartz. The granites and limestone clasts are usually the largest. In all the sections the predominant clast type changes upwards from quartz to limestone to granitoid. Some exposures (eg B99) show large (> 20 m) olistoliths of possibly Upper Ordovician limestones. Depositional environments are interpreted as subaerial alluvial fans and fan deltas draining a hinterland exposing Ordovician 'basement' and newly unroofed Triassic granitoids.

The conglomeratic sequences are overlain by thick (2 km) successions of indeterminate origins, including pale quartzitic sandstone, highly cleaved fine-grained wackes and greenish tuffaceous (possibly resedimented) fine to medium sandstones.

(*d*) *Triassic palaeogeography* (figure 16)

(i) *Lhasa Terrane*

No palaeomagnetic results are available for the Triassic from the Lhasa Terrane. Fragmentation of the Lhasa carbonate platform by extensional tectonics is envisaged, with eventual mantle melting to produce the Quesang volcanics above a back-arc attentuation zone (Pearce & Mei, this volume). These magmo-tectonic processes caused marked bathymetric differences during late Triassic times.

(ii) *Qiangtang Terrane*

The Yaxico/Zhakongjian andesites yield a palaeolatitude (Lin & Watts, this volume) of around 29° ± 14° N for the Terrane in Triassic times. Accepting the andesites as arc-related (Pearce & Mei, this volume), the underlying mature fluviatile clastics imply uplift of basement in the northern Qiangtang Terrane prior to southerly subduction of Jinsha ocean crust. Cessation of subduction was followed by submergence of the arc and establishment of a carbonate platform.

(iii) *Kunlun Terrane*

The coarse clastic rocks of the northern Kunlun represent subaerial and possible subaqueous fans derived from the Triassic plutonic/volcanic arc to the north (Golmud batholith etc) but their ages cannot be directly determined. The sedimentological data suggest that they represent unroofing molasse and thus probably postdate active subduction and possibly collision. The Bayan Har Group repesents deposition along a former continental margin lying at the southern margin of the Kunlun Terrane.

Jurassic (figure 9)

Jurassic rocks are present in the Lhasa and Qiangtang Terranes, but probably do not occur north of the Jinsha suture in the Kunlun Terrane.

(*a*) *Lhasa Terrane*

Kimmeridgian carbonates and siltstones are well-exposed at Xiaqiong Lake (Localities B28, B29). The latter area lies close to the supposed line of the Banggong Suture and may possibly be of Qiangtang Terrane origins. In the lower part of the succession three massive (10–20 m) limestones with abundant stromatoporoids and occasional coral patch reefs are separated by dolomitic siltstones. The siltstones contain interbedded, thin sharply-based sandstones with wave-ripples and flat laminations interpreted as lagoonal washover deposits. Nerinaceid gastropods and thick-spined echinoids in the limestones indicate shallow sublittoral conditions. Beach strand concentrations of foraminiferans are found in the dolomitic siltstones and at least one serpulid-encrusted beachrock horizon occurs. Marine infaunal spatangoids occur at one level.

Around Gyamco (localities B32, B33), in the northern part of the Lhasa Terrane, a thick (> 1.3 km) succession of late Jurassic to ?early Cretaceous clastic sediments is present. The succession begins with monotonous black basinal mudrocks containing subordinate resedimented carbonates rich in molluscs and derived from nearby shallow shelf environments, judging from the abundance of nerinaceid gastropods and rare compound scleractinian coral fragments. Higher up 0.1–0.3 m graded wackes are common, interbedded in thicker (2–5 m) mudrocks with rare wacke units up to 1 m. The wackes are very fine to fine-grained and show sedimentary structures indicative of Bouma A to E divisions. One C division yielded a palaeocurrent towards the west. A divisions frequently contain molluscan debris. These lithofacies are interpreted as basin-plain turbidites probably derived, at least in part, from a colonised shelf which may have lain to the east.

South of Dongqiao, at Loubochong (locality B38), there is an inverted succession of possibly Upper Jurassic sedimentary rocks which stratigraphically overlie vesiculated pillow lavas of oceanic arc affinities (Pearce & Mei, this volume). The topmost pillow lavas are veined by red cherts and overlain by a massive red brecciated and mineralized chert horizon up to 1.5 m thick. This may have an exhalative origin. An overlying bedded greenish chert is succeeded by 5 m of siliceous mudrocks containing thin tuffs and 50 m of silty mudrocks with thin interbedded lenticular cherts. The mudrocks contain the trace fossil *Chondrites*. The topmost horizon contains thin silicified graded beds of turbiditic aspect, with Bouma A–C divisions occasionally present. These lithofacies resemble deposits of resedimented cherts and may have formed on an oceanic arc slope in an area of high oceanic water productivity.

West of Dongqiao, there are outcrops which constrain the age of obduction of the oceanic arc crust previously inferred. At locality B41 a thrust mass of ophiolitic serpentinite is succeeded by 2 m of nodular rock rich in chalcedonic silica and overlain by a yellowish, clayey pisolitic deposit. We interpret this as a silcrete duricrust developed on the thrust serpentinite during a lengthy period of pedogenesis under a seasonally humid climate. An overlying detrital interval, with large chromite-rich clasts and angular reworked chert fragments is succeeded by a second soil horizon of red pisolite-rich mudrock (3.5 m) and a goethite-rich boxstone layer (1.5 m) both rich in chert. This is interpreted as a ferrosiallitic soil, developing perhaps under a more humid climate than the silcrete below. Both soil horizons are succeeded by clastic sediments deposited in hollows upon the underlying duricrust surface. Micaceous muddy siltstones with plant fragments (2.5 m) are cut by thin sharp-based and cross-laminated very fine sandstones of crevasse aspect. The whole sequence is capped by siltstones and mudrocks rich in rootlets, with one thin ferruginous soil horizon. These products of an encroaching, low-energy, coastal plain are succeeded by poorly exposed granule conglomerates rich in very angular chert and limestone clasts and, significantly, chromite grains. The latter indicate continued reworking of serpentinite masses. The fluviatile clastics are overlain by a 0.5 m calcareous very fine sandstone with cross-cutting low angle laminations and numerous escape burrows. This apparently transgressive beach facies is succeeded by > 3.5 m of richly fossiliferous shallow marine limestones with abundant *in situ* colonies of *Cladocoropsis* which, with occasional scleractinian corals, forms a primary framework. The corals date the underlying beds as no younger than Tithonian (late Jurassic).

(*b*) *Qiangtang Terrane*

Thick (5 km) Jurassic successions occur over much of the southern half of this Terrane, from Amdo northwards through the Tanggula Shan to Yanshiping. In the north continental clastics predominate, while marine limestones become increasingly important southwards.

The northernmost proven Jurassic that we encountered lies south of the Tuotuo River, where a coal-bearing sequence of deltaic aspect occurs. Channel sandstones yield evidence of flow towards the south.

In the thick Middle and Upper Jurassic successions exposed around Yanshiping (figures 9, 10) the clastic lithofacies include:

(1) Variegated red/green mudrocks with suncracked surfaces and thin (< 1 m) horizons of calcitic nodules resembling calcretes. These are interpreted as deposits of well-drained, periodically-arid floodplains subjected to periods of slow sedimentation which encouraged soil formation.

(2) Thin red/green mudrocks as above, with thin fine sandstone interbeds (figure 10B). These are sharp-based and often graded. They show planar laminations and internal current-ripple cross-laminations capped by symmetrical, flat-topped and interference ripple trains. They are interpreted as flood crevasse/overbank splays introduced into shallow lakes or bays subject to wave and possibly tidal action prior to desiccation.

(3) Thicker (usually < 4 m) erosive-based fine to medium sandstones show well-developed internal cross-stratification, basal scour marks and rare lateral accretion surfaces (figure 10A). They are interpreted as the deposits of sluggish, possibly meandering, river channels traversing the lower reaches of the Yanshiping coastal plain. Palaeocurrent structures indicate flow to the south and southwest. Some sandbodies yield non-marine bivalves in lag deposits.

(4) Aggregates of thin siltstone and very fine to fine sandstone form coarsening-upward sequences that pass up from green floodplain/lacustrine mudrocks (figure 10C–10D). Internally these are dominated by small-scale cross-lamination of current ripple origin, but with frequent modifications due to waves. Sometimes the coarsening-upwards sequences are capped by thin limestones. The sequences are interpreted as shallow lacustrine infills by small crevasse deltas. Structures indicate flows predominantly towards the west.

(5) Dark grey mudrock alternating with muddy dark molluscan coquinas rich in monotypic *Liostrea* or corbulid bivalves. Occasional algal nodules occur. At least one karstified bedding plane with abundant isocrinoid columnals and ribbed bivalves is present. These are interpreted as the products of brackish-to-marine bay/lagoons that periodically became fully marine. Analogous present-day biofacies occur along the Texas Coast.

As noted, the southern outcrops of Jurassic rocks include more marine carbonates, with common peritidal grainstones (including oolites) and lower-to-mid ramp packstones and wackestones. An oyster-encrusted hardground of shallow subtidal aspects was discovered at locality B49. The overlying beds yield an abundant and varied fauna of bivalves, brachiopods and echinoids of Bathonian or Callovian age (Middle Jurassic; Smith & Xu, this volume, Appendix). Kimmeridgian (Upper Jurassic) calcareous mudrock of shelf-basin origin occurs at locality B50.

These various marine lithofacies frequently interdigitate with fine-grained red alluvial coastal plain mudrocks in the southern area. At several localities thick evaporites are exposed as halokinetic domes and pillows. Close examination of section B51 reveals red/purple

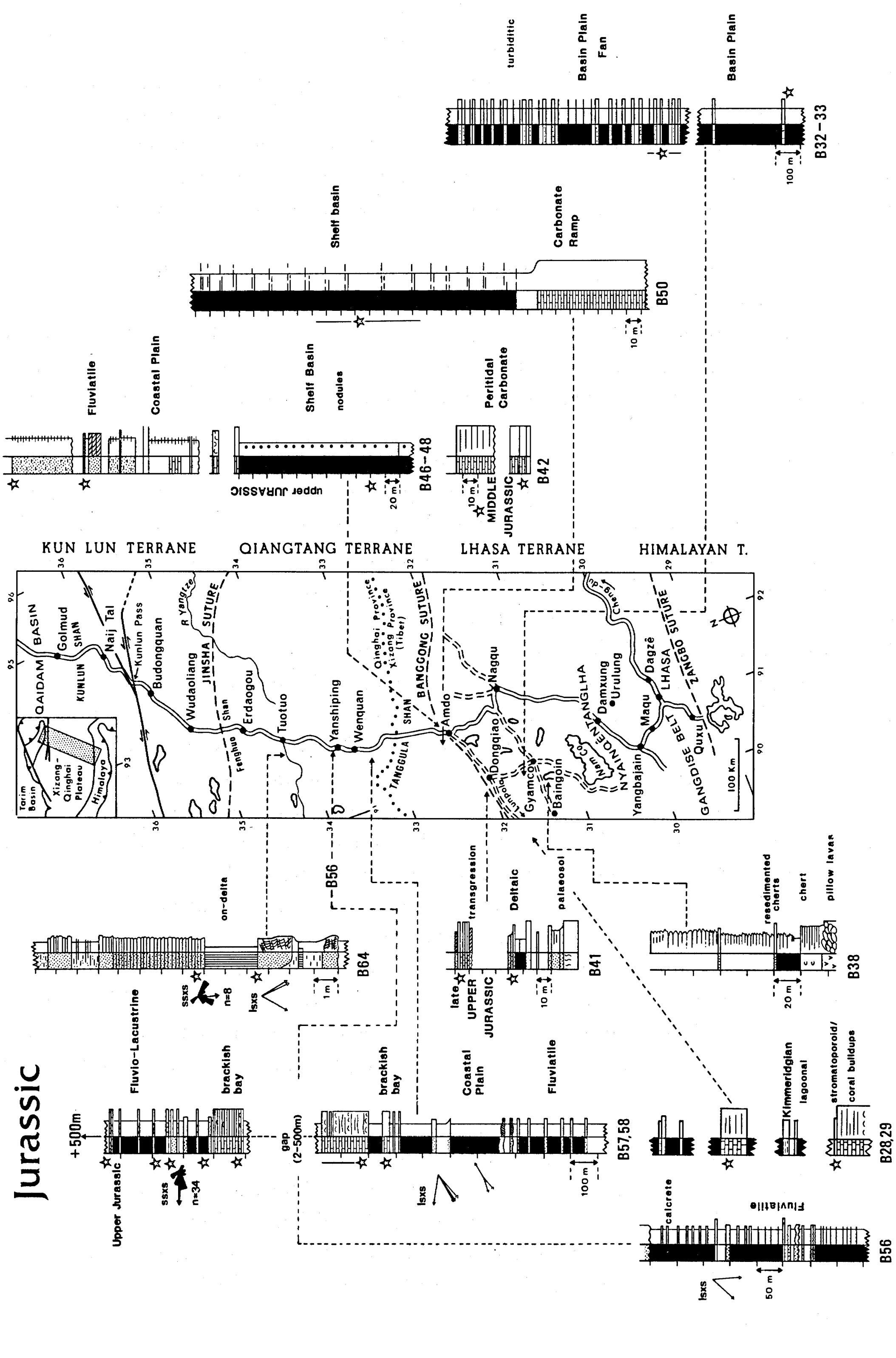

FIGURE 9. Distribution of Jurassic measured sections, their lithofacies, environmental interpretations, age determinations and palaeocurrent distributions. See text for discussion and further data. Key in figure 2.

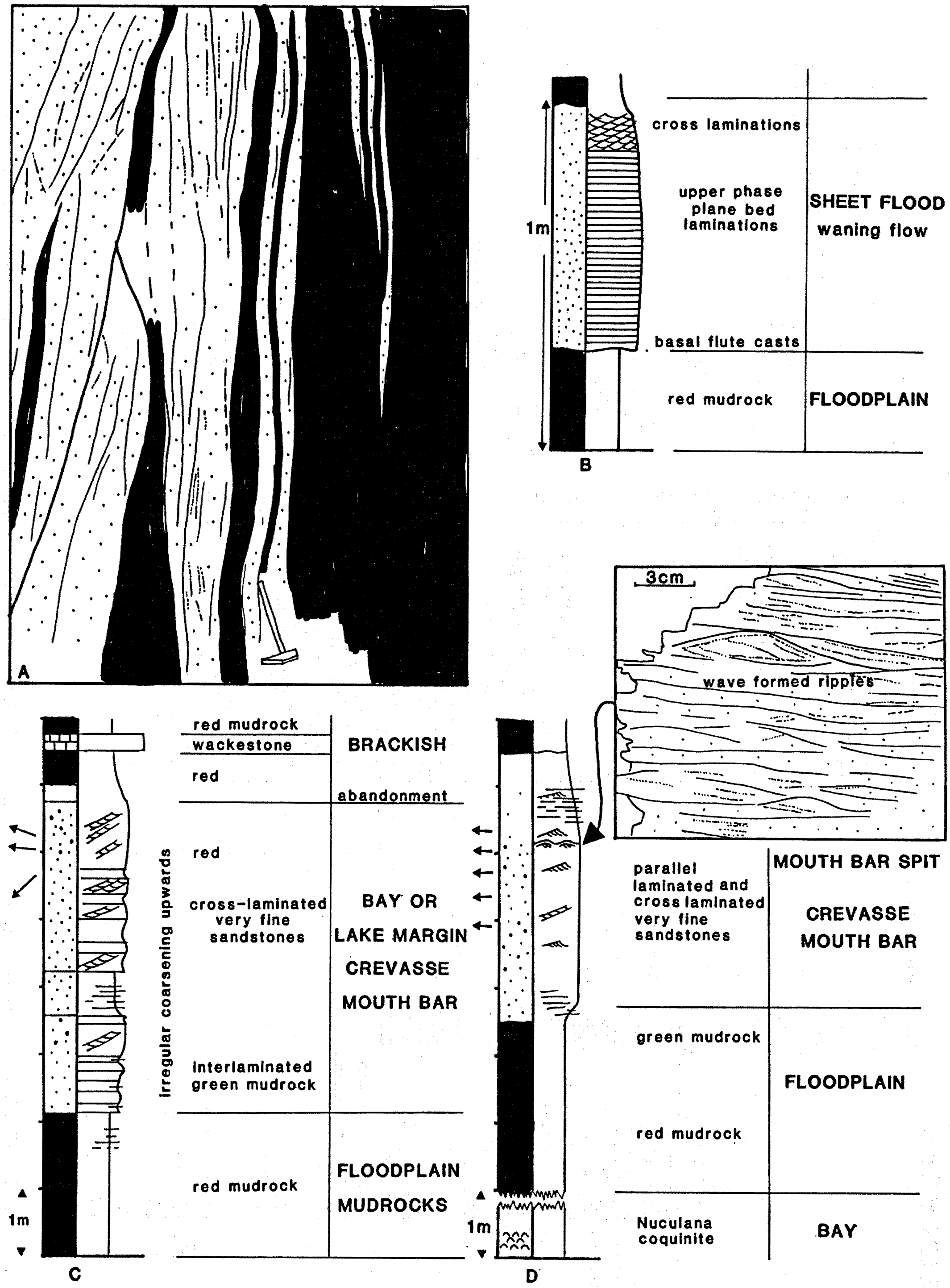

FIGURE 10. Field sketches and logs to illustrate the commoner Middle Jurassic lithofacies of the Qiangtang Terrane around Yanshiping/Wenquan. 10A – Tectonically-vertical bedded fluviatile shallow channel sandstones and floodplain mudrocks. The beds young from right to left. The sandbody to the left of the hammer (shaft is 35 cm long) contains well-developed lateral accretion surfaces of probable point bar origins. Locality B57. 10B – Log to show sheet flood facies. Locality B57. 10C/10D – Logs to show bay/lake infill cycles. Arrows show palaeocurrent azimuths. Locality B58.

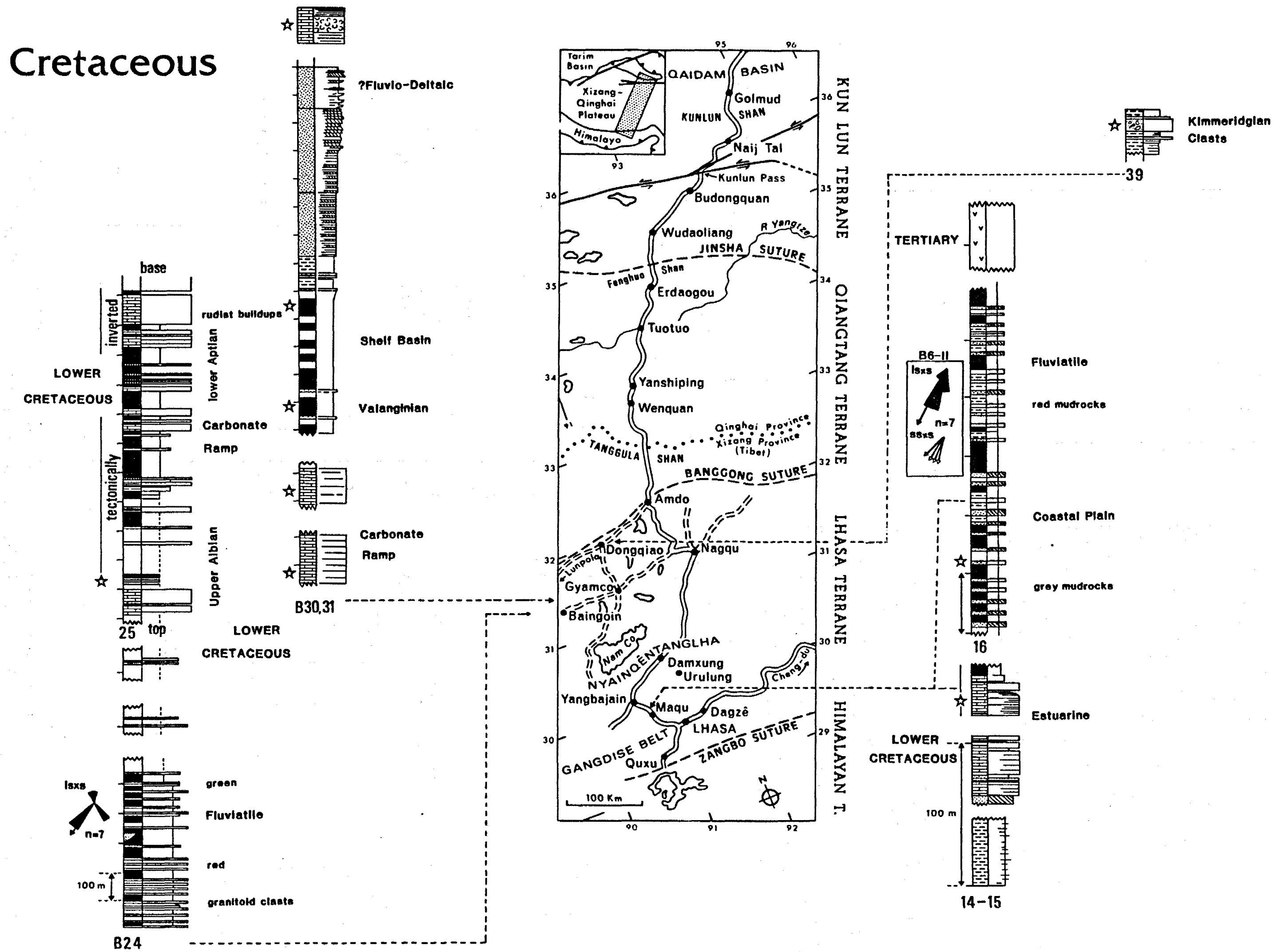

FIGURE 11. Distribution of Cretaceous measured sections, their lithofacies, environmental interpretations, age determinations and palaeocurrent distributions. See text for discussion and further data. Key in figure 2.

laminated fluviatile sandstones overlain by 8 m of gypsum with fine chicken-mesh textures. Originally these were probably chicken-mesh anhydrites of supratidal sabkha origin, indicating that the early Jurassic climate was periodically intensely arid. The gypsum is succeeded by unfossiliferous micrites of uncertain pedigree.

The above lithofacies relationships indicate a regional north-to-south change from continental to marine influences and derivation of generally mature and relatively fine-grained detritus from the north.

(*c*) *Jurassic palaeogeography* (figure 16)

(i) *Lhasa Terrane*

Deposits of the former Banggong oceanic tract indicate development of a fertile oceanic arc slope with extensive cherts. The clastic successions of 'flysch' aspects around Gyamco indicate development of continental margin environments. Subsequent uplift of ophiolitic-capped basins is shown by the development of thick residual duricrusts. Renewed subsidence in very late Jurassic times accompanied several phases of marine transgression which, as will be seen, continued into early Cretaceous times over several parts of the northern and southern Lhasa Terrane.

(ii) *Qiangtang Terrane*

The thick fluviatile Middle to Upper Jurassic of the southern Qiangtang Terrane is interpreted as a wedge of clastic molasse derived from the newly-fused orogenic belt formed by the Kunlun/Qiangtang Terrane collision in late Triassic times (Coward *et al.*, this volume). Palaeocurrents, regional facies trends and fining trends indicate a north to northeast derivation. The clastic wedge was deposited on the southern continental margin of the Qiangtang Terrane and was eventually deformed by the collision of the Qiangtang and Lhasa Terranes during late Middle to early Upper Jurassic times. Palaeomagnetic data from the fluviatile redbeds (Lin & Watts, this volume) yield a palaeolatitude of $39° \pm 8°$ N.

Cretaceous (figure 11)

We observed Cretaceous rocks only in the Lhasa Terrane, where they outcrop widely. The Qiangtang and the Kunlun Terranes appear to have been upstanding non-depositional areas throughout the Cretaceous.

(*a*) *Lhasa Terrane*

No fossiliferous rocks of late Cretaceous age are known in the Lhasa Terrane (see discussion of Yin *et al.*, this volume). To the north of Lhasa there are widespread outcrops of the Linbuzong, Chumulong and Takena Formations. At Sections B14 and B15, near Quesang, the sequence begins with alternating dark carbonaceous muddy siltstones and thinly-bedded (10–50 cm) fine-medium sandstones (> 50 m). The sandstones are sharp-based and faintly cross-laminated. The fine intervals may contain siderite nodules and vertical rootlets. These features indicate a poorly-drained floodplain.

Above a significant exposure gap comes a cross-stratified sandstone followed by alternating limestones, cross-stratified sandstones and mudstones. These yield a hyposaline to mesohaline fauna of oysters, gastropods and ostracods, with occasional horizons of possibly restricted-marine coarse-ribbed bivalves. The limestones are dark wackestones with scattered quartz grains. The sequence is interpreted as bay or estuarine, oscillating between oyster- and gastropod-dominated benthos suggesting fluctuating salinities.

Overlying the limestones is a great thickness (> 1 km) of clastics, belonging to the Takena Formation (figure 12). The lower half of these comprises alternating mudstone, siltstone and fine to medium grained sandstones. The fine beds contain siderite nodules, carbonaceous fragments and siltstone interlaminae. The coarse members range up to 5 m in thickness and are usually sharp-based. The latter are sometimes strongly erosional, with overlying 'lag' concentrates of exotic and intraformational pebbles. Large scale cross-stratification sets are common, sometimes lying between even larger sigmoidal bedding surfaces of lateral accretion origin (figure 12). These lithofacies are interpreted as fluvio-distributary channels which meandered to the southeast through poorly-drained floodplains. The upper half of the succession is similar, but with prominent red colouration suggesting that the floodplains became well-drained, allowing early vadose oxidation. Other outcrops of the Takena redbed facies were examined around Ganpa (localities B6–B11) to the north of Lhasa. These have yielded palaeocurrents generally towards the south. A coarsening-upwards sequence is seen (> 200 m), with increasing amounts of cross-stratified multistorey channel sandstones higher up (figure 12C). If it proves to be part of a regional coarsening-upwards trend then a southwards shift in facies belts is indicated. P. Allen (pers. comm. 1987) has observed similar multistorey pebbly and non-pebbly cross-stratified sandstones of fluviatile origins (possibly of braided channel facies) north of Lhasa at Lhunzhub. Palaeocurrent data suggest that these were deposited by south-flowing rivers.

Thick Cretaceous sequences were also examined around Duba, near Baingoin, some 300 km northwest of Lhasa. Here the probable Neocomian clastics (> 700 m) of the Duba Formation are faulted against Tertiary redbeds (figure 14). Dominated by red/green siltstone and mudrock of floodplain aspects, they contain thin calcrete profiles in places. Scattered throughout are feldspathic sandstones and pebbly sandstones, respectively of sheet-flood and channel origins. Both lithofacies are frequently cross-stratified and indicate a mean flow direction to the southwest. The pebbles include abundant granitoids, cherts and hornfelses. These are thought to have been derived from the nearby Baingoin granitoid pluton, dated at around 121 ± 2 Ma (Harris *et al.* this volume) i.e. middle Neocomian. Above come alternating limestones and mudrocks of the Aptian to Albian Longshan Formation (> 200 m). The inverted sequence at locality B25 begins with several massive rudist limestones of early Aptian age, in which the rudists form primary reefs alternating with orbitolinid-bearing mudrocks. Further up there is a brief phase of fine clastics with a mesohaline community of gastropods and bivalves replacing the orbitolinids. Finally, the sequence passes up into a late-Albian limestone/mudrock sequence in which mudrocks predominate. Abundant orbitolinids indicate shallow lagoonal conditions. The entire sequence was deposited in extremely shallow marine environments with rudist patch reefs and back reef lagoons in which the orbitolinids thrived.

The succession at Xiaqiong Lake (figure 11, localities B30–B31; see also Smith & Xu, this volume, Appendix) also comprises non-marine clastics. It overlies Kimmeridgian stromatoporoid/coral buildups and dolomitic siltstones which may extend up to the Jurassic/Cretaceous boundary. Above there is a rapid change to Berriasian/Valanginian siltstones and ripple cross-laminated and cross-bedded sands. The sands are thin at first (1–5 cm) alternating

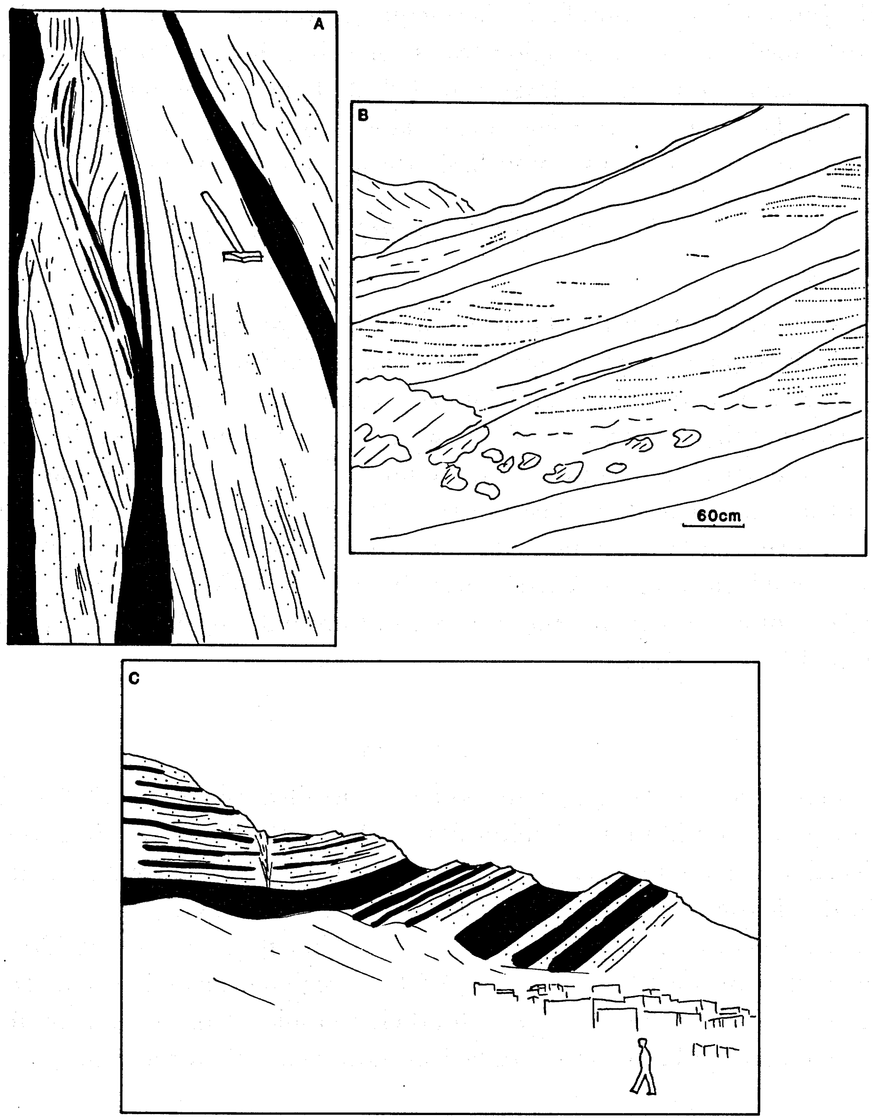

Figure 12. Sketches from photographs and field observations to illustrate fluviatile lithofacies of the Takena Formation in the Lhasa Terrane. 12 A – Tectonically-vertical bedded fluviatile channel sandstones with well-developed lateral accretion surfaces of point bar origins. Mudrocks and siltstones of floodplain and channel-fill origins are shaded. The beds young from right to left. Locality B16. 12 B – Cross-stratified medium-grained sandstones forming part of a thick multistorey sandbody of channel origins. Locality B6. 12 C – Sketch of hillside exposures behind the village of Gampa (looking east) to show a coarsening-upward sequence of fluviatile facies some 150 m thick. Fine-grained units of floodplain origin are shaded black. Locality B7.

with mudstone, but up the sequence thicker (up to 1 m) cross-bedded units predominate, often with sharp-based erosional lower surfaces. These lithofacies are interpreted as fluvio-distributary channel sediments. The upper part of the sequence is dominated by siltstones and fine sandstones with periodic cross-bedded sandstones (20–60 cm) of possible floodplain origins. After a considerable exposure gap, thick-bedded bioclastic packstone limestones with abundant oysters are seen. These have orbitolinid foraminiferans that are Aptian/Albian in age and record a return to shallow marine or restricted marine conditions.

The most northerly outcrop of Cretaceous (locality B39) is also the most difficult to interpret.

Overlying the Jurassic basalt pillow lava–chert sequence south of Dongqiao described previously is a highly deformed melange of conglomerates, breccias, slump folded cherts and turbiditic flysch. The conglomerates contain large rounded clasts of fossiliferous Kimmeridgian limestones, as well as chert and basalt. Hence the melange may have been a 'wild flysch' deposited at the front of a reactivated thrust ramp basin during late Cretaceous or Tertiary times.

(*b*) *Cretaceous palaeogeography* (figure 16)

(i) *Lhasa Terrane*

Palaeomagnetic results from the Takena Formation give a palaeolatitude of 7.6° ± 3.5 °N (Lin & Watts, this volume). We interpret the Cretaceous fluviatile clastics of the area as molasse derived from the north, the hinterland for which must have included the newly-deformed Jurassic sequences of the Qiangtang molassic wedge described previously. Progradation of the clastics was temporarily halted during Neocomian-late Aptian/Albian times when marine transgression led to the deposition of carbonates. Possibly in late Cretaceous times the Takena molasse was deformed into upright folds and eroded prior to extrusion of the arc-related Linzizong andesitic lavas (Pearce & Mei, this volume). The latter represent extrusive portions of the great Gangdise plutonic arc and are dated at around 50 Ma (see Harris *et al*., Isotope Geochemistry, this volume).

Tertiary

There are many areas of Tertiary outcrop across the Geotraverse route, from the northern Lhasa Terrane in the south, to the Kunlun Pass in the north (figure 13). In addition there are very thick Tertiary deposits in the Qaidam Basin just north of the route, but these were not examined in the field and will therefore not be mentioned further.

As we shall see below, the widespread Tertiary sedimentation and subsidence across the entire Tibetan Plateau must have been caused by a regional tectonic event. However, poor dating of the non-marine sequences precludes their tectonic significance being fully exploited at present. Two Tertiary basins were studied in more detail than the rest.

(*a*) *Baingoin/Duba thrust basin*

As shown in figures 13 and 14, this is bounded by a major NW–SE backthrust, which defines the great scarp of the Lang Shan as the Cretaceous hangingwall to the basin. The hangingwall exposes a lower clastic sequence overlain conformably by Aptian/Albian marine orbitolinid limestones (see above). Our fieldwork showed that the fluviatile, possibly Lower Cretaceous, clastics are thrust onto a Tertiary footwall of clastic redbeds.

Adjacent to the thrust (figure 14) there is a poorly-sorted conglomeratic unit containing abundant angular clasts of orbitolinid limestone. The conglomerates are folded into a footwall syncline with a highly developed cleavage on the southwestern limb adjacent to the backthrust. The clasts are identical with the Aptian/Albian limestones outcropping on Lang Shan immediately to the southwest. The conglomerates (> 100 m thick) comprise unstratified, ungraded and matrix-supported units up to 5 m thick, occasionally separated by thin (0.2 m) muddy sandstones. These are interpreted respectively as debris flow deposits with thin impersistent streamflow lithofacies, both presumed to have been deposited on alluvial fans draining to the northeast i.e. away from the thrust hangingwall.

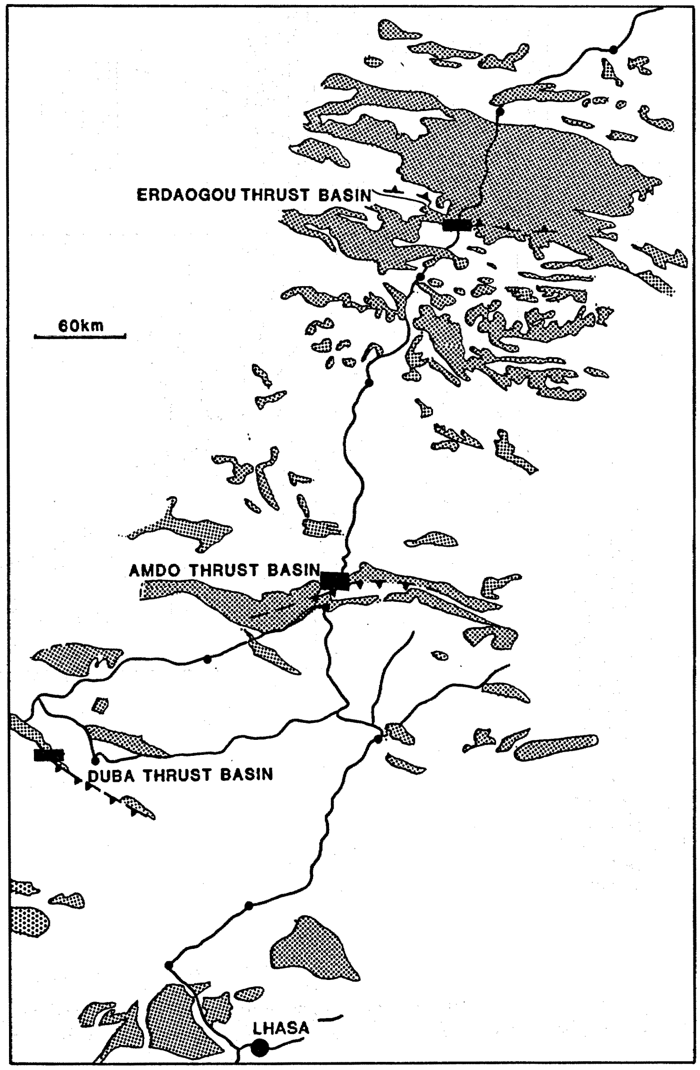

FIGURE 13. Distribution of Tertiary outcrops across the Tibetan Plateau and the location of Tertiary sections studied by us in detail.

Below the conglomerates is a calcareous cross-stratified medium to coarse sandstone member (> 250 m thick) of obvious stream flow origin. Palaeocurrent directions in the northwest of the area are parallel to the line of the thrust, whereas in central areas they run oblique to the thrust outcrop. Cross-stratified sets range from 20–70 cm thick and are predominantly tabular. They occur in stacked sandstone storeys separated by persistent erosion surfaces. The sandstones are interpreted as river channel deposits, probably of sand-bed braided rivers that flowed roughly parallel to the line of the contemporary thrust front. They gradually coarsen-up into the debris flow facies described above, suggesting that alluvial fans from the hangingwall prograded into the axial basin. Clasts of Cretaceous limestones are absent from this sequence, but several large, well-rounded clasts of exotic ignimbrites were found along one erosion surface. These are presumed to have been derived from the Linzizong Group (see Pearce & Mei, this volume).

The oldest sediments, which are not well exposed, include relatively fine-grained siltstones

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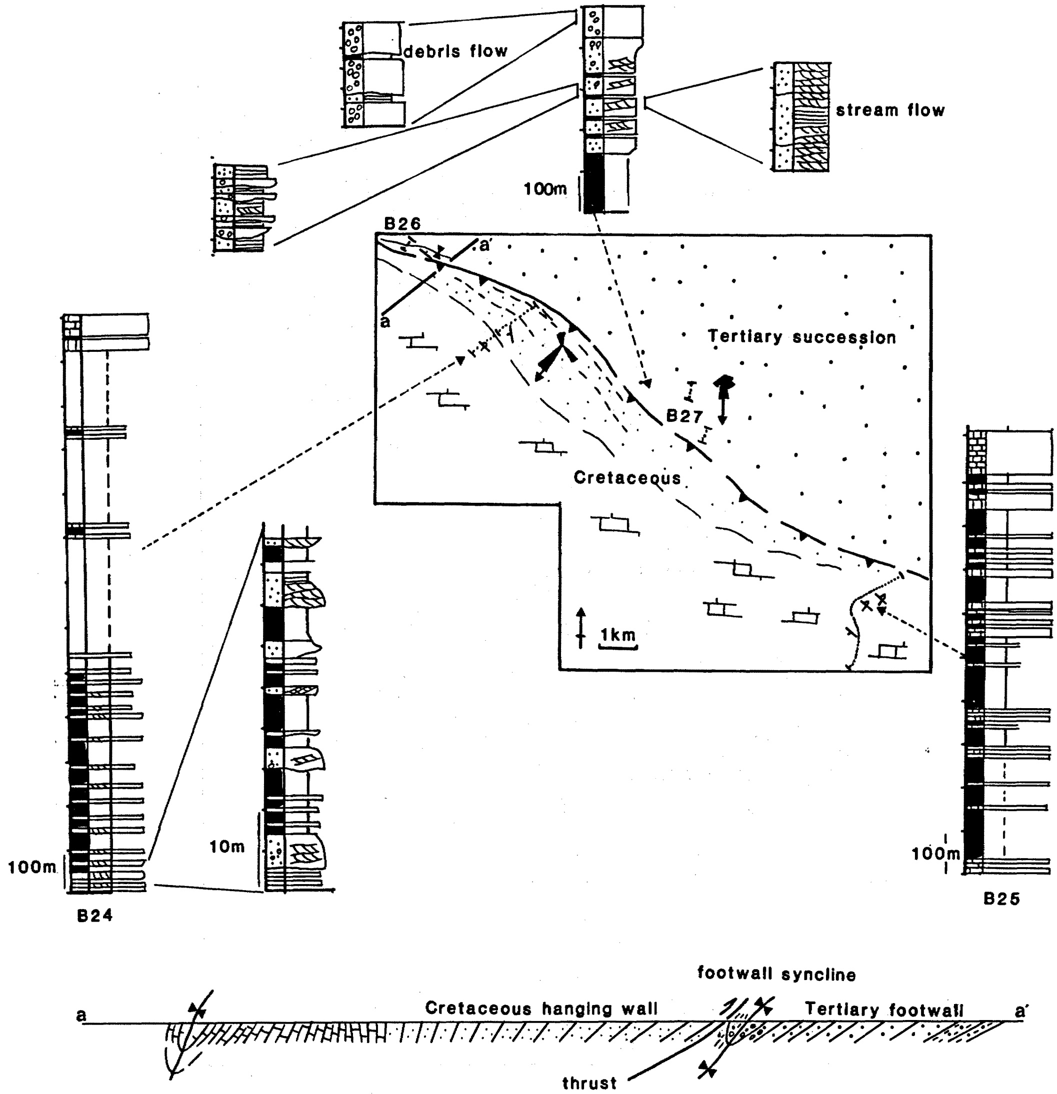

FIGURE 14. Sketch map, logs and section to illustrate the stratigraphy, sedimentology and structure of the Duba thrust basin. Note that the section for B25 is now known to be inverted and is described in true order of deposition in the Cretaceous section of the accompanying text. Rose diagrams indicate palaeocurrent distributions (see Appendix, microfiche, for details). Sketch geological section ignores topography. Localities B24–27.

with sandstone and conglomerate stringers. The latter contain well-rounded micritic pebbles, but with no sign of the distinctive Lang Shan orbitolinid limestone.

The arrangement of the above continental lithofacies strongly suggests that they were generated by a progressively northward-moving thrust fault and growth fold. We visualise the thrust front as eventually cutting out the Mesozoic sequence along its footwall and progressively overriding the alluvium, leading to the observed facies and grain-size trends. Unfortunately we have obtained no fauna or flora from the post-Albian sequence of clastics and thus we cannot be certain about the age of sedimentation and thrusting, save that the possible Linzizong ignimbrite clasts prove a Tertiary age for the sequence.

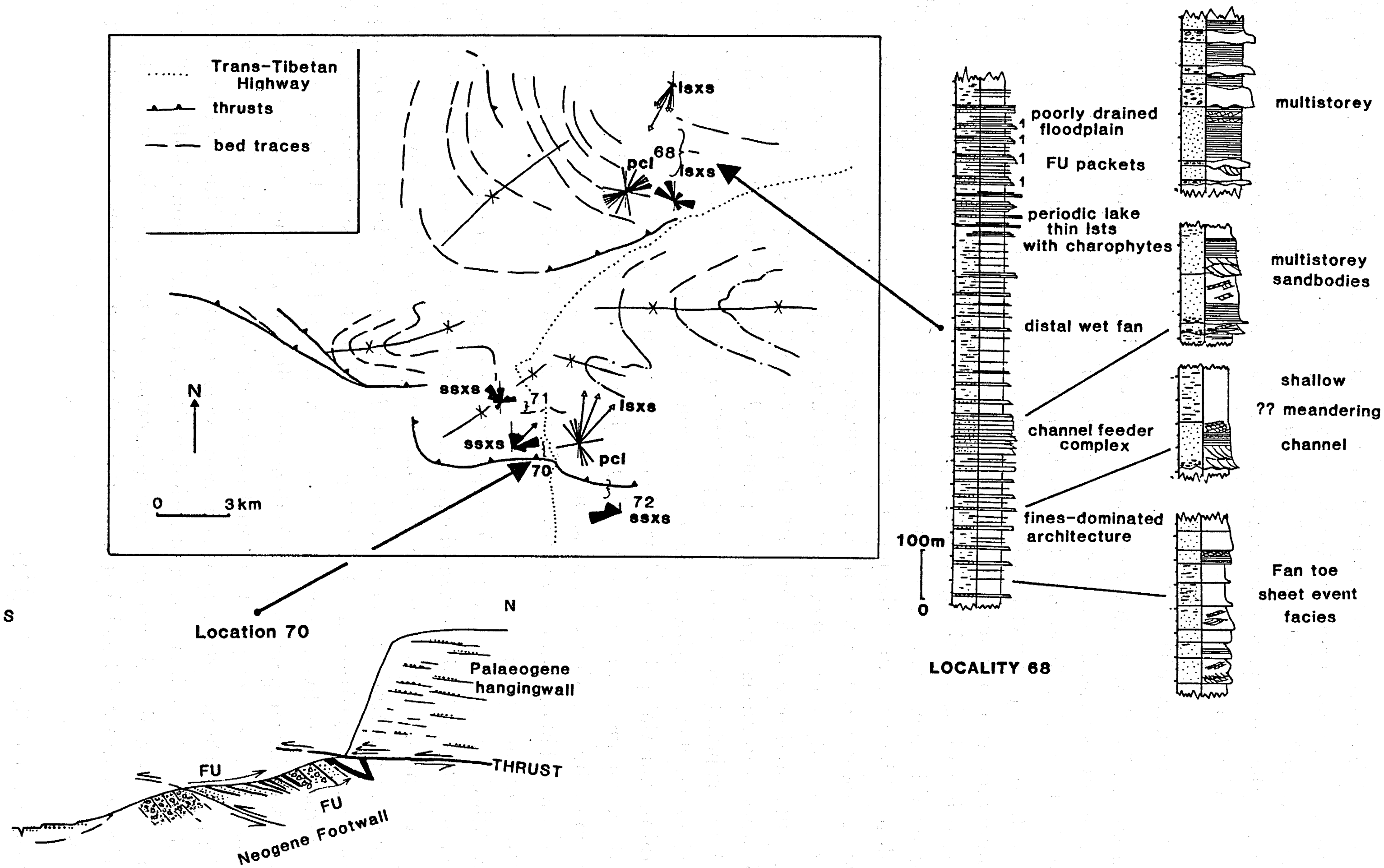

Figure 15. Sketch map (data of MPC, RMS, JFD, WSFK) of structure and bed traces around the Erdaogou Tertiary basin complex. Logs and sketch section show the character of the local Palaeogene succession in the hangingwall of the major thrust at Locality B70. Rose diagrams indicate palaeocurrent distributions. ssxs – small scale cross-stratification; lsxs – large scale cross-stratification; pcl – primary current lineations. Fu – firing upwards.

(*b*) *Erdaogou thrust basin complex*

The most extensive outcrops of Tertiary deposits along the Geotraverse route occur in the Fenghuo Shan, between Erdaogou and Wudaoliang Stations, a distance of some 80 km (figure 13). The rocks are well exposed around Erdaogou and southwards to the River Moron Us (figure 15), where they form part of an imbricate stack of thrust-bound synclines. They overlie and obscure the older lineament of the Triassic Jinsha Suture in the area.

(i) *Erdaogou Station* (locality B68)

Around Erdaogou itself the Tertiary comprises > 1100 m of clastic continental redbeds with rare lacustrine limestones yielding Eocene charophytes. The redbeds are dominated by muddy siltstones interbedded with lenticular fine to medium sandstones (figure 15). The latter, 0.5–3 m thick, lie on sharp scoured surfaces commonly littered with intraformational clasts. Internal sedimentary structures frequently include upper phase plane beds with well-developed primary current lineations, climbing ripple cross-laminations and, less commonly, large-scale trough cross-stratification. Sandstone members frequently fine upwards and extend for 100–400 m along strike normal to the mean northeast palaeoflow direction. Between 330 and 400 m above the base of the section, numerous sandbodies of this type amalgamate to define a multistorey sandbody some 80 m thick. The predominating fine-grained facies comprise siltstones and silty mudrocks with thin (10–50 cm) interbeds of sharp-based graded very fine to fine sandstones containing upper phase plane bed laminations and climbing-ripple cross-lamination. Fine-grained lithofacies in the upper part of the succession contain thin (5–20 cm) limestones. These are dark micritic wackestones, often with subsidiary matrix-supported angular quartz grains, containing Eocene charophytes (see Smith & Xu, this volume), fresh water ostracods and gastropods and plant fragments. Ponds or lakes therefore developed periodically. Similar limestones, interbedded with structureless silty mudrocks, occur at locality B74 to the north of Erdaogou. [There is also a widespread Neogene (Plio–Pleistocene; Smith & Xu, this volume) calcrete in this area.]

The above lithofacies are interpreted as deposits of a large low-gradient alluvial cone, the stacked coarse members of which reflect the persistent location in the mid-fan area of a channel feeder complex. The fine members are predominently of sheet-flood origin. Close modern analogues occur on the Kosi Fan of nothern India. Palaeocurrents from the whole sequence yield a vector mean towards the northeast (figure 15). Distally, occasional pond development is indicated by the charophytic limestones. Above, in the top 100 m of the logged succession, there is a marked change in palaeoflow directions and sedimentary facies. Alternating fine sheet flood sandstones and coarser green channel sandstones include 5–20 cm beds of dark grey mudrock. Copper carbonate staining is common along joints and bedding planes above and below the shale beds. Trough cross-stratification in the channel sandstones indicate flow to the southwest. Clearly a major change in basin geography occurred at this time, with the development of poorly-drained floodplains, possibly due to uplift of a new thrust-related growth fold in the north.

(ii) *River Moron Us* (localities B70, B71)

A thick (> 500 m) succession here is dominated by sheetflood lithofacies similar to those described above. Waning-flow sequences are common, with occasional wave-formed modifications on the sandstones' upper surfaces. Channel sandstones and sandstones thicker than 1.5 m are extremely rare. The fine-grained lithofacies occasionally feature desiccation cracks and small pedogenic calcite concretions. The most characteristic assemblage is coarsening-upwards sequences 5–30 m thick. These grade from silty mudrocks to mudrocks interbedded with sharp-based sandstones, the latter becoming thicker and more frequent upwards. Palaeocurrent directions from small-scale structures indicate persistent flow towards the northeast. The sandstones are thought to record progradational pulses formed during alluvial cone development as distal-fan channel complexes migrated over the fan surface. Tectonic/climatic factors also may have influenced cycle development.

These Palaeogene fluviatile redbeds are thrust over a young (possibly Neogene) sequence of redbeds along a prominent WNW–ESE escarpment which is cut by the clearly antecedent River Moron Us (figure 15). This footwall sequence is noticeably less indurated than that on the Palaeogene hangingwall and has a brick red colouration, in contrast to the drab red-brown of the Palaeogene. It contains some crudely fining-upwards sequences which comprise matrix-supported breccias with angular indurated clasts of the Palaeogene sandstones. These are interpreted as debris flow and talus cones derived from the nearby thrust front. Cross-laminated siltstones and fine sandstones follow, yielding WSW palaeoflow directions. They are interpreted as the deposits of axial streams flowing parallel to the front. A remarkable analogue is seen at the foot of the thrust scarp today, where streamflow deposits of the River Moron Us are eroding and offlapping debris lobes derived from the scarp.

(iii) *East of Erdaogou*

Some 20 km east of Erdaogou a very coarse grained facies occurs (*fide* W. S. F. Kidd & P. Molnar), comprising thick (possibly 200 m) grain-supported conglomerates and coarse sandstones. These appear to rest erosively within finer-grained facies similar to those described above from Erdaogou Station. The clasts include abundant limestone and rare silicic volcanics. These facies may represent the deposits of major axial-feeder channel systems to large alluvial cone systems, the clasts indicating possible southerly derivation from the Triassic limestones and andesites of the Zhakonjian Mountains.

(*c*) *Tertiary palaeogeography* (figure 16)

As noted previously, poor dating of the Tertiary sections precludes a full understanding of the timing and geographic development of the basins. Nevertheless the two examples studied in detail show clearly that sedimentary lithofacies development, provenance and stratigraphic sequences were closely controlled by contemporaneous Palaeogene, Neogene and, indeed, Recent thrust tectonics (see Coward *et al.* and Kidd & Molnar, this volume).

Synopsis of palaeoenvironmental history (figure 16)

(*a*) *Carboniferous*

During the Carboniferous a broad epicontinental sea extended from northern India to the Qilian Shan in the north. The faunas decrease in diversity from north to south, with tropical to subtropical Eurasian reefoidal faunas in the Kunlun Terrane (succeeding fluviatile redbeds derived from the north), and shelf-basin clastics with low diversity faunas in the Lhasa Terrane.

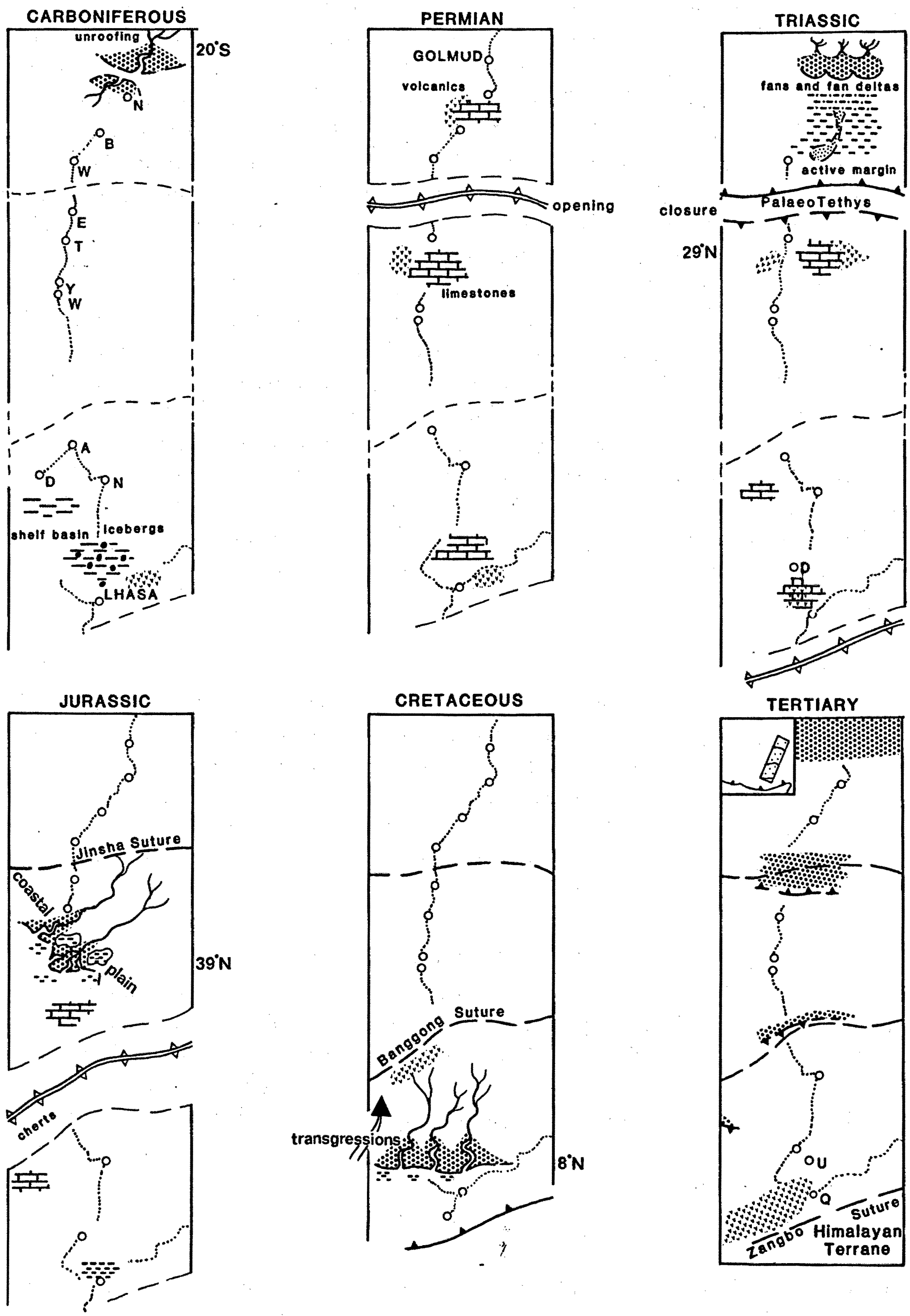

FIGURE 16. Series of very generalised diagrams to show the major lithofacies patterns and palaeogeography of the Tibetan Terranes from Carboniferous to Tertiary times. See the palaeogeographic sections of each geological system in the text for a summary discussion.

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A late Dinantain marine transgression is well marked in the Kunlun Shan, with evidence from the underlying fluvial clastics for the unroofing of an orogenic belt to the north. Palaeomagnetic data indicates a latitude of $20° \pm 20$ °S for the Kunlun Terrane.

(*b*) *Late Carboniferous/early Permian*

Toward the end of the Carboniferous the climate had become significantly cooler, with the result that climatic belts narrowed. Thus deposition of shallow water carbonates with large benthic forams and compound corals continued in the north whilst thick mixtite deposits were laid down on the Lhasa Terrane, indicating that it lay within the iceberg belt. Glaciomarine deposition probably continued into the Sakmarian, contemporaneous with the tillites and other evidence of glaciation elsewhere on the Gondwanan superplate. Thick volcanics northeast of Lhasa are of possible back-arc extensional origins (Pearce & Mei, this volume) and may herald the initiation of breakup of Gondwanaland.

(*c*) *Permian*

The climate appears to have warmed up again during the Qixian (Artinskian) causing the facies and faunal belts to expand. This brought prograding carbonate ramps into the Lhasa region, together with large benthic forams and compound corals. Possibly at this time, and certainly during the early Permian, the first extensive rift volcanics were extruded in the Kunlun Shan. They may signal the beginning of rifting along Palaeo–Tethys.

The Maokouian (early Upper Permian) saw extensive development of shallow shelf carbonates with reefoidal developments reaching as far south as the Lhasa Terrane. Rifting continued throughout the Permian, recorded for example in the Kaixinling Group of the Qiangtang block.

By the late Permian the Palaeo–Tethys was presumably an ocean of significant size. Much of the land to the south appears to have been undergoing erosion at this time as no definite deposits of this age are known.

(*d*) *Triassic*

During Triassic times a major fore-arc accretionary prism of clastics built up along the northern margin of Palaeo–Tethys in response to north-directed subduction. Along the southern margin an extensive early Upper Triassic back-arc volcanic system (the Batang Group) developed. This was relatively short-lived because Norian shelf limestones lie across it, suggesting also that southward subduction had ceased along the Jinsha Suture.

There is evidence in the Lhasa Terrane of renewed Middle Triassic rift volcanics and break-up of the widespread carbonate platform during the Anisian. In the Carnian and Norian, extensive shelf basinal carbonate turbidites developed, and the first oceanic radiolarian cherts are found associated with the Zangbo suture, indicating the initiation and development of a major oceanic rupture.

(*e*) *Jurassic*

North of the Qiangtang Terrane, no marine Jurassic was deposited and the whole area appears to have undergone erosion at this time. A very thick fluviatile/coastal plain sequence of mid-Jurassic age in the southern Qiangtang Terrane represents a molassic wedge derived from the newly-fused orogenic belt formed by the Kunlun/Qiangtang Terrane collision. In the northern part of the Lhasa Terrane marine incursions from a southern shelf penetrated into the coastal plain sequence occasionally. Upper Jurassic cherts and pillow lavas along the line of the Banggong Suture show that this was the site of a possibly minor ocean tract. Ophiolites had been emplaced and flysch basins developed by the end of Jurassic times, but final shortening does not appear to have occurred until well into the early Cretaceous.

(*f*) *Cretaceous*

The area north of the Banggong Suture was progressively uplifted and eroded as a result of the collision between the Lhasa and Qiangtang Terranes, producing the extensive Cretaceous molasse of the Lhasa region. There was also extensive post-collisional volcanism in the northern part of the Lhasa Terrane in Takena Formation times. A major marine transgression from the south during Aptian to early Cenomanian times temporarily halted the deposition of fluviatile clastics over the Lhasa Terrane. Deformation and erosion ensued towards the end of the Cretaceous, but its cause is uncertain.

In the Zangbo suture tract, open ocean sedimentation continued until the Turonian. Olistostromes then formed, marking the onset of obduction.

(*g*) *Tertiary*

Marine sedimentation continued along the Zangbo tract until mid Eocene times. Around Lhasa and at many localities to the north, molassic sedimentation persisted into the early Palaeogene. Thick arc-related volcanic sequences were erupted onto folded and eroded Upper Cretaceous molasse. Thick fluviatile facies accumulated in thrust-bound basins during the Eocene and later, indicating the onset of pervasive crustal shortening.

We thank Perce Allen, F.R.S., for his helpful comments on our work and its presentation. Thanks also to Roy Boud for drafting the complex figures 2, 6, 8, 9 and 11. We also express our gratitude for the herculean labours undertaken by the Chinese logistical support team, particularly to our willing and careful B-group drivers.

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Appendix 1. Palaeocurrent data

APPENDIX 1

Palaeocurrent Data

Figure 17 shows black rose diagrams drawn for all localities with greater than 5 outcrop measurements. Other localities show individual measurements. The rose diagrams are divided into 20° class intervals. Vector means have been calculated for most populations with greater than 5 measurements. Length of vectorial arrows is on the diagram scale with vector magnitude.

The raw data include measurements from small scale cross-stratification (ssx) large scale cross stratification (lsx) and primary current lineation (pcl), each structure being plotted separately. Structures are corrected for tectonic tilting (by a stereographic method) where time permitted accurate dip, strike, pitch measurements. Otherwise direction corrected (by eye) in field. Environments are all fluvial channels unless otherwise indicated.

No.	Locality	Age	Number	Structure	Vector Mean	Environment
6-11	Ganpa area	U. Cret.	n = 7	lsx	vm = 204°	fluviatile channel
6-11	" "	" "	n = 4	ssx	vaa = 206°	" "
16	Quesang	L. Cret.	n = 3	lsx	vm = 111°	" "
24	Duba/Baingoin	L. Cret.	n = 7	lsx	vm = 213°	" "
27	" "	Tertiary	n = 12	lsx	vm = 185°	" "
56	Yanshiping	M. Jur.	n = 2	lsx	vm = 198°	" "
57	N. Amdo	M. Jur.	n = 3	ssx	vm = 181°	" "
57	N. Amdo	M. Jur.	n = 4	lsx	vm = 249°	" "
58	Wenquan	M. Jur.	n = 34	ssx	vm = 271°	minor mouth bars/ crevasses
62	S. of Erdaogou	? Perm.	n = 7	lsx	vm = 244°	fluviatile channel
63	S. or Erdaogou	? Perm.	n = 6	ssx	vm = 201°	turbidites
64	N. of Tuotuo R.	Perm.	n = 8	ssx	vm = 174°	mouth bars
64	" "	"	n = 3	lsx	vm = 173°	fluviatile channel
66	" "	?	n = 11	ssx	vm = 152°	sheet flood splay
66	" "	?	n = 3	lsx	vm = 171°	fluviatile channel

No.	Locality	Age	Number	Structure	Vector Mean	Environment
67	Zhakongjian Mts.	Trias.	n = 5	lsx	vm = 193°	fluviatile channel
68	Erdaogou	Tert.	n = 9	pcl		" "
68	"	"	n = 8	lsx		" "
68	"	"	n = 6	ssx		" "
68	"	"	n = 1	lsx		" "
68	"	"	n = 4	ssx		" "
68	"	"	n = 1	pcl		" "
70	S. Erdaogou	"	n = 6	ssx	vm = 048°	sheet flood splays
70	" "	"	n = 3	lsx	vm = 022°	fluviatile
71	" "	"	n = 4	pcl		"
71	" "	"	n = 13	ssx		"
72/73	" "	Neogene	n = 6	ssx		"
77	" "	Permian	n = 2	ssx		turbidite
83	Bayan Har Gp.	Triassic	n = 1	ssx		contourites
91	?Wanbaigo West Shan	U. Permian	n = 8	ssx	vm = 110°	resedimented tuffs
92B	N. Naij Tal	?Trias	n = 4	lsx	vm = 135°	fluviatile channels
99	N. Naij Tal	?Trias	n = 7	ssx	vm = 305°	" "
103	N. Naij Tal	Carb.	n = 11	lsx	vm = 199°	" "
104	N. Naij Tal	Carb.	n = 18	lsx	vm = 296°	" "
105	N. Naij Tal	Carb.	n = 9	lsx	vm = 273°	" "
107	N. Naij Tal	Carb.	n = 4	lsx	vm = 026°	" "
107	N. Naij Tal	Carb.	n = 5	ssx	vm = 022°	" "
108	N. Naij Tal	Carb.	n = 24	lsx	vm = 210°	" "
108	N. Naij Tal	Carb.	n = 10	lsx	vm = 50°	" "

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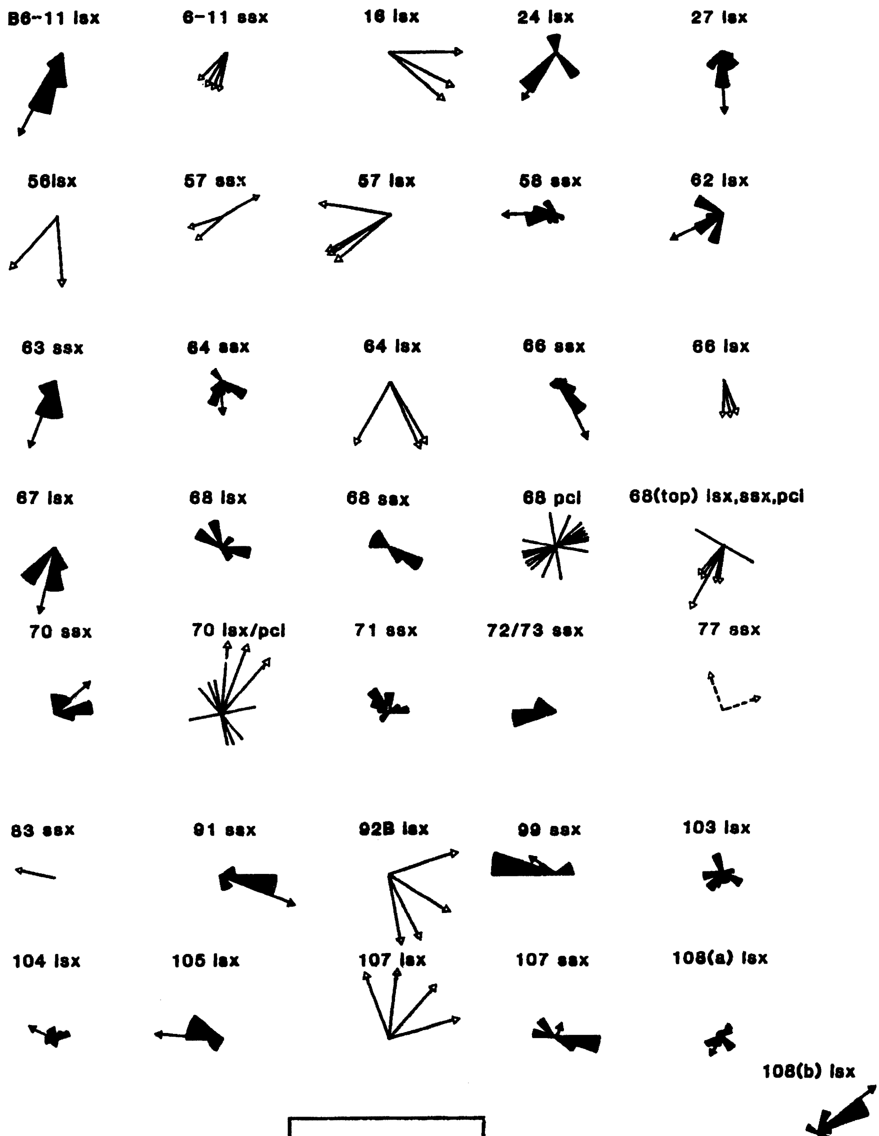

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68 lsx
68 ssx
68 pcl
68(top) lsx,ssx,pcl
70 ssx
70 lsx/pcl
71 ssx
72/73 ssx
77 ssx
83 ssx
91 ssx
92B lsx
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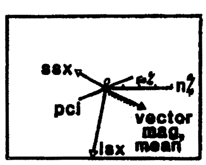
107 ssx
108(a) lsx
108(b) lsx



ssx
pcl
lsx
vector
mag,
mean

FIGURE 17