THE LEMAY GROUP OF CENTRAL ALEXANDER ISLAND

T. H. TRANTER

British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK

The LeMay Group of Alexander Island is one of a number of sequences of thick, deformed and largely unfossiliferous sedimentary rocks that crop out along the west coast of the Antarctic Peninsula and that are generally considered to be part of accretion–subduction complexes associated with the Mesozoic Pacific margin of Gondwanaland (Burn, 1984). Two seasons of fieldwork (1983–84, 1984–85) were devoted to a detailed structural and sedimentological study of the LeMay Group in central Alexander Island in order to provide a more comprehensive view of its stratigraphic and tectonic development.

Central Alexander Island was first visited briefly in 1964–65 (Grikurov, 1971) when the generally deformed and complex nature of the rocks was recognized. Subsequent mapping has extended the known outcrop of the LeMay Group through large areas of central, western, northern and southern Alexander Island (see Burn, (1984)).

The group consists of a thick, deformed sequence of predominantly feldspathic sedimentary rocks of turbiditic origin, with minor but important volumes of basaltic lavas, tuffaceous sedimentary rocks, red and green phyllites and cherts (Fig. 1). It is bounded to the east by the Upper Jurassic–Lower Cretaceous Fossil Bluff Formation, a 4000-m-thick succession of fossiliferous sedimentary rocks (Taylor and others, 1979; Butterworth, 1985). The contact between the two units is probably faulted, although the Fossil Bluff Formation unconformably overlies the LeMay Group at one locality (Edwards, 1980*a*). Intrusions of early Tertiary age occur in the north and south of Alexander Island, and in places the LeMay Group is unconformably overlain by Tertiary volcanic rocks, presumably associated with the plutonics (Burn, 1981). The age of the LeMay Group is very poorly constrained, but palaeontological evidence from the tuffaceous rocks of the northern Lully Foothills suggests a Sinemurian age (Thomson and Tranter, 1986) for this part of the group, whilst radiolaria of probable mid-Cretaceous age have been collected from a chert in northern Alexander Island (Burn, 1984).

The areas covered during the two field seasons include the Lully Foothills and both the east and west flanks of the LeMay Range south from Snick Pass (70° 41′ S) to latitude of 70° 57′ S (Fig. 1). The description of the geology is divided between three geographical areas: the LeMay Range, the Snick Pass area and the Lully Foothills.

LEMAY RANGE

Lithology

The rocks of the LeMay Range consist chiefly of deformed conglomerates, sandstones and shales, with minor volumes of phyllites, pillow lavas and cherts in the west.

Sedimentological study is hindered by the discontinuous nature of exposure, structural complications and a lack of distinctive marker horizons. However, in the least deformed areas of the eastern LeMay Range short sections of strata on the limbs of major folds exhibit the main sedimentary features of the sequence. Here a series of broadly fining-upwards cycles is evident, with conglomerates and sandstones at the bases passing upwards into thinly bedded siltstones and shales.

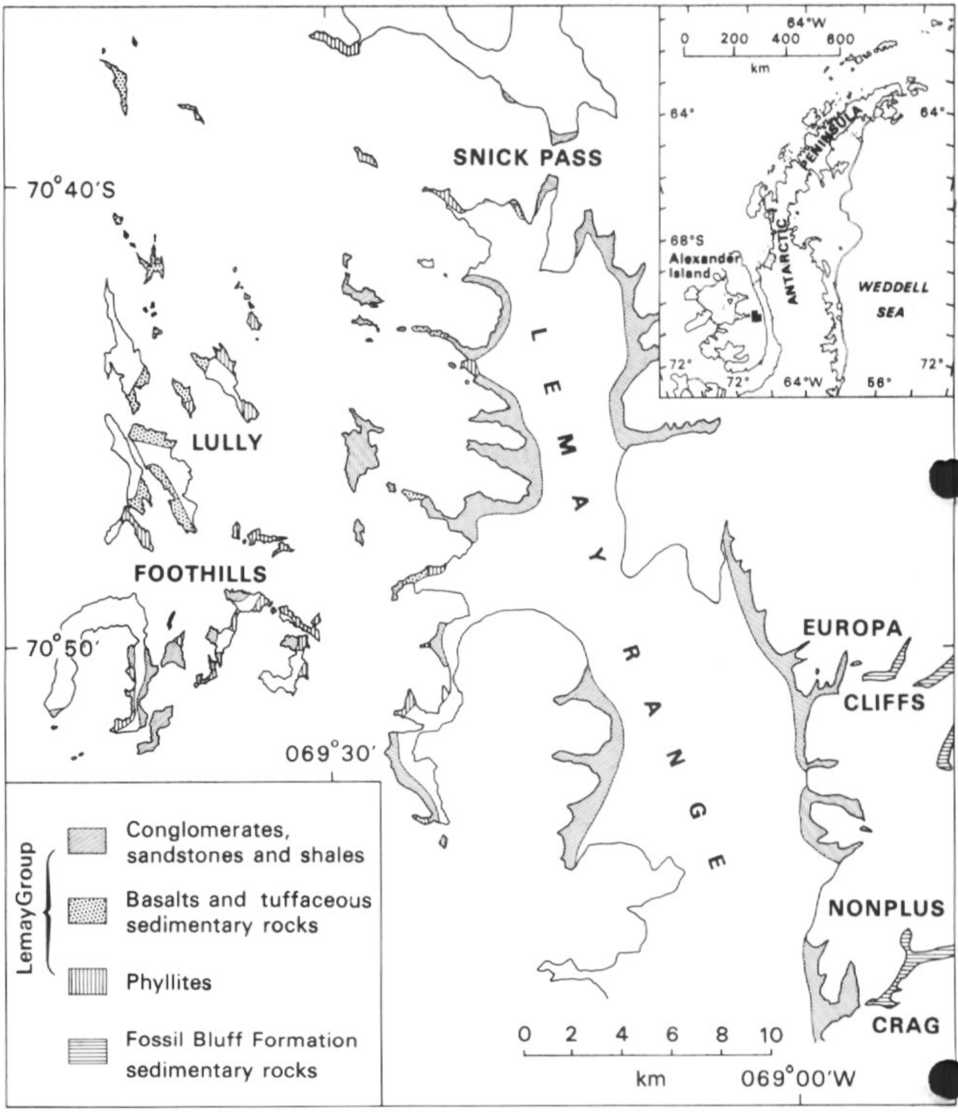

Fig. 1. Sketch map of central Alexander Island showing the main lithological divisions discussed and place names mentioned in the text.

The conglomerates are generally matrix-supported, and form beds up to 30 m thick. They are mainly chaotic, polymict and polymodal, with clast diameters varying from less than 1 cm to more than 10 cm. The larger clasts are well rounded whilst the smaller ones are subrounded to subangular. Common clast lithologies are milky white, structureless vein quartz and fine-grained massive quartzites, with subsidiary plutonic, metamorphic, volcanic and intraformational shale clasts. Both normal and inverse grading occur, and well-developed flame structures of underlying sandstone were observed at the bases of some beds. Sandstone beds and lenses, up to 2 m thick, internally structureless and with planar, sharp or transitional boundaries, occur within

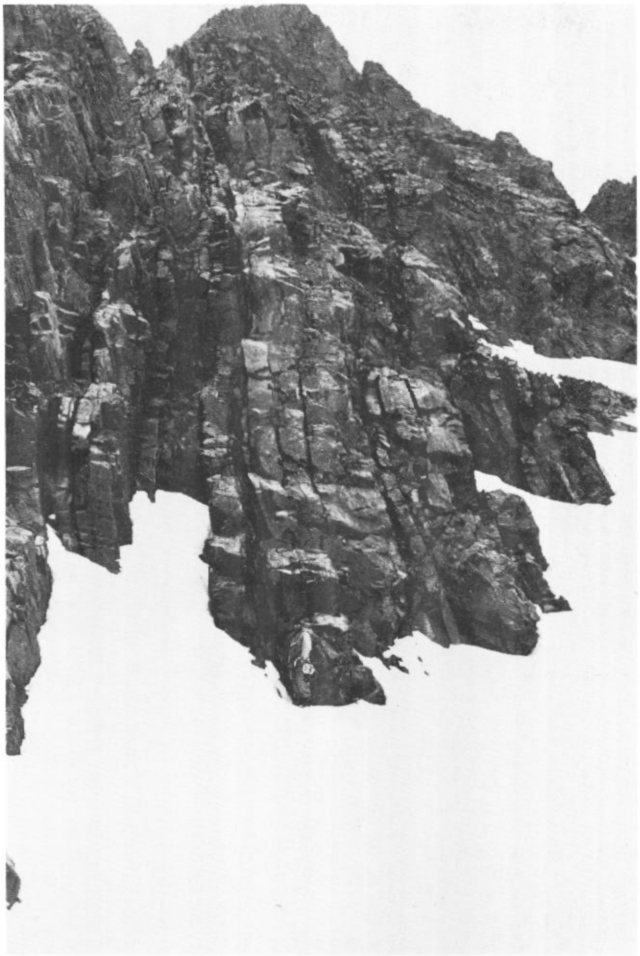

Fig. 2. Parallel-bedded sandstones with thin shale partings passing up (to the right) into more thinly bedded sandstones and thicker shales, central LeMay Range. Note figure for scale.

le conglomerates. There is a marked east–west decrease in the proportion of conglomerate across the LeMay Range and it is virtually absent on the western flanks. This could reflect a true lateral variation, or may be due to exposure of different erosion levels in a sequence with gross vertical grain-size variation.

The sandstones (Fig. 2) vary from coarse to fine-grained, are graded in places and contain lags of conglomerate and mudflake breccia. Much of the sandstone, particularly in the western LeMay Range, is massive and structureless, but sedimentary structures including convolute lamination, synsedimentary faulting and bottom structures, mainly flute casts, are present. Parallel lamination also occurs in the upper parts of sandstone units, in many cases passing upwards into cross-laminated beds and finally into structureless shale.

Siltstones and shales form the upper parts of the fining-upwards sequences and consist of thin (generally less than 20 cm) alternating planar beds (Fig. 3). The shales are highly cleaved and no sedimentary structures are preserved, but the siltstones

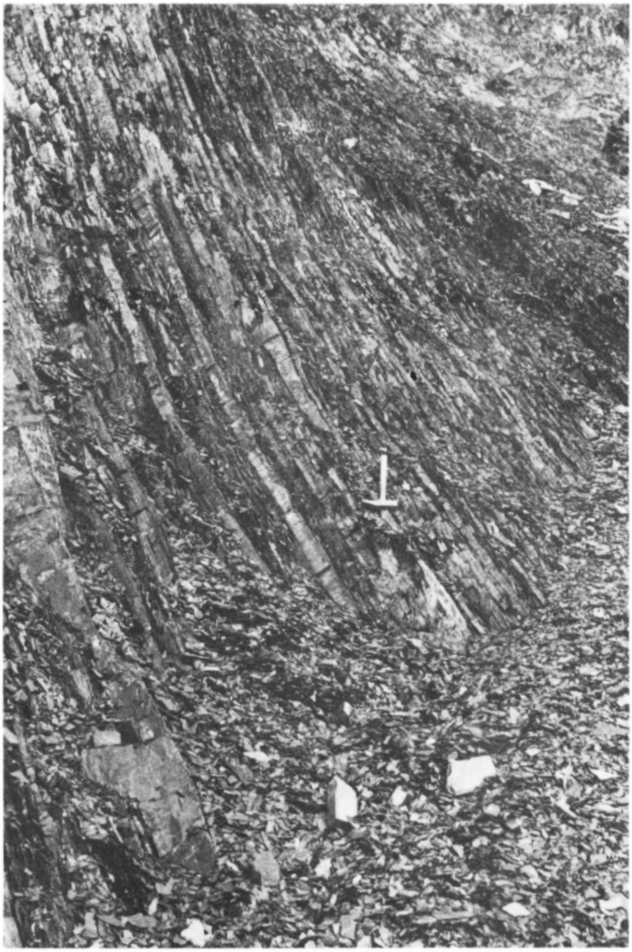

Fig. 3. Thinly bedded siltstones and cleaved shales, eastern LeMay Range. Discontinuous bed in centre is atypical. Hammer shaft is 35 cm long.

exhibit parallel and small-scale cross lamination, lenticular bedding and convolu lamination. In undeformed areas, individual beds can be traced for many metres along strike, with little or no lateral thickness variation.

In parts of the westerm LeMay Range an interbanded sequence of lavas and red, green and grey phyllites, quartzites and cherts is exposed, similar to the rocks of the eastern Lully Foothills immediately to the west although markedly less disrupted. The lavas are commonly pillowed and reach several tens of metres in thickness. The pillows are up to a metre in length and amygdaloidal or vesicular at the margins. Tabular basalt sheets also occur, invariably with tension gashes approximately perpendicular to their surfaces. Interpillow sediment is scarce, although thin skins of cleaved green phyllite occur around the pillows and there are rare small volumes of basaltic breccia between the pillows. The associated red, green and grey phyllites, quartzites and cherts are up to 15 m thick, and original bedding is seen as colour changes. They are invariably folded and cleaved and no sedimentary features are preserved.

Sedimentary environment

The presence of suites of sedimentary structures which are in places organized into well-developed Bouma sequences suggests deposition from sediment gravity flows, probably from turbidity currents. This is in accordance with previous work on the sedimentology of the LeMay Group of northern and central Alexander Island, for which a turbidite fan model has been proposed (Edwards, 1980*b*; Burn, 1984). Edwards (1980*b*) tentatively recognized two distinct facies associations in central Alexander Island, occurring in the LeMay Range and the Walton Mountains about 40 km to the west, and equated these with inner and outer fan associations of a submarine turbidite fan (Mutti and Ricci-Luchi, 1975) respectively. He used the relative geographical positions of these associations, together with sparse palaeocurrent indicators, to suggest an east–west-directed palaeocurrent, the more distal facies association lying further to the west. If the distribution of conglomerates observed in the LeMay Range is a true lateral variation, it is consistent with an easterly sediment source and a broadly westerly transport direction.

Structure

Earlier workers in the LeMay Group (Edwards, 1980*b*; Burn, 1984) recognized its polyphase deformation, with four phases distinguished in northern and central Alexander Island, although correlation within and between areas proved difficult.

The structure of the turbiditic rocks of the LeMay Range is dominated by a series of large-scale folds, best developed in the central and eastern parts of the range. Axial planes strike approximately north–south, and show a distinct variation in dip, from upright in the central part of the LeMay Range to westerly dipping in the east, producing a series of easterly verging, moderately inclined structures (Fig. 4). In addition, there is some easterly directed thrusting in the eastern LeMay Range. Evidence for refolding is rather sparse, but in places minor fold closures associated with the major fold phase have been modified by later deformation. There is no axial planar cleavage developed in the fold hinges – the dominant cleavage, best seen in the finer-grained rocks, being parallel or at a low angle to bedding.

Although many of the boundaries between rock types are sedimentary and conformable, stratal disruption and mixing of lithologies are also common. Bodies of all sizes from sandstone lenses less than a metre in thickness to disrupted sandstone and conglomerate units tens of metres in thickness are enclosed within the less competent and more highly deformed finer-grained units. The boundaries of these bodies are in places unconformable, shattered and marked by slickensided quartz planes, and bedding in the finer lithologies adjacent to the margins is disrupted and folded.

Exposure of the phyllites, quartzites and pillow lavas in the western LeMay Range is less continuous, and the structural elements are less clear. The fine-grained lithologies have a well developed pervasive or narrowly spaced cleavage, dipping to the SE, axial planar to minor folds of bedding. These early folds verge dominantly to the west, and evidence for refolding is scant, although spaced cleavages and kink bands representing later episodes of deformation are present.

Evidence for faulting is sparse, but in the western LeMay Range displacement of a distinctive red cherty horizon indicates normal faults aligned approximately north–south, with down-throws of up to about 200 m to the west, and a further set aligned approximately east–west and probably down-throwing to the north.

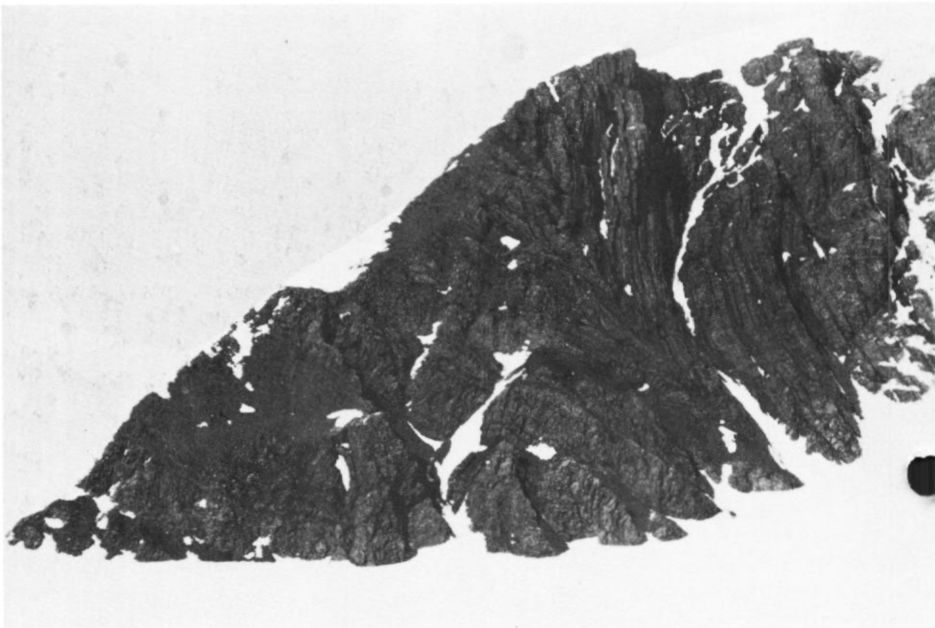

Fig. 4. Moderately inclined syncline in sandstone–shale sequence, eastern LeMay Range. View approximately south. Height of cliff is approximately 250 m.

Snick Pass Area

Lithology

The Snick Pass area includes the most highly deformed rocks seen in central Alexander Island, reaching schistose textures in places. This is the area from which Edwards (1980*b*) recognized high-pressure mineral assemblages of the blueschist facies in metamorphosed basic igneous rocks, one of only two localities in the LeMay Group from which such assemblages have been recorded. The rocks of the Snick Pass area consist of an interbanded sequence of sandstones and shales, phyllites, slates and ?cherts, which are commonly highly cleaved and folded, and minor quantities of basalt. Bedding is apparent within some of the sandstones, but the generally folded and broken nature of the rocks and their strong cleavage development have obscured original sedimentary features in other lithologies and make relationships unclear. The basalts are highly weathered and form either thin bands 10–20 cm thick, or more lenticular bodies up to a metre in thickness. Psammitic and pelitic schists and semischists also occur, probably representing higher-grade equivalents of the sandstones and shales.

Structure

There is evidence for at least three phases of deformation affecting original bedding in the Snick Pass area:

D_1. A pervasive or narrowly spaced cleavage (S_1) is developed parallel to or at a very low angle to bedding. Formation of quartz veins subparallel to bedding and S_1 and some metamorphic segregation may be related to this phase. In the Snick Pass

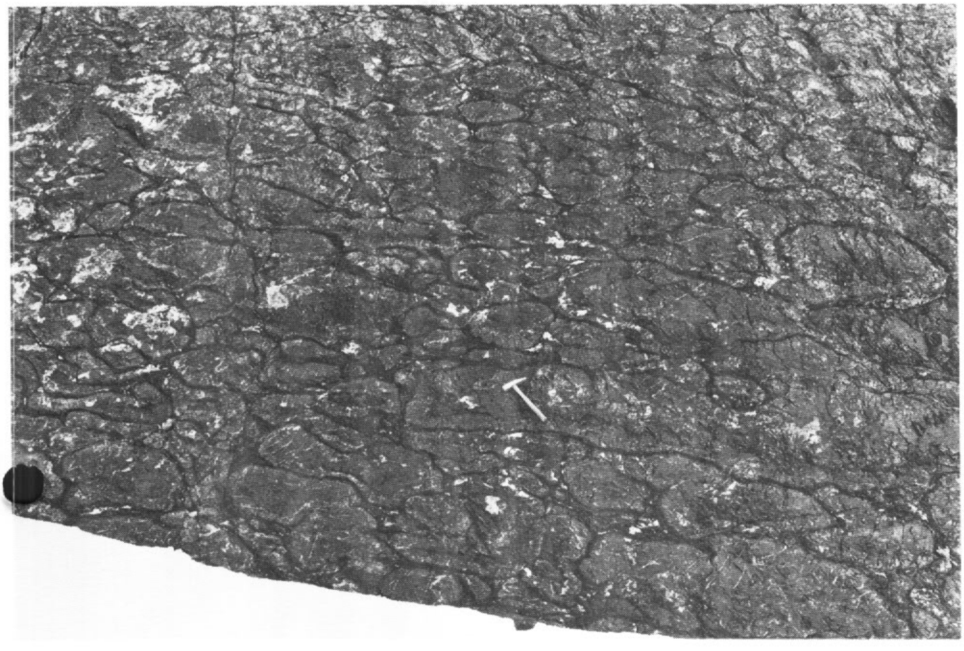

Fig. 5. Pillow lavas, Lully Foothills. Note paucity of interpillow sediment. Hammer shaft is 35 cm long.

area there is no folding associated with S_1, but it is similar to the cleavage developed in slaty and phyllitic lithologies in the western LeMay Range, where it is axial planar to tight or isoclinal folds in interbedded thin quartzitic bands.

D_2. A rare, poorly developed spaced (1–2 cm) fracture cleavage (S_2), dips steeply to the north-east. This is approximately axial planar to minor F_2 folds of S_1 and quartz veins. The F_2 folds have rather variable axial planar orientations but their axes have a consistent plunge to the south-east, parallel to a strongly developed L_2 mineral lineation on cleavage surfaces and a set of rods on a sandstone bedding surface. A large F_2 syncline spans Snick Pass, folding bedding and S_1 cleavage, with an upright axial plane aligned approximately north-west–south-east and an axis plunging gently to the south-east.

D_3. A well-developed spaced S_3 cleavage with planes a few centimetres apart dips steeply to the north-west. This may be associated with a third phase of folding, as at one locality F_2 folds have been refolded by a later phase.

Lully Foothills

Lithology

The Lully Foothills are dominated by volcanically derived rocks, both basaltic lavas and interbedded sedimentary rocks. These are best developed in the northern and western Lully Foothills and include sequences of amygdaloidal or vesicular pillow lavas (Fig. 5). In general there is little interpillow sediment, but at some localities there are hydroclastic basaltic breccias between the pillows. There are also lava flows, occurring as either continuous bands of variable thickness or as lens- or pod-like masses within sedimentary sequences. Chilled margins are apparent in places, and rarely the flows have cindery surfaces.

The sedimentary rocks are mainly tuffaceous, commonly crystal or vitric tuffs and varying from fine to coarse sand grade with some agglomerates. The best-preserved sedimentary features occur in a sequence of tuffs in the northern Lully Foothills from which a small invertebrate fossil assemblage of Early Jurassic (Sinemurian) age was collected (Thomson and Tranter, 1986). Load structures, intraclasts, parallel lamination and small graded units were observed here, while in other parts of the northern and western Lully Foothills, similar structures are widely but sparsely distributed.

Further south in the Lully Foothills, lavas and tuffs are volumetrically less important and the major rock types are sandstones, conglomerates and phyllites. The conglomerates are structureless, matrix-supported and polymodal, with clast diameters ranging from less than 1 cm to more than 75 cm. In contrast to the conglomerates in the LeMay Range to the east, clasts are almost exclusively of volcanic lithologies. The sandstones are internally structureless, varying from fine to coarse-grained. The phyllites are largely red and green, are conformable with the sandstones and conglomerates, and have a well-developed cleavage parallel or at a low angle to lithological boundaries. This strong fabric has obscured any original sedimentary features.

Sedimentary environment

The close association of pillow lavas with interbedded basaltic breccias, lava flows and tuffaceous sedimentary rocks in the northern and western Lully Foothills indicates a submarine environment, the sedimentary material originating as hydroclastic debris from submarine eruptions. Sedimentary structures and faunal evidence (Thomson and Tranter, 1986) indicate that at least some of the original sediment was reworked and transported. Water depth is difficult to determine, but the presence of poorly preserved plant material in the fossil assemblage may indicate a general proximity to a shoreline (Edwards, 1980*c*). Elsewhere in the Lully Foothills, the presence of conglomerates with volcanic clasts indicates reworking of a volcanic source, but the structureless nature of these rocks precludes environmental interpretation. Fining-upwards sequences as seen in the LeMay Range are not developed in the Lully Foothills.

Structure

The massive, competent volcanic lithologies of the northern and western Lully Foothills are comparatively undeformed and dip steeply to the west or south-west. There is, however, a cleavage, parallel or at a low angle to bedding, in some of the tuffaceous sequences, and this is sufficiently well developed in places to obscure most sedimentary features. Minor folding within these lithologies is scarce. Further south, where bedding-parallel cleavage is well developed in the red and green phyllites, upright mesoscopic folds postdating the cleavage trend at approximately 020°.

The eastern margin of the Lully Foothills consists in places of an approximately 150 m thick sequence of highly cleaved red and green phyllites dipping to the north-west and south-west containing large numbers of aligned, tension-gashed pillows, slabs and lenses of basalt and subordinate sedimentary rocks. These inclusions, which vary in size from a few centimetres to several tens of metres, probably represent a ?tectonically mixed analogue of adjacent rocks (Fig. 6). Similar lithologies also occur in the western LeMay Range immediately to the east of the Lully Foothills, but here the strata are much less disrupted, and continuous bedding can be seen. The broken nature of the inclusions set in a fine-grained matrix, their variable shapes and the development of

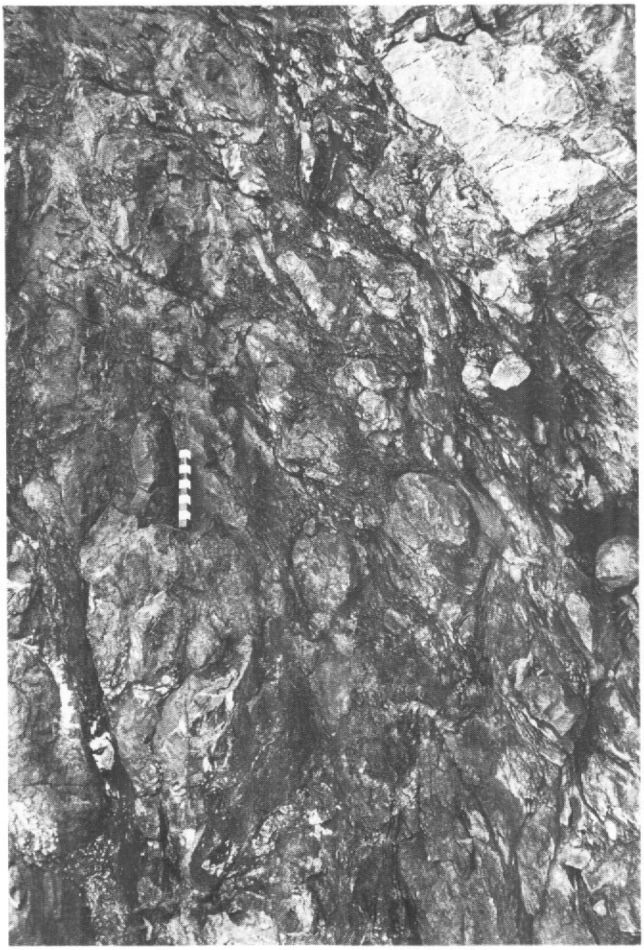

Fig. 6. Broken formation or mélange, eastern margin of Lully Foothills. Slabs and lenses, chiefly of basalt, are enclosed within a cleaved phyllitic matrix. Scale bar is in centimetres.

strong planar fabric in the enclosing phyllite are identical to features described in areas of broken formation or mélange (using the term in the non-genetic sense of Silver and Beutner (1980)), e.g. the Franciscan of California (Cowan, 1985) and the Pacific coast of Alaska (Moore and Wheeler, 1978).

Junction between the LeMay Group and the Fossil Bluff Formation

The boundary between the LeMay Group and the much less deformed sedimentary sequence of the Fossil Bluff Formation in central Alexander Island has only been described from three localities (Bell, 1975; Edwards, 1980*a*). Both faulted and unconformable contacts were recognized, but on the basis of physiographical and aerial observations the boundary has been extrapolated as an approximately north–south-trending normal fault (the LeMay Range Fault) with a downthrow of at least

2000 m to the east (Edwards, 1980*a*). Two localities on the eastern flanks of the LeMay Range, at north-western Europa Cliffs and western Nonplus Crag, through which the postulated boundary passes, were visited.

At both localities there is an abrupt change from the rocks of the Fossil Bluff Formation in the east to those of the LeMay Group in the west, although in neither case is the actual boundary exposed. The Fossil Bluff Formation rocks adjacent to the boundary consist of shales, siltstones, sandstones and conglomerates, the latter composed exclusively of rounded sandstone clasts identical in hand specimen to LeMay Group sandstones. At Europa Cliffs, slightly deformed fossils of ? *Belemnopsis* of Upper Jurassic–lowermost Cretaceous age (P. J. Howlett, personal communication) occur in Fossil Bluff Formation siltstones. The Fossil Bluff Formation rocks adjacent to the boundary are highly cleaved, shattered and, at Nonplus Crag, folded, and are far more deformed than their counterparts further to the east (P. J. Butterworth, personal communication). The fractured and cleaved aspect is consistent with a tectonic boundary, and there is no evidence for an unconformity at either locality.

Discussion

The LeMay Group has been interpreted as the result of deposition and deformation in an active submarine trench environment during Mesozoic subduction along the Pacific margin of Gondwanaland (Burn, 1984). The complex deformation, isolated occurrences of blueschist mineral assemblages and the general inferred sedimentary environment are all broadly consistent with such a model, whilst the existence of broken strata and mélange indicate that mixing and shearing processes, commonly associated with subduction complexes, have taken place.

Perhaps the most noticeable feature of the LeMay Group is the apparent incompatibility of some aspects of its geology with the generally accepted models of subduction–accretion complexes. The volcanic rocks of the Lully Foothills enclosed within the turbiditic sedimentary sequence are rather anomalous, and Smellie (1981) and Burn (1984) proposed that they represent part of a fore-arc basin floored by the subduction complex. However, the recognition of a tectonic boundary represented by the mélange at the eastern margin of the Lully Foothills raises the possibility that the volcanic rocks may be an allochthonous block. This implies that the Early Jurassic fossil age from the northern Lully Foothills cannot be extrapolated with confidence through the rest of the LeMay Group.

Certain structural elements of the LeMay Group are also incompatible with the geometry expected in a subduction-related environment. Seaward-verging folds with landward dipping axial planes and seaward-directed thrusts are cited as typical structures of subduction–accretion complexes (e.g. Seely and others (1974); Dickinson and Seely (1979)). However, in the LeMay Group the occurrence of seaward-dipping strata, eastward(landward)-verging folds with westerly(seaward)-dipping axial planes, and easterly(landward)-directed thrusts is the opposite to this geometry. Burn (1984) suggested that the occurrence of seaward-dipping strata in the LeMay Group could be due to later modification and landward rotation of the complex resulting from the accretion of younger sediments to the west, an effect known from other active margins (e.g. Moore and Karig, 1980). Landward-verging folds and landward-directed thrusts are known from subduction–accretion complexes (e.g. Seely, 1977; Dickinson and Seely, 1979) and may be the result of the physical properties of the accreting sediments, backthrusting, or due to later deformational episodes. Large eastward-directed thrusts of post mid-Cretaceous age occur in the Fossil Bluff Formation of eastern Alexander Island (Taylor and others, 1979) and major eastward-directed shear zones of early

Jurassic–mid–Cretaceous age have been recognized in eastern Palmer Land (Meneilly and others, in press) so the possibility that some structures in the LeMay Group may be related to a later phase of deformation cannot be ruled out.

ACKNOWLEDGEMENTS

I would like to thank Drs D. I. M. Macdonald, A. W. Meneilly and B. C. Storey for their advice and criticism, and R. M. V. Summerson and N. St. J. Young for their assistance in the field.

Received and accepted 10 December 1985

REFERENCES

BELL, C. M. 1975. Structural geology of parts of Alexander Island. *British Antarctic Survey Bulletin*, Nos. 41 & 42, 43–58.

[illegible]N, R. W. 1981. Early Tertiary calc-alkaline volcanism on Alexander Island. *British Antarctic Survey Bulletin*, No. 53, 175–93.

BURN, R. W. 1984. The geology of the LeMay Group, Alexander Island. *British Antarctic Survey Scientific Reports*, No. 109, 65 pp.

BUTTERWORTH, P. J. 1985. Report on Antarctic fieldwork: sedimentology of Ablation Valley, Alexander Island. *British Antarctic Survey Bulletin*, No. 66, 73–82.

COWAN, D. S. 1985. Structural styles in Mesozoic and Cenozoic mélanges in the western Cordillera of North America. *Bulletin of the Geological Society of America*, **96**, 451–62.

DICKINSON, W. R. *and* SEELY, D. R. 1979. Structure and stratigraphy of forearc regions. *Bulletin of the American Association of Petroleum Geologists*, **63**, No. 1, 2–31.

EDWARDS, C. W. 1980*a*. New evidence of major faulting on Alexander Island. *British Antarctic Survey Bulletin*, No. 49 (for 1979), 15–20.

EDWARDS, C. W. 1980*b*. *The geology of eastern and central Alexander Island*. PhD thesis, University of Birmingham, 228 pp. [Unpublished].

EDWARDS, C. W. 1980*c*. Early Mesozoic marine fossils from central Alexander Island. *British Antarctic Survey Bulletin*, No. 49 (for 1979), 33–58.

GRIKUROV, G. E. 1971. Geologischeskoe stroenie tsentral'noy chasti Zemli Aleksandra I (The geological structure of the central part of Alexander I Land). (*In Antarktika, Mezhduvedomstvennaya komissiya po izucheniyu Antarktiki* (Antarctica. Interdepartmental commission for the study of the Antarctic). Moskva, Izdatel'stvo Nauka, 13–42.)

MENEILLY, A. W., HARRISON, S. M., PIERCY, B. A. *and* STOREY, B. C. In press. Major shear zones and faults in Palmer Land and their role in the development of the Antarctic Peninsula orogenic belt. 6th Gondwana Symposium Volume, Ohio.

MOORE, G. F. *and* KARIG, D. E. 1980. Structural geology of Nias Island, Indonesia: implications for subduction zone tectonics. *American Journal of Science*, **280**, 193–223.

[illegible]ORE, J. C. *and* WHEELER, R. L. 1978. Structural fabric of a mélange, Kodiak Islands, Alaska. *American Journal of Science*, **278**, 739–65.

MUTTI, E. *and* RICCI-LUCCHI, F. 1975. Turbidite facies and facies associations. (*In: IX International Sedimentological Congress, Nice*. Field trip A11, 21–36.)

SEELY, D. R. 1977. The significance of landward vergence and oblique structural trends on trench inner slopes. (*In* TALWANI, M. *and* PITMAN, W. C. *eds*. *Island arcs, deep sea trenches and back-arc basins; Maurice Ewing Series 1*, AGU Washington, 187–98.)

SEELY, D. R., VAIL, P. R. *and* WALTON, G. G. 1974. Trench slope model. (*In* BURKE, C. A. *and* DRAKE, C. L. *eds*. *The geology of continental margins*. New York, Springer-Verlag, 249–60.)

SILVER, E. A. *and* BEUTNER, E. C. 1980. Mélanges. *Geology*, **8**, 32–34.

SMELLIE, J. L. 1981. A complete arc-trench system recognised in Gondwana sequences of the Antarctic Peninsula region. *Geological Magazine*, **118**, No. 2, 139–59.

TAYLOR, B. J., THOMSON, M. R. A. *and* WILLEY, L. E. 1979. The geology of the Ablation Point–Keyston Cliff area, Alexander Island. *British Antarctic Survey Scientific Reports*, No. 82, 64 pp.

THOMSON, M. R. A *and* TRANTER, T. H. 1986. Early Jurassic fossils from central Alexander Island and their geological setting. *British Antarctic Survey Bulletin*, No. 70, 23–39.