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Emplacement and reworking of the Marampa Group allothchon, northwestern Sierra Leone, West Africa

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Abstract—The structural evolution and relative age of the Precambrian Marampa Group, a 60 km wide north-northwest trending fold thrust belt is described in detail. The Marampa Group is shown to be unconformably overlain by the Rokel River Group which lies immediately to the east and is separated by a major crustal shear zone from gneisses and amphibolites of the Kasila Group to the west. Previous workers have interpreted the fold thrust belt as a klippe of the adjacent Kasila Group derived from the west or as an autochthonous volcano-sedimentary deposit engulfed by granitic basement. Ages ranging from 500 to >2700 Ma have been suggested. Evidence is presented to show that the important deformation of the Marampa Group clearly predates the deposition of the Rokel River Group and must represent a significant earlier orogenic event. Constraints on the relationship of this older deformation to the 2700-2750 Ma deformation of the Kasila Group are discussed. The earliest structures consist of flat lying thrusts which transported Marampa Group metasediments, with or without their basal metavolcanic formation, eastward from their source basin over the basin margin and onto a flanking heterogeneously deformed older granitic gneiss basement. Subsequent intrusion of megacrystic, now porphyroclastic granites was followed by a major period of crustal extension during which sediments and volcanics of the Rokel River Group were deposited in rift basins. Renewed east-west crustal shortening ascribed to the Pan-African event inverted earlier extensional structures thrusting the Rokel River Group westward over the Marampa Group and leading to local facing confrontations where east dipping faults were reactivated.
The relationship of the Marampa Group to the greenstone belts of Guinea, Liberia and Sierra Leone remains unresolved. © *1997 Elsevier Science Limited.*

Résumé—L'évolution structurale et l'âge relatif du Groupe précambrien de Marampa, une chaîne charriée et plissée d'extension NNW et de 60 km de large, est décrite en détail. Le Groupe de Marampa est surmonté en discordance par le Groupe de la Rokel River qui s'étend immédiatement à l'Est, et est séparé à l'Ouest des gneiss et amphibolites du Groupe de Kasila par une faille crustale transcurrente majeure. Les auteurs précédents ont interprété cette chaîne charriée et plissée comme une klippe du Groupe adjacent de Kasila ou encore comme un dépôt volcano-sédimentaire autochtone envahi par un socle granitique. Des âges variant de 500 Ma à plus de 2700 Ma ont été suggérés. Des arguments sont présentés en faveur d'une déformation importante du Groupe de Marampa qui prédate clairement le dépôt du Groupe de la Rockel River et doit donc représenter un événement orogénique antérieur. Les contraintes sur la relation existant entre cette déformation ancienne et la déformation à 2700-2750 Ma affectant le Groupe de Kasila, sont discutées.
Les structures les plus précoces sont liées à des charriages subhorizontaux qui ont transporté vers l'Est les métasédiments du Groupe de Marampa, avec ou sans leur

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socle métavolcanique, de leur bassin-source sur un bassin marginal et sur un socle granitique plus ancien déformé d'une manière hétérogène. L'intrusion subséquente de granites à mégacristaux (maintenant porphyroclastiques) a été suivie par une période importante d'extension crustale durant laquelle les sédiments et les volcanites du Groupe de la Rockel River se sont déposés dans des bassins de rift. Le raccourcissement crustal est-ouest attribué au Pan-Africain a inversé les structures d'extension préexistantes, charriant le Groupe de la Rokel River vers l'Ouest sur le Groupe de Marampa et induisant localement la réactivation de faille à pente est. Les relations entre le Groupe de Marampa et les ceintures vertes de Guinée, du Liberia et de Sierra Leone restent problématiques.

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INTRODUCTION

The Marampa Group is a narrow, 5-10 km wide, north-northwest trending volcano-sedimentary belt metamorphosed under greenschist- and amphibolite-facies conditions (Fig. 1). The Group is of uncertain, but Precambrian age. It lies upon granitic basement in Sierra Leone and extends north-northwestwards into Guinea (Bufeyev, 1972) where it becomes buried beneath the almost undeformed Ordovician to Devonian age cover of the Bové Basin. In Sierra Leone, the Marampa Group is bounded in the east by the Rokel River Group, a sequence of deformed north-northwest trending sedimentary and volcanic rocks considered to be of late Precambrian to Cambrian age (Allen, 1969; Culver and Williams 1979). The Rokel River Group is in part equivalent to the Precambrian to Cambrian Mali Group (Dallmeyer and Villeneuve 1987; Villeneuve and Dallmeyer 1987). In the west, outliers of the Marampa Group are in tectonic contact with a NNW-trending suite of amphibolites, gneisses and granulites known as the Kasila Group. The contact zone is marked by a 1-4 km wide zone of intensely mylonitised acid gneisses and other rock types displaying evidence for both ductile top to the northeast thrust shear and dextral strike-slip movement. This mylonite belt extends into Liberia where it is known as the Todi Shear Zone (Behrendt and Wotorson, 1970; Thorman, 1976). The north-northwest striking lithological associations of the Rokel River Group, the Marampa Group, the Kasila Group and the underlying basement granites and gneisses constitute the Rokel-Kasila Zone of Cahen *et al.* (1984).

REGIONAL TECTONIC SETTING

The Rokel-Kasila Zone forms part of an approximately north-south trending orogenic belt along the western margin of the West African Craton. This belt is almost continuously exposed through Guinea and into Mauritania as the Bassarides belt (Fig.1) and further north is continuous with the Mauritanide Zone, (Sougy, 1962; Lecorche *et al.*, 1983; Lesquer *et al.*, 1984; Villeneuve *et al.*, 1984). The Rokel-Kasila Zone appears to truncate both Archaean and Eburnean age deformation on the western margin of the West African Craton, but is developed parallel to an important direction of shearing within the granite-greenstone terrane east of the Rokelides.

Archaean deformation in northern Sierra Leone has been divided into two cycles (Macfarlane *et al.,* 1980). Both cycles are considered to involve greenstone belt formation; deposition of sediments, intrusion of mafic to ultramafic lavas, deformation and the intrusion of granites. The older cycle, the Leonean Event, is considered to have an approximately east-west structural trend typified by the elongation direction of thin amphibolitic supracrustals and the enveloping foliated granitic gneisses. Rb-Sr whole rock ages in the range 2950-3200 Ma (Hurley *et al.,* 1975; Hedge *et al.,* 1975) have been considered to relate to this event. The Liberian Event, to which the Marampa Group has been linked, is characterised by an approximately north-south tectonic trend (Rollinson, 1978) considered to be dated by a number of Rb-Sr whole rock ages clustering around a value of 2700 Ma (Hedge *et al.,* 1975; Hurley *et al.,* 1975).

Recent observations by one of the authors (L.I.W.) suggests this analysis is oversimplistic. Landsat image interpretation and detailed field studies of the Sula Mountains and Kangari Hills greenstone belts, considered to be of Liberian age, suggests the main trend of the Archaean deformation is approximately east-northeast, related to north-northwest - south-southeast shortening. Fabrics associated with this deformation are folded on north-northwest axial planes. The north-northwest folding was often accompanied by significant sinistral strike-slip

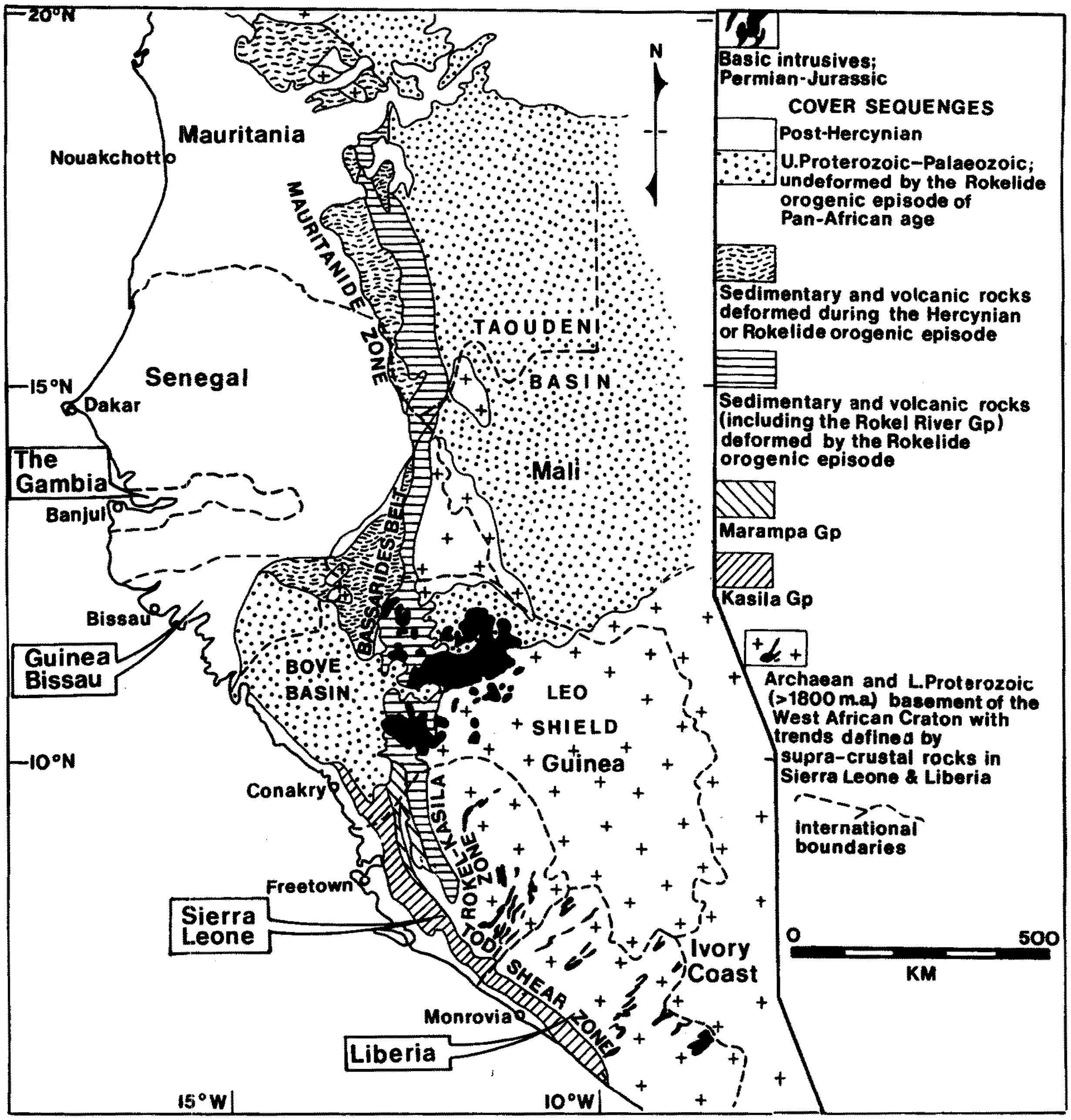


Figure 1. Geological map of western West Africa showing the major tectonostratigraphical units. The north-northwest trending Rokel-Kasila Zone comprising the Marampa Group, the Kasila Group and the sedimentary rocks of the Rokel River Group is shown. Modified from Culver et al. *(1991) and Lecorche* et al. *(1991).*

movement along north-northwest trending lineaments. The east-northeast and north-northwest trending deformations appear to be intimately related within a single orogenic episode, although this does not preclude the possibility of earlier deformation events or later movements along the same shear zones.

The Eburnean (Neoproterozoic) orogenic event within the West African Craton is associated with the deposition of Birrimien supracrustal rocks which form an almost continuous belt through the centre of west Africa; from Niger, southwards into Ghana, and westwards through Burkina Faso, Guinea, Ivory Coast, Liberia and into Mali. The geometry of the Eburnean in west Africa is complex. However Milesi *et al.* (1989) consider the approximately east-west trending Birrimien belt to be separated from the Archaean of Sierra Leone and Liberia to the south by an east-west trending zone of intense deformation, mylonitisation and mixed ages. This can be considered to constitute an Eburnean orogenic belt.

Within the Archaean granite-greenstone terrane, the existence of important north-south trending structures leaves open the possibility that the Rokel-Kasila Zone has its origins as an Archaean lineament. However the structural fabric of the Rokel-Kasila Zone is considered by MacFarlane *et al.* (1980) to transgress the approximately north trending strike of the Liberian age deformation in the granite-greenstone terrane to the east. The zone also apparently truncates the Eburnean orogenic belt. This may imply that formation of the zone post-dates both orogenic belts, although this evidence only proves that Pan-African movements have truncated older structures. It does not preclude the existence of earlier structures in the zone.

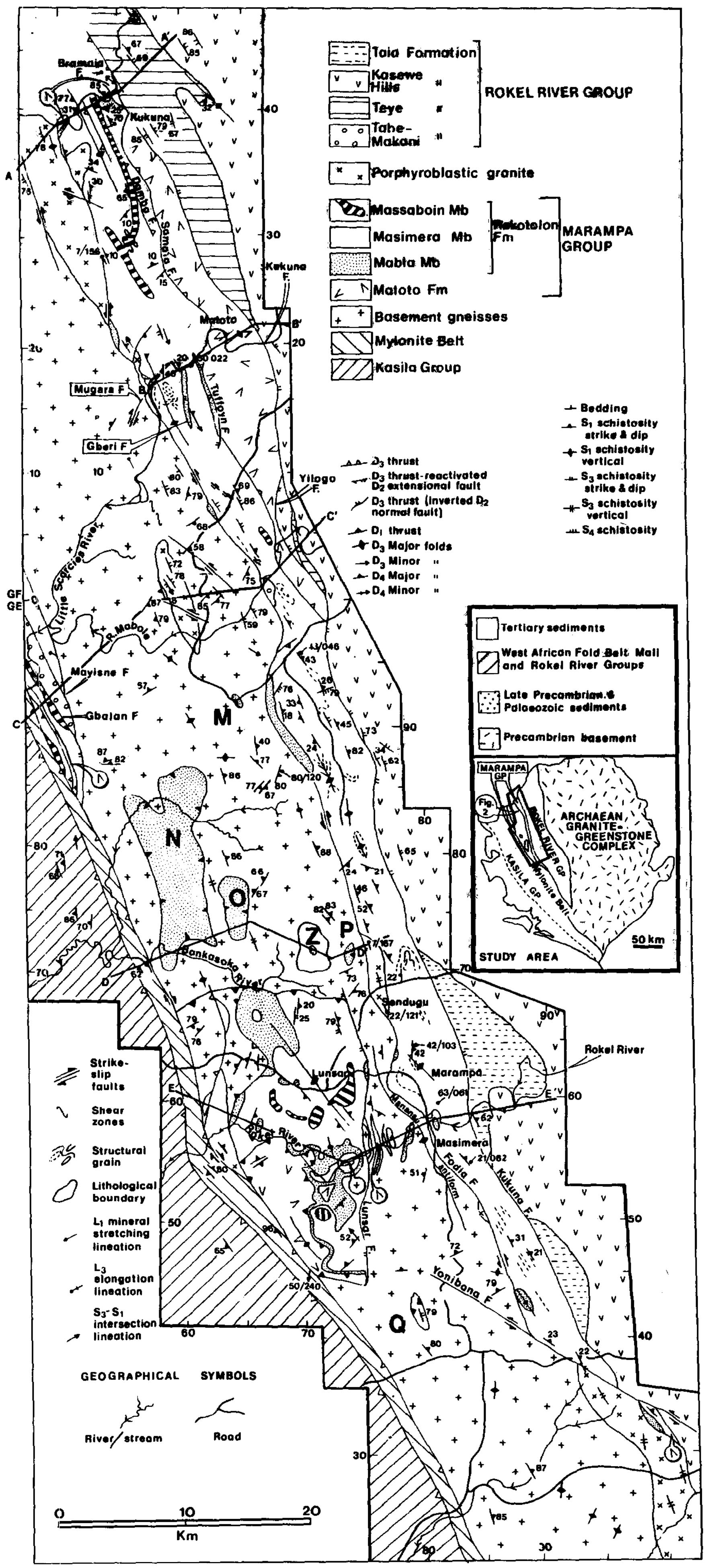
The majority of Rb-Sr whole rock and K-Ar mineral dates from the Rokel-Kasila Zone in both Sierra Leone and Liberia give Pan-African ages (Allen *et al.,* 1967; Hurley *et al.,* 1971; Hedge *et al.,* 1975), suggesting that the Pan-African thermotectonic event of Kennedy (1964) was important. This Late Precambrian to Phanerozoic Pan-African event is locally termed the Rokelide Orogenic Episode (Allen 1969). Eight whole rock Rb-Sr age determinations from samples of gneisses in the Rokel-Kasila Zone gave results in the range 750 to 350 Ma (Hurley *et al.,* 1971; Hedge *et al.,* 1975). These are interpreted as uplift ages. Two K-Ar determinations on muscovite in the Rokotolon Formation of the Marampa Group gave results of 560 ± 20 Ma and 562 ± 15 Ma, respectively (Beckinsale *et al.,* 1980), while the mean K-Ar mineral age of samples from the rocks of the Kasila Group is 520 ± 7 Ma. Generally younger K-Ar ages from the Kasila Group with respect to the Marampa Group suggests this was the last zone to undergo uplift.

The age data imply the Pan-African event was the last to affect the zone. Villeneuve and Cornée (1994) have made palaeogeographical reconstructions of the margins of the West African Craton in the period from 750 Ma to the present day. The main faults which define the Rokel-Kasila Zone are considered to have developed during this broadly Pan-African period of deformation. They attribute thrusting of the Marampa Group over the Rokel River Group to the earliest recognisable phase of deformation during a period when structures were orientated north-south as a result of northeast-southwest compression of the basin associated with dextral strike-slip faulting. Geological support for the importance of the Pan-African event is given by Allen (1969), who suggested that some of the Marampa and Rokel River Group sediments are age equivalents and that the north-northwest trend in the Rokel-Kasila Zone is due to the Rokelide Orogenic Episode. Suggestions that the volcanics of the Rokel River Group and the serpentinites within the Marampa Group constitute a dismembered ophiolite also imply a single tectonic episode to account for the deformation in both groups (Burke and Dewey, 1970; Shackleton, 1977). In this case the tectonic episode is considered to be related to the development of a plate collision orogen.

However, the Neoproterozoic ages are also compatible with the possibility that the deposition of the Marampa Group, or indeed the Rokel River Group, together with much of the deformation in the Rokel-Kasila Zone, is considerably older than the Pan-African event. Williams and Gaudette (*pers. comm.*, in Beckinsale *et al.,* 1980) have determined an upper intercept of 2700 Ma from a U-Pb concordia plot for zircons from gneisses of the Kasila Group and Hurley *et al.* (1971) obtained two single whole rock Rb-Sr ages of 2075 and 2154 Ma from albite-mica schists of the Marampa Group. On the basis of these ages Macfarlane *et al.* (1980) suggest that the Marampa Group was an Archaean greenstone belt in which the mafic-ultramafic rocks at the base of the succession are rooted beneath the belt, although the Marampa Group ages would more logically imply an Eburnean age for the Marampa Group and the earliest deformation in the Rokel-Kasila Zone.

Williams and Culver (1982) suggested that the most penetrative deformation predated the Rokelide Orogenic Episode and that the Marampa Group was Archaean in age. Williams (1988) describes the detail of a supposed Archaean collision causing the closure of a basin between the West African Craton and the Guyana Shield. Part of the sedimentary and volcanic prism was thrust-faulted eastwards onto the Liberian terrane to become the Marampa Group. The rest remained and was "steadily attenuated in a vice-like situation". In this model, which follows the scheme of Hoffman (1985) for the evolution of the Cape Smith Fold Belt in Canada, the Mylonite Belt is the suture zone. The Neoproterozoic event was marked by the creation of a linear trough, an aulacogen or back-arc basin, which became

Figure 2. *Geological map of the Marampa Group and the adjoining country rocks. Mapped using 1:50 000 contoured planimetric sheets, DOS Series 419, and compiled at 1:200 000 by R.S.A.L. The grid is that used on the 1:50 000 topographic maps.*



Tala Formation
Kasewe Hills
Teye
Tabe-Makani
ROKEL RIVER GROUP
Porphyroblastic granite
Massaboin Mb
Masimera Mb
Mabla Mb
Matoto Fm
MARAMPA GROUP
Basement gneisses
Mylonite Belt
Kasila Group
Bedding
S1 schistosity strike & dip
S1 schistosity vertical
S3 schistosity strike & dip
S3 schistosity vertical
S4 schistosity
D3 thrust
D3 thrust-reactivated D2 extensional fault
D3 thrust (inverted D2 normal fault)
D1 thrust
D3 Major folds
D3 Minor
D4 Major
D4 Minor
Tertiary sediments
West African Fold Belt Mali and Rokel River Groups
Late Precambrian & Palaeozoic sediments
Precambrian basement
MARAMPA GP
ARCHAEAN GRANITE-GREENSTONE COMPLEX
ROKEL RIVER GP
KASILA GP
Mylonite Belt
50 km
STUDY AREA
Strike-slip faults
Shear zones
Structural grain
Lithological boundary
L1 mineral stretching lineation
L3 elongation lineation
S3-S1 intersection lineation
GEOGRAPHICAL SYMBOLS
River/stream
Road
Km
Rokel River
Marampa
Masimera
Lunsar
Gendugu
Matoto
Kukuna
Mugara F
Gberi F
Mayisne F
Gbalan F
Yilogo F.
Kukuna F.
Yonibana F
Bankasoka River
Little Scarcies River

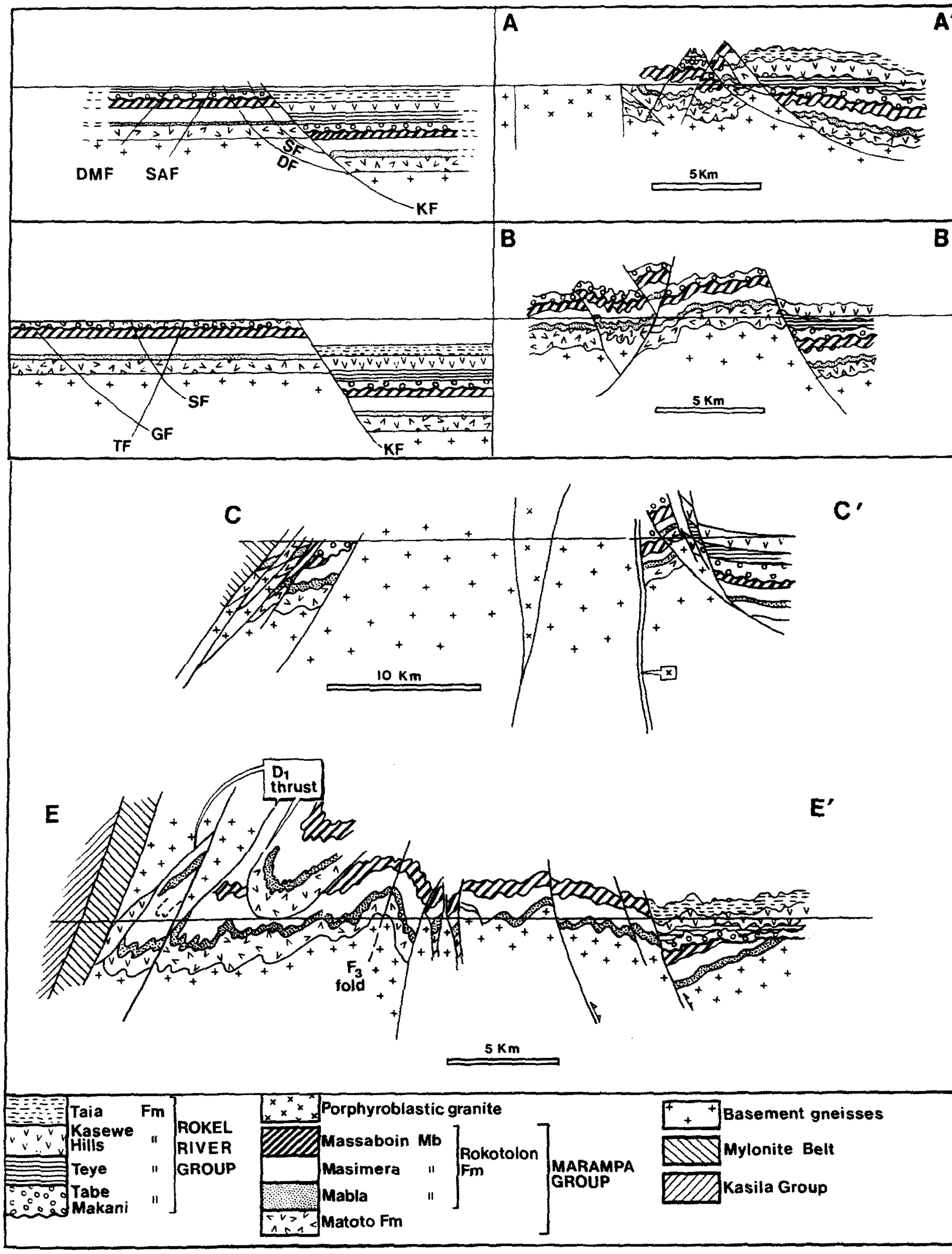


Figure 3. Serial sections across the Rokel-Kasila Zone (see Fig. 2 for locations). Sections AA' and BB' are partially restored to a pre-D_2 template by line length balancing and illustrate the inversion on the Kukuna Fault. Section CC' illustrates the confrontation of D_3 structures across the central basement horst. Note the overstepping Tabe Formation of the Rokel River Group across the Kukuna Fault and right across the central basement horst to the footwall of the Mayisne Fault. Section EE' crosses the zone south of Lunsar and shows D_3 deformation superimposed on local D_1 thrust repetitions of the succession. The D_1 deformation here is transporting the hangingwall sequences towards the northeast out of the section. There is local involvement of the Basement Gneisses in the D_1 thrust system hereabouts.

Table 1. Stratigraphy of the Rokel River Group (Allen, 1969; Culver and Williams, 1979) and the Marampa Group (McFarlane *et al.*, 1980; Latiff, 1993)

Formation/Member		Rock Type
		ROKEL RIVER GROUP
TAIA FORMATION (top not seen)		Grey-green shales and mottled reddish-white shales with feldspathic sandstone bands.
KASEWE HILL FORMATION 200 m		Grey-green augite-andesites, dacitic lavas and tuffs.
TEYE FORMATION 200 m		Purple shale, variegated silty shale with quartzite bands.
TABE-MAKANI FORMATION 180 m		Basal polymict conglomerate overlain by thin shaly sandstone.
		MARAMPA GROUP
ROKOTOLON FORMATION	Massaboin Member 150 m	Quartz-haematite ± sericite schists.
ROKOTOLON FORMATION	Masimera Member 350-450 m	Semi-pelitic quartz-albite-muscovite-chlorite schists: garnet-biotite schists and quartz-mica paragneisses.
ROKOTOLON FORMATION	Mabla Member 2-90 m	Fine-grained layered and coarsely crystalline pure white orthoquartzite with up to 2-5% muscovite and haematite.
MATOTO FORMATION 250-300 m		Chloritic volcanics, pillowed metabasalts, banded meta-andesites and hornblende-plagioclase-epidote schists. Massive pyroxenites, olivine serpentinites, talc-chlorite schists and talc-antigorite schists.

filled with Rokel River Group sediments, which were subsequently deformed and mildly metamorphosed.

METHODOLOGY OF THIS STUDY

This field-based investigation into the structural and tectonic history of the Marampa Group is an attempt to provide the first detailed scientific framework on which models for the geotectonic and palaeogeographical evolution of this key part of the West African crust can be formulated and against which existing models can be tested. Field mapping was carried out on a scale of 1:30 000 using enlarged versions of the 1:50 000 contoured maps of Sierra Leone and aerial photographs. Figure 2 displays the first detailed map of the geology of the Marampa Group.

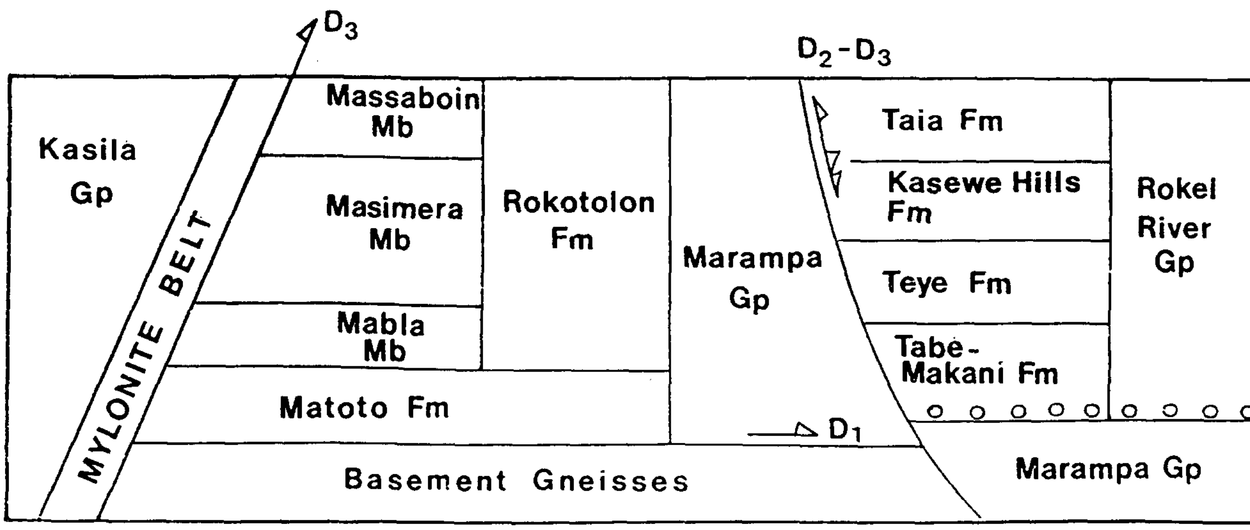
The field data are used to produce interpretations of the palaeogeographical and tectonic history of the Rokel-Kasila Zone. Palinspastic reconstruction of two of the serial cross-sections to a pre-Rokelide template is attempted using the line length balancing method (Dahlstrom, 1969, 1970; Fig. 3). It is accepted that there will be errors in this method because the assumption of a plane strain deformation is only partially correct. Restoration by the area balance method (Elliot and Johnson, 1980) was not used because the original thicknesses of the layers are not known. Restoration of the section across the area south of Lunsar (E-E', Fig. 2) is not attempted because of the known importance of movement of material into and out of the section.

STRATIGRAPHY

The stratigraphical and tectonostratigraphical relationships in the Rokel-Kasila Zone are schematically illustrated in Tables 1 and 2. The Marampa Group rests with a low angle tectonic contact on granitic Basement Gneisses. Following Macfarlane *et al.* (1980), it is subdivided into a lower metavolcanic Matoto Formation and a metasedimentary Rokotolon Formation. The Rokotolon Formation is further subdivided into three Members: the Mabla, Masimera and Massaboin Members (Latiff, 1993). The stratigraphical relationship between the Kasila Group and the Marampa Group is unknown as the two groups are always separated by a shear zone, termed the Mylonite Belt. The rocks exhibit greenschist facies mineral assemblages in the east and increase in metamorphic grade to amphibolite facies in the west (Table 1; Latiff 1993).

The Rokel River Group rests with marked angular unconformity on the Marampa Group and the Basement Gneisses. Clasts of the Basement Gneisses, the Marampa Group and other rock types, occur in poorly-sorted conglomerates of the basal Tabe-Makani

Table 2. Cartoon illustrating the tectonostratigraphical relationships of the lithological associations in the Rokel-Kasila Zone



Formation. The lower Formations of the Rokel River Group, identified further east (Culver *et al.*, 1978; Culver and Williams, 1979) cannot be distinguished in this region. Following Macfarlane *et al.* (1980) all the lithologies of the Rokel River Group below the Teye Formation are grouped into the Tabe-Makani Formation. The Rokel River Group has only been weakly metamorphosed under low greenschist-facies conditions leading to sporadic partial recrystallisation with sericite and chlorite development.

Deformed megacrystic granites intrude the Basement Gneisses and the Marampa Group as stocks and bosses along the line of the Fodia Fault. Similar granite, referred to as monzonites by Obermuller (1941), have been recognised in the Republic of Guinea. These granites are overlain by the Tabe-Makani Formation of the Rokel River Group. The megacrystic granites have a distinctive light pink hue, due to abundant coarse pink microcline porphyroclasts, which allows them to be easily distinguished from the dull grey colour of the Basement Gneisses. Two post-tectonic basic dykes sets, one east-west and the other coast-parallel, intrude all the lithostratigraphic units and the megacrystic granites. They are thought to have been intruded during the onset of Early Mesozoic rifting prior to the opening of the North Atlantic Ocean (Culver and Williams, 1979).

STRUCTURE

The principal outcrop of the Marampa Group occurs in a narrow north-northwest trending fault-bound strip some 5-10 km wide extending over 140 km through Sierra Leone and onwards into Guinea. South-southeastwards it is cut out as the Rokel River Group is faulted directly against Basement Gneisses. The western boundary of this strip is marked by the Fodia Fault, a steep structure across which Marampa Group metasediments are downthrown to the east. The eastern boundary is defined by the Rokel River Group downthrown along the important Kukuna Fault.

A subsidiary fault-bound north-northwest trending strip of Marampa Group occurs further west where it is sandwiched between the Mylonite Belt and Basement Gneisses, eventually being cut out where the Mayisne Fault terminates against the Mylonite Belt. An outlier of the Rokel River Group occurs here as a north-northwest trending strip bounded to the west by the Gbalan Fault. West of the Mylonite Belt lie the west dipping acid and basic gneisses of the Kasila Group (Williams, 1988).

Between the two strips of metasediment, tectonic klippe of the Marampa Group sit upon the Basement Gneisses. The largest of these towards the southern end of the outcrop is terminated to the east by the Lunsar Fault.

A small but important outlier of the Rokel River Group adjoins the Fodia Fault where it is crossed by the Mabole River. The Rokel River Group here lies unconformably upon the Marampa Group and oversteps one of several stock-like intrusions of megacrystic porphyroclastic granite which outcrop in this region (Latiff, 1993). The majority of these stocks lie close to the line of the Fodia Fault.

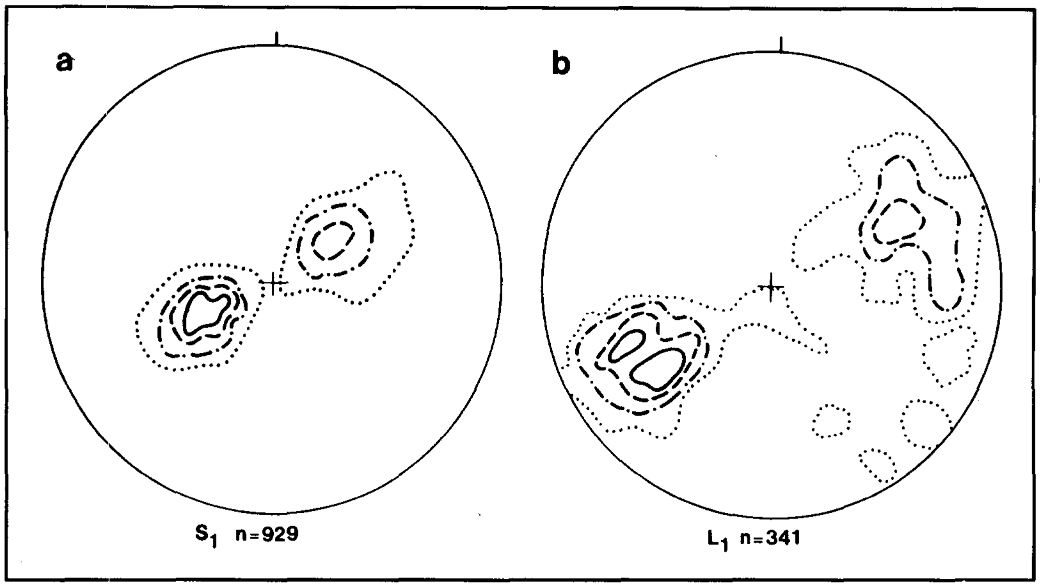


Figure 4. *Equal area lower hemisphere stereographic projections of D_1 fabrics in the Marampa Group showing (a) the bimodal distribution of the poles to S_1 (contours at 2, 4, 6 and 8%) and (b) east-northeast - west-southwest down-dip L_1 stretching lineation due to later refolding (contours at 2, 6, 10 and 14%).*

Deformation chronology

Allen (1969) identified four phases of folding in the Marampa Group according to fold trends and geometries. Macfarlane *et al.* (1980) recognised a simplier deformation sequence with the first event producing a bedding parallel mica schistosity in the Marampa Group only. In this considerably more rigorous study, four discrete phases of deformation are recognised on the basis of regional kinematic studies. The first is recorded by a top-to-the-east layer-parallel shearing deformation, accompanied by folding, in which the Marampa Group moved eastward over adjacent granitic basement.

Deposition of the Rokel River Group accompanied a second phase of extensional deformation during which most of the major faults were formed. However, megacrystic porphyroclastic granites intruded along the line of some of the faults predate the Rokel River Group, suggesting that the extensional deformation may have reactivated already existing structures.

Closure of the extensional basins marks a third major tectonic episode which evolved into a fourth episode of strike-slip movement along discrete zones.

Tectonic emplacement of the Marampa Group (D_1)

All the deformation which precedes and accompanies the emplacement of the Marampa Group over the Basement Gneisses is grouped into a D_1 event. A regionally developed S_1 fabric (Fig. 4) is in lower greenschist metamorphic facies in the east, increasing to amphibolite facies in the west. There is evidence via intrafolial folds of a pre-S_1 cleavage deformation. Final movements on the thrusts, which emplaced the Marampa Group, and on a number of related small scale structures post-date the S_1 foliation. All these structures can be placed in the context of an extended period of progressive deformation.

Structural fabrics

A generally flat-lying L-S tectonite fabric is found in the rocks of the Marampa Group (Fig. 4). The bi-modal distribution of the S_1 cleavage reflects the effects of later north-northwest trending folding during the Rokelide Orogenic Episode. No major folds have been identified but small scale recumbent isoclinal, sometimes intrafolial folds with axes generally trending north-northwest - south-southeast occur. The S_1 fabric is often a closely spaced pressure solution cleavage in which the bedding and cleavage are generally sub-parallel. At the lowest metamorphic grades in the east the S_1 fabric is defined by the alignment of chlorite, actinolite, epidote and albite in metabasic and meta-ultramafic rocks. Westwards these minerals are replaced by pargasitic hornblende, epidote and calcic plagioclase (andesine). In the semi-pelitic and pelitic Masimera Member, S_1 consists of fine-grained aligned muscovite, chlorite and opaque oxides in thin spaced zones that alternate with

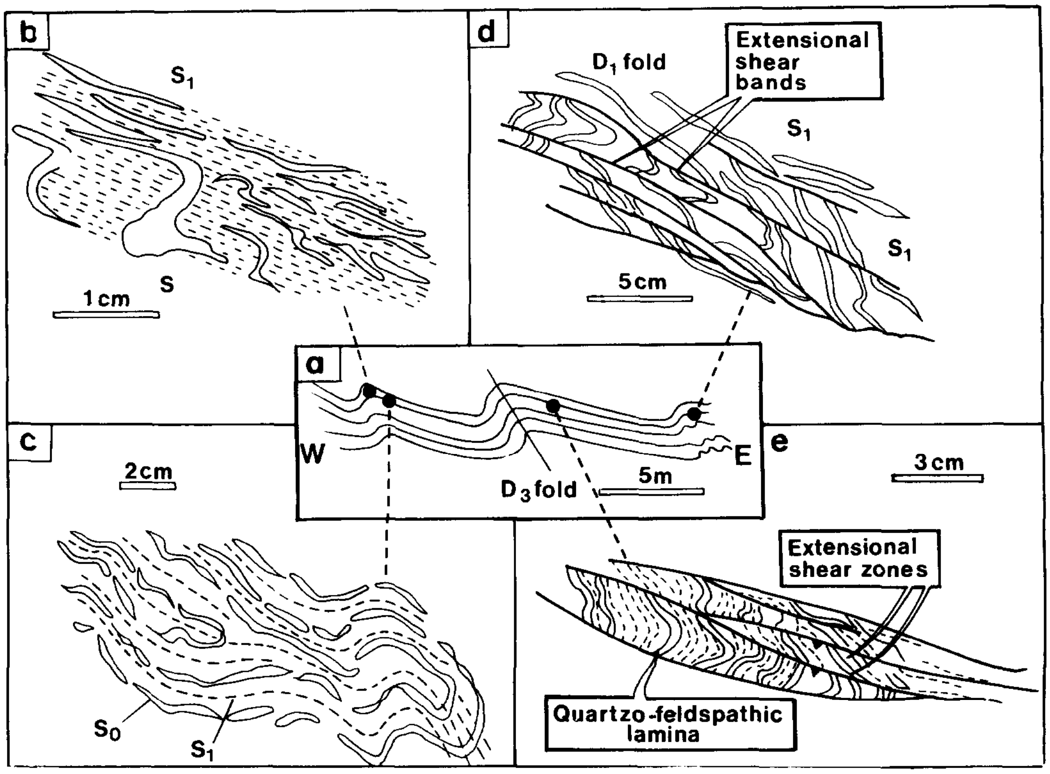


Figure 5. Field sketches of D_1 structures in the Masimera Member, Marampa Group. (a) Cross-section with F_3 folding S_1; note the locations of (b), (c), (d) and (e). (b) S_1 cleavage axial planar to east verging folded quartzo-feldspathic laminae that probably represent relict bedding. (c) S_1 axial planar to a recumbent D_1 fold affected by open F_3 folds, creating a type 3 D_3/D_1 interference structure. The quartzite laminae (S_0) lying in S_1 are boudinaged in the limbs of D_1 folds indicating that S_0 was isoclinally folded and extended prior to the D_3 event. (d, e) S_1 cleavage folded and disrupted by low angle faults that extend S_1 eastward.

quartz and albite bands. Some metapelites preserve an earlier fabric as straight inclusion trails in garnet porphyroblasts.

The early fabric is characterised in places by small scale structures (Fig. 5) which post-date most of the period of fabric formation. Their asymmetry uniformly indicates a top-to-the-east-northeast direction of transport parallel to the restored direction of L_1. Local variations are evident, for example in the area south of Lunsar where the D_1 stretching lineation trends north-northeast. Upward-cutting contractional shear bands in semi-pelitic schists of the Masimera Member are associated with a clast shape-obliquity from which top-to-the-east shear can be deduced. S_1 in the Masimera Member is disrupted in many localities by a series of small-scale, low-angle extensional faults. These truncate and displace the S_1 fabric with a down-to-the-east sense of movement (Fig. 5d, e). The microfabric in these structures is defined by aligned platy muscovite and chlorite, similar to that associated with displaced S_1 fabric, and these small faults run parallel with S_1 outside the fold closures.

An east-northeast direction of transport is also implied by the pervasive development of a strong mineral stretching lineation now folded into a down-dip orientation by later folding (Fig. 4b). In zones of high strain, sheath folds are elongated in a direction almost parallel to the direction of transport.

Relationship between the Basement Gneisses and the Marampa Group

The nature of the contact between the Basement Gneisses and the Marampa Group is critical to the understanding of the tectonics of the Marampa Group. A tectonic detachment between the Marampa Group and the Basement Gneiss can be inferred from the boundary relationships between a number of small outliers of flat lying sheets of Marampa Group overlying the Basement Gneisses. In many of the outliers the lower part of the Marampa Group is absent. Outliers M, N, O, and P (Fig. 2) show the Mabla Member sitting directly on the Basement Gneisses; a thickness of at least 250 m of the Matoto Formation is cut out. In some smaller

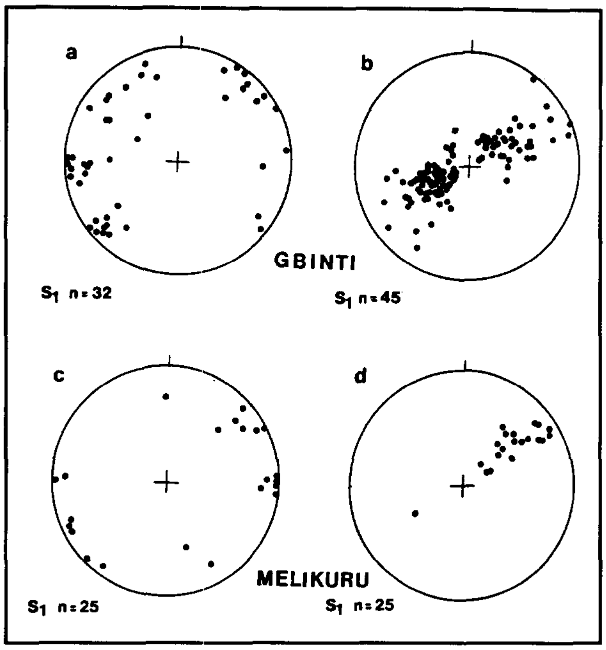


***Figure 6.** The discordance between fabrics in the Basement Gneiss and the overlying Marampa Group. (a) and (c) are stereographic projections of poles to the S_1 fabric in Basement Gneisses in the Gbinti and Melikuru areas, respectively. (b) and (d) are poles to the S_1 fabric in the Marampa Group in the same areas.*

outliers east of the Lunsar Fault, the Mabla Member and the basal Matoto Formation, a total of at least 350 m of thickness, are missing. The middle Masimera Member of the Rokotolon Formation sits directly on the Basement Gneisses at outliers Z and Q. The Marampa Group contact with the Basement Gneiss is exposed in the Lunsar area (GE 737553; grid references refer to the national grid of Sierra Leone). A tectonic contact is clearly demonstrated by 2-6 m of intensely mylonitised Matoto Formation resting on sheared Basement Gneiss. The Matoto Formation mylonites possess a strong east-northeast - west-southwest trending lineation. The basement is involved in this deformation only in the vicinity of the basal décollement. Elsewhere it behaved in a relatively rigid fashion.

Further evidence of tectonic emplacement is the clear discordance in the orientation of the earliest recognisable fabric between basement and cover in the Masimera area, west of the Fodia Fault (GE 801560), and the Gbinti area immediately to the north (Fig. 6). In the Basement Gneisses this fabric is manifested by a compositional banding; biotite ± amphibole enriched layers alternating with bands containing quartzo-feldspathic segregations.

Deposition of the Rokel River Group (D_2)

A significant period of extension (D_2) post-dating emplacement of the Marampa Group is indicated by the large north-northwest - south-southeast trending easterly and westerly dipping faults which control the distribution of the Marampa and Rokel River Groups. The most important of these are the Kukuna Fault, Fodia Fault, Yilogo Fault, Tuffoyim Fault, Samaia Fault and Damba Fault, forming the fault system bounding the western margin of the graben containing the principal outcrops of the Marampa and Rokel River Groups. To the west lie the Mayisne and Gbalan Faults bounding narrow strips of metasediment truncated to the south by the Mylonite Belt. The Lunsar Fault truncates the eastern margin of the principal Marampa Group klippe sitting on the Basement Gneisses in between. It can be demonstrated that all of these faults have a predominantly normal sense of movement.

Localisation of pre-Rokel River Group megacrystic porphyroclastic granitoids along the line of the Fodia Fault suggest that some or all of these faults may have been initiated at an early stage, possibly during extensional collapse of the Marampa orogenic pile.

The geographical restriction of the complete sequence of the Rokel River Group to the hanging wall of the Kukuna Fault and the general distribution of the Rokel River Group, with respect to the pattern of faulting, suggests that deposition of the Rokel River Group was concentrated in extensional fault controlled basins. The concentration of west dipping faults in the west, and east dipping faults in the east, suggests that the central region was a basement horst during this period.

Details of fault geometry

The Kukuna Fault is the easternmost of the two major faults which traverse the area and between which the majority of the Marampa Group outcrops. It constitutes the eastern limit of the Marampa Group and is clearly a fundamental structure. In its hanging wall, different formations of the Rokel River Group abut against the Marampa Group. South of the Yonibana Fault, Basement Gneisses are in the footwall (Fig. 2). Progressively older formations of the Rokel River Group are thrown against the Marampa Group towards the north, suggesting increasing displacement northwards.

The second major fault is the Fodia Fault, west of which only limited parts of the Marampa Group succession occur. In its hanging wall, the

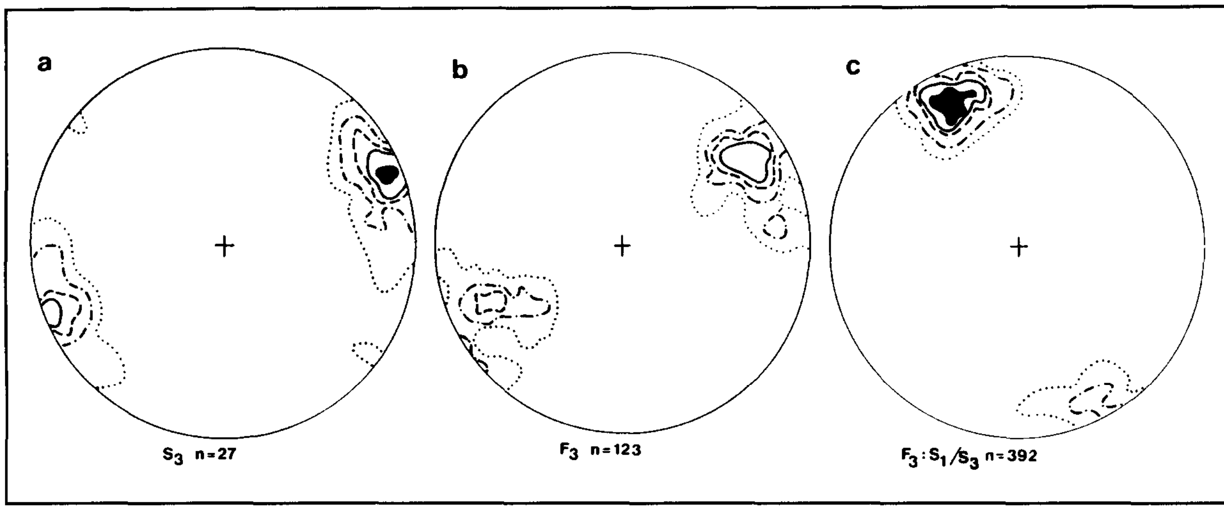


Figure 7. Lower hemisphere equal area stereographic projections of D_3 fabrics in the Marampa Group. (a) Poles to S_3 (contours at 2, 5, 8, 11 and 14%). (b) Poles to F_3 axial planes (same contour intervals). (c) F_3 fold axes and S_1/S_3 intersection lineations (contours at 5, 10, 15, 20 and 25%).

Masimera Member of the Marampa Group is faulted against the Basement Gneisses for the greater part of the length of the fault. At GF 6701 a small outlier of the Tabe-Makani formation of the Rokel River Group lies unconformably on the Masimera Member and oversteps the megacrystic porphyroclastic granite intruded along the line of the fault.

On the western side of the Basement Gneisses, outliers of the Marampa and Rokel River Group are imbricated together in the hanging wall of the Mayisne Fault. The dips of the bedding and structural fabrics are moderately to steeply west. The overall structural relationships suggest that periods of both extension and shortening took place across the fault.

The eastern limit of the largest klippe of the Marampa Group lithologies, which lies towards the southern end of the horst block of the Basement Gneisses, is terminated by the Lunsar Fault. North of the Rokel River, westerly dips in close proximity to the Lunsar Fault suggest that it is a westerly dipping extensional fault, as indicated by the presence of the Marampa Group in the hanging wall and the Basement Gneisses in the footwall.

The Rokelide Orogenic Episode (D_3)

This compressional event (D_3) is characterised by heterogenous deformation which produced north-northwest - south-southeast trending folds and thrust faults and the variable development of an S_3 fabric. The fabric is often defined by the realignment of the earliest mineral fabric and neomineralisation, where actinolite, talc, chlorite, sericite, haematite and rarely biotite have developed in shear zones. All the important extensional syn-sedimentary faults were inverted along all or part of their length as thrust faults.

The central basement horst formed during the earlier extensional episode controlled the style of deformation and allows consideration of the D_3 deformation in terms of three zones (*cf.* Fig. 2, section C-C'):

i) a Central Domain: primarily composed of Basement Gneisses which does not generally show D_3 structures;

ii) an Eastern Domain: east of the Fodia Fault, comprising the Marampa Group and Rokel River Group characterised by generally west verging folds and west directed thrust faults; and

iii) a Western Domain: west of the Lunsar and Mayisne Faults, comprising the Marampa Group, the Mylonite Belt and the Kasila Group. This domain is characterised by east directed thrust faults and east vergent folds.

Fabric data (Fig. 7) combined from all three domains show a well defined structural pattern. The opposed vergence of folds between the Eastern and Western Domains is reflected in a skewed bi-modal distribution of fold axial planes, but cannot be discerned in the S_3 cleavage distribution. The cleavage is generally steeply dipping and folds generally exhibit low plunges to the north-northwest.

There is an increasing east to west metamorphic gradient characterised by very low greenschist facies metamorphism in the Eastern Domain, increasing towards upper greenschist-facies into the Western Domain.

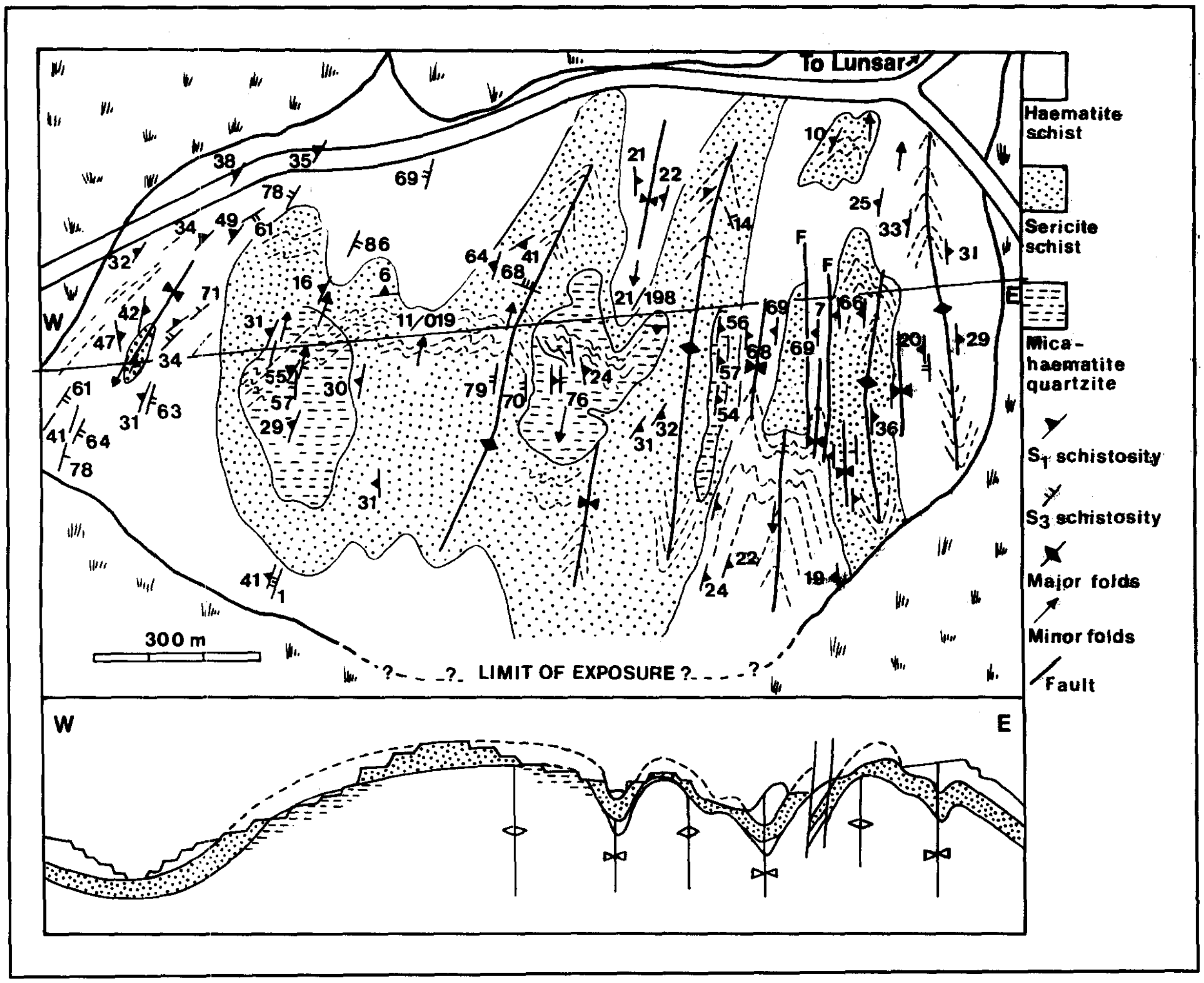


Figure 8. Geological map and cross-section of the Marampa Fe ore mine, GE 735603. The structure is dominated by upright, close to tight F_3 periclinal folds.

Late D_3 deformation is thought to be responsible for much of the movement on the mylonite zone, which carries the Kasila Group eastwards over the Marampa Group and Basement Gneisses. The Mylonite Belt always separates the Kasila Group and the Marampa Group and truncates earlier D_3 folds and thrusts. Although the major direction of movement within the mylonites is down dip, there is evidence of a dextral strike-slip component.

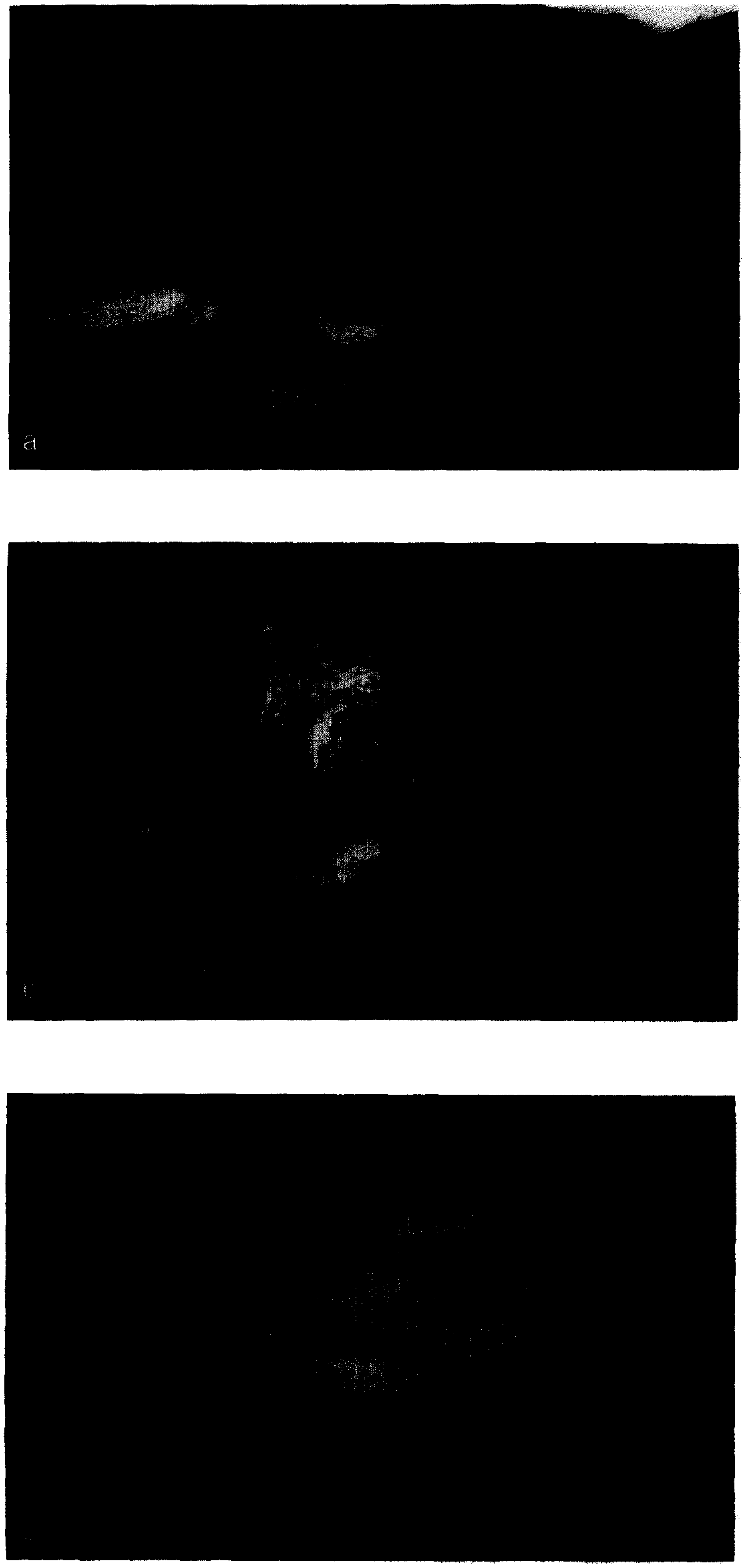
The Central Domain

The Basement Gneiss succession beneath the Marampa Group allochthon rarely contains recognisable D_3 folds, except for a narrow zone between the Lunsar Fault and the Fodia Fault where the domain is very narrow. In this area open and upright, northwest-southeast trending D_3 folds define the hinge zone of the Mamansu Antiform (Fig. 2, *cf.* section E-E').

The Western Domain

Open to tight north-northwest trending, east verging folds are linked to a series of high angle reverse faults. The folds have a first order wavelength of 3-4 km (second order 1 km), while at the outcrop scale they range from metre to millimetre scale folds. The fold geometry is well demonstrated by examples from the Marampa Fe mines (Figs 8 and 9). The faults strike almost parallel to the folds and show top-to-the-east displacements. East directed thrusting is evident in map-scale thrust faults climbing upsection towards the east (Fig. 3, west side of section C-C').

Small-scale structures mirror the map-scale folds and reverse faults. Thrusts dissect the limbs of D_3 folds and the majority indicate east directed transport (Fig. 10). Some are marked by mylonite zones containing a down dip, rodded, stretching lineation.



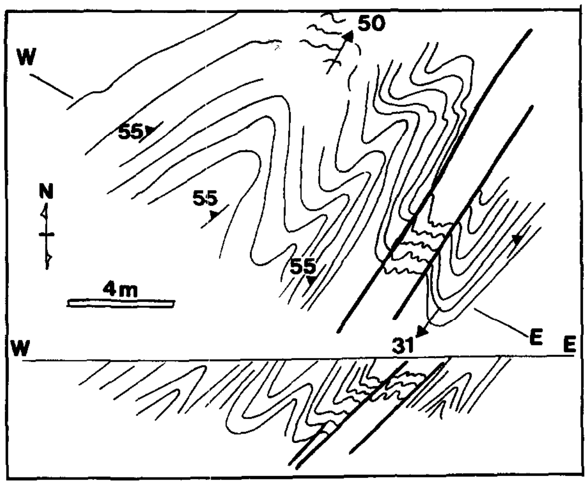


Figure 10. East directed late thrust faults dissecting the overturned limbs of D_3 synforms, Mapoli GE 727545 in the Lunsar area.

The Eastern Domain

The largest structures are the inverted Kukuna and Fodia Faults. The Kukuna Fault still has a net extensional displacement at the surface (Fig. 3), but small-scale structures in the vicinity of the fault suggest the latest movements were contractional. For example in the Masimera area (GE 835585) sheared or brecciated shales of the Taia Formation adjacent to the fault dip east in the hanging wall. The footwall schists of the Masimera Member display westerly verging asymmetric minor folds. The inversion is clear in cross-sections A-A' and C-C' (Fig. 3) where short-cut faults have developed in the footwall to the Kukuna Fault during the D_3 shortening. Some west dipping backthrusts have developed (e.g. the Tuffoyim Fault; section B-B'), but these have only small displacements. Estimates of local shortening values in the Eastern Domain based upon partial restoration and line length balancing of sections A-A', B-B' and the eastern end of section C-C' are 28%, 32% and 28%, respectively.

Between the Kukuna and Fodia Faults, the structure is dominated by a prominent set of north-northwest - south-southeast trending *en echelon* kilometre to centimetre scale periclinal folds. The folds are commonly accompanied by a spaced S_3 crenulation cleavage. Kilometre scale folds are upright to westward inclined and characterised by long east dipping limbs that alternate with shorter west dipping limbs. Parasitic folds in the pelitic and semi-pelitic Masimera Member are tight, gently inclined to overturned and are best developed on the longer east dipping limbs, where they show a constant westward vergence (Fig. 9). Associated thrust faults with top-to-the-west displacements of a few cm are common (Fig. 11).

Deformation in the Mylonite Belt and the Kasila Group

The Mylonite Belt structurally underlies the Kasila Group and has a foliation (S_m) that dips steeply west. The lithologies of the belt are usually blastomylonites containing quartz and feldspar bands that alternate with phyllosilicate rich bands. Towards the south of the belt, S_m is folded. Folds with axes plunging gently northwestwards and the asymmetry of feldspar porphyroclasts parallel to a down dip mineral stretching lineation indicate a top-to-the-east sense of shear. Further north in the vicinity of the Little Scarcies River, a strong mineral stretching lineation plunges gently to moderately southwestwards. Here, asymmetric feldspar augen indicate a dextral strike-slip component of oblique shear.

The footwall tectonic contact is a late D_3 thrust fault, trending north-northwest - south-southeast and dipping west. Along its strike length, this fault transgresses the Basement Gneiss, the Marampa Group and other D_3 faults in the Western Domain. In the hanging wall, tight folds in the Kasila Group fold an earlier fabric. Some of them show a well developed fold-axis-parallel elongation lineation.

DISCUSSION

Emplacement of the Marampa Group

The Marampa Group rests in tectonic contact with the Basement Gneisses and evidence presented in this paper indicates that metavolcanics and metasediments have been transported eastwards from a sedimentary basin not now seen. Omission of part of the stratigraphical sequence requires a model which does not simply shorten the original depositional basin by thrust stacking. In the east-west band crossing the south central part of the map (Fig. 2), the Mabla Member rests directly on

Figure 9. Photographs of the lithologies and structures of the Marampa Group. (a) F_3 chevron fold with angular hinge zone, haematite quartzite of the Massaboin Member of the Rokotolon Formation, Marampa Mines, GE 735603. Photo looking north. (b) West vergent D_3 fold, quartz-albite-sericite-chlorite schists, Masimera Member, Sendugu area, GF 595183. Photo looking north. (c) Near recumbent west vergent asymmetric F_3 folds in quartz-albite-sericite-chlorite schists, Masimera Member, indicating late west directed shear, Rokel River GE 817577. Photo looking south.

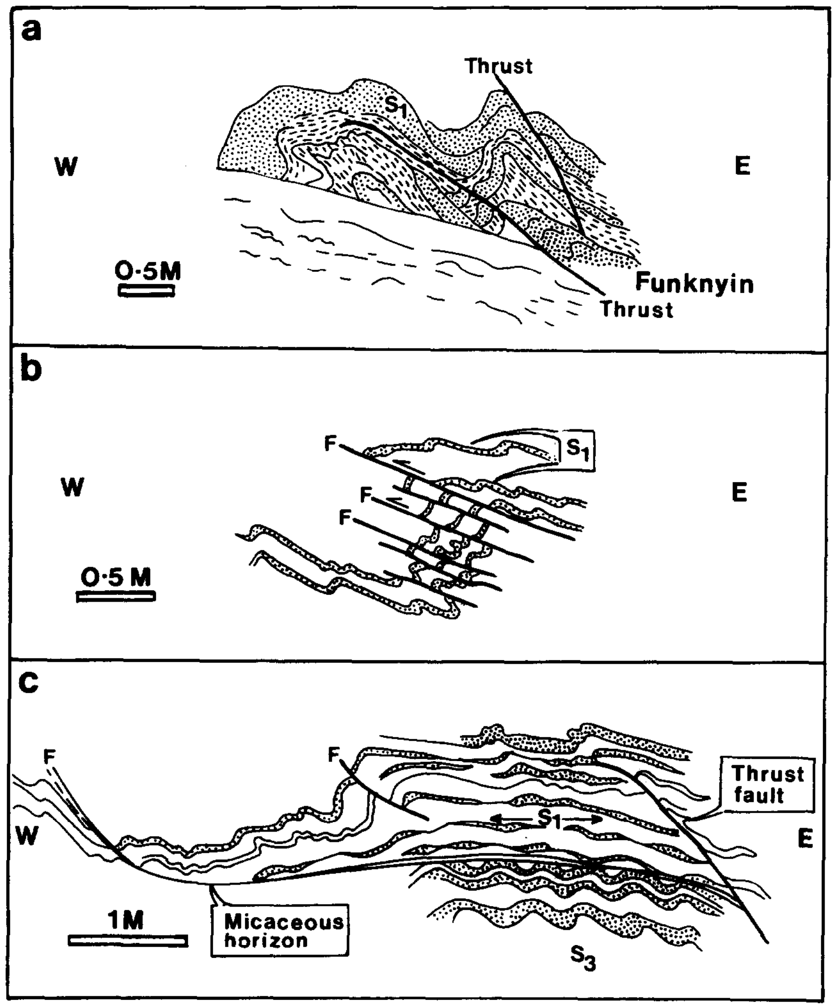


Figure 11. Minor fold and thrust fault relationships in the Masimera Member semi-pelitic schists, Eastern Domain. (a) Minor west transporting thrusts and fault propagation close to tight F_3 folds, Funknyin GE 726838. (b) Small thrust faults dissecting the overturned limb of a westerly verging asymmetric fold, GE 815577 near Mapeles Village. (c) Small thrust with hanging wall ramp and footwall flat, GE 780167 near Marampa Village. The footwall folds show a poorly developed axial planar S_3 cleavage.

basement. Attempts to restore the cross-sections by line length balancing back to an initial configuration (Latiff, 1993) demonstrate a logic for the development of the early thrust systems. Complete restoration of an east-west section north of Lunsar (D-D′, Fig. 2) is attempted in Fig. 12. The model in Fig. 12 is based upon the premise that the Marampa Group was expelled from its source basin onto an adjacent cratonic margin, accounting for the observation that the Mabla Member metasediments are directly in tectonic contact with the Basement Gneisses and that the Basement Gneisses are not widely involved in the D_1 thrusting. An original extensional geometry within the thrust source basin can account for the omissions of stratigraphy within the klippen of the Marampa Group (Fig. 12), though this is by no means a unique solution. In this model a detachment develops at the interface between the basinal volcanic floor (Matoto Formation) and the overlying sediments (Mabla Member). The basal thrust propagates across extensional faults, leaving some of the oceanic sedimentary sequence in the footwall and expelling the hanging wall over the adjacent continental margin.

Northwards and southwards, the Matoto volcanics were involved in the D_1 thrusting and underlie the rest of the Marampa Group. It is suggested that this is because the D_1 basal detachment followed the base of the volcanic sequence, except in the south central section where it stepped up across lateral ramps to the base of the overlying sediments. These ramps are not visible at the present levels of exposure, having either been eroded away above the central

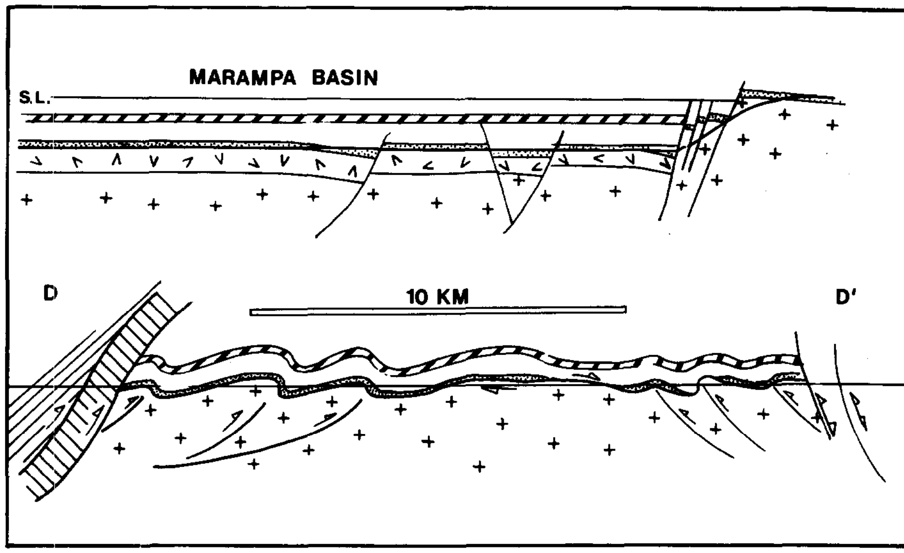


Figure 12. Present day and restored section DD'on Fig. 2. A reconstruction of the D_1 thrust detachement geometry within a pre-D_1 extensional fault basin is shown above the present day cross-section. Ornament as in Fig. 3. The last movements in the Mylonite Belt are at least Pan-African or younger age as the deformed Rokel River Group sediments are truncated.

basement horst or buried beneath the overlying sediments to the east of the Fodia Fault.

Thrust stacking of the Marampa Group and its basement could have provided the burial and heating required to generate megacrystic granite stocks, which were emplaced during a regional tectonic extension (*cf.* Gibbs, 1984). The exact timing between the emplacement of the Marampa Group and this later extension is unknown, but the latter is considered to represent a separate and discrete event. The timing of this event might be resolved by isotope dating of the megacrystic granites.

The evidence presented in this paper provides a detailed scientific analysis of the suggestion of Williams (1988) that the Marampa Group was displaced eastward over an adjoining granite-greenstone terrane from a basin 'in which the Kasila Group represented a distal part'. In Williams' model the Kasila Group continued to be deformed in the basin before being stacked upon the Marampa Group thrust system. Though this study confirms the eastward displacement of the Marampa Group and adds detail to the mechanisms involved and the nature of the post-emplacement deformation of the region, it leaves open the history of the Kasila Group and its relationship to the Marampa Group.

The Kasila Group is always separated from the Marampa Group by the Mylonite Belt which shows varying amounts of dextral strike-slip and oblique-slip movement. A detailed analysis of its history requires further study, however two points can be made. Firstly, the last movements on the Mylonite Belt transect D_3 folds and thrusts and are thus late-D_3 or post-D_3 in age. Secondly, the Kasila Group hosts an early fabric that is folded and cut by folds and thrusts comparable to those formed during the D_3 event in the Marampa Group.

The stratigraphical succession of the Marampa Group is similar to that of the Kambui Supergroup, which Macfarlane *et al.* (1980) consider to be an *in situ* supracrustal sequence engulfed by granitic basement. Recent fieldwork by R.A.S.L. indicates that several areas of the Kambui Supergroup have widely developed thrust faults, mineral stretching lineations and sheath folds. In view of the structural evidence for the allochthonous nature of the Marampa Group, it would be timely to re-examine the current view that the greenstone belts in the Kenema Domain of Sierra Leone, Liberia and Guinea are autochthonous remnants of supracrustal successions.

The Rokel River Group

The thick succession of the Rokel River Group was deposited during a period of pronounced extension in basins contained between D_2 growth faults. It can be argued that the Kukuna Fault was the principal controlling fault forming the western margin of a graben or half graben. The full sequence of the Rokel River Group occurs east of this fault, whereas only isolated remnants of the basal Tabe-Makani Formation are found to the west of it. This suggests that the latter was deposited during an early period of regional subsidence before initiation of the Kukuna Fault.

The Rokelide Orogeny

Previous workers (Allen, 1969; Villeneuve *et al.*, 1990; Culver *et al.*, 1991) have considered that the Rokelide Orogeny resulted from closure of an intracontinental graben, but with a consistent eastward sense of displacement. This paper documents evidence of hitherto unrecognised significant east to west thrusting leading to a confrontation in vergence across much of the Rokel-Kasila Zone in Sierra Leone (*cf.* Villeneuve and Cornée, 1994, Fig. 2a, stage 5; Villeneuve and Dallmeyer, 1987, Fig. 7 where straightforward west over east thrusting is postulated). In Sierra Leone, closure of the Rokel River Basin inverted both east and west dipping basin bounding faults and was accompanied by folding and widespread development of a spaced cleavage. This event produced the structures which dominate the present-day outcrop patterns.

Inversion took place predominantly along pre-existing (D_2) faults with amounts of displacement varying along the strike of the faults. Minimum shortening appears to have occurred in the south, where the younger Taia Formation of the Rokel River Group is in contact with the Marampa Group. Increased shortening towards the north resulted in deeper levels of the Rokel River Group cover unit being juxtaposed with formations of the Marampa Group.

During inversion, thrust displacements were directed towards the central basement horst generated during the D_2 extensional episode giving rise to a D_3 confrontation zone which is illustrated by the section C-C' (Fig. 3).

Simple line length balancing produces average shortening estimates of at least 68% in the Western Domain, compared to a minimum shortening of at least 28% in the Eastern Domain (Latiff, 1993). The greater shortening in the Western Domain could indicate that top-to-the-east was the major direction of tectonic transport. Alternatively, the westerly dipping early faults may have been more favourably orientated for reactivation during D_3 deformation.

Macfarlane *et al.* (1980) considered the D_3 inversion (their D_2 tectonic event) to represent a unidirectional straightforward west over east thrusting across the region. In particular their cross-section shows the Marampa Group thrust over the Rokel River Group on a west dipping fault boundary (named here the Kukuna Fault). The structural evidence outlined above shows that in fact east directed thrust transport occurred along this fault.

Absolute age of the emplacement of the Marampa Group

An Archaean or Proterozoic age for the Marampa event remains an unsolved question. There is no clear evidence to link the Marampa Group with any of the nearby possible correlatives, i.e. the Birrimien supracrustal sequence and the rocks of the Bassaris Belt in Guinea, because of the difficulty of correlation across the younger cover of the Bové Basin.

There remains a need for systematic dating of the rocks of the Rokel-Kasila Zone, most importantly the megacrystic granites and the Rokel River Group. It is intended that the dating of these rocks, together with studies to establish the origin and deformation of the Kasila Group, will be the next phase of this study.

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