STRUCTURAL GEOLOGY OF THE SOUTHEASTERN BLUE MOUNTAINS, JAMAICA

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ABSTRACT

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The structural geology of over 100 km² of Cretaceous rocks in the southeastern Blue Mountains is described for the first time. Full stratigraphic details have yet to be resolved, but it is apparent that the structural evolution was controlled by different responses to deformation of the two dominant rock types. These are a thick massive unit of basaltic volcanics and a thinly bedded sandstone/siltstone/mudstone sequence, separated by thin limestones. Synsedimentary deformation is recognized at the boundary of well-bedded argillaceous and thick arenaceous units.

Tectonic folds have a dominant NW-SE trend, but variations exist within a mosaic of structural domains. Three fault trends are recognized with modes at 040°, 100° and 155°.

INTRODUCTION

The Blue Mountains of Jamaica are composed of a sequence of late Cretaceous rocks which are part of the Blue Mountain Inlier, the largest Cretaceous inlier on the island. The southern margin of the inlier is more complex lithologically and tectonically than the geology to the north and appears to be at a lower structural level. Whilst the southwestern part of the inlier contains rocks resembling a paired metamorphic belt (DRAPER ET AL., 1976) the southeastern Blue Mountains are dominantly a sequence of volcaniclastic sedimentary rocks overlying spilitic lavas. The sedimentary rocks are of Campanian-Maastrichtian age and probably represent the sediments of an island arc associated with subduction involving the Caribbean and North American plates in the late Cretaceous and early Tertiary.

It is emphasized that much work still needs to be done in correlating the stratigraphies of the various well-mapped areas of the Blue Mountain Inlier before an exhaustive structural interpretation can be made. We feel, however, that the impression to be gained from the existing meagre literature on the subject is misleading. The ideas conveyed in this paper then, represent a progress report of continuing work towards a fuller understanding of the structure of the Blue Mountains.

STRATIGRAPHY

The work of KRIJNEN & LEE CHIN (1977a, b, c) is the only serious attempt so far to explain the stratigraphy and geological history of the whole Blue Mountain Inlier. The field-work which forms the basis of their proposed stratigraphic column (Fig. 1) was done mainly in the north and central areas of the inlier. The correlation between the geology of the central and northern Blue Mountains with that to the southeast is made on the basis of two fossiliferous limestones: the Rio Grande Limestone Member and the Fork Limestone Member. These limestones both appear to be present in the area under discussion but their use as marker horizons is limited. This is because the outcrop pattern is very fragmentary and in places the rock has suffered a certain amount of recrystallization which obscures or obliterates the identifiable fauna.

Above the uppermost limestone unit, the Rio Grande Limestone Member, is a very thick sequence of volcaniclastic

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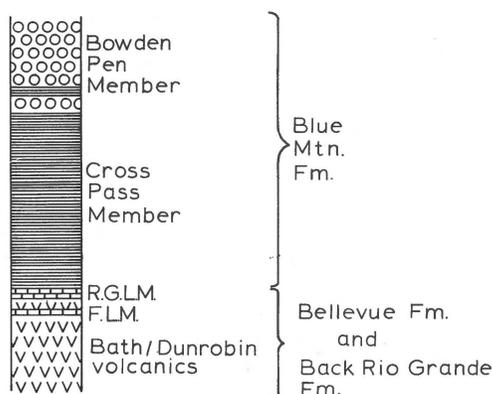[1] Geology Department, University of the West Indies, Mona, KINGSTON, Jamaica.

Fig. 1
Schematic stratigraphic column for the southeastern Blue Mountains based on the terminology of Krijnen & Lee Chin (1977c) for the geology of the north and central Blue Mountains. R.G.L.M. is the Rio Grande Limestone Member and F.L.M. is the Fork Limestone Member.

sediments, partly turbiditic, grading upwards into massive conglomerates. This is the Blue Mountain Formation, which is probably of the order of 2-3 km thick at least. Below the Rio Grande Limestone are volcanic rocks exposed in two separate areas; the Dunrobin volcanics in the west and the Bath volcanics in the east. The base of the Dunrobin volcanics is not seen and it is not clear whether rocks older than the Bath volcanics are exposed. The southward extension of these rocks is intersected by the Plantain Garden Fault, the major fault bounding the southern margin of the Inlier.

The Dunrobin and Bath volcanics show many similar characteristics and are presumed to be of similar age. KRIJNEN & LEE CHIN (1977a) have suggested that these volcanics can be correlated with the Brownsfield Volcanic Member of the Bellevue Formation to the north, which comprises about 600 m of hydrothermally altered, porphyritic, andesite lava flows. The Dunrobin/Bath volcanics are probably very much thicker, between 1 and 2 km, and are very different lithologically from the Brownsfield Volcanic Member. They are aphanitic basalts with spilitic, (BATESON, 1974), and tholeiitic compositions. The presence of pillow structures, high specific gravity (3.0 g cm^{-3}: RODRIGUES, 1977), and thin intercalations of banded cherty sediments suggest a deep-sea environment, probably of abyssal depths. In addition, some of the overlying limestones in the Bath area contain a planktonic fauna.

The contrast between the Brownsfield and the Bath/Dunrobin volcanics is well demonstrated along the Plantain Garden River where the Blue Mountain Inlier is juxtaposed against the Sunning Hill Inlier. WADGE & EVA (1977) have described the geology of the Sunning Hill Inlier and suggest that the succession represents part of the Back Rio Grande Formation, the Bellevue Formation and the Blue Mountain Formation. The volcanic rocks of the Sunning Hill Inlier, the Thornton Formation, are mainly porphyritic basalts and andesites, with associated conglomerates, and resemble the

Brownsfield Volcanic Member of the Bellevue Formation rather than the Bath/Dunrobin volcanics. The Sunning Hill Inlier may represent the succession of the north and central Blue Mountain Inlier downthrown by 2-3 km along the Plantain Garden Fault.

Depth of burial

It is pertinent to the following discussion on the structure and deformation of these rocks to assess their depth of burial. Whilst the rocks of the area under discussion do not have the obvious metamorphic mineral paragenesis and foliation of the low grade Mt. Hibernia Schist Complex to the west (DRAPER ET AL., 1976), some of the rocks contain minerals indicative of very low grade metamorphism: laumontite, pumpellyite, clinozoisite and chlorite. The sandstones and siltstones of the Blue Mountain Formation commonly contain phytoclastic material of high reflectivity (possibly more than 1%). The Lower Eocene Richmond Formation, which overlies the Sunning Hill Inlier, contains phytoclasts in rocks with similar turbidite characteristics to those of the Blue Mountain Formation, but of a much lower reflectivity; a difference that can be appreciated in hand specimen.

Some rocks of the south east Blue Mountains therefore have probably been subjected to temperatures of 200-300°C and pressures of up to 3 kb. This would indicate a maximum depth of burial of about 9 km. The rocks were laid down in the period between 75 and 65 m.y. B.P. Uplift began in the earliest Palaeocene such that by mid-Lower Eocene times, (52 m.y. B.P.), the area of the Sunning Hill Inlier was a shallow carbonate bank. These figures would suggest that up to 9 km of uplift had occurred in that 13 m.y. period.

STRUCTURE

Early ideas of the structure of the Blue Mountain area were based on little actual structural field observations. Chubb (in ZANS ET AL., 1962) states that 'the thick geosynclinal deposits in the Blue Mountain area were strongly folded'. At this time the Wagwater and Blue Mountain faults, which bound the inlier to the west, were believed to be thrust faults. Thus, the style of folding was thought to be alpine, i.e. consisting of tight to isoclinally folded sediments with accompanying thrust faults and extensive metamorphism. As more field work has been carried out this picture has been drastically modified.

KEMP (1971), DRAPER ET AL. (1976) and DRAPER (1977) have shown that strongly metamorphozed rocks are limited to a narrow belt in the southern Blue Mountains. KEMP (1971) failed to find any low-angle faults, and folding in the unmetamorphozed rocks of the southeastern Blue Mountains appears to consist of macroscopic, open structures. No mesoscopic folds were observed by that author in the non-schistose rocks. High-angle faulting was reported to be the most common expression of deformation.
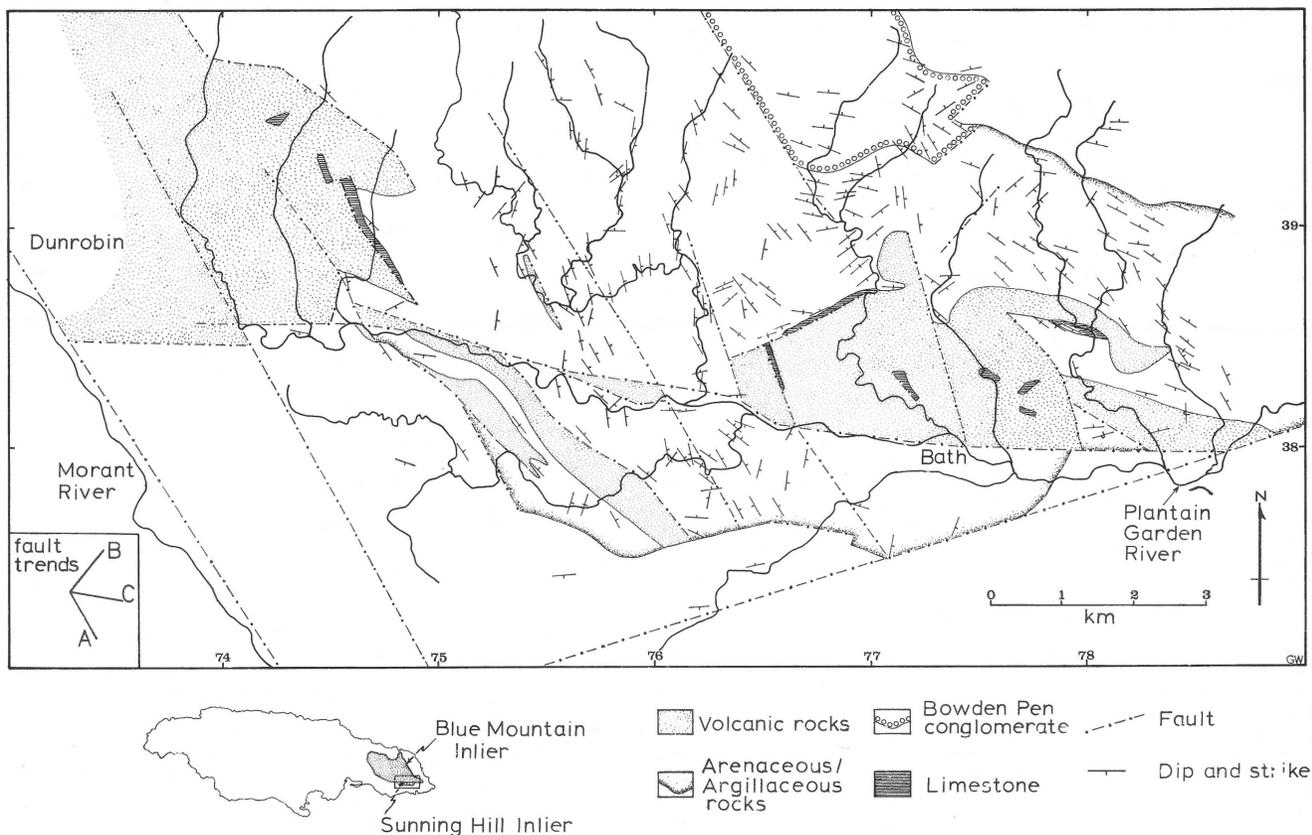
Fig. 2
Structural sketch map of the southeastern Blue Mountains and the Sunning Hill Inlier. Areas without ornament are rocks of Tertiary age. The modes of the three main fault trends are shown.

In BATESON's (1974) description of the Bath area, no mention is made of structure, but from his map it is clear that he considered the dominant structure to be block faulting. More recently the work of KRIJNEN & LEE CHIN (1977b, c) further supports this idea, although no systematic work was undertaken. They do, however, report open macroscopic folding, on a roughly E-W trend, which initiated block faulting.

The structural pattern of the whole Blue Mountain Inlier indicates a regional structural dip to the northeast. KRIJNEN & LEE CHIN (1977b) point out, however, that the Campanian-Maastrichtian sequence is repeated by faulting in the north of the inlier. No such large scale repetition exists in the area of Fig. 2. The dips of the beds in the southeast Blue Mountains seem to be generally steeper than those to the north. Dips of less than 30° are rare and an average of 45-50° is representative of the area. It is difficult to make statements about the structure within the Bath and Dunrobin volcanics as bedding planes and contacts are rarely seen. Where good pillow lava structures are seen in the Dunrobin area they are facing east along a plane dipping approximately 60°.

The most obvious feature of the structural pattern of figure 2 is the natural division of the region into subareas of contrasted dip and strike. Many of the boundaries between these subareas are faults. The strike of the sedimentary rocks adjacent to the volcanic rocks is nearly always parallel or sub-parallel to their boundary. The significance of these subareas is discussed in the following sections.

Folding

Examination of figure 2 indicates that the original sedimentary-volcanic pile represented by the rocks of the area has undergone a substantial amount of deformation. The history of this deformation cannot be explained solely in terms of the tilting of fault blocks (KRIJNEN & LEE CHIN, 1977c).

Minor folding and flexuring is fairly common in the more argillaceous rocks. It is not correct to say, as does KEMP (1971, p. 138) for the equivalent rocks to the west, that minor folding is found only close to major fault zones. Fold amplitudes of up to 1 or 2 m and wavelengths of 10 m are typical. Fold closures are usually angular but interlimb angles of much less than 90° are uncommon. Field data on axial orientations of these minor folds are limited and it is not yet possible to make definite statements about their vergence and relationship to larger scale folding. Minor faults are sometimes associated with the areas of minor folding. Whilst the minor folding is mostly

confined to the more argillaceous rocks, the arenaceous members of the turbidite units (which can be as thin as 3 cm) display a much more competent response to deformation with fracturing and occasionally the formation of boudinage structures. The style of folding is typical of internal buckling of the type described by COBBOLD ET AL., (1971) and is common in multi-layered rocks such as the Cross Pass Member. Boundary conditions are important in controlling this sort of deformation and inhomogeneities may introduce many local complications which we believe to be a major cause of the low definition of girdle patterns in Fig. 3.

In addition to the cyclic turbidite units that are involved in the folding described above, the Cross Pass Member of the Blue Mountain Formation (KRIJNEN & LEE CHIN, 1977a) contains many beds of coarse volcaniclastic sandstone of thickness in the range 10 to 50 m. The junction between these massive units and the more argillaceous lithologies is characteristically the site of complex synsedimentary deformation within the argillaceous rocks. For a distance of 20 m or more adjacent to the massive sandstone, the siltstones and mudstones are broken into small blocks of about 10 m or less in size which are completely disharmonic to one another. Intra-block deformation is common, but extreme convolute folding is not seen. Such structures are interpreted as being of synsedimentary origin and are most common where argillaceous rocks overlie a massive sandstone unit. These zones have been cut by later faulting in some cases. Whilst occasionally a few exotic blocks can be found in some of the lithologies, true olistostromes are not found, neither have tectonic melanges been identified in this part of the Blue Mountains.

Figure 3 shows the structure of the region represented as a series of contoured, lower hemisphere, equal-area plots of poles to bedding for the various subareas. From these data convincing large-scale folding is only evident for area 4, to the east of the Bath volcanics. The fold axes plunge about 20° in a direction 120°; a northern syncline and a more southerly anticline, the latter involving the Bath volcanics at its core are evident from figure 2. Another major fold appears to be truncated by the Plantain Garden Fault further south. None of the other subareas of figure 3 display convincing girdles indicative of major folds of cylindrical form. However, the outcrop pattern of the eastern margin of the Dunrobin volcanics and the sparse data at present available from this area do suggest E.S.E. trending fold axes, which apparently die out to the east.

There is another type of major folding present in these rocks which is not apparent from the equal area plots of figure 3. This is the folding associated with major faults. Vertical bedding and local overturning with the strike parallel or sub-parallel to the fault trace is commonly found in a zone up to 200 m from the fault, which is considered to be the approximate wavelength of the folding. The axes seem to plunge steeply. These folds are laterally impersistent and are considered to be equivalent to those described by GREEN (1977, p. 16), associated with the N-NW and NE trending faults of the Wagwater Belt. WADGE & EVA (1977) show one such fold in their cross section of the Sunning Hill Inlier.

Faulting

The faults in this area of the Blue Mountains are preferentially orientated along three trends. This finding disagrees with the statement of KRIJNEN & LEE CHIN (1977c p. 17). The dominant trend (A) comprises most of the major faults shown in figure 2 and varies between limits of 130° and 160° with a mode of 150°. The length and throw of the faults of trend B are smaller than trend A and many are not marked on figure 2. Their mode is 040° and their limits 030° and 065°. The most important fault in the region, the Plantain Garden Fault, trends 100° and together with a series of smaller faults spatially associated and trending (splaying?) up to 20° from the regional trend, forms trend C.

Although many of the faults are shown with straight or nearly straight traces in figure 2, this reflects the relatively imprecise state of mapping rather than the fact that all the fault planes are vertical. Indeed, where exposed, some of the fault planes depart significantly from the vertical, to values as low as 45°. Lack of stratigraphical control precludes accurate determination of the sense and amount of displacement of these faults but a westerly dip measured on some of the A faults seems to indicate a reverse sense of movement where older volcanics (to the west) are faulted against sedimentary rocks (to the east). The Plantain Garden Fault must have a plane very close to vertical, perhaps dipping southwards, as is observed for some of the minor C faults.

The three fault trends A, B and C seem to be similar to the fault trends 1, 2 and 3 described by GREEN (1977) from the Wagwater Belt. Certainly, the A trend corresponds to the 155° mode for the major faults of the whole island (HORSFIELD, 1974), but as pointed out by KEMP (1971, p. 121) for the south west Blue Mountains, those faults with a trend of 130° are uncommon outside the inlier. Similarly the B trend is rare throughout Jamaica and is not really exactly correlatable with Green's 2 trend.

The role that faulting has played in the subdivision of the region's sedimentary rocks into domains of structural homogeneity is important. Simple tilting of fault blocks, whilst having the effect of swinging the strike of bedding around to that of the faults, cannot explain the drastic change of strike between subareas such as 1 and 2. We suggest that the controlling influence on the development of this structural style is the different response of the massive volcanic rocks and the well-bedded sedimentary rocks to stress. In particular the apparent stress system whose axis of maximum compressive stress was orientated NE-SW and was responsible for the major NW-SE fold axes. The geometry of the volcanic-sedimentary interface would initially be controlled by faulting in the volcanic rocks and by deformation in the incompetent sedimentary rocks which would fold and accommodate themselves around this interface. Subsequent faulting in the
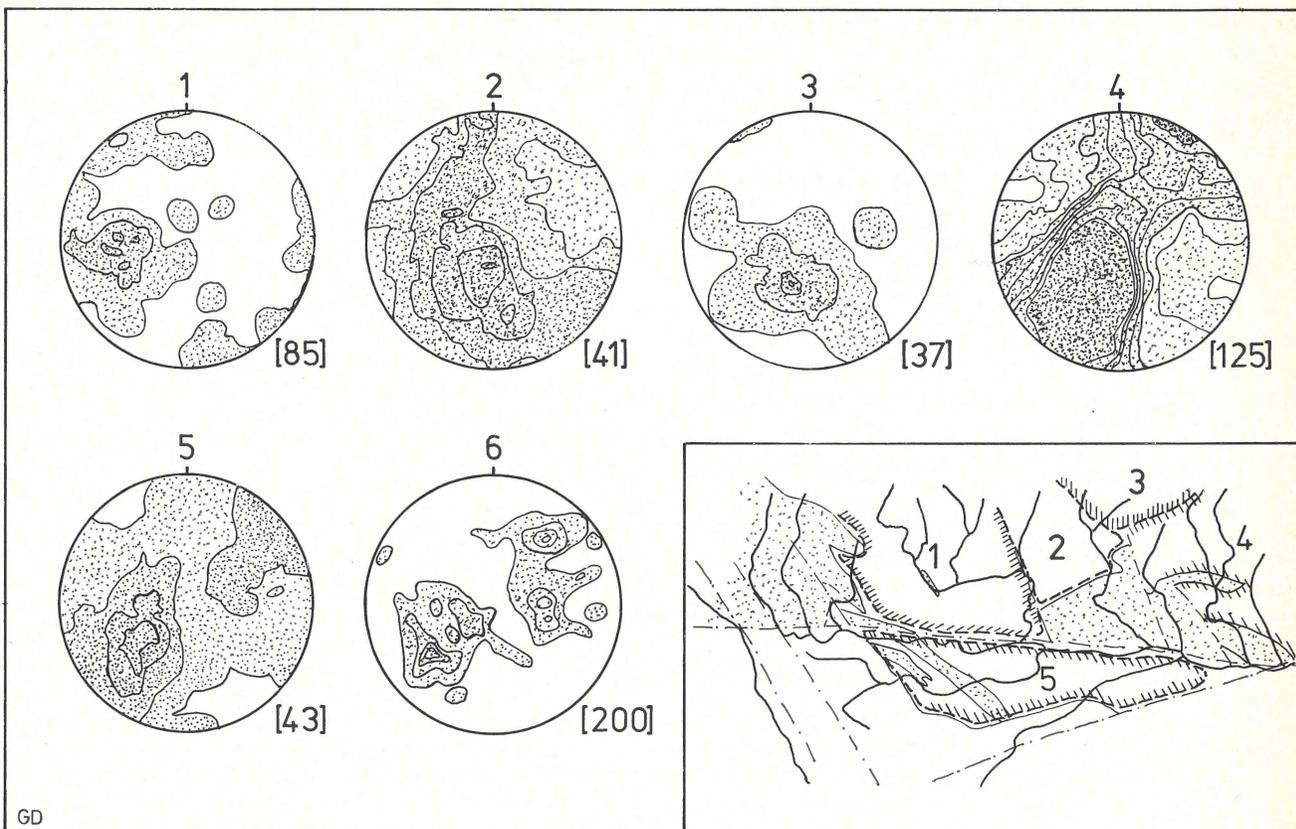
Fig. 3

Lower hemisphere, equal-area projections of poles to bedding for five areas (1-5) in the southeastern Blue Mountains. The diagrams are contoured at intervals of 5% poles per 1% area, with count-circle area of 100/N% of net, where N is the number of observations, according to the method advocated by Starkey (1977). The number of observations is in brackets beside each diagram. Inset is a sketch map of the area of figure 2 showing the location of areas 1-5. Projection 6 is from Kemp (1971) and shows poles to bedding of rocks of similar age in the southwestern Blue Mountains. This diagram is contoured at 1% poles per 1% area with a counting-circle size of 1%.

sedimentary rocks along the trends of the original faulting in the volcanic rocks would effectively subdivide the area structurally, preserving the original folds only in some areas of suitable interface orientation.

DISCUSSION

The concept of Jamaica's structural history as a series of orogenic episodes separated by periods of calm is exemplified by the writing of Chubb (in ZANS ET AL., 1962) and has been followed closely by KRIJNEN & LEE CHIN (1977c) in their description of the Blue Mountain geological history. Jamaica has almost certainly been adjacent to a major plate boundary for perhaps the last 70 m.y. and although the tectonic style has changed during that period, Jamaica is probably undergoing deformations of orogenic magnitude at the present time (HORSFIELD, 1976; BOWIN, 1976) and has done so for much of this period. An alternative approach to that of Chubb's therefore is to view the structural history of the Blue Mountains

as a continuum in which the older tectonic elements interact with a changing stress system.

One aspect of crucial importance to such an approach is the original structure of the island arc, which is particularly relevant if the Bath and Dunrobin volcanics represent the substructures of one of the volcanic islands in the arc. HORSFIELD & ROOBOL (1974, p. 32) suggest a north or northwestward trending arc with subduction from the east or northeast. It is difficult to see where the northward and southward extensions of such an arc would be today, a problem that would be resolved by postulating an island arc closer to an E-W trend. Recognising structural elements produced during the period of active subduction is very difficult considering the magnitude of the later tectonism. Those rocks that were being deposited at the very end of this period (e.g. the Bowden Pen Member of uppermost Maastrichtian age) may have no recognizable structure inherited from the arc itself, whilst the older, more deeply buried rocks may have suffered subduction-related deformation. The domain structural style, evidence of compressive folding and possibly reversed faulting in the

Cross Pass Member are seen as evidence of such deformation.

Palaeocene/L. Eocene times saw the isostatic uplift of the Blue Mountains (HORSFIELD & ROOBOL, 1974) and extensional deformation to produce the Wagwater Belt (GREEN, 1977). In the southeastern Blue Mountains major normal movements and local folding along the A trend faults accompanied the general uplift of several kilometres which may have continued up to the middle Lower Eocene. Just what role the Plantain Garden-Blue Mountain Fault system played in the early Tertiary is difficult to assess. On the evidence of the Lower Eocene facies reported by WADGE & EVA (1977) from the area of the Sunning Hill Inlier there had been no major uplift to the north of the fault at this time. There is no direct evidence for a 4 km sinistral strike-slip component of movement along the Plantain Garden Fault such as the match of geology across the Blue Mountain Fault suggested by GREEN (1977). On the other hand, there is no evidence against such a movement on the Plantain Garden Fault. The lack of geological match across the fault could be a result of the greater degree of lithological variation in the vertical plane in this part of the Blue Mountains. In the Blue Mountain – Yallahs fault system, which is a westward continuation of the Plantain Garden Fault, GREEN (1977) makes the observation that E-W trending sections of the fault have a greater strike-slip component than NW-SE trending sections. Thus, strike-slip movement may even be greater than that reported for the Blue Mountain Fault zone. A vertical component of upthrow of 2-3 km to the north has undoubtedly occurred since the Lower Eocene, much of it achieved since the middle Miocene and continuing into the Pleistocene (CANT, 1972). The horst-like uplift of the Wagwater Graben and the Main Ridge of the Blue Mountains was also achieved during the last 12 m.y., along the A and C trend faults (GREEN, 1977). The continuity of A trend faults across the trace of the Plantain Garden Fault (Fig. 1) rules out the possibility of strike-slip movement on the latter since the last phase of movement on the A faults. This suggests that any strike-slip component of movement occurred in the early development of the late Tertiary uplift, perhaps in response to strike-slip movement and spreading in the Cayman Trough (HOLCOMBE ET AL., 1973). Later strike-slip movements were subsequently taken up entirely in fault zones within the Cayman Trough.

ACKNOWLEDGEMENTS

REFERENCES

Bateson, J. H. 1974 Notes on the geology of the Bath area and their relationship to the Cretaceous rocks of the Blue Mountains – J. geol. Soc. Jamaica 14: 22-30.

Bowin, C. 1976 Caribbean gravity field and plate tectonics – Geol. Soc. Amer. Spec. Paper 169: 79 pp.

Cant, R. V. 1972 Jamaica's Pleistocene reef terraces – J. geol. Soc. Jamaica 12: 13-17.

Cobbold, P. R., J. W. Cosgrove & J. M. Summers 1971 Development of internal structures in deformed anisotropic rocks – Tectonophysics 12: 25-53.

Draper, G. 1977 Regionally metamorphosed rocks in Jamaica – some recent results of studies in metamorphism and deformation – 8th. Carib. Geol. Conf. (abstr).

Draper, G., R. R. Harding, W. T. Horsfield, A. W. Kemp & A. E. Tresham 1976 Low-grade metamorphic belt in Jamaica and its tectonic implications – Geol. Soc. Amer. Bull. 87: 1283-1290.

Green, G. 1977 Structure and stratigraphy of the Wagwater Belt, Kingston, Jamaica – Overseas geol. min. Res. 48: 21 pp.

Holcombe, T. L., P. R. Vogt, J. E. Matthews & R. R. Murchison 1973 Evidence for sea-floor spreading in the Cayman Trough – Earth Planet. Sci. Lett 20: 357-371.

Horsfield, W. T. 1974 Major faults in Jamaica – J. geol. Soc. Jamaica 14: 1-14.

Horsfield, W. T. & M. J. Roobol 1974 A tectonic model for the evolution of Jamaica – J. geol. Soc. Jamaica 14: 31-38.

Kemp, A. W. 1971 Geology of the south-west flank of the Blue Mountains, Jamaica – Unpubl. Ph. D. thesis, U.W.I.: 307 pp.

Krijnen, J. P. & A. C. Lee Chin 1977a Stratigraphy of the northern, central and south eastern Blue Mountains, Jamaica – 8th. Carib. Geol. Conf. (abstr).

—— 1977b Some aspects of the tectonization of the Blue Mountain Massif, Jamaica – 8th. Carib. Geol. Conf. (abstr).

—— 1977c Geology of the northern, central and south eastern Blue Mountains – Unpubl. Rept., Mines and Geology Div., Kingston: 19 pp.

Rodrigues, K. 1977 The geology of the Plantain Garden District, St. Thomas – Unpubl. thesis (undergrad.) U.W.I.

Starkey, J. 1977 The contouring of orientation data represented in spherical projection – Canadian J. Earth Sci. 14: 268-277.

Wadge, G. & A. N. Eva 1977 The geology and tectonic significance of the Sunning Hill Inlier – J. geol. Soc. Jamaica 17.

Zans, V. A., L. J. Chubb, H. R. Versey, J. B. Williams, E. Robinson & D. L. Cooke 1962 Synopsis of the geology of Jamaica – Geol. Surv. Dept. Jamaica Bull. 4: 72 pp.