ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

PRECAMBRIAN TECTONIC ENVIRONMENTS

C. R. ANHAEUSSER

INFORMATION CIRCULAR No. 78

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JOHANNESBURG

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by

C. R. ANHAEUSSER

(Senior Research Fellow, Economic Geology Research Unit)

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INFORMATION CIRCULAR No. 78

May, 1973

INFORMATION CIRCULAR No. 78

(for Restricted Distribution)

The information contained herein has been submitted for publication and represents a contribution to Volume 2 of the Annual Review of Earth and Planetary Sciences to be published in 1974 by Annual Reviews Inc., Palo Alto, California, U.S.A.

PRECAMBRIAN TECTONIC ENVIRONMENTS

ABSTRACT

The present tectonic activity of the earth can be successfully explained by the theory of plate tectonics. Whether or not similar mechanisms, involving sea-floor spreading and continental drift, can also be applied to earlier periods of earth history remains debatable. Cursory examination of the Precambrian geologic record reveals many points of similarity existing between events in the past and those of more recent times. A more critical appraisal, however, discloses significant differences which appear to relate to stages in the evolution of the early crust and developing protocontinents.

In this review attention is focused on the similarities and differences in "geosynclinal" and geotectonic processes through geologic time, especially in the Precambrian. The sedimentary, igneous, metamorphic and deformational changes traced suggest that the events in the Archaean were unique and involved the progressive growth of cratonic and shield nuclei. Consolidation of the continents appear to have continued through Proterozoic times culminating, ultimately, in late Phanerozoic continental fragmentation.

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PRECAMBRIAN TECTONIC ENVIRONMENTS

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1. INTRODUCTION

Since the concept of sea-floor spreading was first introduced by Hess (1962) and Dietz (1961) a voluminous literature has developed to supplement and strengthen the evidence supporting Mesozoic continental drift. Notable advances in the studies of palaeomagnetism, polar wandering and mid-oceanic ridge spreading (Runcorn, 1962; Vine and Matthews, 1963; Vine, 1966) were followed by the formulation of the theory of lithosphere plate tectonics (McKenzie and Parker, 1967; Le Pichon, 1968; Morgan, 1968; Isacks et al 1968; McKenzie, 1972). The emergence of the plate tectonic theory, or "new global tectonics", has been heralded as providing, for the first time, a unifying world-wide explanation for tectonic processes (Dewey and Bird, 1970). The new models for mountain building now involve motions of lithospheric plates and these events take place at divergent and convergent plate junctures. Relegated already to virtual obsolescence (Dickinson, 1971) are the classical geosynclinal concepts that held sway until the mid 1960's before plate tectonic theory became popular.

The concept of plate tectonics has compelled geologists to re-examine nearly all aspects of sedimentation, igneous activity, deformation and metamorphism both regionally and on a global scale. Attention was initially devoted to examining the effects of plate tectonic theory on contemporary geosynclines, island arcs, mountain ranges and oceanic domains (Mitchell and Reading, 1969; Bird and Dewey, 1970; Dewey and Bird, 1970; Coleman, 1971; Dickinson, 1971; Gilluly, 1971; Oxburgh and Turcotte, 1971) but the attractive nature of the concepts and the apparent success of efforts to employ them led to bolder attempts being made (Hamilton, 1970; Bird and Dewey, 1970; McElhinny and Briden, 1971) in applying the plate tectonics model to Palaeozoic and late Precambrian orogenic terranes (Uralides, Appalachian/Caledonian Orogen).

The inevitable sequel has been the growing tendency to administer the same treatment to even older environments with the result that attention has been focused on the Precambrian record to evaluate possible roles for plate tectonic-type mechanisms during early continental evolution (Dewey and Horsfield, 1970). Some opinion has it that ancient mobile belts, and even the Archaean greenstone belts, represent the scars of plate collision between proto-continental fragments, between oceanic crust and continental margins or between island arcs and oceanic crust or continental plates (Gibb, 1971; Gibb and Walcott, 1971; White et al, 1971; Condie, 1972; Talbot, 1973).

How justified is this latter tendency towards applying the plate tectonic hypothesis to earlier geologic time? Before being swept away by the tide of protagonists advocating the acceptibility of the concept it may be advisable to examine the geological past a little more discriminately to ascertain whether or not their enthusiasm is warranted. To attempt this, consideration will be given in the following pages to a critical appraisal focusing on the similarities and differences in "geosynclinal" and geotectonic processes through geologic time, especially in the Precambrian. However, prior to delving into the past geologic record it might be pertinent to remind ourselves briefly of some of the significant aspects arising out of the "old classical" approach to orogenic theory in addition to aspects of the "new global tectonics" and its application to Phanerozoic geosynclinal-orogenic episodes.

2. PHANEROZOIC GEOTECTONIC CHARACTERISTICS

Geosynclines and Orogeny

The concepts of "geosynclines" and "orogeny" have long been regarded by many as virtually synonomous with respect to what they imply in terms of sedimentation, mountain building, deep burial, regional metamorphism, granitization, igneous activity and erosion. The past lack of precise definitions not only caused considerable confusion but also impeded attempts gained at a broader understanding of global geotectonic events. Aubouin (1965) tried to resolve the situation in his review of classical descriptive data and classification schemes of geosynclinal or orogenic cycles. He also made a concerted effort to systematize thinking by defining a basic model which he believed could be successfully applied to geosynclinal regions and which involved a foreland or craton and mio- and eu-geosynclinal furrows or troughs and mio- and eu-geanticlinal ridges or highs. Variations in the types of volcanism, sedimentation and plutonism were allocated to specific parts of the model with deformation, terminating the history of the geosyncline, migrating progressively towards the craton with time.

The classical descriptive models, like those reviewed by Aubouin, are based on much geological data and despite the apparent lack of any satisfactory mechanisms ever being offered, valuable conceptual frameworks were devised to classify tectonic elements. Distinctions could be made between various orogenic episodes in Europe, North America, the Pacific and elsewhere based mainly on characteristic lithologies, metamorphism, and deformational styles. Zwart (1969) found little difficulty comparing and contrasting the Carboniferous Hercynian orogenic belt of Europe with the Tertiary Alpine mountain chain. The Hercynian orogenic belt he found "is characterized by low pressure metamorphism, high geothermal gradients, wide extent, abundant granites, few initial magmatic rocks and a restricted amount of uplift and erosion. The Alpine foldbelt, in contrast, exhibits high pressure metamorphism, low geothermal gradients, narrowness of the chain, scarcity of granites, abundant ophiolites, and strong and rapid uplift". Zwart furthermore contended that the Hercynian and Alpine belts represented two extreme types of mountain building and that older orogenic belts possessing intermediate characteristics were represented by the Caledonian chain of Europe and the Grenville Province in Canada.

Significant differences were also found to exist between the complex orogenic areas of the circum-Pacific region and those of the Atlantic region (Crook, 1969; Matsumoto, 1967). Crook distinguished between "Pacific geosynclines" and "Atlantic geosynclines" the latter exemplified by the model proposed by Aubouin (1965) and applied to the Alpine, Caledonian and Appalachian geosynclines. It was concluded that although Atlantic and Pacific geosynclines are superficially similar, detailed examination reveals significant differences between them which appear to reflect their contrasting geotectonic positions. Whereas Pacific geosynclines seem to be newly formed on a largely simatic floor, marginal to sialic cratons, the Atlantic geosynclines appear to occupy, in part, the sites of older geosynclines, on the trends of which they are discordantly overprinted (Hercynian overprinted by Alpine; Grenville overprinted by Appalachian/Caledonian). Furthermore, the Atlantic geosynclines appear to have occupied positions between cratonic blocks, conventional continental drift reconstructions being accepted.

Singling out the above few examples serve to remind us that plate tectonic theory alone has not been responsible for all the recent advances in the earth sciences and that we still owe much of our present knowledge to the efforts and observations of geologists in the past. Many distinguishing features of orogenic belts, including aspects of volcanism, magmatism, sedimentation, metamorphism and deformation, from a wide range of environments, were thus immediately available for re-evaluation, re-interpretation and translation into terms of the new global tectonics when it emerged.

Plate Tectonics and Orogeny

We know that the earth's present surface is traversed by extensive linear tectonic features, those on the continents and along some continental margins being represented by orogenic belts of diverse age and those in the oceans being represented by mid-ocean ridges, trenches and transform faults which, according to the theory of sea-floor spreading, cannot be older than 200-300 m.y. (Hess, 1962). The youngest major tectonic episodes manifest on the crust are represented by the Tethyan (Alpine/Himalayan) and the circum-Pacific orogenic belts, both of which originated during the early Triassic. As the theory of plate tectonics requires that the plates be generated at oceanic ridges and that they be destroyed at continent-ocean boundaries and complex trench-transform systems (Isacks et al, 1968) there appears to be no difficulty in linking the young mountain belts (Andes) and modern island arcs (Japan) to the causative processes associated with sea-floor spreading and plate tectonics. Provision is also made in the theory for the development of intracontinental Alpine/Himalayan-type orogenic belts by the collision of continental crustal blocks along consuming plate margins (Dewey and Bird, 1970; Mitchell and Reading, 1969).

The contention that Palaeozoic tectonic episodes, like those of the Hercynian, Caledonian, Appalachian, Uralide and Tasman orogenic belts, are also linked to the concept of plate tectonics (Hamilton, 1970; Dewey and Bird, 1970; Bird and Dewey, 1970) immediately presupposes that the continents have drifted more than once in geologic time.

Dewey and Bird (1970) and Dewey and Horsfield (1970) maintained that plate tectonics is too powerful and viable a mechanism in explaining contemporary relationships between continents, orogenic belts and oceans to be disregarded in favour of ad hoc, nonactualistic models for the older orogenic belts on the continents. These and many other authors now advocate that ocean-driven plate mechanisms have been responsible for the growth and evolution of continents for at least 3.0 b.y. [(b.y. = 10^9 years)]. Thus the controversy which continued between 1910 and 1960 questioning the validity of continental drift has taken a dramatic new turn and the inquiry being entered into now does not ask whether Drift has taken place but rather : how often has it occurred throughout geological time?

Following the advent of the plate tectonic concepts little time was lost in re-examining previously studied orogenic belts in terms of the new global tectonics. Several noteable contributions emerged wherein the authors demonstrated how orogenic belts record a variety of events controlled by both plate divergence and convergence (Mitchell and Reading, 1969; McKenzie, 1969; Hamilton, 1970; Dewey and Bird, 1970; Bird and Dewey, 1970). Major sites of divergence are represented by the mid-oceanic rises whilst convergent plate junctures mark the sites of orogeny involving plate consumption, continental collision, stratal crumpling, thrusting, crustal thickening and isostatic uplift, together with accompanying magmatic and metamorphic events, resulting in variable orogenic patterns being created as the circumstances of convergence vary (Dewey and Horsfield, 1970). Thus the new synthesis, unlike the classical geosynclinal approach, does not require a regular sequence of orogenic events to be recognized in the same order in all mountain belts (Dickinson, 1971).

Oceanic Ridges and Transform Faults

The fundamental postulate of plate tectonics is that the earth's surface may be divided into a number of rigid spherical plates, whose boundaries mark the seismic belts of the world (Barazangi and Dorman, 1969; Isacks et al, 1968). Le Pichon (1968) suggested six plates cover the globe and these are being created over the oceanic ridges where Vine and Matthews (1963) first observed the linear magnetic anomalies formed by sea-floor spreading.

Although the oceanic lithosphere (crust of Vp 6-6.5 km/sec. layer extending to upper mantle with Vp $\sim$ 8 km/sec. layer) is approximately 6-8 km thick McKenzie (1972) outlined that the base of plates is now considered to be at the top of the low-velocity zone ($\sim$ 80 km). Reviewing plate tectonics he reported that plate motions are no longer believed to be closely related to the underlying mantle motions. The ridges are thus no longer considered to exist only on the tops of the rising limbs of convection cells, nor trenches only over the sinking limbs.

The essentially linear configuration of the oceanic ridges is disturbed intermittently by offsetting transform faults (Wilson, 1965) at the site of which crustal surface appears to be neither created nor destroyed. Some of these fracture zones like those in the eastern Pacific (Eltanin, Clipperton, Mendocino) are extensive and Morgan (1968) has suggested that the transform faults lie on small circles centred about the poles of relative motion of diverging plates.

The oceanic ridges are locations of active basaltic volcanism having a distinctive composition ranging from high-alumina olivine tholeiites to low-alumina tholeiite (Miyashiro et al, 1969). Other characteristics include low K_2O, TiO_2 and P_2O_5, rather high Al_2O_3, high CaO and very high Na/K ratios (Cann, 1971; Engel et al, 1965). These subalkaline, generally saturated, "oceanic tholeiites" are the dominant basalts of the abyssal ocean floors, mid-oceanic ridges and oceanic volcanic islands and are believed to overly partly residual peridotitic lithosphere. Because the axes of the ridges are characterized by high heat flow these associations, including heterogeneous mixtures of gabbroic and peridotitic magmas (ophiolite complexes), are believed to be derived from relatively shallow depths ($\sim$ 20-60 km) by high degrees of melting of a "pyrolite" source from the upper mantle (Green, 1972a; Ringwood, 1969). Silica undersaturated alkali basalts, derived from the upper reaches of the low velocity zone (70-100 km), occur less commonly in oceanic islands and seamounts.

Oceanic and Continental Edge Arc-Trench Systems

In terms of the new global tectonics the arc-trench regions are the sites of subduction or plate consumption where oceanic crust and lithosphere, created at the mid-oceanic ridges, are returned to the mantle. The precise manner in which this is accomplished is still not fully understood but sufficient is known of the complex history of the arc-trench areas themselves to realise that their distinctive properties link them genetically to the processes accompanying lithospheric plate destruction. Seismically the island chains and trenches are the most active regions on earth being the sites of deep-focus earthquakes originating at depths of 300-700 km with epicentres defining a zone about 250 km wide (Benioff seismic zone; Benioff, 1955) dipping beneath continents or island arcs and extending to depths of 650-700 km. In accordance with the present concept of sea-floor spreading, oceanic crust and lithosphere are thrust or dragged down the Benioff zone and undergo progressive stages of alteration involving metamorphism, phase changes, and fractional melting. Thus hydrated oceanic basalts undergo progressive dehydration and metamorphism from greenschists to amphibolites to granulites to eclogites as the temperature of the initially cool slab rises in a changing pressure realm (Ringwood and Green, 1966; Ringwood, 1969; Green, 1972a). Partial melts of the descending slab, derived from various pressure-temperature regimes, ultimately make their way to surface where they contribute to the development of continental crust. Where the overriding plate margin is capped by oceanic crust the magmatic arc is an intra-oceanic island arc structure (Aleutians, Phillipines) with crustal thicknesses ranging between 12-25 km (Engel, 1970); where it is capped by continental crust, the magmatic arc is a volcano-plutonic complex near the continental margin (Andes). The distinctive calc-alkaline suite, comprised dominantly of the basalt-andesite-dacite-rhyolite volcanic series and their plutonic equivalents, gabbro, diorite, granodiorite and granite, makes up the bulk of the magma introduced in these two situations with tholeiites and shoshonites occurring in subordinate quantities (Jakeš and White, 1972).

Both the extrusive and intrusive phases of magmatism have been shown to vary systematically across island arcs with tholeiitic magmas emplaced closest to the trenches and increasingly more alkaline magma-types (tholeiitic to calc-alkaline to high-K calc-alkaline to shoshonitic) occurring across the arcs towards the continents. Furthermore, the increase in potassium has been related genetically to the dipping Benioff zone beneath the arcs (Jakeš and White, 1969, 1972; Kuno, 1959).

Sedimentation within arc-trench systems is also divergent with volcanogenic materials being dispersed from volcanic centres as volcani-clastic detritus and being deposited in a variety of marine and terrestrial environments within and outside the confines of the arc. Arc-type eugeo-synclinal sequences eventually accumulate and pelagic sediments, basalts and ophiolites all feed steadily into subduction zones, as do clastic turbidites until, ultimately, a characteristic regime of deformation leads to the chaotic tectonic style of the mélanges (Dickinson, 1971; Hsü, 1971).

The occurrence of "alpine-type" peridotites without high temperature contact aureoles in orogenic regions along continental margins has led to the general consideration that these rocks have been tectonically, rather than igneously, emplaced. Coleman (1971) has drawn attention to evidence from New Caledonia and New Guinea which suggests that at the onset of compressional impact between an oceanic and a continental lithospheric plate some "obduction" or overriding can occur where large oceanic-mantle crustal slabs thrust over, or into, continental edges contemporaneously with blueschist metamorphism. Thereafter, continued oceanic lithospheric motions convert to subduction with all the attendant seismic activity and andesitic volcanism and plutonism.

In 1961 Miyashiro drew attention to the existence of "paired metamorphic belts". He recognized that in the Japanese island arc and in other parts of the circum-Pacific region there occur adjacent and parallel metamorphic belts of similar age and distinctly different mineral paragenesis. In any one pair, the inner belt (that closer to the continental side) is characterized by the stability of andalusite at higher levels and of sillimanite in deeper zones, while the outer belt, closer to the ocean, is characterized by the presence of jadeite-quartz and glaucophane. It was recognized that very different temperature-pressure conditions were necessary for the development of these two kinds of metamorphic belts; the inner required high temperature and low pressure while the outer required a combination of low temperature and high pressure. Oxburgh and Turcotte (1971) related these changing pressure-temperature relationships to processes accompanying the descending lithospheric slabs beneath the island arc structures. At the trenches unconsolidated sediments accumulate and are subjected to high pressures before they and the underlying oceanic lithosphere descend and start to melt along the slip zone. Magmas are generated and heat is transferred upward by magmatic convection. Thus there is a direct link between the variations of magma-type, heat flow and metamorphism recorded across arc structures.

Continental Orogeny

The Alps, the Himalayas and the Urals are frequently quoted as examples of orogenic belts produced as a result of two continental blocks colliding during the final stages of ocean floor contraction or consumption (Mitchell and Reading, 1969; Hamilton, 1970; Dewey and Bird, 1970). The mountain belts that form are asymmetrical, being characterized by assemblages thrust over and onto the consumed plates and by remobilized basement near the site of collision. Upthrust wedges of oceanic crust (ophiolites) occur in suture zones (Alpine Ivrea zone; Himalayan Indus suture) regarded as the principal join-lines of collided continental fragments (Dewey and Horsfield, 1970; Gilluly, 1972). As collision-type orogenic belts are the result of compressional forces, magmatic activity within them is less marked, no paired metamorphic zonation is apparent, and the dominant metamorphic assemblages are of the high pressure blueschist facies (lawsonite-glaucophane-jadeite).

3. PRECAMBRIAN EARTH HISTORY

The Phanerozoic Era which records but one eighth of earth history has clearly undergone an extremely varied and complex course of events. If we are to believe in the old maxim "the present holds the key to the past" our task of unravelling the Precambrian record might at a first glance, appear to be insurmountable. Some encouragement to the contrary might be drawn from the fact that even in the oldest Archaean terranes formed 2.5 to ≥ 3.5 b.y. ago the geology can be studied in detail and a sequence of events worked out (Anhaeusser et al, 1969).

The Early Precambrian Crust

Inevitably controversy exists as to the nature of the early crust of the earth. The lack of unanimity concerning this issue was re-emphasized recently at a discussion meeting on the evolution of the Precambrian crust held in London (Anhaeusser, 1973; Shackleton, 1973; Wilson, 1973; Windley, 1973). Broadly two types of Archaean terranes are exposed today : those dominated by high-grade gneisses and migmatites, and those consisting of low-grade granites and greenstone belts. Investigators of the high-grade gneiss terranes such as those in West Greenland (McGregor, 1973) can thus far claim the oldest continental rocks with ages close on 4.0 b.y. [revised Rb/Sr date 3787 ± 85 m.y., S. Moorbath, personal communication 1972] having been reported (Black et al, 1971). In greenstone belt areas some of the oldest dates (3.4 b.y.) appear to be those of granites from the Barberton area in South Africa. Anhaeusser (1973) indicated, however, that the determinations thus far carried out in this region did not include the age of the 7 km thickness of chemically unique mafic and ultramafic rocks (Viljoen and Viljoen, 1969a) found at the base of the greenstone pile. These, it was contended, would be older than all the surrounding granites and migmatites and may have represented a primitive oceanic-type crust. As the nature and development of the earth's crust is of fundamental importance to our understanding of the evolution of continents and the possibly changing geotectonic environments we will examine aspects of the early crust more closely.

Argument in the Archaean terranes revolves around which of the two environments existed first (high-grade gneisses and migmatites versus greenstone belts). On balance the early existence of some sialic crust has been favoured (Poldervaart, 1955; Ramberg, 1964). Even in greenstone belt terranes it was considered at one stage that some thin sialic crust may have been present prior to the development of the volcanic sequences (Anhaeusser et al, 1969; Viljoen and Viljoen, 1969b) but recent investigations in southern Africa and Western Australia suggest that a primordial crust consisting of a stratiform oceanic-type mafic/ultramafic assemblage preceded the granite event in these areas (Anhaeusser, 1971, 1973; Glikson, 1971, 1972). It has been suggested (Windley, 1973) that greenstone belts may have developed diachronously, those in southern Africa forming before those in other shield areas and it might ultimately prove necessary to interpret these Archaean areas separately.

The essential postulate of investigators in the high-grade gneiss areas (Windley, 1973; Windley and Bridgwater, 1971) suggests that the granite-greenstone belt assemblages, which occupy the cratonic areas of the shields, pass downward into granulite complexes that were in existence in Archaean times. Put differently, the granulites would be regarded as the low crustal residue from which granites were derived and which migrated upwards to invade the borders of the overlying greenstone belts (Windley, 1973). Green and Ringwood (1967) subdivided the granulite facies into low-intermediate- and high-pressure regimes. Low pressure (high temperature) granulite facies rocks are difficult to distinguish from amphibolitic rocks with which they are characteristically intimately associated. These could develop at the base of crust 8-9 km thick (Fyfe, 1973) due to steeper thermal gradients in the Archaean caused by more residual heat and higher radioactive element heat production. This presupposes that an overburden at least 8 km thick must have been present prior to the granulite development. If this was of mafic/ultramafic composition it would account for the high proportion of inclusions of this composition caught up in the developing migmatite-gneiss terranes such as those described by McGregor (1973) in West Greenland.

The shield areas are continental or sub-continental areas of crystalline rocks of Precambrian age containing stable cratonic nuclei consisting of complex, low metamorphic grade, granite-greenstone terranes which have been unaffected by any major tectono-thermal event for the last $\sim$ 2.5 b.y. Medium- to high-grade metamorphic areas (amphibolite- granulite facies rocks) are widespread on the shields but occur essentially as linear mobile belts many of which tend to encircle the ancient cratonic nuclei (Anhaeusser et al, 1969). If we are to accept the experimental evidence, depths of burial of these granulites must have greatly exceeded the lower limit of 8 km suggested by Fyfe (1973). Had a granulite environment lain beneath the developing greenstone belts then crustal stabilities inherent in this argument are irreconcilable with the deformational styles so characteristic of the granite-greenstone terranes.

Archaean Greenstone Belts

Greenstone belts are described as the distinctive low-grade metavolcanic and sedimentary assemblages ($\sim 2.5 \geq 3.5$ b.y. old) which occur as scattered remnants on the cratons forming an essential part of the latter. Numerous accounts of their geological characteristics are available (Anhaeusser et al, 1969; Anhaeusser, 1971a, b, 1973; Baragar and Goodwin, 1969; Engel, 1970; Goodwin, 1971; Goodwin and Ridler, 1970; Glikson, 1972; Macgregor, 1951; Viljoen and Viljoen, 1969a, b, 1971; Wilson, 1973). Although minor geological differences are apparent from one shield area to the next Anhaeusser et al (1969) stressed the worldwide uniformity of the stratigraphy, structure, metamorphism, mineralization, associated granites and geotectonic setting of the greenstone belts. Their views are still considered representative of these ancient rock complexes. Refinements to the model originally proposed centre mainly around the increased geochemical knowledge of the volcanic, sedimentary, and granitic rocks in these regions (Anhaeusser, 1971c; Baragar and Goodwin, 1969; Brooks and Hart, 1972; Hart et al, 1970; Hallberg, 1972; Viljoen and Viljoen, 1969a, b, 1971). Of particular significance has been the recognition, in Canada, Western Australia and southern Africa, of a suite of distinctive mafic and ultramafic rocks invariably confined to the lower stratigraphic divisions of greenstone belts and which Viljoen and Viljoen (1969a) referred to as basaltic and peridotitic "komatiites". The only justifiable comparisons, found on earth, of these volcanic rock assemblages occur in present-day abyssal or oceanic settings but their unique geochemistry (in particular high Mg, high Ca/Al ratio, low alkalis) still sets them apart (Anhaeusser, 1973; Viljoen and Viljoen, 1969a). Convincing evidence for the existence of ultramafic liquids extruded as fluid magmas in an aqueous environment were presented by Viljoen and Viljoen (1969a) and it has been shown experimentally by Green (1972a), that the temperature of extrusion of such rocks, which approach the "pyrolite" model compositions of the upper mantle, was at least 1600-1650°C. The experimental studies suggest further that the peridotitic komatiite could have derived from very high degrees of melting (60-80%) of pyrolite while that of the basaltic variety would be lower ($\sim$ 40%). Conditions of melting in the Archaean must therefore have been greatly different from those operating to yield modern mafic/ultramafic magmas. Brooks and Hart (1972) estimated that the geothermal gradients were about twice those at present and must have been due to rapid diapiric ascent of the mantle source rock. The exceptionally high degrees of peridotite mantle melting led Green (1972a, b) to suggest a more catastrophic and rapid magma genesis and he postulated that the greenstone belts could represent altered equivalents of lunar maria formed as a result of major impacts triggering partial melting at depths of 150-300 km. Regardless of which mode of origin one favours for the mafic and ultramafic rocks their unique geochemical properties cannot be over-emphasized and have to be taken into account in any discussion on crustal evolution.

Stratigraphically higher in the average greenstone belts are rocks possessing tholeiitic and calc-alkaline chemical affinities (Anhaeusser et al, 1969; Anhaeusser, 1971b; Baragar and Goodwin, 1969; Viljoen and Viljoen, 1971). Volcanic, pyroclastic and chemical sedimentary assemblages of diverse types appear, often characterized by a remarkably cyclical mode of development (Anhaeusser, 1971b; Goodwin, 1971; Viljoen and Viljoen, 1971). Chemically, these volcanic assemblages are in many ways similar to modern volcanic complexes found in present-day island arcs supporting the contention that the greenstone belts evolved partly as island arc-like complexes in an oceanic geotectonic setting (Anhaeusser, 1973; Engel, 1970; Engel and Kelm, 1972; Folinsbee et al, 1968; Goodwin and Ridler, 1970; Hart et al, 1970; White et al, 1971). Not all the details of Archaean volcanism have yet been resolved as only a limited amount of geochemical data is presently available from selected areas in Canada, Western Australia and southern Africa, but there already appears to be a remarkably similar pattern emerging from these widely separated regions. Hallberg (1972) has rightly pointed out, however, that Canadian greenstone belts appear to have a greater abundance of andesites than the other two areas mentioned. He furthermore holds the view that the proportion of intermediate material has in some instances been greatly overemphasized, and that the assessment of these belts in terms of calc-alkaline differentiation sequences, rather than tholeiitic piles, may not be warranted.

The lower, essentially volcanic, assemblages of greenstone belts are frequently overlain by a wide variety of sedimentary rock types (Anhaeusser et al, 1969), the latter sometimes accompanied by subordinate volcanic members. Little is yet known of the chemistry of these volcanic horizons but they appear, in some instances, to reflect the changing conditions of the crust as the greenstone belts evolved (Anhaeusser, 1971b). In the Kirkland Lake area of Ontario flows of alkali mafic trachytes and a variety of leucitic lavas and pyroclasts have been identified in the Timiskaming sedimentary group by Cooke and Moorhouse (1969) while in the Barberton area in South Africa trachyandesites have been described from the Fig Tree sedimentary sequence (Visser et al, 1956). These two examples appear to be the only reported occurrences of alkalic basalts in the Archaean and their position towards the top of the greenstone belt stratigraphic sequences suggests that they may have been contaminated in their upward journey by having had to pass through a progressively thickening protocontinental crust. The sedimentary sequences generally commence with immature detritus largely derived from the initial volcanic episode and consist mainly of graywacke-shale associations, banded ironstones, jaspilites and cherts. These essentially volcanogenic and chemical sediments are often succeeded sequentially by more arenaceous assemblages comprising conglomerates, quartzites, sub-graywackes and shales derived from heterogeneous provenance areas, including granitic-metamorphic terranes.

Petrologic and geochemical studies of the changes that occur in Archaean sedimentary successions have revealed secular increases with stratigraphic height, of ensialic components, and findings of this nature have been used (Condie et al, 1970) to support arguments favouring the progressive unroofing of pre-volcanic, granite-migmatite basements. However, Anhaeusser (1973) pointed out that in the Barberton greenstone belt in South Africa the basal volcanic pile, which is approximately 15 km thick, contains no unequivocal clastic ensialic sediment. Instead the earliest sedimentary rocks interlayered with the volcanic members comprise mainly chemical precipitates (banded iron formation, chert, minor carbonates) as well as volcanogenic debris (tuffs, agglomerates). Incipient detrital sedimentation, he maintained, resulted only after island arc emergence and from erosion of granites, gneisses and migmatites that evolved progressively as a consequence of partial melting and fragmentation of the primitive oceanic lithosphere.

Archaean greenstone belts or "orogens" have characteristics which resemble in many ways the more recent Pacific/Alpine-type orogenic belts and attempts have often been made to compare and equate the ancient volcanic assemblages with the ophiolites, or initial magmatic phases of geosynclines or island arcs, while the sedimentary successions have been compared with the flysch and molasse assemblages, also of geosynclines. Anhaeusser et al (1969) contended, however, that the evolutionary development of the granite-greenstone terranes was sufficiently distinctive to warrant consideration in terms other than those generally applied to younger orogenic belts and, recently, Douglas and Price (1972) and Engel and Kelm (1972) outlined their impressions of some of the analogous and contrasting features of Archaean and post-Archaean orogenic belts and their changing tectonic styles. It is to these aspects that we now turn our attention.

4. PRECAMBRIAN GEOTECTONIC EVOLUTION

Australia, Canada and southern Africa between them, contain a remarkably complete record of crustal evolution which spans more than 3.5 b.y. of time. These areas therefore hold the clues to many of the problems associated with the earth's early history and it is from them that we must seek to confirm or denounce proposals equating Phanerozoic tectonic styles and events with those now fossilized in Proterozoic and Archaean terranes.

Archaean Structural Style

Examination of most maps depicting greenstone belts within ancient cratonic nuclei reveals a distinctive pattern of relationships between the greenstone belts and their surrounding granitic terrane. In marked contrast to the extensive, linear, Pacific/Alpine-type orogenic belts, with length-to-width ratios exceeding 100:1 (Engel and Kelm, 1972), those of the Archaean (rarely exceeding 5:1) display highly irregular patterns well-illustrated by Macgregor's (1951) "gregarious batholith" map depicting the Rhodesian craton (Figure 1a). Referred to also as the "granite-greenstone pattern" by Anhaeusser et al (1969) the ancient greenstones, which at an earlier stage

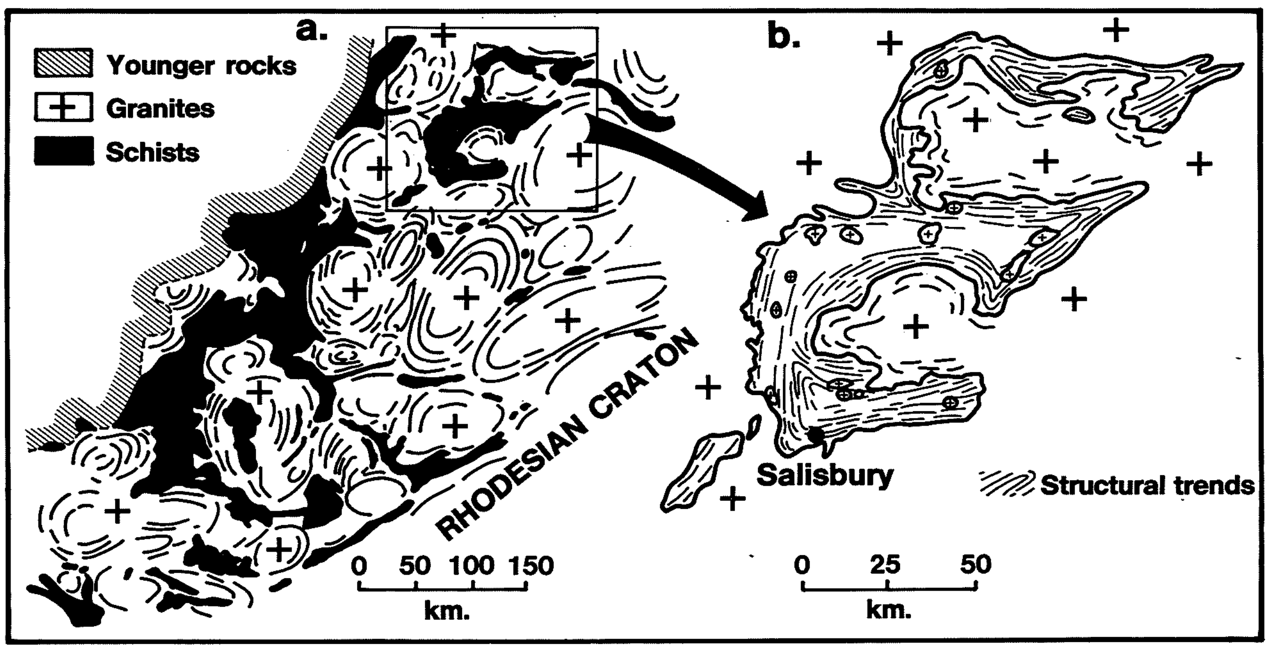

Figure 1 : Archaean structural style explained by (a) the "gregarious batholith" map of Rhodesia (after Macgregor, 1951) and (b) the "granite-greenstone pattern" exemplified by the arcuation in the Salisbury - Mt. Darwin greenstone belt (after Anhaeusser et al, 1969).

probably covered the entire Rhodesian as well as Transvaal cratons of southern Africa (Anhaeusser, 1973), were fragmented, partly assimilated and migmatized and complexly folded in response to gravitational adjustments during the upwelling of granitic melts. That the granites were responsible for most of the thermal and dynamic metamorphism of the greenstone belts into which they intruded there is little doubt. They were furthermore responsible for the typical arcuate structures common to many belts (Figure 1b).

The distinctive deformational styles of the Archaean complexes deserve added attention as the events during these times were unique. In broad terms their tectonic history is seen as having developed in two stages. During the early part of the first stage the extensive, primitive, ensimatic lithosphere underwent localized partial melting and calc-alkaline island arc-type volcanism developed in linear subsiding troughs while areas adjacent were invaded and migmatized by early sodic (trondhjemitic) melts (Anhaeusser, 1971c, 1973). These melts may have been derived by processes involving large-scale gravitational instability of the oceanic lithosphere following upon which the lower part of the basaltic crust may have converted to eclogite ($\rho \simeq 3.5$) overlying mantle peridotite ($\rho \simeq 3.3$) in the manner suggested by Ringwood and Green (1966). This gravity instability would initiate the sinking of lithospheric slabs, eventually causing eclogite masses to descend into the mantle where, at depths of 100-150 km, they would undergo fractional melting giving rise to the calc-alkaline magma series (Green and Ringwood, 1968). Liquids of this composition would, due to their lower densities ($\rho \simeq 2.8$), make their way diapirically upwards, precipitating processes of protocontinental growth and accretion.

On this rapidly changing crust large greenstone rafts would find themselves in a thoroughly unstable geotectonic setting and during the latter phases of Stage 1, gravity slumping of volcanic and sedimentary troughs began (Figure 2a). As the gravity induced deformation proceeded, in a manner

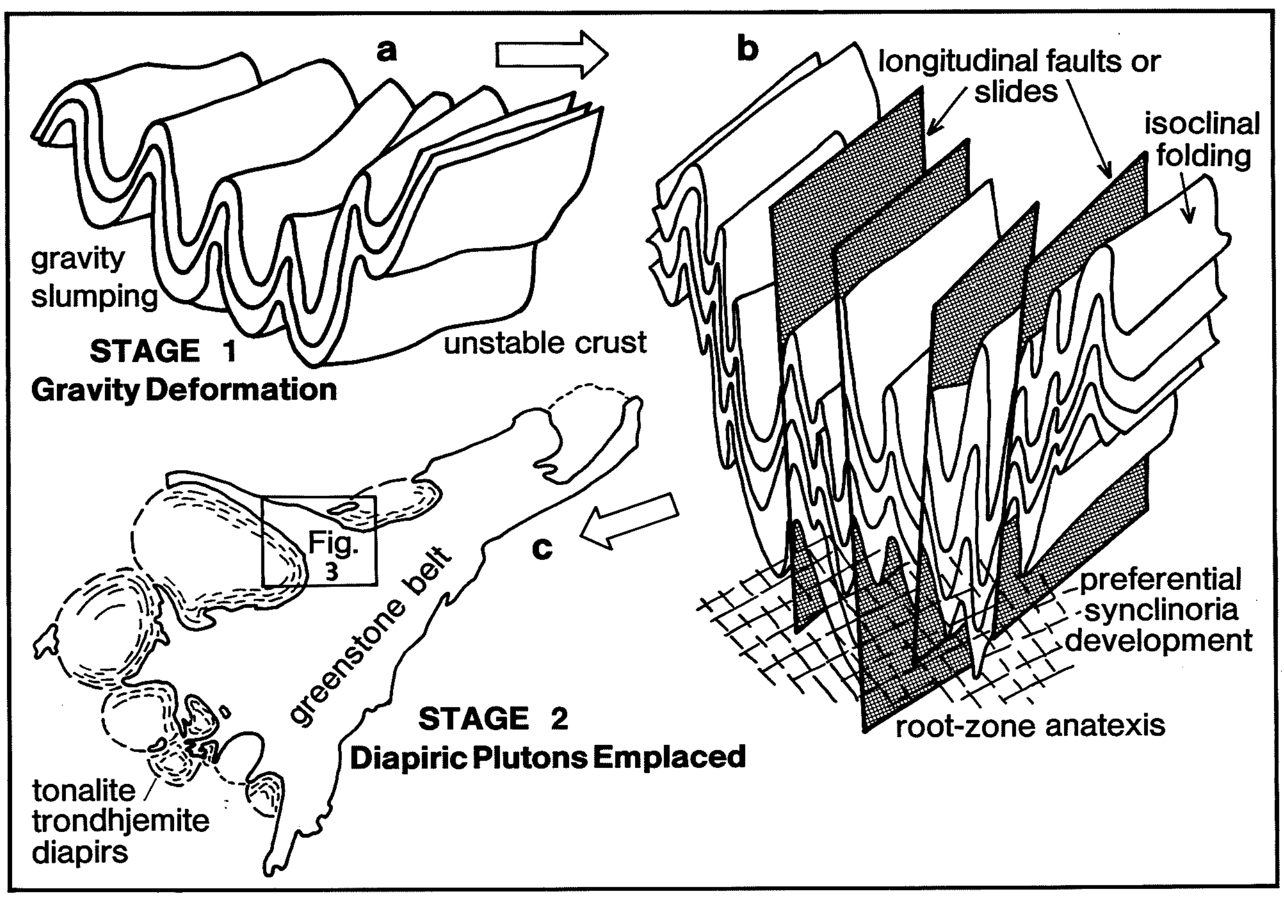

Figure 2 : Schematic illustrations depicting the episodic Archaean greenstone belt deformation. Stage 1 : Gravity deformation on unstable crust. (a) passive slumping and warping (b) intensified isoclinal folding, faulting and root-zone anatexis. Stage 2 : Emplacement of diapiric plutons responsible for the structures shown in Figure 3.

imitated experimentally by Ramberg (1967), variably plunging isoclinal folds were formed in preferentially developing synclinoria (Figure 2b), and steeply inclined longitudinal faults or slides were generated, the latter frequently eliminating intervening anticlinal folds. Deeper infolded greenstone belts may have had their root-zones affected by differential anatectic melting. These melts were probably responsible for the discrete diapiric tonalite/trondhjemite plutons frequently found emplaced around the greenstone belt margins (Stage 2, Figure 2c) and, less commonly, as small stocks in the axial zones of some greenstone belts like those in the Salisbury - Mt. Darwin belt in Rhodesia (Macgregor, 1951; Figure 1b). Support for root-zone anatexis follows from gravity investigations carried out over some greenstone belts. Despite surface and underground mine observations demonstrating vertically to sub-vertically dipping lithological units the gravity interpretations so far suggest essentially rounded or "saucer-shaped keels that do not extend to great depths. [Average depth 3-4 km, extending possibly to approximately 8 km. B.W. Darracott, personal communication 1973 and manuscript in preparation].

The structures produced during Stage 1 were essentially linear features with folds having wave lengths and amplitudes smaller than those found in Pacific-Alpine orogenic belts (Engel and Kelm, 1972). The deformation produced by the Stage 2 diapiric granite plutons was, on the other hand, responsible for the intensification of Archaean structural complexity. The pluton or, in some cases, batholith emplacement, either singly or collectively, produced many of the striking arcuate "schist belt tongues" seen protruding into the surrounding granites. Structures typically resulting from granite diapirism are shown in Figure 3 which schematically illustrates part of the Barberton greenstone belt in South Africa. Briefly the deformational events appear to have taken place sequentially in the following order :-

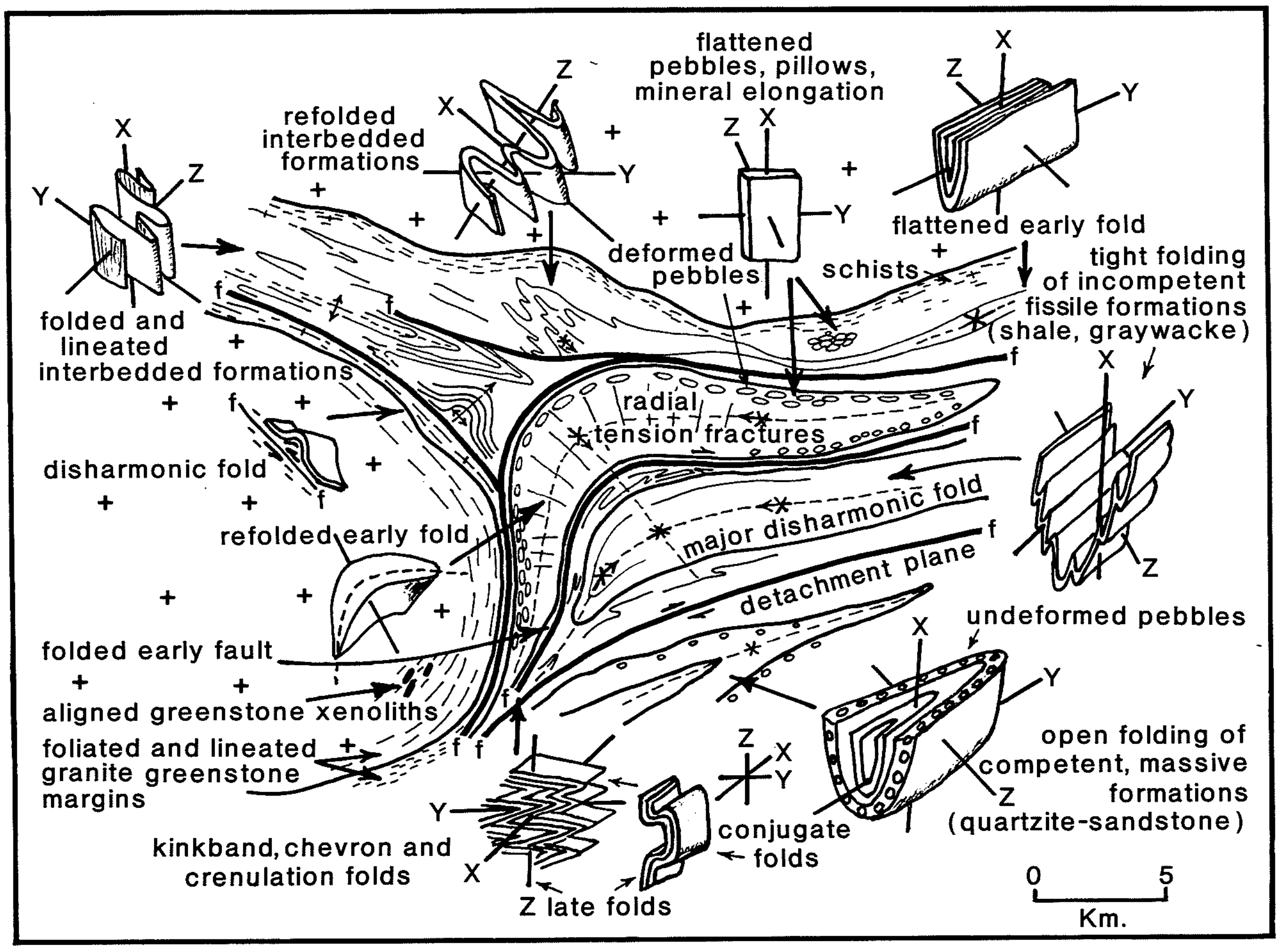

Figure 3 : Schematic diagram illustrating the main tectonic elements and strain indicators in an Archaean greenstone belt deformed by emplacement of marginal diapiric granite plutons. Region depicted forms part of the Barberton greenstone belt, South Africa.

(1) The diapiric plutons prized off, stoped and assimilated much of the greenstone belt margins, often becoming more basic and filled with inclusions as the volcanic rocks were engulfed.

(2) As the granites rose they were accompanied by a concomitant downsagging of the adjacent greenstones, and the pluton margins developed a pronounced foliation and lineation.

(3) Greenstone xenoliths close to the granite contacts became aligned in the foliation directions of the gneisses, parallel to the greenstone belt margins which also developed a strong schistosity parallel to the granite contacts.

(4) Differential compression of the interbedded greenstone belt formations produced isoclinal folding, pebble and pillow flattening, and mineral re-orientation.

(5) Because of the varied nature of the lithologies involved considerable competency contrasts existed and a variety of fold styles resulted.

(6) Early planes of weakness were reactivated producing transcurrent faults, drag and disharmonic folds and numerous attendant second and higher order faults, fractures, and joints.

(7) Final stage vertical adjustments resulted in superimposition of small- and large-scale folding (conjugate, chevron and kinkband folds).

In summary, therefore, the distinctive structural style of the Archaean complexes, which initially involved deep, gravity induced, infolding, provides added support for a thin, unstable, early crust. That the initial deformations developed essentially under the influence of gravity (as opposed to compressional tectonics accompanying crustal shortening) is borne out by the following three features characteristic of most greenstone belts :-

(1) Very low grades of regional (dynamic) metamorphism.

(2) The irregular distribution or absence of all-pervasive, thoroughly penetrative structures (cleavage-schistosity) and

(3) The preferred tendency for synclines to form and anticlines to be faulted out by high-angled slides.

Metamorphism and Plutonism

Archaean metamorphism, like Archaean tectonism, is distinctive in that it is generally of a low pressure-high temperature (Abukuma) variety. Absent, except for an isolated occurrence described from India (S. Uadarajan, 1968 - reported in Shackleton, 1973), are the blueschist metamorphic assemblages like those found in the Phanerozoic orogenic belts and, absent also, are any signs of the "paired metamorphism" so characteristic of the circum-Pacific island arcs. Thus on two counts metamorphism provides some problems for proponents of sea-floor spreading and plate tectonics during the Archaean. Other significant features of Archaean metamorphism (Engel, 1970) are the telescoped nature of the metamorphic aureoles at granite-greenstone contacts and the bimodal nature of the mineral facies (amphibolite-greenschist). Anhaeusser et al (1969) maintained, in addition, that metamorphism and deformation were intimately related, the sequence usually being of two or more periods of mineral development and deformation, followed by widespread post-tectonic recrystallization and late-stage retrogression in the waning phases of metamorphism.

Areas of highest metamorphic grade occur adjacent to volatile, K-enriched, granitic phases (including stocks and pegmatites) while the metamorphic grade adjacent to the Na-rich plutons is generally of a low grade suggesting that these diapirs were semi-consolidated bodies, more competent than the greenstones which they shouldered aside in their upward journey.

Archaean geothermal gradients, it was mentioned earlier, appear to have been greater than those of the present. Some of this heat presumably permitted partial melting to take place at shallower depths and may have been largely absorbed in the destructive processes of lithospheric conversion (ensimatic to ensialic) prior to 3.0 b.y.

Archaean Plate Tectonics

Much supporting evidence is currently available to suggest that greenstone belts developed in, or formed an integral part of, an oceanic crustal environment. Although reference has been made to several striking analogies between events in the Archaean and those in the Phanerozoic orogenic belts and arc-trench systems (even gold mineralization is common to both environments) recognition must be made of the significant differences. It is possible that these differences are due only to the antiquity of the greenstone belt environments and do not reflect real differences in crustal processes. If such be the case then some form of sea-floor spreading this far back in time does not appear unreasonable. As mentioned earlier several attempts have already been made to relate the plate tectonic model to the Archaean (Dewey and Horsfield, 1970; Talbot, 1973; White et al, 1971), and although the idea of such a comparison is certainly attractive, present knowledge accounted for, how are we ever going to prove it *beyond all reasonable doubt?*

5. PROTEROZOIC GEOTECTONIC EVOLUTION

Sufficient evidence is available to allow us to state with great confidence that the continents drifted apart from one or more macrocontinents (Pangaea, Laurasia, Gondwanaland) during Mesozoic times, while convincing plate tectonic arguments have gained many supporters for Paleozoic drift. The numerous similarities between Archaean orogens and those of the modern Pacific/Alpine-type likewise make any suggestion of ancient sea-floor spreading most alluring. It is, however, the intervening timespan of the Proterozoic that provides "drifters" with their greatest challenge. Let us then now consider some evolutionary aspects of Proterozoic earth history.

Cratonization and the Development of Continents

The Proterozoic has generally been used to define a period of earth history extending between approximately 0.7 - 2.5 b.y. Originally intended to express *time of first life* the term "Proterozoic" has fallen into much misuse and now connotes, to many workers using it, the period immediately following the stabilization of the granite-greenstone terranes. As this stabilization has taken place at different times on different continents the tectonic usage of the term Proterozoic should be avoided. In South Africa for example the crust appears to have stabilized sufficiently at about 3.0 b.y. to enable a number of interior cratonic basins to develop prior to 2.5 b.y. (Pongola, Messina, Dominion Reef and Witwatersrand sequences). Stages in the evolution of the early Precambrian crust of this region of southern Africa have been outlined by Anhaeusser (1973) who attempted to demonstrate how the developing Archaean granite suite had successively invaded, fragmented, and migmatized an originally oceanic domain thereby converting it into a cratonic proto-continental nucleus which underwent progressive crustal thickening from below (granite underplating; Engel, 1970).

The vast granite "flooding" in the Archaean was unique in earth history and appears to have been unrelated to any currently accepted process involving metamorphism and orogenesis. It was therefore suggested that these anorogenic granites were largely derived from a fractional process in the mantle (Roering, 1967). The events leading towards cratonization once initiated, appear to have developed rapidly thereafter, resulting in protocontinental growth and the eventual emergence of vast shield areas which were to form the continental nuclei. Much debate exists as to whether or not the continental areas have grown and differentiated through geologic time. Engel (1963) argued that the tectonic structure of North America supported the concept of continental growth about an older core by marginal accretion. This, he implied, involved the regeneration of initial crust largely completed between 2.5 - 3.5 b.y. ago, as well as the addition of new material from the mantle. Similar but uni-directional continental accretion appears possible across Australia and the Antarctic, while in South Africa there is some support for east to west accretionary development dating back from 3.5 b.y. (Anhaeusser, 1973).

Whatever the processes involved were it is clear that the deeply infolded Archaean greenstone belts of the ancient cratons were eventually superseded by extensive stable platforms and interior basin development, the latter only mildly folded, faulted and regionally metamorphosed (Anhaeusser, 1973; Douglas and Price, 1972; Goodwin, 1971). Absent in the Proterozoic, except for the apparently unique "Coronation geosyncline" described by Hoffman (1973), which occurs on the margin of the northwest Canadian shield, are geosynclines or orogenic belts of the Phanerozoic Pacific/Alpine-type.

The degree of preservation and the vast expanses of the sequences that developed on the shields suggest that long continued relative tectonic stability prevailed. Supporting this too is the nature of the sediment found in the interior basins. In contrast to the thick, immature detritus deposited rapidly in subsiding Archaean greenstone depositories the sediments in the Proterozoic basins comprise more mature orthoquartzites, dolomites and limestones, chert and banded and granular iron formations. The volcanic associations likewise changed from essentially sequential, K-deficient, komatiitic, oceanic tholeiitic, and calc-alkaline magma-types to extensive (flood basalt), thick, non-sequential, chemically diverse volcanism including continental tholeiitic basalts, andesites, trachytes and rhyolites showing evidence of K-enrichment.

Proterozoic Plate Tectonics

Although much theoretical support exists for Proterozoic plate tectonics and sea-floor spreading surprisingly few accounts are available where these ideas have been put to the test in nature. Gibb (1971) and Gibb and Walcott (1971) have proposed that the Slave and Superior Provinces of the Canadian shield were once contiguous and formed a single protocontinent that split apart 2.4-1.6 b.y. ago leaving the great arc of eastern Hudson Bay. The boundary between the Churchill and Superior structural provinces was also considered to represent a suture 3200 km in length characterized by distinctive rock types and geophysical anomalies. These authors suggested, furthermore, that rifting and oceanic crust developed between the Slave and Superior regions permitting sea-floor spreading to take place. One must conclude that some extraordinary and rapid changes then had to occur within the zone now occupied by the Churchill Province (minimum width 1000 km) enabling it to consolidate and permit stable shelf and interior basin deposition of extensive platform dolomites and limestones, blanket orthoquartzites, arkosic wedges and "Superior-type" iron formations (Davidson, 1972).

Palaeomagnetic data appears to favour continents, or fragments of continents drifting about more than once in the geologic past (McElhinny and Briden, 1971) but palaeomagnetists themselves admit that much has still to be done to provide convincing support or rejection of this possibility.

Studies of the cluster patterns of available radiometric age data on continental basement rocks throughout the world did not, according to Hurley and Rand (1969), support pre-Mesozoic drift. Their findings led them to conclude that two (or one) ancient nuclei had remained as coherent masses with growth patterns largely peripheral and concentric about the ancient nuclei in their pre-drift positions. Reviewing the possibility of pre-Permian global tectonics Engel and Kelm (1972) also concluded that "the ensialic nature of most Proterozoic orogenic belts and their lithic components as well as their interrelations to Archaean terranes indicate that they evolved in large part on and between the closely spaced Archaean protocontinental clusters. These underwent deformation, refractionation, and thickening as the Proterozoic orogens evolved, but without the major fragmentation, widespread dispersion, and recollision of continents typical of the post-Permian".

Precambrian Mobile Belts

Traversing the shield areas and surrounding the cratonic nuclei are highly metamorphosed and granitized mobile belts which Anhaeusser et al (1969) maintained formed an integral part of the crystalline shields. The mobile belts are characterized by complex folding, faulting and granitization and are considered to represent reworked cratonic material, with or without infolded younger supracrustal rocks (Anhaeusser et al, 1969; Mason, 1973; Wynne-Edwards, 1969, 1972). The high-grade metamorphism, coupled with distinctive linear transcurrent dislocation and high heat flow is suggestive of these belts being related to mantle activity.

It has been argued that these mobile belts represent suture zones resulting from continent-continent collision, but this explanation is not well-supported by those familiar with the circum-cratonic mobile belts of central and southern Africa. Apart from the geometrical difficulties inherent in imposing collision-type reasoning to the areas rimming the old cratons many of these mobile belts provide evidence suggesting that they were stable areas prior to ca 3.1 b.y. (van Breemen and Dodson, 1972). The Messina formation in the Limpopo belt of southern Africa with its metaquartzites, magnetite quartzites, marbles and calc-silicate rocks represents a distinct cover sequence of about this age, superimposed onto which are a number of subsequent tectono-thermal events extending from 2.69 b.y. to the present (Mason, 1973). Experimental studies of metamorphic conditions in these essentially granulite facies environments suggest that depths of burial of between 15-30 km were necessary to produce the distinctive high pressure/temperature mineral assemblages so characteristic of the mobile belts (Bahnemann, 1972; Wynne-Edwards, 1972). Instead of being regarded as collision zones these high-grade gneiss belts appear rather to have been involved in vertical tectonic motions, superimposed upon which are the effects of strain possibly brought about by craton rotation. The high heat flow measurements, coupled with the positive gravity anomalies recorded over many mobile belts (Everingham and Fraser, 1971; Wynne-Edwards, 1972), suggests furthermore that the mantle may approach shallower depths in these regions. Mantle disturbances within or adjacent to these inherent weak zones of the shields are considered responsible for igneous magmatic activity (Anhaeusser et al, 1969; Mason, 1970, 1973) giving rise to the distinctive mafic/ultramafic and anorthositic complexes like those in the Grenville, West Greenland, the Limpopo and elsewhere (Wynne-Edwards, 1972; Windley and Bridgwater, 1971; Mason, 1973). They may also have triggered magmatic activity on the cratons (Great Dyke, Bushveld, Sudbury).

Some of the mobile belts on the continents may furthermore be related in some way to present-day transform faults in the oceans. A glance at the maps of Africa and South America shows a number of indentations or offsets of the coastline, most of which are linear features that can be traced directly into mobile belts on the continents (De Loczy, 1970; Anhaeusser, in preparation). Should their relationship to transform faults be proved then it may suggest that the continents have been sited over a framework of ridges and transform faults that were possibly initiated well back in the Archaean and over which Pangaea, Laurasia and Gondwanaland may have lain until Mesozoic drift rent them apart.

Summarizing, the high-grade metamorphic nature of the mobile belts, their circum-cratonic disposition, variable geochronological histories and early development of platform-type cover sequences suggests that mechanisms other than continental collision will have to be sought to explain their particular characteristics.

6. DISCUSSION

On the basis of what has been discussed the history of the earth can be divided into three principal stages of evolution. During the Archaean which ended ca 2.5 b.y. ago the foundations were laid for the development of the continental masses. The evidence suggests that the continental nuclei, comprising the ancient greenstone-granite terranes may have evolved diachronously during the earliest geologic times and that from approximately 3.0 b.y. settled down to a unified steady state of growth and consolidation. Events leading to this stage were complex and probably reflect the earth's attempts to gain equilibrium as the core, mantle and crust formed. The nature of the primitive crust is still being debated but evidence from the oldest recognizable rock sequences - the ancient greenstone belts - points to an early ensimatic lithosphere which underwent progressive phases of fragmentation, migmatization and granitization. The ancient greenstone belts appear as remnants of this primitive environment and geologically are analogous to modern island arc systems. Despite the many similarities, however, the earliest Precambrian displays a unique sequence of events never again repeated in later times. Significant differences in the types and styles of volcanism, sedimentation, deformation and metamorphism exist to support this viewpoint. The primitive, unstable environment was ideally suited to adjustment by gravitational influences manifested in the "flooding by granite diapirism" of vast ensimatic lithospheric areas. The step-wise development of anorogenic granites culminated in the welding together of protocontinental landmasses which became the shield nuclei.

Once established as unified shield areas the continents continued to grow thicker and more widespread and much of the Proterozoic was given over to consolidation and stabilization built largely upon Archaean foundations. Intracontinental orogenesis or mobile belt development appeared as a response to mantle activity beneath the landmasses and vertical tectonic movements have exposed extensive areas of granulite terrane. In these as well as in neighbouring cratonic areas igneous magmatic activity often accompanied the mobile belt readjustments.

The enlarged ensialic landmasses, continuously harassed by mantle processes, themselves became progressively unstable and fragmented in a manner accounted for in terms of the new global tectonics. The continents did not split apart in any random manner but broke up mainly along linear mobile belts that had undergone successive stages of tectono-thermal reactivation, in some cases traceable back in time into the Archaean or early Proterozoic. Insufficient evidence is available at this point of time to reject entirely, however, the views currently popular suggesting widespread continental drift throughout earth history.

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Acknowledgement

Many thanks are due to Mr. Andrew Button for his very helpful criticism of the original manuscript.

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