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Abstract

Aspects of the stratigraphy of Archaean greenstone belts in Western Australia, the Transvaal, Rhodesia, and India are reviewed. Early Precambrian volcanic sequences are classified in terms of two stratigraphically and petrogenetically distinct assemblages, termed primary greenstones and secondary greenstones. Primary greenstones consist of mafic-ultramafic volcanic sequences, including an acid volcanic component. The widespread occurrence of such ultramafic and mafic enclaves in the earliest granites suggests that these rocks are relicts of a once extensive ultramafic - mafic crust which either dates back to a supposed meteorite bombardment phase about 4 b.y. ago, and/or represents continuing generation of oceanic crust throughout the Archaean. The secondary greenstones consist of a bimodal mafic-felsic volcanic assemblage and/or of basalt-andesite-rhyolite cycles. The bimodal suite is commonly accompanied by an ultramafic component. The secondary greenstone are thought to have evolved within linear troughs developed in partly cratonized regions, where primary greenstones were earlier intruded by sodic granites. Both primary and secondary greenstones have been identified in India, in the Swaziland System, and in Rhodesia. In Western Australia at least three and possibly more volcanic - sedimentary cycles can be traced, all containing an ultramafic component; the mafic-felsic bimodal suite is well developed

In India, ultramafic volcanic enclaves in the Dharwar gneiss dome appear to predate the Dharwar greenstone belts, which include cross-bedded quartzite at their base. Because the principal greenstone belts of the Superior and Slave provinces in places overlie granites, and have only a minor ultramafic component, they compare with secondary greenstones. Mafic enclaves in 3 b.y. old gneisses in Manitoba and the Slave Province

may represent pre-Keewatin greenstone cycles. The

greenstone belt is regarded as the geological entity whose evolution effected a transformation from oceanic crust into sialic shield - a process which took place in different parts of the Earth at different times, and which was terminated by a global thermal event about 2.6 b.y. ago.

1. EARLY AND CURRENT CONCEPTS ON GREENSTONE BELTS

The identification of primary volcanic, sedimentary, and geochemical features in low-grade metamorphosed Archaean sequences has resulted in the accumulation of data placing constraints on models of early crustal evolution. Before the application of the results of isotopic dating, the study of the Precambrian was inherently beset by assumptions such as, for example, that increasing metamorphic grade denotes increasing age, or that the crust must have been completely recycled at some stage, or that a world-wide sial formed when the Earth first cooled. It has been widely assumed, and indeed still is by some, that Precambrian igneous-metamorphic suites are partly obliterated counterparts of orogenic series analogous to Phanerozoic ones, as for example "Precambrian provinces represent a long series of orogenic cycles, each of which, though having distinctive peculiarities of its own, is essentially the same kind as the later Caledonian, Hercynian and Alpine cycles" (Holmes, 1948). Similar uniformitarian views have survived the advent of the plate tectonics theory, and modern literature on the Precambrian is characterized by attempts at correlating structural, geophysical, igneous, and geochemical lineaments and boundaries with possible early plate boundaries (Gibb and Walcott, 1971; Katz, 1972; Condie, 1972; Thorpe, 1972; Davidson, 1973; Chase and Gilmer, 1973; Talbot, 1973).

In particular, Precambrian geologists were impressed by the broad stratigraphic similarities between lithological assemblages of Archaean greenstone belts and those of island arc-trench systems (Gill, 1961; Wilson et al., 1965; Folinsbee et al., 1968; Goodwin, 1968, 1971; Green and Baadsgaard, 1971; White et al., 1971; Anhaeusser, 1973), or Alpine-type geosynclines (Pettijohn, 1943; Anhaeusser et al., 1968; Glikson, 1968, 1970; Weber, 1971; Srinivasan and Sreenivas, 1972). The latter comparisons are based on successive occurrence in greenstone belts of a eugeosynclinal-type volcanic association, a flysch-like sequence of turbidites, and in turn a molasse-like conglomerate-rich assemblage in ascending stratigraphic order. Similarities between the Archaean bimodal mafic-felsic volcanic suite and the Alpine spilite-keratophyre suite were also referred to in support of the latter analogy.

Notwithstanding uniformitarian comparisons, many petrological, geochemical, structural, and stratigraphic data from Archaean greenstone belts appear to be incompatible in detail with those of modern tectonic domains (Table 1). MacGregor (1951) drew attention to the unique granite-greenstone patterns of the Rhodesian shield, which he interpreted in terms of differential subsidence of narrow segments of a mafic volcanic layer which overlay a granitic basement. This model was developed further by Talbot (1968) and Fyfe (1973), who regarded the diapiric granites as mantled gneiss domes arising from anatexis and remobilization of sial. Recently it was suggested that Archaean greenstone belts may have evolved in rifted zones developed between diverging sial plates (Windley, 1973). The differences between the granite-greenstone system in the eastern Transvaal and younger orogenic belts were stressed by Anhaeusser et al. (1969). In particular, the recognition of a basal ultramafic-mafic extrusive assemblage in the Swaziland System (Viljoen and Viljoen, 1969a, 1971) has shown that fundamental distinctions exist between Archaean and younger volcanic activity. That important geochemical differences exist between Archaean and younger volcanic and plutonic suites was demonstrated by studies in North America (Wilson et al.,1965; Baragar, 1966, 1968; Baragar and Goodwin, 1969; Hart et al., 1970; Condie et al., 1970; Goodwin, 1971; Condie and Lo, 1971; Arth and Hanson; 1972; Condie, 1972, 1973; Condie and Baragar, 1974; Jahn et al., 1974), South Africa (Viljoen and Viljoen, 1969a, 1969c; Hunter, 1974; Anhaeusser, 1971; Glikson and Taylor, unpublished results), India (Naqvi and Hussain, 1973a, 1973b; Viswanathan, 1974; Sreenivas and Srinivasan, 1974; Naqvi et al., 1974) and

Australia (O'Beirne, 1968; Glikson, 1968, 1970, 1971; Glikson and Sheraton, 1972; Hallberg, 1972; Hallberg and Williams, 1972; Williams and Hallberg, 1973).

The divergence of concepts on the origin and evolution of Archaean greenstone belts stems not only from differences in the emphasis placed upon either their similarities to, or their differences from, younger systems, but also to a large extent from marked differences between the greenstone belts themselves. Bearing in mind that the time span during which greenstone belts are known to have evolved (3.8 - 2.6 b.y.) exceeds 1.2 billion years, it would have been surprising indeed had not this been the case. It is the aim of this paper to compare the elements of stratigraphy of Archaean volcanic successions in Western Australia, Southern India, Transvaal, and Rhodesia, and to consider environmental models with reference to crustal evolution in the early Precambrian.

2. VOLCANIC STRATIGRAPHY OF GREENSTONE BELTS

Kalgoorlie System Yilgarn shield, Western Australia

Horwitz and Sofoulis (1965) classified the stratigraphy of greenstone belts in the Kalgoorlie-Norseman area in terms of two major volcanic-sedimentary sequences separated by an unconformity which is accompanied by a conglomerate. This unconformity was also mapped in the Coolgardie-Kurrawang area, where a type-section of the Kalgoorlie System includes three ultramafic-mafic assemblages, termed Coolgardie, Mount Robinson, and Red Lake greenstones (Glikson, 1968, 1970; Kriewaldt, 1969) (Fig. 1). McCall (1969) and students of the University of Western Australia have studied the upper part of this succession in the Lake Lefroy area. Williams (1970, 1973), on the basis of regional mapping east and north of Kalgoorlie, established a stratigraphic column consisting of three volcanic-sedimentary associations, each including a mafic-ultramafic volcanic succession overlain conformably by acid volcanic rocks and derived sediments (Fig. 1). These cycles are separated from one another by pronounced unconformities and/or stratigraphically consistent chert layers. A detailed synthesis of stratigraphic information from the Kalgoorlie-Norseman area carried out by Gemuts and Theron (1973) confirmed this subdivision. Durney (1972) documented an unconformity about 400 km north of Kalgoorlie, where older greenstones and an associated granodiorite underlie younger greenstones which are in turn intruded by younger granite. Rb-Sr isotopic determinations assign an age of 2.7 b.y. to the older granodiorite (Roddick et al., 1973), whereas the younger granites of the Kalgoorlie region were dated as ca 2.6 b.y. old (Turek and Compston, 1971). Possibly, cycles 1 and 2 of Williams (1970) are even older than the ca 2.8 b.y. age assigned to some migmatitic gneisses in the Kalgoorlie area (deLaeter et al., 1973), whereas the age of cycle 3 is restricted by ages of the older and younger granites to the 2.7 - 2.6 b.y. range. The older granites consist of sodium-rich gneissic types (Glikson and Sheraton, 1972), and intrude in anticlinal positions where they are enclosed by rocks of the first and second cycles. The younger granites include adamellites and porphyritic types, and may also intrude units of the third cycle (Williams et al., 1973; Gemuts and Theron, 1973); the latter granites have not been affected by regional metamorphism (Glikson, 1968), which is dated in the Kalgoorlie area as ca 2.67 b.y. (Turek and Compston, 1971). Stratigraphic columns of the Kalgoorlie System and an interpretation of field relationships are presented in Figures 1 and 2.

The stratigraphy outlined above pertains to the linear north-northwest-striking greenstone belts of the Wiluna-Kalgoorlie-Norseman Zone. This area, defined as the Kalgoorlie subprovince, is flanked on the west and on the east by the Southern Cross and Laverton subprovinces, which differ from the Kalgoorlie subprovince in several important ways (Williams, 1973). Only or mainly one greenstone cycle is recognized in the Southern Cross and Laverton terrains, and has been correlated by Williams (1973) with cycle 1 of the Kalgoorlie subprovince. Basal parts of cycle 2 are found in synclinal positions in the Laverton subprovince. The exposure of only the lower stratigraphic sections in the Laverton and Southern Cross terrains is consistent with their denudation to a deeper level and with an interpretation of the Kalgoorlie subprovince as a downfaulted or rifted zone. It is also in accord with the average eastward tilting of the Yilgarn shield in the Perth-Coolgardie cross-section (Glikson and Lambert 1974;

Mathur, 1974). It follows from the stratigraphic correlation of Williams (1973) that volcanics of the 1st cycle may have originally extended over most of the Yilgarn shield area, possibly as an almost continuous layer. However, this layer does not necessarily represent the earliest volcanic crust of this region, and evidence for the existence of a yet older volcanic cycle has been found in the Edjudina area north-northeast of Kalgoorlie (Williams et al., 1973).

The mafic-ultramafic assemblages display both lateral and vertical changes in the proportions of the various components - which include metamorphosed pillowed to massive tholeiite, dolerite, gabbro, porphyritic gabbro, high-Mg volcanics, peridotitic volcanics, differentiated ultramafic and mafic sills and lenses (Williams and Hallberg, 1973), chert, banded iron formations, and minor extrusive and intrusive acid rocks. The lowermost greenstone cycle (cycle 1) includes small-scale mafic to felsic calc-alkaline cycles which include andesite (Williams, 1973) and acid tuffs and rhyolitic flows (Bye, 1971), and are typically capped by banded iron formations. Banded iron formations are more common in the Southern Cross and Laverton subprovinces than in the Kalgoorlie subprovince. Ultramafic rocks on the other hand are more abundant in the Kalgoorlie subprovince (Williams, 1973). In contrast to cycle 1, cycles 2 and 3 display abrupt alternations of ultramafic-mafic and acid volcanic-clastic associations. Another difference between the cycles is the exclusive occurrence of oligomictic volcanically-derived conglomerates above the greenstones of cycle 1, and the appearance of polymictic conglomerates at upper parts of cycles 2 and 3. The uppermost conglomerates include pebbles of jaspilite and sodic granite (Glikson, 1968), signifying uplift and denudation of cycle 1 rocks in neighbouring areas at late stages in the evolution of the Kalgoorlie System.

Dharwar System, southern India

Recent reviews of the stratigraphy of the Dharwar greenstone belts and of the relationships between these successions and the surrounding granite-gneiss terrain (Pichamuthu, 1967, 1970a, 1970b, 1974; Srinivasan and Sreenivas, 1969, 1972; Radhakrishna, 1974) show that the Dharwar System includes at least three cycles, and that ultramafic-mafic enclaves in the gneisses may represent relics of pre-Dharwar volcanic rocks. The latter are examplified by the Nuggihalli ultramafic zone, which trends northwest between Mysore and Dodguni, and has previously been regarded as intrusive, and by mafic-ultramafic rocks in the Kolar and Bababudan greenstone belts. This interpretation is supported by the pre-3.1 b.y. age of the Kolar rocks (Naqvi et al., 1974).

The pre-Dharwar volcanics include low-K tholeiites, high-Mg volcanics, and serpentinized ultramafic rocks (Viswanathan, 1974; Naqvi, 1974; Naqvi et al., 1974). The extrusive origin of some of these rocks is evidenced by pillow structures and quench textures. Chemical analyses of some of these rocks compare with those of 'basaltic komatiites' described from the lower part of the Onverwacht Group in South Africa (Viswanathan, 1974). The mafic and ultramafic enclaves in the Peninsular Gneiss display well pronouced thermal metamorphic aureoles along their contacts with the gneiss, attesting to the intrusive nature of the latter. An age of about 3.3 b.y. was recorded from hornblend schist in the Hutti gold field (Sarkar and Miller, 1969) defining the pre-Dharwar mafic-ultramafic volcanics as the oldest formations identified in Southern India (Radhakrishna, 1967, 1974).

No unequivocal intrusive relations have been found between the Peninsular gneisses and the Dharwar volcanic-sedimentary belts themselves; i.e., the Chitaldrug, Shimoga, and Gadag belts; the arguments in favour of such relations are based on structural discordances between the gneisses and the greenstones, and on thermal aureoles in inclusions, which may, however, be of pre-Dharwar age (see Pichamuthu, 1967; 1970a; 1970b; 1974). Those who favour unconformable relationships between the Peninsular Gneiss and the Dharwar belts point to the occurrence in the latter of a basal orthoquartzite-carbonate association (Srinivasan and Sreenivas, 1968, 1972), and to the occurrence of granite-derived arenites and conglomerates. It must be borne in mind, however, that the term 'Peninsular gneiss' pertains to a wide range of acid plutonic and metamorphic rocks dated within the 2.6 - 3.1 b.y. interval (Crawford, 1969), and that probably older rocks occur within this complex, as suggested by the 3250 ± 50 m.y. age of gneiss pebbles from a conglomerate near Kaldurga (Venkatasubramanian and Narayanaswamy, 1974). It is thus clear that the Peninsular gneiss contains pre-Dharwar phases, syn-Dharwar phase (i.e., Champion gneiss) and post-Dharwar phases (i.e., in the Closepet granite-gneiss suite).

Aswanatharayana (1968) suggested that three thermal episodes affected the Dharwar System, about 3 b.y., 2.6 - 2.3 b.y., and 2 b.y. ago. It is possible, however, that the oldest phase pertains to what Radhakrishna (1967, 1974) considers as pre-Dharwar relicts, and the youngest phase to age resets which postdate the development of the greenstone belt. The stratigraphy of the Dharwar System, as correlated by Srinivasan and Sreenivas (1972) in the Bababudan, Shimoga, Chitaldrug and Kolar belts, is (from top to bottom):

- Red beds, shales, silts and sandstones (G.R. Series).
    - Local unconformity
    - Closepet granites (ca 2.4 b.y., Crawford, 1969). Also younger phases of the peninsular gneiss.
- Greywackes (Rainbennur greywackes, Shimoga belt).
- Jaspilite, banded iron formations, pyritic chert (Shimoga, Chitaldrug and Kolar belts).
- Champion gneiss.
- Basalt-keratophyre association, including ultrabasics in the Kolar belt (Grey Trap Rainbennur Series).
- Crits, greywackes and conglomerates.
    - Unconformity
- Orthoquartzite, carbonate, oligomictic conglomerates (Dodguni Series)
- Ultramafic rocks

- Unconformity
- Banded iron formations, quartzite, conglomerate, basalt-felsite association (confined to Bababudan belt; correlation with other belts is uncertain).
  - Major unconformity
- Older phases of Peninsular gneiss and ultramafic enclaves.

It is possible that the ultramafics underlying the Dodguni series are stratigraphic equivalents of the Nuggihalli ultramafics and other enclaves in the Peninsular gneiss. Further geochronological studies are required to elucidate the relationships between the different granite phases and the Dharwar cycles.

Swaziland System

Kaapvaal Shield, Transvaal

Regional mapping in the Barberton Mountain Land area (Visser et al., 1956) has documented what has been shown to be the best exposed greenstone belt in Africa, and even world-wide. Detailed investigations in parts of this area (Anhaeusser et al., 1968, 1969; Viljoen and Viljoen, 1969a, 1969b, 1969c, 1969d, 1969e, 1969f) have shown that the Jamestown Complex, previously regarded as intrusive, is in fact a sequence of ultramfic and mafic extrusive and hypabyssal rocks comprising tholeiites, dolerites, high-Mg basalts, peridotitic flows, minor acid volcanic and pyroclastic rocks, chert, and limestone - stratigraphically termed Onverwacht Group.

The lower part of the Onverwacht Group consists principally of ultramfic to mafic flows and sills, and is divided into three formations, which in ascending stratigraphic order include the Sandspruit, Theespruit, and Komati Formations - a subdivision made possible thanks to the distinctive lithology of the Theespruit Formation, which includes acid tuff and chert intercalations (Viljoen and Viljoen, 1969a). The Komati Formation is overlain by the Middle Marker, a thin but stratigraphically consistent unit of quartz keratophyre, chert, and carbonates - interpreted as a major discontinuity possibly reflecting movements related to the emplacement of the 'ancient tonalites' (Viljoen and Viljoen, 1969a). Isotopic dating of diapiric tonalite and trondhjemite which intrude the lower part of the Onverwacht Group gave ages in the range 3.4 - 3.2 b.y. (Allsopp et al., 1968; Oosthuyzen, 1970). Rb-Sr isotopic work on greenstones indicated an age of at least 3.5 b.y. (Jahn and Shih, 1974).

The upper part of the Onverwacht Group is compositionally distinct from the lower part: it consists of numerous mafic-felsic cycles, which include pillowed or massive tholeiitic basalts capped by acid volcanic assemblages accompanied by chert and carbonate. Andesitic and ultramafic volcanics occur on a minor scale. The age of this sequence is limited to the 3.3 - 3.0 b.y. range, as defined by the age of the Middle Marker unit (Hurley et al., 1972) and of the intrusive Nelspruit migmatite (Allsopp et al., 1968), respectively. The upper part of the Onverwacht Group is unconformably overlain by a sequence of greywacke, slate, and jaspilite of the Fig Tree Group, which is in turn succeeded by siltstone, quartzite, and polymictic conglomerates of the Moodies Group. The latter includes minor trachytic flows (Anhaeusser et al., 1969). Both the Fig Tree and Moodies Group include detritus derived from the Onverwacht Group and from yet unidentified granites (Anhaeusser et al., 1969; Hunter, 1974; Glikson and Taylor, in prep.).

<u>Rhodesian greenstone belts</u>

The earliest greenstones in the Rhodesian shield are enclaves of mafic and ultramafic rocks and banded iron formations scattered in gneissic tonalites dated at ca 3.3 b.y. (Bliss and Stidolph, 1969; Wilson, 1973). These xenoliths are particularly abundant in the Selukwe area, where they have been referred to as "pre-Sebakwian" by Stowe (1968). However, the enclaves appear to be distinguishable from the Sebakwian Group rocks in their type areas between Selukwe and Gwelo only or mainly by their higher metamorphic grade (pyroxene hornfels facies). The type Sebakwian Group rocks themselves, originally termed "magnesian series" by MacGregor (1932), include serpentinized ultramafics, talc schist, banded iron formations, and chert. Some of the ultramafics are of intrusive origin (Harrison, 1968) however, Viljoen and Viljoen (1969g) drew attention to stratigraphic and lithological similarities between the Sebakwian Group and the lower part of the Onverwacht Group. Thus, little-disturbed enclaves of a stratigraphic column analogous to that of the Theespruit-Komati succession occur near Que Que within the Rhodesdale tonalite near its intrusive contact with the Midlands greenstone belt. Wilson (1973) also remarks on the volcanic origin of at least some of the Sebakwian rocks.

The Rhodesdale pluton is dated as ca 3.3 b.y., and is structurally and petrologically similar to the 'ancient tonalites' of the Barberton Mountain Land. A critical outcrop on the Sebakwe River north of Que Que contains a conglomerate which unconformably overlies talc schists of the Sebakwian Group, and includes pebbles of gneiss similar to that of the Rhodesdale pluton. The conglomerate is overlain by the Bulawayan Group, which consists of mafic-acid volcanic cycles analogous to those of the upper sequence of the Onverwacht Group (Bliss and Stidolph, 1969; Viljoen and Viljoen, 1969g). Similar unconformities were recorded along the north-eastern boundary of the Shangani batholith. These observations are significant with respect to the origin of the Middle Marker unit in the Barberton Mountain Land, suggesting that the upper part of the Onverwacht Group may have post-dated the emplacement of the early tonalites (Viljoen and Viljoen, 1969a).

The Bulawayan Group includes a lower mafic assemblage accompanied by minor ultramafic flows and intercalated chert. Available chemical analyses (Phaup, 1973) indicate the common occurrence of low-K tholeiites. Upper stratigraphic levels show a progressive increase in andesitic to rhyolitic volcanic associations, stratigraphically defined as the Maliami River Formation (Harrison, 1968). These rocks grade laterally and vertically into derived clastic sediments, which were not always mapped from sediments of the overlying Shamwaian Group. The latter group consists of quartz-mica schist, phyllite, banded iron formations, and conglomerate (Bliss and Stidolph, 1969; Wilson, 1973).

(3) SIGNIFICANCE OF ARCHAEAN ULTRAMAFIC-MAFIC VOLCANICS

Shields of the southern hemisphere abound in mafic-ultramafic relics of what appear to have been extensive volcanic layers older than the earliest granites dated in those areas. Thus, cycle 1 of the Kalgoorlie System, the Nuggihalli ultramafics and other enclaves in the Peninsular gneiss, the lower Onverwacht Group and the Sebakwian Group, represent the earliest units in their respective areas. The shield-wide scale on which these rocks occur, including their high-grade equivalents within Archaean granulite terrains (Wilson, 1971; Pichamuthu, 1970b; Sen, 1974; Radhakrishna, 1974; Glikson and Lambert, in prep.), the lack of evidence for pre-existing granites or sialic crust in their vicinity (Viljoen and Viljoen, 1969a; Glikson, 1972), and the inability of isotopic methods to place older age limits on them, render these rocks the nearest equivalents to 'vestiges of the beginning' in Archaean granite-greenstone terrains.

This is not to say that the exposed ultramafic-mafic units are necessarily representative of the oldest volcanic cycles within their respective areas. As indicated above, cycle 1 in the Kalgoorlie System may well overlie still older cycles (Williams et al., 1973). Likewise, greenstone cycles of the Pilbara system in northwestern Australia may well be older than cycle 1, as suggested by the ca 3.1 b.y. age of the intrusive granodiorites (de Laeter and Blockley, 1972). The existence of volcanic cycles older than the Onverwacht Group and Sebakwian Group is likewise probable. Nor is it intended to imply that the earliest recognizable mafic-ultramafic units are relics of the primordial Earth's crust, for it is envisaged that the crustal layer which formed at the time when the Earth cooled must have been largely destroyed by the major meteorite impact phase recorded at

4.0 - 3.9 b.y. on the moon, and which must have affected the Earth (Green, 1972). It is not impossible, however, that relics of the pre-impact crust have been preserved in some regions of the Earth; such rocks can be expected to display extensive brecciation, shatter-cone fractures, vitrification, and high-pressure mineralogical transformations (for example, see Milton et al., 1972). It can be expected that these impacts triggered world-wide volcanic activity arising from deep fracturing of the lithosphere, and consequent rise and adiabatic partial melting of mantle diapirs. It is conceivable that some of the earliest ultramafic-mafic enclaves in Archaean shields indeed represent vestiges of impact-induced volcanism (Green, 1972). On the other hand, because komatiite-type volcanics are known from sequences 2.7 - 2.6 b.y. old in Western Australia and Canada (Nesbitt, 1971; Hallberg and Williams, 1972; Pyke et al., 1973), where they may overlie thick sedimentary units, they cannot be regarded as the exclusive product of impact events, but rather as the result of endogeneous processes normal in the Archaean.

As suggested by Viljoen and Viljoen (1969a; 1969b) and supported by petrochemical calculations (McIver and Lenthall, 1974; Cawthorn and Strong, 1974), komatiite-type volcanics represent the products of between 30 percent melting of pyrolite (i.e., low-K tholeiites) and near-complete melting of pyrolite (i.e., extrusive peridotites of the Sandspruit Formation). The constant composition of the low-K tholeiites, as contrasted to the variable chemistry of the high-Mg basalts (Hallberg and Williams, 1972), can perhaps be interpreted in terms of a coexistence of mobile and stable source regions, i.e. partial melting in rising diapirs and the low-velocity zone, respectively. Although high-Mg basalts are known from post-Archaean sequences (Cox et al., 1965; Dallwitz, 1968; Gale, 1972; McIver, 1972), the komatiite suite is best developed in the Archaean. Available data, however, do not allow meaningful chemical comparisons to be made between the Archaean komatiites and more recent analogues. On the other hand, the major-element characteristics of

Archaean low-K tholeiites are m nly consistent with those of modern low-K oceanic tholeiites, allowing detailed consideration of more subtle variations (Glikson, 1970; 1971).

Chemical data from the Kalgoorlie System, from the lowemost and pre-Dharwar volcanics, and from the lower Onverwacht Group and the Sebakwian Groups, indicate that tholeiitic basalts associated with the komatiite suite are much depleted in K, Rb, Cs, Sr, Ba, Zr, Hf, U, and Th (Hallberg, 1971; Naqvi et al., 1974; Viljoen and Viljoen, 1969a; Phaup, 1973). Zr-Y- Ti plots fall into the field of oceanic tholeiites as delineated by Pearce and Cann (1971, 1973) (Hallberg and Williams, 1972). Chondrite-normalized rare-earth patterns of Archaean mafic rocks from Western Australia and the Transvaal show near-flat curves and no La and Ce depletion (White et al., 1971; Glikson and Taylor, in prep.). The lack of such depletion was referred to by White et al., (1971) in support of the island-arc analogy; however, oceanic tholeiites showing such patterns are also known (Schilling, 1971).

The Fe/Fe+Mg ratios of the Archaean tholeiites are generally high, like those of olivine-depleted oceanic tholeiites (Miyashiro et al., 1969; Shido et al., 1971) and of island arc tholeiites (Jakes and Gill, 1970). However, in contrast to the latter, Ni, Cr, and Co abundances in Archaean tholeiites are similar to those of modern oceanic tholeiites, suggesting little fractionation of olivine. The high Fe/Fe+Mg ratios may therefore be a characteristic of the primary undifferentiated magma, and may have potential implications for mantle composition and core segregation (Glikson, 1971, 1972). The low to intermediate Al levels of the Archaean tholeiites (about 14-15% Al_2O_3) preclude flotation and concentration of plagioclase, and also suggest a shallow level of magma equilibration, as the breakdown of plagioclase under pressures greater than 5 kb (Green and Ringwood, 1967) would lead to alumina enrichment. The Archaean tholeiites include both olivine-normative and quartz-normative varieties, and according to Green's (1971, p. 713) basalt petrogenetic grid, the maximum depth from which the olivine tholeiites could have been derived is about 60 km, whereas shallower levels of equilibration are indicated for quartz-normative tholeiites. The scarcity of undersaturated basalts in the Archaean (with few exceptions stratigraphically above the mafic-ultramafic suites; McIver and Lenthall, 1974), renders it unlikely that the depth of partial melting exceeded 60 km, or that partial melting within the depth range of 15-60 km was under 25 percent (see Green, 1971). It is therefore likely that the bulk of the magma equilibrated at depths shallower than 15 km, where evolution of nepheline-normative melts is arrested, and that little magmatic fractionation of olivine took place.

These considerations suggest that the low-K tholeiites evolved within environments to which modern mid-ocean ridges or back-arc spreading centres offer the closest analogues. This interpretation is in accord with the nature of the sediments intercalated with the early mafic-ultramafic units, which include chert, jaspilite, and graphitic slate. It is not inconsistent with the occurrence of acid volcanic and pyroclastic rocks above mafic-ultramafic cycles, as such are also known from modern oceanic domains (Bonatti and Arrhenius, 1970). However, the abundance of the associated acid volcanics, as well as the predominance of the komatiite suite, must be regarded as temporally unique features of Archaean volcanism.

(4) SIGNIFICANCE OF ARCHAEAN MAFIC-FELSIC AND CALC-ALKALINE VOLCANICS

In contrast to the ultramafic-mafic suites considered in the preceding section, which evolved in environments showing no evidence of pre-existing or proximal sialic crust, stratigraphically younger greenstone, such as those of cycle 3 of the Kalgoorlie System, the Dharwar System, the upper part of the Onverwacht Group, and the Bulawayan Group, rest on post-granite unconformities and/or include granite-derived arenites and conglomerates. With the possible exception of the Kalgoorlie System, these greenstones include only a minor proportion of ultramfic material. The predominant volcanic assemblage is bimodal, consisting of tholeiitic basalts and dacitic to rhyolitic volcanic assemblages which form discrete cycles in this ascending order. Andesites were reported from the Dharwar, Bulawayan, and upper Onverwacht Groups, but they appear to be less abundant than either mafic or felsic rocks, and are rare in cycles 2 and 3 rocks of the Kalgoorlie System (Viljoen and Viljoen, 1969c; Bliss and Stidolph, 1969; Phaup, 1973; Hallberg, 1971; Williams, 1970, 1973).

In searching for modern analogues of the Archaean mafic-felsic and calc-alkaline volcanic assemblages, there can be little doubt that island arc-trench systems offer the closest resemblances. This comparison has been particularly favoured by Canadian geologists, who pointed out the cyclic calc-alkaline nature of the volcanicity, the abundance of andesites and pyroclastic extrusives, the thick sequences of turbidites, and the evidence for older granites or sial in the vicinity of the greenstone belts (Gill, 1961; Wilson et al., 1965; Folinsbee et al., 1968; Goodwin, 1968; 1971; Baragar and Goodwin, 1969; Green and Baadsgaard, 1971; Jahn et al., 1974). The abundance of andesites (Baragar and Goodwin, 1969), the occurence of high-Al basalts at Noranda (Baragar, 1968), and of volcanics showing shoshonitic affinities in northwestern Ontario (Smith and Longstaffe, 1974), are all compatible with the island-arc interpretation. A basal conglomerate containing granitic pebbles and units of cross-bedded orthoquartzites underlie a thick basalt-andesite succession at Goose Lake, Manitoba, testifying to proximal or underlying granite basement (F.J. Elbers, pers. comm., 1974). Similar characteristics are displayed by volcanics of the upper part of the Onverwacht Group and the Bulawayan Group, Dharwar volcanics, and in part cycle 3 of the Kalgoorlie System (Williams, 1973). However, the Archaean sequences also contain ultramafic extrusives unknown in island arcs. Moreover, pending further geochemical studies it appears from available data that the Archaean assemblages display a pronounced mafic-felsic polarity, andesites being relatively uncommon in the Kalgoorlie System (Hallberg, 1972), the upper part of the Onverwacht Group (Viljoen and Viljoen, 1969), the Bulawayan Group (Bliss and Stidolph, 1969; Phaup, 1973), and the Dharwar System (Naqvi et al., 1974).

Further considerations of the greenstone belt - island-arc analogy indicate differences in the chemistry of the volcanic rocks, in particular of the tholeiitic basalts. Whereas the bulk of island arc mafic volcanics are high-Al tholeiites and calc-alkaline basalts, most Archaean tholeiites have low to intermediate Al contents, with a few exceptions such as at Noranda (Baragar, 1968). Fe/Fe+Mg ratios of tholeiites from Canadian Archaean calc-alkaline suites are equally high or higher than in island-arc basalts (Glikson, 1971). Ni, Cr, and Co abundances in Archaean rocks are higher by factors of two or three than in basalts of island arcs (compare Baragar and Goodwin, 1969; Hallberg, 1972; Naqvi and Hussain, 1973a, 1973b; Taylor et al., 1969; Gill, 1970; and Delong, 1974). The latter features militate against olivine fractionation, which is considered an important process in island-arc petrogenesis. Nor is magnetite separation, regarded by Osborn (1962) as responsible for the development of the calc-alkaline suite, consistent with the high Fe/Fe+Mg ratios in the Archaean rocks; thus low oxygen fugacities in Archaean magmas is indicated, in agreement with the low Fe_2O_3/FeO ratios of these rocks (Goodwin, 1968; Glikson, 1968; Hallberg, 1972). Condie and Baragar (1974) showed that tholeiites from the Abitibi belt have negative Eu anomalies similar to those of lunar highland volcanics (Gast, 1972), possibly confirming very low oxygen fugacities and retention of Eu in Fe^{++} sites of residual or refractory pyroxene.

Structural considerations also suggest that fundamental differences exist between Archaean greenstone belts and modern island arcs. The typical arcuate granite-greenstone pattern has not been observed in island arcs, although its existence at deeper crustal levels cannot be precluded. Whereas the distribution of arc-trench systems is controlled by compressive continent-ocean plate boundaries, no evidence is at hand for continental environments in the Archaean - i.e., no platform volcanic-sedimentary sequences of the type common in the Lower Proterozoic are known. Instead, Viljoen and Viljoen (1969a) suggest that the upper Onverwacht Group has formed within narrow depositories which postdated the emplacement of the 'ancient tonalites'. This is supported by thickness variations of volcanic and sedimentary units across the strike of greenstone belts. It is envisaged that the upper greenstone sequence evolved within subsiding or rifted zones developed above the tonalite-intruded and partly cratonized early ultramafic-mafic crust (Glikson and Lambert, in prep.) (Fig. 4). The occurrence of ultramafic volcanics within upper greenstone sequences suggests that mantle diapirs continued to form concomitantly with the development of mafic-felsic and calc-alkaline suites.

The bimodal volcanic suite of greenstone belts has been interpreted in terms of progressive partial melting of subducted mafic crust (Barker and Petermann, 1974). However, such a mechanism should have resulted in acid to basic volcanic cycles, whereas cycles of greenstone belts move from basic to acid. Moreover, no experimental data exist to explain the compositional polarity in terms of partial melting processes. Whereas a mafic-felsic gap has been suggested on theoretical grounds by Yoder (1973), the experimental studies of Green and Ringwood (1968), which show that acid melts can be produced by partial melting of eclogite (pH_2O = pload), do not imply a compositional gap upon further melting. That the acid volcanics of the Onverwacht Group have formed under pressure exceeding 9 kb is indicated by the occurrence of resorbed quartz phenocrysts in keratophyres, and by REE patterns which suggest garnet fractionation (Glikson and Taylor, in prep.). Thus, the scarcity of andesites in bimodal volcanic suites may reflect consistent gravity fractionation of garnet from hydrous melts.

(5) 'PRIMARY' AND 'SECONDARY' GREENSTONES

The preceding discussion suggests that no single mode of origin is applicable to the different greenstone suites - there are greenstones and greenstones. Whereas a variety of assemblage types showing different ratios of volcanic to hypabyssal rocks, ultramafic to mafic rocks, and mafic to felsic rocks occur, Archaean volcanic suites lend themselves to a broad division on the basis of their relationships to the encompassing granites, the nature of associated sediments, and evidence on original lateral extent, as follows:

'Primary' greenstones - Mostly mafic-ultramafic volcanic cycles, minor mafic-felsic and intermediate volcanics; chemical sediments and volcanically-derived clastics; no evidence exists for exposure of pre-existing granites within or near the volcanic domain. These rocks occur at low stratigraphic levels within greenstone belts, and are widespread as inclusions in the earliest intrusive granites.

'Secondary' greenstones - Mostly mafic-felsic or calc-alkaline volcanic cycles; variable ultramafic component; volcanically-derived and granite-derived clastic sediments; unconformably overlie granites and 'primary' greenstone cycles. Original extent restricted to linear troughs.

The field and geochronological relations between primary and secondary greenstones and the enveloping granites are portrayed in Figs 2 and 3.

There are exceptions to this classification. For example, the occurrence of calc-alkaline volcanic units within cycle 1 of the Kalgoorlie System is inconsistent with the proposed scheme. Also, the proportion of ultramafic rocks differs in the different areas; for example, in the Kalgoorlie System cycle 3 abounds in chlorite-tremolite high-Mg metabasalts and cogenetic sills (Doepel, 1969; Williams, 1970). As is evidenced by the multiplicity of cycles in the Kalgoorlie System, it is not true that only two major greenstone suites occur in any particular shield. Nor is it intended to imply contemporaneity of either 'primary' or 'secondary' greenstone suites in different shields. For example, geochronological data clearly suggest that the uppermost cycle in the Yilgarn Shield (2.7 - 2.6 b.y.) and the upper part of the Onverwacht Group (3.2 - 3.0 b.y.) are not contemporaneous (Fig. 3). On the other hand, no older Rb-Sr age limits can be placed on the lowermost cycles of the Kalgoorlie System, the lower part of the Onverwacht Group, the Sebakwian Group, and the Nuggihalli ultramafics, unless assumptions are made about the original (pre-metamorphic) Rb/Sr ratios in these rocks.

It will be interesting to test the above classification in the Canadian, North Atlantic, Kola, Siberian, and Ukrainian shields. Litholigically and geochemically the Canadian Keewatin-Abitibi and Yellowknife greenstone belts appear to be akin to secondary greenstones. However, mafic-ultramfic inclusions in 3 b.y. - old gneisses in eastern Manitoba may be derived from still earlier volcanic cycles (Ermanovics, 1974). Furthermore, the stratigraphic relationships of pillowed and quench-textured volcanics in Ontario and the Abitibi belts are not clear (see Pyke et al., 1973), as is the case with quench-textured ultramafics of the Thompson belt in Manitoba (J.J. Hubregtse, pers. comm., 1974).

Because of the synclinal structure of greenstone belts and the occurrence of primary greenstone at low stratigraphic levels, these rocks can be expected to be more abundant than secondary greenstones at relatively deeper crustal levels of Precambrian Shields - i.e., in association with higher-grade metamorphic zones (Glikson and Lambert, in prep.). Crustal tilting of the Yilgarn shield eastward (Mathur, 1973), the Dharwar Shield northward (Pichamuthu, 1967), the Kaapvaal Shield westward, and the Superior Shield eastward (Bell, 1971) are reflected by seismic data, basement-cover relations, and considerations based on metamorphic grade. In each of these instances the metamorphic grade increases toward the more deeply eroded uplifted part of the shield. Mafic and ultramafic enclaves abound in the gneiss-granulite terrain of the Wheat Belt in Western Australia (Wilson, 1958, 1971). The Nilgiri granulites in southern India abound in mafic enclaves (Pichamuthu, 1970b; Radhakrishna, 1974), and the Nuggihalli ultramafics are likewise associated with deeper crustal levels of the Dharwar Craton. Hunter (1970) described ultamafic and mafic enclaves from the 'ancient gneiss complex' in Swaziland, and remarked on the scarcity of metasediments. Possibly the 'ancient gneiss complex' can be interpreted in terms of coeval roots of the Swaziland System, where synclinal keels and enclaves of Onverwacht Group rocks were intruded by the 'ancient tonalites' under amphibolite-facies conditions.

(6) CONCLUSIONS

(1) Archaean greenstone suites in shields of the southern hemisphere can be classified in terms of two broad categories, denoted as 'primary' greenstones and 'seconday' greenstones.

(2) Primary greenstones are principally, although not without exception of mafic-ultramafic composition, and appear to have evolved as extensive volcanic layers within ensimatic oceanic ridge-type environments.

(3) Secondary greenstones, which postdate primary greenstones within any individual area, are principally bimodal mafic-felsic or mafic-intermediate felsic including a relatively minor ultramafic component. This volcanism postdated granites, and has been confined to linear troughs.

(4) Each shield contains both 'primary' and 'secondary' greenstones; however, whether or not this classification is applicable in the Yilgarn and Pilbara Shields should be assessed by further stratigraphically-controlled geochemical studies.

(5) Primary greenstone relics abound in Archaean gneiss-granulite terrains, which are interpreted as coeval roots of granite-greenstone terrains.

(6) Field evidence from Archaean terrains and igneous geochemical data indicate evolution from ensimatic crustal environments to partly cratonized and fully cratonized domains, a trend supported by geochemical and isotopic data from Archaean sediments (Veizer, 1973; Naqvi and Hussain, 1972; Jakes and Taylor, 1974).

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Table 1. A Comparison of some principal features of Archaean greenstone belts, Proterozoic terrains, Alpine geosynclines, and island arcs.

	Archaean greenstone belts	Proterozoic volcanic sequences	Alpine geosynclines	Island arc and Cordillera chains
Geotectonic setting	Outliers within intrusive granites, up to several hundred km long	Continental shields: platform cover, or within inter-cratonic mobile belts	Along continent - continent ocean closure collision sutures; several thousand km long (i.e., Alpine-Himalaya belt)	Ensimatic, parallel to continent-ocean boundaries, or juxtaposed with sial-sima boundaries. Several thousand km long (i.e., circum Pacific belt).
Intrusive assemblages	Subvolcanic mafic to ultramafic sills; tonalitic, trondhjemitic, and granodioritic early plutons; adamellitic and syenitic late plutons	Large mafic dykes and layered lopoliths; granodiorites, granites and alkali granites, rapakivi granites	Ophiolite complexes; large serpentinite and gabbro sheets (part of upper mantle), granodiorite and granite	Early trondhjemite and granodiorite; late shoshonitic intrusions and porphyries
Volcanic assemblages	Bimodal mafic-felsic suites, abundant ultramafic volcanics (komatiites), basalt-andesite-rhyolite cycles (in Canada). Pillowed basalts common. Alkaline volcanics rare, but occur at high stratigraphic levels. Acid volcanic lenses and pyroclastics are common.	Abundant mafic and acid volcanics, often in acid to mafic sequence. Pillowed basalts not very common. Alkaline volcanics rare	Ophiolite complexes: spilites, low-K tholeiites, quartz keratophyres, less commonly andesites	Andesites, island-arc tholeiites, high-alumina tholeiites, calcalkaline basalts, shoshonitic volcanics, abundant pyroclastic deposits
Chemistry of volcanics	Low-K oceanic-type tholeiites very common; Na-rich rhyolites very common; Flat REE patterns in tholeiites, but highly fractionated in acid volcanics	Continental-type K-normal tholeiites predominate. Acid volcanics are mostly K-rich. Andesites are relatively minor	Spilitized low-K oceanic-type tholeiites, Na-rich acid volcanics (quartz keratophyres)	Island arc tholeiite series and calc-alkaline volcanics are Al-rich, highly depleted in ferromagnesian trace elements, and with fractionated REE patterns for mafic intermediate and acid volcanics
Sedimentary assemblages	Greywacke-shale association predominates; carbonaceous shale; chert; banded iron formations; conglomerates (both polymictic and monomictic); very minor carbonates and quartzites. Pure shale units are rare	Abundant quartzite (cross bedded); feldspathic sandstones, shales and carbonates; banded iron formations locally abundant; greywackes present, but less common than quartzose sandstones	Flysch assemblage - turbidite greywacke, shale, and carbonates; chert and radiolarian chert; Molasse, impure sandstone, lithic sandstone and conglomerate. Boulder breccias and olistostromes (tectonic slumps)	Volcanogenic lithic greywackes, redeposited lithic and crystal tuffs, shales, abundant foraminiferal carbonate, boulder conglomerates and breccias
Successions	Ultramafic-mafic volcanics, mafic-felsic volcanics, greywacke-slate units, polymictic conglomerates in ascending stratigraphic order.	No systematic pattern generally predominates; mafic volcanics commonly overlie acid volcanics. However, some Proterozoic basins have geosynclinal - successions (Coronation geosyncline and Labrador trough)	Ophiolite complexes (including the spilite-keratophyre association), flysch sequences, molasse in this stratigraphic order.	Oceanic tholeiite substratum; mixed island arc tholeiite-calcalkaline volcanic shoshonite sequences, with turbidites and carbonate at variable stratigraphic levels
Typical structures and metamorphism	Synclinal outliers downfolded and down-faulted between granites; anticlines commonly accompanied by major faults; strike faults common; mainly gravity tectonics; mainly low-pressure green-schist facies metamorphism	Either little deformed platform cover, or strongly folded and faulted (including rifted) sequences in mobile belts. Metamorphism: up to greenschist in platforms, up to granulite (mostly low pressure) in mobile belts	Highly compressional tectonic features common: thrusts, nappes, tectonic melange. Foreland troughs. High-pressure metamorphism may occur	Strong vertical faulting, broad folding within fault blocks, tectonic slides and slumps. Rift zones. High-pressure metamorphism may occur

CAPTIONS

Fig. 1. Generalized composite stratigraphic columns in the Kalgoorlie System, Western Australia, and the Barberton Mountain Land.

(A) East and north of Kalgoorlie (Williams, 1970; Williams et al., 1973): DF - Dewtop Formation; MF - Morelands Formation; Gv - Gindalbie Formation, acid volcanics; Gc - Gindalbie Formation, clastic sediments; MU - Mulgabbie Formation; GUv - Gundockerta Formation, acid volcanics; GUc - Gundockerta Formation, acid volcaniclastics; GUt - Gundockerta Formation, turbidites; KF - Kalpini Formation.

(B) Coolgardie-Kurrawang area (Glikson, 1968): CG - Coolgardie greenstones; GS - Gunga siltstones; MRG - Mount Robinson greenstones; BS - Brown Lake sediments; RG - Red Lake greenstones; BS - Black Flag sediments; KC - Kurrawang conglomerate.

(C) West Lake Lefroy area (McCall, 1969): TD - Town Dam greenstones; CB - Causeway Beds; MB - Mandila Beds; WB - Wanda Wanda Beds; YG - Yilmia greenstones; KC - Kurrawang conglomerate.

(D) Norseman area (Doepel, 1973): PF - Penneshaw Formation; NF - Noganyer Formation; WF - Woolyeenyer Formation; MKF - Mount Kirk Formation.

(E) Barberton Mountain Land (Anhaeusser, 1973): SF - Sandspruit Formation; TF - Theespruit Formation; KF - Komati Formation; HF - Hooggenoeg Formation; KF - Kromberg Formation; SF - Swarkoppie Formation; FG - Fig Tree Group; MG - Moodies Group.

Lithological symbols are as for Figs 2 and 4.

Fig. 2. Interpretation of field relationships between major Archaean rock units in Western Australia, India and South Africa - Rhodesia. No detailed comparison with the observed stratigraphy in any of the above systems is intended, and the figure is meant to portray the general concept of the relations between primary greenstones,

secondary greenstones, older granites, younger granites, and high-grade gneiss-granulite complexes.

Fig. 3. Interpretation of isotopic and geological data from the Barberton Swaziland, Rhodesia, Dharwars, Philbara, and Yilgarn terrains.

Barberton: 1 - lower part of Onverwacht Group; 2 - Middle Marker; 3 - 'ancient tonalites'; 4 - Dalmein pluton; 5 - upper part of Onverwacht Group; 6 - Bosmanskop pluton; 7 - Hood granite; 8 - pegmatite intruded into Fig Tree Group; 9 - Nelspruit migmatite and Lochiel granite; 10 - Mpageni granite; 11 - metamorphism of felsic lavas of the upper part of the Onverwacht Group.

Swaziland: 1 - amphibolites of the 'ancient gneiss complex', intruded by tonalites (Sr87/86 initial = 0.7006, Hunter, 1974); 2 - younger gneiss (Sr87/86 initial = 0.7048); 3 - younger gneiss (Sr87/86 initial = 0.7022-0.7060); 4 - Mbabane pluton.

Rhodesia: 1 - Sebakwian Group; 2 - Rhodesdale granite (ancient tonalites); 3 - Bulawayan Group; 4 - granites; 5 - granites.

Dharwars: 1 - Nuggihalli ultramafics and other ultramafic-mafic enclaves in the Peninsular gneiss; 2 - hornblende schist in Hutti mines (metamorphic age); 3 - gneiss pebbles near Kaldurga; 4 - Dharwar greenstone belts; 5 - Peninsular gneiss in northern Mysore; 6 - Peninsular gneiss; 7 - Amphibolite, Kolar greenstone belt; 8 - Peninsular gneiss.

Pilbara: 1 - Warrawoona Succession, including at least two greenstone cycles; 2 - older granodiorites; 3 - Mosquito Creek Succession; 4 - adamellites, in part tin-bearing.

Yilgarn east (Kalgoorlie System): 1 - greenstone cycles nos. 1 and 2 - Menangina gneiss; 3 - older granodiorite, Jones Creek; 4 - greenstone cycle no. 3; 5 - regional metamorphism; 6 - younger granites (adamellites).

Yilgarn west (Wheat Belt): 1 - basic granulite and amphibolite enclaves in gneiss; 2 - older low-Rb gneisses; 3 - younger high-Rb granites.

Sources of the data are given in the text.

See p. 13 for discussion of early meteorite impacts.

Fig. 4. A model of the evolution of Archaean greenstone belts and cratons (after Glikson and Lambert, in prep.).

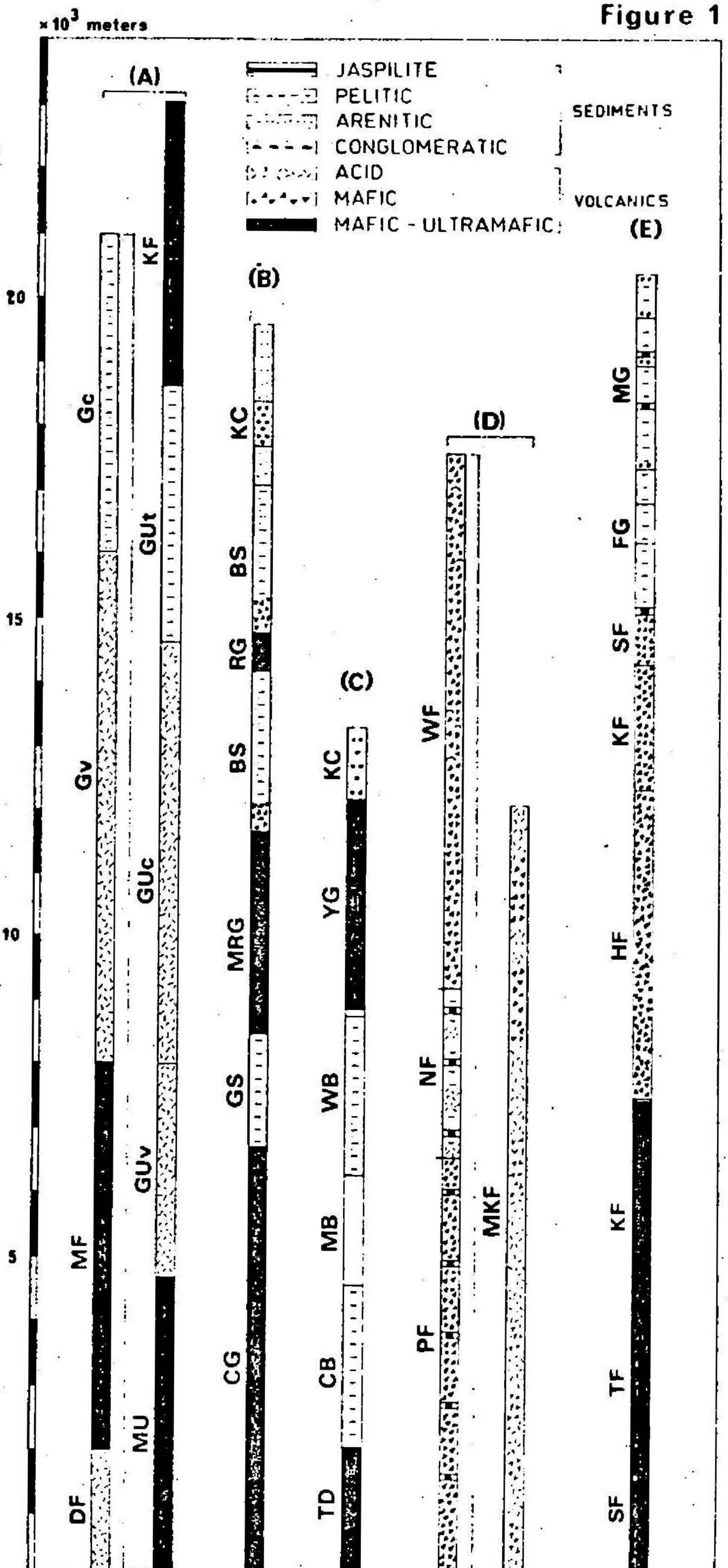
1 - Rifting of mafic-ultramafic crust and partial melting of subjacent mantle diapirs.

2 - Partial melting of eclogite and/or amphibolite of subsiding crustal segments gives rise to sodic melts and granite diapirs.

3 - Differential vertical movements of the granitic diapirs and intervening segments of ultramafic-mafic crust account for the development of linear troughs in which the secondary greenstones and associated sediments accumulate.

4 - A world-wide anatectic-metamorphic episode at ca 2.6 b.y. gives rise to younger granites, which rise toward and spread at high crustal levels (Viljoen and Viljoen, 1969d, e; Glikson and Sheraton, 1972; Glikson and Lambert, 1973).

Figure 1



Record 1975/34

M(S)430

Figure 2

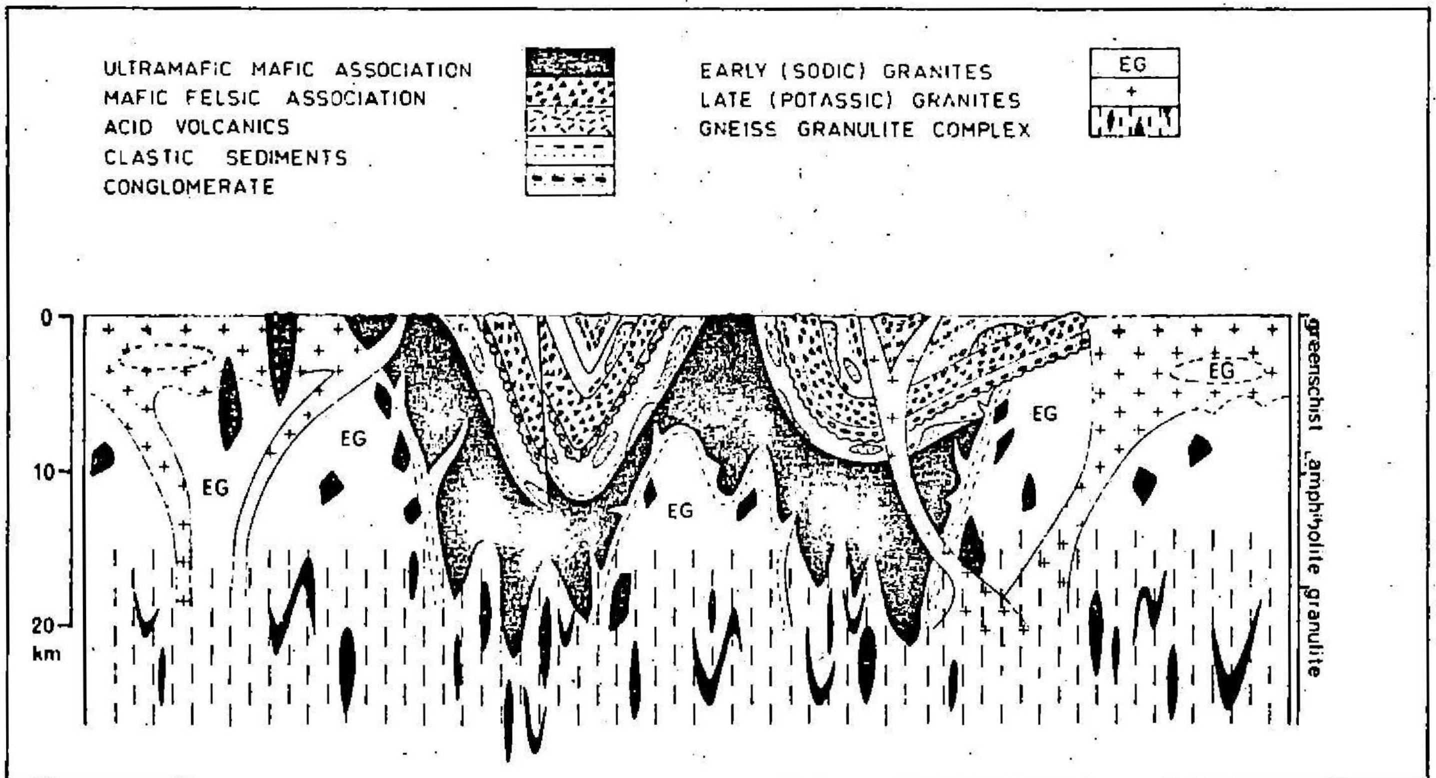


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Figure 3

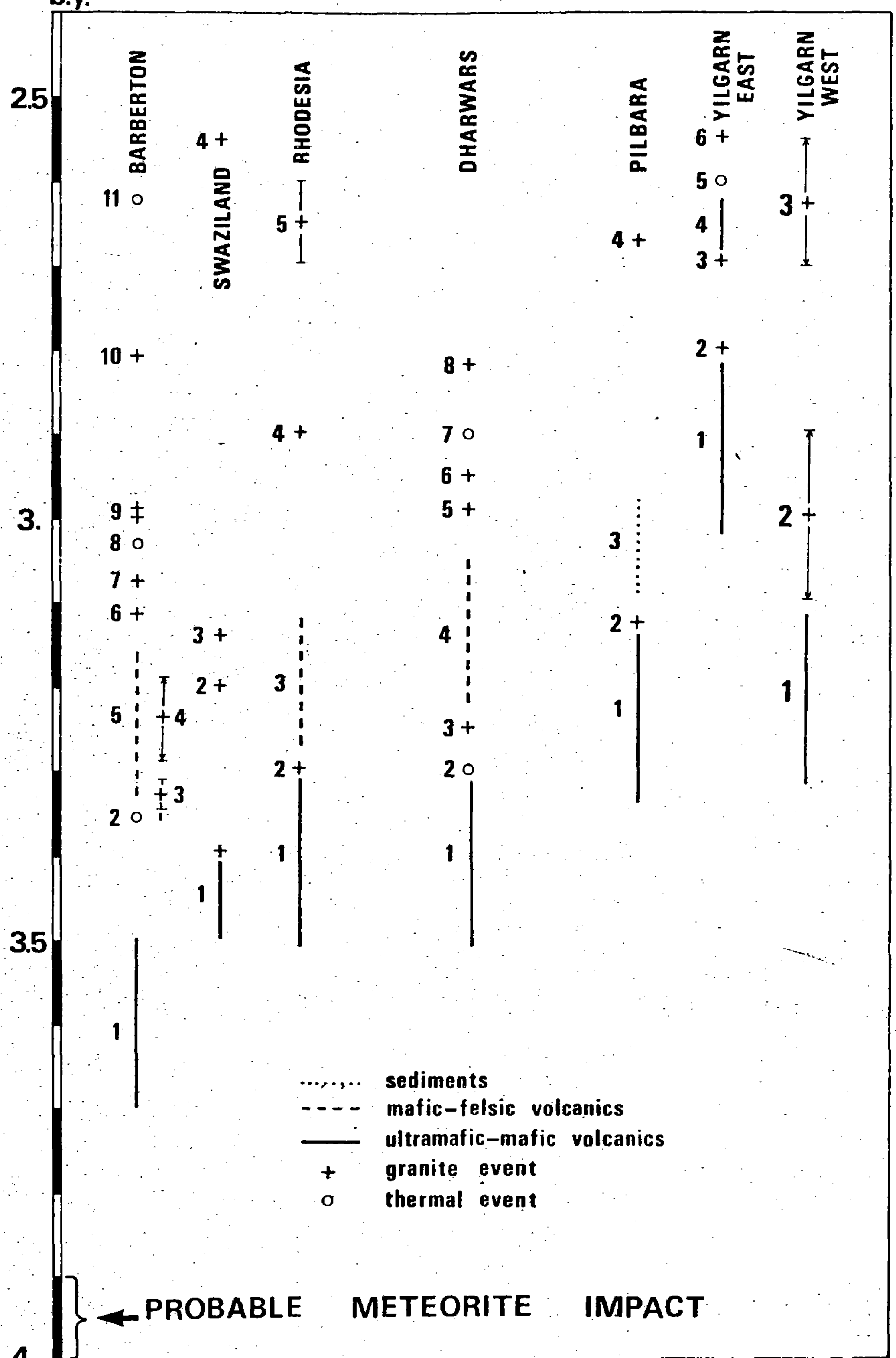

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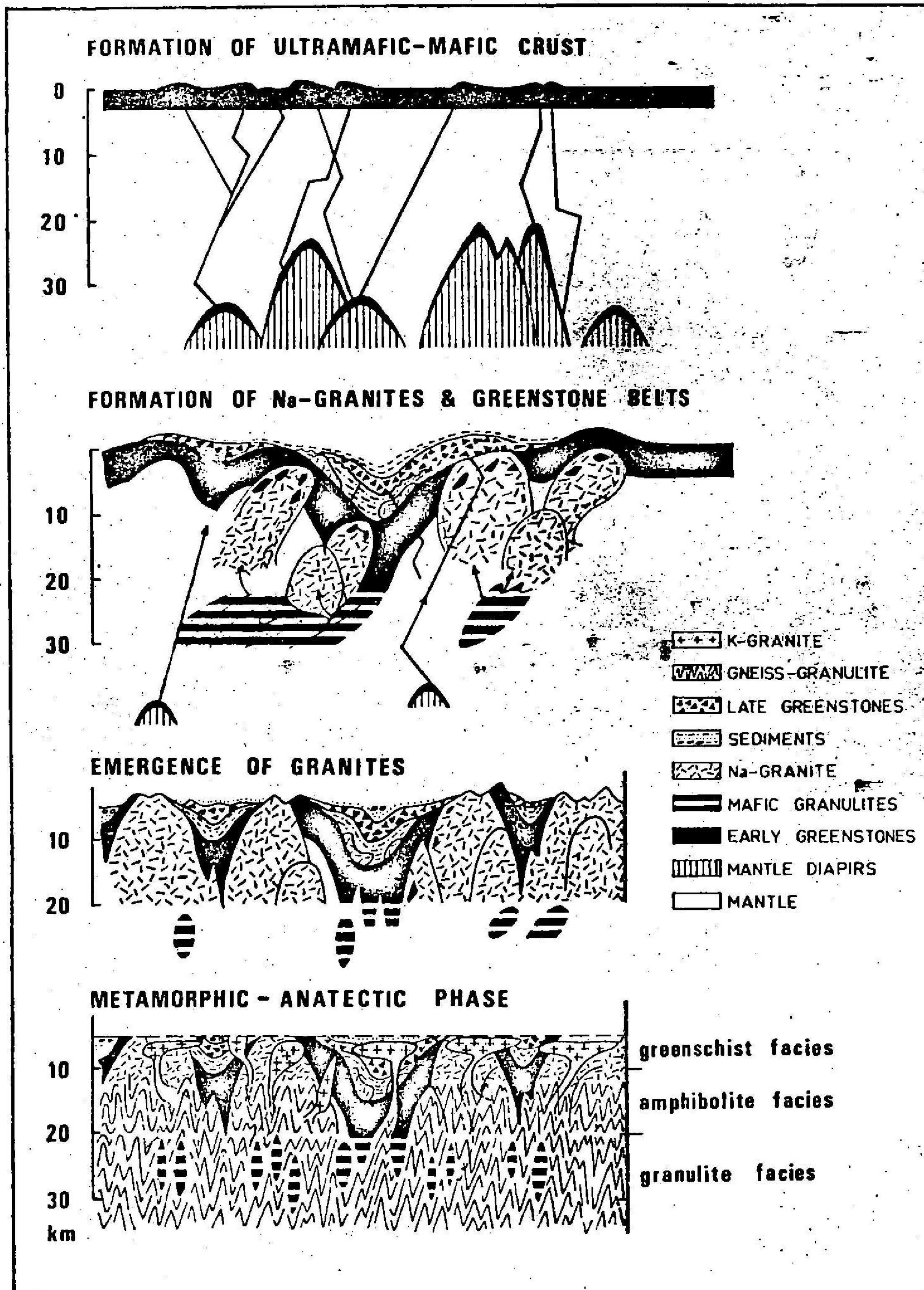
Figure 4



FORMATION OF ULTRAMAFIC-MAFIC CRUST
0
10
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30
FORMATION OF Na-GRANITES & GREENSTONE BELTS
10
20
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K-GRANITE
GNEISS-GRANULITE
LATE GREENSTONES
SEDIMENTS
Na-GRANITE
MAFIC GRANULITES
EARLY GREENSTONES
MANTLE DIAPIRS
MANTLE
EMERGENCE OF GRANITES
10
20
METAMORPHIC - ANATECTIC PHASE
10
20
30
km
greenschist facies
amphibolite facies
granulite facies