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THE DOMINION GROUP: A REVIEW OF THE LATE ARCHAEAN VOLCANO-SEDIMENTARY SEQUENCE AND IMPLICATIONS FOR THE TECTONIC SETTING OF THE WITWATERSRAND SUPERGROUP, SOUTH AFRICA

M.C. JACKSON

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by

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ABSTRACT

The Dominion Group is a volcano-sedimentary sequence of Archaean age underlying the Witwatersrand Supergroup in the western Transvaal and northern Orange Free State Provinces, South Africa. It has recently been dated at 3074 Ma and unconformably overlies granitoid basement, 3250 to 3080 Ma in age. In its type area west and north of Klerksdorp, the sequence consists of a basal clastic sedimentary unit, the Rhenosterspruit Formation, overlain by mafic amygdaloidal lavas, the Rhenosterhoek Formation, and capped by massive quartz-feldspar-phyric felsic volcanics, the Syferfontein Formation. In the type area the Group attains a maximum thickness of about 2.5 km. In the Ottosdal area, northwest of Klerksdorp, the Group comprises clastic sediments, felsic volcanics and subordinate mafic lavas. In the upper portion of the felsic volcanic strata lensoidal bodies of fine-grained, thinly bedded pyrophyllite, known as "wonderstone", may represent altered, fine-grained, tuffaceous sediments. Mafic amygdaloidal lavas in the collar of the Vredefort dome, a maximum of 240 m thick, are correlated with the Rhenosterhoek Formation. Boreholes indicate a subsurface extent of up to 40,000 km2 for the Dominion depositional basin.

Two mineralized conglomerate horizons in the Rhenosterspruit Formation have been mined for gold and uranium. The bulk of the clastic sediments consists of arkosic quartzite and sericitic schists, possibly largely derived from the underlying weathered granitoid palaeosol. The mafic lavas and felsic volcanics are of greenschist metamorphic grade in the Klerksdorp-Ottosdal areas and of higher amphibolite facies grade in the Vredefort area.

Geochemically, the Dominion volcanics are a bimodal sequence consisting of subalkaline basaltic andesite and rhyolite. Iron and titanium enrichment with differentiation indicate a dominantly tholeiitic series. Incompatible trace elements are generally enriched in both mafic and felsic volcanics; however, relative depletions of Nb and other high field strength elements, along with Nd isotopic data, suggest a "subduction component" in the mantle source of the mafic magmas. The felsic volcanics were probably generated by partial melting of crustal sources and their petrogenesis is not directly related to that of the mafic lavas.

General stratigraphic sequence, age, and geochemical similarity suggest a possible correlation of the Dominon Group with the Nsuze Group of the Pongola Supergroup in Natal Province and Swaziland. Although possibly of similar age, other suggested correlates, e.g. the Kanye Volcanics, the Kraaipan Group, and the Zoetlief Volcanics, have lithological and or petrochemical differences which argue against direct correlation.

The Dominion volcanics, along with contemporaneous granitoid intrusions, represent a period of extensive magmatic activity centered on the tectonically active northwestern flank of the successor Witwatersrand depositional basin. The tectonic environment was probably one of continental or continental-margin rifting, perhaps a back-arc basin related to an earlier or contemporaneous subduction zone to the north. If detrital

gold in the Witwatersrand sediments was locally derived from exhalative or shallow-level lode deposits the volcanics could have been an important component of the hydrothermal system producing the gold-bearing sulphide deposits along with contemporaneous hydrothermally-altered granites.

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INTRODUCTION

The Dominion Group is a supracrustal sequence containing clastic sediments and volcanic rocks of late Archaean age which unconformably overlies granitoid basement and underlies the gold-bearing sediments of the Witwatersrand Supergroup. As such it is a potentially important indicator of the tectonic setting just prior to initial Witwatersrand Supergroup deposition, and is a possible component of the hinterland; the provenance area of the clastic sediments (including detrital economic minerals) of the subsequent Witwatersrand Basin. The Dominion Group is the oldest member of the so-called Witwatersrand Triad which also includes the Witwatersrand Supergroup and the Ventersdorp Supergroup.

As a result of its limited and poor surface exposure, the Dominion Group has not been well studied. Although minor economic U-Au mineralization was exploited in basal clastic sediments of the group during the first half of this century, its stratigraphic position far beneath the Central Rand Group of the Witwatersrand Supergroup, which contains the vast majority of the gold-bearing reefs, and its apparently restricted areal distribution in the western portion of the Witswatersrand Basin, have resulted in a general lack of interest and information on the Dominion rocks.

Recent age dating of detrital zircons and granitoid basement in the Witwatersrand hinterland (Robb et al., 1990a, 1991) has shown that felsic igneous rocks of roughly Dominion age (3100-3010 Ma) were a significant component of the source material feeding the basin of deposition of the West Rand Group (lower Witwatersrand Supergroup). Thus, constraints imposed by the petrochemistry of the Dominion Group volcanics have important implications for the palaeoenvironment just prior to the deposition of the auriferous reefs of the overlying Central Rand Group.

This review summarizes available information on the Dominion Group including the various interpretations of its environment of deposition and relationship to the overlying Witwatersrand Supergroup.

Tectonic Models

The Dominion Group supracrustals have been variously considered as the initial depositional products of the Witwatersrand Basin, and therefore part of the Witwatersrand Supergroup (Nel, 1927, 1934a, 1934b, 1935), or as the result of deposition in an entirely separate precursor basin or proto-basin (Bickle and Eriksson, 1982; Watchorn, 1980; Tankard et al., 1982). The geochemistry of the Dominion volcanics has been interpreted as indicating: (1) an origin by Andean-type continental-margin arc volcanism in an Archaean plate convergence zone (Burke et al., 1986; Crow and Condie, 1987) on the basis of presumed calc-alkaline andesitic composition of the mafic metavolcanics, or (2) as a bimodal tholeiitic basalt - rhyolite association (Bowen et al., 1986; Marsh et al., 1989) more characteristic of deposition in a failed continental rift-basin tectonic setting (Bickle and Eriksson, 1982; Stanistreet and McCarthy, 1991).

The Dominion Group is the basal unit of a thick, semi-continuous and quasi-conformable supracrustal sequence commonly known as the Witwatersrand Triad (Hamilton and Cooke, 1960; SACS, 1980); the overlying members of the triad are the largely sedimentary Witwatersrand Supergroup and the mainly volcanic Ventersdorp Supergroup. Each member of the triad is generally thought to represent a separate, but related, successor depositional basin (Bickle and Eriksson, 1982; Burke et al., 1986; Clendenin et al., 1988).

Winter (1987) summarized postulated tectonic models for the Witwatersrand Basin. These include the "taphrogenic basin model" after Brock and Pretorius (1964) and Pretorius (1981); the "intracratonic, alluvial plain, lacustrine model" after Vos (1975); and the more recently favoured "cratonic foreland basin model" (Burke et al., 1986; Winter, 1987). While the Witwatersrand Supergroup is generally agreed to conformably overlie the Dominion Group, recently acquired reliable age dating indicates a long time span for deposition of the Witwatersrand Supergroup (>300 Ma: Barton et al., 1989; Robb et al., 1990a), between the upper Dominion felsic volcanics (3074 Ma, Armstrong et al., 1990, in press) and the base of the Ventersdorp Supergroup (2714 Ma, Armstrong et al., 1990, in press), and thus, it is important to establish the spatial and temporal relationship between the different members of the triad. Was Dominion Group volcanism and sedimentation simply a precursor to subsequent Witwatersrand Basin clastic deposition in a similar tectonic environment? Or does the Dominion represent an earlier, separate event which may provide key elements to an understanding of the important transition from the basement "Archaean style" granite-greenstone belt tectonic setting to the development of later "Proterozoic style" platformal sedimentation and mineralization?

STRATIGRAPHY

Klerksdorp-Ottosdal Area

The status of the rock sequence comprising the Dominion Group has evolved from early recognition as initial deposits of the Witwatersrand sequence to that of a separate entity divided into three formations. Molengraaff (1905) gave the name "Dominion Reef Series" to mineralized conglomerates and associated sericite schists and quartzites in the Klerksdorp area. Nel (1934b) mentioned volcanic rocks occurring at the base of the Witwatersrand system in the Parys-Vredefort and Klerksdorp-Ventersdorp areas which were overlain conformably by the Orange Grove Quartzite, the basal formation of the lower Witwatersrand West Rand Group. Nel (1934a, 1935) proposed the use of Molengraaf's "Dominion Reef Series" to include two volcanic units conformably overlying the sediments. He described the volcanics as "lavas and light-grey bedded ashy-looking rocks." And "curious cherty amygdaloidal rocks... Interbedded with the amygdaloidal varieties is a dense quartz-porphyry." (Nel, 1934a, p. xxxv). A thick sequence of felsic volcanics north of Ottosdal was correlated with the Dominion Reef Series by Nel et al. (1937). This sequence contains the massive pyrophyllite deposits known as "Wonderstone" which Nel et al. (1937) considered to be altered volcanic ash units.

More detailed studies of the "Dominion Reef Series" (now called Dominion Group) followed those of Molengraaf and Nel (Truter, 1949; Von Backström, 1952, 1962; Simpson, 1954; Liebenberg, 1955; Malan, 1959; Heimstra, 1968a, b; Simpson and Bowles, 1977). Most detailed studies concentrated on the basal clastic sedimentary unit hosting the economic U-Au deposits in two conglomeratic reefs at the Dominion Mine and Afrikaaner Leases Mine in the Klerksdorp area (e.g. Liebenberg, 1955; Malan, 1959).

Du Toit (1954) considered the Dominion Reef Series to be "apparently conformable below the Orange Grove Quartzite". Von Backstrom (1952), however, found evidence for a disconformable relationship in the Ottosdal area. He divided the Series into: basal sediments, succeeded by an andesitic lava, and capped by an upper rhyolite unit locally called granophyre.

The South African Committee for Stratigraphy (SACS) assigned the Dominion to group rank and divided it into three formations (SACS, 1980). The distribution of surface outcrops and interpreted subsurface occurrence of the Dominion Group is shown in Figure 1. A general lithostratigraphic column depicting the Dominion Group in various areas is shown in Figure 2. As pointed out by Bowen et al. (1986, p. 298) the SACS terminology (SACS, 1980) is in error in reversing the names of the lower two formations. The correct terminology is given in Figure 2 and discussed below. This terminology is also reported by Watchorn, 1980, 1981; Tankard et al., 1982; M. Bowen, 1984; T. Bowen, 1984; Burke et al., 1986; Crow and Condie, 1987; and others, and is generally accepted by workers in the area (M. Brink, pers. comm., 1990).

The three formations comprising the Dominion Group are, from base to top: the Rhenosterspruit Quartzite Formation, the Rhenosterhoek Andesite Formation, and the Syferfontein Porphyry Formation (terminology of SACS, 1980, as modified after Bowen et al., 1986). Bowen et al. (1986) also recommended a change in the SACS terminology from Rhenosterhoek Andesite Formation to Rhenosterhoek Formation, which will be used here, because it is not primarily composed of andesite. Likewise, it is here recommended that the terms "Quartzite" and "Porphyry" be dropped from the Rhenosterspruit Quartzite Formation and Syferfontein Porphyry Formation, since the former is composed dominantly of lavas and tuffs, and includes conglomerates in the type area (Malan, 1959; Watchorn, 1980, fig. 4), and the latter comprises mafic lavas, pyroclastics, and other lithologies (e.g."Wonderstone") as well as porphyry (SACS, 1980, fig. 3.1.3; Bowen et al., 1986, fig. 2).

SACS (1980, p. 96) describes the lithology of the three formations of the Dominion Group as follows:

> "The Rhenosterspruit (changed from Rhenosterhoek) Quartzite Formation is made up of grey quartzite, yellow sericitic quartzite, and conglomerate bands, two of which that have been extensively exploited for gold and uranium are known as the "Upper" and "Lower Dominion Reefs". The Formation lies on an uneven surface of granite and in places the "Upper Reef" rests directly on granite. In the type area it is 60 m thick; in the Ottosdal area it ranges from 90-120 m and contains a 3-m-thick band of lava (Von Backstrom, 1962, p. 8). The apparently conformable overlying Rhenosterhoek Formation (changed from Rhenosterspruit Andesite Formation) comprises a succession of green and grey andesitic lavas with subordinate tuffs in the uppermost 150 m in the type area. Around Ottosdal (Von Backstrom, 1962, p. 9) the lower part of the lava contains intercalated bands of sediments up to 40 m thick. In the type area of the

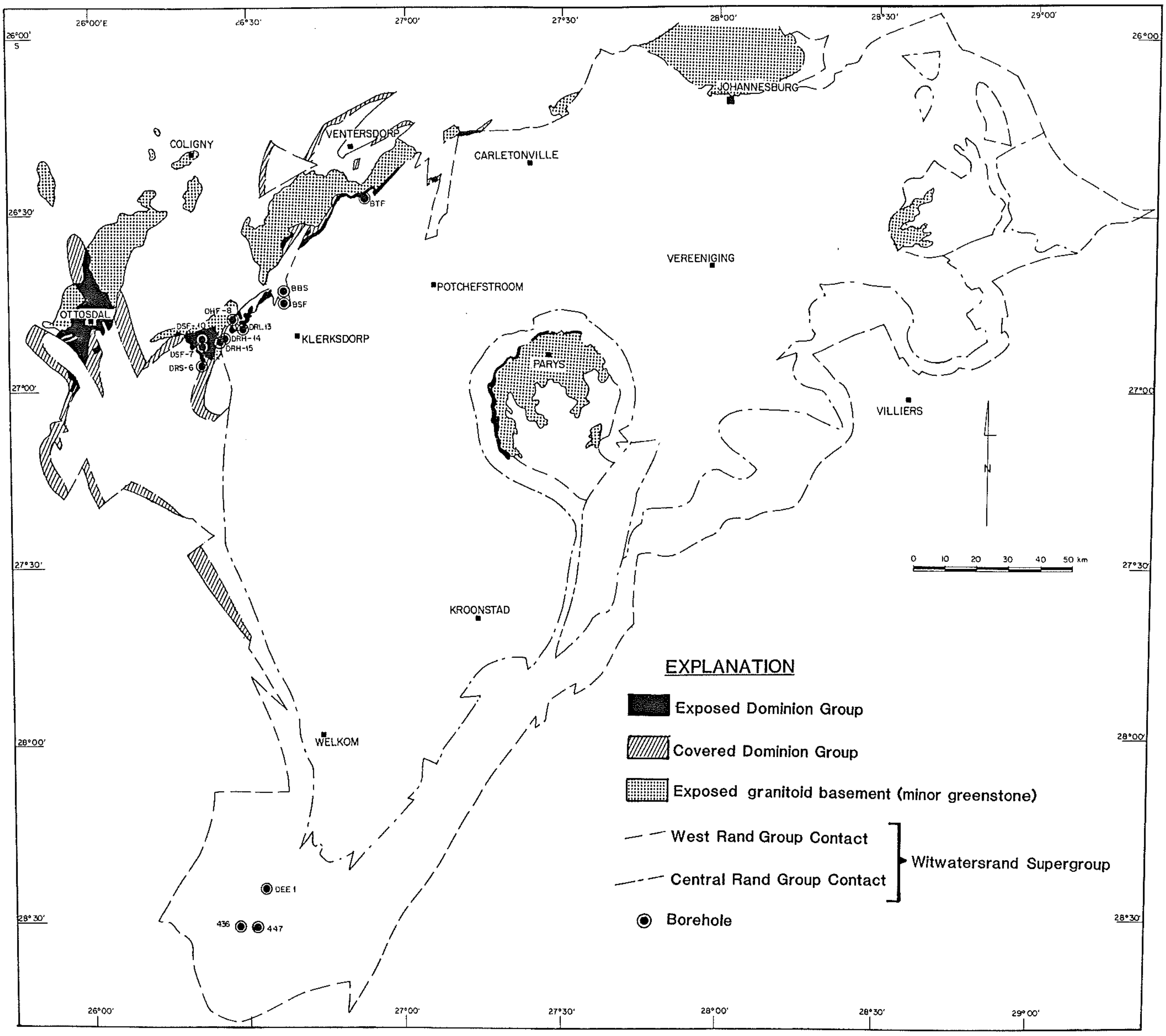

Figure 1: Map showing the distribution of Dominion Group outcrop, probable sub-outcrop, exposed granitoid basement (modified from Pretorius et al., 1986), and the location of boreholes sampled by Crow and Condie (1987) and M. Bowen (1984), T. Bowen (1984), Bowen et al. (1986) and Marsh et al. (1989) and discussed in text.

succeeding Syferfontein Porphyry Formation, a distinction can be made between a lower 750 m of medium-grained porphyry, a middle 500 m of silicified porphyry and an upper 300 m again of medium-grained porphyry (fig. 3.1.3). The "Wonderstone" occurs within the upper unit."

According to SACS (1980) the total thickness of the Dominion Group is about 2250 m at the old Dominion Mine (about 30 km west of Klerksdorp), whereas it is only a maximum of 240 m thick near Vredefort (Nel et al., 1939, p. 38-39).

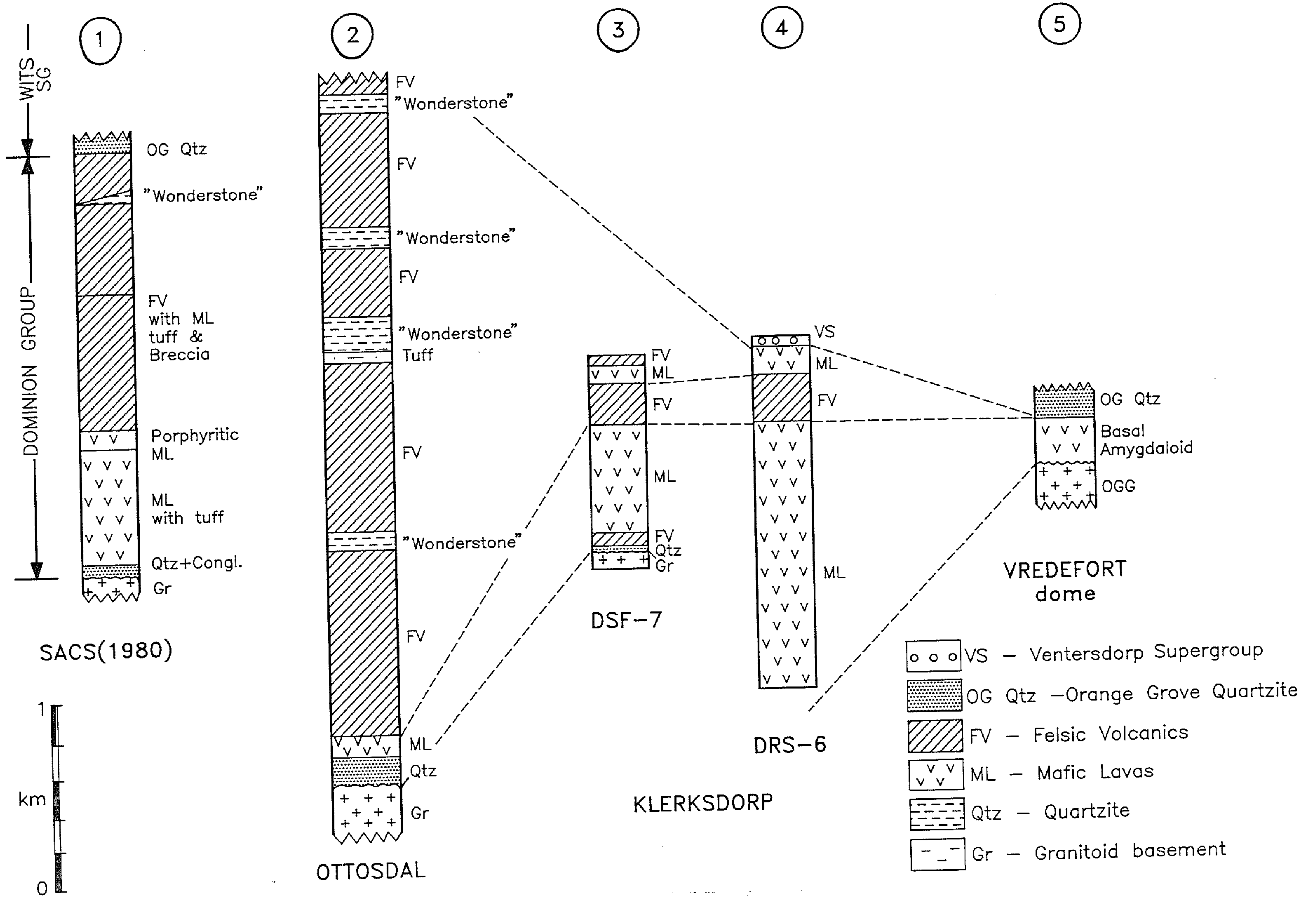

Figure 2: *Generalized stratigraphic column (1) of the Dominion Group with recommended terminology for the three formations, after SACS (1980), as modified by Bowen et al. (1986) and others (see text), compared to: (2) approximate stratigraphic column for the Ottosdal area (after Von Backström, 1952, 1962), (3 and 4) two boreholes in the Klerksdorp area (after Bowen et al., 1986), and the maximum thickness of Dominion Group mafic lavas in the Vredefort area (after Nel, 1927).*

Vredefort Area

In the collar of the Vredefort structure, dark grey, amygdaloidal metavolcanics, called the "basal amygdaloid" (Hall and Molengraaff, 1925), were correlated with the "Dominion Reef Series" by Nel (1934b). This mafic volcanic unit probably correlates with the Rhenosterhoek Formation in the Klerksdorp and Ottosdal areas. The lower sediments of the Rhenosterspruit Formation and the upper Syferfontein Formation are not recognized in the Vredefort area, although Nel (1934b) noted the presence of "a few small inconsistent lenses of altered sediment" within the basic amydaloidal lava. Nel (1934b) stated that the maximum thickness of the Dominion in the area is 240 m.

DISTRIBUTION

Known outcrops of the Dominion Group in the Transvaal and Orange Free State are shown in Figure 1. SACS designated outcrops in the Ottosdal area, between Ottosdal and Klerksdorp, and north and west of Parys and Vredefort in the collar of the Vredefort structure as type localities of the Dominion Group (SACS, 1980, fig. 3.1.1). This implies a basin of deposition a minimum of 70 km (N-S) by 170 km (E-W) for the extent of the Rhenosterhoek Formation mafic volcanics (area = 11,900 km2) and a smaller area of about 3500 km^2 for the more restricted Rhenosterspruit and Syferfontein Porphyry Formations. Tankard et al. (1982) estimated an area of coverage of about 15,000 km^2. An examination of the map of the Witwatersrand Basin (Pretorius et al., 1986; Figure 1) showing subsurface as well as outcrop distribution of the Group indicates an area of up to 20,000 km^2.

The restriction of the lower clastic sediments and upper felsic volcanics to the western part of the basin, where the Dominion Group attains its maximum known thickness [about 2.7 km near Klerksdorp according to Watchorn (1980) and Tankard et al., (1982)] and possibly over 3 km in the Ottosdal area (see Figure 2), suggests that this area was more proximal to the volcanic vents and sedimentary provenance than the Vredefort area to the east. The reduced thickness of the mafic lavas of the Rhenosterhoek Formation in the Vredefort area and their apparent pinchout in the northeastern and southwestern collar support this interpretation.

Suboutcrop

The suboutcrop extent of the Dominion Group outside the type localities is not well known. Boreholes indicate a subsurface extension from the westernmost outcrops, about 20 km west of Ottosdal, about 120 km to the southeast (Figure 1; Pretorius et al., 1986). A total of 32 boreholes, listed in the compilation of Werdmuller et al. (1990), are reported to have intersected parts of the Group. Most of these reported holes were collared within Dominion rocks at the surface in the type localities northwest of Klerksdorp and north of Ottosdal. Most were drilled through lower Dominion lithologies and into granitoid basement at relatively shallow depths of about 40 m to a maximum of about 1100 m. Eighteen of these boreholes reportedly intersected one or both of the mineralized conglomerate horizons (upper and lower Dominion reefs) at depths ranging from 56 to 1070 m. A few boreholes went through about 100 to 350 m of Ventersdorp Supergroup before encountering Dominion, e.g. about 20 km southeast of Ottosdal (Werdmuller et al., 1990; p. 20).

As the borehole compilation shows, there are many boreholes cited within, or close to, known Dominion outcrops, for which no descriptive logs are recorded. Many of these holes presumably penetrated part or all of the Dominion Group. Furthermore, there are many instances of "uncorrelated lava", "quartzite", or "greenstone" above granitoid basement in the boreholes listed that could be Dominion lithologies. Dominion lavas would be particularly difficult to identify in those cases where boreholes are logged as passing directly from Ventersdorp lavas into granitoids without intervening Witwatersrand Supergroup rocks.

Robb and Meyer (1985, 1990) reported that 64 out of 162 boreholes drilled in the Witwatersrand hinterland (i.e. north, northwest and west of the Witwatersrand Basin) intersected Dominion Group. The majority of these reported intersections (62) were in areas within the known extent of the Dominion, near the Ventersdorp, Hartbeesfontein, and Ottosdal-Coligny granitoid domes. However, two of the holes were in areas beyond the known limits of the Group, one in the area of the West Rand Anticline and one in the area west of Welkom (Robb and Meyer, 1985; Table 1).

Robb and Meyer (1986) discussed several boreholes 30 to 120 m deep, in the Varkenskraal area of the West Rand about 20 km northwest of Carletonville, which were collared in Dominion lavas and quartzose sediments above granitic basement. One hole in this area was collared in dolomite of the Chuniespoort Group and passed through Black Reef Quartzites and Dominion Group before hitting the basement at a depth of 416 m. The upper portion of the granitoid basement in the Varkenskraal area is described as "a granitic palaeoregolith which grades downward into fractured and often altered and pyritiferous granites" (Robb and Meyer, 1986, p. 2).

Finally, there are published descriptions of boreholes with Dominion Group intersections up to 2 to 3 km in thickness which are not recorded in the compilation of Werdmuller et al.(1990), e.g., M. Bowen (1984), T. Bowen (1984), Bowen et al. (1986) and Crow and Condie (1987). So, clearly, there is some latitude for postulating a greater subsurface extent for the Dominion Group than that which is currently a part of the public record.

Three boreholes south of Welkom reportedly intersected probable Dominion Group volcanics, both mafic amygdaloidal lavas and overlying felsics beneath the Orange Grove Quartzite, at depths of about 750 to 1800 m below surface (Figure 1). One hole intersects a section about 1 km thick. If correct, this interpretation greatly increases the known extent of the Dominion Basin to approximately 40,000 km .

AGE

The age of the Dominion Group has only recently been reliably established. When the clastic sediments and volcanics in the area of the old Dominion Mine west of Klerksdorp were first recognized their lithologic similarity and apparent conformity with the overlying Witwatersrand sequence suggested an age just slightly older than the lower Witwatersrand. Similarly, in the Vredefort area, Nel (1934b) considered the "basal amygdaloid" to be the basal member of the Witwatersrand sequence overlying Archaean granite. The general lack of deformation and significant metamorphism of the Dominion rocks, similar to that of the Witwatersrand sediments, and in contrast to the Archaean metavolcanics (e.g. the

TABLE 1. Chemical Analyses of Dominion Group Samples.

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
SiO2	55.7	51.86	77.31	50.28	48.26	54.76	59.08	68.21	65.39	71.85	51.7	50.6	55.9	53.2	52.8	53.1	75.2	56.2
TiO2	1.15	0.67	0.43	0.78	0.82	1.14	1.81	0.80	0.74	0.51	0.68	0.83	0.63	1.18	0.83	0.99	0.52	2.4
Al2O3	14.35	14.26	10.31	12.30	12.28	14.15	11.18	12.54	12.40	12.39	13.1	13.9	14.0	14.8	14.2	14.1	12.1	32.8
Fe2O3	0.65	--	1.02	12.14	11.90	11.48	13.10	6.10	7.88	4.92	11.0	12.0	8.6	11.9	11.6	10.9	4.6	1.3
FeO	8.65	10.27	3.46	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MnO	0.20	0.16	0.03	0.20	0.17	0.15	0.14	0.06	0.11	0.07	0.17	0.17	0.15	0.17	0.18	0.15	0.05	--
MgO	7.30	7.63	0.46	11.02	7.13	4.60	2.24	0.58	0.48	0.66	9.10	7.88	6.76	5.18	7.39	6.01	0.84	0.5
CaO	8.95	9.86	0.17	7.35	10.09	7.15	5.07	1.80	2.77	0.96	8.74	8.11	7.01	5.90	5.71	8.43	0.53	0.5
Na2O	2.2	4.55	1.75	2.44	1.54	3.93	2.58	4.05	4.24	3.06	2.17	3.63	5.15	4.23	5.00	3.70	5.22	--
K2O	trace	0.61	2.83	0.34	0.07	0.84	2.07	2.99	2.40	3.01	0.12	0.94	0.26	1.22	0.61	0.86	0.99	--
P2O5	0.20	0.14	0.12	0.18	0.18	0.36	0.66	0.26	0.20	0.12	0.17	0.20	0.15	0.37	0.20	0.16	0.14	--
H2O+	--	--	2.41	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H2O-	0.2	--	0.19	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
L.O.I.	0.75	--	--	2.63	6.89	1.24	2.06	1.98	2.86	1.86	2.83	2.16	2.01	2.13	2.34	2.26	1.00	6.6
Total	100.30	100.01	100.49	99.66	99.33	99.80	99.99	99.37	99.47	99.41	99.78	100.42	100.62	100.28	100.86	100.66	101.19	100.30
Ba	--	--	--	184	23	267	674	749	475	361	52	674	143	770	362	295	216	--
Rb	--	12	--	9	1	23	104	55	87	100	10	42	8	48	24	34	35	--
Sr	--	568	--	237	357	413	259	196	334	87	360	358	410	503	203	291	129	--
Nb	--	1.2	--	3.0	3.9	7.4	13.6	13.7	15.2	14.4	3.8	4.3	3.1	6.3	3.7	5.2	11.0	--
Y	--	16	--	18	21	30	43	30	36	24	15	20	14	26	21	18	28	--
Zr	--	88	--	74	84	165	279	288	240	262	93	104	84	189	103	117	223	--
Ni	--	--	--	353	287	85	23	9	11	8	318	344	247	119	202	264	3	--
Co	--	--	--	74	63	55	56	16	20	11	40	48	53	39	43	42	5.2	--
Cr	--	--	--	1262	1242	40	10	4	4	5	510	675	678	22	636	295	2.1	--
Sc	--	--	--	--	--	--	--	--	--	--	18	24	28	19	23	20	6.7	--
V	--	--	--	226	218	232	319	51	19	20	195	237	181	262	247	181	--	--
La	--	--	--	9	9	20	36	51	41	51	7.8	11	13	19	10	10	29	--
Ce	--	--	--	17	27	49	83	97	80	93	20	27	29	47	26	26	58	--
Nd	--	--	--	14	16	32	51	43	37	37	--	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--	--	--	--	2.8	3.6	3.4	5.9	3.5	3.1	4.6	--
Eu	--	--	--	--	--	--	--	--	--	--	0.75	1.00	1.00	1.50	1.00	0.96	0.97	--
Tb	--	--	--	--	--	--	--	--	--	--	0.40	0.50	0.50	0.80	0.52	0.50	0.71	--
Yb	--	--	--	--	--	--	--	--	--	--	1.0	1.4	1.4	1.7	1.3	1.4	2.2	--
Lu	--	--	--	--	--	--	--	--	--	--	0.16	0.22	0.23	0.27	0.2	0.22	0.33	--

Sources of Data

Sample

1 - "Basal Amygdaloid" from Rietpoort, north of Parys [Hall and Molengraaff, 1925, p.24-25].
2 - "Rhenosterhoek lava" [Tankard et al., 1982, Table 4-2, no. 2: cited from H. Va. Eales, pers. comm., 1980; average of 2 analyses].
3 - "Rhyolite" from Dominion Reef system on Gestoptefontein 145 [von Backstrom, 1952, Table III, no. 9].
4 - "Dominion basic lava DB52" from base of Rhenosterhoek Fm., Borehole DSF-10 [Bowen et al., 1986, Table II; T. Bowen, 1984, Fig. 2.2].
5 - "Dominion basic lava DB7" from base of Rhenosterhoek Fm., Borehole DSF-7 [Bowen et al., 1986, Table II; T. Bowen 1984, Fig. 2.2].
6 - "Dominion basic lava DB53" 60 m above DB52, Borehole DSF-10 [Bowen et al., 1986, Table II; T. Bowen, 1984, Fig. 2.2].
7 - "Dominion basic lava DB72" lower Rhenosterhoek Fm., 1200 m below contact with Syferfontein Fm., Borehole DRS-6 [Bowen et al., 1986, Table II; T. Bowen, 1984, Fig. 2.2].
8 - "Dominion porphyry DP37" lower Syferfontein Fm., 90 m above contact with Rheonsterhoek Fm., Borehole DSF-7 [Bowen et al., 1986, Table II; T. Bowen, 1984, Fig. 2.2].
9 - "Dominion porphyry DP48" 240 m above DP37, Borehole DSF-7 [Bowen et al., 1986, Table II; T. Bowen, 1984, Fig. 2.2].
10 - "Dominion porphyry DP276" upper Syferfontein Fm., 670 m above contact with Rhenosterhoek Fm., Borehole DRH-15 [Bowen et al., 1986, Table II; T. Bowen, 1984, Fig. 2.2].
11 - Rhenosterhoek Fm., Borehole BTF, Sample 2d [Crow and Condie, 1987, Table I].
12 - Rhenosterhoek Fm., Borehole BSF, Sample 12 [Crow and Condie, 1987, Table I].
13 - Rhenosterhoek Fm., Borehole BSF, Sample 8 [Crow and Condie, 1987, Table I].
14 - Rhenosterhoek Fm., Borehole BSF, Sample 11 [Crow and Condie, 1987, Table I].
15 - Rhenosterhoek Fm., Borehole BBS, Sample 16 [Crow and Condie, 1987, Table I].
16 - Rhenosterhoek Fm., Borehole BBS, Sample 4 [Crow and Condie, 1987, Table I].
17 - "Felsic porphyry" from Syferfontein Fm., Sample D-4 [Crow and Condie, 1987, Table I].
18 - "WONDERSTONE" from Wonderstone Mine, Mean of three analyses: Nos. A, B, & C [Nel et al., 1937, p. 13].

Barberton greenstone belt), suggested to most early workers that these "platformal" deposits were laid down during the early Proterozic, a time of more stable tectonism compared to the Archaean.

With the recent advent of accurate dating by the single zircon U-Pb technique, reliable ages of many rock units in southern Africa have been pushed back into the Archaean period. Thus, in spite of their "Proterozoic" tectonic style, all three units of the so-called Witwatersrand Triad, the Dominion Group, the Witwatersrand Supergroup, and the Ventersdorp Supergroup, are now assigned to the Archaean if the arbitrary convention of an Archaean/Proterozoic boundary at 2.5 Ga is used (Plumb and James, 1986; also see Master, 1990).

The age of the granitoid basement nonconformably underlying the Dominion was dated at roughly 2.7 to 3.0 Ga (Allsopp, 1964; Hunter, 1974b). In the Vredefort area the Outer Granite Gneiss, nonconformably underlying the Dominion mafic lavas, was dated at 3080 + 20 Ma (Hart et al., 1981). More recent work, yielding more precise dates on zircons, has shown that pre-Dominion granitoids range from as old as 3250 Ma in the Kimberley area (Drennan et al., 1990) to as young as 3096 Ma, for the Westerdam dome (Robb et al., 1991). Two granites in the Dominion type area near Hartbeesfontein have been dated at 3120 Ma (Armstrong et al., in press) and 3174 Ma (Robb et al., 1991).

Early efforts at radiometric dating of the Dominion Group and the Witwatersrand ores included Pb isotopic dating of detrital uraninite (Louw, 1954) and galena in quartz veins from the Dominion reef (Burger et al., 1962; Nicolaysen et al., 1962). Nicolaysen et al., (1962) concluded that the Pb isotopic composition of the galenas indicated that the detrital "parent" uraninites, from which the radiogenic Pb in the vein galena was derived, crystallized about 3100 Ma. This hypothesis was supported by whole rock and monazite dating of Dominion Reef samples and the conclusion reached was that "...the deposition of the Dominion Reef conglomerate took place at some time less than 3100 ± 100 million years ago." (ibid, p. 19). Van Niekerk and Burger (1969) dated two samples of Dominion volcanics overlying the sediments in the area of the Dominion Reef Mine at 2800 + 60 Ma (207Pb/206Pb on leach solutions of sulphide concentrates), recalculated to 2725 + 75 Ma by Cahen et al., 1984).

Recent U-Pb dating of zircon from the Syferfontein Formation has now reliably established the age of the upper Dominion Group at 3074 ± 6 Ma Armstrong et al., 1990, in press). The dated sample, designated DRL-13/B, came from near the top of the formation in borehole DRL-13 (Figure 1). Zircons in the sample are described as follows:

> "Most zircons from this fine-grained quartz-feldspar porphyry are euhedral, with some subhedral grains showing rounded pyramidal terminations. Most show variable interior zoning and clear massive margins. No break between the zoned and the massive zircon is distinguishable, and both appear to have formed in one continuous episode. Colours vary, with the more zoned areas showing deep shades of pink and grey but becoming clearer in the massive outer areas. Radial fracturing is common." (Armstrong et al., in press).

The interpreted age of 3074 ± 6 Ma is based on 5 concordant and 4 discordant analyses.

A sample of basement granitoid was also dated by Armstrong et al. (1990; in press). Sample DRL-7, from borehole DRL-7 (Figure 1), yielded an age of 3120 + 5 Ma, ^{207}Pb/^{206}Pb age on 10 zircon grains. This age is consistent with the field relationships and indicates a maximum age for the lower Dominion Group.

LITHOLOGY AND PETROGRAPHY

Granitoid Basement

The basement underlying the Dominion Group is composed of older granitoid intrusives, which are eroded to an uneven surface and, in places, deeply weathered to chloritic and/or sericitic schists representing palaeosols (Button and Tyler, 1981). Nel (1935) noted that "Granite converted into quartz-sericite schist occurs along the base of the Dominion Reef Series to the south-west of Hartbeesfontein." But thought that "as the formation there had been subjected to both faulting and folding it is probable that this alteration is the result of differential movement along the contact..." (ibid, p. 28). Grandstaff et al. (1986) and Kimberley and Grandstaff (1986) described the mineralogy and chemistry of a palaeosol beneath the Dominion Group, obtained from three boreholes, drilled by Anglo-American Corporation, about 25 km north of Ottosdal. These workers described the stratiform nature of the altered zone, its transitional lower contact into relatively fresh granite, and the progressive increase in alteration toward the contact with Rhenosterspruit Formation, and concluded that it represents a Precambrian palaeosol, albeit, one later modified by metasomatism and metamorphism. Although, "In some areas along the Dominion contact the palaeosol has been sheared and disrupted by bedding-plane faults, ... the degree of shear is slight as the disrupted zones die out laterally on a thin-section scale" (Grandstaff et al., 1986, p. 109). Along with the occurrence of detrital uraninite in the Dominion reefs, the palaeosol composition was taken to indicate a relatively reducing atmosphere in Dominion time, with $_pO_2$ = 0.02% to 0.5% PAL (Present Atmospheric Level) and $_pCO_2$ = 5 to 30 PAL (ibid, 1986, p. 128). Robb and Meyer (1986) recognized palaeosol and palaeoregolith at the contact of granitoid basement and overlying sediments of the Dominion Group or later formations in numerous boreholes on the Rand Anticline in the West Rand area.

Malan (1959) also recognized the possibiltiy that the so-called "black schist" at the contact between the granitoid basement and the Dominion Reef System in the Dominion Reefs Mine and Klerksdorp Consolidated Goldfields Mine "originated from highly deformed felspathic detritus derived, fairly locally, from the granite by processes of physical denudation" (Malan, 1959; p.7). He felt, however, that this type of "black schist" (regolith/palaeosol) was of "local and limited extent, and that in general, (it) can be considered to be a highly sheared granite" (ibid, p.7).

The granitoid basement is poorly exposed to the north and northwest of Dominion outcrops in the type localities near Klerksdorp and Ottosdal. Three structural domes are recognized: the Ventersdorp dome, the Hartbeesfontein dome, and the Ottosdal-Coligny dome. The compositon of these bodies varies from granodiorite to adamellite and they are described as medium to coarse-grained, grey to red coloured, massive to weakly foliated, with abundant pegmatoid bodies. Parts of the domes show extensive alteration and development of unusual mineral assemblages (Robb and Meyer, 1985; 1986; 1990). The age of the granitoid basement is discussed above.

Malan (1959) described the granitoid basement in the area of the Dominion Reefs and Klerksdorp Consolidated Goldfields mines as a light-grey, medium-to-coarse-grained rock, usually equigranular-hypidiomorphic in texture, but occasionally porphyritic, with potassium feldspar phenocrysts up to 15 by 17.5 cm in size. The average mode is 42% potassium feldspar, 35% plagioclase (andesine) and 23% quartz with less than 1% mafic minerals (Malan, 1959; p.6-7).

The Outer Granite Gneiss, underlying the Dominion mafic lavas in the collar of the Vredefort dome, is composed of coarse-grained, relatively homogeneous granite which grades into strongly layered and foliated trondhjemites and granodiorites with increasing distance from the unconformable contact, a change thought to indicate increasing depth in a crustal section by Hart and others (1990a, b, 1991).

Rhenosterspruit Formation

The basal clastic sedimentary unit of the Dominion Group overlies Archaean granitoid basement with erosional nonconformity. It consists of a 20m to 120m thickness of coarse arkosic quartzites, grits, conglomerates, and sericitic schists (Watchorn, 1980, 1981). The best exposures of the unit occur on the farm Oorbietjiesfontein IP292 (south of Hartbeesfontein), where well-sorted pebble conglomerate and arkosic quartzites about 20 m thick, strike 305° and dip 23° SW.

Although all workers have agreed that the contact between the granitoid basement and the overlying clastic sediments of the Rhenosterspruit Formation is an erosional unconformity, and this has recently been substantiated by accurate age dating, the contact itself is gradational, as noted by Malan (1959). The "black schist" comprising the upper few metres of granite is in places difficult to distinguish from the "green schist", a "highly sheared gritty arkose" forming the basal few meteres of the overlying clastic formation (ibid, p. 8-9). This suggests the local derivation of at least the lowermost part of the Rhenosterspruit Formation from the underlying (weathered?) granite, an interpretation that is supported also by the euhedral shape of zircons in the "green schist" (ibid, p. 9).

Two conglomerates near the base of the formation were exploited in the past for economic concentrations of uranium and gold.

Watchorn (1980, p. 3-4) described the reefs as follows:

> "The Lower Reef is a large-pebble conglomerate which non-conformably overlies the greenschist footwall (Plate 1B; Watchorn, 1980). Individual clasts are predominantly rounded vein-quartz, with a mean diameter of 7,5 cm, although occasional cobbles may reach 17,5 cm (Malan, 1959). The conglomerate has a coarse sericitic sandstone matrix and is up to 120 cm in thickness, including occasional thin lenses of sandstone. This conglomerate is primarily auriferous, with only minor and sporadic uranium mineralization (Hiemstra, 1968a).
>
> The Upper Reef in the Rhenosterspruit Formation is generally a small-pebble conglomerate, with a mean thickness of 22,5 cm (Plate 1C; Watchorn, 1980). It is a relatively persistent horizon and is

chiefly a uranium-bearer, with little or no associated gold (Simpson, 1954). The bulk of the mineralization in the Upper Reef is contained in what Malan (1959) refers to as a 2,5 cm "argillaceous band" within which there is a significant concentration of heavy minerals. This lamina is generally developed at the top contact of the Upper Reef and, excluding the heavy-mineral fraction, is composed essentially of chlorite, with occasional biotite flakes and quartz grains and pebbles."

Heimstra (1968a, p. 3) described the "argillaceous band" at the top of the Upper Reef as a "one inch thick" ..."consolidated black sand rich in uranium, gold and heavy minerals", and Liebenberg (1955, p. 115) reported:

"The thin uraniferous band capping the Dominion Reef conglomerate consists of a fine-grained mixture of chlorite, leucoxene, quartz and sericite."

As described by Malan (1959) and Watchorn (1980), the Rhenosterspruit Formation above the reefs at the Dominion Reefs Mine is composed mainly of volcanics (see Watchorn, 1980, fig. 4), with "intercalated tuffs, lavas, and clastics" and "a gradual upward-increase in interbedded volcanic units", the lavas are described as "porphyritic andesites" forming "lensoid bodies with a maximum thickness of 60 m" (Watchorn, 1980, p. 4).

Heimstra (1968a, b) made detailed studies of the petrography and geochemistry of the uraniferous Dominion Reef (Upper Reef conglomerate). He demonstrated the well rounded form of uraninite and its hydraulic equivalence with monazite and zircon, supporting a detrital placer origin in concert with the views of Liebenberg (1955). On the other hand, gold in the Dominion reefs was found to occur "typically as extremely irregular hackly grains" (Heimstra, 1968a, p. 18) and, like the Witswatersrand reefs, was considered to be "mainly authigenic in its present form" (Liebenberg, 1955). Other detrital heavy minerals found in the matrix of the quartz pebble conglomerate are: garnet, chromite, zircon, ilmenite, cassiterite and monazite (Liebenberg, 1955). Malan (1959) and Watchorn (1980) called attention to the significantly different heavy-mineral populations of the Upper and Lower Reefs.

"The Lower Reef is characterized by a concentration of gold, leucoxene, zircon, and, occasionally, uraninite, whereas the mineralogy of the Upper Reef is far more diverse. It contains appreciable uraninite, monazite, and zircon, intermediate amounts of cassiterite, pyrite and arsenopyrite, and garnet, and generally low gold contents." (Watchorn, 1980, p. 6).

Watchorn (1980) attributed this mineralogical variation to different source areas for the two placer deposits, speculating "that the Lower Reef was derived from an essentially granitic hinterland, whereas the (more diverse) mineralogy of the Upper Reef suggests that it is the product of a complex granite-greenstone terrane with associated sediments and pegmatites". He attributed this change "to a tectonically-controlled switch in the provenance-area".

Other than the detailed mineralogical work described above, there have been few sedimentological studies made on the Rhenosterspruit Formation. Limited palaeocurrent data were provided by Watchorn (1980,

1981) who measured the orientation of 14 trough cross-beds on the farm Oorbietjiesfontein IP292 (south of Hartbeesfontein). He interpreted these as indicating a unimodal, westerly direction of progradation, in a "braided fluvial regime"; and found a north-south alignment of the long axes of 42 elongate pebbles and cobbles in the Lower Reef (same location), deposited by vertical accretion within the major channels of the fluvial system, by rolling along the channel floor with their long axes perpendicular to the mean (westerly) flow direction. On the other hand, previous workers had generally considered the provenance area to be to the north or northwest, similar to that assumed for the Witwatersrand Basin (Malan, 1959, p. 69).

Rhenosterhoek Formation

The volcanic formation overlying the basal clastic sediments is composed mainly of mafic, amygdaloidal lavas, with a few interbeds of tuffs and felsic porphyry. The formation is best exposed in scattered outcrops between Klerksdorp and Ventersdorp, and in the north, northwest and west parts of the collar of the Vredefort dome. It consists of homogeneous, fine-grained, aphyric lava usually containing abundant amygdales filled with quartz ± calcite ± chlorite ± pyrite. The filled voids are generally sub-spherical to irregular in shape and 2-10 mm in diameter, forming 10-20% of the rock. Locally, amygdales may constitute up to 80 volume percent and large, elongate, irregular pods of quartz may reach 5 cm X 20 cm in size.

The petrography of Rhenosterhoek volcanics was described by Crow and Condie (1987, p. 219) as "composed chiefly of varying proportions of sodic plagioclase, chlorite, tremolite-actinolite, carbonate, and epidote with traces of quartz, sphene, magnetite and clinozoisite" with a few samples containing relic plagioclase phenocrysts.

Bowen et al. (1986) described samples from seven boreholes intersecting the Rhenosterhoek Formation in the Klerksdorp area as comprising "basic to intermediate lavas intercalated with occasional sedimentary horizons and flows of porphyritic silicic volcanics". They found that "original igneous textures are generally well preserved", most of the lavas being "aphanitic fine-grained to microcrystalline, with intersertal to hyalopilitic fabrics", but "metamorphic mineralogy is that of the greenschist facies". Some of the lavas are sparsely porphyritic and "the more basic lavas can generally be recognized by fine grain size and the presence of a high proportion of tremolite-actinolite" while more silicic lavas are "coarser grained and contain relic skeletal mafic minerals" (ibid, p. 301). Marsh et al. (1989, p. 41) noted that amphibole is less abundant in the evolved mafic lavas and is pleochroic, and that: "Rare phyric lavas generally have evolved chemical compositions and the sparsely distributed phenocryst phase is plagioclase."

Syferfontein Formation

The uppermost formation of the Dominion Group is generally described as consisting mainly of massive quartz-feldspar porphyry with only local breccia textures, amygdaloidal or spheroidal structures, and flow banding, along with minor intercalations of mafic to intermediate lavas and tuffs. The best exposures of this unit are on the farm Syferfontein 303 IP about 35 km west of Klerksdorp and many similar outcrops occur intermittently along strike to the northwest towards Ventersdorp (Figure 1). Similar felsic porphyries are widespread in the Ottosdal area, but here the rocks are ubiquitously altered and silicified. Volcaniclastic sedimentary units now converted to "Wonderstone" are a significant component of the upper Syferfontein Formation in the Ottosdal area (Figure 2).

The boreholes studied by the Bowens and co-workers were mostly collared within the Syferfontein Formation [except hole DRS-6 (see Bowen et al., 1986, fig. 2)]; therefore they were generally able to sample only the middle to lower portions of the formation, up to 660 m out of a maximum known thickness of 1500 m (ibid, p. 301). They described typical samples of the numerous thick quartz-feldspar porphyry units (which may represent lava flows or densely welded pyroclastic flows) as follows:

> "Phenocrysts make up 5-10% of the rock and consist of euhedral alkali feldspar and oligoclase, anhedral quartz and, in some specimens, Fe-Ti oxides, either singly or in glomeroporphyritic aggregates. Plagioclase phenocrysts are frequently fritted and those of quartz are rounded and embayed. Both plagioclase and alkali feldspar phenocrysts are extensively altered to secondary calcite or sericite. The groundmass varies from microfelsitic to spherulitic and comprises alkali feldspar, quartz, chlorite, epidote, actinolite, stilpnomelane, sphene and clacite, the mafic minerals all being of secondary origin." (Bowen et al., 1986, p. 302).

Oligoclase is the dominant phenocryst phase and the alkali feldspar phenocrysts are microperthite, according to Marsh et al. (1989, p.41). In non-spherulitic samples the groundmass is described as coarser grained with an "allotriomorphic assemblage of quartz and feldspar with minor chlorite, epidote, amphibole and sphene" (ibid, p.41).

Whereas, the amygdaloidal mafic lavas of the Rhenosterhoek Formation cannot be readily distinguished from similar rocks in the Ventersdorp Supergroup macroscopically or petrographically, the Syferfontein porphyries can generally be distinguished from the quartz-feldspar porphyries of the Makwassie Formation (upper Ventersdorp Supergroup) by the more highly porphyritic nature and more abundant and obvious quartz phenocrysts in the latter (Bowen et al., 1986). Furthermore, Bowen et al. (1986) demonstrated that distinct chemical compositions, especially the contents of certain immobile trace elements, characterize volcanics of the Dominion Group and Ventersdorp Supergroup, as discussed in the following section.

GEOCHEMISTRY

Sediments

Heimstra (1968b) presented data on the trace element composition (Ag, As, Co, Cr, Cu, Fe, Mo, Ni, Ti, Pr, Pt, Sn, Zn, La, Ce, Nb, Nd, Y, Zr, as well as Au and U) of the Upper Reef in the Dominion Reefs Mine. He found "high degrees of correlation...between elements present in detrital minerals and uranium"; but, a "relatively low degree of correlation... between gold and uranium", and concluded that these data were best explained by "sedimentary concentration of heavy minerals and the subsequent limited redistribution of gold" (Heimstra, 1968b, p. 67).

Mafic Lavas

The two volcanic formations overlying the Rhenosterspruit clastic sediments were considered to be mainly composed of "basaltic andesite and tuff" overlain by "acid lava, with subordinate layers of tuff, andesitic lava, volcanic breccia and quartz-feldspar porphyry" by Tankard et al. (1982, p. 119). Burke et al. (1986) thought that the position of the Dominion Group above a weathered granitoid basement, representing continental crust, and the "andesitic-rhyolitic nature of the Dominion lavas" indicated that they "possess strong affinities to Andean arc-type rocks, and that they are unlike the volcanic rocks deposited in either island-arc or continental-rift settings" (Burke et al., 1986, p. 446). However, their conclusions were based on a limited number of geochemical analyses of Dominion lavas [e.g. only five chemical analyses of the Dominion Group had been published before 1979 (Bowen et al.,1986; p. 298)]; later workers have come to slightly different conclusions as to the tectonic setting of Dominion Group volcanism. A more extensive geochemical data base has recently been provided by the work of Crow and Condie (1987), M. Bowen (1984), T. Bowen (1984), Bowen et al. (1986) and Marsh et al. (1989).

Crow and Condie (1987) reported major and trace element analyses of 17 samples of Rhenosterhoek Formation lavas from three boreholes, drilled by Anglo American Corporation, between Klerksdorp and Ventersdorp (locations shown in Figure 1). They concluded "that the volcanics are basaltic andesites and andesites with calc-alkaline affinities" and "incompatible trace-element distributions are similar to those of modern andesites from evolved island arcs or continental-margin arcs" (ibid, p. 217). Although they only analysed one sample of the upper felsic Syferfontein Formation they recognized that the Dominion Group is a bimodal volcanic assemblage but "with the mafic end member represented chiefly by andesites rather than by basalts" (ibid, p. 226). This compositional bimodality is "atypical of Andean arcs" as is the sparsity of pyroclastic rocks, arguing against the tectonic model of Burke et al. (1986). Crow and Condie (1987) called attention to "the relatively restricted geographic distribution of the Dominion Group" and suggested it "may have formed during the incipient stages of development of...a foreland basin" in which the overlying Witwatersrand Supergroup was subsequently deposited. Selected geochemical analyses of Rhenosterhoek Formation samples from Tankard et al. (1982), Crow and Condie (1987), and others are shown in Table 1.

The most extensive and detailed petrological work to date, on the volcanic units of the Dominion Group, is that done by M. Bowen (1984) and T. Bowen (1984) and colleagues, reported in Bowen et al. (1986) and Marsh et al. (1989). In a pair of M.Sc. theses, the Bowens made detailed studies of 17 boreholes drilled by Anglo American Prospecting Services west and south of Klerksdorp. Seven boreholes intersected Dominion Group stratigraphy [these boreholes were located about 20 to 60 km southwest of the ones sampled by Crow and Condie (1987), see Figure 1], and six of these went through the entire Rhenosterhoek and Rhenosterspruit Formations into the underlying granitoid basement.

Analytical data on selected samples of mafic lavas ("basic lavas") and felsic volcanics ("acid porphyries") from the Dominion Group reported by Bowen et al. (1986, Table 2) and Marsh et al. (1989) are shown in Table 1. These data show that the Dominion Group volcanics in the Klerksdorp area are subalkaline (Figure 3); dominantly a low-alkali tholeiitic

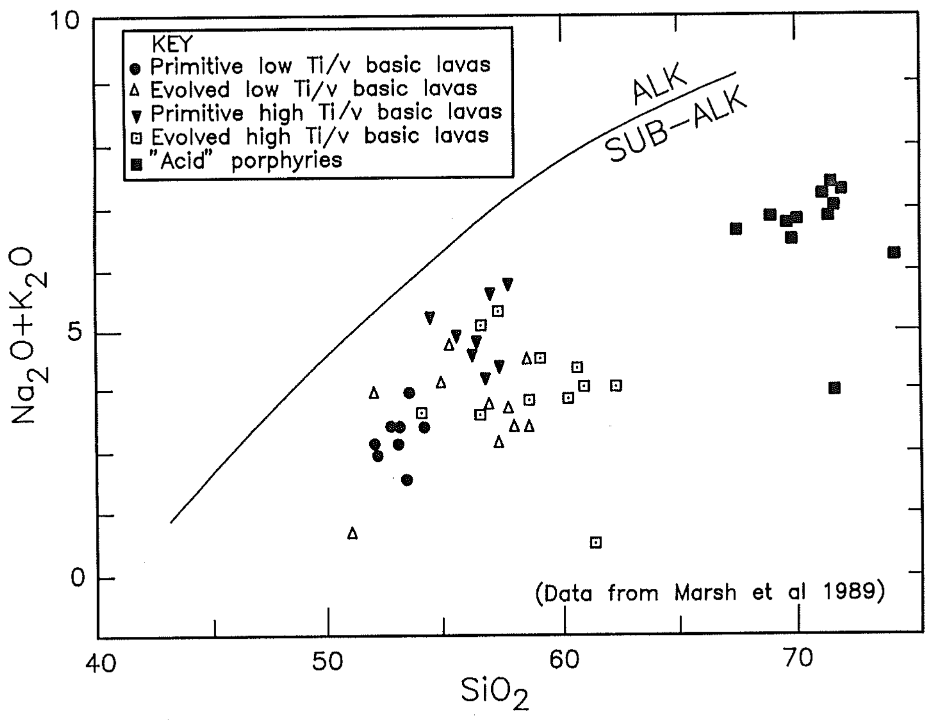

Figure 3: Total alkalies (Na_2O +K_2O) versus SiO_2 diagram with dividing line between alkaline and sub-alkaline series after Irvine and Baragar (1971). Data for Dominion Group volcanics from Marsh et al. (1989) plotted.

sequence ranging from basalt to rhyolite. The sequence is bimodal in terms of SiO_2 content with modes at about 56% and 70% for the mafic and felsic volcanics, respectively (Bowen et al., 1986, fig. 4). Marsh et al. (1989) divided the mafic lavas into four types based on their Ti/V ratios and degree of fractionation: (1) primitive low Ti/V, (2) evolved low Ti/V, (3) primitive high Ti/V, and (4) evolved high Ti/V.

On AFM (Figure 4) and FeO total/MgO vs. SiO_2 (Figure 5) diagrams the tholeiitic nature of the evolved mafic lavas and the felsics is demonstrated by their iron-enrichment trends. However, most of the primitive lavas of both low and high Ti/V types plot in the calc-alkaline field on Figure 5 and the primitive high Ti/V lavas plot in the calc-alkaline field on Figure 4. The significance of this is difficult to evaluate since alteration has undoubtedly affected major element chemistry, especially silica and alkali contents. Thus, the apparent calc-alkaline nature of the primitive mafic lavas may be due to a relative increase in SiO_2 and alkali contents due to alteration. The overall trend of iron enrichment with increasing SiO_2 apparent in Figure 5 and the increase in TiO_2 with increasing FeO* (Figure 6) in the mafic lavas are characteristic of a tholeiitic series.

In Figure 7 the content of selected "immobile" elements (those generally agreed to be unchanged by low temperature metamorphic and alteration processes) are plotted for selected samples of Dominion Group mafic lavas (data from Marsh et al., 1989). The elements are normalized to contents in "primitive mantle" and arranged in order of increasing compatibility with "oceanic basalt" from left to right (Hofmann, 1988). This "spider diagram" reveals the general level of incompatible element enrichment in the four mafic lava types identified by Marsh et al. (1989).

TABLE 2. Selected, Representative Chemical Analyses of Nsuze Group Volcanics (data from Armstrong et al., 1986, Tables IIA, IIB, IIC, IID & III)

Sample	MS36	WR9	WR1	AS24	WR12	OS39	HKS31	PKB18	WR13	OS43	WR16	WR11
Rock Type	Basalt	Basalt	Basalt	Bas-And	Bas-And	Andesite	Andesite	Dacite	Dacite	Rhyolite	Rhyolite	Rhyolite
SiO_2	54.8	53.7	52.2	54.9	57.3	64.8	62.2	67.9	66.9	75.2	71.7	73.1
TiO_2	0.57	0.63	1.09	0.97	0.70	0.96	1.00	0.84	0.70	0.39	0.60	0.49
Al_2O_3	12.8	15.2	15.3	14.7	16.6	13.7	14.0	12.6	13.6	12.9	12.1	11.5
Fe_2O_3*	10.7	11.6	13.2	10.8	14.2	7.6	11.7	8.4	8.0	4.1	6.4	6.2
MnO	0.32	0.28	0.26	0.22	0.36	0.60	0.41	0.21	0.10	0.09	0.14	0.09
MgO	8.3	7.3	4.8	6.0	3.4	1.2	1.4	1.2	1.1	0.22	0.29	0.19
CaO	9.5	8.0	9.3	8.5	3.8	6.2	5.1	2.9	3.8	0.86	1.5	1.5
Na_2O	2.7	2.7	3.0	2.6	2.4	2.1	2.1	2.8	1.6	0.93	2.9	2.3
K_2O	0.19	0.46	0.79	1.1	1.0	2.5	1.8	3.0	3.9	5.2	4.1	4.4
P_2O_5	0.11	0.14	0.09	0.21	0.16	0.25	0.26	0.18	0.15	0.05	0.19	0.11
Total	100	100	100	100	100	100	100	100	100	100	100	100
L.O.I.	1.9	2.2	1.6	1.9	4.2	5.8	5.2	2.2	2.2	1.9	1.6	0.7
MG#	62.2	57.0	43.2	55.3	35.4	27.3	22.3	26.2	25.5	12.2	10.6	7.3
Fe_2O_3*/MgO	1.3	1.6	2.8	1.8	4.2	6.3	8.4	7.0	7.3	18.6	22.1	32.6
CaO/Al_2O_3	16.7	12.7	8.5	8.8	5.4	6.5	5.1	3.5	5.4	2.2	2.5	3.1
Na_2O/K_2O	14.2	5.9	3.8	2.4	2.4	0.8	1.2	0.9	0.4	0.2	0.7	0.5
Ba	11	94	132	239	232	408	275	309	404	938	606	455
Rb	3.7	9	25	43	22	86	53	112	131	196	132	131
Sr	115	250	403	198	296	157	247	221	147	80	159	93
Nb	2.7	4.1	3.6	10	6	11	9	14	21	34	26	13
Y	17	17	19	37	24	31	28	38	53	86	59	37
Zr	78	88	83	175	143	230	166	247	332	532	430	268
Ni	151	116	93	63	14	7	13	12	13	8	9	8
Cr	--	558	144	44	35	10	40	10	8	--	7	8
V	--	213	182	204	207	136	148	105	109	2	20	7
Ce	21.8	26.8	--	50.6	43.1	93.0	69.8	91.6	56.7	180.0	116.8	105.1
Nd	11.4	13.5	--	23.5	20.3	37.4	28.9	36.3	26.9	71.8	46.6	40.4
Sm	2.74	3.16	--	5.07	4.22	7.1	6.1	6.9	5.83	14.9	9.1	7.6
Gd	3.19	3.41	--	5.37	4.30	6.5	5.32	6.3	6.2	14.8	8.3	6.8
Yb	1.56	1.66	--	3.32	1.73	2.99	2.58	3.22	4.06	8.9	4.82	3.53

MG# - Magnesium Number (=100Mg2+/Mg2++Fe2+)
REEs in ppm analysed by stable isotope dilution technique.

The two primitive low Ti/V (group 1) samples are very similar with low incompatible element contents and large negative Nb anomalies and small negative Zr anomalies. The evolved low Ti/V (group 2) and primitive high Ti/V (group 3) samples are similar at higher incompatible element contents, and the evolved high Ti/V (group 4) sample shows the most differentiated spidergram with the highest incompatible element content. All mafic lava samples plotted in Figure 7 have broadly parallel spidergrams with

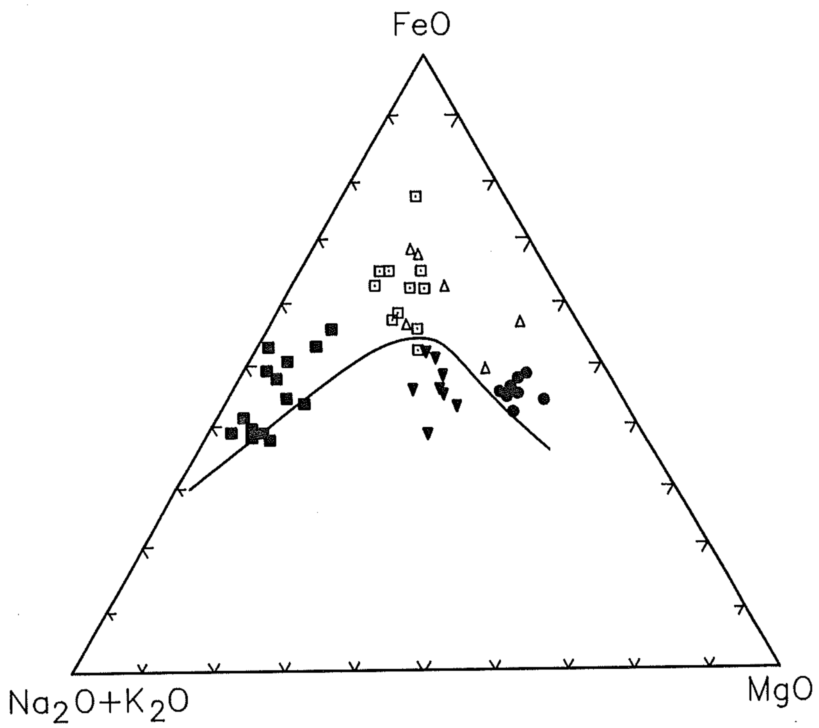

Figure 4: AFM diagram; A = Na_2O+K_2O, F = total Fe, M = MgO, with dividing line between alkaline and sub-alkaline series after Irvine and Baragar (1971). Data for Dominion Group volcanics from Marsh et al. (1989) plotted.

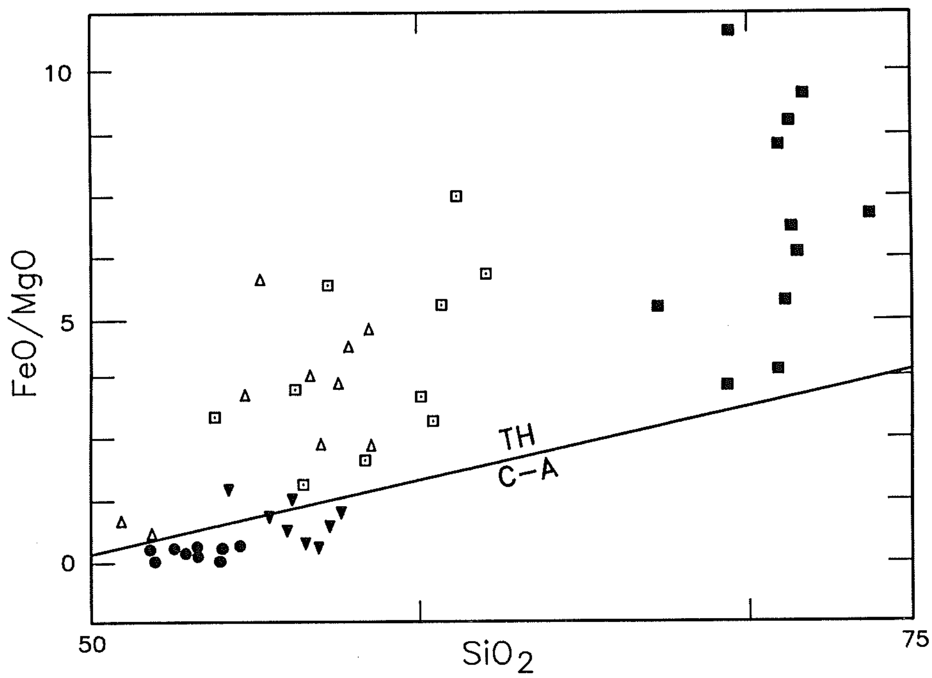

Figure 5: FeO/MgO versus SiO_2 diagram (FeO* = total Fe as FeO) with dividing line between tholeiitic (Th) and calc-alkaline (C-A) series after Miyashiro (1974). Data for Dominion Group volcanics from Marsh et al. (1989) plotted.*

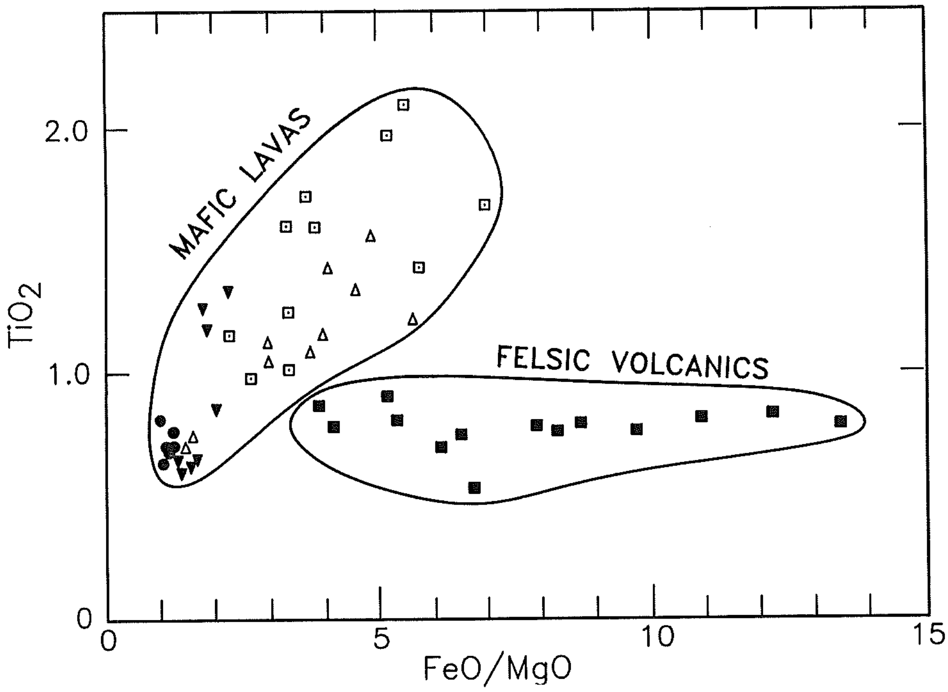

Figure 6: *TiO_2 versus FeO*/MgO diagram. Data for Dominion Group volcanics from Marsh et al. (1989) plotted. Note the lack of TiO_2 enrichment with increasing FeO*/MgO in the felsic volcanics in contrast to the trend of the mafic lavas.*

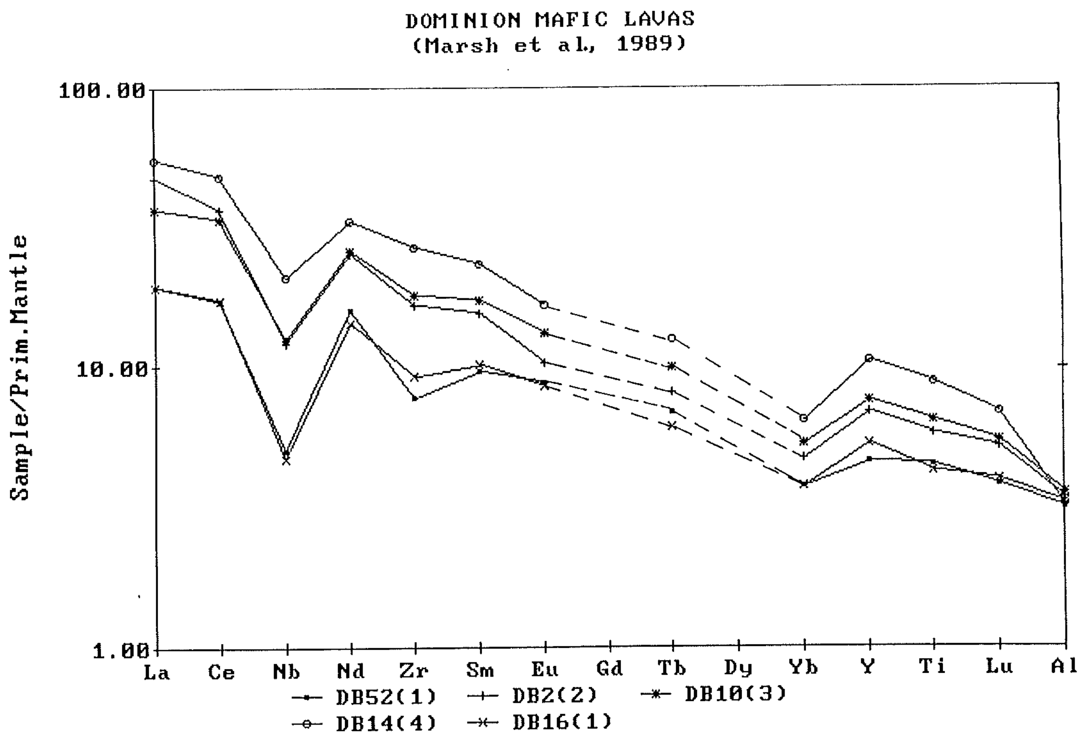

Figure 7: *Spider diagram for Dominion Group mafic lavas. Trace elements normalized to "primitive mantle" values of Hofmann (1989) arranged in order of increasing compatibility with "oceanic basalt" from left to right along the x axis. Data for typical primitive (1) and evolved (2) low Ti/V, and primitive (3) and evolved (4) high Ti/V mafic lava types from Marsh et al. (1989).*

Nb anomalies. This is consistent with progressive differentiation, either by fractional crystallization or decreasing degrees of partial melting, from the most primitive (group 1) to most evolved (group 4) sample. However, other geochemical evidence suggests that low Ti/V and high Ti/V series evolved along separate fractionation paths (Marsh et al., 1989).

The contents of certain immobile trace elements were found to be diagnostic characteristics of Dominion volcanics by Bowen et al. (1986) and allowed discrimination from samples of Ventersdorp and other Witwatersrand Triad lavas. Specifically, Dominion mafic lavas were found to plot in a distinct field on a Zr/P vs. P/Ti diagram (Figure 8): generally having lower Zr/P at slightly higher or equivalent P/Ti, compared to the lower Klipriviersberg and Allanridge Formations of the Ventersdorp Supergroup; and lower P/Ti at equivalent Zr/Ti, compared to the upper Rietgat and Goedgenoeg Formations of the Ventersdorp Supergroup and the Crown Lava of the Witwatersrand Supergroup (Bowen et al., 1986, fig. 11). The higher Zr contents of the felsic volcanics places them in a distinct field above the mafic lavas (Figure 8). The mafic lavas plot in a broad field reflecting a range in P/Ti for the low and high Ti/V types. It should be noted that although the majority of mafic lavas reported by Marsh et al., (1989) and Crow and Condie (1987) plot in the field for Dominion mafic lavas defined by Bowen et al. (1986) on Figure 8, this field is gradational with the lower Ventersdorp lavas. Several Dominion Group mafic lavas thus plot on the boundaries of the fields defined for the Klipriviersberg and Allanridge Formations and four samples (two from Marsh et al., 1989, and two from Crow and Condie, 1987) actually plot in the Klipriviersberg field.

In a more detailed study of the trace element geochemistry of the same Klerksdorp area borehole samples discussed by Bowen et al. (1986), Marsh et al. (1989) speculated on the petrogenesis of the Dominion volcanics. They explained compositional variation within both low and high Ti/V mafic lava groups by processes of low-pressure fractional crystallization of typical tholeiitic mineral phases. They found a large

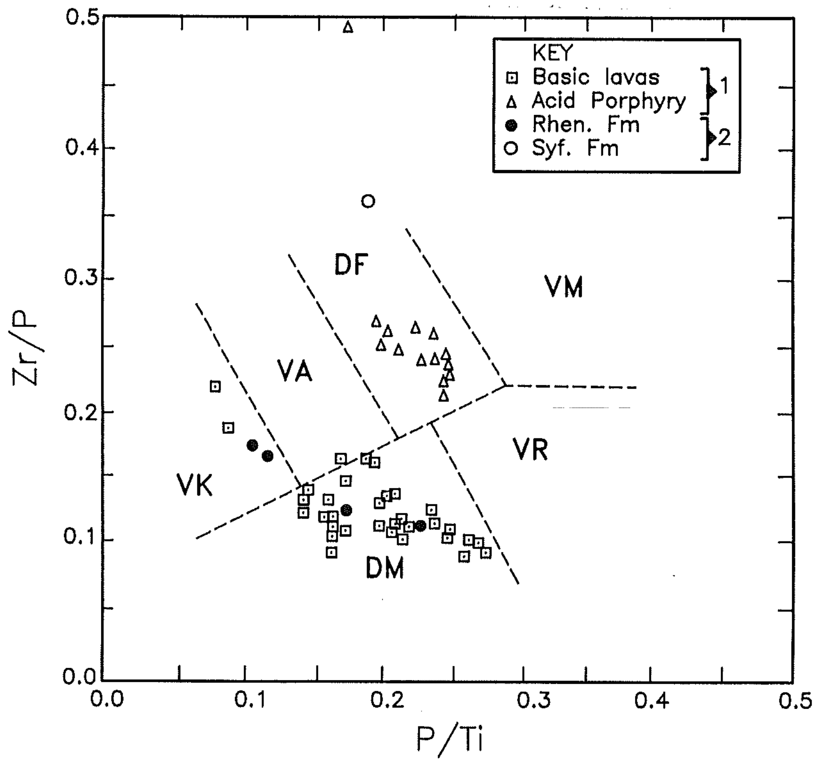

Figure 8: Zr/P versus P/Ti diagram used by Bowen et al. (1986) to discriminate the Dominion Group volcanics from those of the Ventersdorp and Witwatersrand Supergroups. Data for Dominion Group volcanics from Marsh et al. (1989) and Crow and Condie (1987) plotted.

compositional range among the most primitive (Mg-rich) basalts of the low Ti/V group and a lack of correlation between Mg/Fe ratio (magnesium number) and "incompatible" trace element contents (elements not readily incorporated in mafic minerals, such as Zr and Ce). The basalts are enriched in the light rare earth elements (LREE), with respect to chondritic abundances, and have low to negative epsilon Nd isotopic values (i.e. initial $^{143}Nd/^{144}Nd$ ratios which are chondritic or less than chondritic).

Marsh et al. (1989) favoured a petrogenetic model involving enrichment of the mantle source in incompatible trace elements. They suggested that heterogeneity and incompatible-element enrichment of the Dominion mantle source may have been a result of subduction tectonics, but stated that the composition of the Dominion lavas is not typical of Andean-type arc volcanics (as advocated by Burke et al., 1986); this apparent contradiction is explained by appealing to an ancient subduction event for the mantle enrichment while assuming that the lavas may have been erupted in a continental rift zone (in concert with Bickle and Eriksson, 1982). However, this model is based on the old age of 2725 Ma for the Dominion lavas, and the more reliable new age of 3074 Ma would require a contemporaneous subduction mechanism according to their isotopic model (J.S. Marsh, pers. comm., 1991).

Felsic Volcanics

Bowen et al. (1986) showed that the felsic volcanics ("acid porphyries") of the Dominion Group could be discriminated from those of the Ventersdorp Supergroup (Makwassie Formation) and the Crown Lava Formation on the basis of Ti, Al, Mg, P, V, Y and Zr contents. On Figure 8, the Dominion felsites occupy a field at high Zr/P, with lower P/Ti than the Makwassie porphyries but about the same P/Ti as the Dominion mafic lavas.

The felsic volcanics are rhyodacites to low-Si rhyolites with mean SiO_2 contents of 70.33 wt. % (Marsh et al., 1989, p. 50). Their compositions plot near the 1-2 kb piercing points in the An-Or-Q-H_2O system (granite minima), suggesting multiple saturation with two feldspars and quartz (ibid., Fig. 9). Although the felsites show continuity with the mafic lavas on some variation diagrams, several factors argue against direct fractional crystallization of a similar mafic parent: (1) the silica gap; (2) the low P, Zr, Ti, Y, middle and heavy REE, but similar LREE and Nb in the felsites compared to evolved mafic lavas; and, (3) the lower $^{143}Nd/^{144}Nd$ in the felsites (ibid., p. 59). For example, on a plot of TiO_2 vs. FeO total/MgO (Figure 6) the mafic lavas show a fractionation trend of increasing TiO_2 with increasing FeOtotal/MgO, whereas the felsites plot in a distinct field showing increasing FeOtotal/MgO at constant TiO_2.

The best petrogenetic model for the origin of the felsic volcanics probably involves partial melting of crustal sources. However, Marsh et al. (1989) were unable to identify a source of suitable composition to satisfy all compositional parameters, and, due to a lack of information on the proximal palaeolithosphere, they concluded that "detailed modelling of partial melting processes (is) unjustified" (ibid., p.60).

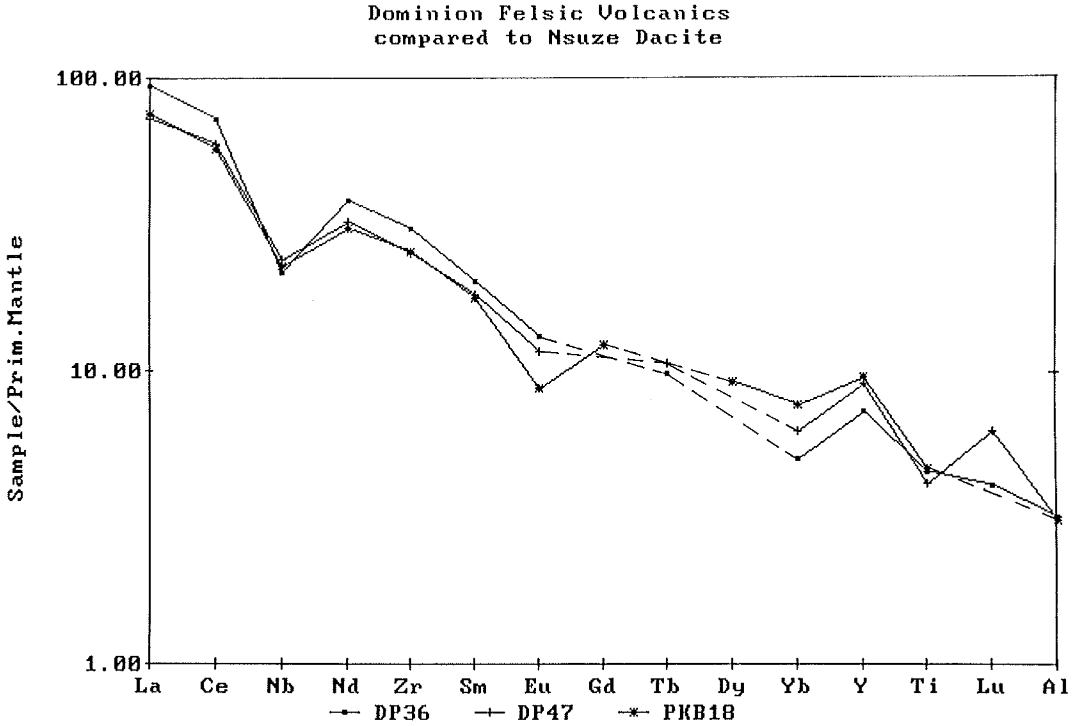

Figure 9: Spider diagram showing Dominion Group felsic volcanics (samples DP36 and DP47; Marsh et al., 1989) compared to an Nsuze dacite sample of similar SiO_2 content (sample PKB 18; Armstrong et al., 1986). Trace elements normalized as in Figure 7.

POSSIBLE CORRELATIVES

In addition to its relatively well-defined occurrences in locations in the southwestern Transvaal and western Orange Free State, where its stratigraphic position can be readily ascertained [i.e. above granitoid basement and below the lower Witswatersrand (Orange Grove Quartzite Formation, West Rand Group) sequence], possible correlatives of the Dominion Group have been identified by various workers, at widely separated localities on the Kaapvaal Craton, on the basis of lithologic/stratigraphic similarities and/or near equivalent radiometric ages. These include the Nsuze Group of the Pongola Supergroup in Swaziland and Natal in the southeastern part of the Kaapvaal Craton, the Kanye Volcanic Group of the west-central Transvaal, and the Zoetlief Group in the western Transvaal and northern Cape provinces (see below). In addition, certain sedimentary or volcanic sequences of uncertain stratigraphic or structural setting have been postulated as belonging to the Dominion Group.

One such problematical unit is the Vaalrand quartzite succession which occurs near Balfour in the southeastern Transvaal. Outcropping poorly in a structurally complex area, this 550 m thick sequence of quartzites and conglomerates has posed correlation difficulties for many years because it is unlike the distal facies of the West Rand Group generally found in this area. Some workers have speculated that it is equivalent to the Moodies Group of the Swaziland Sequence. Anhaeusser (1990) reviewed the Vaalrand problem and concluded that this succession more closely resembled arenaceous sediments found in the Dominion Group or Pongola Supergroup than the more immature clastics of the Moodies Group, but that it most likely comprises: "...Witwatersrand lithologies tectonically disrupted and steepened within the area of influence of major faults...".

Nsuze Volcanics

The Pongola Supergroup in northern Natal, southeastern Transvaal, and Swaziland, comprises the lower volcanics of the Nsuze (formerly Insuzi) Group and the overlying sediments of the Mozaan Group which may have been deposited in an Archaean continental rift zone (Burke et al., 1985). A sedimentary sequence about 800 m thick at the base of the Nsuze Group, including conglomerate, arenites and volcaniclastics (Watchorn and Armstrong, 1980), rests unconformably on granitoid basement recently dated at 3028(± 14) Ma by the Rb/Sr whole-rock method (Barton et al., 1983). This is overlain by a middle volcanic and volcaniclastic unit and an upper sedimentary and volcaniclastic unit, for a total maximum thickness for the Nsuze Group of about 8 km (Weilers, 1990).

Early age dating suggested that the Pongola Supergroup was older than the Witwatersrand Triad, e.g. 3083(± 150) Ma by Rb-Sr whole-rock method (Burger and Coertze, 1973) and 3030(± 90) Ma by U-Pb on zircons (recalculated from Burger and Coertze, 1973, by Burke et al., 1985). However, recent, more precise, U-Pb dating on zircons from felsic volcanics of the Nsuze Group gave an age of 2940(± 22) Ma (Hegner et al., 1984). A minimum age of the Pongola Supergroup is given by a date of 2871(± 30) Ma on the cross-cutting Usushwana Intrusive Suite (Hegner et al., 1984).

The similar stratigraphic sequence of the Nsuze and Dominion Groups (i.e. clastic sediments overlain by mafic-felsic volcanics) led to speculation that these two groups were correlatives. The Nsuze, like the Dominion, unconformably overlies granitoid basement and is overlain by arenaceous sediments which are slightly mineralized. The sedimentary Mozaan Group has thus been considered by some to be a correlative of the Witwatersrand Supergroup (e.g. Beukes and Cairncross, 1991), although its lesser thickness (maximum about 5 km) and lack of economic gold deposits would make it a poor cousin at best.

Weilers (1990), in a review of the Pongola Supergroup, concluded that the new age data preclude a direct correlation of the Nsuze and Dominion Groups and that the Mozaan Group is similar in age to the lower Witwwatersrand (West Rand Group) but older than the upper Witwatersrand (Central Rand Group).

The geochemistry of the Nsuze Group has been discussed by Armstrong et al. (1982), Burke et al. (1985), Groenewald (1985), Armstrong et al. (1986), and Preston (1987), and was summarized by Weilers (1990). Burke et al. (1985) emphasized the bimodal nature of Nsuze volcanism in a continental setting to propose deposition in a continental rift zone. Armstrong et al. (1982, 1986) showed that the lavas are a subaerial tholeiitic sequence erupted in a continental setting with compositions ranging from basalt through rhyolite. Preston (1987) and Weilers (1990) felt that alteration and possible unique Archaean tectonic conditions made petrotectonic classification of the Nsuze volcanics a futile exercise.

Some selected, representative chemical data on Nsuze Group volcanics are shown in Table 2 and mean compositions of mafic and felsic volcanics are compared to Dominion Group data in Table 4.

Although present dating indicates a somewhat younger age for the Nsuze Group, the similar stratigraphic sequence and setting, and the correlation of the overlying clastic sediments of the Mozaan Group with the West Rand Group, suggests that the Nsuze represents the best of the several potential candidates for a Dominion Group correlative. The chemistry of the Nsuze Group is very similar to the Dominion volcanics (Table 4), especially in the contents of the immobile incompatible trace elements (Figure 9).

Kanye Volcanics

The Kanye volcanics are a sequence of felsic igneous rocks which occur beneath the Lobatse Volcanic Group in southeastern Botswana and the west-central Transvaal, South Africa. They have also been called the Kanye Volcanic Formation (Mortimer, 1984, Aldiss et al.,1989) or the Kanye Volcanic Group (Crockett, 1971a, 1972; Tyler, 1978, 1979a, b). The Lobatse Group is generally correlated with the Ventersdorp Supergroup (Tyler, 1979b) and thus the older Kanye volcanics have been considered by some early workers to correlate with the felsic volcanics of the Dominion Group. The Kanye volcanics are presently thought by some workers to be intruded by the Gabarone Granite Complex to the north. However, the contact relations are indistinct and gradational, and the massive nature of the Kanye felsites, has led others to consider them to be a contact phase of the granite or an extrusive equivalent (Wright, 1961; Key and Wright, 1982; Key, 1983). Wright (1961) did not recognize a distinction between the Kanye volcanics and the Lobatse Volcanic Group.

Poldevaart (1952) considered the Gabarone granite to be intrusive into the Kanye volcanics, with the resulting development of a contact zone of variably migmatized and recrystallized felsites. Crockett (1969) felt that this contact metamorphism had recrystallized the entire thickness of Kanye volcanics. Key and Wright (1982) and Key (1983), however, considered the Kanye volcanics to be "The outer felsites represent(ing) quenched primary magma..." of the same magmatic event which produced the Gabarones granite, and therefore, "the entire sequence from rapakivi granite to massive felsites (are) the differentiated products of a single high-level intrusive magmatic body" (Key and Wright, 1982, p. 109).

Rb/Sr whole-rock ages on the Kanye volcanics range from 3421(± 150) Ma to less than 2000 Ma (Key, 1976, cited in Tyler, 1979a, Table 1). Harding et al. (1974, cited in Key and Wright, 1982) considered the older (approx. 3000 Ma) ages to be more reliable, the younger dates reflecting thermal resetting of the Rb/Sr system during later metamorphic events as has been widely demonstrated elsewhere in the Kaapvaal Craton (Button et al.,1981). This older age for the volcanics supports the intrusive model for the granite proposed by Poldevaart and Crockett.

For the Gabarone Granite Complex, Rb/Sr whole-rock and isochron ages, as well as K/Ar mineral age data, span a similar range of more than 1000 Ma (Sibiya, 1988, fig. 8a). A more reliable U-Pb zircon age of 2830(± 10) Ma was recently obtained on a single zircon from one phase of the Gabarone Complex in Botswana, but it is possible that the numerous phases of the complex span a wide age range (Sibiya, 1988).

Tyler (1978, 1979a) considered the Gabarone Granite Complex in South Africa to be intrusive into the Kanye Volcanic Group on the basis of apparent contact metamorphism of the latter and observations of felsic (Kanye) xenoliths within the granite (Crockett, 1971b). He suggested that the restriction of the Kanye felsite, along with the Ventersdorp Supergroup in this area, to the boundaries of the Swartruggens graben, indicated that it "constitutes a proto-basinal phase of the development of the Ventersdorp Supergroup" (Tyler, 1979a).

Major-element chemical analyses of Kanye volcanic samples reported by Tyler (1979a, Table 3) are similar to the composition of Dominion Group Syferfontein Formation felsics in terms of SiO_2 content, they are both mainly low-silica rhyolites with an average of about 72 wt.% SiO_2. However, Kanye felsites have much lower TiO_2, Fe_2O_3*, MgO and P_2O_5, as well as Loss on Ignition contents, and higher contents of Al_2O_3, CaO, Na_2O and K_2O than Dominion samples (Table 4). The trace element compositions are also distinct, with Kanye volcanics having much higher contents of the incompatible trace elements, especially Nb, Y, and Zr (Table 4, Figure 10). Thus the Kanye volcanics and Syferfontein Formation have quite different chemical compositions. They also differ petrographically in that the former contains phenocrysts of potassium feldspar while the latter is plagioclase (+ quartz) - phyric. This argues against any direct correlation between the Kanye Volcanics and the Dominion Group. On the other hand, alteration and silification are common in the volcanics of both these sequences and further work needs to be done, especially determinations of the relatively "immobile" trace elements, as well as precise age dating of the Kanye volcanics to definately discount a correlation.

Kraaipan Group

Roughly 150 to 200 km west of the Klerksdorp-Ottosdal type area of the Dominion Group, the Kraaipan Group, a deformed sequence of metasediments and metavolcanics, occurs in isolated north-trending linear outcrops through the Kalahari sands over a wide area extending from the Botswana border south to Vryburg, Delareyville and Amalia in the northeastern Cape and far western Transvaal Provinces.

The Kraaipan Group is a widespread but poorly exposed sequence of greenschists, amphibolite, chert, jaspilite and banded iron formations. It is intruded by granitic gneiss, is older than the Zoetlief volcanics (see below), and was generally thought to be of early Archaean (Swazian) age (SACS, 1980). However, recent U-Pb zircon dating of a felsic schist sample from the Kraaipan north of Schweizer-Reneke indicates an age equivalent to the upper part of the Dominion Group. Robb et al. (1991) reported that "a poor-quality, heterogeneous zircon population" reveal a tentative age of 3066 ± 40 Ma. It is thus possible that the Kraaipan is a distal equivalent of the Dominion Group, representing rift-related volcanism that developed closer to the edge of the continental margin (Robb et al., 1991).

Zoetlief Volcanics

The Zoetlief Group, a succession of volcanic and sedimentary rocks in the northeastern Cape Province, has been correlated with the Dominion Group by some workers (SACS, 1980). However, SACS (1980) now correlates this group with parts of the Ventersdorp Supergroup and recent age dating, although failing to provide a definitive crystallization age, are supportive of this correlation (Walraven et al., 1990).

TABLE 3. *Chemical Analyses of Samples from the Kanye Volcanics*

[A.] Data with L.O.I.

Sample	1	2	3	4	5	6	7	8
SiO2	70.03	70.98	73.05	72.90	71.07	74.19	69.41	70.52
TiO2	0.45	0.49	0.41	0.47	0.52	0.50	0.17	0.52
Al2O3	15.18	13.96	12.75	12.10	12.05	11.34	13.71	13.28
Fe2O3	--	--	--	--	3.72	3.16	2.77	--
FeO	--	--	--	--	1.49	1.32	1.16	--
Fe2O3*	5.07	4.38	3.92	3.96	--	--	--	5.47
MnO	0.10	0.10	0.14	0.18	0.08	0.02	0.11	0.03
MgO	0.00	0.36	0.16	0.38	0.47	0.47	0.23	0.20
CaO	1.41	0.95	0.78	0.88	0.79	0.16	0.23	0.97
Na2O	4.11	3.99	3.85	3.50	4.15	2.27	0.47	3.97
K2O	2.66	4.53	5.60	5.22	5.14	5.44	10.92	4.62
P2O5	0.12	0.13	0.11	0.07	0.14	0.08	0.07	0.10
L.O.I.	0.56	0.58	0.13	0.73	0.00	0.00	0.53	0.24
Total	99.69	100.45	100.90	100.39	99.62	98.95	99.78	99.92
Fe2O3*/MgO	--	12.2	24.5	10.4	11.4	9.8	17.6	27.4
CaO/Al2O3	0.09	0.07	0.06	0.07	0.07	0.01	0.02	0.07
Na2O/K2O	1.5	0.9	0.7	0.7	0.8	0.4	0.0	0.9
Ba	--	--	--	--	676	804	2319	920
Rb	--	--	--	--	232	245	276	194
Sr	--	--	--	--	47	35	9	80
Nb	--	--	--	--	36	40	27	19
Y	--	--	--	--	106	92	58	67
Zr	--	--	--	--	832	855	441	529
Ni	--	--	--	--	10	11	6	4
Cr	--	--	--	--	170	166	6	2
V	--	--	--	--	9	14	5	14
La	--	--	--	--	101	116	126	--
Ce	--	--	--	--	222	215	201	--
Nd	--	--	--	--	80	88	62	--
Yb	--	--	--	--	9	4	4	--

[B.] Data recalculated to 100% without L.O.I.

Sample	1	2	3	4	5	6	7	8
SiO2	70.64	71.07	72.49	73.15	71.34	74.98	69.93	70.75
TiO2	0.45	0.49	0.41	0.47	0.52	0.51	0.17	0.52
Al2O3	15.31	13.98	12.65	12.14	12.10	11.46	13.81	13.32
Fe2O3*	5.11	4.39	3.89	3.97	5.23	4.53	3.96	5.49
MnO	0.10	0.10	0.14	0.18	0.08	0.02	0.11	0.03
MgO	0.00	0.36	0.16	0.38	0.47	0.47	0.23	0.20
CaO	1.42	0.95	0.77	0.88	0.79	0.16	0.23	0.97
Na2O	4.15	4.00	3.82	3.51	4.17	2.29	0.47	3.98
K2O	2.68	4.54	5.56	5.24	5.16	5.50	11.00	4.63
P2O5	0.12	0.13	0.11	0.07	0.14	0.08	0.07	0.10
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Ti/Zr	--	--	--	--	3.8	3.5	2.3	5.9
Zr/Nb	--	--	--	--	23.1	21.4	16.3	27.7
Zr/Y	--	--	--	--	7.8	9.3	7.6	7.9

1 - Bluish-grey felsite, Wildebeestkop 2 KO, Marico District, sample #98A (Tyler, 1979a, Table 3).
2 - Masssive felsite, No. 140, Gabarone Road, Gabarone District (Hutton et al., 1974).
3 - Red porphyritic felsite, Wildebeestkop 2 KO, Marico District, sample 90.3.A (Tyler, 1979, Table 3).
4 - Kanye Volcanic Group felsite, Ramotswa District, Botswana (Harding et al., 1974, samp. no. K.V.G. 10,
5 - Sample DTA1800, Kanye rhyolite (Aldiss, in prep., Table 3).
6 - Sample DTA2017, Kanye rhyolite (Aldiss, in prep., Table 3).
7 - Sample DTA2500, Mabutsane rhyolite (Aldiss, in prep., Table 3).
8 - Sample 91313-2, Kanye Volcanic from Botsalana Game Reserve, analysed at Dept. Geology, Wits Univ. 9/91

TABLE 4. Comparative Mean Chemical Analyses of Dominion Group Volcanics and Possible Correlatives

Sample	1	2	3	4	5
N	69	32	12	7	2
SiO_2	56.05	69.78	54.59	67.82	73.16
TiO_2	1.08	0.81	1.06	0.72	0.52
Al_2O_3	14.18	12.92	14.67	12.64	11.78
Fe_2O_3*	11.82	6.70	14.11	8.94	4.88
MnO	0.16	0.08	0.28	0.14	0.05
MgO	5.25	1.13	4.19	0.92	0.47
CaO	7.16	2.01	6.85	3.01	0.47
Na_2O	3.02	3.16	2.83	2.28	3.23
K_2O	0.97	3.16	1.19	3.35	5.33
P_2O_5	0.31	0.25	0.22	0.18	0.11
Total	100	100	100	100	100
Fe_2O_3*/MgO	2.25	5.93	3.37	9.72	10.38
Na_2O/K_2O	3.11	1.00	2.38	0.68	0.61
Ba	453	768	247	391	740
Rb	28	86	35	114	238
Sr	430	187	255	145	41
Y	28	30	34	40	99
Zr	159	282	177	268	844
Nb	7.0	14	8.7	15	38
Ni	139	11	48	11	10
Cr	328	4.5	109	22	168
V	256	54	--	--	12
La	21	48	23	54	109
Ce	46	92	42	99	218
Nd	26	40	--	--	84

1 - Mean Dominion Group mafic lava (Bowen et al., 1986, Table IV, no.9).
2 - Mean Dominion Group felsic porphyry (Bowen et al., 1986, Table IV, no.8).
3 - Mean Nsuze Group basaltic andesite (Armstrong et al., 1982, Table I).
4 - Mean Nsuze Group dacite (Armstrong et al., 1982, Table I).
5 - Mean Kanye felsic volcanic, samples DTA1800 & DTA 2017 (Aldiss, in prep., Table 3).

N - Number of samples in mean.
Fe_2O_3* - Total Fe as Fe_2O_3.
Major elements recalculated to 100% volatile-free.

In summarizing possible Dominion Group correlatives, SACS (1980) suggested that the following units previously correlated with the Dominion Group should be assigned to other sequences:

"(1) The Insuzi Series (now Nsuze Group) is part of the Pongola Sequence.

(2) The Godwan Formation is part of the Transvaal Sequence.

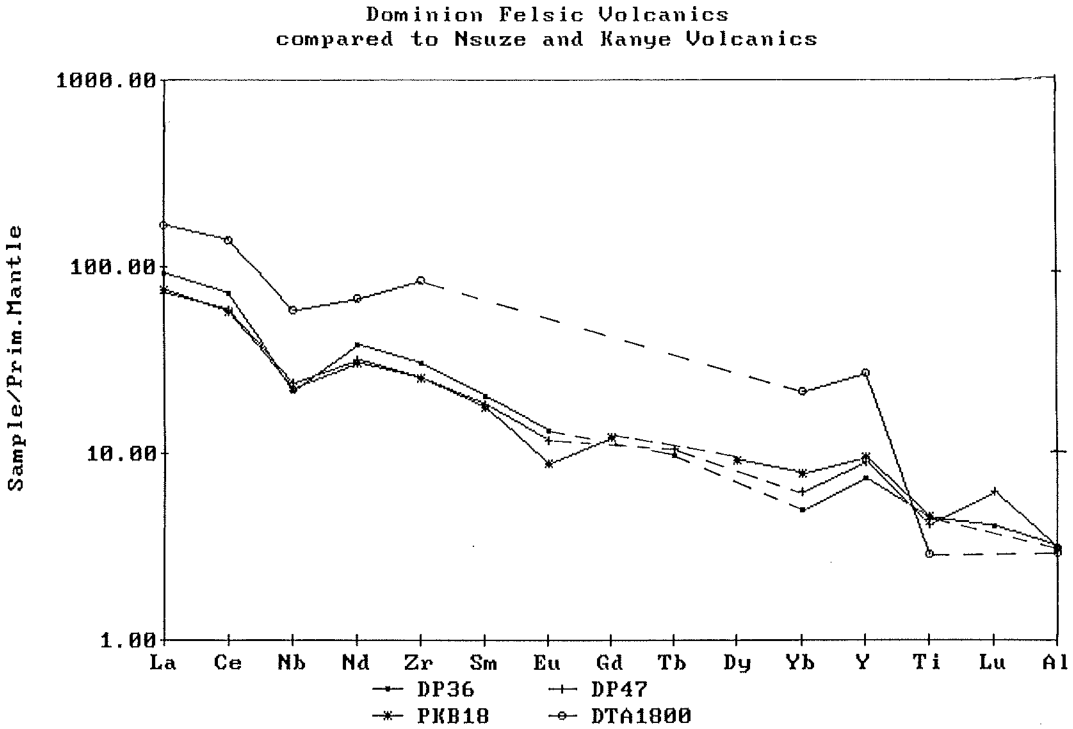

Figure 10: Spider diagram showing Dominion Group felsic volcanics and Nsuze dacite compared to Kanye felsic volcanic (sample DTA1800; Aldiss, in prep.). Trace elements normalized as in Figure 7. Note different scale compared to Figures 7 and 9.

(3) The Uitkyk Formation is part of the Pietersburg Group.

(4) The succession between Groblersdal and Dennilton has been named the Groblersdal Group, as it has been found to be appreciably younger than the Dominion Group.

(5) The volcanics and associated rocks forming the strip running west from around Thabazimbi have been assigned provisionally to the Ventersdorp Supergroup.

(6) The so-called pre-Ventersdorp lavas [Kanye Volcanics] between Mafeking and the Botswana border are probably Ventersdorp correlates."

The conclusions of the SACS group were that the extent of the known Dominion Group is "now restricted to the western Transvaal between Ottosdal in the west and the Vredefort Dome in the east" and that "there are no known correlates" (SACS, 1980, p. 96). However, the new radiometric age data indicate an equivalent age for at least part of the Kraaipan Group; the similar stratigraphic position and sequence of the Nsuze Group of the Pongola Supergroup, with an age equivalent to the lower Wits; and the still unknown age, but lithologic and stratigraphic similarity of the Kanye Volcanics, along with other late Archaean volcanics on the fringes of the Wits Basin (e.g. Welkom area boreholes), indicate that the possible existence of Dominion correlatives is still a moot question. Recent work by Myers (1990) indicates that the Godwan Group may be in part correlative with the Dominion Group.

DISCUSSION AND CONCLUSIONS

The foregoing review of available information on the Dominion Group raises a number of questions which require further work to answer. The Dominion stratigraphic sequence begins with a thin clastic sedimentary unit which has a marked similarity to the Witwatersrand Supergroup, including U-Au mineralization in two conglomeratic reefs. The Rhenosterspruit sediments were apparently locally derived from the detritus of granite weathering, laid down in a braided fluvial environment, the uraninite and other heavy minerals possibly derived from a source to the east of the Klerksdorp area. The source was apparently of diverse composition and possibly more uranium-rich than that responsible for most economic reefs in the Central Rand Group. But how did it differ in detail and where was it located?

Unlike the Witwwatersrand sequence, volcanic activity apparently began soon after initiation of Dominion Group sedimentation with mafic lavas and tuffaceous units soon predominating over sedimentation. Mafic and felsic volcanics of mainly subaerial nature are interbedded throughout the Dominion stratigraphy, but the felsic volcanics become dominant towards the top of the sequence in the western part of the depositional basin. The thick units of quartz-feldspar porphyry of the Syferfontein Formation probably were deposited by widespread, subaerial, pyroclastic flows. Tuffaceous units and fine-grained clastic sediments occur throughout the Dominion sequence but are more prominent near the base and in the upper parts in the Ottosdal area. This suggests that volcanism started slowly, reached a peak, in terms of volume per unit time, in the mafic extrusions of the middle Rhenosterhoek Formation, and then declined and was localized in the west (Ottosdal area) during deposition of the Syferfontein Formation.

Relatively thick and numerous occurrences of "Wonderstone" (if they do represent altered fine-grained tuffs), and the common, pervasive alteration of the felsic volcanics in the Ottosdal area suggest this may have been a shallow subaqueous, volcanic source region, possibly a large caldera or cauldron. The Vredefort area at the eastern end of the basin, appears, by contrast, to have been a distal depository for widespread mafic lavas and occassional, thin, intraflow argillaceous units.

The bimodal tholeiitic basalt - rhyolite geochemistry of the Dominion Group is consistent with a palaeotectonic environment of continental rifting, as proposed by Bickle and Eriksson (1982) and Clendenin et al. (1988). The basalts were probably derived by partial melting of an upper mantle source, modified by fluids in a way similar to modern subduction-zone environments with little or no contamination by continental crust. The felsic magmas probably formed by direct melting of lower crustal components and were not directly related to the mafic lavas petrogenetically.

A possible modern analogue of this tectonic scenario is that of the Basin and Range Province of the western U.S.A. More specifically, the Snake River Plain of Idaho, where an arcuate rift valley extends about 600 km and is characterised by voluminous Neogene bimodal (basalt-rhyolite) lavas and pyroclastics along with interlayered volcaniclastic, lacustrine and fluvial sediments (Leeman, 1989).

Tectonic Setting and Implications for Witwatersrand Basin Gold Deposition

Since the Dominion Group volcano-sedimentary package directly underlies the Witwatersrand Supergroup, the tectonic setting in which it was deposited has a direct bearing on the environment of deposition of the Witwatersrand succession.

Although a broad consensus has been reached regarding the general depositional setting of the Witwatersrand sediments, the source and mode of deposition of the voluminous gold ores is still a matter of debate.

The lower Witwatersrand, West Rand Group, consisting of mainly fine-grained iron-rich shales with subordinate sandstones and conglomerates, is considered to have originated in a marine shelf-tidal environment (Watchorn, 1981). The more restricted upper Witwatersrand, Central Rand Group, dominated by coarser clastics and containing the bulk of the mineralized horizons, accumulated in a shallow, braided-stream, alluvial setting (Vos, 1975; Pretorius, 1975, 1976). The tectonic environment is generally believed to have been in a foreland basin on the cratonward side of a collision zone now marked by the Limpopo Belt to the north of the Kaapvaal Craton (Burke et al., 1986, Winter, 1987). Active tectonic events on the margins of the basin accompanied by magmatic activity probably caused continuous changes in the nature of the hinterland source area during Central Rand Group deposition (Myers, et al., 1990; Robb et al., 1990a, 1991; Stanistreet and McCarthy, 1991). The dramatic coarsening-upward stratigraphy of the Witwatersrand sequence has been interpreted as indicating an increase in tectonic activity with time associated with basin shrinkage (Vos, 1975; Pretorius, 1976; Myers et al., 1990).

While most current workers favour a detrital origin for gold along with uranium, pyrite and other heavy minerals, some still hold to a hydrothermal mechanism for gold deposition during regional metamorphism (Phillips, 1987; Phillips and Myers, 1987; Phillips et al.. 1987). Others have called on chemical dissolution of gold during weathering from a regionally extensive source area and transportation to the basin in solution (Reimer, 1984; Reimer and Mossman, 1990).

Sedimentological studies have shown that the source of detritus was to the north and west of the Central Rand basin (see Tankard et al., 1982, fig. 4-9). The basement in this area of the western Transvaal is poorly exposed and few studies have directly addressed the problem of identifying the source of gold in the hinterland if it is indeed a detrital component. Most workers have traditionally favoured a source in a greenstone-dominated hinterland similar to the Barberton Mountain Land (Viljoen et al., 1970; Minter 1978; Pretorius, 1976, 1981) because lode gold deposits found in this and other Archaean greenstone belts worldwide are relatively common. There are two main problems with this hypothesis: first, although the hinterland north and west of the Witwatersrand Basin is poorly exposed, it seems to be dominated by Archaean granitoids rather than greenstones; secondly, even if abundant greenstones existed in the hinterland and are not now recognized due to cover by Kalahari sands, removal by erosion, or other reasons such as post-Witwatersrand granitoid intrusion, this seems an inadequate model because of volume considerations. The vast volume of gold which has been removed from Witwatersrand mines is orders of magnitude greater than that found in even the largest and most productive greenstone belts in the world, and is more than thirty times greater than the production from all the South African greenstone belts, including Barberton, Murchison, Pietersburg, Sutherland, and others, combined (Hutchinson and Viljoen, 1988).

Alternatives to the greenstone-source model that still accept a detrital source for the gold and uranium include weathering of Archaean iron formations (Au) and granite (U) (Hirdes, 1984) or volcanics within the Witwatersrand Supergroup (Reimer, 1984, 1985). Robb and Meyer (1985, 1990) recently proposed the novel idea that hydrothermally altered granites (HAGS), which have been identified in the hinterland, were the source of gold and uranium. Although HAGS are enriched in gold and other trace elements compared to more typical unaltered Archaean granites, this theory as well as the others suffers from the same volumetric inadequacy problem as the original greenstone-source model.

A compelling idea, which incorporates the active tectonism on the Witwatersrand Basin margin, explains the detrital nature of the ores without the hinterland volume problem, explains the generation of HAGS, and suggests an important role for Dominion Group volcanism in the origin of Witwatersrand gold deposits, was proposed by Hutchinson and Viljoen (1988).

> "The source of the abundant Witwatersrand gold was endogenous within the basin rather than exogenous to it. Detrital gold was derived along the margin of the basin by reworking of proximally deposited, gold-rich, pyritic, sulphide-facies exhalites. These were formed near hydrothermal discharge vents along the active, down-faulted northwestern margin of the basin. The proximal sulphidic exhalites passed basinward into oxidic ferruginous shales and iron-formations that inherited a low, but still anomalous gold content, and that now comprise the various ferruginous marker beds in the Witwatersrand Supergroup. The hydrothermal discharge system along the basin's margin was generated by the extensive, shallow marine volcanism that accompanied Dominion Group and to a much lesser extent West Rand Group sedimentation. It was also responsible for alteration of these, and of adjacent basement rocks, producing hydrothermally altered granites (ibid, p. 169)."

The general stratigraphy and petrochemical nature of the Dominion Group is consistent with the palaeotectonic setting of a continental margin rift zone. Although the chemical signature of the volcanics is not strictly analogous with that of modern continental-margin subduction zones, as has been proposed by some workers, there is a "subduction component" to the geochemistry. This apparent contradiction might be explained by a subduction-type event which modified the mantle source of the Dominon volcanics, and a tectonic setting in a continental back-arc basin which allows tapping of subduction-type magmatic sources in an extensional environment. Again this would be somewhat analogous to the Neogene Basin and Range Province of the western U.S.A. where bimodal volcanism has been related to a broad zone of back-arc extensional response to east-dipping subduction.

If the endogenous-exhalative model for the origin of gold in the Witwatersrand is correct, a back-arc basin setting for the Dominion Group would be consistent with the tectonic setting of the Tertiary Kuroko deposits of Japan at a convergent plate boundary, and the association of subaqueous tholeiitic mafic lavas and calc-alkaline felsic volcanics common to many Archaean exhalative volcanogenic massive sulphide deposits

(Hutchinson, 1973). Where the tectonic environment can be identified, mainly in Phanerozic examples, the largest of these deposits occur at convergent plate boundaries, but on a more local scale many are associated with extensional rift basins, such as in the Bathurst district of Canada and the Green Tuff belt (Kuroko district) of Japan (Franklin et al., 1981).

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