*Communs geol. Surv. Namibia*, ***11*** *(1996), 49-53*

# Precise U-Pb zircon ages for early Damaran magmatism in the Summas Mountains and Welwitschia Inlier, northern Damara belt, Namibia

**P.P. Hoffman[1], D.P. Hawkins[2], C.E. Isachsen[2] and S.A. Bowring[2]**
[1]*Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138, USA*
[2]*Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

Three new U-Pb zircon ages are reported for early Damaran, rift-related, igneous rocks in northern Namibia. An age of 756 ± 2 Ma for the Oas quartz syenite intrusion, western Welwitschia Inlier, provides a minimum age for lower Nosib Group terrigenous sedimentation in that area. An ash-flow tuff near the top of the Lower Naauwpoort Formation (upper Nosib Group) in the Summas Mountains and a rhyolite lava flow in the Upper Naauwpoort Formation (lower U gab Group) directly north of the Summas Mountains have statistically identical ages of 746 ± 2 and 747 ± 2 Ma, respectively. The age equivalence indicates that the contact between the sampled Upper and Lower Naauwpoort Formations represents either a brief hiatus or a tectonic repetition. Rift-related magmatism in northern Namibia is similar in age to that in northwest India, the Trans-Antarctic Mountains, and the northern Cordillera and southern Appalachians of North America.

## Introduction

Igneous rocks related to Neoproterozoic continental rifting occur sporadically for 400 km along the northern margin of the Damara belt in northern Namibia (Fig. 1) (Miller, 1983). Alkaline and peralkaline rhyolite ash-flow tuffs predominate, but other felsic extrusive rocks, epizonal intrusions and subordinate mafic rocks also occur (Smit, 1962; Frets, 1969; Miller, 1974, 1980, 1983; Hedberg, 1979). Their great thickness (up to 6.6 km) and highly localized distribution suggest that emplacement was associated with tectonic extension and/or cauldron-subsidence structures. Volcanism is principally associated with the upper part of the Nosib Group, regionally comprised of non-marine feldspathic sandstones and conglomerates deposited in an extensional tectonic regime (Hedberg, 1979; Miller, 1983). Locally, igneous activity continued during deposition of the lower Ugab Subgroup (Miller, 1980), a mixed association of syn- to post-extensional carbonates and terrigenous sediments. Conceivably, the igneous activity coincided with continental breakup at the southern promontory of the Congo craton (Hoffmann, 1994).

Previous attempts to date the igneous activity have yielded imprecise and partly conflicting results. Whole-rock Rb-Sr systematics of devitrified volcanic rocks of the upper Nosib Group (Naauwpoort Formation) have isochron ages of 557 ± 10 Ma (De Villiers, 1968) and 521 ± 45 Ma (Hawkesworth *et al.*, 1983), interpreted as metamorphic ages. Zircons from two quartz porphyry rhyolite lavas in the lowest exposed part of the Naauwpoort Formation in the Summas Mountains (Fig. 1) yielded discordant U-Pb upper intercept ages of 750 ± 60 and 728 ± 40 Ma (Miller and Burger, 1983). The zircon ages are statistically indistinguishable from a whole-rock Rb-Sr isochron age of 764 ± 60 Ma for the Lofdal nepheline syenite in Welwitschia Inlier (Fig. 1), which is included in the rift-related igneous suite on petrogenetic grounds but is not physically in contact with the Nosib Group (Hawkesworth *et al.*, 1983). However, the nearby Oas quartz syenite, which intrudes lower Nosib Group sediments in Welwitschia Inlier (Frets, 1969), yields Rb-Sr whole-rock isochron ages of 840 ± 13 and 652 ± 11 Ma, interpreted as intrusive and metamorphic ages respectively (Kröner, 1982). If the older isochron is accepted as a minimum age for the intrusion, then a major hiatus must exist between the lower Nosib Group sediments and the upper Nosib Naauwpoort volcanics. On the other hand, Tegtmeyer and Kröner (1985) analysed three size-fractions of zircons from a marginal phase of the Oas quartz syenite and regressed the U-Pb ratios obtained to a chord (MSWD=1) having upper and lower intercept ages of 2124 +68/-54 and 736 +133/-141 Ma, respectively. The latter is presumed to reflect the intrusive age and is statistically consistent with a concordia intercept age, based on three zircon fractions from the central part of the intrusion, of 783 ± 18 Ma (Burger and Kröner, unpublished data cited in Tegtmeyer and Kröner, 1985).

To help resolve these uncertainties, samples of upper Nosib Group rhyolite lava and Oas quartz syenite from Welwitschia Inlier were collected for U-Pb zircon geochronology, as were samples of upper Nosib Group ash-flow tuff and lower Ugab Subgroup rhyolite lava from the Summas Mountains (Fig. 1). Results from all but the first of these samples are reported and discussed below. Single- and multi-grain fractions were hand-picked for analysis from the clearest, least cracked, inclusion-free zircons. The selected grains were air-abraded until all facets had been removed, and then analysed by conventional isotope dilution thermal ionization mass spectrometry according to the methods described by Bowring *et al.* (1993).

## Oas quartz syenite, Welwitschia Inlier (sample PH.10.93)

The Welwitschia Inlier is a satellitic basement massif south of the larger Kamanjab Inlier, located near the junction of the Damara and Kaoko belts (Fig. 1). The two inliers are flanked by Damaran strata, comprising three groups (Nosib, Swakop/Otavi, Mulden) separated by angular unconformities. The Oas hornblende-quartz syenite is a medium-grained, epizonal, intrusive body, about 50 km$^2$ in area, situated near the southwestern end of the Welwitschia Inlier (Fig. 2). Its northern margin is intrusive into pre-Damaran Huab gneiss and its western margin intrudes pebbly feldspathic quartzite of the lower Nosib Group (Frets, 1969). Its southern contact is faulted and/or overlain non-conformably by carbonates and fine clastics of the Swakop Group. West of the Gas intrusion, the upper Nosib Group includes rhyolitic lava and ash-flow tuff (Naauwpoort Formation) and porphyritic bostonite (Blaukrans porphyry), none of which is in contact with the Gas intrusion. Frets (1969) presents clear cut evidence that the Gas intrusion post-dates the lower Nosib Group and pre-dates the lower Swakop Group. He concludes that the intrusion is broadly co-eval with upper Nosib Group volcanism and with an extensive swarm of east- to east-northeast-striking fel-

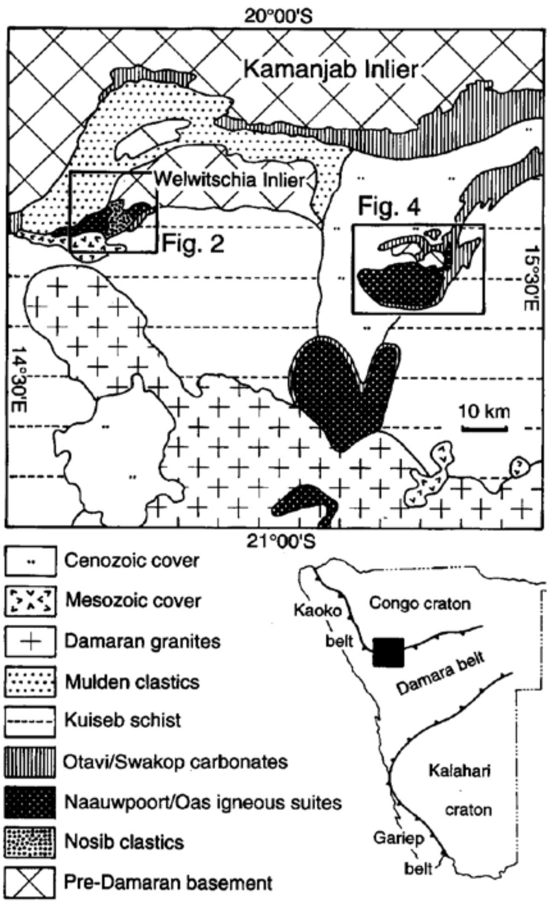


**Figure 1:** Distribution of early Damaran igneous rocks (Naauwpoort volcanics and Oas intrusion) south of Kamanjab Inlier near the junction of the Damara and Kaoko belts (modified from Miller, 1974). The areas detailed in figures 2 and 3 are shown.

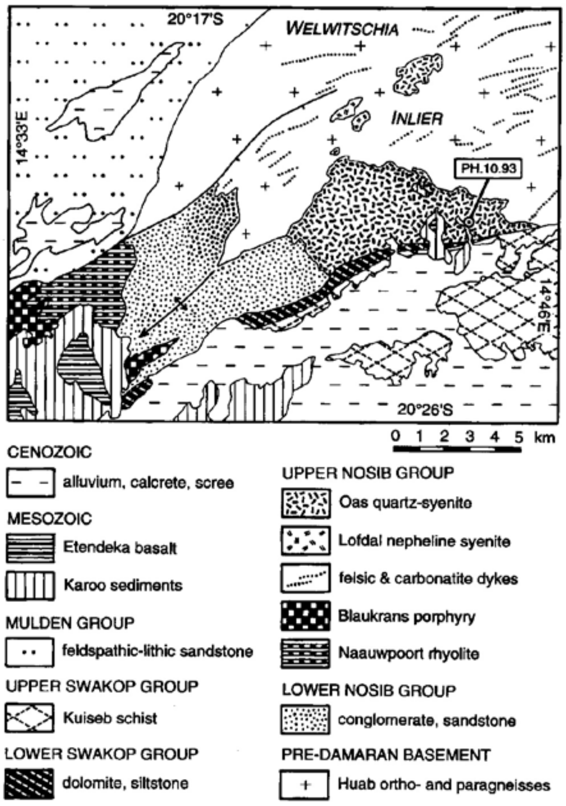


**Figure 2:** Geological sketch map of the western Welwitschia Inlier area (modified from Frets, 1969), showing the Oas quartz syenite sample site (PH.10.95).

sic and carbonatite dykes cutting basement rocks north and east of the Gas intrusion.

Sample PH.10.93 was collected at 20°21'45"S, 14°43'30"E, 1.5 km east of the Cretaceous Honerub outlier near the center of farm Oas 486. The location is in the east-central part of the Oas intrusion. Heavy mineral separates from the 35 kg sample were divided into five magnetic fractions and eight zircon grains were hand-picked for analysis from the least magnetic fraction. Two 300 µm grains and one 200 µm grain were analysed individually (fractions nm1.Z1-3); five smaller grains (50-100 µm) were analysed collectively (fraction nm1.Z4). The analysed grains were clear, euhedral prisms. Although free of visible inclusions, the two largest grains (.Z2 and .Z3) did contain fine cracks. The analytical data are given in Table 1 and plotted on a concordia diagram (Fig. 3). All four fractions are concordant and yield a weighted mean ($^{207}Pb/^{206}Pb$) age of 756 ± 2 Ma, which is taken as the time of intrusion.

### Upper Nosib ash-flow tuff, Summas Mountains (sample PH.12.93)

The Summas Mountains Inlier is a 150 km$^2$ exposure of Naauwpoort volcanic rocks (Miller, 1974, 1980) situated on the boundary between the Otavi fold belt to the north and the allochthonous Outjo fold belt to the south (Hoffmann, 1987), 60 km east-southeast of the Oas quartz syenite (Fig. 1). The main mass of the mountains is a structural dome (Fig. 4), exposing alkaline to per-alkaline rhyolite ash-flow tuff and subordinate quartz-feldspar porphyry having a composite stratigraphic thickness in excess of 6.6 km (base not exposed) (Miller, 1980). These rocks have been correlated with the upper Nosib Naauwpoort Formation west of the Welwitschia Inlier and are called "Lower Naauwpoort Formation" in the Summas Mountains (Miller, 1980) to distinguish them from volcanic rocks in the overlying Ugab Subgroup.

Sample PH.12.93 was collected at 20°29'30"S, 15°17'30"E high on the northeast flank of the Summas Mountains dome near the eastern boundary of farm Renosterkop 389. According to Miller (1980), the sampled unit should lie about 1000 m stratigraphically below the Nosib/Ugab unconformity. Lithologically, the sample is a purplish-grey, feldspar-phyric, vitric, ash-flow tuff. A moderately strong tectonic foliation (dipping 70° to N20°E) is superimposed on a primary(?) eutaxitic foliation (dipping 88° to S10°W).

Zircons separated from the sample are largely clear to pale yellow, elongate, euhedral prisms, mostly 100-200 µm in length. Five weakly magnetic (m0) and six magnetic (m6) fractions were hand-picked for analysis. They range from clear and flawless to slightly cracked and containing fine, dark inclusions. Four of the magnetic grains were analysed individually (m6.Z1-4); the other analysed fractions ranged from three to ten grains each. Both single and multi-grain fractions define a discordant array indicating the presence of inherited components (Fig. 3). Three concordant analyses and one discordant analysis define an upper intercept age of 746 ± 2 Ma (lower intercept = -17 ± 113, MSWD = 0.19), which is taken as the age of upper Nosib Group volcanism at the sample site.

**Lower Ugab rhyolite lava, Summas Mountains (sample PH.11.93)**

The north side of the Summas Mountains dome is a fault zone across which the thick ash-flow tuffs and porphyries of the Lower Naauwpoort Formation are truncated. Rocks of the overlying Ugab Subgroup directly onlap pre-Damaran Huab gneisses and schists north of the fault zone (Fig. 4) (Miller, 1980). Regionally, the Ugab Subgroup is a mixed assemblage of dolomites, quartzites and schists correlative with the Abenab Subgroup of the Otavi fold belt to the north (SACS, 1980). It is overlain disconformably by a unit of diamictite and iron formation. This is correlated with the Chuos Formation which forms the base of the Khomas Subgroup. The latter is equivalent to the Tsumeb Sub-group of the Otavi fold belt. On the east flank of the Summas Mountains dome, Lower Naauwpoort ash-flow tuffs are di-

**Table 1:** U-Pb analytical data

| Sample fraction | wt. (µg) | U (ppm) | Pb (ppm) | (Pb)c (pg) | $^{206}Pb/^{204}Pb$ | $^{208}Pb/^{206}Pb$ | $^{206}Pb/^{238}U$ | %err | $^{207}Pb/^{235}U$ | %err | $^{207}Pb/^{206}Pb$ | %err | Ages (Ma) $^{206}Pb/^{238}U$ | $^{207}Pb/^{235}U$ | $^{207}Pb/^{206}Pb$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Note:* (1) | (2) | (3) | (3) | (4) | (5) | (6) | (7) | (8) | (7) | (8) | | | | | |
| Oas Quartz syenite: PH10-93 | | | | | | | | | | | | | | | |
| nm1 Z1 | 3.7 | 536 | 69 | 2.3 | 7026 | 0.136 | 0.12440 | (.15) | 1.10510 | (.16) | 0.06443 | (.06) | 755.6 | 755.8 | 755.8 |
| nm1 Z2 | 27.6 | 405 | 52 | 4.8 | 18243 | 0.129 | 0.12423 | (.21) | 1.10350 | (.23) | 0.06442 | (.09) | 754.9 | 755.0 | 755.5 |
| nm1 Z3 | 21.6 | 472 | 63 | 38.4 | 2064 | 0.151 | 0.12452 | (.12) | 1.10658 | (.15) | 0.06445 | (.09) | 756.5 | 756.5 | 756.5 |
| nm1 Z4 | 1.4 | 550 | 70 | 1.3 | 4469 | 0.125 | 0.12449 | (.23) | 1.10681 | (.25) | 0.06448 | (.10) | 756.4 | 756.6 | 757.5 |
| Lower Naauwpoort ash-flow tuff: PH12-93 | | | | | | | | | | | | | | | |
| m0 Z1 | 11.0 | 92 | 13 | 2.4 | 3441 | 0.219 | 0.12402 | (.29) | 1.10646 | (.31) | 0.06470 | (.09) | 753.7 | 756.5 | 764.7 |
| m0 Z2 | 9.1 | 79 | 11 | 2.1 | 2765 | 0.224 | 0.12233 | (.36) | 1.08149 | (.40) | 0.06412 | (.16) | 744.0 | 744.4 | 745.5 |
| m0 Z3 | 6.1 | 70 | 9 | 1.8 | 1867 | 0.214 | 0.12314 | (.51) | 1.09681 | (.55) | 0.06460 | (.18) | 748.6 | 751.8 | 761.3 |
| m0 Z4 | 12.0 | 134 | 18 | 7.3 | 1715 | 0.225 | 0.12243 | (.27) | 1.08301 | (.31) | 0.06416 | (.14) | 744.5 | 745.1 | 746.8 |
| m0 Z5 | 13.5 | 73 | 12 | 32.0 | 251 | 0.216 | 0.12288 | (.42) | 1.09005 | (.65) | 0.06434 | (.45) | 747.1 | 748.5 | 752.8 |
| m6 Z1 | 12.2 | 78 | 11 | 13.3 | 531 | 0.243 | 0.11484 | (.48) | 1.01590 | (.56) | 0.06416 | (.26) | 700.8 | 711.8 | 746.8 |
| m6 Z2 | 13.8 | 50 | 7 | 6.3 | 878 | 0.228 | 0.12463 | (.61) | 1.11471 | (.63) | 0.06487 | (.15) | 757.1 | 760.4 | 770.1 |
| m6 Z3 | 1.5 | 328 | 45 | 3.4 | 1166 | 0.235 | 0.12283 | (.82) | 1.08621 | (.84) | 0.06414 | (.18) | 746.8 | 746.7 | 746.1 |
| Upper Naauwpoort rhyolite: PH11-93 | | | | | | | | | | | | | | | |
| nm5 Z1 | 2.5 | 258 | 34 | 5.7 | 1657 | 0.214 | 0.12180 | (.37) | 1.07839 | (.39) | 0.06421 | (.13) | 740.9 | 742.8 | 748.6 |
| nm5 Z2 | 2.5 | 308 | 41 | 6.6 | 902 | 0.180 | 0.12041 | (.58) | 1.06496 | (.63) | 0.06415 | (.23) | 732.9 | 736.3 | 746.5 |
| nm5 Z3 | 2.9 | 241 | 32 | 1.9 | 2873 | 0.188 | 0.12216 | (.39) | 1.08072 | (.42) | 0.06416 | (.13) | 743.0 | 744.0 | 746.9 |
| m6 Z1 | 1.8 | 258 | 34 | 2.3 | 1595 | 0.184 | 0.12290 | (.61) | 1.08722 | (.65) | 0.06416 | (.21) | 747.2 | 747.2 | 747.0 |
| m6 Z4 | 2.5 | 574 | 84 | 34.5 | 310 | 0.220 | 0.11365 | (.37) | 1.00616 | (.59) | 0.06421 | (.41) | 693.9 | 706.9 | 748.5 |

*Notes:* (1) all fractions are air abraded zircons. m. nm = magnetic, non-magnetic at indicated degree of tilt on a Frantz isodynamic separator operated at 1.4 to 1.6 amps. (2) sample weights estimated using a video monitor with a gridded screen are known to within 40%. (3) expressed as ppm U and ppm radiogenic Pb. (4) picograms common Pb. (5) measured ratio corrected for fractionation - Pb fractionation correction is 0.12%±0.04% per atomic mass unit (amu) for multicollector analyses and 0.15%±0.04% per amu for single collector analyses. (6) radiogenic Pb. (7) corrected for fractionation, spike, blank and initial common Pb: U blank =1pg±50%, Pb blank = 3.5pg±50% (for fractions containing less than 3.5pg common Pb, the total comon Pb was assumed to be blank); initial comon Pb composition calculated from Stacey and Kramers (1975) using the interpreted age of the sample. (8) errors given in percentage at the two-sigma confidence interval.

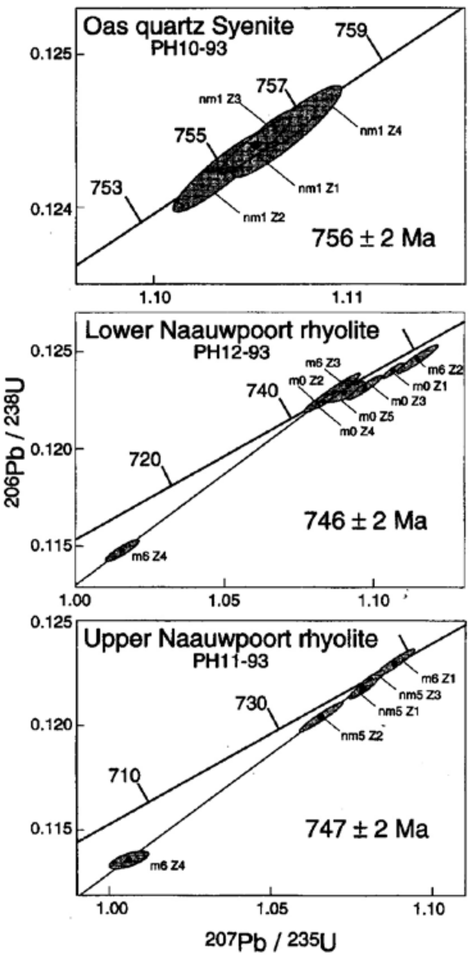


**Figure 3:** Concordia diagrams for zircons from the Oas quartz-syenite, Lower Naauwpoort ash-flow tuff and Upper Naauwpoort rhyolite lava. Ages (Ma) are marked on the concordia curves and individual analyses are depicted as 2 error ellipses identified by fraction number (see text and table).

rectly overlain by well-bedded rhyolite lapilli tuffs and intercalated tuffaceous siltstone and dolomite, all of which are assigned to the lower Ugab Subgroup (Miller, 1980). The lower Ugab volcanic rocks were termed "Upper Naauwpoort Formation" by Miller (1980) to distinguish them from the ash-flow tuffs and porphyries in the core of the Summas Mountains.

Directly north of the Summas Mountains, the top of the Lower Naauwpoort Formation is not exposed and the base of the Ugab Subgroup is composed of poorly sorted boulder conglomerate and paraconglomerate derived from the Huab basement (Fig. 4). Above the conglomerate are rhyolite lavas and tuffs, intermediate porphyries, greenstones, and conglomerates composed of volcanic and subordinate gneiss and quartzite clasts. If the fault zone bounding the Lower Naauwpoort ash-flow tuffs and porphyries is a cauldron subsidence structure, the Upper Naauwpoort volcanics may be related to "resurgent doming" (Smith and Bailey, 1968) of the cauldron. Alternatively, the Lower Naauwpoort Formation and lower Ugab rocks to the east and northeast may have been thrust northward over the Huab gneiss and lower Ugab strata exposed directly north of the Summas Mountains (K.H. Hoffmann, *pers. comm.*, June 1994).

Sample PH.11.95 was collected at 20°28'40"S, 15°17'25"E on the north side of the Löwenfontein River near the east boundary of farm Renosterkop 389. The sample site lies directly north of the Summas Mountains and the fault zone bounding the Lower Naauwpoort Formation (Fig. 4) (Miller, 1980). The 35 kg sample was collected from a reddish, spherulitic, feldspar-phyric, massive to flow-banded, rhyolite lava dome that overlies lower Ugab paraconglomerate and dolomitic sandstone. The base of the Ugab Subgroup is not exposed directly beneath the sampled rhyolite but, according to Miller (1980), the paraconglomerate should represent the basal unit. The paraconglomerate is a dark greenish grey phyllite containing matrix-supported boulders of Huab gneiss up to 1.5 m in diameter.

Zircons separated from the rhyolite are mostly clear, stubby, euhedral prisms, 100-200 μm in length. Five single grains, three magnetic (m6) and two non-magnetic (nm5.Z1-2), and one multi-grain fraction (nm.Z3) were analysed (Fig. 3). The data define an upper intercept age anchored by one concordant analysis of 7471: 2 Ma (lower intercept = -15 ± 147; MSWD = 0.34), which we take to be the eruptive age of the rhyolite lava dome.

## Conclusions

Our results imply that igneous activity associated with early Damaran extensional tectonism at the southern promontory of the Congo craton lasted for at least 10 m.y. Lower Nosib Group rift-related sedimentation began before intrusion of the Oas quartz-syenite at 756 ± 2 Ma and volcanism in the Summas Mountains lasted at least until 746 ± 2 Ma.

Rift-related magmatism at about 750 Ma is globally widespread, presumably associated with the fragmentation of a Neoproterozoic supercontinent. It occurs in the basal Windermere Supergroup of western North America (Roots and Parrish, 1988; Devlin *et al.*, 1988) and the basal Beardmore Group of the Trans-Antarctic Mountains (Borg *et al.*, 1990; Storey *et al.*, 1992). These sequences developed on conjugate margins of the Pacific basin (Moores, 1981; Ross, 1991; Powell *et al.*, 1993; Li *et al.*, 1995). Contemporaneous intraplate magmatism occurred in northwestern India (Crawford and Compston, 1970; Kochhar, 1994) and southeastern North America (Aleinikoff *et al.*, 1995; Fetter and Goldberg, 1995). These areas evolved into continental margins bordering the Mozambique (Dalziel, 1981; Stern, 1994) and Iapetus oceans, respectively, although the latter did not finally open until the Vendian (Williams and Hiscott, 1987; Kumarapeli *et al.*, 1989; Kamo

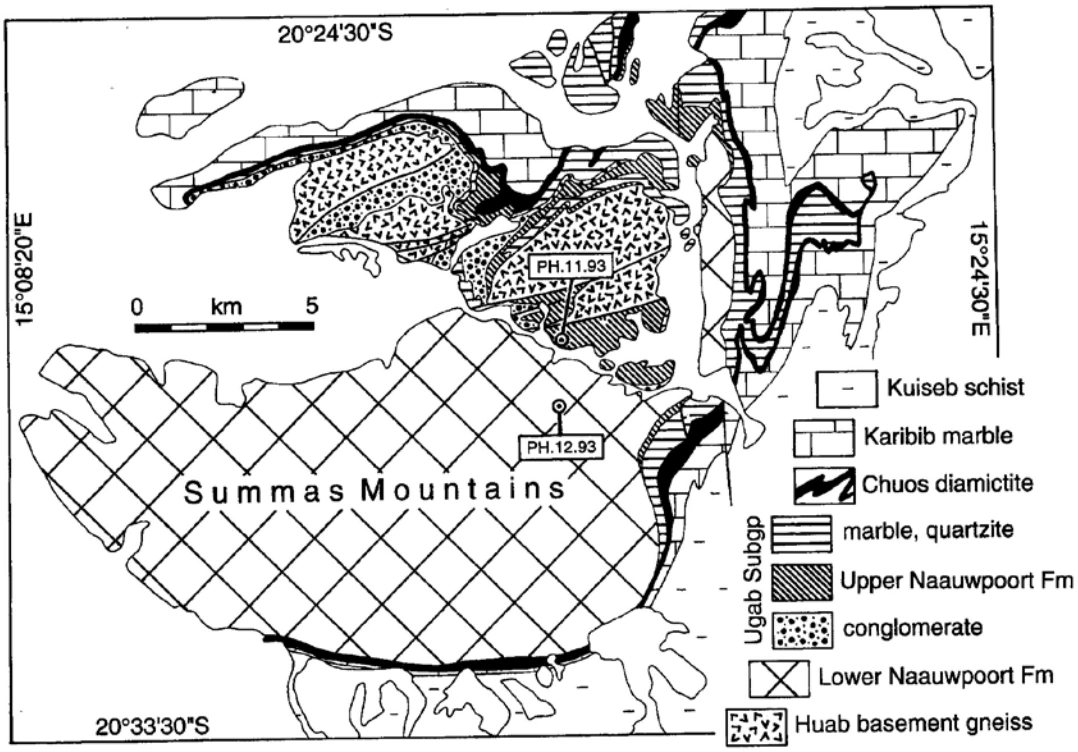


**Figure 4:** Geological sketch map of the Summas Mountains area (modified after Miller, 1980), showing the Lower (PH.12.93) and Upper (PH.11.93) Naauwpoort rhyolite sample sites.

*et al.*, 1989, 1995).

Young (1995) proposed that Neoproterozoic glacial deposits fall into two age groupings, the older (Sturtian-Rapitan: ca 750 Ma) associated with the opening of the Pacific basin and the younger (Miranoan-Varanger: *ca* 600 Ma) associated with opening of the Iapetus basin. The age of 746 ± 2 Ma for the Lower Naauwpoort Formation establishes a maximum age for the glaciogenic Chuos Formation east of the Summas Mountains and, assuming stratigraphic equivalence of the Ugab and Abenab Subgroups (SACS, 1980), the age of 747 ± 2 Ma should be a minimum age for the glaciogenic(?) Varianto Formation, which occurs discontinuously at the top of the Nosib Group in the Otavi fold belt. The Varianto and Chuos Formations appear to belong to Young's (1995) older glacial suite (Hoffmann, 1994), but tectonic links between the opening of the Adamastor basin (Hartnady *et al.*, 1985; Stanistreet *et al.*, 1991) in southwest Gondwanaland and the contemporaneous opening of the Pacific basin remain unresolved.


### Acknowledgements

This study was undertaken as an adjunct to a continuing programme of geological mapping and related topical studies of the Otavi fold belt in the Kunene District, supported jointly by the Geological Survey of Namibia, the National Science and Engineering Research Council and the University of Victoria (Canada), and the National Science Foundation and Harvard University (U.S.A). Andrew Bekker and Hu Guowei assisted with sample collecting and Kathy Davidek prepared the samples for zircon picking. We are grateful to N.J. Beukes, K.H. Hoffmann and R.McG. Miller for relevant discussions. Richard Armstrong and Roy Miller made valuable comments on the manuscript.


### References


Aleinikoff, J.N., Zartman, R.E., Walter, M., Rankin, D.W., Lyttle, PT. and Burton, W.C. 1995. U-Pb ages of metarhyolites of the Catoctin and Mount Rogers Formations, central and southern Appalachians: evidence for two pulses ofIapetan rifting. *Am. J. Sci.*, **295**, 428-454.

Borg, S.G., DePaolo, D.J. and Smith, B.M. 1990. Isotopic structure and tectonics of the central Trans-Antarctic Mountains. *J. geophys. Res.*, **95**, 6647-6667.

Bowring, S.A, Grotzinger, J.P., Isachsen, C.E., Knoll, A.H., Pelechaty, S.M., and Kolosov, P. 1993. Calibrating rates of Early Cambrian evolution. *Science,* **261**, 1293-1298.

Crawford, A.R. and Compston, W. 1970. The age of the Vindhyan System of Peninsular India. *J. Geol. Soc.*, **125**, 351-371.

Dalziel, I.W.D. 1991. Pacific margins of Laurentia and East Antarctica-Australia as a conjugate rift pair: evidence and implications for an Eocambrian supercontinent. *Geology,* **19**, 598-601.

De Villiers, J. 1968. Geochronology. *6th ann. Rep. Precamb. Res. Unit, Univ. Cape Town*, 34-36.

Devlin, W.J., Brueckner, H.K., and Bond, G.C. 1988. New isotopic data and a preliminary age for volcanics near the base of the Windermere Supergroup, northeastern Washington, U.S.A. *Can. J. Earth Sci.*, **25**, 1906-1911.

Fetter, A.H. and Goldberg, S.A. 1995. Age and geochemical characteristics of bimodal magmatism in the Neoproterozoic Grandfather Mountain rift basin. *J. Geol.*, **103**, 313-326.

Frets, D.C. 1969. Geology and structure of the Huab-Welwitschia area, South West Africa. *Bull. Precamb. Res. Unit, Univ. Cape Town*, **5**, 235 pp.

Hartnady, C., Joubert, P. and Stowe, C. 1985. Proterozoic crustal evolution in southwestern Africa. *Episodes,* **8**, 236-244.

Hawkesworth, C.J., Gledhill, A.R., Roddick, J.C., Miller, R. McG. and Kröner, A. 1983. Rb-Sr and $^{40}$Ar/39Ar studies bearing on models for the thermal evolution of the Damara belt. *In*: Miller, R.McG., (ed.) *Evolution of the Damara Orogen*. Spec. Publ. geol. Soc. S. Afr., **11**, 323-338.

Hedberg, R.M. 1979. Stratigraphy of the Ovamboland Basin, South West Africa. *Bull. Precambr. Res. Unit, Univ. Cape Town*, **24**, 325 pp.

Hoffmann, K.H. 1987. Application of tectono-stratigraphic terrane analysis in the Damara Province of central and northern Namibia. *In*: Abstract Volume. A.L. du Toit Golden Jubilee Conference on Tectonostratigraphic Terrane Analysis. *Roy. Soc. and Geol. Soc. S. Afr., Cape Town*, 25-27.

Hoffmann, K.H. 1994. New constraints on the timing of continental breakup and collision in the Damara belt. *Abstracts - Proterozoic Crustal and Metallogenic Evolution*. Geol. Soc. and geol. Surv., Namibia, **30**.

Kamo, S.L., Gower, C.F., and Krogh, T.E. 1989. Birthdate for the Iapetus Ocean? A precise U-Pb zircon and badddeleyite age for the Long Range dikes, southeast Labrador. *Geology,* **17**, 602-605.

Kamo, S.L., Krogh, T.E., and Kumarapeli, P.S. 1995. Age of the Grenville dyke swarm, Ontario-Quebec: implications for the timing of lapetan rifting. *Can. J. Earth Sci.*, **32**, 273-280.

Kochhar, N. 1994. Role ofMalani anorogenic magmatism in the crustal evolution of the northwest Indian shield. *Abstracts - Proterozoic Crustal and Metallogenic Evolution*. Geol. Soc. & geol. Surv. Namibia, Windhoek, **43**.

Kröner, A. 1982. Rb-Sr geochronology and tectonic evolution of the Pan-African Damara belt of Namibia, southwestern Africa. *Am. J. Sci.*, **282**, 1471-1507.

Kumarapeli, P.S., Dunning, G.R., Pintson, H. and Shaver, J. 1989. Geochemistry and U-Pb zircon age of comenditic metafelsites of the Tibbit Hill Formation, Quebec Appalachians. *Can. J. Earth Sci.*, **26**, 1374-1383.

Li, Z.X., Zhang, L. and Powell, C.McA. 1995. South China in Rodinia: part of the missing link between Australia-East Antarctica and Laurentia? *Geology,* **23**, 407-410.

Miller, R.McG. 1974. The stratigraphic significance of the Naauwpoort Formation of east central Damaraland, South West Africa. *Trans. geol. Soc. S.Afr.*, **77**, 363-368.

Miller, R.McG. 1980. Geology of a portion of central Damaraland, South West Africa/Narnibia. *Mem. geol. Surv. S. Afr., S.W.Afr. Ser.*, **6**, 78 pp.

Miller, R.McG. 1983. The Pan-African Damara orogen of South West Africa! Namibia. *In*: Miller, R.McG., (ed.) *Evolution of the Damara Orogen*. Spec. Publ. geol. Soc. S. Afr., **11**, 431-515.

Miller, R.McG. and Burger, A.J. 1983. U-Pb zircon age of the Early Damaran Naauwpoort Formation. *In*: Miller, R.McG., (ed.) *Evolution of the Damara Orogen*. Spec. Publ. geol. Soc. S. Afr., **11**, 267-272.

Miller, R.McG. and Schalk, KE.L. 1980. Geological map of South West Africa/Namibia (1: 1 000 000). *Geol. Surv. Namibia*, Windhoek, 4 sheets.

Moores, E.M. 1991. Southwest U.S.-East Antarctica (SWEAT) connection: a hypothesis. *Geology,* **19**, 425-428.

Powell, C.McA., Li, Z.X., McElhinny, M.W., Meert, J.G. and Park, J.K 1993. Paleomagnetic constraints on timing of the Neoproterozoic breakup of Rodinia and Cambrian formation of Gonwana. *Geology,* **21**, 889-892.

Roots, C.P. and Parrish, R.R. 1988. Age of the Mount Harper volcanic complex, southern Ogilvie Mountains, Yukon. *In*: *Radiogenic Age and Isotopic Studies: Report 2*. Geol. Surv. Can. Pap., **88-2**, 29-35.

Ross, G.M. 1991. Tectonic setting of the Windermere Supergroup revisited. *Geology,* **19**, 1125-1128.

SACS (South African Committee for Stratigraphy) 1980. Damara Sequence. *In*: Kent, L.E. (compiler), *Stratigraphy of South Africa, Part 1*. Handbook Geol. Surv. S. Afr., **8**, 415-438.

Smit, J.M. van der Merwe. 1962. Stratigraphy and metamorphism of the Otavi Series south-east of Otavi, South West Africa. *Trans. geol. Soc. S. Afr.*, **65**, 63-78.

Stanistreet, I.G., Kukla, P.A. and Henry, G. 1991. Sedimentary basinal response to a Late Precambrian Wilson cycle: the Damara orogen and Nama foreland, Namibia. *J. Afr. Earth Sci.*, **13**, 141-156.

Stern, R.J. 1994. Arc assembly and continental collision in the Neoproterozoic East African orogen: implications for the consolidation of Gondwanaland. *Ann. Rev. Earth Planet. Sci.*, **22**, 319-351.

Storey, B.C., Alabaster, T., Macdonald, D.I.M., Millar, I.L., Pankhurst, R.I. and Dalziel, I.W.D. 1992. Upper Proterozoic rift-related rocks in the Pensacola Mountains, Antarctica: precursors to supercontinent breakup? *Tectonics,* **11**, 1392-1405.

Smith, R.L. and Bailey, R.A. 1968. Resurgent caldrons. *In*: Coats, R.R. and others, (eds.) *Studies in Volcanology*. Geol. Soc. Am. Mem., **116**, 613-662.

Tegtmeyer, A. and Kröner, A. 1985. U-Pb zircon ages for granitoid gneisses in northern Namibia and their significance for Proterozoic crustal evolution of southwestern Africa. *Precamb. Res.*, **28**, 311-326.

Williams, H. and Hiscott, R.N. 1987. Definition of the Iapetus rift-drift transition in western Newfoundland. *Geology,* **15**, 1044-1047.

Young, G.M. 1995. Are Neoproterozoic glacial deposits preserved on the margins of Laurentia related to the fragmentation of two supercontinents? *Geology,* **23**, 153-156.