DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY

EVOLUTION OF THE MIDDLE PROTEROZOIC CHANDABOOKA CALDERA, GAWLER RANGE ACID VOLCANO-PLUTONIC PROVINCE, SOUTH AUSTRALIA

(Submitted for publication in J. geol. Soc. Aust.)

by

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Rept.Bk.No. 77/107
G.S. No. 5926
D.M. No. 510/77

20th September, 1977.

CONTENTS

FIGURES

12. FMA diagrams and graphs of SiO_2 versus $Na_2O + K_2O$ for phases in the Gawler Range province, Kokatha area.

13. Columnar jointing in a rhyodacite ignimbrite sheet in the andesite-rhyodacite dome and flow unit. Photograph is looking east at the face of the upper section in Fig. 10; sample 201 is from the ignimbrite sheet.

14. Cross section through the compound cooling unit of the lower outflow facies, Chandabooka Dacite on the north slope of Chitanilga Hill. The location of the silicate analysis samples on Fig. 4 defines the line of section.

15. Amygdaloidal rhyolite flow in the rhyolite-rhyodacite ignimbrite unit near the western shore of Lake Harris.

16. Vertical contact with a sill-like apophysis between Hiltaba Granite and recrystallised Chandabooka Dacite near sample locality 196, Fig. 4.

17. Detail of Hiltaba Granite-Chandabooka Dacite contact near sample locality 196, Fig. 4, showing the absence of chilling in the medium grained granite against the contact with recrystallised rhyodacite.

18. FMA plot of 69 unaltered volcanic and intrusive rocks from all major units in the Gawler Range province, Kokatha area.

TABLES

1. Stratovolcano Phase: chemical data for major (%) and trace (p.p.m.) elements, and CIPW weight percent norms. Sample localities are shown on Fig. 4. Analyses are listed in ascending stratigraphical order in each unit.

2. Premonitory Caldera Phase: chemical data for major (%) and trace (p.p.m.) elements, and CIPW weight percent norms. Sample localities are shown on Fig. 4. Groups of analyses arranged in ascending stratigraphical order are 182, 201, 236, 242; 247, 246, 245; 251, 252, 250.

3. Caldera Phase: chemical data for major (%) and trace (p.p.m.) elements, and CIPW weight percent norms. Sample localities are shown on Fig. 4 except 180 which is 2 km east of 186. Groups of analyses arranged in ascending stratigraphic order are 187, 188, 189; 223, 224, 225, 176; 227, 278.

4. Post-caldera Phase and Intrusive Phase: chemical data for major (%) and trace (p.p.m.) elements, and CIPW weight percent norms. Sample localities are shown on Fig. 4, except 192 which is 8 km northeast of map area.

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ABSTRACT

Volcanism associated with the Middle Proterozoic Gawler Range acid volcano-plutonic province was initiated in the Kokatha area by the construction on Archaean basement of a large stratovolcano composed mainly of tholeiitic basalt and potassic basaltic andesite erupted from a mantle-derived ultramafic diapir.

Crustal melting above the diapir generated acid magma, rich in silica and potassium, which rose by major block stoping to form a subvolcanic magma chamber. Leakage from this chamber during the premonitory caldera phase gave rise to small explosive and effusive eruptions around an incipient ring-fracture zone. In the caldera phase, the eruption of voluminous rhyodacite to dacite ignimbrite from the subvolcanic magma chamber resulted in collapse of the roof partway through the eruption to form the Chandabooka caldera, 15 km by 10 km across: the ignimbrite comprises a thick compound cooling unit, the Chandabooka Dacite, of which both the caldera and outflow facies are preserved. Resurgent doming and subsequent uplift of the caldera block by 1 km

followed in the post-caldera phase, accompanied by minor acidic volcanism. Flat-roofed stocks of the primitive S-type Hiltaba Granite and a major dyke swarm intruded the volcanic pile to complete the volcano-plutonic episode.

REGIONAL SETTING

The Gawler Range Volcanics as defined by Blissett (1975) are predominantly a flat-lying pile of terrestrial acid ignimbrites which cover 25 000 km^2 in southern central South Australia (Fig. 1). Together with the comagmatic Hiltaba Granite and scattered related volcanics and granites they constitute a major acid volcano-plutonic province (Ustiyev, 1965; Branch, 1967b) with an area of at least 200 000 km^2 mainly within the Gawler Craton (Fig. 1). Webb (in Radke & Webb, 1976) and Webb (1977), participating with Blissett and Radke in a regional study of the province, has obtained Middle Proterozoic ages between 1525 Ma and 1457 Ma for the volcanics and intrusives (using the decay constant $\lambda Rb^{87} = 1.42 \times 10^{-11} y^{-1}$).

In a tectonic synthesis of the Gawler Craton, Thomson (1976) and Webb & Thomson (1977) concluded that the Gawler Range acid volcano-plutonic province was generated during the Late Carpentarian as a post-tectonic magmatic event in the Archaean Gawler Craton: the transitional tectonism stage of Plumb (1976). This is similar to the setting envisaged by Branch (1963; 1966; 1967a, b; 1969) for the upper Palaeozoic acid volcano-plutonic province of northern Queensland, which has many features in common with the Gawler Range province.

Over most of their area the ignimbrite sheets in the Gawler Range Volcanics are flat-lying (Crawford, 1963; Blissett, 1977) and, although original glass in the ignimbrites is now finely devitrified, delicate textures such as shards and perlitic cracks are well preserved (Figs 2, 3). Much of the volcanic pile is almost undeformed and has suffered only erosion and block faulting over the past 1500 Ma. Strong deformation is restricted to zones near some faults where the volcanics are tilted to near-vertical (Turner, 1975).

Generally, the volcanic pile is about 1 km thick and comprises one or more dacite, rhyodacite, or rhyolite ignimbrite sheets associated with minor lavas and air-fall tuffs of similar composition. However, south of Kingoonya (Fig. 1) two more complicated areas have been recognised. In the first area, near Kokatha homestead 65 km south of Kingoonya, the first-recognised caldera in the province - the Chandabooka caldera (Branch, 1975, 1977 and this paper) - is nested within the Chitanilga Volcanic Complex which contains one of the rare basaltic sequences in the Gawler Range Volcanics (Blissett, 1975). The second area, 50 km further south near Lake Everard, comprises the Glyde Hill Volcanic Complex (Blissett, 1975; Giles, 1977) which is suspected to be another eruptive centre.

THE KOKATHA AREA

The area mapped in detail near Kokatha homestead is shown in Figure 4, with a cross-section (Fig. 5) and a tectonic interpretation map (Fig. 6). Much of the area is covered by Cainozoic deposits which form widespread arid sandy plains and salt lakes at an average elevation of

140 m above sea level. Hills of volcanics and granite rise above the plains to a maximum elevation of 314 m above sea level at Chitanilga Hill (Fig. 7).

On Figure 4 the reference outlines the proposed stratigraphic and structural sequences in the area: these are illustrated diagramatically on Figure 8a. Four phases of volcanic activity are recognised (stratovolcano phase, premonitory caldera phase, caldera phase, and post-caldera phase) each comprising one or more eruptive units, followed by one intrusive phase. All the names used for phases and units are informal except the Hiltaba Granite (Compston _et al._, 1966) and Chandabooka Dacite (Blissett, 1975). The sequence of events interpreted here, where part of the volcanic succession is repeated across a caldera margin by faulting, differs from Blissett (1975) who considers that the volcanic units are stacked in an easterly dipping sequence which he named the Chitanilga Volcanic Complex, overlain by the Chandabooka Dacite (Fig. 5). The evidence for my interpretation is given in this paper.

Nomenclature

Volcanic rocks such as _rhyolite_, _dacite_, _basalt_, are distinguished by their silica percentage (Fig. 8b): the percentages used are similar to those proposed by Lowder (_in_ Blissett, 1975) who based them on natural populations in the province (see histogram, Fig. 8b). However, as discussed in the section on the basalt-rhyolite bimodal unit, the andesites in the Kokatha area are not calcalkaline, so the prefix potassic is used to indicate their chemical characteristic. The nomenclature of intrusive rocks follows Streckeisen (1976).

Ignimbrite is synonymous with ash-flow tuff (Smith, 1960a, pp. 800-801; 1960b; Ross & Smith, 1961), and may be non-welded; or incipiently, moderately or densely welded. For brevity in this paper the lithological term ignimbrite also carries the connotation of an ash-flow cooling unit (Smith, 1960a), hence ignimbrite in the appropriate context implies ignimbrite sheets which may be either simple or compound cooling units.

Caldera is used to denote a structure which at the time of formation was, as proposed by Williams (1941) a large, roughly circular or oval topographic depression in the central area of a volcano or volcanic complex. The term 'Chandabooka caldera' is used deliberately to envoke an impression of the palaeoenvironment at the time volcanism was active in the area, although no topographic expression of the caldera is preserved because of subsequent resurgence (Smith & Bailey, 1968) and erosion. It is assumed that calderas associated with acidic volcanism are the surface expression of ring complexes (Branch, 1967a, 1976; Walker, 1975; Bussell et al., 1976).

Terms such as moat, outflow and caldera facies, post-resurgence dome, together with the general structural model upon which my interpretation is based are described by Smith & Bailey (1968); Lipman (1975); Bailey et al., (1976); Byers et al., (1976); Elston & Northrop (1976); Steven & Lipman (1976). These authors, through their detailed studies in southwestern U.S.A., have contributed significantly to our understanding of the processes and products of acid volcanism.

BASEMENT TO THE VOLCANIC PILE

Late Archaean or early Proterozoic gneissic granite (Webb & Thomson, 1977) intruding basic calc-silicates and pillow lavas (Forbes et al., 1977) crop out in a few isolated areas on the western and northern sides of the Kokatha area (Fig. 4). These represent the older rocks in the Gawler Craton which form the basement to the Gawler Range Volcanics. Xenoliths and xenocrysts of basement rocks occur in some of the overlying volcanic units, particularly in the premonitory caldera phase when explosive activity was prevalent.

STRATOVOLCANO PHASE

Volcanic activity associated with the Gawler Range Volcanics was initiated in the Kokatha area 1525 $\pm$ 15 Ma ago by the construction of a large stratovolcano. Remnants of this volcano are preserved in two areas: the western area on the westerly slopes of Chitanilga Hill; and the eastern area 3 km east of Kokatha homestead. These remnants were designated by Blissett (1975) as units Bac_1, Bac_3, Bac_4 amongst the six units comprising the Chitanilga Volcanic Complex, but in future it would be more appropriate to restrict the term Chitanilga to the succession representing the stratovolcano.

In the western area the volcanic pile is about 1400 m thick and dips 30° east (Figs 4, 9). The lowest exposed volcanics crop out 800 m east of the nearest Archaean basement, so the basement unconformity cannot be observed. However, shallow drilling by Asarco (Dodds, 1969) has shown that volcanics underlie most of the intervening area. The top of the pile is overlain with a slight unconformity by the lower outflow facies of the Chandabooka Dacite.

In the eastern area the exposed volcanics are about 200 m thick and dip 15^{o} east (Figs 4, 10). They are preserved within the Chandabooka caldera and the caldera-margin fault truncates them on the western side. The volcanics are overlain with a very slight unconformity by the basal unit of the premonitory caldera phase.

The correlation of the eastern volcanics with the western volcanics provides some of the evidence for the existence of the caldera. This correlation is based on the presence of unusual potassic basaltic andesite flows in both sequences (Table 1, samples 171, 172 and 241, 240) and on their absence elsewhere in the Gawler Range province. If these flows are correlated, structural data dictate that the sequence is repeated by faulting (Fig. 5). I interpret this fault as the caldera-margin fault, and conclude that the eastern sequence was uplifted to its present position by resurgent doming soon after the caldera had formed.

Basalt-rhyolite bimodal unit

Tholeiitic basalt, potassic basaltic andesite and potassic andesite flows comprise three-quarters of the preserved stratovolcano (Figs 4, 9, 10; Table 1). However, the lowest exposed volcanic (Fig. 9) is an incipiently to moderately welded dacite ignimbrite, and other acid volcanics are interbedded higher in the basic pile (Fig. 10).

The basalts and andesites are all non-porphyritic, sometimes amygdaloidal, dark grey to blackish green fine even grained rocks (Fig. 11). They consist mainly of calcic plagioclase microlites, scattered opaque grains, and rare fresh olivine, pyroxene, and hornblende (in andesite only), more commonly pseudomorphed by bowlingite, chlorite, uralite or epidote. The only gabbro found in the area (sample 258 from a dyke) consists of approximately equal amounts of labradorite and clinopyroxene. In the andesite, staining shows that alkali feldspar is restricted to the groundmass.

Chemical analyses are tabulated in Table 1. The average of the most primitive basic rocks (samples 198, 220, 194, 258) is similar to the average continental tholeiite (Hyndman, 1972, p. 171) although considerable variation exists for iron and magnesia. When plotted on a FMA diagram (Fig. 12a) the analysed basalts, basaltic andesites and andesites define a typical tholeiitic iron-enrichment trend, confirming the tholeiitic affinity of this suite of rocks.

Dacite to rhyolite ignimbrites, interbedded with the basic flows, form simple cooling units up to 100 m thick (Fig. 9). The ignimbrites range from red-brown to grey as the degree of welding increases from incipient to dense. All the ignimbrites contain 10 to 25% phenocrysts ranging up to 2 mm across, surrounded by a devitrified groundmass in which shards and fiamme 0.5 to 7 cm long are common. In dacite most phenocrysts are sodic plagioclase, but alkali feldspar increases from rhyodacite to rhyolite, and quartz is common only in rhyolite. Rhyolite flows and thin beds of crystal, vitric or lithic-rich airfall tuff, lapilli tuff and chert are interbedded with basic flows and ignimbrites in both the western and eastern sequences.

TABLE 1. Stratovolcano Phase: chemical data for major (%) and trace (p.p.m.) elements, and CIPW weight percent norms. Sample localities are shown on Fig. 4 . Analyses are listed in ascending stratigraphical order in each unit.

UNIT	Basalt-Rhyolite Bimodal Unit (western area)									Basalt-Rhyolite Bimodal Unit (eastern area)							Dykes	
SAMPLE	203	173	219	220	198	170	171	172	222	241	240	239	238	237	261	206	194	258
ROCK TYPE	Dacite	Dacite	Rhyodacite	Basalt	Basalt	Rhyodacite	Potassic basaltic andesite	Potassic basaltic andesite	Potassic andesite	Potassic basaltic andesite	Potassic basaltic andesite	Rhyolite	Rhyolite	Potassic andesite	Dacite	Potassic andesite	Basalt	Gabbro
SiO_2	67.61	66.75	70.90	52.38	52.25	70.34	54.42	54.31	56.91	53.46	53.71	73.79	75.87	58.06	65.21	62.80	51.09	50.00
TiO_2	.52	.66	.26	1.09	.76	.45	1.99	2.26	1.70	1.68	1.71	.30	.28	1.14	.83	.93	1.81	3.38
Al_2O_3	15.54	16.65	14.34	14.87	13.96	14.97	14.09	14.22	14.98	14.39	14.54	13.05	12.09	14.34	13.90	13.99	13.64	12.79
Fe_2O_3	1.59	.87	1.48	4.84	2.82	1.19	3.58	3.83	3.18	6.18	5.58	1.27	2.24	3.49	3.14	2.57	6.32	5.07
FeO	1.65	2.51	.51	4.20	6.20	1.16	7.76	6.95	5.30	6.15	6.60	1.77	.32	6.00	3.15	4.70	7.08	9.40
MnO	.09	.12	.05	.18	.15	.09	.18	.18	.26	.18	.20	.05	.02	.19	.11	.12	.22	.17
MgO	1.03	1.46	.46	6.83	8.89	.64	3.22	3.11	2.80	3.11	2.88	1.23	.31	3.19	1.43	2.10	4.87	4.13
CaO	2.79	1.32	1.25	9.22	7.44	1.48	6.36	6.36	4.99	6.51	6.20	.66	.19	5.15	2.80	4.29	8.83	8.81
Na_2O	4.19	2.94	3.87	2.40	2.77	3.58	2.86	3.04	3.73	3.18	3.52	1.25	5.46	3.59	3.25	3.55	2.32	1.85
K_2O	3.92	3.95	4.49	1.05	1.45	5.11	2.96	2.71	3.16	2.39	2.11	5.00	2.17	2.36	3.82	3.29	1.04	.76
P_2O_5	.20	.18	.07	.09	.21	.09	.76	1.15	.89	.37	.41	.03	.06	.23	.16	.19	.16	.30
H_2O+	.72	1.97	-	-	1.32	.69	1.16	1.34	-	-	-	-	-	-	1.40	.90	1.44	-
H_2O-	.08	.11	-	-	.14	.03	.04	.06	-	-	-	-	-	-	.08	.04	.12	-
L.O.I.	-	-	1.12	1.47	-	-	-	-	.81	1.10	1.11	1.46	.55	1.20	-	-	-	1.08
TOTAL	99.94	99.50	98.80	98.62	98.36	99.83	99.39	99.52	98.71	98.70	98.57	99.86	99.56	98.94	99.28	99.47	98.94	97.74
q	21.10	29.44	28.73	7.93	1.43	26.08	8.65	10.11	9.71	9.39	8.94	44.12	35.48	12.02	23.80	17.31	9.91	12.79
c	0.00	5.72	1.04	0.00	0.00	1.09	0.00	0.00	0.00	0.00	0.00	4.53	.57	0.00	0.00	0.00	0.00	0.00
or	23.42	23.96	27.16	6.39	8.84	30.46	17.81	16.32	19.07	14.47	12.79	30.02	12.95	14.27	23.08	19.73	6.31	4.65
ab	35.74	25.53	33.51	20.89	24.18	30.55	24.64	26.20	32.22	27.56	30.55	10.74	46.64	31.07	28.11	30.74	20.15	16.19
an	12.10	5.52	5.88	27.49	22.06	6.81	17.18	17.48	15.12	18.38	18.11	3.13	.56	16.42	12.33	12.71	24.37	25.19
di	.44	0.00	0.00	14.97	11.73	0.00	8.20	5.76	3.45	9.89	8.75	0.00	0.00	6.72	.65	6.30	15.74	14.75
hy	3.41	6.84	1.17	12.77	25.55	2.18	12.59	11.38	10.31	6.99	8.26	4.94	.78	11.57	5.39	7.45	10.20	11.48
mt	2.33	1.29	1.08	7.22	4.22	1.74	5.29	5.66	4.71	9.18	8.30	1.87	.29	5.18	4.66	3.80	9.41	7.60
il	1.00	1.29	.51	2.13	1.49	.86	3.85	4.37	3.30	3.27	3.33	.58	.54	2.22	1.61	1.79	3.53	6.64
ap	.48	.44	.17	.22	.51	.22	1.84	2.78	2.16	.90	1.00	.07	.14	.56	.39	.46	.39	.74
Rb	125	145	-	-	40	185	85	80	-	-	-	-	-	-	-	95	75	-
Sr	490	440	-	-	550	245	500	530	-	-	-	-	-	-	-	360	250	-
Ba	1200	2200	-	-	800	1550	2200	1850	-	-	-	-	-	-	-	1250	5600	-
Pb	30	170	-	-	8	40	55	16	-	-	-	-	-	-	-	38	340	-
Mo	<10	6	-	-	<4	6	<4	<4	-	-	-	-	-	-	-	<10	<4	-
Cu	10	20	-	-	76	4	8	4	-	-	-	-	-	-	-	16	56	-
Zn	90	58	-	-	91	64	147	152	-	-	-	-	-	-	-	102	137	-
Ni	12	35	-	-	280	<5	10	<5	-	-	-	-	-	-	-	14	30	-
V	55	140	-	-	300	38	320	230	-	-	-	-	-	-	-	200	440	-
U	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<4	-	-

The analyses of the acid rocks (Table 1) when plotted on a FMA diagram (Fig. 12a) form a cluster clearly separated from the cluster of potassic basaltic andesites and andesites, but lying on the continuation of the tholeiitic trend displayed by the basic rocks. On both the plot of SiO_2 versus $Na_2O + K_2O$ (Fig. 12a) and SiO_2 versus time (Fig. 8c) the western and eastern sequences each display a silica gap of about 10% SiO_2 between the basic/intermediate and acid rocks. These data suggest the magmatic association in the stratovolcano phase is bimodal (cf. Christiansen & Lipman, 1972, pp. 253-254). On the other hand Figures 8c and 12a show that the silica gap for the western sequence occurs from 57 to 67% SiO_2, and for the eastern sequence from 65 to 75% SiO_2: when the data are combined the silica gaps tend to disappear.

A hint of a possible explanation for this situation is given by the few trace element analyses available (Table 1), and a consideration of the timing of the acid events. The first dacite erupted (sample 203) and the following dacite tuff (173) contain 490 and 440 ppm Sr. These values are high, and more like the content for basalt when compared with similar volcanic rocks elsewhere in the world (Hedge, 1966; Ewart & Stipp, 1968; Zielinski & Lipman, 1976). In contrast, the rhyodacite analysed for Sr higher in the western sequence (170) and the andesite at the top of the eastern sequence (206) with 62.8% SiO_2 (i.e., near the middle of the silica gap for the western sequence) both contain average Sr for their silica content and are similar to acidic volcanics erupted in the succeeding phases related to caldera formation.

One possible interpretation of these meagre data is that the first acid volcanics erupted are associates of the tholeiitic magma and together with the bulk of the volcanics in the western sequence display a bimodal character, with a silica gap between 57 and 67% SiO_2. Later volcanics with SiO_2 greater than 60%, particularly those in the eastern sequence, complicate this pattern because they are precursors of the following dominantly acid magma derived by crustal melting (discussed in the section on petrogenesis).

PREMONITORY CALDERA PHASE

During the premonitory caldera phase, small explosive and effusive intermediate to acid eruptions occurred from vents located along the first fractures to open in the potential caldera-margin zone. These eruptions represent early leakage from the magma chamber which subsequently supplied the Chandabooka Dacite. Smith & Bailey (1968) refer to this phase as Stage 1 in their resurgent caldera cycle: regional tuminescence - due to magma insurgence, broad doming, and initial formation of a ring-fracture system. As occurs elsewhere in the world, the caldera site in the Kokatha area is associated closely with an earlier major stratovolcano (Matumoto, 1943; Steven & Lipman, 1976).

The three units comprising the premonitory caldera phase are found now only in the Chandabooka caldera (Figs 4, 6). Many of the beds in the units are restricted in their aerial extent by pre-existing topographic relief and the small size of the eruptive events. As a consequence, beds and units are discontinuous, and the overall thickness ranges from a few metres to about 500 m.

Andesite-rhyodacite unit

The andesite-rhyodacite unit is the first in the premonitory caldera phase, and exposed remnants are confined to the southwest corner of the caldera. Here the unit has a thickness ranging from 1 to about 50 m, and lies with possibly a very slight unconformity on the uppermost potassic andesite in the eastern sequence of the basalt-rhyolite bimodal unit (Fig. 10). One kilometre to the east a tilted block 0.5 km by 1 km and 50 m thick of the andesite-rhyodacite unit is found overlying the succeeding rhyolite-rhyodacite dome and flow unit of the premonitory caldera phase (Figs 4, 5): this is due to a trapdoor effect whereby a consolidated slab of the earlier unit was lifted on the roof of a later intrusive rhyolite dome.

The basal bed in the andesite-rhyodacite unit is a distinctive greyish black to very dusky red porphyritic rhyodacite containing scattered xenoliths up to 25 cm across of basement acid gneiss and common xenocrysts derived from the xenoliths of quartz and glomeroporphyritic feldspar, together with fine crystals of sodium-rich hornblende from assimilated basic calc-silicates. These xenoliths and xenocrysts indicate that the first eruption in the premonitory caldera phase was highly gas-charged and tore material from the volcanic conduits. This bed is one to a few metres thick and is probably an airfall tuff, but it may be a block-rich base-surge deposit because it grades impercepibly upwards into a densely welded ignimbrite sheet 3 to 4 m thick with abundant xenocrysts and well developed columnar jointing (Figs 10, 13). The few overlying beds range from flow-banded rhyodacite to dacite and silica-rich potassic andesite

TABLE 2 . Premonitory Caldera Phase: chemical data for major (%) and trace (p.p.m.) elements, and CIPW weight percent norms. Sample localities are shown on Fig. 4 . Groups of analyses arranged in ascending stratigraphical order are 182, 201, 236, 242; 247, 246, 245; 251, 252, 250.

UNIT	Andesite - Rhyodacite Unit					Rhyolite - Rhyodacite Dome and Flow Unit													Dacite Rhyolite Unit
						Generally massive							Good flow banding			Disrupted	Contorted	Brecciated	
SAMPLE	182	201	236	242	254	247	246	245	178	244	248	249	251	252	250	253	185	255	211
ROCK TYPE	Rhyodacite	Rhyodacite	Dacite	Rhyodacite	Andesite	Rhyolite	Rhyodacite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyodacite	Rhyodacite	Rhyodacite	Dacite
SiO_2	69.24	69.87	64.20	71.78	62.28	73.75	72.78	73.53	74.59	74.04	74.07	74.82	73.42	73.40	74.08	71.19	70.32	72.72	67.94
TiO_2	.58	.56	.80	.46	.91	.35	.39	.42	.30	.24	.31	.29	.41	.35	.31	.51	.44	.43	.85
Al_2O_3	13.46	13.58	14.29	12.67	14.41	12.51	12.74	12.89	12.43	13.00	12.16	12.26	12.64	12.58	12.54	13.20	14.15	13.83	13.72
Fe_2O_3	2.60	1.88	2.80	2.11	3.25	1.77	1.71	1.10	2.35	1.26	1.87	1.85	1.77	2.00	1.87	2.75	2.50	2.07	1.25
FeO	2.00	2.06	3.40	1.04	3.75	1.14	1.41	1.74	.48	.71	.96	.60	1.04	.60	.70	.83	.72	1.15	3.90
MnO	.08	.09	.18	.07	.13	.06	.07	.07	.04	.03	.05	.04	.06	.03	.05	.07	.06	.05	.11
MgO	1.04	.82	1.80	.64	2.13	.40	.41	.33	.39	.36	.35	.35	.26	.38	.23	.52	.75	.57	.87
CaO	1.80	1.30	3.02	1.08	2.66	.63	.74	.60	.15	.28	.75	.17	.90	.33	.74	1.18	.80	.37	2.68
Na_2O	5.28	4.00	3.70	3.11	2.64	3.38	3.62	3.28	3.22	2.95	3.46	2.84	3.49	3.37	3.55	4.08	5.96	.93	2.36
K_2O	2.77	4.47	3.90	5.89	5.42	5.08	5.04	4.99	5.55	5.81	4.88	5.62	4.84	5.38	5.02	4.08	3.14	5.52	3.77
P_2O_5	.14	.14	.16	.10	.20	.06	.07	.08	.04	.04	.05	.04	.08	.05	.04	.12	.10	.06	.21
H_2O+	.46	.76	-	-	-	-	-	-	.46	-	-	-	-	-	-	-	.67	-	1.64
H_2O-	.06	.14	-	-	-	-	-	-	.04	-	-	-	-	-	-	-	.17	-	.04
L.O.I.	-	-	.98	.70	1.58	.53	.47	.71	-	.84	.83	.61	.47	.69	.48	.85	-	1.95	-
TOTAL	99.51	99.68	99.23	99.65	99.36	99.66	99.45	99.74	100.03	99.56	99.74	99.49	99.38	99.16	99.61	99.38	99.78	99.65	99.34
q	23.53	25.55	18.72	28.80	17.02	33.10	30.46	33.36	34.00	34.08	33.70	36.44	32.88	32.59	32.71	29.33	21.49	45.78	31.85
c	0.00	.14	0.00	0.00	0.00	.46	.16	1.21	.96	1.47	0.00	1.31	.22	.75	.02	.22	0.00	5.93	1.42
or	16.53	26.74	23.45	35.17	32.75	30.28	30.08	29.77	32.94	34.77	29.15	33.58	28.91	32.28	29.92	24.46	18.75	33.38	22.81
ab	45.11	34.25	31.85	26.58	22.84	28.84	30.93	28.01	27.36	25.27	29.59	24.29	29.84	28.95	30.29	35.02	50.95	8.05	20.44
an	4.90	5.60	11.07	3.26	11.73	2.76	3.25	2.48	.49	1.14	3.28	.59	3.99	1.33	3.44	5.15	2.62	1.48	12.21
di	2.55	0.00	2.54	1.17	.35	0.00	0.00	0.00	0.00	0.00	.12	0.00	0.00	0.00	0.00	0.00	.57	0.00	0.00
hy	2.12	3.56	6.31	1.07	8.26	1.17	1.70	2.57	.98	.91	.83	.88	.65	.96	.58	1.31	1.62	1.45	7.26
mt	3.81	2.76	4.13	2.27	4.82	2.59	2.50	1.61	.81	1.71	2.38	1.24	2.39	1.03	1.53	1.45	1.25	2.69	1.87
il	1.11	1.08	1.55	.88	1.77	.67	.75	.81	.57	.46	.60	.56	.79	.68	.59	.98	.84	.84	1.65
ap	.34	.34	.39	.24	.48	.14	.17	.19	.10	.10	.12	.11	.19	.12	.10	.29	.24	.15	.51
Rb	100	150	-	-	-	-	-	-	190	-	-	-	-	-	-	-	105	-	160
Sr	270	240	-	-	-	-	-	-	90	-	-	-	-	-	-	-	180	-	230
Ba	1040	1500	-	-	-	-	-	-	1440	-	-	-	-	-	-	-	1120	-	1600
Pb	28	28	-	-	-	-	-	-	22	-	-	-	-	-	-	-	16	-	34
Mo	6	<4	-	-	-	-	-	-	4	-	-	-	-	-	-	-	4	-	<10
Cu	16	12	-	-	-	-	-	-	8	-	-	-	-	-	-	-	16	-	6
Zn	84	79	-	-	-	-	-	-	64	-	-	-	-	-	-	-	72	-	104
Ni	<5	28	-	-	-	-	-	-	10	-	-	-	-	-	-	-	<5	-	8
V	<5	70	-	-	-	-	-	-	10	-	-	-	-	-	-	-	25	-	45
U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6

flows (Table 2), mostly with basement xenocrysts.

When plotted on a FMA diagram and the graph of SiO_2 versus Na_2O + K_2O (Fig. 12b) these rocks coincide with the more acid rocks of the preceding stratovolcano phase, and overlap the silica gap indicated by the western sequence of that phase (Fig. 8c). Rhyodacite 182 in this unit is one of the rare acidic rocks in the Kokatha area with Na_2O greater than K_2O; the excess sodium is probably derived from the abundant sodium-rich hornblende xenocrysts in this sample.

Rhyolite-rhyodacite dome and flow unit

The rhyolite-rhyodacite dome and flow unit rests on the andesite-rhyodacite unit where it is present (Figs 4, 10); elsewhere the base of the unit is not exposed. Although the unit appears on Figure 4 as a shallow-dipping bed with a fairly uniform width, it comprises a coalesced pile of rhyolitic domes and short flows with a maximum aggregate thickness of 300 m closest to the caldera margin.

Dark to moderate red-brown finely porphyritic rhyolite grading into rhyodacite predominates in this unit (Table 2, Fig. 12b). Alkali feldspar phenocrysts 0.5 to 2 mm across are ubiquitous and comprise 5 to 10% of the rock; a few percent of small quartz phenocrysts are common together with less common hornblende and rare basement xenoliths. Near the bottom of the rhyolitic pile most of the flow texture is obliterated by spherulitic devitrification, but banding becomes more obvious and contorted towards the top. A dyke 2 m wide at sample locality 253 contains rhyodacite with disrupted flow banding resembling eutaxitic texture caused by vertical gas streaming.

At many localities the top of the dome and flow unit is marked by a coarse breccia. In some instances contorted lava grades upwards into the breccia suggesting autobrecciation. However, in the area along strike from sample locality 255, the breccia forms a sheet 2 m thick which may be a dome-collapse avalanche deposit (MacDonald, 1972).

Dacite-rhyolite unit

Following the effusive events of the rhyolite-rhyodacite dome and flow unit, the dacite-rhyolite unit indicates an increase in explosive and possibly laharic activity prior to the onset of the caldera phase. The unit ranges in thickness from 10 to 50 m and is exposed above the dome and flow unit only near the western and southern margins of the Chandabooka caldera.

Thin flows and ignimbrite sheets of dark grey to greyish red porphyritic dacite and rhyodacite containing basement xenoliths and xenocrysts are most common. These are interbedded in part with rhyolitic lapillistone, crystal-lithic tuff and reworked tuff possibly representing a lahar deposit.

CALDERA PHASE

A voluminous eruption of dacite to rhyodacite ignimbrite occurred in the Kokatha area 1511 $\pm$ 36 Ma ago. It is envisaged that when the ring-fracture zone was sufficiently well established at the end of the premonitory caldera phase, it became possible to trigger the eruption of innumerable ash flows which succeeded each other so rapidly that a thick compound cooling unit was formed. During the early part of the eruption ash flows spread widely. Later, the magma chamber roof collapsed along the ring fracture zone to form a caldera: eruptions which occurred concurrently with the collapse were ponded mainly in the caldera.

The Chandabooka Dacite as originally defined by Blissett (1975) forms an irregular saucer-shaped structure 15 km wide and 10 km long, the western two-thirds of which occur in the map area (Fig. 6). I consider this dacite to represent the ignimbrite sheet preserved within the Chandabooka caldera, and on this basis it is designated the caldera facies. In addition, in this paper the Chandabooka Dacite is extended to include thick rhyodacite ignimbrite assigned by Blissett (1975) to unit Bac_2 which crops out on the eastern slopes of Chitanilga Hill and in several areas to the north: because this dacite is outside the caldera it is designated the outflow facies.

Chandabooka Dacite: caldera facies

Densely welded devitrified porphyritic dacite to rhyodacite ignimbrite which constitutes the caldera facies is typically greyish red grading to black where welding is intense. Near the western margin of the caldera the sheet dips 5 to 10^{o} east, but in the centre, towards the eastern edge of the mapped area, it is almost horizontal. The preserved thickness of 300 m is a minimum because the top of the unit everywhere is the present erosion surface.

The compound nature of the ignimbrite is shown best by several repeated zones of various degrees of welding and bands of columnar jointing or sheet jointing where welding is more intense. Generally the ignimbrite contains 15 to 25% phenocrysts 2 to 5 mm long of cream plagioclase, scattered quartz and rare hornblende, in a groundmass which ranges in texture from finely devitrified with a diffuse eutaxitic texture to microspherulitic.

The chemical analyses in Table 3 show that the caldera facies ranges from dacite to rhyodacite. On the FMA diagram, and the graph of SiO_2 versus Na_2O + K_2O (Fig. 12c) the analyses cluster in a small area indicating that only subtle changes in magma composition occurred during the eruption interval represented by the preserved succession. However, as suggested in the next paragraph, this succession probably represents a minimum of one-third of the erupted thickness, so evidence of compositional zoning as found in some ignimbrite sheets (e.g. Lipman *et al.*, 1966) would not be expected.

Chandabooka Dacite: outflow facies

Rhyodacite ignimbrite similar in appearance and composition to the caldera facies comprises the outflow facies of the Chandabooka Dacite. The facies is 650 m thick at Chitanilga Hill where it unconformably overlies the basalt-rhyolite bimodal unit of the stratovolcano phase and is unconformably overlain by the rhyolite-rhyodacite ignimbrite unit of the post-caldera phase. Thus the outflow facies provides a better estimate of the minimum true thickness of the Chandabooka Dacite than the caldera facies where no cover rocks are preserved: by analogy with many Tertiary calderas (e.g. Lipman, 1975; Bailey *et al.*, 1976; Byers *et al.*, 1976; Elston & Northrop, 1976, p. 6) and by using the thickness of the outflow facies as a guide, the caldera facies originally may have been at least 1 000 m thick.

TABLE 3 . Caldera Phase: chemical data for major (%) and trace (p.p.m.)elements, and CIPW weight percent norms. Sample localities are shown on Fig.4 except 180 which is 2 km east of 186. Groups of analyses arranged in ascending stratigraphic order are 187, 188, 189; 223, 224, 225, 176; 227, 278.

UNIT	Chandabooka Dacite: caldera facies									Lower outflow facies						Upper outflow facies		
SAMPLE	187	188	189	180	184	186	190	202	212	223	224	225	176	226	229	227	228	230
ROCK TYPE	Dacite	Rhyodacite	Rhyodacite	Dacite	Dacite	Rhyodacite	Rhyodacite	Dacite	Rhyodacite	Rhyodacite	Rhyodacite	Rhyodacite	Rhyodacite	Rhyodacite	Rhyodacite	Rhyodacite	Rhyodacite	Rhyodacite
SiO_2	67.88	69.30	69.69	67.72	68.00	72.16	69.73	66.61	69.05	71.34	70.27	70.77	70.22	70.75	70.31	69.99	70.26	69.95
TiO_2	.64	.58	.56	.72	.69	.35	.58	.70	.57	.39	.39	.38	.41	.41	.52	.60	.58	.55
Al_2O_3	14.10	13.78	13.73	13.74	13.57	12.87	13.58	13.75	13.59	13.95	14.07	13.96	13.88	15.06	14.34	14.43	14.53	14.28
Fe_2O_3	1.64	1.89	1.30	2.22	1.92	1.97	1.37	1.77	1.44	1.69	1.95	1.78	1.79	2.32	1.73	2.69	2.87	1.77
FeO	2.88	2.35	2.66	2.77	3.01	1.10	2.70	2.84	2.50	1.25	1.10	1.19	1.42	.39	1.19	.58	.39	1.19
MnO	.12	.07	.11	.06	.10	.07	.09	.08	.09	.14	.07	.08	.10	.06	.10	.12	.10	.14
MgO	.76	.90	.76	.86	.75	1.04	.67	.96	.61	.32	.46	.39	.46	.29	.37	.40	.17	.48
CaO	2.00	1.12	1.56	2.17	2.09	.24	1.79	1.82	1.91	.73	.64	.69	.73	.52	.90	.89	.95	1.37
Na_2O	3.22	3.44	3.26	3.38	3.66	3.12	3.32	3.33	3.66	3.97	4.49	4.00	4.22	3.21	4.17	3.91	4.52	3.92
K_2O	5.17	4.99	5.04	4.65	4.78	5.01	5.04	4.64	4.64	5.36	4.93	5.52	5.15	5.54	5.30	5.36	4.90	5.04
P_2O_5	.17	.15	.14	.21	.19	.06	.14	.18	.14	.06	.06	.07	.06	.06	.09	.11	.06	.10
H_2O+	.96	.89	1.08	1.15	.65	1.21	.87	1.35	1.15	-	-	-	.57	-	-	-	-	-
H_2O-	.04	.03	.02	.09	.01	.11	.01	.17	.07	-	-	-	.03	-	-	-	-	-
L.O.I.	-	-	-	-	-	-	-	-	-	.56	.55	.57	-	1.17	.60	.77	.47	.66
TOTAL	99.58	99.49	99.92	99.75	99.42	99.31	99.90	98.18	99.42	99.76	98.98	99.40	99.04	99.78	99.62	99.85	99.80	99.45
q	23.38	26.39	26.28	24.49	22.87	33.64	25.73	24.23	25.02	25.86	23.79	24.72	23.99	29.93	23.76	24.79	23.27	24.78
c	0.00	1.06	.42	0.00	0.00	2.07	0.00	.39	0.00	.44	.34	.32	.19	3.03	.33	.85	.21	.13
or	30.99	29.91	30.14	27.89	28.60	30.21	30.07	28.36	27.92	31.92	29.59	33.00	30.91	33.19	31.62	31.96	29.15	30.14
ab	27.63	29.52	27.90	29.02	31.34	26.93	28.36	29.13	31.52	33.85	38.58	34.23	36.26	27.53	35.62	33.38	38.49	33.56
an	8.88	4.64	6.91	8.72	6.57	.82	7.35	8.12	7.08	3.26	2.83	3.00	3.28	2.22	3.91	3.73	4.35	6.22
di	.05	0.00	0.00	.67	2.25	0.00	.59	0.00	1.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hy	5.04	4.23	5.04	4.05	3.79	2.64	4.45	5.31	3.53	1.32	1.16	1.22	1.81	.73	1.01	1.01	.43	1.29
mt	2.41	2.78	1.91	3.27	2.82	2.82	2.01	2.65	2.13	2.47	2.69	2.61	2.64	.27	2.53	.53	0.00	2.60
il	1.23	1.12	1.08	1.39	1.33	.68	1.11	1.38	1.10	.75	.75	.73	.79	.79	1.00	1.15	1.04	1.06
ap	.41	.36	.34	.51	.46	.15	.34	.44	.34	.14	.14	.17	.14	.14	.22	.26	.14	.24
ru	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.03	0.00
Rb	170	180	190	150	155	165	170	170	160	-	-	-	165	-	-	-	-	-
Sr	240	190	215	180	200	75	215	205	220	-	-	-	155	-	-	-	-	-
Ba	1500	1350	1340	1340	1320	1220	1350	1720	1550	-	-	-	2140	-	-	-	-	-
Pb	42	24	135	22	26	55	32	32	34	-	-	-	32	-	-	-	-	-
Mo	<4	4	<4	4	4	8	<4	<4	<10	-	-	-	6	-	-	-	-	-
Cu	8	16	16	12	20	8	8	14	10	-	-	-	8	-	-	-	-	-
Zn	92	82	87	47	102	102	73	102	114	-	-	-	92	-	-	-	-	-
Ni	<5	<5	5	10	<5	<5	<5	25	10	-	-	-	<5	-	-	-	-	-
V	45	25	35	45	35	10	25	60	30	-	-	-	8	-	-	-	-	-
U	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-

A thin airfall tuff bed divides the outflow facies into a lower sheet 500 m thick and an upper sheet 150 m thick. The lower sheet in a well exposed section at Chitanilga Hill is seen clearly to be a compound cooling unit (Fig. 14). Zones of contorted banding in the section resembling flow banding represent either rheoignimbrite (Rittmann, 1958; Schmincke & Swanson, 1967) or laminar flow layers (Chapin & Lowell, 1975) distorted by slumping. The upper sheet is identical in composition to the lower one, but it is not so obviously a compound cooling unit.

The tuff bed separating the lower and upper outflow facies is generally a few metres thick, although in places it has been removed by the passage of the upper ash flow. It can be traced over a strike length of 2.5 km north of Kokatha homestead then disappears under Cainozoic cover to reappear briefly 9 km further north, near Lake Harris (Fig. 4). Everywhere the tuff is slightly sheared due to differential movement between the two ignimbrite sheets. Individual beds 0.5 to 5 cm thick range from dark yellow-brown to blackish red crystal-lithic to vitric-lithic airfall tuff. This tuff possibly represents a brief hiatus in the eruption of the Chandabooka Dacite caused by a short burst of more explosive activity when caldera subsidence began.

Table 3 and particularly Figure 12c show that the outflow facies is on average about 1% richer in total alkalis and 1.5% richer in silica than the caldera facies. Similar and larger differences are common in Tertiary analogues (Lipman, 1975, table 4; Byers *et al.*, 1976, fig. 9) due to the effects during eruption of winnowing, ponding, and distance from the source. Although in the Chandabooka Dacite chemical differences exist between the caldera and outflow facies, cluster analysis of all rocks from the Kokatha area shows a higher degree of correlation between these two facies than with all other units. The resulting structural correlation of the caldera facies with the outflow facies provides additional evidence for the existence of the caldera margin fault (Fig. 5).

CALDERA FAULTING, COLLAPSE BRECCIA AND RESURGENT DOMING

Circumstantial evidence presented in the preceding section suggests that partway through the eruption of the Chandabooka Dacite the Chandabooka caldera block about 15 km long and 10 km wide subsided at least 350 m. The main caldera fault is exposed only in the headwaters of a small gully 2.5 km northeast of Kokatha homestead, just east of sample locality 262 (Fig. 4). However, the outcrop evidence of large lenses of strong brecciation, metasomatic alteration and abundant patches of drusy quartz in a zone 50 m wide is not the result of the primary displacement, but of secondary reverse movements which occurred subsequently during resurgent doming and later phases younger than the rhyolite-rhyodacite ignimbrite unit in the post-caldera phase.

Penecontemporaneously with caldera collapse, breccia slides derived from the caldera walls intertongue with the upper ash flows ponded in the caldera (Lipman, 1976) and grade upwards into caldera-lake sediments (Fig. 8a). In the Chandabooka caldera erosion has removed all deposits of this nature, if they ever existed, but it is important that they be looked for in every caldera because they indicate an environment in which volcano-sedimentary ore deposits may form (Branch, 1976).

Following caldera collapse, Smith & Bailey (1968) recognise a stage of resurgent doming in the caldera with the consequent development of a moat between the dome and the caldera rim. In the Chandabooka caldera the resurgent dome is represented by an off-centre anticline (Figs 5, 6) similar to the dome in the Long Valley caldera (Bailey *et al*., 1976) although evidence for a keystone graben is absent. Dips on the flanks of the dome range from 5^{o} to 15^{o}, making it a prominent structural feature in a province where anticlines are rare.

Concurrently with the doming, uplift of the entire caldera block commenced and continued until the end of the post-caldera phase by which time it had risen about 1 km to its present position relative to the surrounding volcanic pile.

POST-CALDERA PHASE

The post-caldera phase comprises a disparate set of units preserved in the Kokatha area which represent the waning stages of volcanic activity related to the Chandabooka caldera.

Rhyolite dome unit

An inlier surrounded by Cainozoic deposits 5 km north of New Monties well comprises three large areas of flow-banded red-brown porphyritic rhyolite (Table 4) which may be interpreted as a group of post-resurgence domes constructed in the caldera moat (cf. Smith & Bailey, 1968). On the other hand, these domes are petrologically similar to the rhyolite-rhyodacite dome and flow unit in the premonitory caldera phase and could be correlated with this unit.

Rhyolite-rhyodacite ignimbrite unit

Outside the Chandabooka caldera, and overlying the upper outflow facies of the Chandabooka Dacite with an angular unconformity of about 5^{o}, is a succession of thin ignimbrites with a minimum thickness of 200 m (Figs 4, 5). It is unknown whether this unit was erupted from vents related to the Chandabooka caldera or from a distant source such as the small caldera-like segment exposed on the shore of Lake Harris (Fig. 6).

Slightly reworked rhyolite crystal tuff in a bed 0.5 m thick overlies the upper outflow facies of the Chandabooka Dacite 1.5 km northnortheast of Kokatha homestead. This is followed by a succession of mainly rhyolite ignimbrites (Table 4) in simple cooling units a few to several tens of metres thick, with interbedded airfall tuff, polylithic volcanic breccia and thin, commonly amygdaloidal rhyolite flows (Fig. 15).

Many of the ignimbrites are colourful rocks with long black or purple fiamme surrounded by a red-brown devitrified matrix porphyritic in quartz and alkali feldspar. Other ignimbrites are green and lithic-rich. Where some ignimbrites are most intensively devitrified the rock is a chalky purple brown with a porous texture, resulting from fine secondary vesiculation within the pumices during devitrification.

Rhyolitic breccia pipe

A breccia-filled pipe punctures the rhyolite-rhyodacite ignimbrite unit 2 km northeast of Kokatha homestead. The pipe is about 400 m in diameter and is filled by a heterogeneous assortment of blocks up to 1 m across of acidic and rare basic volcanics in a tuffaceous matrix.

Rhyolite dykes

Rhyolite dykes generally a metre or more wide and from a few metres to over a kilometre long intrude all the volcanic units. Only the five largest dykes are shown on Figure 4. The dykes follow the most common joint directions and trend either north, northeast, or northnorthwest.

INTRUSIVE PHASE

Subvolcanic, flat-roofed stocks of Hiltaba Granite intruded the volcanic pile outside the Chandabooka caldera 1478 $\pm$ 38 Ma ago. It is probable that a stock of similar granite underlies the caldera (Fig. 5, based in this respect on Bailey et al., 1976, fig. 8). A major north-trending rhyodacite-rhyolite dyke swarm intruded the eastern end of the caldera about 20 Ma later.

Hiltaba Granite

Two rectilinear stocks of Hiltaba Granite crop out in the western third of the Kokatha area (Figs 4, 6). Although relief in the area is low, the vertical walls and flat roofs to the stocks can be seen clearly in some places (Fig. 16, and contacts south and northeast of Chitanilga Hill). Near the middle of the stocks strongly developed horizontal jointing on the higher hills indicates that the stocks are barely unroofed. Contacts with the country rock are sharp (Fig. 17): on one side the granite retains

TABLE 4 . Post-caldera Phase and Instrusive Phase: chemical data for major(%) and trace (p.p.m.) elements, and CIPW weight percent norms. Sample localities are shown on Fig.4 , except 192 which is 8 km northeast of map area.

UNIT	Rhyolite Dome Unit	Rhyolite - Rhyodacite Ignimbrite Unit								Rhyolite Dykes		Hiltaba Granite			Greisens & other hydrothermally altered rocks					
SAMPLE	207	175	181	208	231	232	233	234	235	193	215	195	196	218	197	221	256	257	262	192
ROCK TYPE	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyodacite	Rhyolite	Rhyolite	Rhyolite	Granite	Granite	Granite						
SiO_2	73.72	75.26	74.74	76.08	75.14	76.42	73.76	71.32	74.77	75.68	79.28	76.37	76.78	76.11	76.79	60.07	50.17	48.93	52.52	75.64
TiO_2	.24	.21	.22	.17	.16	.15	.38	.51	.48	.17	.31	.17	.12	.19	.16	.49	2.20	1.44	1.64	.08
Al_2O_3	12.84	12.14	12.70	11.68	12.85	12.64	12.48	14.34	11.98	11.68	9.66	11.73	11.85	12.08	13.55	15.42	31.57	36.39	16.61	11.52
Fe_2O_3	1.12	2.58	1.56	2.30	1.57	.90	2.14	1.96	2.65	.77	2.92	.97	1.12	..61	1.57	1.12	10.29	7.95	6.35	4.07
FeO	.80	.39	.76	.35	.39	.20	.18	1.40	.30	1.15	.50	.68	.46	.95	1.02	1.33	.34	.03	7.75	.55
MnO	.03	.04	.05	.02	.05	.02	.05	.04	.03	.04	.02	.04	.01	.03	.06	.17	.02	.08	.05	.42
MgO	.18	.12	.09	.15	.15	.12	.49	.33	.20	.22	.34	.11	.08	.10	.18	6.40	.13	.07	1.04	.12
CaO	.72	.19	.56	.11	.44	.17	.22	.63	.36	.90	.21	.41	.33	.44	.10	6.97	.26	.17	.58	.24
Na_2O	3.15	3.14	2.14	1.86	2.33	3.15	3.21	2.25	4.25	2.04	4.40	3.04	2.98	2.90	.32	1.88	1.55	.65	1.01	.13
K_2O	5.50	5.03	6.18	5.68	5.40	5.32	5.51	5.54	3.82	5.50	1.85	5.16	5.16	5.54	4.17	4.01	1.77	1.53	9.10	3.21
P_2O_5	.04	.03	.02	.02	.03	.01	.07	.10	.09	.03	.03	.04	.08	.01	.02	.08	.06	.05	.28	.01
H_2O+	.72	.57	.50	.92	-	-	-	-	-	1.26	.55	.51	.71	.73	1.86	-	-	-	2.46	2.59
H_2O-	.08	.05	.04	.10	-	-	-	-	-	.04	.07	.11	.11	.03	.02	-	-	-	.09	.19
L.O.I.	-	-	-	-	1.07	.65	.61	1.16	.47	-	-	-	-	-	-	1.60	1.52	2.48	-	-
TOTAL	99.15	99.76	99.55	99.45	99.58	99.75	99.73	99.58	99.40	99.38	100.15	99.34	99.79	99.72	99.82	99.54	99.88	99.77	99.48	98.78
q	33.13	37.59	37.75	43.83	40.46	37.58	33.31	35.97	35.01	40.82	45.97	38.41	39.52	36.93	59.58	11.99	34.37	40.06	7.15	64.53
c	.50	1.27	1.54	2.36	2.48	1.43	1.01	3.80	.42	.71	.11	.50	.97	.55	8.55	0.00	27.22	34.41	4.86	7.73
or	33.04	29.98	36.87	34.10	32.39	31.72	32.84	33.26	22.81	33.13	10.98	30.88	30.80	33.08	25.16	24.19	10.63	9.29	55.47	19.76
ab	27.09	26.79	18.28	15.99	20.00	26.88	27.39	19.34	36.33	17.59	37.39	26.04	25.47	24.79	2.76	16.23	13.33	5.65	8.81	1.15
an	3.37	.75	2.67	.42	2.02	.78	.64	2.51	1.21	4.35	.85	1.80	1.13	2.14	.37	22.25	.91	.53	1.08	1.17
di	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.80	0.00	0.00	0.00	0.00
hy	.66	.30	.23	.38	.38	.30	1.23	1.02	.50	1.85	.85	.52	.20	1.25	.89	12.73	.33	.18	9.24	.31
mt	1.65	.79	1.99	.71	.97	.28	1.69	2.89	0.00	1.14	.78	1.42	1.18	.88	2.32	1.66	0.00	0.00	9.50	3.03
il	.46	.40	.42	.33	.31	.29	.73	.98	.71	.33	.59	.33	.23	.36	.31	.95	.77	.24	3.21	..16
ap	.10	.07	.05	.05	.07	.02	.17	.24	.22	.07	.07	.10	.19	.02	.05	.19	.14	.12	.68	.02
ru	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.83	1.35	0.00	0.00
Rb	180	185	210	210	-	-	-	-	-	190	70	265	385	310	310	-	-	-	-	340
Sr	80	80	55	80	-	-	-	-	-	75	48	45	40	30	15	-	-	-	-	45
Ba	1950	1150	1190	2450	-	-	-	-	-	1120	1200	350	450	270	310	-	-	-	-	110
Pb	12	38	40	26	-	-	-	-	-	36	8	32	120	44	12	-	50	60	50	9200
Mo	<10	4	6	<10	-	-	-	-	-	6	<10	<4	4	<10	4	-	-	-	-	<4
Cu	12	12	12	4	-	-	-	-	-	4	4	<2	4	8	4	-	56	74	32	16
Zn	73	48	60	86	-	-	-	-	-	51	36	37	24	52	124	-	92	245	122	740
Ni	10	5	5	2	-	-	-	-	-	<5	2	<5	<5	8	5	-	84	18	34	<5
V	<10	10	10	15	-	-	-	-	-	8	<10	10	10	20	5	-	-	-	-	5
U	4	-	-	6	-	-	-	-	-	-	6	-	-	12	-	-	6	6	<4	-

a uniform medium grain size adjacent to most contacts, while on the other side the volcanic country rock has a saccharoidal texture caused by recrystallisation for several metres away from the contact.

The granite is uniformly leucocratic, orange-pink grading to reddish brown, medium grained, and free of xenoliths. Quartz (30%) is commonly associated with alkali feldspar (70%) in graphic intergrowths, with biotite, muscovite and fluorite as accessories.

Table 4 shows the granite is high in silica and very low in magnesia, characteristic of a minimum crustal melt. The high potassium content suggests the melt was derived from an acid gneiss or sedimentary source, designated an S-type granite by Chappel & White (1974). However, when using their other criteria to distinguish S and I-type granitoids, the Hiltaba Granite with Mol. $Al_2O_3/(Na_2O + K_2O + CaO) = 1.36$, 0.67% normative corundum, and $Sr^{87}/Sr^{86} = 0.7040$, more closely resembles an I-type. On the other hand, the Chappell and White concept was derived from Palaeozoic granites and it is highly probable that while S and I-type granites exist in the Precambrian, different criteria distinguish them. Considering all the evidence, it is concluded that the Hiltaba Granite is an S-type, but that the source material was more primitive, possibly because it had not passed through sufficient metamorphic or weathering cycles to acquire the chemical tags which characterise the Palaeozoic crust.

Rhyodacite-rhyolite dykes

A major swarm of north-trending coarsely porphyritic red-brown rhyolite to rhyodacite dykes intrudes the volcanics at the eastern end of the Chandabooka caldera. The dykes are 5 to 50 m wide and may be traced for up to 10 km outside the area of Figure 4 (Blissett, 1977). They represent the last vestige of igneous activity in the Kokatha area.

ECONOMIC POTENTIAL

Veins, pods and small dykes of hydrothermally altered volcanics and granite are scattered through the area. Some are greisens directly related to the Hiltaba Granite (Table 4, samples 197, 192); others localised in a zone 1.5 km wide west of the exposed caldera-margin fault may be related partly to fumarolic activity associated with late-stage resurgent fault movements (samples 256, 257, 262).

No mineral deposits have been found in the Kokatha area. However, the high Pb and Zn content of sample 192 and in samples analysed by Asarco (Dodds, 1969), together with the higher than average U content of sample 218 indicate the potential for mineralisation associated with the granite, and sediments derived from it.

Nevertheless, it is the recognition of the caldera structure and subsequent events which holds most promise for the discovery of economic deposits (Lipman *et al.*, 1976). Steven & Lipman (1976) conclude that in the San Juan volcanic field 'the primary function of calderas in mineralisation (thus) appears to be the preparation of zones of weakness in the roofs of major magma chambers. If conditions at depth are favourable, some of these zones are the sites of recurrent igneous intrusion and extrusion, locally accompanied by hydrothermal activity and mineralisation'. On this basis, alluvium-covered areas around the projected Chandabooka caldera margin (Fig. 6) are highly prospective for silver, lead, zinc, copper, molybdenum, tin, tungsten and gold ores.

PETROGENESIS

With the present stage of knowledge it is prudent to speculate only briefly on the petrogenesis of the Gawler Range acid volcano-plutonic province as represented in the Kokatha area. This is particularly so if the assumption is correct that the eruption of each major ignimbrite sheet is accompanied by the collapse of a separate caldera (Smith & Bailey, 1968; Steven & Lipman, 1976, table 1): it implies that in the Gawler Range province, where several large ignimbrites have been recognised, other calderas or their ring complex equivalents will be found. As further calderas are recognised and studied our understanding of the magmatic history of the province will be enhanced.

Consider the petrological evidence. In the description of the basalt-rhyolite bimodal unit of the stratovolcano phase it was concluded that the first volcanics erupted in the Kokatha area were related to the continental tholeiite magma suite, and ranged in composition from basalt to rhyolite with a silica gap between 57 and 67% SiO_2. On the other hand, the Hiltaba Granite, intruded 45 Ma later, represents the last magma generated in the area and is presumed to be derived by minimum melting of acid gneiss or sedimentary crustal rocks to produce a melt rich in silica and potassium.

In addition, the siliceous and potassic character and large volume of all the volcanics related to the Chandabooka caldera suggests that they too were derived from a source similar to that for the Hiltaba Granite. Hence two quite different magma sources are indicated for the Gawler Range province.

The increasingly siliceous character of the province with time is shown graphically in Figure 8c, and a composite FMA diagram is given in Figure 18. However, no obvious hiatus is evident on these figures between the trends representing each magma series; yet the continuity of trends is probably fortuitous: all of which highlights one of the problems which may be encountered if a simplistic interpretation is made of variation diagrams.

Consider next the structural evidence. In the Carpentarian the Gawler Craton was a large, relatively stable crustal block (Fig. 1) which possibly extended east into New South Wales. The Gawler Range province in general, and the Kokatha area in particular, is located well within the craton and thus represents a continental-interior magma province.

Combining the petrological and structural evidence the following petrogenetic model for the Kokatha area is proposed. Ultramafic magma generated in the mantle beneath the Gawler Craton rose as a diapir and intruded the crust. Basic magma which reached the surface from this source was erupted during the stratovolcano phase. However, the bulk of the diapir remained at depth as a heat source which melted crustal rocks and generated a small batholith. Acid magma in a cupola above this batholith rose by major block stoping near to the surface and provided the subvolcanic magma chamber above which the Chandabooka caldera evolved. Later cupolas containing less-volatile magma are represented by the Hiltaba Granite.

ACKNOWLEDGEMENTS

I am grateful to the Australian Research Grants Commission for financially supporting my field work and, together with the South Australian Department of Mines ~~and Energy~~, the chemical analyses carried out by the Australian Mineral Development Laboratories. Many of my ideas have evolved during stimulating discussion with colleagues, and I thank especially Bob Smith, Roy Bailey, Frank Byers, Peter Lipman, Wolfgang Elston and Chuck Chapin all in the U.S.A., Christopher Oftedahl in Norway, and Allan White, Alan Webb and Hugh Blissett in Australia. Colin Smith, David Marsden and Tom Sullivan, under the direction of Bruce Thomas and Barry Frost skilfully drafted the figures. This paper is published with the permission of the Director, South Australian Department of Mines ~~and Energy~~.

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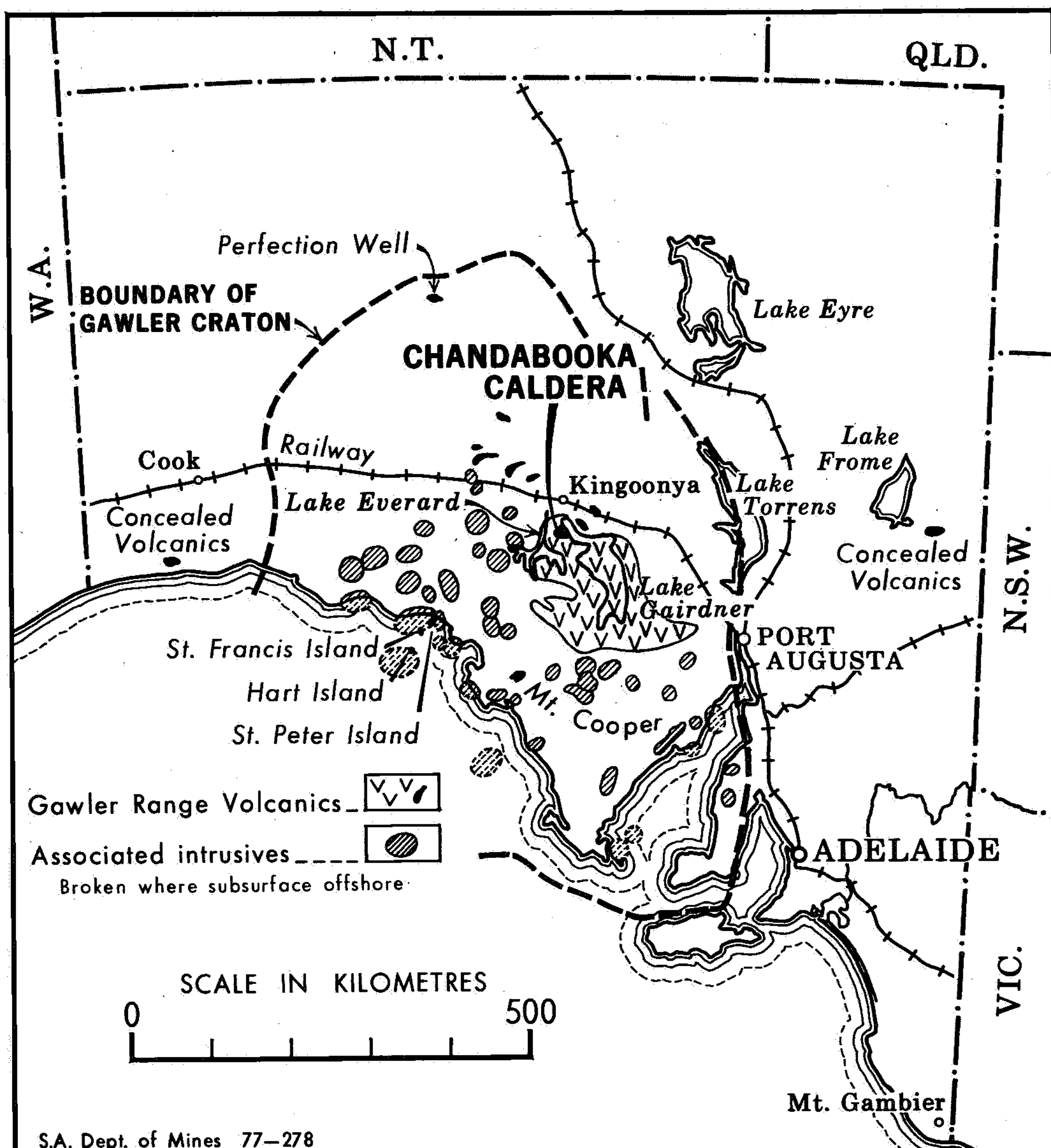


1. Locality map showing the extent of the Gawler Craton, and the position of the Chandabooka caldera in relation to the volcanic and intrusive phases of the Gawler Range acid volcano-plutonic province. The outline of many of the related intrusives is interpreted from geophysical data only (after Thomson, 1976; and personal communication).

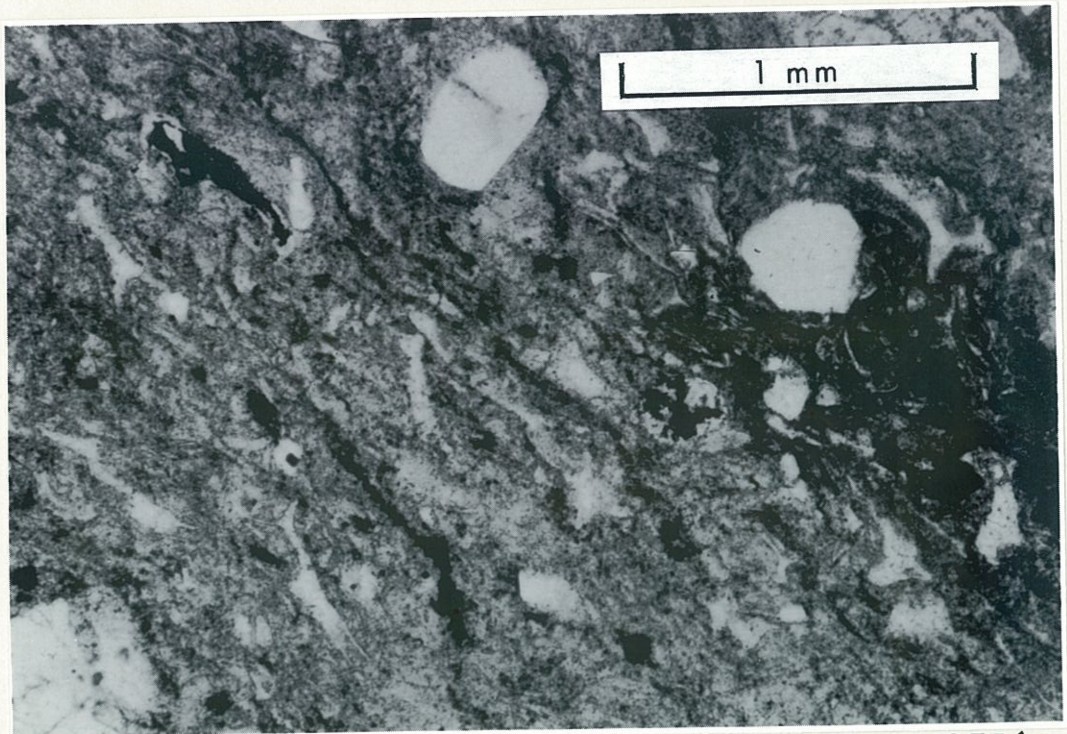
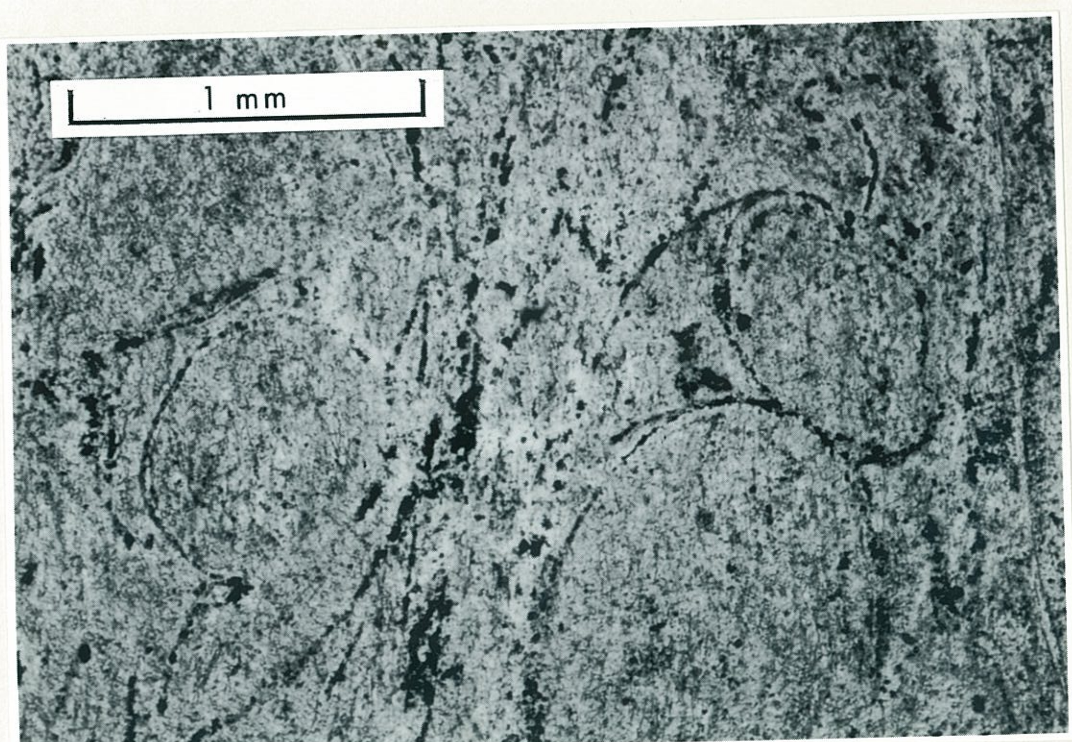


photo no: 29554.

2. Undistorted shards in a finely devitrified incipiently welded rhyolite ignimbrite (Table 4, specimen 181).



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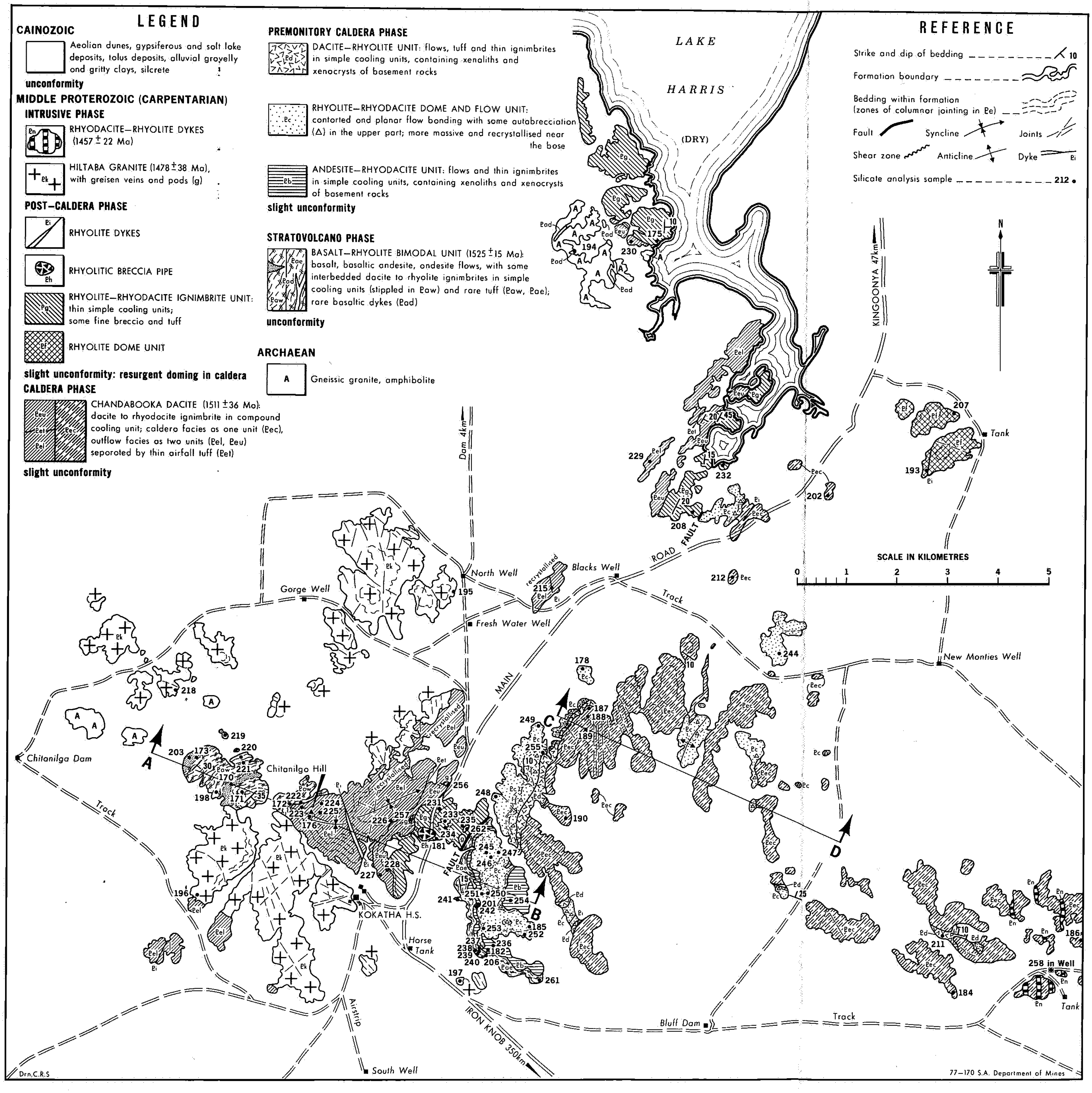
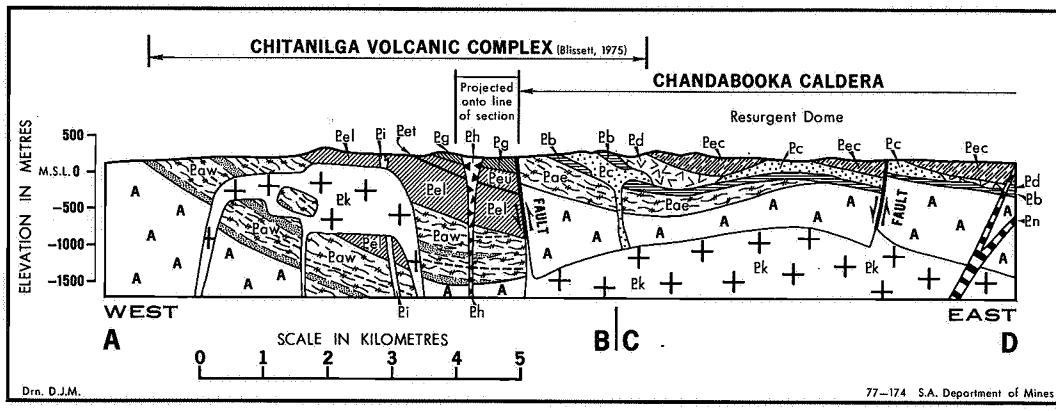
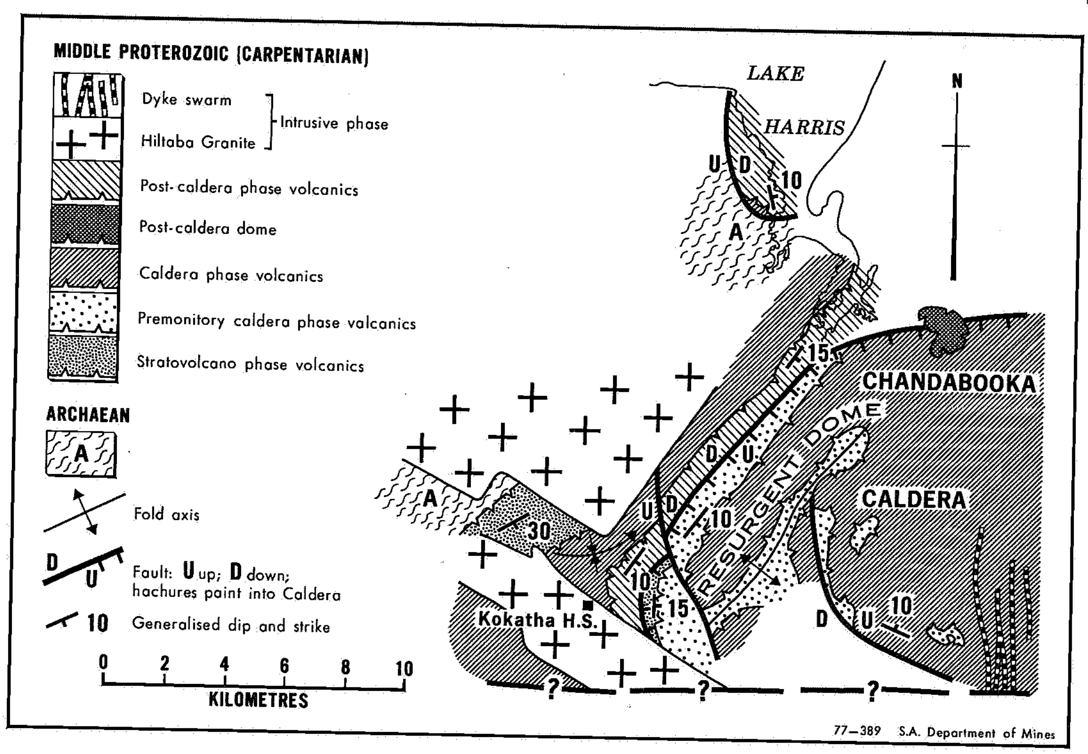
3. Perlitic cracks outlined by opaques in a finely devitrified rhyolite ignimbrite from the premonitory caldera phase.



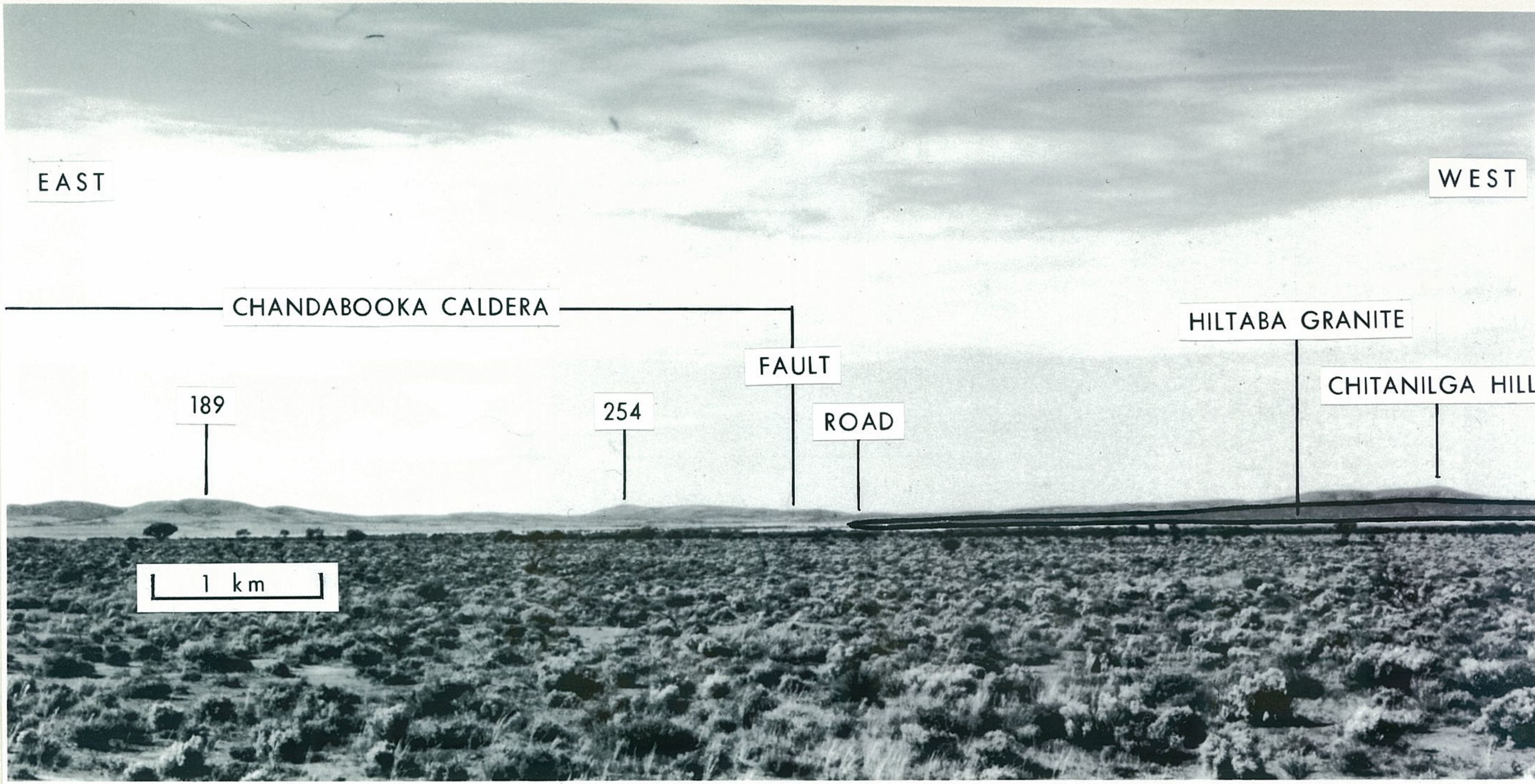
4. Geological map of the Kokatha area.



5. Cross-section A-B, C-D of the Kokatha area: line of section and symbols as on Fig. 4.



6. Tectonic interpretation map of the Kokatha area.



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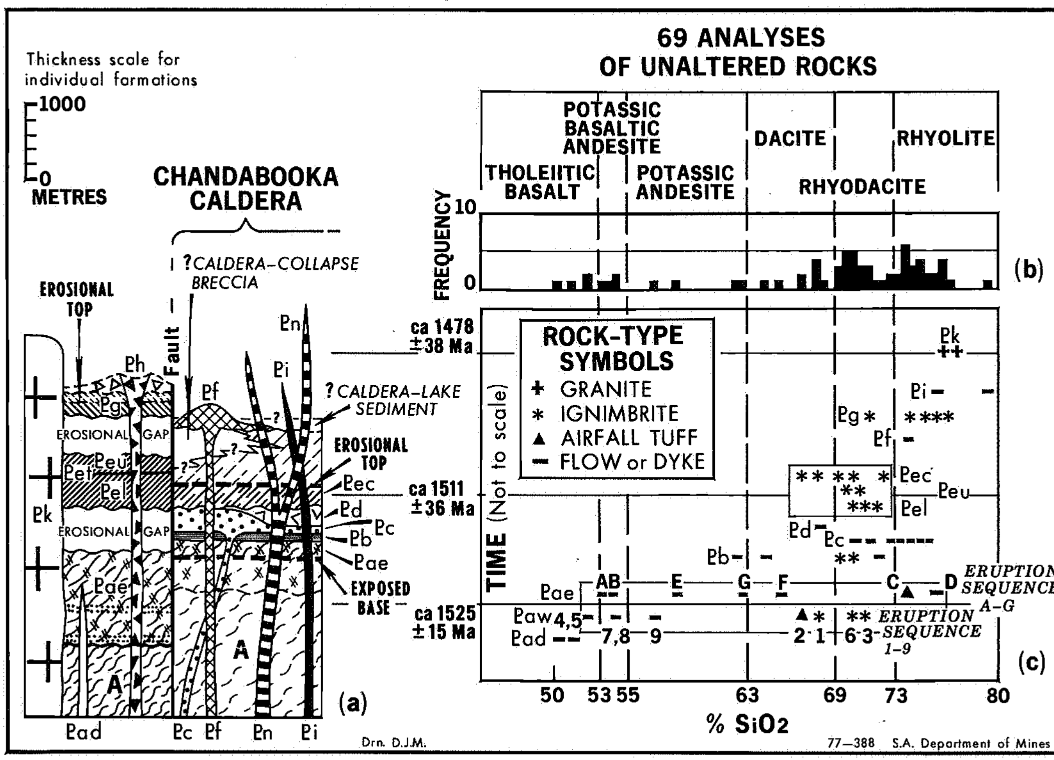
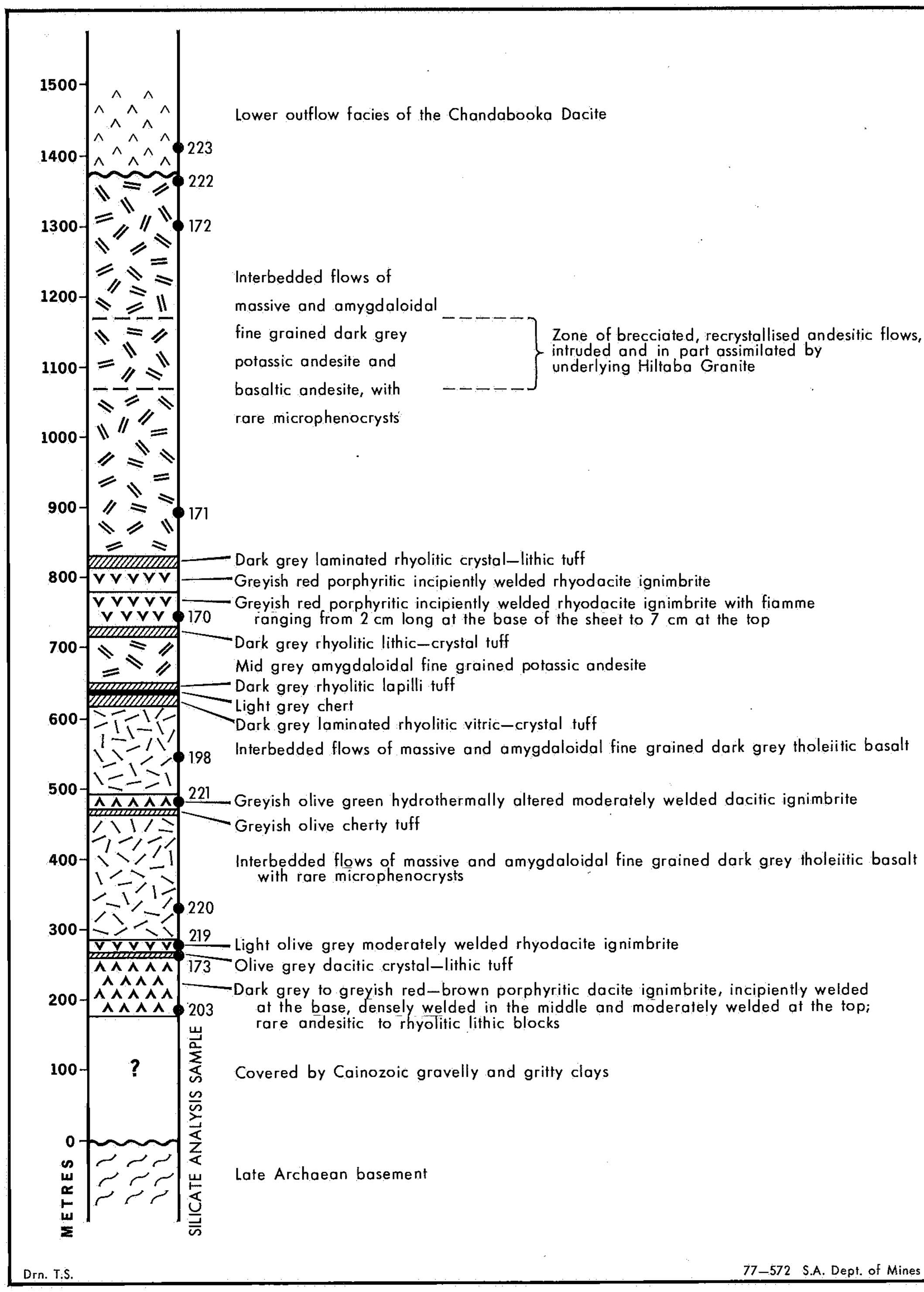
7. Panoramic view of volcanic and granite hills in the Kokatha area, looking south from near Lake Harris. The numbers refer to sample localities on Fig. 4.



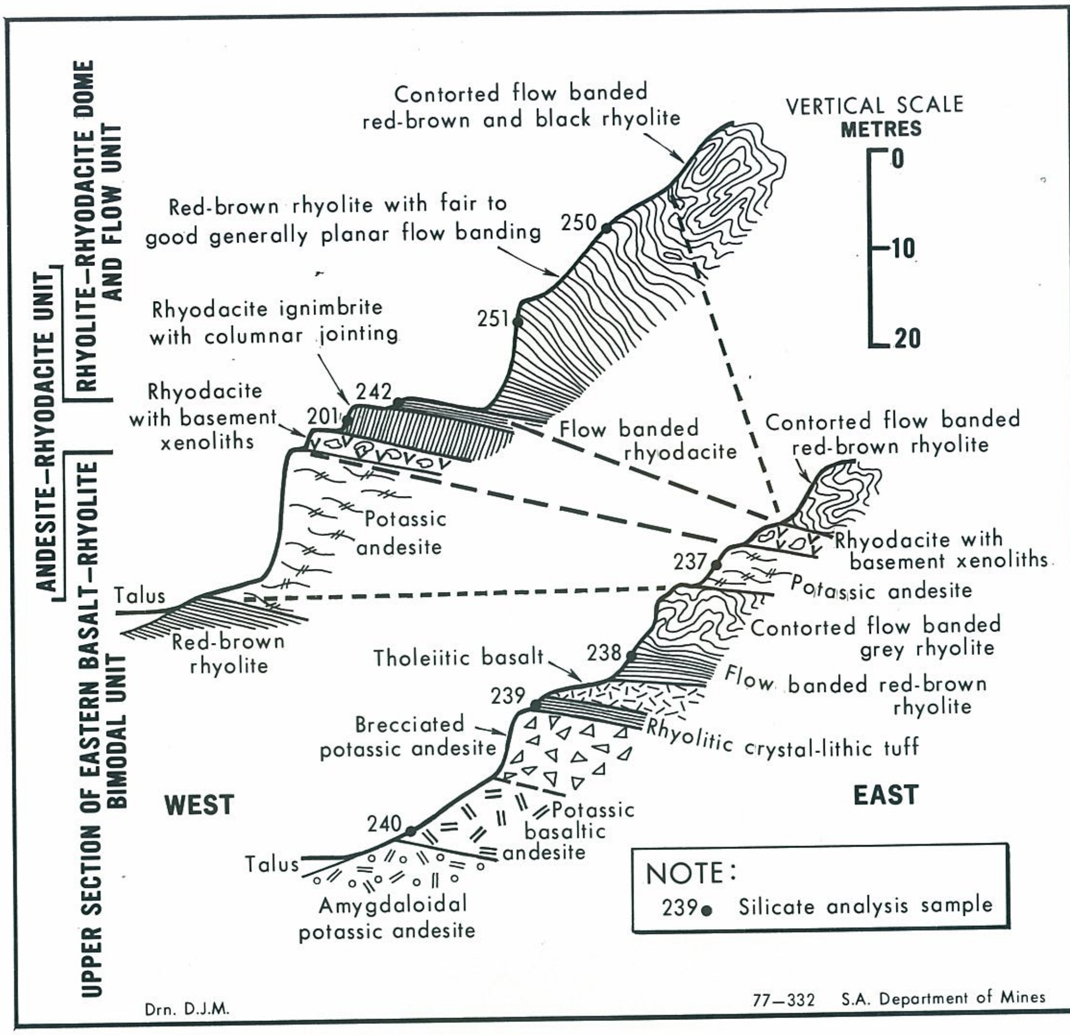
8. (a) Diagrammatic cross section illustrating the correlation of units inside and outside the Chandabooka caldera; symbols as on Fig. 4.

(b) Petrological classification of the Gawler Range Volcanics in relation to the frequency distribution of the rock types and their silica percentage.

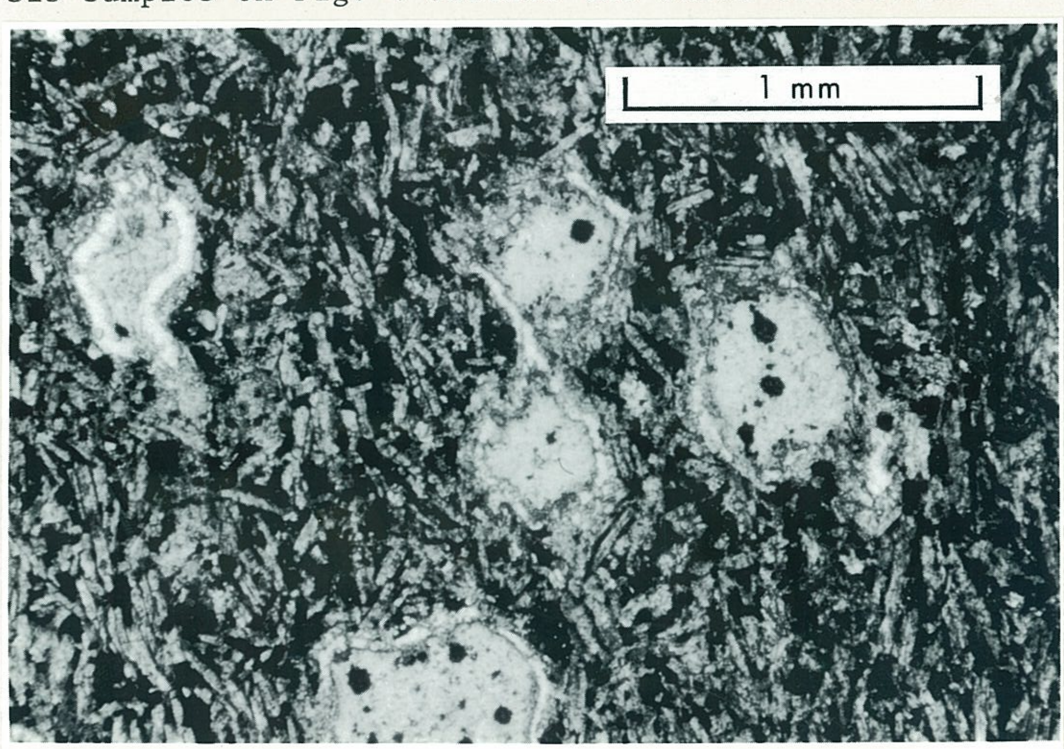
(c) Variation of silica content with time in the Gawler Range province as represented in the Kokatha area.



9. Stratigraphical column through the basalt-rhyolite bimodal unit, western sequence, on the west slope of Chitanilga Hill. The location of the silicate analysis samples on Fig. 4 defines the line of section.

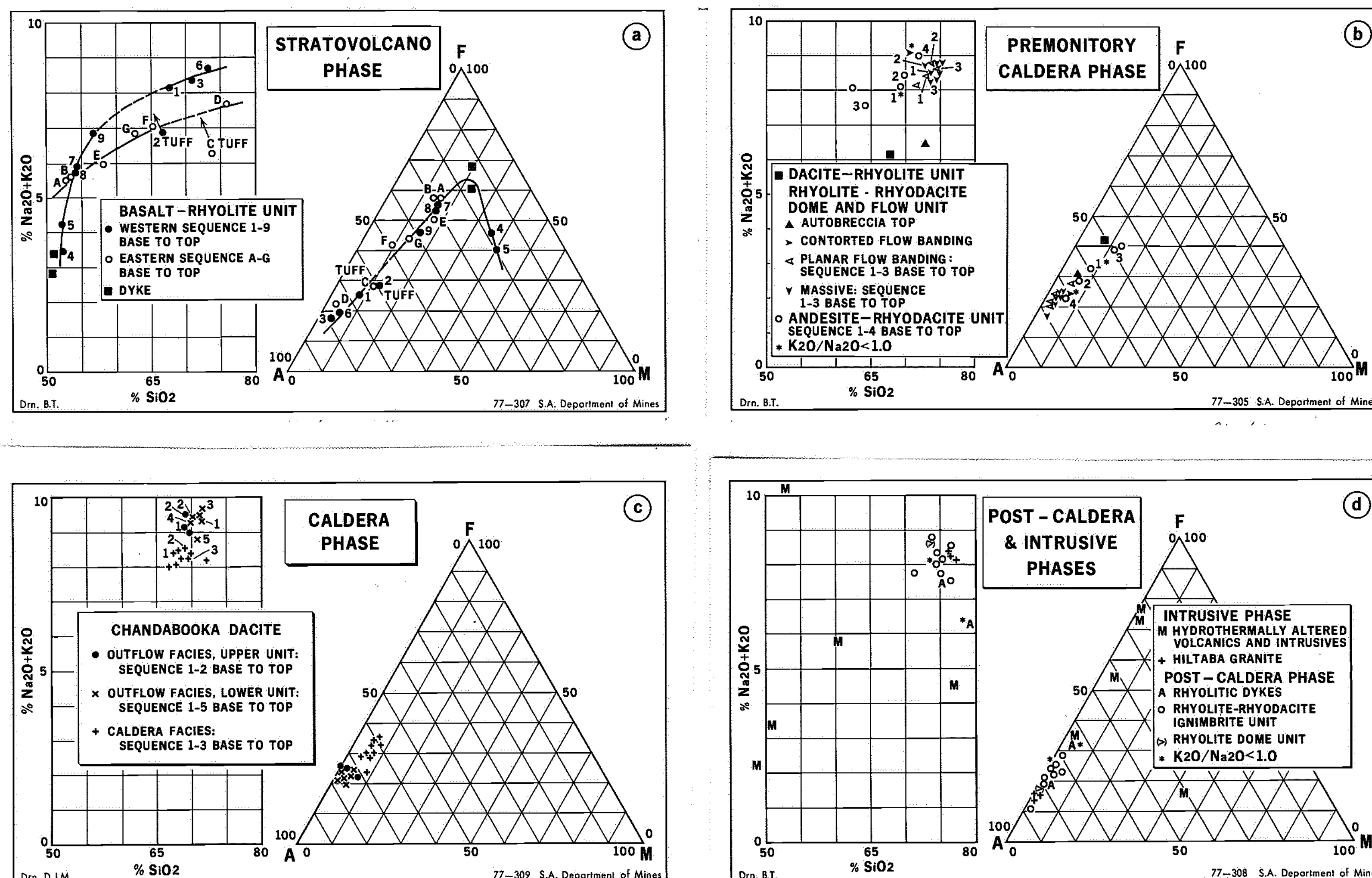


10. Correlation between cross sections through the eastern basalt-rhyolite bimodal unit, andesite-rhyodacite unit, and rhyolite-rhyodacite dome and flow unit 3 km east of Kokatha homestead. The location of the silicate analysis samples on Fig. 4 defines the lines of section.



11. Amygdaloidal theoleiitic basalt with microlites of calcic plagioclase, chlorite and opaque grains, from the western basalt-rhyolite bimodal unit.

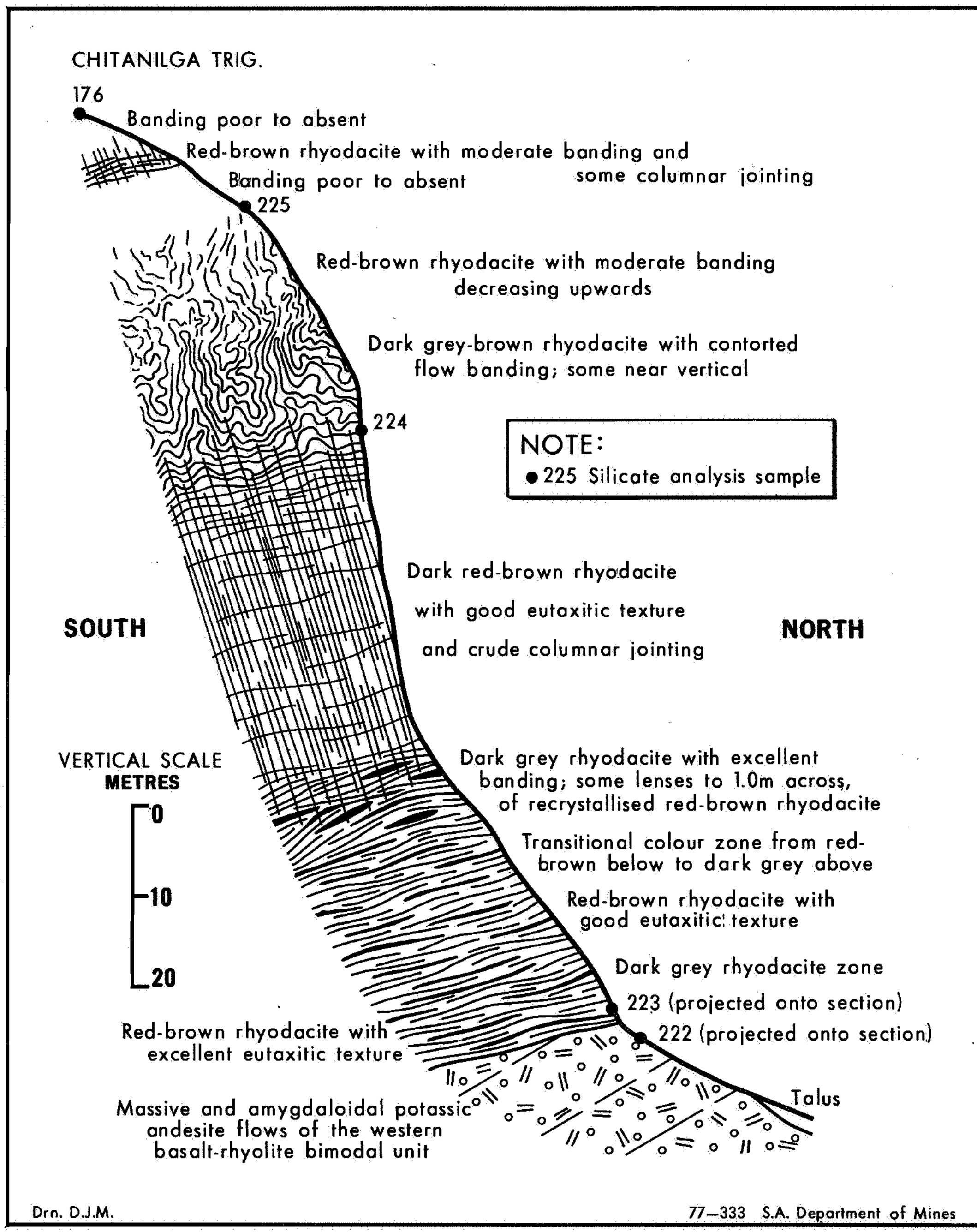
photo no: 29557.



12. FMA diagrams and graphs of SiO_2 versus $Na_2O + K_2O$ for phases in the Gawler Range province, Kokatha area.

photo no: 29558.

13. Columnar jointing in a rhyodacite ignimbrite sheet in the andesite-rhyodacite dome and flow unit. Photograph is looking east at the face of the upper section in Fig. 10; sample 201 is from the ignimbrite sheet.



14. Cross section through the compound cooling unit of the lower outflow facies, Chandabooka Dacite on the north slope of Chitanilga Hill. The location of the silicate analysis samples on Fig. 4 defines the line of section.

photo no: 29559.

15. Amygdaloidal rhyolite flow in the rhyolite-rhyodacite ignimbrite unit near the western shore of Lake Harris.

photo no: 29560.

16. Vertical contact with a sill-like apophysis between Hiltaba Granite and recrystallised Chandabooka Dacite near sample locality 196, Fig. 4.

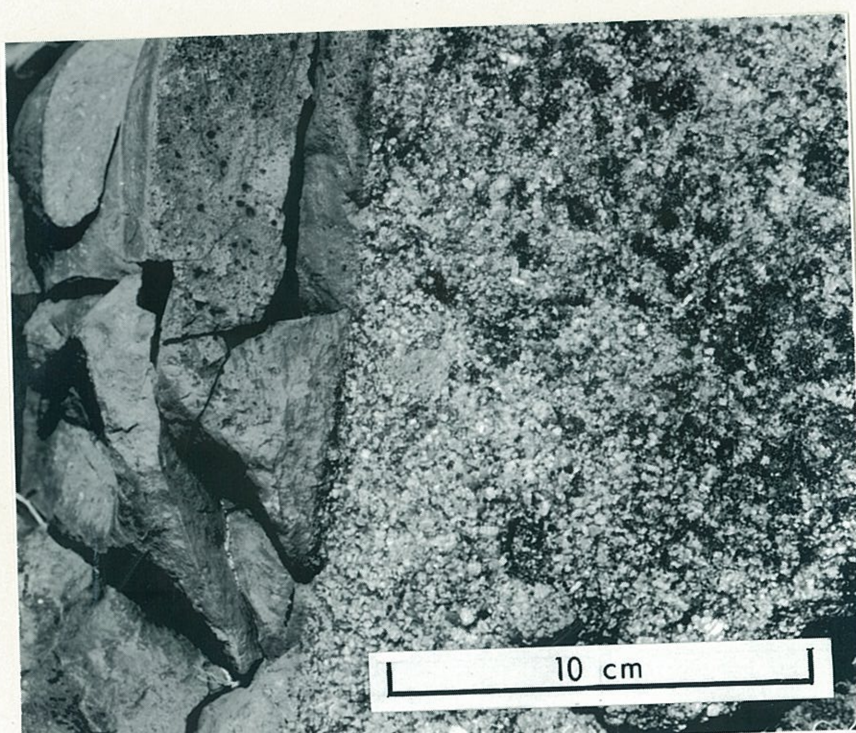
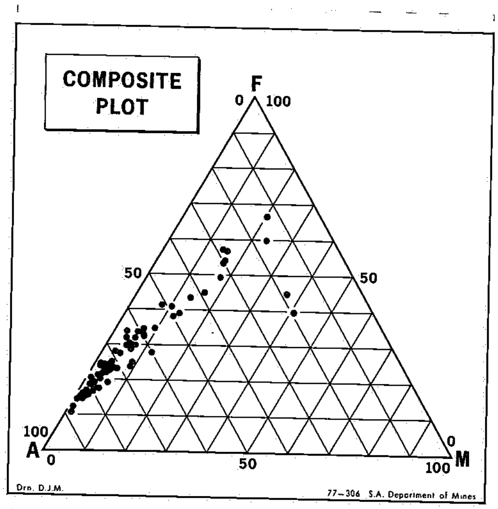


photo no: 29561.

17. Detail of Hiltaba Granite-Chandabooka Dacite contact near sample locality 196, Fig. 4, showing the absence of chilling in the medium grained granite against the contact with recrystallised rhyodacite.



18. FMA plot of 69 unaltered volcanic and intrusive rocks from all major units in the Gawler Range province, Kokatha area.