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The Permo-Jurassic alkaline province of Tadhak, Mali: Geology, geochronology and tectonic significance

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ABSTRACT

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The Tadhak alkaline complexes, located along the eastern edge of the West African craton in northeastern Mali, intrude the 2 Ga old basement or the overlying Pan-African nappes and are covered by Cretaceous sediments. This magmatic activity was accompanied by doming and rifting. Northnortheast trending normal faults define two crustal segments exhibiting variously sized (< 1 km to 17 km) intrusive complexes. These comprise eroded undersaturated ring-complexes with occasional carbonatites in the west and high-level phonolitic plugs with shallow intrusive nepheline syenites in the east.

New Rb–Sr isotopic data indicate 100 Ma of within-plate magmatic activity in the area without any obvious age progression. In addition to the Adrar Tadhak complex (262 ± 7 Ma), the following intrusions have been dated: Tirkine (215 ± 11 Ma), Anezrouf (184 ± 14 Ma) and Tidjerazraze–In Imanal (161 ± 5 Ma). A clear break thus exists with the Cambrian alkaline granite province of the Iforas located on the opposite side of the Pan-African suture. $^{87}Sr/^{86}Sr$ initial ratios are similar throughout (between 0.7044 and 0.7049) which indicates a bulk Earth isotopic composition. The conclusion of exclusively mantle origin ("Dupal composition") previously demonstrated for the Adrar Tadhak complex can now be extended to the other complexes. This implies repeated tapping of a single mantle source throughout the life of the province.

The described magmatic and tectonic Permo-Jurassic activity has been triggered by intraplate stresses focussed along the pre-existing Pan-African suture zone. Together with similar features in Europe and Africa, the Permo-Jurassic Tadhak alkaline province heralds the progressive break-up of Pangaea and the opening of the Atlantic Ocean.

Introduction

The Tadhak province (Fig. 1) was discovered during the exploration of the Iforas (1941–1948) by R. Karpoff (1960) who linked this anorogenic magmatism to the "Nigritian". This is a late Precambrian unit which he defined in the Adrar des Iforas, a hundred kilometres further to the east. There, he described Nigritian conglomerates, arkoses, ignimbrites and rhyolites, unconformably overlying the folded Pharusian (Upper Proterozoic volcano-sedimentary sequences of the Pan-African belt) and cut by alkaline granite plutons. Recent work has shown that the Iforas alkaline granite province (Ba et al., 1985) is Cambrian in age (560–540 Ma, Liégeois and Black, 1984) and, although displaying all the usual characteristics of A-type granites, is clearly related to the closing stages of the Pan-African orogeny (Liégeois and Black, 1987). The latter results from the collision between the passive margin of the West African craton (WAC) and the active margin of the Tuareg shield (Black

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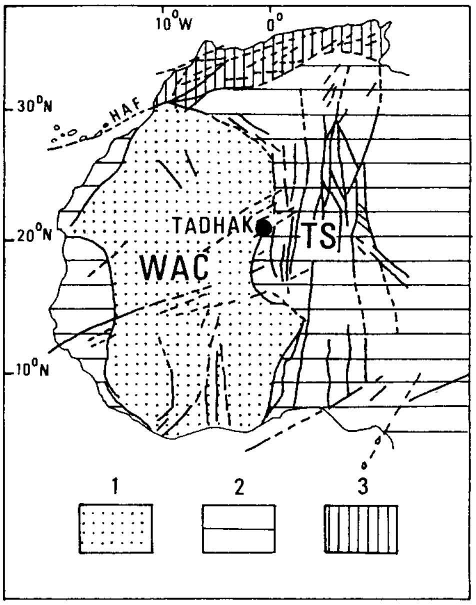

Fig. 1. Major structural domains in West Africa and location of the Tadhak province at the intersection of N–S Pan-African mega-shear zones and WSW–ENE trending Variscan and Alpine faults. *1*. West African craton (*WAC*) stable since 2 Ga; *2*. Pan-African domains (*TS*=Tuareg shield); *3*. Alpine domain (*HAF*=Haut-Atlas fault).

et al., 1979; Caby et al., 1981). The suture is marked by basic and ultrabasic rocks bordering the eastern edge of the WAC (Bayer and Lesquer, 1978) on which have been thrust nappes comprising dismembered ophiolites and passive margin material (Fabre et al., 1982).

By contrast, the largest complex of the Tadhak province, Adrar Tadhak, has been dated as Permian (Liégeois et al., 1983). The aims of this paper are to present a global view of the province which comprises several types of complexes and a wide variety of rock types including carbonatites; to chronologically relate the magmatism to the regional structures; and to set constraints on the origin and geodynamic significance of the province.

Description of the province

This work is based on a United Nations Project (U.N.D.P.–U.N.R.F.N.R.E.) focussed on carbonatites, the presence of which was first mentioned by Barrère (1959) and confirmed by Fabre et al. (1982). The U.N. Project carried out detailed mapping and drilling of the carbonatite occurrences (Sauvage and Savard, 1985) and a reconnaissance survey with R. Black of the entire province. Detailed mineralogical and geochemical studies of samples collected have been carried out by Benziane (1988) and will be published as a separate paper.

The Tadhak complexes (Fig. 2) cropping out in a 100 km×40 km area intrude the 2 Ga old basement of the eastern edge of the West African craton and for some of them the overlying Pan-African nappes. They are partially covered by Cretaceous and Quaternary sediments. Doming is revealed by the absence of Upper Proterozoic and Palaeozoic sediments of the Taoudenni basin (Bronner et al., 1980), the Cretaceous sandstones resting directly on the 2 Ga old basement (Figs. 1 and 2), and by the present erosion level of the Adrar Tadhak and Tirkine complexes. Contemporaneous rifting is demonstrated by the Tesoffi graben outcropping in a 10 km wide and 175 km long strip bound by NNE–SSW to N–S trending normal faults parallel to the gravimetric highs marking the Pan-African suture (Fig. 2). It is filled with poorly-sorted arkosic sandstones and conglomerates of fluviatile origin of an estimated thickness of around 2000 m (Karpoff, 1960). Pebbles are largely composed of Taoudenni materials (undeformed limestone and dolomite) which confirms that Taoudenni sediments were deposited in the Tadhak area before being eroded during doming. They comprise also metaquartzites derived from the Timetrine Pan-African nappes and rock detritus from Adrar Tadhak. This latter observation coupled with the local fenitization of the rift sediments at In Imanal demonstrate the contemporaneity of the magmatism and of the graben.

Persistent instability along the Pan-African suture zone is well shown by the Tilemsi elongated basin superposed on the Tesoffi graben, the accumulation of more than 1500 m of Cretaceous sediments in the Gao trough and by upturned Cretaceous beds along the northnortheast trending normal faults between Tadhak and Tidjerazraze. These faults separate the Tadhak province into two segments (Fig. 2), with eroded complexes (Adrar Tadhak, Tirkine) in the west and superficial volcanic plugs invaded by high-level plutonic intrusions (In Tifinar, Tidjerazraze) in the east.

Three groups can be distinguished, the first two

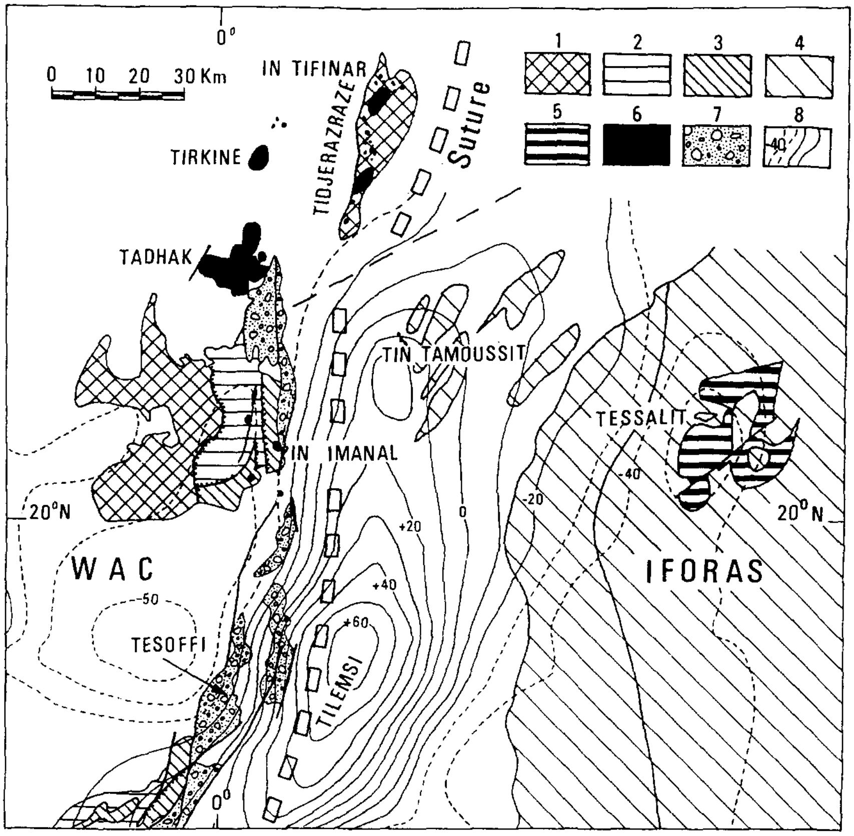

Fig. 2. Simplified geological map of the Tadhak province. *1*. 2 Ga old granitoids of the West African craton (WAC). *2*. Pan-African quartzite nappes; *3*. Pan-African ophiolitic remnants; *4*. Adrar des Iforas Pan-African belt; *5*. Cambrian alkaline granite complex; *6*. Permo-Jurassic Tadhak undersaturated alkaline complexes; *7*. Permo-Jurassic Tesoffi rift sediments; *8*. Cretaceous to Recent cover sediments. Dashed and solid lines with numbers indicate Bouguer gravimetric anomalies indicated at 10 milligals intervals (Fabre et al., 1982) marking the Pan-African suture.

located in the western segment (Figs. 3–6), the third in the eastern one (Fig. 7):

(1) The spectacular Adrar Tadhak (17 km in diameter) and to the north the Tirkine (5 km) are large ring-complexes composed essentially of miaskitic nepheline syenites.

(2) Small complexes (Anezrouf: 2 km, In Imanal: 3 km, Adiounej: 2.5 km, In Imadial: 0.8 km; Tekawelt: 1.5 km) are located in the south of the province and are characterized by the presence of foid-rich rocks and carbonatites. The Tadhakeast ring-complex (2 km) cutting the eastern margin of Adrar Tadhak is classed in this group.

(3) Two main complexes (In Tifinar, Tidjerazraze) comprising high-level miaskitic and agpaitic nepheline syenites, preceded by numerous small phonolite necks form a N–S alignment in the northeast of the province and three small plugs (Tin Tamoussit) occur further to the southeast, near the suture.

Adrar Tadhak (group I, Fig. 3) is by far the largest complex after which the province has been named. To the west, it cuts the 2 Ga old basement and is partially masked by the Tesoffi conglomerates and by a thin veneer of Cretaceous sandstones or nodular limestones when not covered by the Quaternary. It is composed of five mappable concentrically disposed units: (a) an outer ring 1.5–2 km wide displaying a pronounced steeply inward dipping (70°) primary igneous lamination and very rapid lateral variations in composition and in texture (finegraine porphyritic, medium-grained equigranular, pegmatitic). It consists mainly of a biotite aegirine-

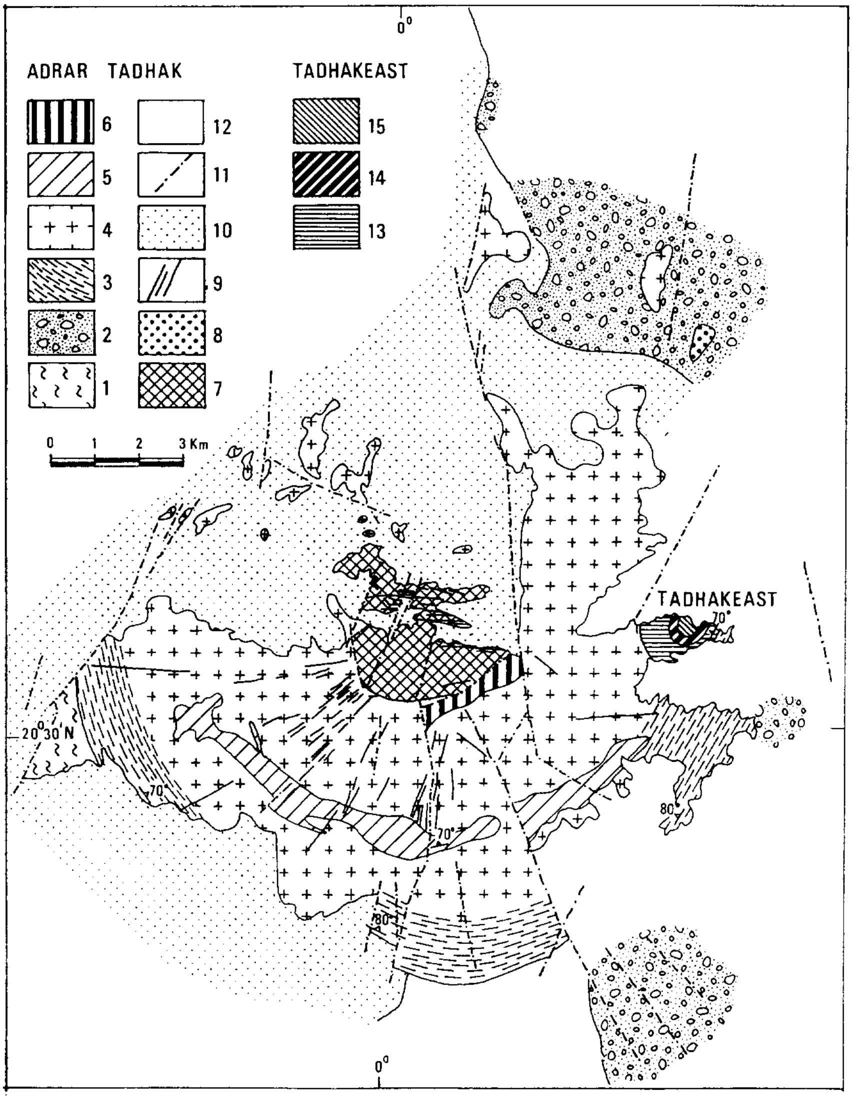

Fig. 3. Geological map of *Adrar Tadhak* (Group I) and *Tadhakeast* (Group II) complexes. *1.* 2 Ga old granitoids; *2.* Tesoffi rift sediments; *3.* biotite aegirine-augite nepheline syenite displaying pronounced primary igneous lamination; *4.* aegirine-augite hastingsite biotite nepheline syenite; *5.* hololeucocratic cancrinite syenite; *6.* melteigite, ijolite, pyroxenite and glimmerite; *7.* titanite hedenbergite Ti-hastingsite nepheline syenite; *8.* biotite Ti-hastingsite syenite; *9.* various dykes; *10.* Cretaceous to Recent cover sediments; *11.* faults; *12.* sand; *13.* leucocratic cancrinite biotite aegirine-augite juvite; *14.* mesocratic biotite aegirine-augite microjuvite; *15.* dark aegirine-augite microjuvite.

augite nepheline syenite but a variety containing equal quantities of aegyrine-augite and melanite occurs to the southeast of the complex where varieties with nepheline altered to cancrinite are also present. (b) Nepheline syenites with weak igneous lamination containing a combination in variable proportion of aegirine-augite, hastingsite and biotite which may contain enclaves of malignite; in the central and northern part of the complex the most frequent facies is a hastingsite biotite albite nepheline syenite. (c) A highly altered hololeucocratic syenite in which nepheline is entirely transformed into white mica and cancrinite and any pre-existing Fe–Mg minerals have been destroyed. It forms an arcuate ridge within unit 2 constituting the highest relief of the Adrar and displays an inward dipping igneous lamination (70°). (d) An ENE–WSW oriented band bounded by faults comprising melteigite, ijolite, pyroxenite and glimmerite (ultramafic rock consisting almost entirely of phlogopite). (e) A central circular stock of hedenbergite Ti-hastingsite nepheline syenite with an isotropic fabric containing abundant large crystrals of honey-coloured titanite. Around it are centered radial dykes of nepheline microsyenite and tinguaite. A coarse-grained silica-saturated biotite Ti-hastingsite syenite occurs as a smaller inlier to the northeast of the massif.

Tirkine (group I, Fig. 4) also shows typical forceful emplacement characteristics: steep inward dipping magmatic planar structure, presence of a magmatic breccia centered on radial dykes and fractures and rapid lateral variations in texture and composition. It comprises two main unit: (a) an outer ring displaying a pronounced igneous lamination parallel to the contacts as indicated by the feldspar lathes and ferro-magnesian minerals. It constitutes the major part of the intrusion made up of biotite hastingsite albite nepheline syenite, the fold being less abundant in the southwest where it is cut by a 700 m large body of medium to coarse-grained sodalite Na-diopside biotite hastingsite nepheline-rich syenite; there is in the southern tip of the complex a small E–W ridge of biotite aegyrine-augite nepheline-rich syenite displaying planar magmatic fabric steeply dipped into the north and cut by numerous decimetric sills of very fine-grained microsyenite of similar composition; (b) a 1.5 km wide circular intrusion in the centre composed of medium to coarse-grained titanite biotite hastingsite nepheline syenite displaying an isotropic fabric. It contains enclaves of a mesocratic coarse-grained nepheline syenite rich in kaersutite and titanite which occurs as an individual body in the southeast. The magmatic breccia is composed of a porphyritic mesocratic biotite diopside kaersutite malignite containing enclaves of a melanocratic malignite. This rock displays an orthocumulate structure and a similar mineralogy. The metric radial dykes consist of nepheline microsyenite. A phonolitic neck is present near the centre of the complex. Three small outcrops of biotite hastingsite nordmarkite occur 4 km to the north of the complex.

The five complexes associated with carbonatites (Fig. 5) are located to the south. They do not display a pronounced magmatic lamination.

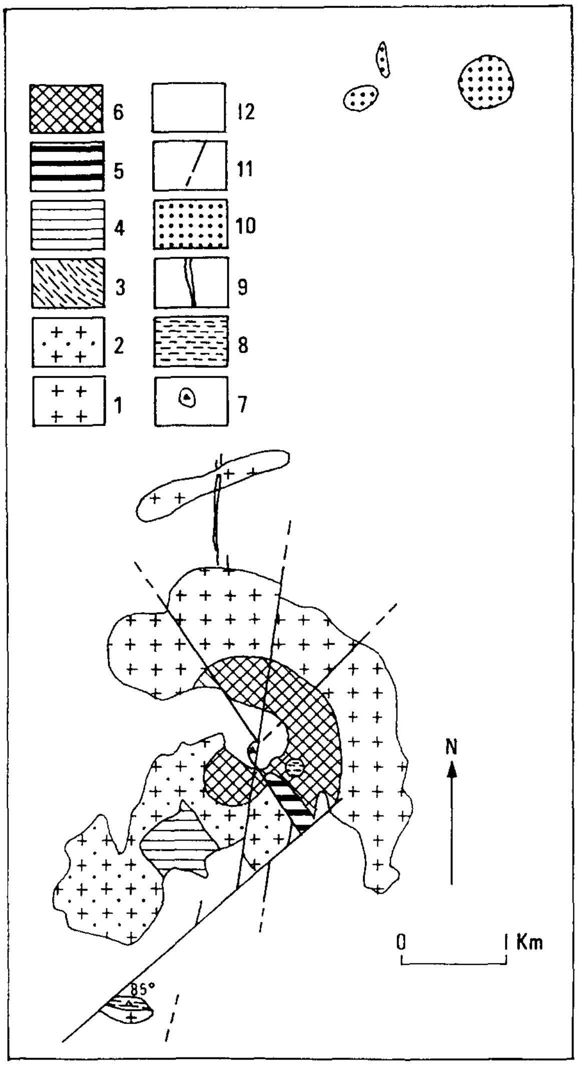

Fig. 4. Geological map of the *Tirkine* complex (Group I). *1.* Biotite hastingsite albite nepheline syenite; *2.* same lithology as 1 but nepheline poor; *3.* biotite aegirine-augite nepheline syenite displaying pronounced primary igneous lamination; *4.* sodalite Na-diopside biotite hastingsite nepheline syenite; *5.* mesocratic coarse-grained titanite kaersutite nepheline syenite; *6.* medium to coarse-grained titanite biotite hastingsite nepheline syenite; *7.* magmatic breccia; *8.* phonolite plug; *9.* nepheline microsyenite dykes; *10.* biotite hastingsite nordmarkite; *11.* faults; *12.* sand.

Adiounedj (group II, Fig. 6a) is characterized by the absence of apparent structures and by the presence of a large mass and numerous dykes of rodbergite (haematite and ferrocarbonates) which can be related to the 1.5 km wide rodbergite massif of Tekawelt and other small massifs located on the same N–S fault (Fig. 5). Adiounedj comprises also an in-

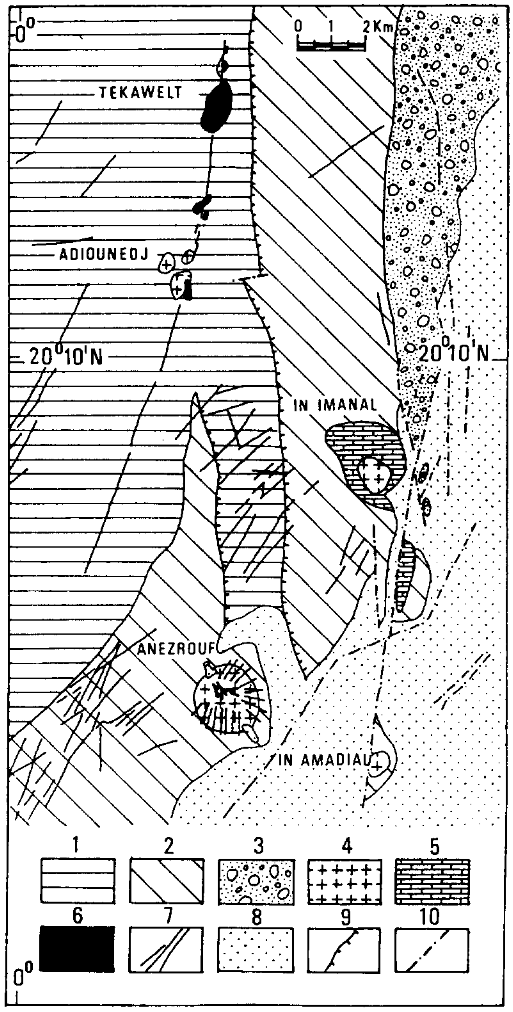

Fig. 5. General map of carbonatite occurrences (Group II). *1.* Pan-African quartzite nappes; *2.* Pan-African ophiolitic remnants; *3.* Tesoffi rift sediments; *4.* nepheline syenite; *5.* carbonatite; *6.* rodbergite; *7.* dykes; *8.* Cretaceous cover sediments; *9.* basal thrusts; *10.* faults.

tensely fenitized cancrinite sodalite aegirine-augite nepheline syenite and a ferrocarbonatite containing purple fluorite and REE minerals (synchysite, parisite); drilling has shown that a glimmerite is present at depth. The massif is finally cut by a magmatic breccia, fenitized phonolite and tinguaite, carbonatite dykes, alkaline lamprophyres and fluorite veins.

In Imanal (group II, Fig. 6b) shows some ring patterns in the carbonatites, abundant in this massif. Four phases of carbonatites whose centres probably move to the northwest with time have been identified. They were preceded by an undersaturated complex which has been intensely fenitized: it comprises nepheline syenites, ijolites, urtites cut by phonolite, tinguaite and alkaline pegmatite dykes. They are all seen as relics as fenitization has largely transformed this complex to a rose-salmon rock composed of 90% K-feldspar. This process also affected the country-rocks, essentially in the south. The last carbonatite phase, to the northwest, has not induced fenitization and is associated with apatitolite (min. 95% of apatite) occurring as independent bodies and as enclaves in the carbonatite. The last manifestations are veins of barytes and fluorite. Most of the carbonatites are dolomitic (80–95%) and contain apatite, pyrochlore and magnetite. Fe-biotite and melanite are also sometimes present. Ferrocarbonatite (Fe oxide coloured Mg-Ca carbonates) systematically associated with REE mineralizations (synchysite, parisite, no pyrochlore) are also present everywhere, but in smaller amounts. Drilling of the white spathic carbonatite present in the centre of the massif has revealed porphyritic carbonatite with centimetric dolomitic crystals and metric accumulation sequences composed at the top of white carbonates and at the bottom of centimetric euhedral crystals of aegirine-augite or Fe-biotite, apatite and pyrochlore. The pyroxene and the mica are not present together.

Anezrouf (group II, Fig. 6c) shows two arcuate dykes presented in the southwest. The older outer ring is a pyroxenite containing nepheline and biotite (+apatite, calcite, sodalite, fluorite, titanite and pyrite). It is cut by an inner ring of ijolite composed of abundant nepheline and poikilitic calcite surrounding a diopside. The major part of the complex is a medium-grained red nepheline syenite containing cancrinite, sodalite, aegirine-augite and abundant accessory minerals (pyrochlore, zircon, fluorite,...) which is intruded by a nepheline microsyenite (often brecciated), then by a radial phonolite and tinguaite dykes. The latter are centered on an intensely fenitized zone with rodbergite and apatitolite. Drilling has shown the existence at depth of a cylindrical body of carbonatite inclined to the northnorthwest. This was predicted by the presence of radial dykes and the fenitization of the country-rocks essentially occurring to the northnorthwest.

In Amadial (group II, Fig. 6d) is a small complex

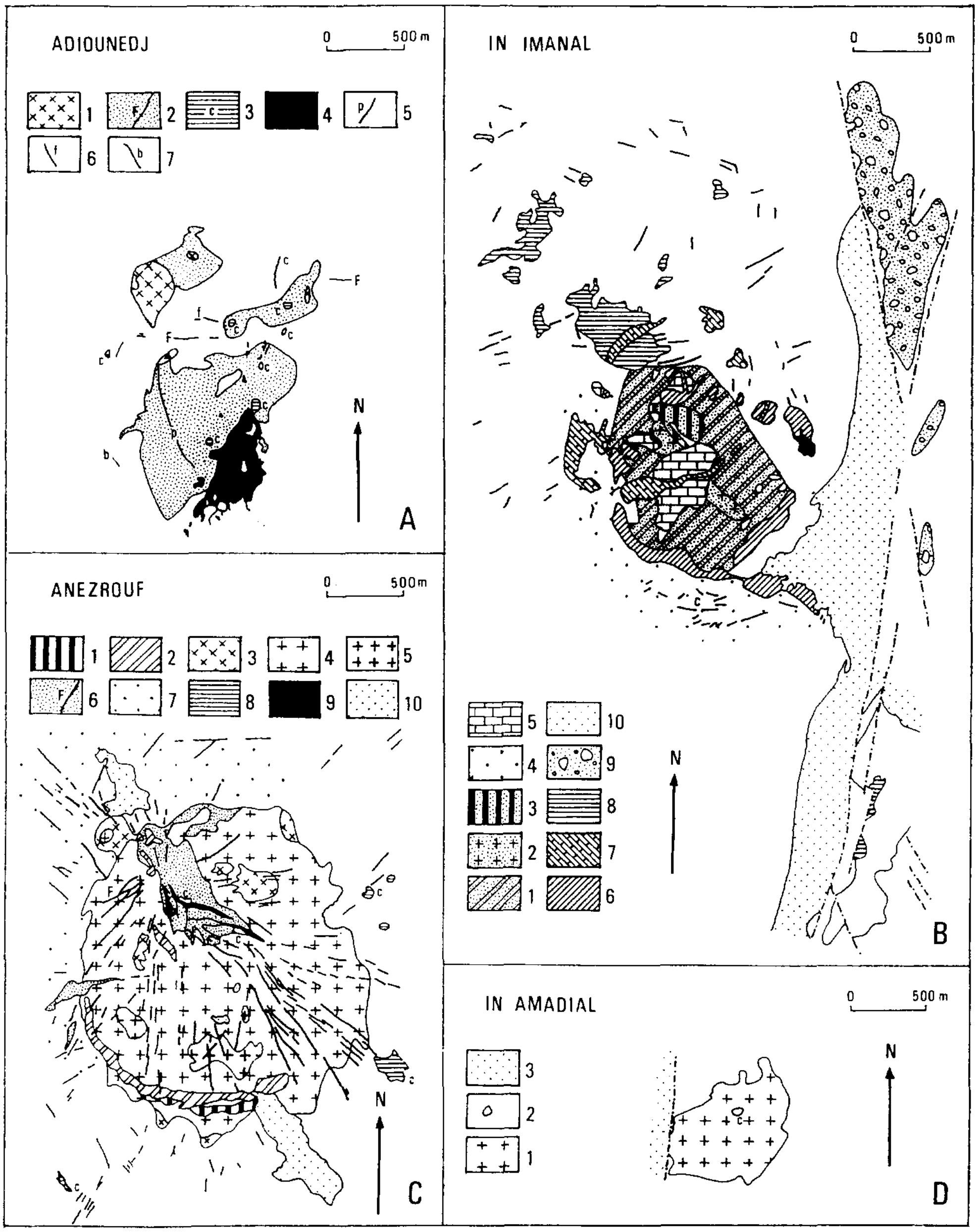

Fig. 6. Geological maps of Group II complexes, on the same scale. Dykes and faults are represented as in Fig. 5. (A) *Adiounedj*. *1*. Cancrinite sodalite aegirine-augite nepheline syenite; *2*. fenitized nepheline syenite; *3*. carbonatite; *4*. rodbergite; *5*. phonolite dykes; *6*. fluorite veins; *7*. barytes veins. (B) *In Imanal*. *1*. Fenitized ijolite; *2*. feinitized nepheline syenite; *3*. fenitized pyroxenite; *4*. fenitized country-rocks; *5*. white spathic carbonatite; *6*. to *8*. various kinds of carbonatites; *9*. Tesoffi rift sediments; *10*. Cretaceous cover sediments. (C) *Anezrouf*. *1*. Pyroxenite; *2*. ijolite; *3*.nepheline microsyenite; *4*. nepheline syenite; *5*. pegmatitic nepheline syenite; *6*. fenitized nepheline syenite (*F*=fenitized dykes); *7*. fenitized country-rocks; *8*. carbonatites; *9*. rodbergite; *10*. Cretaceous cover sediments. (D) In Amadial. *1*. Nepheline syenite; *2*. carbonatite enclave; *3*. Cretaceous cover sediments.

(800 m) composed of a nepheline syenite locally porphyritic (centimetric nepheline) containing as major constituents perthitic K-feldspar and aegirine-augite. Enclaves of ijolite, phonolite dykes, dolomitic carbonatite are present which indicate several phases of intrusion. The fenitization is weak.

Tadhakeast (Fig. 3) may belong to group II. Two kilometres in diameter, it comprises three annular structures: (1) an external ring of leucocratic cancrinite biotite aegirine-augite microjuvite showing an internally dipping (70°) magmatic lamination cut by microjuvite sills; (2) an intermediate ring of mesocratic biotite aegirine-augite microjuvite; (3) a circular core composed of dark aegirine-augite microjuvite also found as a cone-sheet in ring 2.

Tidjerazraze–In Tifinar N–S alignment (group III, Fig. 7a) comprises numerous volcanic plugs sometimes associated with plutonic rocks extending over a distance of 30 km from In Tifinar to Tin Teborak, with to the east, northeast oriented dyke swarms. Intrusions forming this alignment cut the 2 Ga old basement and are limited to the east by a N20°E oriented major fault east of which outcrops only the Meso–Cenozoic cover. Tidjerazraze–In Tifinar is thus situated on the shoulder of the rift. This less well-known group of intrusions is characterized by both miaskitic and agpaitic phonolites invaded by miaskitic and agpaitic syenites. In the Tidjerazraze complex (Fig. 7b), nepheline syenites with variable texture and pegmatitic patches, but with no igneous lamination cover an area of 12 km² and invade phonolites. Three successive phases displaying a concentric structure have been distinguished: an outer sodalite biotite diopside aegirine-augite hastingsite nepheline syenite intrusive in the phonolites to the southwest; an arcuate band of sodalite analcime hedenbergite aegirine hastingsite arfvedsonite nepheline syenite separated by a screen of haüyne aegirine phonolite from a central stock of aenigmatite arfvedsonite aegirine nepheline syenite with pockets of eudialyte bearing pegmatite. Eudialyte, catapleiite, wöhlerite and mosandrite have been identified as important accessory minerals in the agpaitic nepheline syenites and associated pegmatites.

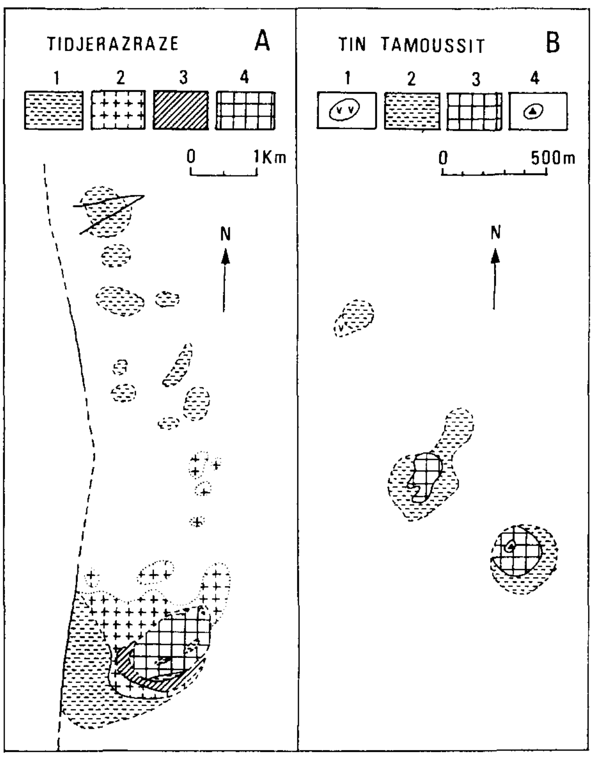

Fig. 7. Geological maps of Group III complexes. (A) *Tidjerazraze* alignment. *1.* Phonolites; *2.* sodalite biotite diopside aegirine-augite hastingsite nepheline syenite; *3.* sodalite analcime hedenbergite aegirine hastingsite arfvedsonite nepheline syenite; *4.* eudialyte aenigmatite arfvedsonite aegirine nepheline syenite. (B) *Tin Tamoussit* plugs. *1.* Lavas; *2.* phonolites; *3.* eudialyte nepheline syenite; *4.* pyroclastic breccia.

The three *Tin Tamoussit* plugs (group III, Fig. 7c) lie just east of the Pan-African suture and are of limited extension (from 0.1 to 0.5 km). They are composed of phonolites intruded by eudialyte nepheline syenite. Pyroclastic breccias and lavas are also present.

Geochronology

New Rb–Sr results are quoted in Table 1. In addition to Adrar Tadhak which has given an age of 267±7 Ma (Liégeois et al., 1983), we have obtained the following results: Tirkine: 215±11 Ma, SrIR=0.70477±10, MSWD=5.36, 8WR (Fig. 8a); Anezrouf: 184±14 Ma, SrIR=0.70473±10, MSWD=0.60, 5WR (Fig. 8b); Tidjerazraze: 161±5 Ma, SrIR=0.70435±10, MSWD=0.54, 7WR (Fig. 8c).

Tidjerazraze yields an excellent isochron whose age marks the end of magmatic activity in the Tadhak province. The complexes associated with carbonatites (Group II) are a little older (ca. 184 Ma). One fenitized sample has been analysed (2AZ01) and falls well above the Anezrouf isochron, suggesting an input of radiogenic Sr from the 2 Ga basement during the fenitization. This process could explain the weak scatter of the Tirkine complex

TABLE 1

Rb–Sr results

No.	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
1. Tirkine				
T54	102	882	0.3345	0.70589 ± 5
T55	165	1038	0.4598	0.70635 ± 3
T61	159	534	0.8615	0.70745 ± 4
T64	135	530	0.7369	0.70674 ± 2
T69	58.8	2338	0.0727	0.70513 ± 4
T70	159	824	0.5582	0.70644 ± 6
T72	167	401	1.205	0.70849 ± 5
T73	57.1	3457	0.0478	0.70470 ± 4
T81	109	1244	0.2534	0.70513 ± 5
2. Anezrouf				
1AZ01	121	1308	0.2676	0.70539 ± 4
1AZ02	264	635	1.203	0.70789 ± 3
1AZ05	72.2	1815	0.1151	0.70501 ± 2
2AZ01	133	1073	0.3586	0.70663 ± 3
2AZ05	131	1160	0.3267	0.70557 ± 4
AZ202	91.2	1362	0.1937	0.70532 ± 4
3. Tidjerazraze				
T99	189	314	1.742	0.70826 ± 6
T101	203	179	3.283	0.71204 ± 5
T102	140	400	1.013	0.70660 ± 2
T105	98.6	1132	0.2519	0.70493 ± 2
T107	190	104	5.290	0.71635 ± 5
T109	151	179	2.441	0.70988 ± 2
T115	95.4	646	0.4272	0.70536 ± 2

The isotopic composition and the concentration analyses were carried out at the Belgian Centre for Geochronology (MRAC-ULB). Rb and Sr concentration was measured by X-ray fluorescence. Errors on Rb/Sr and $^{87}Rb/^{86}Sr$ ratios are 2%. Errors on $^{87}Sr/^{86}Sr$ are given at the 2σ level in 10^{-5}. Normalisation for $^{86}Sr/^{88}Sr = 0.1194$. $\lambda Rb = 1.42 \cdot 10^{-11}$ a^{-1} (Steiger and Jäger, 1977).

(MSWD = 5.36) as the sample with the higher $^{87}Sr/^{86}Sr$ 215 Ma ago (T55) has been collected close to a zone of fenitization. Unaffected mineralogy implies however a weak influence of fenitization on the analyzed samples. The T81 sample is a late microsyenitic dyke and has been omitted in the calculation.

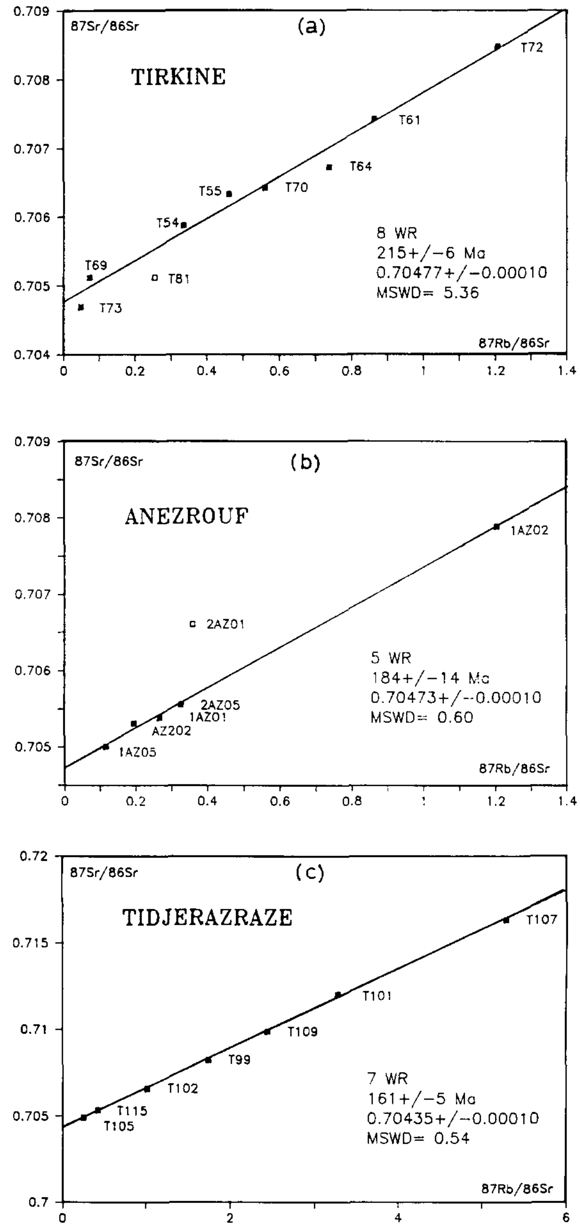

Fig. 8. Rb–Sr isochrons of the Mesozoic complexes of the Tadhak province. (A) Late Triassic age for the Tirkine complex; sample T81 is a late dyke (not included in the calculation); (B) mid Jurassic age for the Anezrouf complex; sample 2AZ01 is fenitized (not included in the calculation) (C) late Jurassic age for the Tidjerazraze alignment. The ages and margins of error (at 2σ level) were calculated following Williamson (1968).

Interpretation and conclusions

These results show that the magmatism of the Tadhak province lasted 100 Ma in a relatively small area (100 × 50 km) with no obvious age progression and that it is clearly distinct from the Cambrian Iforas alkaline granite province (Ba et al., 1985) lying 100 km to the east.

The Sr initial ratios are very comparable during the 100 Ma of magmatic activity: from 0.7043 to 0.7048, with the oldest one (Adrar Tadhak) in the middle of the bracket (0.70457). We can then infer that the petrogenetic conclusion of Weis et al.

(1987) based on Pb and Sr isotopes on Adrar Tadhak can now be applied to the whole province: an exclusively mantle origin with "Dupal" characteristics i.e. isotopic compositions of current South Atlantic and Indian Ocean island basalts (OIB). This implies prolonged tapping of a single mantle source throughout the life of the Tadhak province, from 270 to 160 Ma, a period during which the Tadhak area shifted over an estimated distance of 2500 km from latitude 15°S (270 Ma) to latitude 10°N (160 Ma) (Smith et al., 1981). That does not fit with the notion of a hot spot above a fixed mantle plume (Morgan, 1972). The homogeneous mantle source required for the Tadhak province either moved with the plate or was available over a great distance. In both cases, reactivation of pre-existing lithospheric structures, here the Pan-African suture, at the intersection of N–S Pan-African megashears and WSW–ENE trending Variscan and Alpine faults (Fig. 1), clearly controlled the localization of the province. Hence, a northerly extension of the province beneath the Tanezrouft sedimentary cover can be envisaged.

The stresses inducing major tectonic reactivation are likely to be related to important events along plate margins (Black et al., 1985). The initial stages of the Tadhak province occurred at the end of the Alleghenian orogeny with closure of the Phoibic ocean up to Early Permian (McKerrow and Ziegler, 1976) contemporaneously with formation of the Rockall trough (Russell and Smythe, 1983), alkaline plutonic activity in the Oslo graben and in Corsica and major dextral transcurrent movements along the E–W Pyrenean and Haut-Atlas faults (Fig. 1; Arthaud and Matte, 1977). Reactivation of the old Pan-African suture with associated Tadhak magmatism is in the same family of events. The last stages of Tadhak activity (185–160 Ma) were synchronous to the tholeiitic dolerite dyke swarms of West Africa correlated with those of North America (Bertrand and Westphal, 1977), both linked to the opening of the Central Atlantic Ocean.

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