A new lithostratigraphic framework for the Anti-Atlas Orogen, Morocco

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Abstract

A new lithostratigraphic nomenclatural framework is proposed for the Anti-Atlas Orogen of Morocco, to replace the previous chronostratigraphic scheme. All the lithostratigraphic units of the Anti-Atlas Orogen are well represented in the Sirwa, Kerdous and Sarhro inliers and examples from these areas are given prominence, though correlates in other areas are given, where known. The oldest, Palaeoproterozoic, rocks of the cratonic basement form the northern part of the West African Craton and can be subdivided into a series of Complexes (made up of constituent Groups, Suites etc.), depending on geographical outcrop (e.g. the Zenaga and Kerdous Complexes in the Sirwa and Kerdous inliers respectively). The Neoproterozoic rocks deposited on this basement are termed the Anti-Atlas Supergroup, within which five groups of volcano–sedimentary units (Taghdout, Jbel Lkst, Sarhro, Iriri, and Bou Azzer Groups) and various intrusive igneous rocks are recognised (e.g. Ifzwane and Toudma Suites). These units are related to the earliest passive margin, oceanic and island-arc development phases of the orogen between /C24800 and 660Ma. The earliest Pan-African deformation (at /C24660Ma) resulted from closure of the ocean basin, SW-directed thrusting and accretion of the island-arc remnants. Continued prolonged convergence gave rise to a sinistral transpressional regime in which late syn- to post-tectonic continental volcanic and clastic sequences of the Ouarzazate Supergroup were deposited. The first rocks of this new tectonic regime were deposited in narrow, tectonically active, strike-slip pull-apart rift basins (Bou Salda, Mgouna, Tafrout and Anzi Groups) and the juxtaposition of ophiolitic remnants in major strike-slip shear belts. These were followed by the deposition of the much more areally extensive continental volcano–sedimentary molasse, the volcanic components of which were erupted from several interfingering volcanic centres, often associated with caldera complexes and sub-volcanic alkaline granites (Toufgrane, Tanghourt and Guellaba Suites). The proposed lithostratigraphic scheme encompasses all the major rock units identified in the literature from the orogen and is flexible so that new, lower-ranking, units can be placed at the appropriate stratigraphic level in future. This framework is supported by new high-precision U–Pb zircon dates that have recently become available.

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1. Introduction

The Anti-Atlas Orogen of Southern Morocco is amongst the most important segments of the major Pan-African (~0.5Ga) belt system of North Africa. The orogen is exposed in a series of sporadic SW–NE trending outcrops that stretch over 700km across southern Morocco (Fig. 1). The belt is over 150km wide in the...
central part, west of Ouarzazate. Scattered outcrops of related rocks in NW Algeria show that from SE Morocco, the belt continues southeastwards with a NW–SE trend. The Anti-Atlas orogen comprises two main sequences of rocks—a metamorphic basement of Paleoproterozoic (~2 Ga) age and the Neoproterozoic rocks of the orogen proper. The Paleoproterozoic rocks form the northern margin of the West African Craton mainly outcropping in the Reguibat Shield in Mauritania and Algeria. The Paleoproterozoic basement is exposed in a series of uplifted inliers (“boutonnieres”), surrounded by the Neoproterozoic rocks that were locally deformed with the basement during the Pan African Orogeny.

Over the past decade, there has been a considerable volume of research on the Anti-Atlas Orogen, and a number of broadly comparable models for the evolution of the belt have been proposed (e.g. Hefferan et al., 1992; Saquaque et al., 1992; Fekkak et al., 2000; Ennih and Liégeois, 2001; Thomas et al., 2002; Walsh et al., 2002). Most of these have concentrated on sedimentological–volcanological, structural, geochemical and, more recently, geochronological studies. However, apart from the study of the Sirwa Inlier by Thomas et al. (2002), few regional mapping and synthetic stratigraphic studies have been published. More importantly, there is no broadly accepted lithostratigraphic framework for the Anti-Atlas orogen as a whole.

In March 2002, the 19th Colloquium of African Geology was held in El Jadida, Morocco and large number of papers on Anti-Atlas geology were presented. Following the meeting a field excursion was held in the Sirwa–Sarhro region of the central/eastern Anti-Atlas and a number of regional correlations became very clear. In this paper, we review what is currently known about the geological evolution of the central and eastern part of the Anti-Atlas Orogen and construct a new lithostratigraphic framework for all the various rock sequences involved. One of the main purposes of the paper is to erect the framework in such a way so that, in future, newly identified units can be formally named and slotted into the appropriate stratigraphic position.

2. Existing chronostratigraphic system versus a lithostratigraphic approach

Up until the late 1990s the Precambrian of Morocco was traditionally subdivided according to chronostratigraphic principles. This involves a basic subdivision into 3 “Systems” with PI = Archean or Paleoproterozoic; PII = Lower and Middle Neoproterozoic and PIII = Upper Neoproterozoic (e.g. Choubert, 1963). Each “P”-stage was then further subdivided into various
“Series” (e.g. PIII\(^1\), PIII\(^2\), PIII\(^3\), oldest to youngest). Of course this system assumes that the age of the rocks is known, and that has not been the case in the Anti-Atlas (until recently) with a marked dearth of reliable isotopic age-data. If the ages were not known, the higher the metamorphic grade the rocks, the older they were assumed to be. This simplistic picture is now known to be usually misleading and often downright erroneous. The resulting legends on geological maps were very confusing, with a multiplicity of terms such as “complexes”, “series”, “chains” and “massifs”. Often these terms were restricted to very small geographically defined rock masses, such that the regional stratigraphic relations were difficult to understand.

Presently, an international body, the IUGS (International Union of Geological Sciences) and its organs for stratigraphy, the ICS (International Commission on Stratigraphy) and the ISSC (International Subcommission on Stratigraphic Classification) recommends a lithostratigraphic approach. Rock masses are classified and correlated on their lithological characteristics and grouped together accordingly (Supergroups down to Groups, Subgroups, Formations and Members etc. for layered sedimentary and volcanic sequences and Suites, Complexes etc. for plutonic igneous and some metamorphic rocks). The lithostratigraphic approach adopted here for the Anti-Atlas Orogen, follows the first attempt at such an approach in the region. This project was initiated by the Council for Geoscience of South Africa for a 7 x 1:50000 geological mapping area in the Sirwa Inlier (Thomas et al., 2002) and the British Geological Survey in the Kerdous, Bas Draa and Sarhro regions (BGS, 2001a–h). In collaboration with other research groups in Morocco and elsewhere, we attempt here to broaden this system to cover the entire eastern Anti-Atlas. Hopefully, in future, this stratigraphic framework can be applied throughout the Anti-Atlas orogen and possibly to adjacent Pan-African belts. In the following system, all names that we propose should be adopted as formal lithostratigraphic terms are shown in **bold** type when first used in most cases, we have only mentioned formalised names at the group level, though certain critical formations are also quoted.

3. Palaeoproterozoic basement (2200–2030 Ma)

The medium-grade metamorphic and plutonic rocks upon which the Neoproterozoic rocks in the Anti-Atlas were deposited are now well established as Palaeoproterozoic in age within a range of 2200–2030 Ma (Ait Malek et al., 1998; Thomas et al., 2002). They thus represent products of the Eburnian–Birimian erogenic event recognised in many parts of the West African Craton. In Morocco, the rocks outcrop in a number of isolated “boutonnieres”, of which the largest, the Zenaga inlier (part of the larger Sirwa inlier) represents part of an

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*Fig. 2. Map of distribution of Palaeoproterozoic basement in the Anti-Atlas region.*
Eburnian orogen (Fig. 2). The Zenaga inlier, like all the other Palaeoproterozoic inliers in the Anti-Atlas belt, is characterised by similar older sequences of layered supracrustal schists, paragneisses and migmatites, interpreted as polycyclic metamorphosed volcano–sedimentary rocks, intruded by various plutonic rocks which are predominantly granitic to granodioritic in composition.

In perhaps the best-known example of a basement inlier, the outcrop at Zenaga, the Palaeoproterozoic rocks are termed the Zenaga Complex (Figs. 2 and 3). The complex consists of supracrustal schists, gneisses and migmatites known as the Zenaga Group. The Zenaga Group is possibly dated at ~2170 Ma, based on the U–Pb zircon SHRIMP dates obtained from relict zircon cores from intruding granites (Thomas et al., 2002). In future, subdivision of the Zenaga Group into formations may be possible. The schists are intruded by a number of calc-alkaline plutonic rocks, three of which have been dated by Thomas et al., 2002—the Assourg Tonalite (2037 ± 7 Ma) the Azguemerzi Granodiorite (2032 ± 5 Ma) and the Tazenakht Granite (2037 ± 9 Ma = Tamazzara Granite of Thomas et al., 2002). It is proposed that these rocks be collectively grouped into the Tazenakht Suite.

Similarly, in the Kerdous inlier, the Kerdous Complex comprises Palaeoproterozoic rocks comparable to those of the Zenaga Complex, though of lower metamorphic grade (Figs. 2 and 3). The oldest supracrustal
rocks, equivalent to the Zenaga Group, are schists, phyllites and psammites of probable turbiditic origin, known as the Had-n-Tahala Group (BGS, 2001a,b). Several calc-alkaline granites that have been dated by the U–Pb zircon PIMMS method intruded these rocks. They fall in a similar age range to those of the Tazenakht Suite and include the Amaghouz Granite (2042 ± 1 Ma), the Anammr Granite (2058 ± 11 Ma) and the Tahala Granite (2060 ± 12 Ma; BGS, 2001a). Some granites which intrude the Had-n-Tahala Group gave older dates, but with poor precision, such as the Agrsiyf Granite which gave 2263 ± 38 Ma and the Zawyat Granite at 2187 ± 33 Ma (BGS, 2001a,b). All these plutonic bodies have been included in the Tazeroaulnt Suite. If the two groups of ages are confirmed in the future, an additional suite name should be given to the older group.

The Palaeoproterozoic basement inliers of Bas Drâa, Tagagra d’Akka, Ighrem and Tagragra de Tata also contain older low-grade (mainly greenschist facies) supracrustal metamorphic rocks, intruded by porphyritic calc-alkaline granites. These latter granites have given similar U–Pb SHRIMP and PIMMS zircon dates: Sidi Sai’d Granite (Bas Drâa) — 1987 ± 20 Ma; Aït Makhloul Granite (Ighrem inlier) — 2050 ± 6 Ma Targant and Oudad Granites (Tagragra de Tata inlier) — 2046 ± 7 Ma and 2041 ± 6 Ma respectively (Aït Malek et al., 1998; Walsh et al., 2002). These granites are included in the Kerdous Suite.

The proposed lithostratigraphic nomenclature is limited to the Zenaga, Kerdous, Tagragra de Tata and Ighrem Complexes. In time, when other areas are studied, new names (e.g. Complexes, Suites, etc.) can be introduced, if necessary, to describe the rocks specific to that particular geographic area.

4. Neoproterozoic sequences (800–550 Ma)

As is the general case in West Africa, no Mesoproterozoic rocks are known in the Anti-Atlas Orogen. In Thomas et al. (2002), a lithostratigraphic scheme was proposed for the Sirwa Inlier, which can serve as the basis for the whole eastern Anti-Atlas Orogen. In general, the Neoproterozoic geology of this area is characterised by a number of rock sequences that are related to the evolution of the orogen in terms of its palaeogeography and tectonic setting. For the highest-order lithostratigraphic units, the term Anti-Atlas Supergroup is proposed to encompass all the Neoproterozoic volcano-sedimentary rocks of the Anti-Atlas Orogen that were deposited before initial basin closure during the Pan-African Orogeny. Fig. 3 shows a generalised stratigraphic log of the named units proposed.

5. Middle Neoproterozoic rifting of the West African Craton, ocean-floor and island-arc formation, flysch sedimentation (Anti-Atlas Supergroup: ~800 Ma to ~680 Ma)

The oldest rocks of the Anti-Atlas Supergroup comprise three discrete sequences related to the rifting and break-up of the northern margin of the West African Craton (represented by a passive margin sequence), the production of oceanic crust (preserved as metamorphosed ophiolitic remnants) and island-arc formation (thrust sheets of calc-alkaline meta-volcanic and plutonic rocks) in the period ~800(?) to 740 Ma. The three broadly coeval products of this early extension–ocean formation–subduction phase were grouped by Thomas et al. (2002) into a “Bleída Group”, with various named components. However, as all but the passive margin sequence are allochthonous (i.e. the ophiolitic and island-arc remnants), we propose here that they should not form part of the same lithostratigraphic group. Thus, the passive margin shallow-water sequence preserved along the northern edge of the Zenaga Complex at the time of rifting of the West African Craton is termed the Taghdout Group (Fig. 3). In Thomas et al. (2002), this sequence was called the Taghdout Subgroup, part of the Bleída Group. However, for the reasons stated above, the Bleída Group thus defined is not acceptable in terms of lithostratigraphic principles, so the passive margin sequence is upgraded to group status. It is in turn subdivided into three formations of basalt, dolomite-shale and quartzite respectively, well exposed in the Type Area near Taghdout village, where a total of some 1500 m of strata are preserved. It may be that the term “Bleída” could be used in future to describe some of the rock sequences in the Bleída area.

The Taghdout Group is associated with a swarm of doleritic dykes, sills and irregular sheet-like bodies that form a network of intrusions into the Zenaga Complex and sills within the lower part of the Taghdout Group. These rocks, geochemically akin to continental tholeiites are termed the Ifzwane Suite and are thought to be associated, along with the lower basalts of the Taghdout Group (Agouni Formation), with the early rifting of the West African Craton.

In the Kerdous inlier, a comparable history is recorded. Mature sandstones equivalent to the ‘Serie des Calcaires et Quartzites’ are interpreted as having been deposited in a shoreline environment (Hassenforder, 1987). This thick succession of quartzites was termed the Jbel Lkst Group by BGS (2001c) and is the probable equivalent of the Taghdout Group. As at Zenaga, the rocks are intruded by an extensive suite of dolerites and gabbros termed the Toudma Suite (BGS, 2001c) that are the probable equivalents of the Ifzwane Suite. In the Bas Drâa, Tagagra d’Akka and the Tagragra de Tata inliers, comparable swarms of continental tholeitic
metadoleritic dykes are recognised, cutting the Palaeo-
protérozoic basement. Continental margin sedimentary
rocks like the Taghdout and Jbel Lkst Groups are sim-
ilarly recognised in these inliers.

Probably broadly coeval with the passive margin se-
quencies of the Taghdout and Jbel Lkst Groups, which
are only developed at the northern margin of the West
African Craton, are the allochthonous ocean-floor rocks
(ophiolites) which were produced as the floor of the
ocean basin grew to the north of the passive margin.
The largest, best-preserved and most complete ophiolitic
fragment is developed at Bou Azzer in the SE Anti-At-
las. This area is thus designated as the Type Area of
the Bou Azzer Group (Fig. 3), which includes all the
ophiolitic fragments of the Anti-Atlas. The other two
main outcrops are in the Sirwa region at Khazama
and Nqob (Thomas et al., 2002). The Bou Azzer Group
includes all rocks associated with the ocean floor, and
comprises mantle harzburgites, layered gabbros, sheeted
dykes, and submarine pillow basalts. Associated intru-
sive rocks such as the plagiogranites can also be given
formal names. An example of the latter from near Bou
Azzer has recently been dated at ~760Ma (Admou
et al., 2002). In due course, the various components of
the Bou Azzer Group may be given formal lithostrati-
graphic names, such as the Nqob and Khazama Ophi-
olites in the Sirwa area. All the ophiolitic fragments are
fault-bound and were tectonically transported to their
present positions during the later stages of the Pan-Afri-
can Orogeny.

The third, allochthonous component of the early oce-
nic realm is composed of rocks that were produced in
an island arc setting which formed by subduction of
the oceanic crust north of the West African Craton mar-
gin (Fig. 3). The products of the island arc comprise
medium-grade biotite-rich (andesitic) schists (Tachouk-
acht Schists) and associated deeper layerd tonalite
orthogneisses (Iriri Migmatite). The formal term Iriri
Group is proposed for this sequence. It also includes
the Ourika Complex, a lithologically similar schist-
gneiss assemblage exposed to the north, in the High At-
las of the Ourika valley. The Iriri Group rocks are all
tectonic contact with other units. The protolith of the Iriri Migmatite has been dated at
743 ± 14Ma (Thomas et al., 2002), confirming that it
formed slightly after the ocean crust that is dated at
~760Ma (Admou et al., 2002).

At about 750 ± 100Ma, therefore, an ocean basin
and island arc(s) had developed north of the West Afri-
can Craton. The Taghdout Group represents the proxi-
mal, shallow-water sediments, deposited at the rifted
passive margin. More distally, the ocean basin was being
filled with an enormous thickness of flysch-like turbiditic
sediments and clastic rocks known as the Sarhro Group.
In the Sirwa Inlier the thickness of the group is hard to
ascertain, due to the scattered nature of the exposures,
it is estimated that the original thickness is thought to exceed 8000m
(Thomas et al., 2002). In this area, the Sarhro Group
is subdivided into six formations. The lowermost four
formations are dominated by the products of deep-water
flysch sedimentation, and volcanic and volcaniclastic
rocks derived from the developing Iriri island arc, whilst
the upper two formations are characterised by coarse,
immature clastic sediments (conglomerates and ark-
oses). It is thought that the change from deep-water fly-
isch to coarse clastic sedimentation was brought about
by a change in plate movement vectors from early exten-
sion (ocean growth) to later contraction (closure and
infilling of the basin), which culminated in the Pan-Afri-
can Orogeny, dated at ~660Ma (Thomas et al., 2002).

In terms of the age of the Sarhro Group, the only di-
rect constraints are that the rocks are older than 615Ma,
the age of the oldest granite (Ida Ou-llloun batholith)
that intrudes them (see below). Furthermore however,
the Sarhro Group may be older than 660Ma, the age of
metamorphic zircons in the Iriri Group, associated
with the early part of the Pan-African Orogeny that de-
forms the group (Thomas et al., 2002). In addition, it
is noteworthy that one of the lowermost (flysch) forma-
tions contains a number of glacial diamicite horizons
(Thomas et al., 2002). Assuming that these diamicites
are equivalent to one of the widespread Neoproterozoic
diamicites found throughout Gondwana, the correla-
tion must be with the older (~700Ma) unit, as the
younger glacial event (~600Ma) took place after the
deforation of the Sarhro Group. With regard to regio-
nal correlations, it appears that similar flysch-like se-
quences characterise the Jebel Sarhro massif and
include the “Tidiline Series” of Leblanc (1973), the Sidi
Flah, Kelaa Mtgouna, Boumalne and Imiter Groups of
Feekkak et al. (2001) and the Habab Group of BGS
(2001e,f). It is proposed that the term Sarhro Group
be applied to all of these, with local subdivisions
at sub-group and formation level within each inlier or
massif. It is also possible with more work that the early
flysch facies of the present Sarhro Group, associated
with the opening oceanic basin could be lithostrati-
ographically separated from the later coarse clastic rocks
associated with basin contraction and infill.


The Pan African Orogeny, which in the Anti-Atlas is
represented by the closure of the ocean basin and subse-
quently accretion of the island arc(s) onto the northern
ripped edge of the West African Craton is not associated
with any volcano-sedimentary sequences or igneous
rocks. The dating of the collision is probably bracketed
between ~660Ma (metamorphic zircons, Thomas et al.,
2002) and ~680Ma (Leblanc and Lancelot, 1980). Thus,
there is a hiatus in the geochronological record between 660 and 615 Ma. The early part of the collision history is represented by SW-directed thrusting and crustal stacking of, for example, the Taghdout Group onto the northern margin of the Zenaga Complex, and by folding, cleavage development and greenschist facies metamorphism in the Sarhro Group.

7. Late orogenic history (Ouarzazate Supergroup: 615–550 Ma)

Magmatic rocks first break the hiatus in recorded sedimentary and magmatic events during the Pan-African Orogeny. In the Sirwa inlier two vast (>750 km²) post-kinematic, composite high-K calc-alkaline (HKCA) batholiths of gabbro-diorite-granodiorite-granite were emplaced into, and contact metamorphosed, the deformed Sarhro Group rocks. In the Sirwa area these plutonic rocks have been grouped into the Assarag Suite (Fig. 3). The Ida Ou-Illoun batholith was dated at 615 Ma, while the rocks of the Askouen batholith are somewhat younger at ~580 Ma (Thomas et al., 2002). In the Tiwit/Ikniwn area of the Jebel Sarhro massif, several HKCA granites, granodiorites and igneous charnockites (Errami, 2001; Errami et al., 2002), known as the Bardouz Suite, intrude the Sarhro Group (BGS, 2001e,f), whilst the equivalent rocks in the Ker douss Inlier are termed the Guellaba Suite. Such granitoids are thus typical of the Anti-Atlas Orogen and new suites will doubtless be identified in due course in different areas. The available reliable zircon dates on the HKCA granitoids range from 615 to 580 Ma (Ait Malek et al., 1998; De Wall et al., 2001; Levresse et al., 2001, Thomas et al., 2002; Inglis et al., 2004), either reflecting episodic emplacement or part of an as yet incompletely defined continuum.

All the volcano–sedimentary rocks that were deposited after the Anti-Atlas Supergroup have been grouped into the Ouarzazate Supergroup. During the time spanned by the intrusion of the Assarag Suite in the Sirwa area, a restricted sequence of bimodal volcanic (basalts and rhyolites) and coarse-clastic rocks was being deposited in fault-bounded grabens. These rocks form the first evidence of post-accretion deposition in the Anti-Atlas and represent precursors to the much more extensive molasse which follows. In the Sirwa region, some 2000 m of these rocks occur in two narrow, restricted fault-bounded troughs where they are known as the Bou Salda Group (c.f. Bou Salda Formation in Thomas et al., 2002). Two associated rhyolites (Tadmant and Tamriwine Rhyolites) have given identical U–Pb SHRIMP ages of 605 Ma (Thomas et al., 2002). Throughout the Anti-Atlas Orogen these early post-collision rocks occur in narrow fault-bound grabens and tend to have high tectonic dips of between 70° and vertical. It is suggested that the grabens in which these rocks were deposited were strike-slip, pull-apart basins. The basins are interpreted to have developed in a sinistral transpressional regime initiated by continued post-collision convergence, along major strike-slip zones such as the Anti-Atlas Major Fault.

Similar proto-molasse sequences have been recorded in the Jebel Sarhro massif near Imiter, where huge-boulder conglomerates are developed. In this area, the sequence appears to be quite thick and the term Mgouna Group is proposed. In the Kerdous Inlier, the “Serie d’Anezi” (Choubert et al., 1973) occupies a similar lithostratigraphic position. This volcaniclastic succession was subdivided by BGS (2001a,b) into the basal Tafrat Group (dominated by dacitic to rhyolitic ignimbrite) and the overlying Anzi Group (dominated by sandstone and conglomerate derived from the Tafrat Group).

Unconformably overlying the plutonic rocks of the Assarag Suite and the “proto-molasse” of the Mgouna, Tafratw, Anzi and Bou Salda Groups lies the upper part of the Ouarzazate Supergroup. These rocks comprise several groups, composed of thick and regionally extensive sequences of lavas, volcaniclastic rocks and coarse-grained immature clastic and epiclastic sedimentary rocks, which covers more than 60 000 km² encompassing the entire Anti-Atlas Orogen. The rocks are associated with alkaline sub-volcanic granite complexes, basic and acid dyke swarms, various rhyolitic plugs, domes and necks and gabbroic bodies. Due to the rapid and extreme fades variation (both sedimentary and volcanic) typical of such sequences, coupled with the recognition that some of the volcanic rocks were extruded from multiple interfingering volcanic centres, the lithostratigraphic subdivision of the upper Ouarzazate Supergroup over the entire orogen will undoubtedly prove to be incredibly time-consuming and complex. For example, in the Sirwa Inlier, Thomas et al. (2002) recognised that the volcanic rocks of the upper Ouarzazate Supergroup (their Ouarzazate Group) were the products of five broadly coeval interfingering volcanic centres, each with its own stratigraphy, and each subject to almost metre-scale facies variations. The different centres are here designated groups, subdivided into formations, if the centre was dominated by volcano–sedimentary rocks, or Formations for thinner, less extensive sequences, or Complexes for those centres dominated by sub-volcanic plutonic rocks in caldera complexes. Thus, in the Sirwa region alone the upper part of the Ouarzazate Supergroup is subdivided into three Groups (with a total of 13 Formations and 35 Members), one Formation and one Complex. It will clearly take a long time and require much effort for the entire Ouarzazate Supergroup to be formally lithostratigraphically subdivided in this fashion. In other areas, the Ouarzazate Supergroup was subdivided into separate subgroups on lithological grounds, not related
Table 1
Comparative lithostratigraphic nomenclature of the Anti-Atlas Orogen, with the scheme proposed by this study

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<td>Basement complexes</td>
<td>Granitoids</td>
<td>Kerdous, Draa Complexes:</td>
<td>Zenaga Complex:</td>
<td>Not present</td>
<td>P1</td>
<td>2200 to 2035Ma: Eburnian basement</td>
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<td>Tazeroualt and Mechebbouk Suites</td>
<td>Tazenacht Suite</td>
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<td>Had-n-Tahala and Draa Groups</td>
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<td>Schists</td>
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to extrusion from different volcanic centres. The rhyolitic volcanism of the upper part of the Ouarzazate Supergroup spanned the period 575 to about 550 Ma (Mifdal et al., 1985; Thomas et al., 2002; BGS 2001a–f; Walsh et al., 2002).

The upper part of the Ouarzazate Supergroup is associated with multiple high-level alkaline granite intrusions and sub-volcanic caldera complexes. Many of these are polyphase, with up to three phases recognised. In the Sirwa Inlier, these complexes are grouped within a single Toufghrane Suite (with 13 named granites) that spans the period 575–560 Ma (Thomas et al., 2002).

In the Kerdous and Bas Draa inliers, an equivalent suite of 10 syn- to post Ouarzazate Supergroup granites, spanning the period 545–579 Ma, have been termed the Guellala Suite (BGS, 2001a,g,h). Similarly in the Iknwin/Tiwit area of Jbel Sarhro, two high-level granites are included in the Tanghourt Suite (BGS, 2001e,f).

Thus, utilization of this framework provides for the formal recognition of additional intrusive suites in other parts of the Anti-Atlas Orogen. The multitude of associated mafic and acid dykes and rhyolitic plugs associated with the Ouarzazate Supergroup have not been formally named at this stage.

Disconformably following the Ouarzazate Supergroup in the Anti-Atlas Orogen are a thick sequence of carbonate–siliciclastic shale rocks with locally developed volcanic rocks that are termed the Tata and Taroudant Groups. The Precambrian–Cambrian boundary falls within the lowermost part of the sequence (Landing et al., 1998). These rocks developed within a gradually subsiding transtensional foreland basin (Tindouf Basin) that formed over, and to the south of, the Anti-Atlas orogen and sedimentation continued through the Palaeozoic and Mesozoic. The Tata and Taroudant Groups are thus not considered to be part of the Anti-Atlas Supergroup, but the lowermost unit of the next supergroup cycle (Tindouf Supergroup?), which falls outside the scope of this article.

8. Conclusion

The new lithostratigraphic system proposed for the Anti-Atlas Orogen is summarised in Table 1, where it is compared to the old chronostratigraphic nomenclature. It appears to encompass all the major units reported from throughout the orogen and is flexible enough so that, in future, newly recognised units (especially at the Formation, Member and Suite rank) can be added at the appropriate stratigraphic level. The scheme allows for both layered volcano–sedimentary and intrusive units to be incorporated and fits well with proposed evolutionary models of the belt:

1. Early continental break up of West African Craton (passive margin sedimentation: parautochthonous Taghdout and Jbel Lkst Groups) and continental tholeiitic magmatism (Ifzwane, Toudma Suites), possibly from ~800 Ma;
2. Continued extension, ocean crust formation (allochthonous Bou Azzer Group ophiolitic fragments), subduction and island-arc formation (allochthonous Iriri Group tectonic slivers) in the interval 800–740 Ma;
3. Within the now-established ocean basin, flysch sedimentation (lower turbiditic Sarhro Group) took place, certainly before 615 Ma, probably before 660 Ma and maybe before 700 Ma;
4. End of extension phase, plate movement vector reversal to convergence, ocean basin shrinks and fills (upper clastic Sarhro Group) culminating, probably at about 660 Ma, in;
5. Ocean basin closure, Pan-African accretion of Iriri island-arc onto northern margin of WAC, SW-directed thrusting, deformation of all pre-accretion rocks (grouped collectively into the Anti-Atlas Supergroup) including tectonic emplacement of remnant slivers of island-arc(s) (Iriri Group);
6. Continued and prolonged relative SW–NE movements give rise to major sinistral transpression zones such as the AAMF, causing lateral tectonic emplacement of allochthonous oceanic crustal ophiolitic slivers (Bou Azzer Group). Early high-K, calc-aluminous granitoid suites intruded at ~615 Ma (Assarag and Bardouz Suites). The entire volcano–sedimentary pile associated with this tectonic phase is termed the Ouarzazate Supergroup. Into this active transpressive tectonic setting, the lower part of the Ouarzazate Supergroup (Bou Salda, Mgouna, Tafrawt and Anzi Groups) were deposited in narrow strike-slip, pull-apart grabens at ~605 Ma. Emplacement of HKCA batholiths continued to 580 Ma (episodic or continuous?);
7. True continental molasse volcano–sedimentary rocks of the upper part of the Ouarzazate Supergroup were deposited in settings associated initially with still-active major strike-slip fault zones from ~580 Ma. Followed by more extensive overlapping deposition and magmatism from numerous interfering volcanic centres (many with exposed sub-volcanic caldera complexes and associated alkaline granites: Toufghrane, Guellala, Takatart and Tanghourt Suites), due to orogenic collapse and regional extension from 575 to 545 Ma;
8. Posterior to the Anti-Atlas Orogen, subsidence of extended crust (transtension), marine incursion and major foreland basin formation (Tindouf Basin) from latest Neoproterozoic times into the Lower Palaeozoic (Tata and Taroudant Groups).
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