CONTENT

1 ABSTRACT

1.1 Geology, geochemistry and geochronology

This map explanation presents the results of a four-year reconnaissance-mapping project in northern Mozambique and represents a significant revision of the pre-existing understanding of the geology of the area. An overview of the main geological units is shown in Figure 1.1.

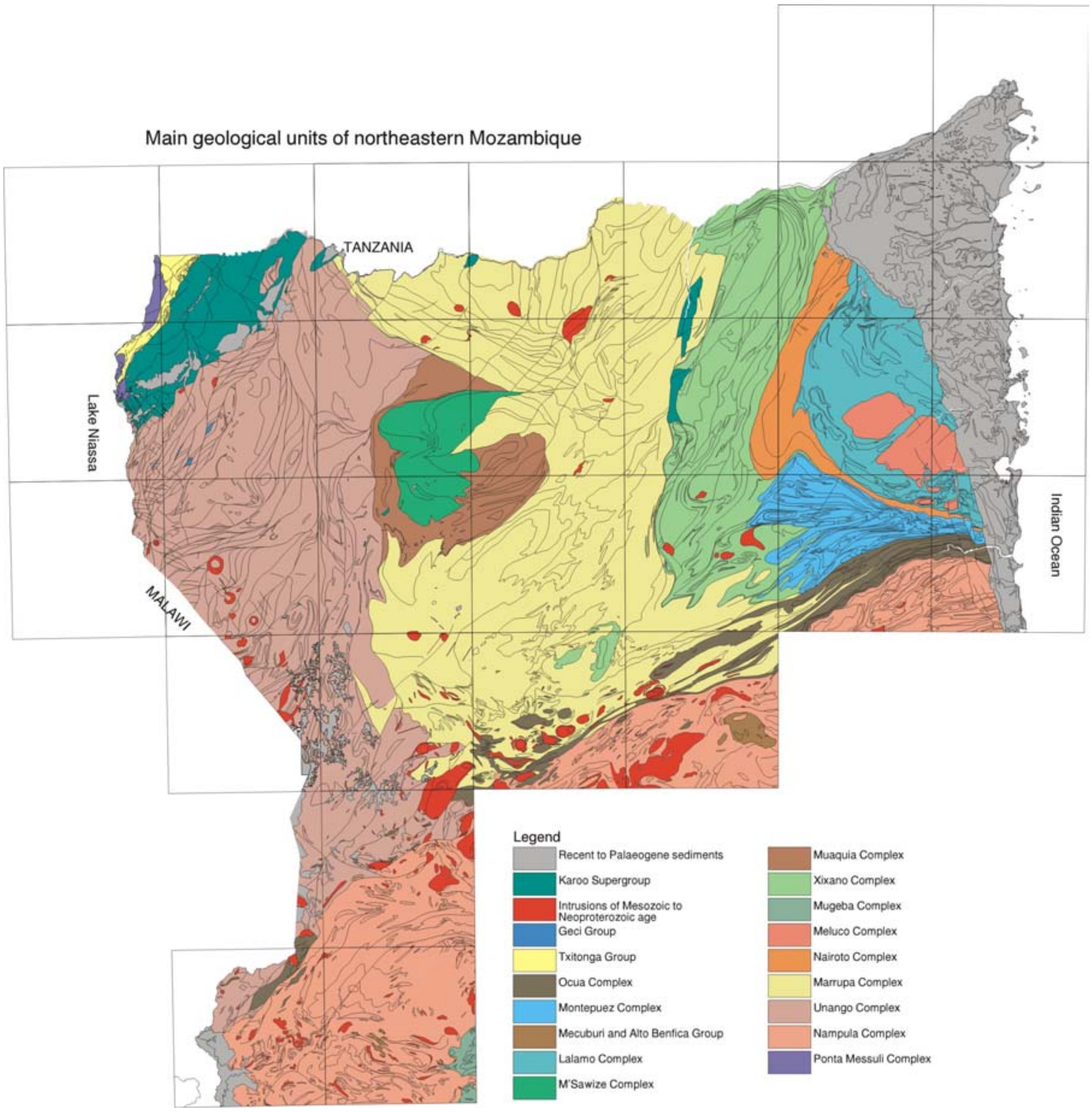

Figure 1.1: Overview of the main geological units in northeastern Mozambique.

The main units are:

<u>*Ponta Messuli Complex:*</u> This complex is found along the shore of Lago Niassa. Some of its component units are unique in the region. The northern areas are occupied by migmatitic gneiss of supracrustal origin containing cordierite and sillimanite. The southern part of the Ponta Messuli Complex is dominated by augen gneiss. The Ponta Messuli Complex has been shown to be the oldest unit in the region, giving a Palaeoproterozic metamorphic age (1,95

Ga), and containing detrital zircons with a minimum age of 2074±11 Ma. Sm/Nd model ages also indicate that Archaean material has been involved in the formation of the complex.

Nampula Complex: The Nampula Complex is the structurally lowest of the Mesoproterozoic tectonostratigraphic crustal blocks in northern Mozambique (Figure 1.1). It occupies the southern part of all the sheets that define the southern limit of the area described. The lithodemic and lithostratigraphic units comprise a sequence of supracrustal gneisses, the *Molócuè Group*, which is migmatised to various degrees, and an even older suite of granitoid gneisses known as the *Mocuba Suite* (dated at 1123-1148 Ma). These supracrustal and granitoid rocks were intruded by various intermediate to acid intrusives, now orthogneisses, the *Culicui Suite* (dated at 1028– 1087 Ma). Many of the units encountered are very highly migmatised. The orthogneisses include I- and A-type granitoids. These basement rocks make up about 90% of the surface area of the Complex, the remainder being comprised of two overlying units of metasedimentary gneisses, the *Mecuburi* and *Alto Benfica Groups,* which were deposited unconformably on the Nampula Complex later than 630 Ma. The Alto Benfica Group contains detrital zircons covering a wide age span, back to 3,31 Ga.. Subsequently, the Nampula Complex was intruded by syn- to post-tectonic, Pan-African granitoid plutons, dykes and sheets of the *Murrupula Suite* and the *Malema Suite* during the Cambrian. The western margin of the Nampula Complex, was intruded by a number of Jurassic syenite and nepheline-syenite plutons, plugs, sheets and dykes, representing alkaline activity along the southern termination of the East-African rift system.

Unango Complex: The Unango Complex dominates the geology of the western part of Niassa Province (Figure 1.1): it extends from the border with Tanzania, where it is partly overlain by the Karoo rocks of the Maniamba Graben, to 15^0 30' S, and from Lago Niassa and the Malawi border in the west to 36^0 30' E, northeast of Mavago, where it is overthrust by the Marrupa Complex and overlain by a klippen consisting of the Muaquia and M'Sawize Complexes. South of this nappe it has a tectonic contact with the Marrupa Complex. It was emplaced structurally above the Nampula Complex during the Pan-African Orogeny. The boundary between these two complexes is a complex series of northeast-southwest-trending, anastomosing, steep shear zones, evidence of which was only rarely observed in the field. The Unango Complex is dominated by acid to intermediate orthogneisses, partly at granulite grade and partly retrogressed. Migmatisation of variable character is extensive. Some components show little indication of having been exposed to granulite-facies metamorphism. Most of the granodioritic rocks plot in the field of I-type granites and about 50% of the granites have compositions similar to fractionated I-type rocks, whereas other granites plot in the A-type field together with syenitic rocks. Monzodioritic to monzonitic rocks plot both in the field of fractionated I-type and A-type granites. High-grade paragneisses locally predominate in the west along the border with Malawi. Many of the units within the complex are bounded by elements in a network of anastomosing shear zones. Ten samples of various orthogneisses of the Unango Complex range in intrusion age from 1065±16 to 975±33 Ma. In addition three samples of paragneiss were dated by different methods giving peak amphibolite- to granulite-facies Pan-Afrcan metamorphism between 553±13 and 525±9 Ma.

Marrupa Complex: The Marrupa Complex is one of the most extensive tectonostratigraphic units in northern Mozambique (Figure 1.1): it is dominated by orthogneisses of acid to intermediate compositions, while mafic orthogneisses and paragneisses are subordinate. The gneisses vary from being homogeneous and rather fine-grained, to more coarse-grained, and include banded and migmatitic varieties. From the mineral assemblages present, the rocks seem to have undergone amphibolite-facies metamorphism. This differs from the adjoining units, which have experienced granulite-facies conditions. Geochemical data show that the complex is dominated by normal and fractionated I-type granitoids in addition to rocks with a clear A-type affinity. Thirteen age determinations have been carried out on rocks from the Marrupa Complex, most of them granite and granitic gneiss. The ages of the protoliths are 968-1026 Ma with uncertainties of 8-19 Ma, while metamorphic overprints are Pan-African ages of 521-562 Ma (uncertainties of 5-15 Ma).

Nairoto Complex: The Nairoto Complex forms a 15-30 km wide north-northeast - south-southwest trending belt that runs from the central part of sheet 1139 Mueda southwards along the contact between sheets 1238 Xixano and 1239 Meluco. North of Montepuez there is a major fold with axial plane trending north-northeast - south-southwest that turns the unit to a west-northwest-east-southeast direction. Eastwards the complex comprises a 10-15 km wide belt across sheets 1339 Montepuez and 1340 Mecufi. The complex thus comprises an arc-shaped belt wrapped around the Lalamo Complex. The contacts to the latter are clearly tectonic. The orthogneisses are commonly magnetite-bearing, and the belt shows pronounced positive anomalies in the aeromagnetic data. The Nairoto Complex consists mainly of a suite of felsic orthogneisses with varying degrees of migmatisation. Geochemically they are calc-alkaline with granitic to tonalitic compositions, and can be classified as normal I-type granitoids. Granitic to granodioritic varieties predominate. A few minor lenses of paragneiss were found. There are no indications that the metamorphic grade has exceeded amphibolite facies. A psammitic gneiss has yielded a zircon with an interpreted crystallisation age of 976 ±5 Ma, with a metamorphic overprint at 579 ±10 Ma. Intrusion ages of 1044 ±44 and 1019 ±36 Ma have been reported for biotite gneiss and amphibolite respectively.

Meluco Complex: The Meluco Complex occurs in two large oval dome-like structures in the southwest part of sheet 1239 Meluco (Figure 1.1). The largest of these structures continues onto sheet 1240 Quissanga-Pemba. Three much smaller, restricted structures occur on sheets 1339 Montepuez and 1340 Mecufi. The Meluco Complex consists of orthogneisses mainly of granitic to granodioritic composition, with tonalitic rocks as a subordinate component. The geophysical data on the two large dome structures show a rather irregular, folded pattern in contrast to the supracrustal rocks in the surrounding Lalamo Complex, which have a very banded pattern that seems to wrap around the Meluco Complex. The idea that the Meluco Complex is a basement for the supracrustal rocks is therefore plausible. Where the contact between the complexes has been observed it is a thrust, with the rocks of the Lalamo Complex thrust over the Meluco Complex in a "top-to-the-south" movement.Geochemical data on granodioritic/granitic gneiss from the Complex indicate a high-K calc-alkaline character: the rocks can be classified as fractionated I-type granitoids. The western granite dome yields an intrusion age of 947±21 Ma. The easternmost granite yields an almost identical intrusion age of 946±12 Ma. Metamorphic overprint of the latter sample is dated to 585±13 Ma

Mugeba Complex: The Mugeba Complex forms a klippe, the westernmost part of which is poorly exposed in the southeast corner of sheet 1636 Mocuba. It consists of a range of granulitic gneisses underlain by mylonitic to flaser orthogneiss, which forms the base of the structure.

Xixano Complex: Its highly distinctive radiometric signature facilitated recognition of this Complex as a new tectonostratigraphic unit. It extends from the Tanzanian border, east of Rio Lugenda to the Lurio belt and includes two outliers within the Marrupa Complex on sheets 1437 Malema and 1337 Marrupa, a large, north-south-trending body near Nipepe and another isolated mass to the west, in the Monte Macicoro area. A third small mass is found at Tele on sheet 1338 Namuno. The major part of the complex consists of metasupracrustal rocks enveloping predominantly mafic igneous and granulitic rocks that comprise the core of a regional north-northeast - south-southwest-trending synform. The paragneisses include various forms of mica gneiss and schist, quartz-feldspar gneiss, metasandstone, quartzite and marble. Felsic orthogneisses occur with the paragneisses, mainly in the northern and eastern part of the complex. The metamorphic grade within the Xixano Complex is dominantly amphibolite facies although granulite-facies rocks are preserved within tectonic lenses.The contact to the underlying Marrupa Complex in the west is a major shear zone that was subsequently folded against the Lurio belt in the south. The shear zone contact with the Montepuez Complex in the east is also strongly folded. A major shear zone also separates the Xixano Complex from the Nairoto Complex in the east.

The oldest dated rock in the Xixano Complex is a weakly deformed metarhyolite from sheet 1338 Namuno, which gives a reliable extrusion age of 818±10 Ma. A similar age 799±44 Ma, was obtained from a granitic gneiss further northeast. The intrusive age of an enderbitic gneiss from a tectonic lens in the northeastern part of sheet 1238 Xixano is 742±16 Ma. The age of granulite facies metamorphism, 735±4 Ma is recorded by a banded granulite from the northern part of sheet 1338 Namuno.

Muaquia Complex: The complex occurs around the conjunction of sheets 1336 Majune, 1337 Marrupa, 1236 Mavago and 1237 Mecula. The Muaquia Complex is very heterogeneous. It includes a wide range of acid to intermediate orthogneisses as well as lenses and bands of paragneiss, including quartzite, quartz-rich two-mica schists, amphibolite and calcsilicate rock. Its textures are mainly blastomylonitic and mylonitic and deformation increases towards the border wth the Unango Complex to the west. The rocks show widely separated indications of an early high-pressure metamorphic event.

M'Sawize Complex: The M'Sawize Complex lies mainly on sheets 1236 Mavago and 1237 Mecula. It overlies the Muaquia Complex and is partly surrounded by it (Figure 1.1). The M'Sawize Complex includes granodioritic to gabbroic gneiss. Metatonalite, metagabbro with amphibolite and banded migmatite with minor migmatitic granite. The Complex is underlain by faults and shear zones, which are related to extensional movement. A tonalite within the Complex has yielded an age of 640±4 Ma. Unlike the other complexes in the region the M'Sawize Complex is dominated by mafic to intermediate rocks: they are of I-type.

Lalamo Complex: The Lalamo Complex is situated east and north of the Nairoto Complex and overlain by the Cenozoic to Mesozoic sedimentary rocks of the Rovuma Basin (Figure 1.1). It consists predominantly of various metasupracrustal rocks; biotite gneiss, meta-sandstone, quartzite, marble, amphibolite and conglomerate and minor meta-igneous rocks of granitic to ultrabasic composition. The rocks of the Lalamo Complex have generally experienced amphibolite-grade metamorphism.The western contact with the Nairoto Complex is a shear zone, along which a dextral movement cuts off the various units of the Lalamo Complex. The lithologies are rather similar to those in the Montepuez Complex, but the Nairoto Complex always separates these two complexes, except in the extreme east where the contact is a shear zone. Since they also have a totally different tectonic style they are distinguished as two complexes on the map. It has been observed that the Lalamo Complex has been thrust upon the Meluco Complex, which might represent a basement for the supracrustal rocks. A granitic gneiss from the north-central part of sheet 1239 Meluco has given an intrusion age of 696±13 Ma. This indicates that rocks of the Lalamo Complex are younger than those of the Meluco Complex.

Alto Benfica and Mecuburi Groups: The Alto Benfica Group is a stratified quartzitic metasedimentary package that lies upon, and is restricted to, the Mesoproterozoic Nampula Complex basement. It occurs as a series of narrow, isolated lens-shaped outcrops in the region around Alto Benfica in the central-southern part of sheet 1636 Lugela-Mocuba and in the easternmost part of sheet 1635 Milange. The main lithology is matrix-supported metaconglomerate, which contains biotite granite, and leucogranite gneiss pebbles with fresh pink K-feldspar. The clasts are set in a medium- to coarse-grained matrix of feldspathic quartzite.

The Mecuburi Group occurs in an area of ~500 km^2 on sheet 1438 Ribáuè-Mecuburi. The contacts of the Mecuburi Group with the surrounding gneisses of the Nampula Complex are not exposed, but there is good circumstantial evidence to suggest that the contact is unconformable, rather than tectonic: 1) The Group appears to regionally overlie and locally overstep different units of the Nampula Complex, 2) No evidence of shearing was observed at the contacts, even in localities that can only be a few tens of metres from observed contacts, 3) Coarse conglomeratic units contain boulder-sized clasts that may be correlated with lithologies in the adjacent, underlying Nampula Complex. The main lithologies are: Gneissic metaconglomerate with meta-arkosic gritstone, and biotite gneiss, locally conglomeratic and with sillimanite nodules.

Montepuez Complex: The Montepuez Complex forms a wedge-shaped unit of strongly deformed para- and orthogneisses in the southeast part of the mapped area. It comprises orthogneisses ranging from granitic to amphibolitic in composition, and paragneisses comprising mainly quartzite, meta-arkose, marble, quartz-feldspar gneiss and biotite gneiss. The rocks are strongly folded into tight and isoclinal folds on all scales, and have later been cut by a number of mainly northeast-southwest trending shear zones. The strong deformation makes the lithologic succession very complex with large variations on all scales both within and between the lithologies. The rock assemblage have generally experienced amphibolite grade metamorphism. A leucosome in a paragneiss in the western part of the complex was dated to 942 ± 14 Ma with a metamorphic overprint at 599±10 Ma. Chemostratigraphic dating of marbles in the Complex suggests their deposition between 1100 and 1050 Ma.

Ocua Complex: The Ocua Complex is a tectonic mélange, mainly comprised of granulitic lithologies. In the east, on sheet 1339 Montepuez and 1340 Mecufi, it is situated between the Nampula and Montepuez Complexes. It forms the core, in general, of a 25-30 km wide shear belt called the Lurio belt, comprising strongly deformed, often mylonitic lithologies. The lithologies are granulitic gneisses of both felsic and mafic character, orthogneisses of granitic to amphibolitic compositions, and paragneisses including biotite gneiss, quartz-feldspar gneiss, quartzite and meta-arenite. The structures most visible on the aeromagnetic and radiometric data over the Lurio belt are a moderately northwest-dipping, southwest-northeast-trending lithological banding, and megascopic isoclinal folds with moderately reclined axial surfaces parallel to this direction. The high-strain Lurio belt fades progressively to the southwest, where it becomes infolded within the Marrupa Complex and, to a lesser extent, the Nampula Complex. Farther to the southwest, on sheets 1535-6 Insaca-Gurúè and 1636 Milange, the complex contains a series of belt-like bodies, layers and lenses on all scales, which are concentrated along the northeast-southwest-trending tectonic zone that separates the Nampula and Unango Complexes. Thus they occur mainly in the contact shear zone belt itself, but also infolded with the Nampula and Unango Complexes on either side.

The Ocua Complex is probably a composite unit, containing slices of the adjoining rock units, deformed, transposed and dismembered during Pan-African tectonic events, and not originally a separate rock unit. Lithologically, the Lurio belt can thus be regarded as containing a tectonic melange including granulites and sheared gneisses and metasediments. The traditional separation into “supracrustal” and “intrusive” gneisses cannot be made confidently for large parts of the complex. Amphibolite- to granulite-facies metamorphism and deformation in the Ocua Complex is bracketed between 578 ±10 and 540 ±7 Ma.

Txitonga Group: The Txitonga Group is bounded by the Ponta Messuli Complex to the west, and the Karoo Supergroup to the east. It is 10-25 km wide and occupies a rugged, high mountainous area, extending from the Tanzanian border to south of Cobué on Lago Niassa, a distance of nearly 100 km. The Group is dominated by metasedimentary rocks, mainly metagreywacke, metasandstone, quartz-mica schist and chlorite-rich schist. In the northern part of the unit there are numerous bodies of metagabbro, greenstone, greenschist and minor felsic metavolcanic rocks. There are indications that metamorphic conditions have varied along the length of the Group. In the northern areas the metamorphic grade may not have exceeded greenschist facies. Garnet and staurolite are found in the Cobué area, which indicates amphibolite facies. A late retrogressive event has affected both the Txitonga and most of the Ponta Messuli lithologies, leading to regional sericitisation and local carbonatisation. The Group hosts the important Niassa Gold Belt. A quartz-feldspar porphyry in the Group has been dated to 715±20 Ma, while Re-Os dating of sulphides from the Gold Belt yielded an age of ~483 Ma.

Geci Group: The Geci Group occurs as several, tectonically dissected, intensively sheared, folded and mylonitised lenses within Unango Complex granulite rocks northwest of Lichinga.. The dominant rocks are calcarenites, dolarenites, calcite matrix-supported and dolostone clast-supported carbonate breccias. In places, primary depositional features are well preserved. The least-altered $^{87}Sr/^{86}Sr$ and $\delta^{13}C$ ratios suggest an apparent depositional age of either 590-585 or 630-625 Ma. This provides a lower age limit for juxtaposition of the low-grade Geci group rocks and granulite-facies rocks of the Unango Complex.

Neoproterozoic to Palaeozoic intrusions: A great variety of igneous rocks that are not an integral part of the Meso- to Neoproterozoic gneiss complexes have been distinguished. They range in age from Neoproterozoic to Jurassic, although syn- to post-tectonic Pan-African intrusions predominate. Some of these intrusives are clearly related, and comprise distinct intrusive suites. They include:

- The Monte Naumale and Monte Chissindo (799±8 Ma) alkaline intrusions in the Unango Complex: both bodies have a potential for special metals of various types.
- The *Monte Miruei Suite* of granite gneiss pods in the southeastern part of the Unango Complex, dated at 749±20 Ma.
- The *Murrupula Suite*, found in the area south of sheets 1437 Malema and 1438 Ribáuè-Mecuburi. It consists of. older sheet-like syntectonic bodies of foliated biotite granite orthogneiss, and younger intrusions of undeformed to weakly deformed granite.
- The *Malema Suite*, comprising Pan-African monzonitic, syenitic and granitic bodies as well as charnockitic rocks in the southern part of the area mapped. On sheets 1437 Malema and 1438 Ribáuè-Mecuburi the suite includes seven sub-circular to ellipsoidal plutons, including three zoned, granitoid ring complexes along a north-northeast-oriented line parallel to the Lurio belt.
- The *Niassa Suite*, comprising several granitic to syenitic Pan-African intrusions that form prominent mountains from Meponda in the north, southeastwards along the border with

Malawi, to south of Mandimba. Intrusion ages of 507±4 and 514±35 Ma have been obtained. There are four major ring complexes on sheets 1334 Meponda and 1335 Lichinga, namely Monte Metonia, Monte Livigire, Monte Nicucule and Monte Chande. Except for Monte Chande, they are all mainly syenitic in composition. Monte Chande consists of alkali-syenite surrounding a core of alkali-granite. The highest and most impressive mountains, Monte Lissiete and Serra Lipane on sheet 1435 Mandimba are underlain by 'late' granites and associated syenites.

Karoo Supergroup: The Karoo strata of the Maniamba Graben in Niassa Province (Figure 1.1) include a lower sequence with 'coal measures' of Permian age attributed to the Ecca Group. The overlying upper Karoo siliciclastic sediments are of probable upper Permian/Triassic to Jurassic age. The graben system developed by rifting throughout Karoo deposition and is up to about 10 km deep in its centre. Smaller, tectonically bounded blocks of Karoo sediments are found in the northwestern part of Cabo Delgado Province (two) and east and southeast of Lichinga on sheets 1335 Lichinga (two) and 1336 Majune (two).

Kimberlites: Kimberlites occur as dykes up to 3 m thick and isometric bodies in the southern part of the Maniamba Graben. The occur along four northwest-southeast-trending zones, and one east-northeast – west-southwest-trending zone They are macrocrystic hypabyssal Group Ia kimberlites based on their mineralogy and whole rock geochemistry. Mineral and Sr isotope data confirm the Group I classification. A phlogopite Rb-Sr mineral isochron provides a Lower Cretaceous estimate of 138±8,5 Ma for emplacement of one of the isometric bodies. Geophysical data acquired in 2005 indicate that kimberlites may also be found further north in the graben.

Rovuma Basin: The history of the basin is directly linked to the progressive break-up of southern Gondwana: the sedimentary succession of the basin can be divided into five tectono-stratigraphic mega-sequences reflecting the different break-up stages: Pre-rift during the Permo-Triassic, syn-rift during Triassic to Early Jurassic, early drift during Mid-Jurassic – Mid-Cretaceous, late-drift during Mid-Cretaceous to Oligocene, and deltaic progradation during Oligocene to present time. The lithostratigraphy of the Basin has been reassessed based on field results, petrography and micropalaeontological data, in the light of the above tectonic development. Oil seeps are known from several parts of the basin and there is increased interest in the hydrocarbon potential of the area.

1.2 Geochemical classification

Sampling for geochemical analyses mostly covers amphibolite- to granulite-facies meta-igneous rocks and is representative of the spectrum of rock types of the various complexes and rock units in the investigated area. Table 1.1 summarizes the main compositional parameters: within each complex there is considerable variation from subordinate mafic to ultramafic lithologies to a diversity of intermediate to acid rocks.

The granitic to charnockitic rocks of the Unango, Marrupa, Nampula, Nairoto, Meluco, Lalamo and Montepuez Complexes appear to be broadly similar in composition and consist mainly of metaluminous, medium- to high-K (shoshonitic), calc-alkaline rocks. All of these complexes contain subordinate mafic to ultramafic rocks. In contrast, the Xixano, Muaquia, M'Sawize and Ocua Complexes reveal abundant mafic to intermediate, low-K orthogneisses, and some amphibolite. In the Xixano Complex, the evolved rocks appear to have a bimodal distribution including low-K tonalite and high-K granite.

In general, the magnesian mafic rocks may represent fairly juvenile additions to the crust. However, most of the high-K granitic to charnockitic rocks probably represent a significant degree of recycling of previously formed crust. Plutonic rocks of this type are commonly emplaced in relatively mature continental arcs and as large, post-collisional batholiths following terrane accretion. Syn- to post-tectonic intrusive rocks, including the ring complexes of the Niassa Suite, are high-K calc-alkaline to shoshonitic to highly alkaline, and exhibit very high values for several trace elements (e.g. Zr, Ba, Sr and LREE). The evolved alkaline complexes (syenites) are generally regarded as products of post-collisional and/or anorogenic magmatism. The geochemical data (Table 1.1) support the model for terrain assembly presented below in showing the geological and geochemical contrast between the mainly felsic lower tectonostratigraphic levels (Ponta Messuli to Meluco Complexes) and the significantly more juvenile overlying complexes (Xixano to Lalamo Complexes) assembled during the Pan-African orogeny.

Complex/Suite	N	General classification	SiO_2 (wt %)	K_2O (wt %)	Other characteristics
Niassa Suite	14	Mainly shoshonitic A-type	60.9 – 77.5	4.5 – 7.7	High LREE and HFS-elements
Malema Suite	16	Mainly shoshonitic A-type	52.4 – 75.0	1.9 – 6.2	High LREE and HFS-elements
Murrupula Suite	9	High-K calc-alkaline to shoshonitic	54,8 – 74.9	2.0 – 5.7	
Neoproterozoic plutons, undiff.	17	High-K calc-alkaline to shoshonitic	46.2 – 76.8	0.1 – 6.7	High/variable Zr, Ba, Sr and LREE
Txitonga Group	4	Mafic, low-K to intermed. high-K rocks	47.0 – 75.9	0.4 – 5.9	Partly high Ba and LREE
Ocua Complex	25	Ultramafic and low-K to medium-K, calc-alkal, metaluminous rocks	39.8 – 75.3	0.2 – 8.5	Predominantly mafic to intermediate
Montepuez Complex	9	Medium-K to high-K calc-alkaline	43.3 – 76.0	0.1 – 4.7	Predominantly intermediate to acid
Lalamo Complex	19	Medium-K to high-K calc-alkaline	36.1 – 76.4	0.01 – 5.4	Partly high Zr, Ba, Sr and LREE
M'Sawise Complex	6	Low-K calc-alkaline	45.0 – 63.5	0.3 – 1.2	Predominantly mafic to intermediate
Muaquia Complex	9	Low-K to medium-K calc-alkaline	44.9 – 78.2	0.1 – 3.5	Predominantly mafic to intermediate
Xixano Complex	47	Low-K calc-alkaline and high-K calc-alkaline	39.7 – 77.7	0.1 – 5.6	Abundant mafic rocks. Tonalite and granite
Meluco Complex	4	High-K calc-alkaline	66.8 – 68.7	4.0 – 4.9	
Nairoto Complex	6	Medium-K calc-alkaline	60.3 – 70.4	1.2 – 3.3	
Marrupa Complex	81	Medium-K to high-K calc-alkaline	42.3 – 78.9	0.3 – 6.1	Mainly intermediate to felsic; commonly high Ba
Unango Complex	125	Medium-K to high-K calc-alkaline	43.1 – 78.4	0.8 – 6.9	Very wide range in composition
Nampula Complex	44	Medium-K to high-K calc-alkaline	49.7 – 77.2	0.6 – 7.3	Partly high Zr, Ba, Sr and LREE
Ponta Messuli Complex	2	Mafic calc-alkaline granodiorite and amphibolite			

Table 1.1Summary of compositional features for the main groups of rocks (N=no. of samples).

1.3 Pre-Karoo Geochronology, Metamorphism and Tectonics

The gneissic complexes from west to east, are (Figure 1.1):

- The Ponta Messuli Complex, along Lago Niassa, consists of 1.95 Ga Palaeoproterozoic high-grade basement: its contact with the Txitonga Group, which is dominated by low-grade metasediments, is tectonic but it is unclear whether it is a thrust or a tectonized nonconformity..
- The Unango, Marrupa and Nampula Complexes consist mainly of 1.1-1.0 Ga granitoid gneisses, associated with slivers of metasediments. These complexes were affected by Pan-African metamorphism from 560-520 Ma, commonly at granulite facies in the Unango Complex. The Unango and Nampula Complexes show widespread Pan-African granitic plutonism. The Marrupa and Unango Complexes are juxtaposed along northwest-verging tectonic contacts: this is interpreted as a top-to-northwest imbricated nappe sequence.
- The Xixano Complex includes lenses of granulite juxtaposed with various metasedimentary rocks along greenschist- to amphibolite-facies shear zones. Granulite-facies metamorphism is dated at 735±4 Ma.
- The Lalamo and Montepuez Complexes include abundant metasediments and felsic metavolcanic rocks. Available data for the Montepuez Complex suggest deposition of marble units between 1100 and 1050 Ma (chemostratigraphic dating) and deposition of clastic sediments sometime after 942±14 Ma (age of a detrital zircon).
- The Geci Group, in part preserves primary depositional features and primary isotopic composition. Chemostratigraphic data suggest two apparent depositional age intervals of either 590-585 or 630-625 Ma. The Geci Group, metamorphosed in greenschist facies, was juxtaposed with the much higher grade Unango Complex, as a result of late Pan-African shearing.
- The metasediments of the Alto Benfica and Meecuburi Groups were deposited in small, possibly strike-slip, grabens at ~600 Ma. They were subsequently internally deformed and metamorphosed to sillimanite grade during the Pan-African event.
- The Lurio belt separates the Nampula Complex to the south from the Marrupa and Montepuez Complexes to the north in the eastern part of the region. It is cored by granulite lenses decreasing in abundance to the west, and by highly sheared leucogneisses. These lithologies have been assigned to the newly established Ocua Complex. Granulite-facies metamorphism and deformation is bracketed to 580-530 Ma. The Lurio belt does not always correspond to a major lithological break between the Nampula, Marrupa and Montepuez Complexes, and is consequently not interpreted as representing a Pan-African suture zone.

The sequence of tectonic events is envisaged as follows:

- A granulite-facies metamorphic event is recorded at 735±4 Ma in the Xixano Complex. Preservation of these granulites suggests a phase of northwest-southeast-oriented crustal extension after 735 Ma, responsible for their partial exhumation.
- Structures from the western sector of the Lurio belt (Ribáuè-Malema area) differ remarkably from those observed in its eastern sector (Montepuez region). Tight to isoclinal folds with north-northwest-dipping axial planes and roughly down-dip plunging axes and stretching lineations are common. We refer to these features as "Proto-Lurio". No clear kinematic indicators could be identified, which precludes assigning of these structures to a specific tectonic phase. Nonetheless, the Proto-Lurio event can be envisaged as being responsible for the exhumation of early Pan-African granulites. The youngest of these granulites are reported in the Mugeba klippe, south of the Lurio belt, and have a published age of ~614±8 Ma. Therefore, the Proto-Lurio tectonic event probably post-dates 615 Ma.

- A post-615 Ma top-to-northwest directed nappe-stacking episode juxtaposed the distinct tectonic slices, the Ponta Messuli, Txitonga, Unango, Marrupa, Muaquia, M'Sawize and Xixano Complexes, listed from west to east with increasing structural level in the nappe stack. Field evidence strongly supports the tectonic origin of the terrain contacts and confirms their northwest-directed thrusting kinematics. While the Unango Complex shows granulite-facies metamorphic grade with recorded P up to 15.3 kbar, the overlying Marrupa and Xixano Complexes show amphibolite-facies conditions during this event.

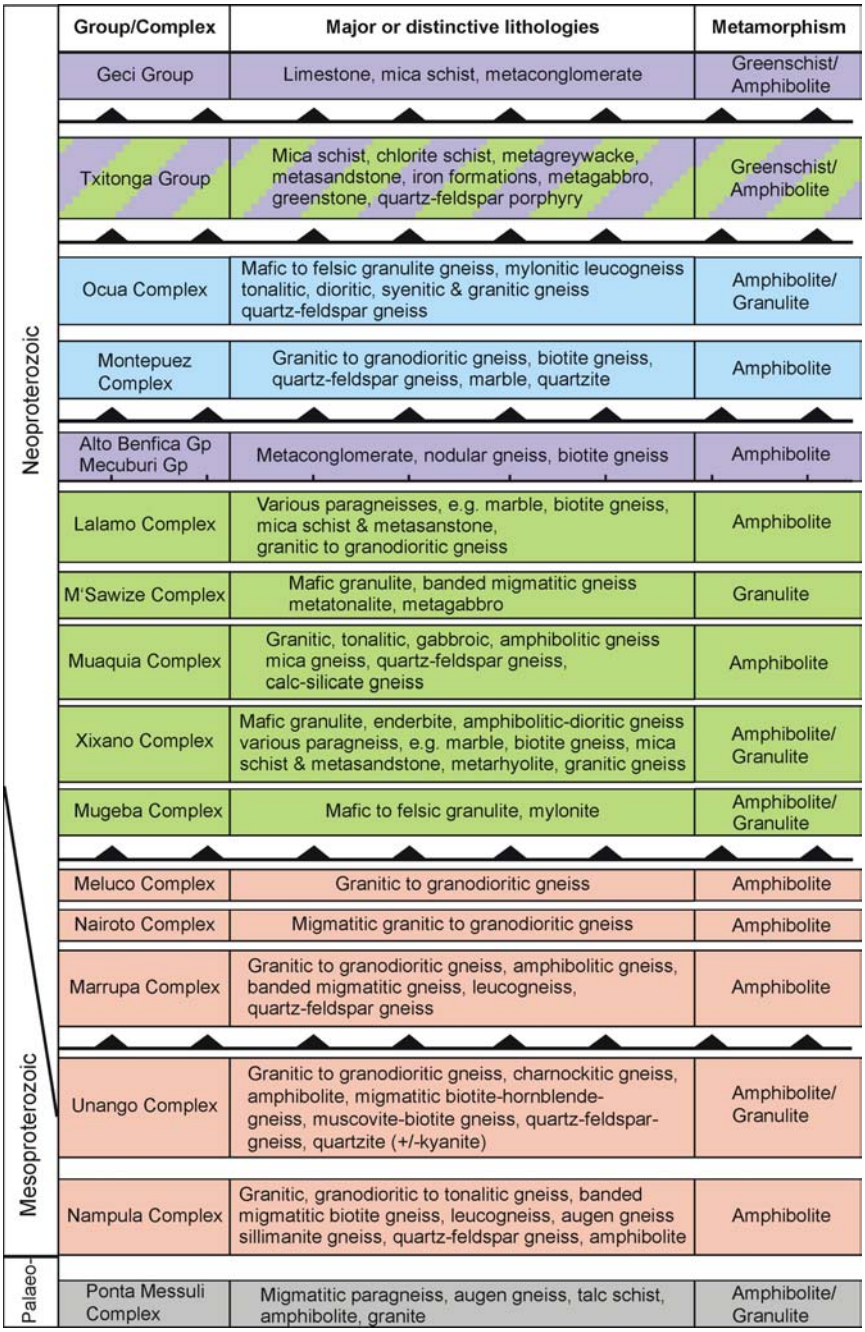

Figure 1.2: Tectonostratigraphic overview of the Proterozoic units in northern Mozambique. The Karoo sediments and the Jurassic-Neogene sediments of the Rovuma Basin overlie the gneiss complexes unconformably. Tectonic boundaries are shown by the saw-tooth lines.

- The high-resolution geophysical data allow the identification of a crustal-scale set of east/east-northeast- west/west-northwest-trending upright, open to tight folds that can be followed from the Tanzanian border to the Lurio belt and further south in the Nampula Complex. Fold axes plunge moderately to the west/west-southwest. Field observations confirm the geometry of the folds and their importance. The Lurio belt (especially its eastern sector) is part of this geometrical framework, with its mylonitic foliation folded isoclinally around east/east-northeast - west/west-northwest-trending axes. The belt underwent strong flattening with granulite bodies being highly attenuated, segmented and retrogressed in response to the extreme pure-shear strain that affected the whole region. The isoclinal folds that characterize the belt reached a stage of strain hardening, which resulted in strain accommodation being taken up by crustal-scale sets of conjugate ductile shear zones. These are identifiable from the outcrop scale to the regional scale based on geophysical data. The eastern sector of the Lurio belt, where the overall structural grain swings to an east-west orientation, reflects the local, strong control of such an east-west-trending ductile shear zone. Strain-accommodation within the Lurio belt (via isoclinal folding and conjugate shear zones) is more intense than in the surrounding blocks (open to tight folding and conjugate shear zones) because of the Proto-Lurio structure, which acted as a zone of mechanical weakness, leading to preferential strain accommodation. Nonetheless, evidence of the south/south-southeast- north/north-northwest-directed regional compression is found throughout the region, leading not only to the above-mentioned crustal-scale east/east-northeast- west/west-northwest-trending folds, but also to intense structural reworking of pre-existing tectonic features. Geochronological results constrain the age of the regional compression to between 580 and 530 Ma. High-pressure granulite facies metamorphism is recorded in the Lurio belt. The peak conditions were followed by a stage of near-isothermal decompression.
- 530 Ma monazite ages from mylonitic fabrics associated with top-to-northwest extensional structures constrain a renewed phase of crustal extension co-axial with the prior compressional event. Field evidence of extensional structures deflecting and cutting through folds of the previous compressional event was found within the eastern sector of the Lurio belt and to the north, at least as far as the Tanzanian border.
- Pan-African granites are widespread and follow specific structural trends. Ring complexes and alkali granite intrusives within the Lurio belt have been assigned to the Malema Suite. The emplacement of such magmatic complexes was most likely facilitated by the overall crustal thinning starting at 530Ma.
- Northeast-southwest-trending sinistral shear zones northwest of the Lurio belt record late Pan-African ages ranging from 480 to 445 Ma. We interpret these to be lateral ramps defining the western margins to the displaced blocks that accommodated the overall crustal thinning.

1.4 Mineral resources and potential

<u>Gold:</u> The Niassa Gold belt (NGB) is the most important gold district in the area. Artisanal mining of alluvial and primary gold in quartz veins has been performed since 1990 along Lago Niassa from the Tanzanian border towards Cobuè in the south, ~90 km north-south and up to 25 km east-west. The estimated total gold production is 5-12 t/a (Lächelt 2004). The most important gold mining areas currently include Cagurué, Long Bay/Miazini, M'Papa, 0A and M'Popo (0D) in the northern part of the belt.

Primary gold occurs in quartz veins in low-grade metasedimentary rocks and associated mafic dykes of the assumed Neoproterozoic Txitonga Group. The veins are associated with north-south-/northeast-southwest-trending shear zones of probable Ordovician age, related to the juxtaposition of the NGB as an exotic tectonic sliver against the western margin of the Unango terrane. Re-Os dating of the sulphide mineralisations gives a preliminary age of about 483 Ma. The productive zones in the alluvial fields are 0,5-5 m thick, and the gold content of the alluvium is 5-30 g/t. Minor gold panning has been reported along several rivers in other areas: Rio Chimulicamuli, Rio Lugenda, Rio Lureco.

Copper and nickel-copper: Slabs of finely laminated metasiltstone containing abundant disseminated malachite and with extensive malachite (and locally azurite) coatings are found 50 km northwest of Marrupa on the north bank of the Rio Lureco. The secondary copper mineralisation (>1 % Cu and ~100 g/t Ag) is clearly derived from disseminated copper sulphides in the host rock. This poorly exposed area is worthy of follow-up, especially as this mineralisation is similar to that seen in the Central African Copper Belt. Minor nickel-copper mineralisations occur in mafic intrusives in various complexes, but these are not considered to rpresent a major potential.

Iron and iron-titanium: Massive magnetite-ilmenite ore occurs in high-grade rocks near Lago Niassa. Ilmenite-magnetite lenses and veins are found in fine-grained biotite gneiss and massive magnetite-quartz forms minor hills in the southeast part of the mapped area. Thin and extensive layers of massive magnetite have been investigated north of the Rio Lurio in the eastern part of Cabo Delgado Province.

Enrichments of the heavy minerals, ilmenite, rutile and zircon are found all along the coast in both aeolian and beach sand, although more frequently in the vicinity of the major rivers. In the Murrubue deposits, 20 km south of Pemba, most heavy minerals occur in red aeolian sand. The sand dunes are up to 30 m high. A small body, a few m thick, with 5-10 % heavy minerals and a potential of up to 10 Mt has been investigated by Iluka Resources..

Special metals: Several alkaline intrusions of Neoproterozoic age, with enrichment of the special metals; REE, U, Ta and Nb are located within the Unango Complex in the western part of Niassa Province; these are Monte Naumale, Monte Chissindo and Rio Lucuisse. The most common ore-bearing minerals in these are pyrochlore, columbite, zircon and columbotantalite. Probably the most interesting of these is the Monte Naumale Syenite, in which a Na-pyroxene-amphibole rock contains, on average, about 400 ppm U and Th, 1000 ppm Nb, and 20-10,000 ppm Ta. Ore-bearing lenses with a thickness of 1-4 m, and lengths up to 100 m are recorded. There is also a potential for special metals in pegmatites though this has yet to be documented for the pegmatite fields in Niassa and Cabo Delgado Provinces.

Graphite: Graphite-bearing mica schist and gneiss are found in different tectonic complexes in Cabo Delgado Province. Horizons up to several kilometres long and 10-100 m thick contain fine- to coarse-grained graphite, commonly 5-20 % C. High-quality graphite is mainly metamorphic, although minor local enrichments are related to tectonic activity. The Ancuabe graphite mine, owned by Kenmare Resources PLC, was in operation from 1994 to 1999. A reserve of 1 Mt of ore grading 10 % graphite was determined. Graphite-bearing mica gneiss is medium-grained and banded comprising graphite, biotite, quartz and feldspar. Medium to coarse graphite-flakes (3-8 mm) are enriched in 5-20 cm thick bands and lenses over a thickness of 2-3 m. The graphite-bearing sequence has an undulating, nearly flat-lying foliation and seems to comprise the top of an open antiform. Local enrichment of graphite and thickening of the graphite-rich bands is observed in minor folds. Very coarse-grained graphite occurs along quartz veins.

Carbonate minerals: Marble and limestone are registered in different sequences of Mesoproterozoic to Mesozoic age. Mesoproterozoic (~1100 Ma) medium- to coarse- grained marbles form major proportions of several complexes in Cabo Delgado Province. Pure calcite marble comprises only minor parts. The marbles are commonly variably dolomitised as in the well-known Montepuez marble, or comprise pure dolomite marble. A thin horizon of magnesite has also been found. Small-scale lime production has been carried out from the limestone of the Geci Group (590 Ma) in Niassa Province.

Quartz, quartzite: A few quartz bodies in both provinces may represent a potential resource for silica production. Detailed studies of the chemistry and quality of the resources should be carried out. Kyanite quartzites may have great value as a source of high-purity quartz. Preliminary analysis of a sample from the Rio Levele deposit, 40 km southeast of Mavago, shows very low values of combined Al+Ti+Li, < 45 ppm. This kyanite quartzite is several kilometres long and more than 30 m thick, and includes minor amounts of muscovite, plagioclase, titanite, rutile, zircon and lazulite.

Coal: The most extensive coal resources occur in the Karoo Supergroup in the southwest part of the Maniamba Graben, in Niassa Province. Resource estimates up to 224 Mt have been presented. The seams, 0,8-1 m thick, occur in the Ecca Group (K2 and K4).

Dimension stone: The most important dimension stone deposit in the area at present is the marble 4 km north of Montepuez owned by the Marmonte Lda. Production exceeded 1000 m^3 in 1986, but is now (2004) only 50 m^3/year. Blocks are transported to Pemba, where the company produces slabs of three qualities; white (*branco*), grey (*cinzento*) and mixed (*magram*). The marble is commonly bedded on a dm-m scale, and locally includes minor lenses or bands of amphibolite. Large-scale open to tight folding is common. Test quarrying has been carried out on a marble close to Mazeze. The colour banding in this deposit makes the rock very decorative, but its coarse grain-size is a problem for polishing. There is a great potential for exploitation of other metamorphic and igneous rocks as dimension stone. Both massive and decorative rocks are found. However, extensive exploitation is heavily dependent on development of infrastructure and market potential.

Precious/semi-precious stones: Various precious and semi-precious stones are found in northeastern Mozambique, most commonly tourmaline, beryl (aquamarine), garnet, corundum, amazonite and crystalline quartz. They occur mostly in granitic pegmatite veins, but alluvial and eluvial occurrences also exist. Among the more interesting areas for the pegmatites are Marrupa, southeast of Mueda and Mirrote. Pigeon-blood coloured, corundum crystals up to 12 mm long and 20 mm across also occur in schistose, coarse-grained plagioclase-pyroxene-biotite rock east of Chiure.

Kimberlite: Kimberlites, 43 dykes and 4 pipes, that cut into Karoo sedimentary rocks were found in the southwest part of the Maniamba Graben in the late 1970s. One of the pipes has yielded a Rb/Sr age of around 138 Ma. Diamondiferous kimberlites have not been verified so far. The samples studied by this project are macrocrystic hypabyssal Group Ia kimberlites, based on their mineralogy, whole rock geochemistry and analyses of macrocrysts and groundmass minerals. Several additional occurrences of kimberlite dykes and pipes are indicated in the recently acquired airborne magnetic data. Further investigations of the whole graben as well as its immediately adjacent basement are recommended. Rocks resembling lamproites have been discovered in the Xixano Complex: such rocks can have a potential for diamonds (as illustrated by the Argyle field in West Australia).

Hydrocarbons: Potential source rocks are considered to be present in the syn-rift and early drift sequence throughout the Rovuma Basin, but little has been documented. Analyses of the several seeps encountered in the basin point to two distinct types of oils, proving that there are active petroleum systems. These are interpreted as having been derived from source rocks of Jurassic and/or older age. The basin contains several intervals of good quality reservoir rocks. The pre-late drift continental deposits (pre-Lower Cretaceous) found onshore in the northwest Rovuma Basin are generally expected to show mostly low net-to-gross ratios due to diagenesis, but the contemporaneous paralic and shallow marine clastics to the east and southeast are expected to have fair to good reservoir potential, with moderate to minor reduction of porosity. The Aptian-Albian succession comprises reservoir sands of good quality.

Summary of resource potential: Gold in the Niassa Gold belt is economically the most significant known mineral resource in northeastern Mozambique today. The kimberlites of the Maniamba graben have great potential if they are found to be diamond-bearing. Heavy minerals, graphite, copper, special metals and high-purity quartz could also be of great economic interest, while construction material and precious stones are important on a local scale. Economically viable hydrocarbon fields, if they were to be discovered in the Rovuma Basin could overshadow all other resources.