Prepared in cooperation with the Ministry of Petroleum, Energy and Mines, Islamic Republic of Mauritania

Second Projet de Renforcement Institutionnel du Secteur Minier de la République Islamique de Mauritanie (PRISM-II)

Uranium in the Islamic Republic of Mauritania:

Phase V, Deliverable 81

By Gregory L. Fernette

Open-File Report 2013–1280 Chapter N

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Multiple spellings are used in various literatures, and may be reflected in the text.

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or for stratigraphic nomenclature.

The report is being released in both English and French. In both versions, we use the French-language names for formal stratigraphic units.

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Uranium in the Islamic Republic of Mauritania

Summary

Mauritania has 80 known uranium mineral occurrences and is the current focus of active exploration for uranium by a number of private companies. Seventeen occurrences have had resource estimates published and can be considered as mineral deposits. Fourteen of these are calcrete-type deposits with a total resource of 138.3 million tonnes at an average grade of 331 ppm U_3O_8. The three bedrock-hosted deposits are granite hosted vein/shear zone type deposits with a total resource of 46.5 million tonnes at a grade of 248 ppm U_3O_8.

All of the deposits and the majority of the other uranium occurrences are found in the Paleoproterozoic Rgueïbat Shield in areas underlain by the Cortege de Yetti, the Complexe de Tmeïmichatt Ghallamane and the Complexe d'Adam Esseder. This area is also visible in the PRISM airborne radiometric data as an extensive >4 ppm equivalent uranium anomaly.

Uranium occurrences are also reported in the Tasiast-Tijirit Terrane of the Archean Rgueïbat Shield, the Mauritanide Belt, and the Coastal Basin. Geologic environments permissive for eight types of uranium deposits are recognized in Mauritania. These deposit types include: calcrete, granite-hosted vein/shear, alkaline intrusive, unconformity-associated, quartz pebble conglomerate, phosphate, sandstone, and red bed-type uranium deposits.

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
decimeter (dm)	0.32808	foot (ft)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
megagram (Mg)	1.102	ton, short (2,000 lb)
megagram (Mg)	0.9842	ton, long (2,240 lb)
metric ton per day	1.102	ton per day (ton/d)
megagram per day (Mg/d)	1.102	ton per day (ton/d)
metric ton per year	1.102	ton per year (ton/yr)
	Pressure	
kilopascal (kPa)	0.009869	atmosphere, standard (atm)
kilopascal (kPa)	0.01	bar
	Energy	
joule (J)	0.0000002	kilowatt hour (kWh)

ppm, parts per million; ppb, parts per billion; Ma, millions of years before present; m.y., millions of years; Ga, billions of years before present; 1 micron or micrometer (μor μm) = 1×10^{-6} meters; Tesla (T) = the field intensity generating 1 Newton of force per ampere (A) of current per meter of conductor

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Coordinate information is referenced to the World Geodetic System (WGS 84)

Acronyms

AMT	Audio-magnetotelluric
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
BIF	Banded iron formation
BLEG	Bulk leach extractable gold
BGS	British Geological Survey
BRGM	Bureau de Recherches Géologiques et Minières (Mauritania)
BUMIFOM	The Bureau Minier de la France d'Outre-Mer
CAMP	Central Atlantic Magmatic Province
CGIAR-CSI	Consultative Group on International Agricultural Research-Consortium for Spatial Information
DEM	Digital Elevation Model
DMG	Direction des Mines et de la Géologie
EC	Electrical conductivity
EMPA	Electron Microprobe Analysis
EM	Electromagnetic (geophysical survey)
EOS	Earth Observing System
eU	Equivalent uranium
GGISA	General Gold International
GIF	Granular iron formation
GIFOV	Ground instantaneous field of view
GIS	Geographic Information System
HIF	High grade hematitic iron ores
IHS	Intensity/Hue/Saturation
IAEA	International Atomic Energy Agency
IOCG	Iron oxide copper-gold deposit
IP	Induced polarization (geophysical survey)
IRM	Islamic Republic of Mauritania
JICA	Japan International Cooperation Agency
JORC	Joint Ore Reserves Committee (Australasian)
LIP	Large Igneous Province
LOR	Lower limit of reporting
LREE	Light rare-earth element
METI	Ministry of Economy, Trade and Industry (Japan)
MICUMA	Société des Mines de Cuivre de Mauritanie
MORB	Mid-ocean ridge basalt
E-MORB	Enriched mid-ocean ridge basalt
N-MORB	Slightly enriched mid-ocean ridge basalt
T-MORB	Transitional mid-ocean ridge basalt
Moz	Million ounces
MVT	Mississippi Valley-type deposits
NASA	United States National Aeronautics and Space Administration

NLAPS	National Landsat Archive Processing System
OMRG	Mauritanian Office for Geological Research
ONUDI	(UNIDO) United Nations Industrial Development Organization
PRISM	Projet de Renforcement Institutionnel du Secteur Minier
PGE	Platinum-group elements
RC	Reverse circulation drilling
REE	Rare earth element
RGB	Red-green-blue color schema
RTP	Reduced-to-pole
SARL	Société à responsabilité limitée
SEDEX	Sedimentary exhalative deposits
SIMS	Secondary Ionization Mass Spectrometry
SNIM	Société National Industrielle et Minière (Mauritania)
SP	Self potential (geophysical survey)
SRTM	Shuttle Radar Topography Mission
SWIR	Shortwave infrared
TDS	Total dissolved solids
TIMS	Thermal Ionization Mass Spectrometry
TISZ	Tacarat-Inemmaudene Shear Zone
TM	Landsat Thematic Mapper
UN	United Nations
UNDP	United Nations Development Program
US	United States
USA	United States of America
USGS	United States Geological Survey
UTM	Universal Transverse Mercator projection
VHMS	Volcanic-hosted massive sulfide
VisNIR	Visible near-infrared spectroscopy
VLF	Very low frequency (geophysical survey)
VMS	Volcanogenic massive sulfide deposit
WDS	Wavelength-dispersive spectroscopy
WGS	World Geodetic System

Second Projet de Renforcement Institutionnel du Secteur Minier de la République Islamique de Mauritanie (PRISM-II)

Uranium in the Islamic Republic of Mauritania:

Phase V, Deliverable 81

By Gregory L. Fernette[1]

1 Introduction

This report presents a review of known uranium mineralization in Mauritania and the delineation of geologic tracts permissive for the occurrence of uranium deposits. The work is being completed by the U.S. Geological Survey (USGS) under contract to the Government of Mauritania as a part of the Second Projet de Renforcement Institutionnel du Secteur Minier de la République Islamique de Mauritanie (PRISM-II).

The original scope of the report covered only sedimentary rock-hosted uranium mineralization. As work progressed it was realized that there were significant deposits and potential for other types of uranium mineralization. Consequently, the scope of the report has been expanded to include all potential uranium deposit types.

This report is based on a review of available data. No field work specific to the uranium evaluation was carried out by the USGS. The data review covered a wide variety of data sources including:

1. Geologic and metallogenic reports from the PRISM Project (Gunn and others, 2004, Lahondère, Le Métour, Salpeteur, and others, 2003; Lahondère, Thieblemont, Goujou, and others, 2003, 2005, 2008; Marot, 2003; Nagel, 2008; O'Connor and others, 2005; Pitfield and others, 2004; Salpeteur, 2005).
2. The PRISM Mineral Occurrence Database (Marsh and Anderson, 2015).
3. Geochemical data from the PRISM Project (Eppinger and others, 2015).
4. Airborne geophysical data from the PRISM Project (Finn and Anderson, 2015).
5. Satellite imagery (Rockwell and others, 2015).
6. Reports from companies active in uranium exploration in Mauritania including annual reports, quarterly reports, press releases, and web sites.

2 Uranium Exploration in Mauritania

Mauritania has a long history of uranium exploration beginning in the 1960s (Marot, 2003). Uranium exploration in Mauritania and worldwide declined in the 1980s and 1990s due to low uranium prices. In the past ten years uranium prices have increased with a consequent increase in exploration worldwide including in Africa (Schatz, 2008, Wadley, 2008). Starting in

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2006 Mauritania has seen a significant increase in uranium exploration, much of which was the result of data generated by the PRISM Project. Major activity has been led two Australian companies: Forte Energy (formerly Murchison United) and Aura Energy.

Uranium exploration in Mauritania has taken place over three time periods. During the first period, from 1959 to 1982 ECA (ECA International, Australia), TCMN, Minatome, and Cogema Mining, Inc., carried out exploration in the Northern Rgueïbat Shield (Marot, 2003). During the same period, Bureau de Recherches Géologiques et Minières (BRGM) identified mineral occurrences, including uranium, during their geologic mapping programs. The second period was from 2000 to 2004 during which the BRGM and the British Geological Survey (BGS) undertook regional geological mapping, geochemical surveys, and airborne geophysical surveys as a part of the PRISM project (Gunn and others, 2004, Lahondère, Le Métour, Salpeteur, and others, 2003; Lahondère, Thieblemont, Goujou, and others, 2003; 2005, 2008; Marot, 2003; O'Connor and others, 2005; Pitfield and others, 2004; Salpeteur, 2005). During both periods of work each geologic team verified previously reported mineral occurrences and recorded new ones found during the course of field work. The mineral occurrences were then compiled into a database covering the entire country (Coats, undated; Mankelow and others, 2001).

The third period, roughly from 2006 to the present, consists of exploration by private companies. This has been prompted by increased demand for uranium and higher prices, augmented by the attractiveness of the Mauritanian fiscal and legal regime applicable to mining. In Mauritania, considerable interest has been attracted by the PRISM data, in particular the airborne radiometric data.

In 2012 there were at least five private companies active in uranium exploration in Mauritania including Alba Minerals, Allecto Minerals, Aura Energy, Forte Energy, Gryphon Minerals and OreCorp (fig. 1). Of these Aura Energy and Forte Energy are the most active with Aura Energy planning on starting production on some projects by 2016 (Mining Review, 2012).

3 Uranium Mineralization in Mauritania

3.1 Geologic Background

Mauritania has five geological provinces which are used as an underlay for the maps in this report. A brief description of each province is given below to provide background for the discussion that follows. The reader is referred to the references, in particular the PRISM reports, for more details on the geology of Mauritania.

Rgueïbat Shield

The Rgueïbat Shield underlies most of northern Mauritania. It is bounded by the Paleozoic Tindouf Basin to the north, the Mesoproterozoic to Mesozoic Taoudeni Basin to the southeast and the Pan-African, Caledonian, and Variscan fold-thrust belt of the Mauritanides in the southwest and west-northwest. The shield is made up of two tectonostratigraphic domains separated by a NNE-SSW regional zone of intense ductile shearing up to 40 kilometers (km) wide (Pitfield and others, 2004). The western domain is made up largely of Meso- to Neoarchean gneisses and granitic rocks (Schofield and others, 2006, 2007). The eastern domain consists mainly of Paleoproterozoic granitic and supracrustal rocks assembled during the ca. 2.1 Ga Eburnean Orogeny (Lahondère, Thieblemont, Goujou, and others, 2003; 2004).

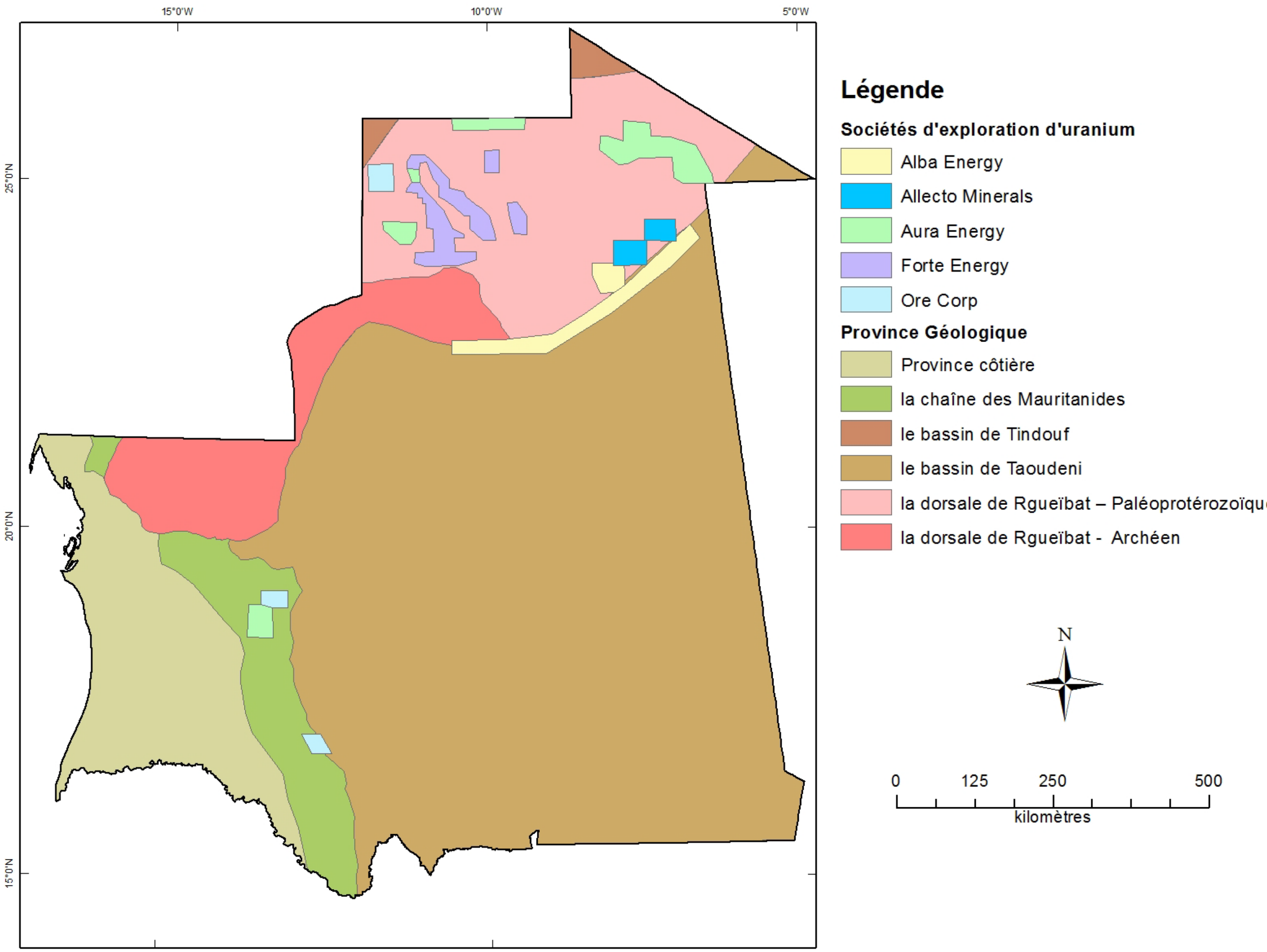

Figure 1. Uranium exploration areas in Mauritania.

Taoudeni Basin

The Taoudeni Basin underlies most of central and southern Mauritania and is one of the major structural units of the West African craton, with an aerial extent of more than 2,000,000 square kilometers (km^2) (Villeneuve, 2005). The basin is composed of a Mesoproterozoic to Mesozoic succession, up to 6,000 m thick, which is dominated by continental or shallow marine siliciclastic deposits characterized by low subsidence rates, condensed successions and major unconformities (Lahondère, Thieblemont, Goujou, and others, 2003; Pitfield and others, 2004).

Tindouf Basin

The Tindouf Basin forms an elongated west-southwest to east-northeast trending asymmetrical trough which bounds the Rgueïbat Shield on the north. The southern flank of the basin, which is exposed in the northwestern and northeastern corners of Mauritania, is made up of gently dipping Late Ordovician glacial deposits, Silurian shales, and a thick sequence of Devonian and Early Carboniferous shales and limestones (Lahondère, Thieblemont, Goujou, and others, 2003; Villeneuve, 2005).

Mauritanide Belt

The Mauritanide Belt consists of an east verging fold-thrust belt extending along the west margin of the Taoudeni Basin and parts of the southwestern and western margins of the Rgueïbat Shield. The belt was thrust onto the West African Craton in late Paleozoic (Variscan) time (Villeneuve, 2008). In Mauritania the belt consists of an imbricated collage of Neoproterozoic to Lower Paleozoic rocks with local tectonic inliers and thrust slices of Archean to Paleoproterozoic basement (Pitfield and others, 2004).

Coastal Basin

The Coastal Basin underlies Mauritania west of the Mauritanide Belt. The basin contains Mesozoic to Cenozoic sediments that thicken seawards as the basement is progressively down-faulted along rift-margin faults. The basinunconformably overlies the western part of the Mauritanides (Pitfield and others, 2004).

3.2 Known Uranium Occurrences

The PRISM mineral occurrence database originally contained 33 uranium occurrences. Eight of the occurrences were radiometric anomalies rather than mineral occurrences so these records were removed from the database. Review of private company reports led to the identification of 55 new uranium occurrences. These were added to the PRISM database bringing the total reported uranium occurrences in Mauritania to 80 (Marsh and Anderson, 2015). The locations of the new uranium occurrences were captured from maps contained in company reports. Due to the small size of the source maps the uncertainty in the locations of individual occurrences is probably on the order of several kilometers. A large number of company reports were reviewed and used in the preparation of this report. A complete list of company reports is given in the appendix. Individual reports are cited in the text and listed in the references where they provided specific information.

Based on a review of the geologic and exploration data, uranium occurrences were classified according to type of mineralization and level of exploration. Of the 80 uranium occurrences, 70 percent are calcrete type mineralization (table 1, figure 2). Mineralization at 16 other occurrences is hosted by granitic bedrock and is associated with veins and (or) shear zones.

One occurrence is hosted by black shale and the type of mineralization at the remaining 13 is unknown.

Table 1. Types of uranium occurrences in Mauritania.

Deposit Type	Number	Percent
Calcrete	56	70
Granite-hosted vein-shear	12	15
Pegmatite	1	1
Black Shale	1	1
Unknown	10	13
Total	**80**	**100**

The level of exploration for uranium occurrences was grouped into three classes based on the amount of exploration work completed (table 2, fig. 3). A “deposit” is an occurrence where sufficient exploration has been done so that a resource estimate can be made. A total of 17 occurrences, 21 percent of the total, meet these criteria. A “prospect” is an occurrence where surface and (or) subsurface exploration such as mapping, sampling, pitting and (or) drilling has been completed but there are insufficient data to complete a resource estimate. An “occurrence” has little exploration beyond the identification of the presence of uranium minerals with limited sampling and geologic data. It should be noted that uranium minerals are reported at all occurrences.

Table 2. Level of exploration of uranium occurrences in Mauritania.

Exploration Status	Definition	Number	Percent
Deposit	Resource estimate completed.	17	21
Prospect	Surface and (or) subsurface exploration.	15	19
Occurrence	Visit and (or) sampling.	48	60
Total		**80**	**100**

At present (September 2012), there are no active uranium mines in Mauritania, however Aura Energy is in the process of completing economic evaluations of its deposits and plans to start production in 2016 (Mining Review, 2012)

3.3 Uranium Deposits and Significant Prospects

There are 12 known uranium deposits in Mauritania, including 3 granite-hosted deposits and 9 calcrete deposits (tables 1 and 3). All of the deposits are located in the northern Rgueïbat Shield (figs. 2 and 4). The total estimated resources of the deposits are 183.8 million metric tons (Mt) with an average grade of 310 ppm U_3O_8 (table 3). The calcrete deposits total 138.3 Mt at 331 ppm U_3O_8 versus 46.5 Mt at 248 ppm U_3O_8 for the granite-hosted deposits. All of the deposits are owned by either Forte Energy or Aura Energy.

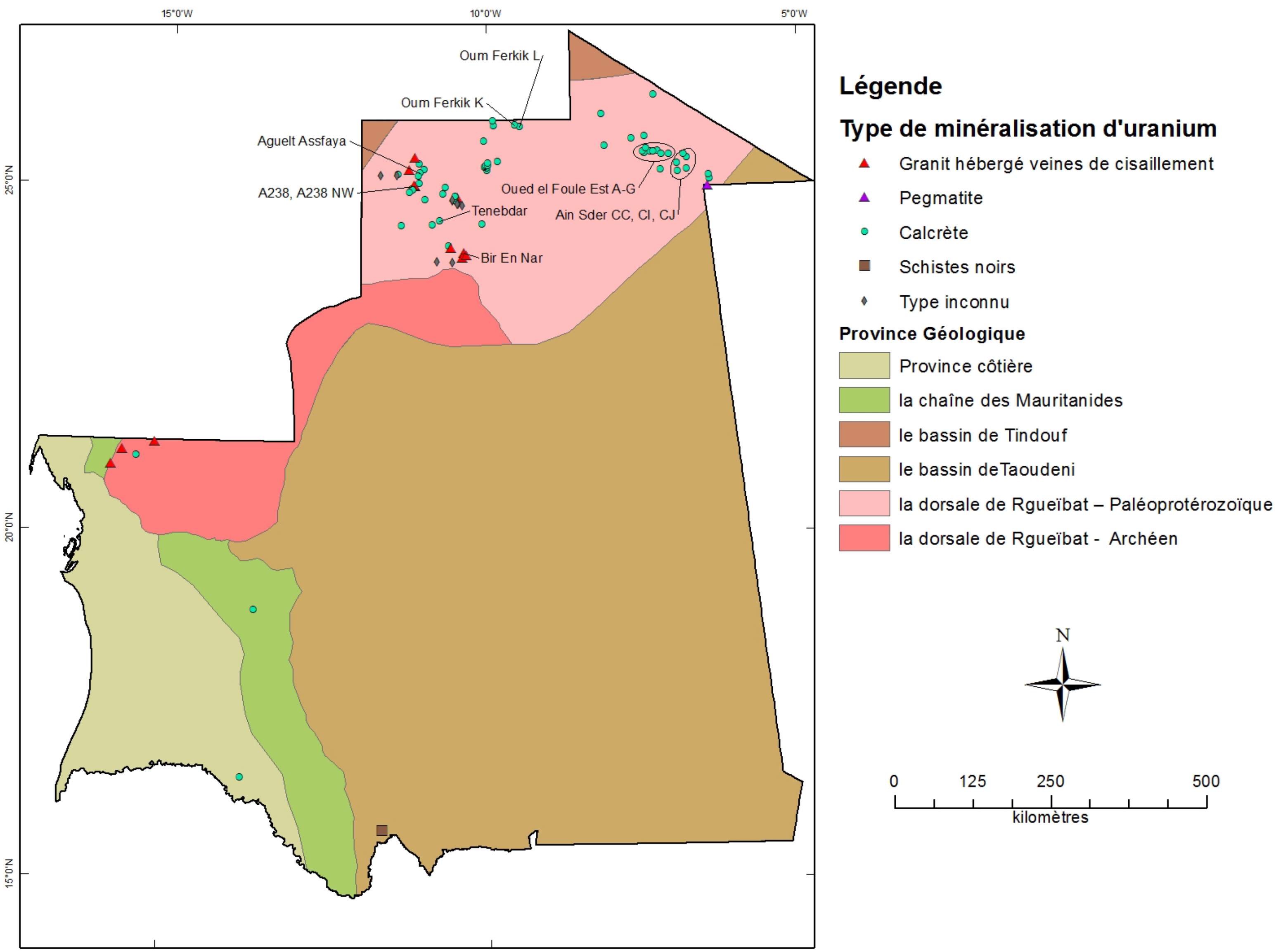

Figure 2. Uranium deposits and occurrences in Mauritania.

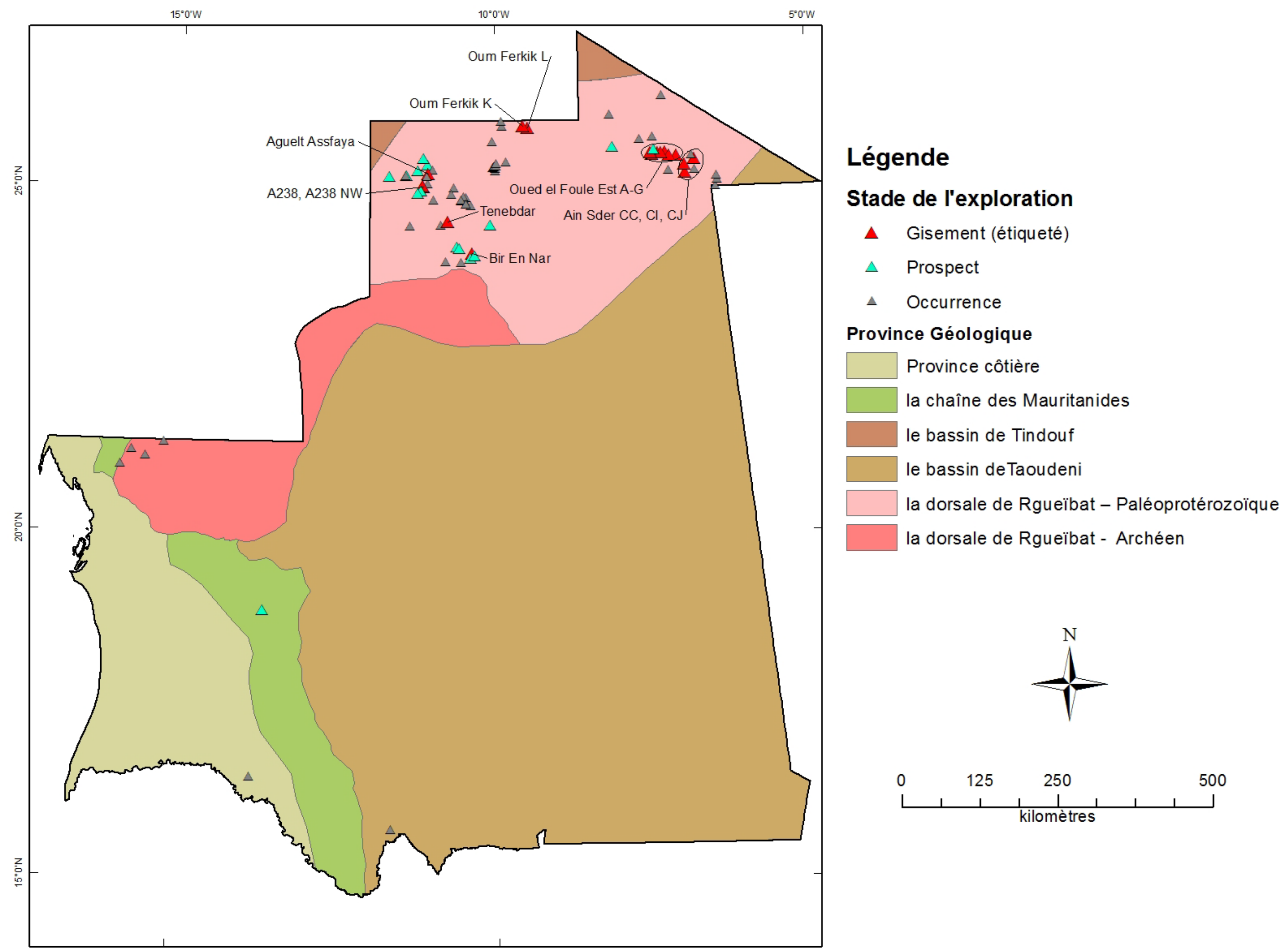

Figure 3. Exploration stage of uranium occurrences in Mauritania.

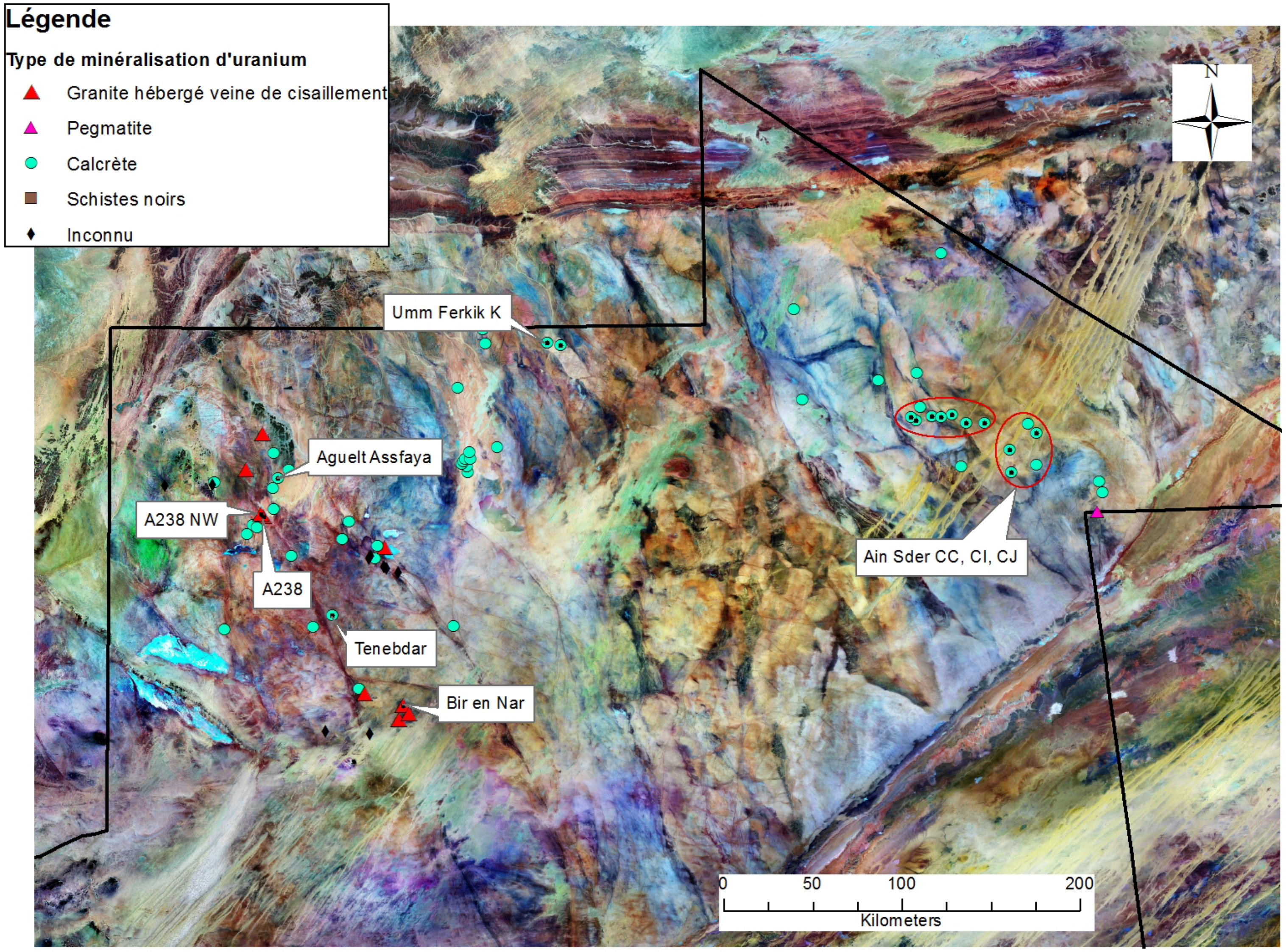

Figure 4. Uranium occurrences of northern Mauritania on Landsat Image base from Global Land Cover Facility.

Aura Energy has focused its exploration on calcrete-hosted deposits, listed in table 3. Their initial license applications were based on exploration targets selected after a review of the PRISM Project data. Since beginning exploration in 2008, Aura has discovered a large number of calcrete type uranium prospects and completed Joint Ore Reserve Committee (JORC) compliant resource estimates for nine deposits (table 2).

Table 3. Uranium deposits of Mauritania.

Deposit Name	Company	Resource Type	Resource	
			Tonnes	U_3O_8 (ppm)
Ain Sder C1	Aura	Inferred	9,900,000	350
Ain Sder CJ	Aura	Inferred	7,600,000	360
Ain Sder CC	Aura	Inferred	8,600,000	330
Oum Ferkik L	Aura	Inferred	11,900,000	330
Oum Ferkik K	Aura	Inferred	4,500,000	240
Oued El Foule Est A-E	Aura	Inferred	17,200,000	370
Oued El Foule Est FG	Aura	Inferred	6,300,000	300
Tenebdar	Aura	Inferred	2,600,000	210
Aquelt Assfaya	Aura	Inferred	68,700,000	330
Bir En Nar	Forte	Indicated and Inferred	1,330,000	704
A238	Forte	Inferred	42,800,000	233
A238NW	Forte	Inferred	2,400,000	266
Total			**183,800,000**	**331**

Sources of data: Aura Energy (2011e), Forte Energy NL, 2010d, 2012e.

Note: The grades and tonnages listed above are all JORC compliant estimates of “Indicated” or “Inferred” resources at a 100 ppm U_3O_8 cutoff grade.

In the calcrete-hosted occurrences uranium mineralization is found associated with calcrete in weathered granitic rocks that typically show strong radiometric anomalies (figure 5), (Aura Energy, 2009a). The uranium minerals are uranium vanadate; tyuyamunite or carnotite, and commonly extend to a depth of 5 meters (m) (fig. 6) (Aura Energy, 2010d). Aura’s first exploration programs consisted of ground radiometric surveys, pitting, trenching and drilling of airborne radiometric anomalies. Ongoing exploration is now finding mineralization without airborne radiometric expression (Aura Energy, 2012d).

Forte Energy initially focused its exploration on granite-shear zone type deposits and holds concessions over the three deposits listed in table 2 however they also have a number of calcrete prospects. Forte, under its former name of Murchison United, acquired its first exploration licenses in Mauritania in 2007. Area selection was based on a review of PRISM data (Murchison United, 2008).

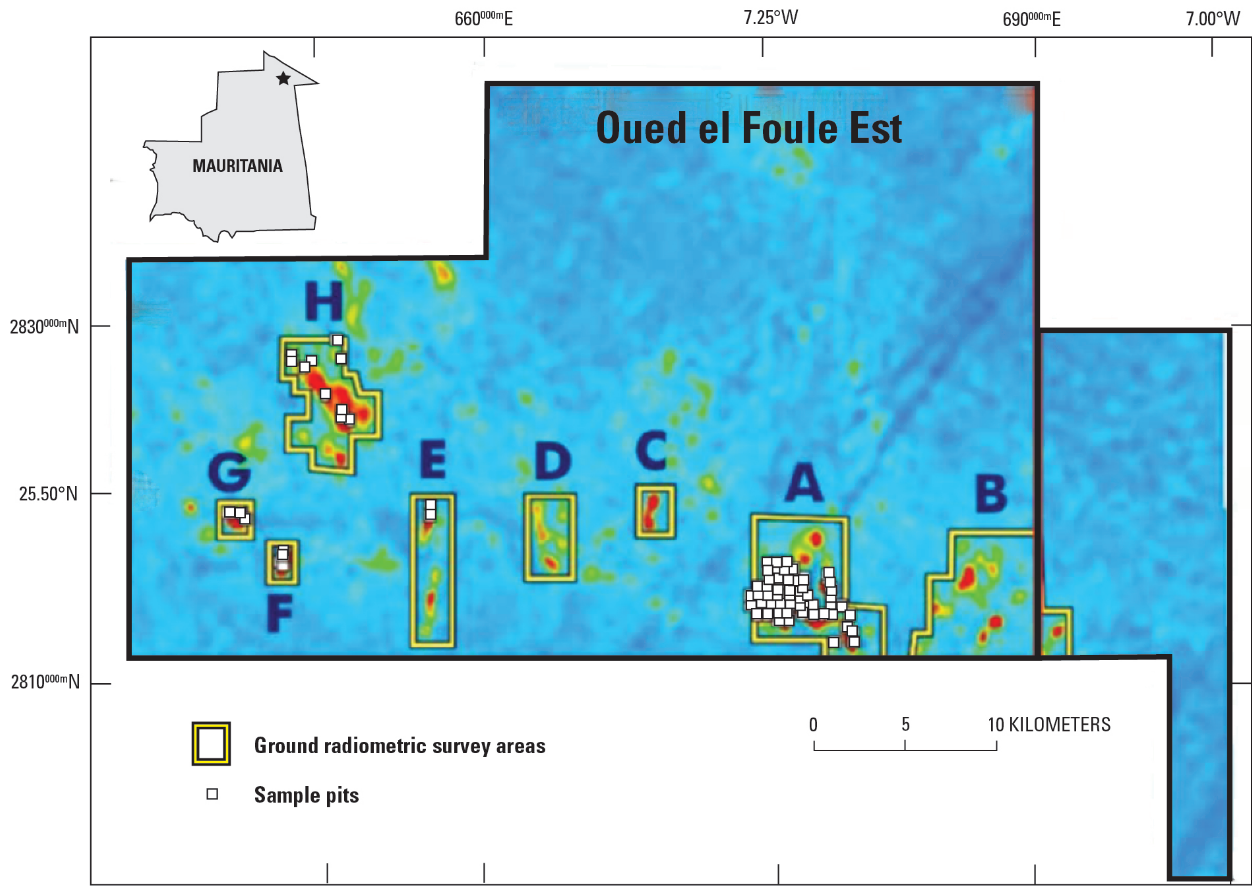

Figure 5. Map of the Oued el Foule Est calcrete uranium deposits, Mauritania (modified from Aura Energy, 2009a).

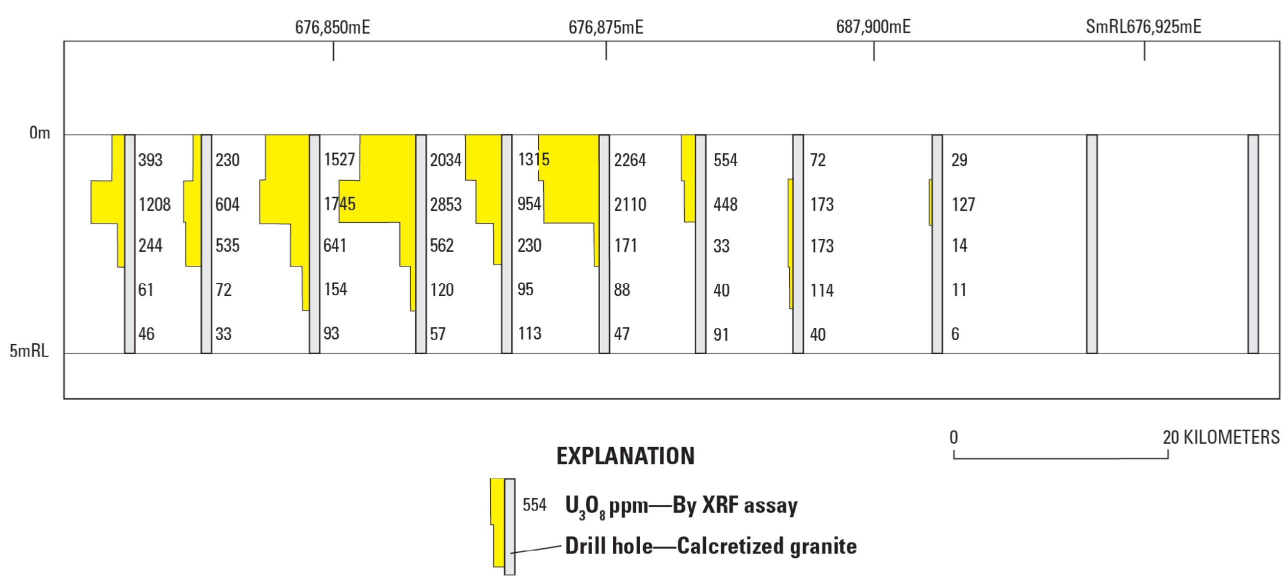

Figure 6. Cross section (vertical exaggeration 5X) of the Oued el Foule Est Area A calcrete uranium deposit, Mauritania (modified from Aura Energy, 2010d).

Forte's first exploration target was the Bir en Nar area where uranium mineralization was discovered by Cogema in the 1970s (Marot, 2003). Cogema drilled several holes at Bir en Nar in the 1970s and then ceased exploration in Mauritania, presumably due to low uranium prices. Marot (2003) was unable to locate the prospect during their surveys in 2002–2003. By 2010, the company had completed a resource estimate for the Bir en Nar deposits and discovered two additional deposits: A238 and A238 NW plus numerous other prospects. The deposits have a JORC compliant indicated and inferred resource of 1.33 Mt at 704 ppm U_3O_8 based on 5,575 m of core and reverse circulation drilling (Forte Energy, 2010d).

At the Bir en Nar deposit uranium mineralization is hosted by granitic intrusive rocks within a major northwest trending shear zone (fig. 7). The deposit consists of three northwest trending mineralized zones which dip to the northeast at 50 to 60 degrees (fig. 8). "Red" alteration is common in mineralized granite although uranium values also are found in unaltered granitic rock. Syenite and episyenite pods within the shear zone also host uranium minerals (Forte Energy, 2009).

The A238 and A238 NW deposits are located 135 km northwest of Bir en Nar along the same shear zone (fig. 4). The deposits were discovered by follow up of a PRISM airborne radiometric anomaly which located uraniferous calcrete. Drilling intercepted uranium mineralization in a shear zone below the calcrete (Forte Energy, 2010f; Forte Energy, 2012e). Both deposits are located within cataclastic zones along the contact between potassium (K)-feldspar granite to the northeast and U-Th- rich granite to the southwest (figs. 9 and 10). The mineralization occurs with mylonitized granitic rock with the shear zones. A large area of unmineralized silica-hematite alteration and smaller areas of silicification occur to the northeast of the A238 deposit. The A238 NW deposit occurs on a splay of the main shear zone northwest of the A238 deposit (fig. 9).

In addition to the deposits discussed above, there are 15 uranium prospects which have been explored to varying degrees. All of the prospects are located in northern Mauritania (figs. 3 and 4). The best described uranium prospects are three Forte Energy bedrock prospects in the Bir en Nar area including Beso, M52, M60 and the 247 prospect located further north. All four prospects consist of mineralized fracture and shear zones cutting granitic rocks. Hematization, often described as "red alteration" is commonly associated with uranium enrichment (Forte Energy, 2010e). Red breccia and to a lesser extent granitic rock with quartz veins are the most common host rocks. The mineralization at the prospects commonly occurs in multiple variably dipping zones (Forte Energy, 2010e).

3.4 Other Uranium Occurrences

There are numerous other uranium occurrences in the northern Rgueïbat Shield, the majority of which are calcrete-hosted mineralization (figs. 2 and 4). In the Tenebdar area (fig. 4) there are a number of bedrock occurrences (2103, 2130, 2135, 2141, 2198 and 2439) where rock samples contain >100 ppm uranium (Eppinger and others, 2015). According to descriptions in the PRISM database the rocks are granitic intrusive rocks with "red" alteration, silicification and brecciation (Eppinger and others, 2015). One occurrence, El Merre, located near the western border of Mauritania is unique in that it is described in the PRISM mineral occurrence database as sulfides and fluorite hosted by a pegmatite (Marsh and Anderson, 2015).

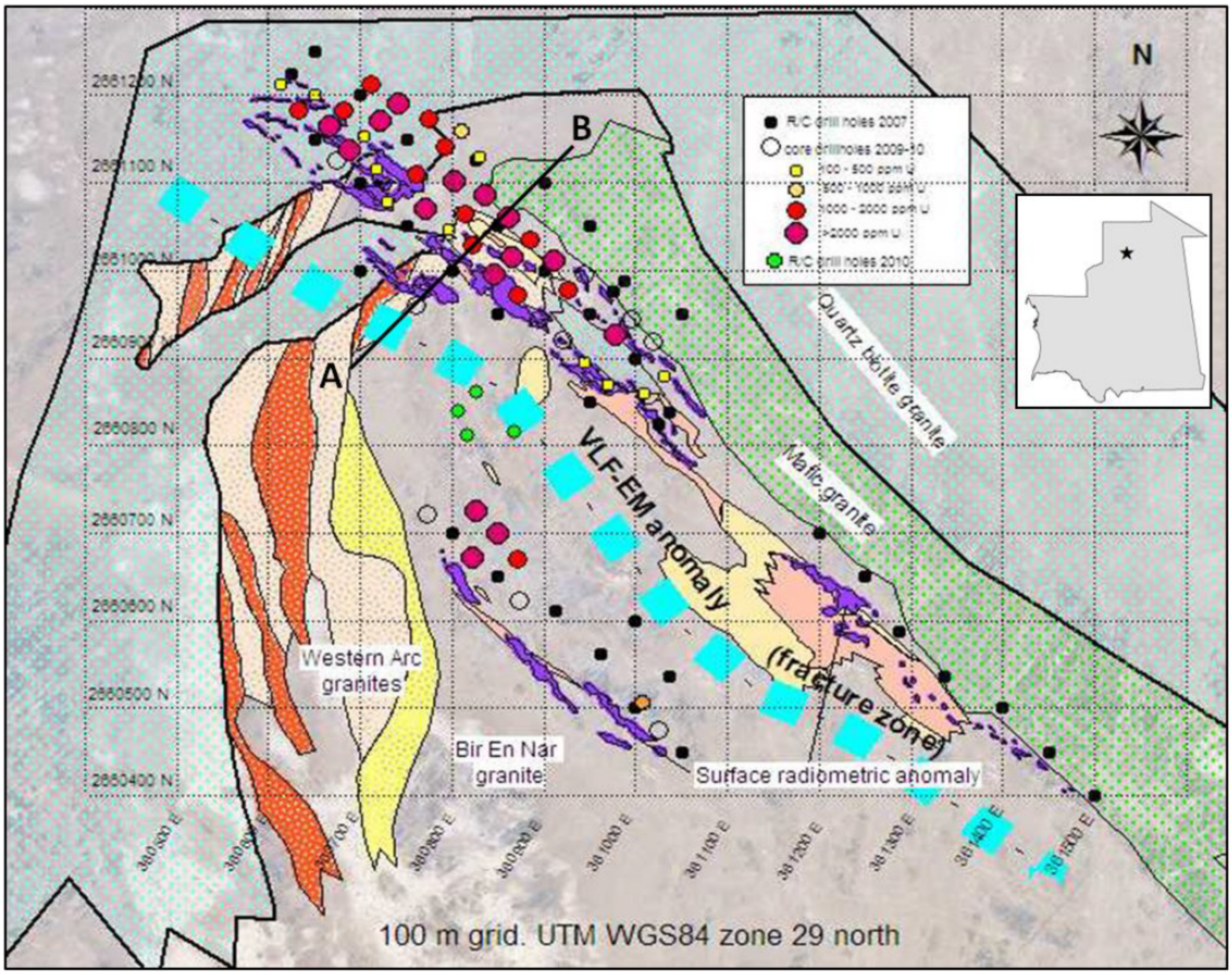

Figure 7. Geologic map of the Bir en Nar uranium deposit, Mauritania (Forte Energy, 2010c). Used with permission.

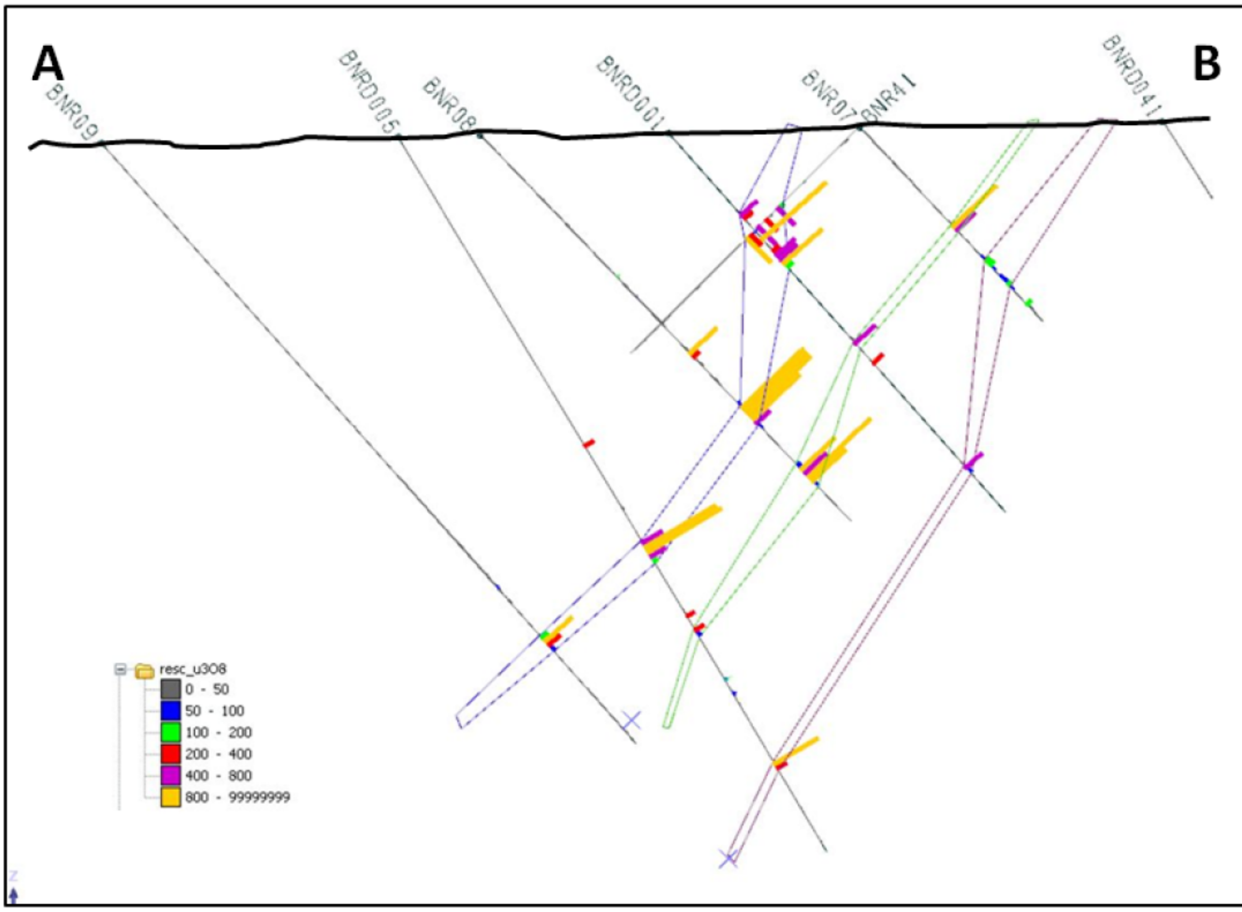

Figure 8. Cross section of the Bir en Nar uranium deposit, Mauritania (Forte Energy, 2010c). Used with permission.

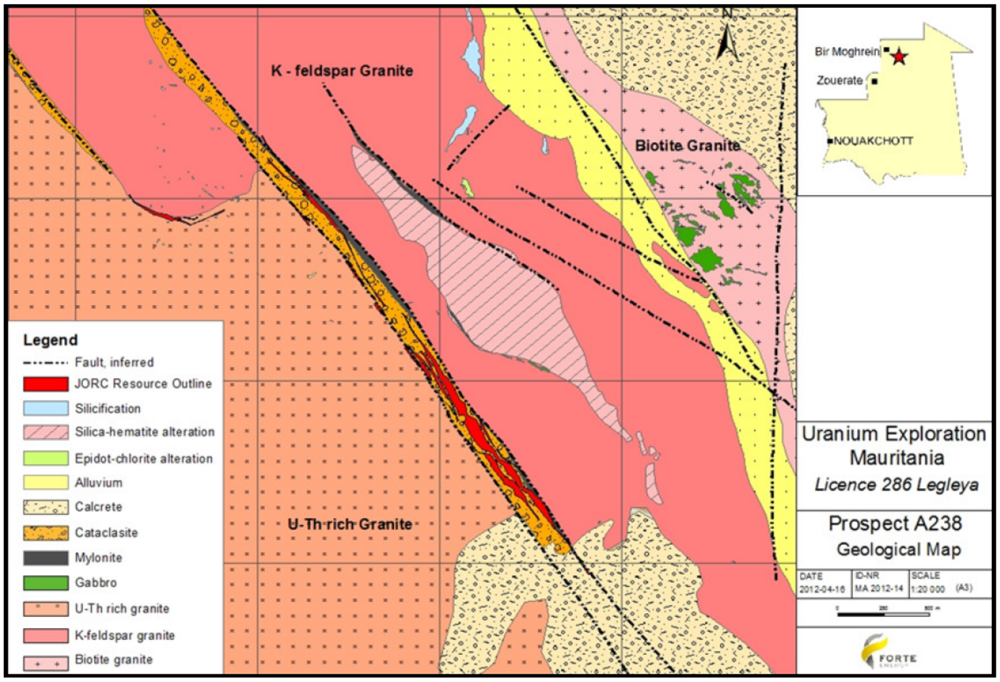

Figure 9. Geologic map of the A238 and A238NW uranium deposits, Mauritania (Forte Energy, 2012h). Used with permission.

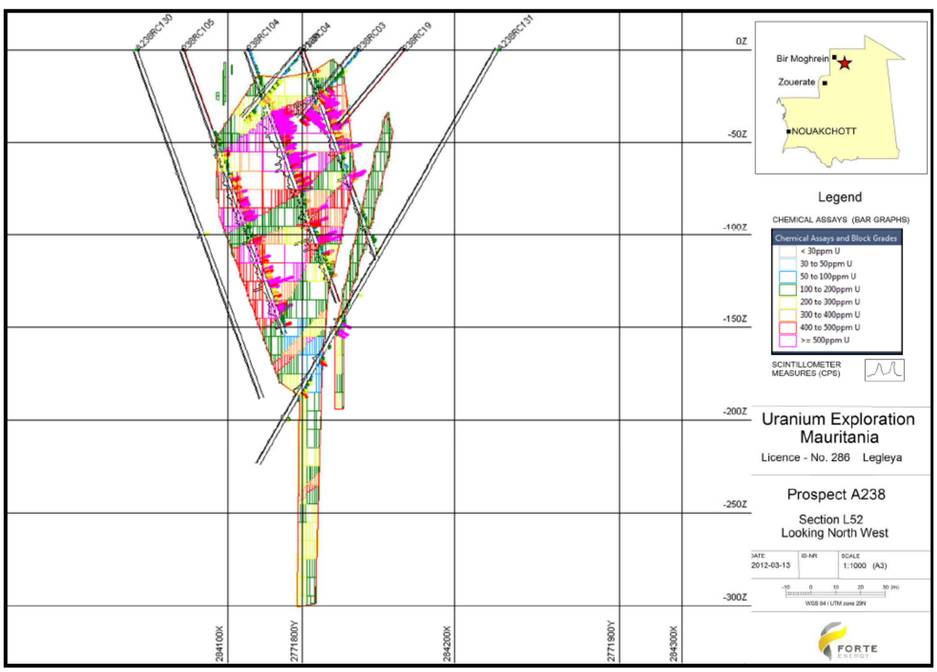

Figure 10. Cross section of the A238 uranium deposits, Mauritania (Forte Energy, 2012e). Used with permission.

There are a few uranium occurrences in other geologic provinces of Mauritania (table 4, fig. 2). In northwestern Mauritania, in the Tasiast Terrane of the Archean Rgueïbat Shield there are four uranium occurrences. Three of these are classified as granite-hosted vein/shear type mineralization and one as a calcrete occurrence based on limited descriptions from the PRISM database (Marsh and Anderson, 2015).

Table 4. Distribution of uranium occurrences in Mauritania by geologic province.

Province	Number	Percent
Mauritanides	3	4
Rgueïbat - Archean	4	5
Rgueïbat - Paleoproterozoic	73	91
Total	**80**	**100**

There are three uranium occurrences in the Mauritanide Province, one of which, the Al Fai prospect, has been the focus of exploration by Aura Energy. The prospect was identified from PRISM airborne radiometric data (Aura Energy, 2009b). At Al Fai, uranium minerals occur in Quaternary gravels which overly calcrete. Grades of up to 137 ppm U_3O_8 are reported from sample pits (Aura Energy, 2009b). The prospect was drilled in 2011 but the results have not been released (Aura Energy, 2011e).

In the southern Mauritanide Province, the El Faraa occurrence consists of carnotite associated with barite in black shale (Donzeau and others, 1982; Salpeteur, 2005). The HR 8016 occurrence, located just west of the boundary of the Mauritanide Province in an area underlain by Cenozoic alluvial deposits has no description. Because of its setting, it was classified as a calcrete occurrence.

4 Delineation of Permissive Uranium Tracts

A “permissive tract” is an area where the geology permits the existence of one or more specific types of mineral deposit (Singer and Menzie, 2010). The delineation of areas permissive for any type of mineral deposit depends on an understanding of the geologic characteristics of the target deposit type which are often summarized as a “deposit model.” Mineral deposit models have been published for a number of uranium deposit types (Cox, 1986; Finch; 1992, Grauch and Mosier; 1986; Jefferson, Thomas, Ghandi, and others, 2007a, b; Nash, 2010; Roscoe and others, 1993; Ruzika, 1993; Turner-Peterson and Hodges, 1986; Wenrich and others, 1995).

Uranium deposits are very diverse and occur over a wide range of geologic environments and ages (Cuney, 2009). Classification of uranium deposits has changed as levels of exploration and consequent knowledge of the deposits increased (Cuney and Kyser, 2008; Skirrow and others, 2009). The most commonly used classifications of uranium deposits are based mainly on host rock and morphology (Nash and others, 1981; Dahlkamp, 1993; IAEA, 2009). In recent years classifications of uranium deposits based on processes or “mineral systems” have been proposed (Cuney, 2009; Skirrow and others, 2009; Kreuser and others, 2010).

4.1 Types of Uranium Deposits and Environments in Mauritania

In preparing the permissive tracts for Mauritania the classification of International Atomic Energy Agency (IAEA) (2009) was used. This classification groups uranium deposits into sixteen types which are listed in table 5. A brief description of each deposit type and its critical geological features is given below. Except where otherwise noted the descriptions are summarized from IAEA (2009).

Table 5. IAEA Classification of uranium deposits[1].

Deposit Type
Unconformity Associated
Sandstone Hosted
Roll Front
Tectonic-lithologic
Basal Channel
Tabular
Hematite Breccia (IOCG)
Quartz Pebble Conglomerate
Vein type (Granite related)
Intrusive Hosted
Caldera Related
Metasomatic
Surficial (Lignite and Calcrete)
Collapse Breccia
Phosphorite
Black Shale
Metamorphic

[1]From IAEA (2009)

4.1.1 Surficial Deposits

Surficial uranium deposits are broadly defined as young (Tertiary to Recent) near-surface uranium concentrations in sediments or soils. These deposits usually have secondary cementing minerals including calcite, gypsum, dolomite, ferric oxide and halite. The most important surficial uranium deposits are those hosted by lignite and calcrete.

The critical geological conditions for lignite hosted deposits (Kreuser and others, 2009) are:

- Intramontane and (or) intracratonic basin and graben environments that received large amounts of clastic sediments from uranium enriched hinterlands and organic matter.
- Stable cratonic environments with incised paleodrainage systems.

The Taoudeni Basin received large amounts of clastic sediments from the eastern Rgueïbat Shield which contains abundant granitic rocks which are enriched in uranium as shown by airborne radiometric data (fig. 13). The eastern Rgueïbat Shield is also a stable cratonic environment with some incised paleodrainages (Lahondère, Thieblemont, Goujou, and others, 2003). However, climatic conditions in Mauritania have precluded the deposition of recent organic rich sediments which could form lignite. For this reason no tracts for lignite-hosted uranium were delineated.

Uranium deposits in calcrete (calcium and magnesium carbonates) are the most economically significant of the surficial deposits (Lehman, 2008). In calcrete uranium deposits, uraniferous calcrete bodies are typically interbedded with sand and clay, which are usually cemented by calcium and magnesium carbonates (Carlisle, 1983). Calcrete deposits form in regions where uranium-rich granites were deeply weathered in a semi-arid to arid climate (Bowell and others, 2008).

Liu and Jaireth (2011) summarize the critical geologic features necessary for the formation of calcrete-hosted uranium deposits as follows:

- Presence of source rocks for uranium such as granites, and for vanadium such as mafic igneous rocks or iron-rich sedimentary rocks such as banded iron formation (BIF).
- Presence of paleovalleys and (or) paleochannels that contain calcrete.
- Hydrologic discharge system of reasonable size with active recharge systems and discharge areas such as playa lakes.

Calcrete uranium deposits were first reported in Mauritania in the 1970s (Briot, 1984). Exploration for calcrete-type uranium deposits is now common in Africa, in particular since the Langer Heinrich calcrete uranium deposit in Namibia was put into production (Wadley, 2008, Kinnaird and Nex, 2008). The majority of the uranium occurrences in Mauritania are calcrete type. Of these most are located in northern Mauritania on the Paleoproterozoic portion of the Rgueïbat Shield.

The eastern Rgueïbat Shield is largely underlain by Paleoproterozoic granitic rocks (Lahondère, Thieblemont, Goujou, and others, 2003). These rocks are enriched in uranium as shown by airborne radiometric data (fig. 13) and would provide a source for uranium. Mafic igneous rocks also occur in the eastern Rgueïbat Shield and these would provide a source for vanadium. Calcrete deposits known as "Hamada" and paleodrainages are widespread in the eastern Rgueïbat Shield (Lahondère, Thieblemont, Goujou, and others, 2003), whereas laterite and ferricrete are more common in western and southern Mauritania (Pitfield and others, 2004). The hydrologic conditions of the eastern Rgueïbat Shield are also permissive as it is a large discharge area and also has numerous playa lakes (Lahondère, Thieblemont, Goujou, and others, 2003).

The distribution of known calcrete uranium occurrences in the Paleoproterozoic Rgueïbat Shield does not correspond with the mapped distribution of Hamada. In the western part of the Paleoproterozoic the calcrete uranium occurrences correspond with the mapped extent of the Complexe d'Adam Esseder and cailloutis de reg (desert pavement). To the east, the calcrete uranium occurrences are in areas underlain by the Cortège du Yetti. The same areas generally correspond to the >4 ppm equivalent uranium (eU) area in the airborne radiometric data. In detail the majority of the calcrete uranium occurrences correspond with >10 ppm eU radiometric anomalies. This is probably due to the fact that companies exploring for uranium have selected their initial targets based on a review of PRISM data.

Lahondère, Thieblemont, Goujou, and others (2003), citing Gevin (1960) and Mestraud (1975) state that the Hamada deposits are of Pliocene age. The lack of correspondence between the distribution of Hamada and of known calcrete uranium occurrences could be interpreted in two ways depending on the age of the uranium mineralization. One interpretation would be that the calcrete formed in pre-Pliocene time and that the Hamada covers the deposits. The second would be that the calcrete uranium mineralization formed in post-Pliocene time and only occurs in areas where bedrock was exposed to more recent weathering. At the present time there is no data on the age of the surficial uranium mineralization so a conclusion cannot be reached.

4.1.2 Intrusive-Related Deposits

Intrusive-related uranium deposits consist of disseminated primary, non-refractory uranium minerals; dominantly uraninite, uranothorianite and (or) uranothorite hosted by intrusive or anatectic rocks. IAEA (2009) differentiates five subtypes of intrusive deposits are based on host rock petrology: alaskite type, porphyry related, peralkaline syenite type, carbonatite type and pegmatite hosted.

The alaskite type consists of disseminated uranium minerals in alaskite bodies of which Rossing in Namibia is the best known example (Nex and Kinnaird, 2008). Uranium is present in porphyry copper deposits where it is recovered as a by-product. Examples include Bingham Canyon, Twin Buttes, and Yerington in the United States. The peralkaline syenite-type deposits comprise uranium bearing syenitic domes and stocks, for example, Pilansburg in South Africa. In carbonatite type deposits, for example, Phalaborwa in South Africa, uranothorianite is recovered as a by-product of copper mining. Pegmatite deposits consist of granitic and syenitic pegmatite dikes containing uraninite.

The regional-scale geologic features which are critical for intrusive-related uranium deposits (Skirrow and others, 2009, Kreuser and others, 2010) are:

- Metamorphic belts with abundant granite and pegmatite that formed in formerly active continental margins.
- Alkaline igneous complexes, A-type and High I-type granitic suites, and intracontinental rift settings.
- Highly fractionated peralkaline magmas, which have high potassium, thorium, and (or) uranium radiometric expression.
- Regional scale albitic or carbonate alteration zones.

In Mauritania, the Paleoproterozoic portion of the Rgueïbat Shield displays many of these features. The region contains metamorphic belts, abundant granitic and alkaline intrusive rocks and displays anomalous potassium, thorium and uranium (fig. 13) in airborne radiometric data (Finn and Anderson, 2015, Lahondère, Thieblemont, Goujou, and others, 2003). The area is also host to the majority of the uranium occurrences in Mauritania (fig. 2).

Alkaline intrusive rocks occur in the Richat carbonatite and the Bou Naga complex (Lahondère, Thieblemont, Goujou, and others, 2003, Pitfield and others, 2004). The Richat structure is a large structural dome located within the Neoproterozoic to Ordovician part of the Taoudeni Basin. (Matton and Jebrak, 2004, Matton and others, 2005). The central part of the structure is a limestone-dolomite shelf that surrounds a kilometer-scale siliceous breccia and is intruded by basaltic ring dikes, kimberlitic intrusions, and alkaline volcanic rocks. Carbonatite dikes and lesser sills occur in the southern and western part of the structure and extrusive and intrusive alkaline rocks occur in the central part. Brecciated and silicified zones in the center of the Richat structure represent hydrothermal karst which formed as a result of doming over an underlying pluton (Matton and others, 2005). The age of intrusion and hydrothermal activity have been dated at 99 to 98 Ma (Matton and others, 2005).

The Bou Naga complex is an alkaline intrusive complex exposed in a window in the Mauritanide Belt (Blanc and others, 1992; Gunn and others, 2004). The eastern part of the complex consists of rhyolite sills. The western part comprises a complex mixture of syenite and alkaline granite which has been dated at 682 Ma. (Blanc and others, 1992). PRISM airborne radiometric data shows an equivalent uranium anomaly over the complex and a number of PRISM rock samples collected within the western part of the complex are anomalous in uranium (Eppinger and others, 2015, Finn and Anderson, 2015).

The Paleoproterozoic Tigsmat el Akhdar alkaline complex is located in the northeastern Rgueïbat Shield and consists of two alkaline intrusive bodies about 50 km apart. The Tabatanate intrusive is a 5–6 km diameter circular granite body with a nepheline syenite core (Lahondère, Thieblemont, Goujou, and others, 2003). Marot and others (2003) report the presence of disseminated pyrite in the intrusive rocks and an occurrence of alluvial rare earth minerals on the eastern margin. The Gara el Hamoueid intrusive is an elongate 7 km long aegrine augite syenite body with two occurrences of barite-fluorite veins (Marot and others, 2003; Marsh and Anderson, 2015).

4.1.3 Metasomatic Deposits

Uranium deposits of this type are related to alkaline metasomatites, which are typically developed in ancient shields, where they form stockworks controlled by long-lived faults. The deposits are characterized by regional sodic metasomatism (Na_2O enrichment, SiO_2 depletion) and intense carbonate and hematite alteration and are typically of Proterozoic age (Kreuser and others, 2010). The largest uranium deposits in sodium metasomatites occur in the Kirovograd Ore District, Ukraine. Other regions with similar deposits are Beaverlodge district in Canada.

Geological features critical to the occurrence of metasomatic uranium deposits as summarized by Kreuzer and others (2010) are:

- Multiply deformed metamorphic belts.
- Regional metasomatism.
- Presence of large scale fault zones.

The Paleoproterozoic portion of the Rgueïbat Shield contains multiply deformed metamorphic belts and a number of major northwest-trending fault zones however there are no reports of regional metasomatism (Lahondère, Thieblemont, Goujou, and others, 2003).

4.1.4 Metamorphic Deposits

Metamorphic uranium deposits form by redistribution of uranium from enriched country rocks during regional and contact metamorphism. The deposits typically form along faults and shear zones. The best studied example of a metamorphic uranium deposit is Mary Kathleen in Australia.

The geologic features critical for the occurrence of metasomatic uranium deposits (Skirrow and others, 2009) are:

- Metamorphic belts.
- Major crustal scale faults and shear zones to focus fluid flow.
- Presence of sodic (albite) and/or iron-rich alteration.

The Paleoproterozoic portion of the Rgueïbat Shield consists of multiply deformed metamorphic belts and a number of major northwest-trending fault zones, however there are no reports of large scale albite and (or) iron-rich alteration (Lahondère, Thieblemont, Goujou, and others, 2003). Iron-rich alteration is reported in the vicinity of a number of uranium occurrences (Forte Energy, 2009, 2010e; Marsh and Anderson, 2015).

4.1.5 Vein-Type Deposits

Uranium-bearing vein deposits occur in a broad range of lithologies and geologic environments including acidic intrusives (granite, and so forth) volcanics, metasediments and sedimentary rocks (Ruzika, 1993, Kreuser and others, 2010). The styles of mineralization in vein-type uranium deposits include: (1) true veins and stockworks composed of ore and gangue minerals in granite, contact metamorphic rocks and in adjacent meta-sediments; and (2) disseminated mineralization in episyenite bodies (a silica poor, micaceous, vuggy alteration product of granite) that are commonly gradational into veins. Vein-type uranium deposits range in age from Proterozoic to Tertiary. The most important examples are found in France and Czechoslovakia.

The regional geologic features critical to the occurrence of vein-type uranium deposits (Kreuser and others, 2010) are:

- Metamorphic belts, preferably in post orogenic cratonic environments.
- Calcalkaline felsic plutonic and volcanic rocks that are cut by major faults and shear zones.

The Paleoproterozoic portion of the Rgueïbat Shield is a post cratonic environment with deformed metamorphic belts and a number of major northwest-trending fault zones (Lahondère, Thieblemont, Goujou, and others, 2003). Episyenite is reported at the Bir en Nar uranium deposit (Forte Energy, 2009).

4.1.6 Unconformity-Related Deposits

Unconformity-related deposits comprise massive pods, veins and (or) disseminations of uraninite spatially associated with major unconformities that separate Archean sedimentary rocks and (or) Paleoproterozoic metamorphic basement from the overlying Paleoproterozoic to Mesoproterozoic siliciclastic basins. Two sub-types of unconformity related deposits have been recognized reflecting both stratigraphic and structural control. The main age of most known deposits is between 1.74 and 1.39 Ga (Grauch and Mosier, 1986).

This type of deposit is now being referred to as “Unconformity Associated” (Jefferson and others, 2007b) reflecting increased knowledge of the genesis of the deposits. Examples of this deposit type are Athabasca Basin deposits in Canada and the Jabiluka deposits in Australia. Unconformity associated deposits are the highest grade uranium deposits known (Lehman, 2008).

The critical regional geologic features of unconformity associated uranium deposits (Jefferson, Thomas, Quirt and others, 2007; Jefferson, Thomas, Ghandi and others; 2007, Nash, 1982; Skirrow and others, 2009; Kreuser and others, 2010) include:

- Intracratonic epicontinental or foreland basins with thick, permeable sandstone sequences that unconformably overlie uranium-rich crystalline basement.
- Oxidized permeable sandstones overlying the unconformity.
- A basin age of ~2.4 to 1.8 Ga.
- A major disconformity between the basement and the overlying basin.
- Crustal-scale fractures and structural complexity with evidence for fault reactivation during basin development.
- A source of highly oxidized fluids such as diagenetic fluids buffered by evaporates.
- Regional-scale alteration in the basal sandstones and along basement faults.

- Presence of reductants such as carbonaceous material, graphite, hydrocarbons or sulfides.

Gunn and others (2004), Nagel (2008) and O'Connor and others (2005) have suggested that the unconformity between the Taoudeni Basin and the Rgueïbat Shield is permissive for unconformity associated uranium deposits. Alba Minerals has obtained exploration licenses over the unconformity in eastern Mauritania and is exploring for unconformity associated uranium deposits (Alba Minerals, 2012b).

Age may be an important constraint on unconformity-associated uranium deposits as most deposits occur in basins between ~2.4 to 1.8 Ga in age (Jefferson, Thomas, Quirt and others, 2007; Skirrow and others, 2009). According to Lahondère, Thieblemont, Goujou and others (2003) sedimentation in the Taoudeni Basin began at about 1.0 Ga. This conclusion is based on an Rb/Sr age date of 998 Ma of glauconite from the Char Group, the oldest unit in the basin (Clauer, 1981; Clauer and others, 1982). However, more recent δC chemostratigraphy (Teal and Kah, 2005; Kah and others, 2012) and Re-Os dating of organic-rich sediments by Rooney and others (2010) indicate a 1.1 Ga age for the Atar Group which overlies the Char Group. This indicates that the onset of sedimentation in the Taoudeni Basin was at >1.1 Ga and that the Char Group may be much older than previously thought (Rooney and others, 2010). The unconformity between the Char and Atar Groups is basin-wide which could indicate a substantial time interval between the two groups. Rooney and others (2010) suggest that the Char Group may be at least 200 Ma older than the Atar Group based on an extrapolation of the difference between Rb-Sr and Re-Os ages in the Atar Group. This would put the onset of sedimentation in the Taoudeni Basin at ~1.3 Ga.

At this age the Taoudeni Basin would still be younger than basins which host unconformity-associated uranium deposits and would probably not be considered permissive for this deposit type. However, Jefferson, Thomas, Quirt and others (2007) note that the youngest basin being explored for unconformity-associated uranium in Canada is the Neoproterozoic (<1,200 Ma) Borden Basin which is in the same age range as the Taoudeni Basin.

The relationship between unconformities and uranium mineralization in general was studied by Markwitz and others (2010) who carried out an empirical spatial analysis of various types of uranium deposits in Australia. They found that there was a strong spatial correlation between unconformities and uranium deposits. They concluded that:

> "The results of this study highlight the importance of unconformities in uranium minerals systems as possible fluid pathways and/or surfaces of physico-chemical contrast that could have facilitated the precipitation of uranium, not only in classical unconformity style uranium deposits but in several other styles of uranium mineralization as well."

This suggests that the unconformity between the Taoudeni Basin and the Rgueïbat Shield is permissive for unconformity associated uranium deposits.

4.1.7 Phosphorite Deposits

Uraniferous phosphorite deposits consist of synsedimentary, disseminated uranium minerals in marine phosphate-rich rocks or phosphorite deposits that formed in continental shelf environments (Cathcart, 1978; Mosier, 1986). Phosphorite deposits constitute large uranium resources, but are very low grade, typically 25–150 ppm uranium, which is recovered as a by-product of phosphoric acid production (Ragheb, 2010). By-product uranium is recovered mainly from phosphate deposits in Morocco and the United States.

There are 29 phosphate occurrences in Mauritania (Marsh and Anderson, 2015). The majority of these occur in three areas: in Eocene rocks in southwestern Mauritania (Bougjo and Jiddouo, 1989), in Cambrian tillites in the western Taoudeni Basin and in the area north of Bou Naga on the west edge of the Taoudeni Basin (Flicoteaux and Trompette, 1998).

In southwestern Mauritania phosphorite deposits occur in Eocene sedimentary rocks of the Bofal Formation (Boujo, 1983; Bougjo and Jiddouo, 1989). Two deposits have been explored; Bofal and Loubboira and have total estimated resources of 94 million tonnes with an average grade of 19.8 per cent P_2O_5 (Boujo and Jiddouo, 1989). These phosphate deposits are now being developed by an Indian company (Mahrouf, 2010; N-P-K World, 2010). Boujo and Jiddouo (1989) report that the Bofal deposits have an average uranium content of 80 ppm.

The other phosphate occurrences in Mauritania consist of small occurrences of phosphate-bearing rock and most have very little data (Flicoteaux and Trompette, 1998; Marsh and Anderson, 2015).

4.1.8 Sandstone-Hosted Deposits

Sandstone uranium deposits occur in carbon- and (or) pyrite-bearing fluvial (less commonly marine), arkosic, medium to coarse-grained sandstones that contain, are interbedded with, and bounded by less permeable horizons. With few exceptions, sandstone uranium deposits are of diagenetic-epigenetic, low temperature origin. Uranium precipitates from oxidizing solutions by reducing conditions caused by a variety of reducing agents within the sandstones (for example, carbonaceous material, sulfides, hydrocarbons, and iron magnesium minerals such as chlorite) (Finch, 1982). Major known sandstone deposits range in age from Paleozoic to Tertiary. Age may provide an important constraint on the occurrence of sandstone uranium deposits as fossil land plants, which did not become common until the Silurian, often provide the reductant for precipitation of uranium (Nash and others, 1981; Turner-Peterson and Hodges, 1986). However, other sources of reductants such as hydrocarbons are also associated with sandstone uranium deposits (Jaireth and others, 2008).

IAEA (2009) recognized four subtypes of sandstone uranium deposits: roll-front, tectonic-lithologic, basal channel, and tabular. Roll front deposits are zones of uranium-matrix impregnation that crosscut sandstone bedding and extend vertically between overlying and underlying less-permeable horizons. Tectonic-lithologic deposits are discordant to the surrounding strata. They occur along permeable fault zones with linguiform impregnation of the adjacent clastic sediments (for example, tongue-like impregnations extending away from faults into the surrounding country rock). Basal channel deposits occur in paleo-channels filled with thick permeable alluvial-fluvial sediments. Uranium mineralization is predominantly associated with detrital plant debris in ore bodies that display in a plan view an elongated lens or ribbon-like configuration and in cross section view a lenticular or, more rarely, a roll shape. Tabular uranium deposits consist of uranium matrix impregnations that form irregularly shaped lenticular masses within reduced sediments. Tabular deposits are subdivided into the intrinsic and extrinsic carbon subtypes and the vanadium-uranium deposit subtypes. Examples of sandstone uranium deposits in Africa are Imouraren and Arlit in Niger, Mikouloungou in Gabon and several prospects currently being explored in the Karoo sediments in Mozambique and Tanzania (Schatz, 2008).

Skirrow and others (2009) summarized the regional geologic features necessary for the formation of sandstone uranium deposits as follows:

- Intracratonic, continental or intermountain basin setting with a basement of continental crust.
- Deposition of sandstones in continental fluvial or a mixed fluvial-marine environment.
- Age of the basin younger than 2.4 Ga with most basins younger than Devonian.

- Presence of a topographic gradient such as primary depositional dip, tilting or compression and (or) extension, at the time of mineralization.
- Hydrologically connected permeable immature sandstones as aquifer and host rock.
- Presence of reductants such as plant fossils or hydrocarbon fluids.

There is potential for sandstone uranium deposits in Mauritania including uranium associated with "red bed" type sediment-hosted copper mineralization in the Taoudeni Basin (Nagel, 2008), in arkosic sandstones in the Taoudeni Basin (Marot and others, 2003) and in the Cenozoic Gorgol Formation in the Coastal Basin Province (Gunn and others, 2004).

The Taoudeni Basin records discontinuous marine and continental sedimentation from the Mesoproterozoic to the Cenozoic (Blumenberg and others, 2012; Gunn and others, 2004; Kah and others, 2012; Lahondère, Thieblemont, Goujou and others, 2003; Marot and others, 2003; Rooney and others, 2010). Review of the detailed lithologic descriptions in Pitfield and others (2004), Lahondère, Thieblemont, Goujou and others (2003) and Marot and others (2003) show that the Char Formation, the basal part of the Atar Group, the Oujaft Formation, and the Continental Intercalair contain terrestrial fluvial sandstones which are permissive hosts for uranium deposits. The source for the sediments was mainly the Rgueïbat Shield which has abundant granitic rocks which are enriched in uranium as indicated by airborne radiometric data (Finn and Anderson, 2015).

There are two petroleum systems developed in the Taoudeni Basin; one in the upper Proterozoic and a second in Paleozoic rocks (Amadou, 2008; Mohamed, 2006; Reynolds, 2008). The source rock for the Proterozoic system is algal stromatolites in the Atar Formation (Reynolds, 2008; Blumenberg and others, 2012; Kah and others, 2012). In the Paleozoic system the source rocks are Silurian-Devonian marine black shales of the Gara Bouya Ali Group (Amadou, 2008). Plant fossils are reported in the Cretaceous Continental Guide (Lahondère, Thieblemont, Goujou, and others, 2003). The petroleum source rocks and plant fossils provide a potential reductant necessary for the deposition of uranium (Jaireth and others, 2008).

The Taoudeni Basin has several of the elements necessary for the formation of sandstone uranium deposits including tectonic setting, host rocks, uranium enriched source rocks and a source of organic matter. However, depositional dips within the basin are <0.5 degrees (Kah and others, 2012). This could inhibit fluid movement within and between units, a process which is important in the formation of sandstone uranium deposits (Finch, 1982; Nash and others, 1981; Jaireth and others, 2010).

4.1.9 Quartz-Pebble Conglomerate Deposits

Quartz-pebble conglomerate uranium deposits are restricted to early Paleoproterozoic intracratonic basins (older than 2.3–2.4 Ga) that were formed by the downwarp of Archean basement rocks that include granites. Host rocks for this deposit type typically consist of trough cross-bedded, quartz-pebble conglomerate beds with a pyritic matrix interbedded with quartzite and argillite. This suite of lithologies typically occurs as basal units in fluvial to deltaic braided stream systems. These deposits are mined primarily for gold and uranium is produced as a co-product. The most important deposits of this type are in the Witwatersrand Basin in South Africa and Elliot Lake in Canada. The Tarkwa deposits in Ghana are similar to the Rand deposits but have not produced significant uranium. Age may be an important constraint on the occurrence of this deposit type as the temporal distribution may be restricted to the Archean and early Paleoproterozoic due to oxidation of Earth's atmosphere beginning in about 2.2 Ga (Roscoe and Minter, 1993; Skirrow and others, 2009).

Kreuser and others (2009) summarize the critical geological features of quartz-pebble conglomerate gold-uranium deposits as follows:

- Continental rift basin setting.
- Submature to mature cross bedded polymict conglomerate host rocks.
- Age possibly restricted to Archean and Paleoproterozoic.

O'Connor and others (2005) suggest that the Formation de Seyala is permissive for quartz pebble gold-uranium type mineralization. The Formation de Seyala occurs in a small area in Central Mauritania and consists of conglomerate and ferruginous quartzite of Paleoproterozoic age.

4.1.10 Hematite Breccia Complex Deposits

Deposits of this group which are also known as Iron Oxide Copper-Gold (IOCG) deposits occur in hematite-rich breccias and contain uranium in association with copper, gold, silver and rare earth elements (Hitzman and Valleta, 2005). Uranium is a by-product in this deposit type but because of the size of the deposits, production can be significant. For example, the Olympic Dam deposit in Australia is one of the world's largest uranium producers (Skirrow and others, 2009).

The Guelb Moghrein deposit in west central Mauritania is considered by many to be an IOCG deposit (Fernette, 2015, and references therein). Guelb Moghrein is being mined for copper and gold but does not contain anomalous uranium (JICA, 2005). For this reason the tracts defined as permissive for IOCG type mineralization (Fernette, 2015) are not considered permissive for uranium in IOCG deposits.

Salpeteur (2005) suggests that several copper-iron occurrences in the Procession of Mbédia Achar in the southern Mauritanide Belt might be IOCG type mineralization. Fernette (2015) reviewed the data on these mineral occurrences and concluded that they were volcanogenic massive sulfide type mineral occurrences which typically do not contain anomalous uranium.

No tracts were delineated for uranium in hematite-breccia deposits for this report.

4.1.11 Black Shale Deposits

Black shale hosted uranium mineralization consists of syngenetic, uniformly disseminated uranium in organic-rich, pyritic marine shale deposited in epicontinental basins. The organic matter is of a sapropelic-bituminous or humic, coaly nature derived from planktonic marine algae and land plant debris (for example, wood spores). Uraniferous black shales are widespread but few are being mined due to their low grades. The main example of this deposit type which is being mined is the Ranstad deposit in Sweden.

The critical geological features for the formation of black shale-hosted uranium deposits as summarized by Kreuser and others (2009) are:

- Tectonically stable terranes with low sedimentation rates.
- Brackish to normal marine environment.
- Aerobic to reducing conditions.
- Shallow epicontinental basin environments.
- Laminated very fine grained black shales with high organic and sulfide contents.

In the southern Mauritanides the El Faraa occurrence consists of carnotite associated with barite in black shale of the late Proterozoic (Vendian) Group de Teniagouri (Donzeau and others, 1982; Salpeteur, 2008). The lithologic descriptions of the Teniagori Group do not mention black shales. Pitfield and others (2004) describe the main lithologies as arenaceous mudstones and barite-bearing dolostones which are interpreted as periglacial lacustrine or marine deposits. There are numerous rock geochemical samples in the area of the El Faraa occurrence which do not show anomalous uranium values (Eppinger and others, 2015). Therefore it is not possible to draw a meaningful permissive tract for black shale hosted mineralization using this.

No tracts were delineated for black shale hosted uranium.

4.1.12 Caldera or Volcanic Related Deposits

Caldera related volcanic deposits occur within or in close proximity to volcanic calderas filled by complex assemblages of mafic to felsic volcanic rocks and intercalated clastic sediments (Nash, 2010). Uranium mineralization is largely structurally controlled, occurring in intrusive veins or stockworks in volcanic intrusions, diatremes, and flow or bedded pyroclastic units. Examples of this deposit type include the Streltsovskoe deposit in the Russian Federation and McDermitt in the United States.

Critical features for caldera or volcanic related uranium deposits (Kreuser and others, 2009, Nash, 2010) are:

- The presence of calderas with strong peralkaline affinity.
- Cauldron subsidence structures indicating multiple episodes of extension and collapse.
- Caldera-related volcanogenic sedimentary rocks.

No calderas are reported in Mauritania. Consequently no tracts were delineated for volcanic-hosted uranium.

4.1.13 Collapse Breccia Pipe Deposits

Collapse breccia pipe deposits occur as vertical chimney-like structures that are filled with fragments of wall rock (Finch, 1992). Uranium was introduced into the pipes by moving groundwater and deposited in response to changes in temperature and (or) pressure or to changes in chemical environment. The uranium minerals occur in the interstices between breccia fragments and in fractures in the annular ring that separates the breccia-filled column from the surrounding wall rock (Wenrich and others, 1995). The best examples of collapse breccia uranium deposits are the deposits in the “Arizona Strip” in the United States (Wenrich, 1985). The Tsumeb deposit in Namibia is an African example (Wenrich and others, 1995).

Wenrich and Sutphin (1989) and Kreuser and others (2009) summarize the critical features necessary for the occurrence of breccia pipe uranium deposits as follows:

- Flat lying sedimentary strata.
- A long period of cratonic stability.
- Thick limestone sequence overlying sandstone.
- Karst formation.

The key criteria for determining areas favorable for this type of deposit such as the presence of paleokarst are not reported in Mauritania. For this reason no tracts were delineated for collapse breccia-hosted uranium.

5 Permissive Tracts for Uranium Deposits

5.1 Methodology

The delineation of the permissive tracts for this report was done in three stages. The first stage consisted of a review of available data on uranium deposits and potential uranium deposits in Mauritania including deposits that are present in the surrounding region. The PRISM metallogenic reports were particularly valuable as each team described not only the known occurrences in their region but also permissive environments. The uranium deposit types highlighted by the PRISM teams are summarized in table 6.

Table 6. Uranium deposit types suggested by PRISM Project teams.

Area	Reference	Target Type	Description
North	Marot and others (2003)	Calcrete	Hamadas and recent alluvia in the Requibat Shield
		Mesothermal shear zone related.	Tenebdar bedrock occurrences
		Shallow intrusive associated, shear zones, carbonatites, alkaline intrusive	Guelb Richat (carbonatites), Tenebdar lineaments in the Requibat Shield.
		Sandstone hosted and unconformity related	Taoudeni Basin
South	Gunn and others (2004)	Unconformity related	Tauoudeni basin-Requibat unconformity.
		Red-bed Uranium	Taoudeni Basin
		Phosphate	Phosphate occurrences in the Taoudeni basin
		Sandstone Uranium	Coastal basin, Eocene fluvial sediments of the Gorgol Formation.
		Phosphate-Eocene	Bofal Formation.
Central	Nagel (2008)	Sedimentary “red bed”	Potential
		Unconformity related	Potential
		Phosphate	Secteur d’Akadnech
Extreme South	Salpeteur (2005)	Black shale	Group of Téniagouri (El Faraa occurrence)
		IOCG	Procession of Mbédia Achar, Cu-hematite-magnetite occurrences
		“uranium roll”	Group of Téniagouri
Northwest	O’Connor and others (2004)	Unconformity related.	Potential
		Paleoplacer quartz Au-U	Formation de Seyala
		Phosphate	Eocene sediments

The second stage of the process was to review and compile supporting data. These data included the PRISM mineral deposit database, geochemical sample data and airborne geophysical data.

The PRISM Project collected 8,061 rock samples and 21,057 samples of unconsolidated material including regolith, soil and sediment (Eppinger and others, 2015). Of these 3,118 rock samples and 2,717 unconsolidated samples were analyzed for multiple elements including uranium. For this evaluation the samples which had been analyzed for uranium were extracted from the database and anomalous uranium values determined by simple statistics (tables 7 and 8). The average uranium content of continental crust is 2.7 ppm (Rudnick and Gao, 2003). This provides the “background” value which was used as a basis for identification of anomalous values in the PRISM data. Strongly anomalous samples are listed in table 9.

Table 7. Uranium geochemistry of rock geochemical samples.

Range (ppm U)	Number of Samples	Percent of Total
<10	2,952	94.7
10-50	166	5.3
50-100	14	0.7
100-200	5	0.3
>200	5	0.2
Totals	**2,953**	**100**

Data extracted from the PRISM Project geochemical sample database (Eppinger and others, 2015).

Table 8. Uranium geochemistry of unconsolidated geochemical samples.

Range (ppm U)	Number of Samples	Percent of Total
<5	2,567	94.48
5-10	140	5.15
10-50	8	0.29
>50	2	0.07
Totals	**2,717**	**100.00**

Data extracted from the PRISM Project geochemical sample database (Eppinger and others, 2015).

In the PRISM rock samples 94.7 per cent of the samples contained less than 10 ppm uranium. All values above this are considered anomalous. The majority of the anomalous samples contain between 10 and 50 ppm uranium with 24 samples containing more than 50 ppm. Forte Energy and Aura Energy use a 100 ppm U_3O_8 (84 ppm uranium) as a cutoff grade. By this measure samples which contain more than 100 ppm uranium are potentially economic. All of the samples which contain more than 100 ppm uranium were collected at or near uranium occurrences, principally in the Tenebdar area near the Bir en Nar deposit. Uranium in PRISM rock samples is shown in figure 11.

Of the 2,717 samples of unconsolidated material 94.5 per cent contain less than 5 ppm uranium (table 8). Ten samples contain more than 10 ppm uranium and are considered to be strongly anomalous. Uranium in unconsolidated geochemical samples from the PRISM Project is shown in figure 12.

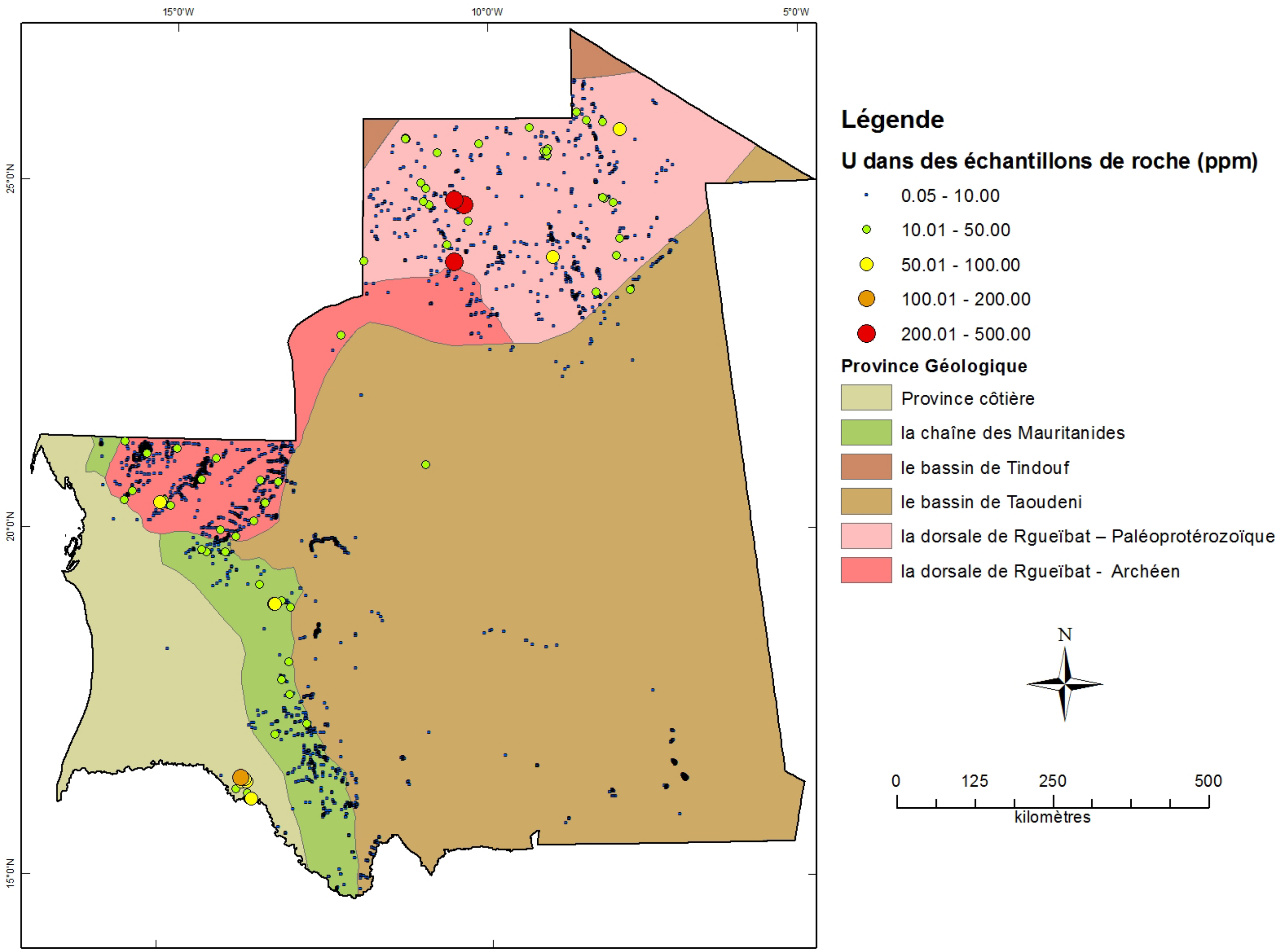

Figure 11. Uranium concentration in PRISM rock samples.

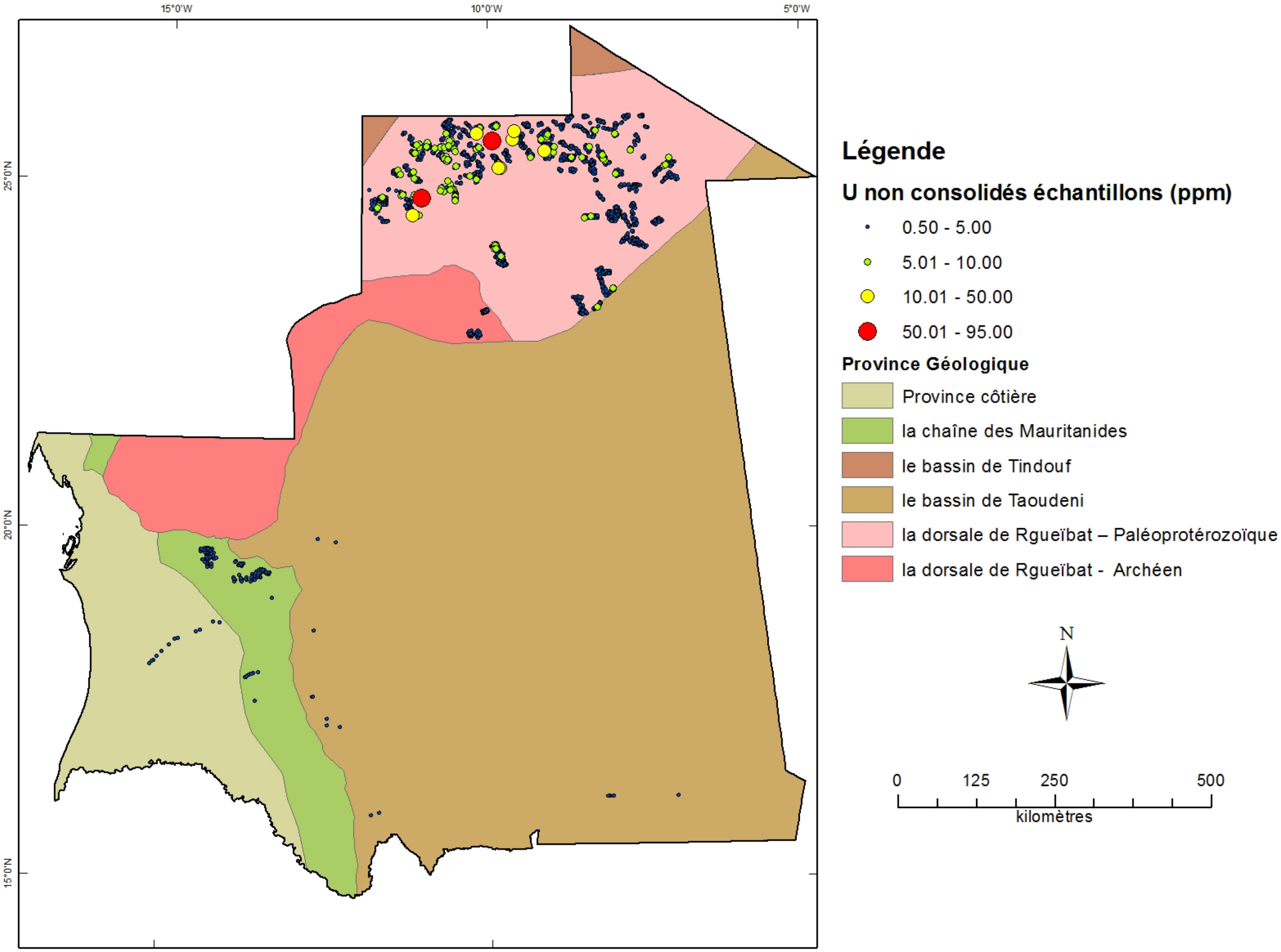

Figure 12. Uranium concentration in PRISM unconsolidated samples.

Table 9. PRISM geochemical samples with strongly anomalous uranium values.

Sample Number	Latitude	Longitude	Type	U (ppm)	Geologic Province	Geologic Unit	Associated Uranium Occurrence
241000048	24.760260	-10.392560	Rock pit	500.0	Rgueïbat	Complexe d'Adam Esseder	Unnamed 2130
231000085	23.942810	-10.552750	Rock pit	348.0	Rgueïbat	Cortège de Gleïbat Tenebdar	Unnamed 2439
231000084	23.942020	-10.554570	Rock pit	328.0	Rgueïbat	Cortège de Gleïbat Tenebdar	Unnamed 2439
241000057	24.831381	-10.552780	Rock pit	291.0	Rgueïbat	Groupe de Legleya	Near Unnamed 2135
241000052	24.832310	-10.554700	Rock pit	249.0	Rgueïbat	Groupe de Legleya	Unnamed 2135
241000101	24.788219	-10.469620	Rock chip	185.5	Rgueïbat	Groupe de Legleya	Unnamed 2198
241000054	24.832270	-10.554370	Rock pit	155.0	Rgueïbat	Groupe de Legleya	Unnamed 2135
161300200	16.450000	-13.770000	Rock grab	108.5	Rgueïbat	Quaternaire, Reg (gravillons de latérite)	Unnamed
241000061	24.844339	-10.544170	Rock pit	106.5	Rgueïbat	Groupe de Legleya,	Unnamed 2141
241000037	24.781790	-10.459590	Rock chip	103.5	Rgueïbat	Groupe de Legleya	Unnamed 2103
241112580	24.821831	-11.057910	Regolith	94.8	Rgueïbat	Quaternaire, Dépôts de sebkha	None
250909897	25.643780	-09.938110	Regolith	82.2	Rgueïbat	Quaternaire, Hamada	Iquelt
250910065	25.259100	-09.804230	Regolith	16.8	Rgueïbat	Complexe de Tmeïmichatt Ghallamane	None
250908839	25.663260	-09.607830	Stream	15.0	Rgueïbat	Complexe d'Adam Esseder	None
250910070	25.257160	-09.829130	Regolith	14.1	Rgueïbat	Complexe de Tmeïmichatt Ghallamane	None
250908431	25.489950	-09.102760	Regolith	14.1	Rgueïbat	Quaternaire, Hamada	None
241112556	24.570539	-11.197680	Regolith	11.9	Rgueïbat	Complexe d'Adam Esseder	None
251010254	25.756983	-10.182167	Regolith	10.2	Rgueïbat	Quaternaire, Cailloutis de reg	Iquelt
250909287	25.787901	-09.583633	Regolith	10.2	Rgueïbat	Quaternaire, Dépôts de sebkha	None
250910066	25.258381	-09.809480	Regolith	10.0	Rgueïbat	Complexe de Tmeïmichatt Ghallamane	None

Data extracted from the PRISM Project geochemical sample database (Eppinger and others, 2015)

Airborne magnetic and radiometric surveys were carried over large areas of Mauritania as a part of the PRISM Project (Finn and Anderson, 2015). The uranium channel of the radiometric surveys is the most useful for helping to delineate tracts which are permissive for uranium deposits. These data clearly show that much of the Rgueïbat Shield is anomalous in uranium (fig. 13). The uranium channel data were queried and new grids which showed the anomalous areas at 4–10 ppm, 10–20 ppm and >20 ppm equivalent uranium (eU) were prepared. In addition to the uranium radiometric channel the potassium and thorium radiometric channels and aeromagnetic data were also used in the tract delineation process.

Additional data sets that were used in the delineation of permissive tracts were (1) the Mauritania mineral occurrence database (Marsh and Anderson, 2015); (2) a separate database of uranium occurrences compiled during the preparation of this report; (3) processed Landsat-7 ETM+ imagery; and (4) where available ASTER imagery (Rockwell and others, 2015).

5.2 Permissive Tracts for Uranium Deposits

For purposes of the delineation of permissive tracts the IAEA (2009) deposit groups have been simplified to eight classes. Vein type, metasomatic, metamorphic, and most intrusive-related deposits have similar characteristics at the scale of the available data. In addition, the known bedrock occurrences for which there is the most, albeit still very limited geologic data, have characteristics of all of these deposit types. For this reason these deposit types were grouped into "granite-hosted vein/shear" type deposits for the purpose of delineating permissive tracts. Some intrusive deposits are distinctive, such as carbonatite and alkaline intrusive related and were retained as a separate class of "alkaline intrusive-hosted" deposits. As noted above, tracts for four types of deposits were not delineated: IOCG, black shale, caldera or volcanic related, and solution collapse breccia deposits.

The classes of uranium deposits for which permissive tracts were delineated are:

1. calcrete,
2. granite-hosted vein/shear,
3. alkaline intrusive-hosted,
4. unconformity-associated,
5. quartz pebble conglomerate-hosted,
6. phosphate-hosted,
7. sandstone-hosted, and
8. sediment-hosted (red bed) type.

A total of 51 tracts considered permissive for a variety of types of uranium deposits were delineated. The permissive tracts for each deposit type are described below and shown on figures 14 through 18.

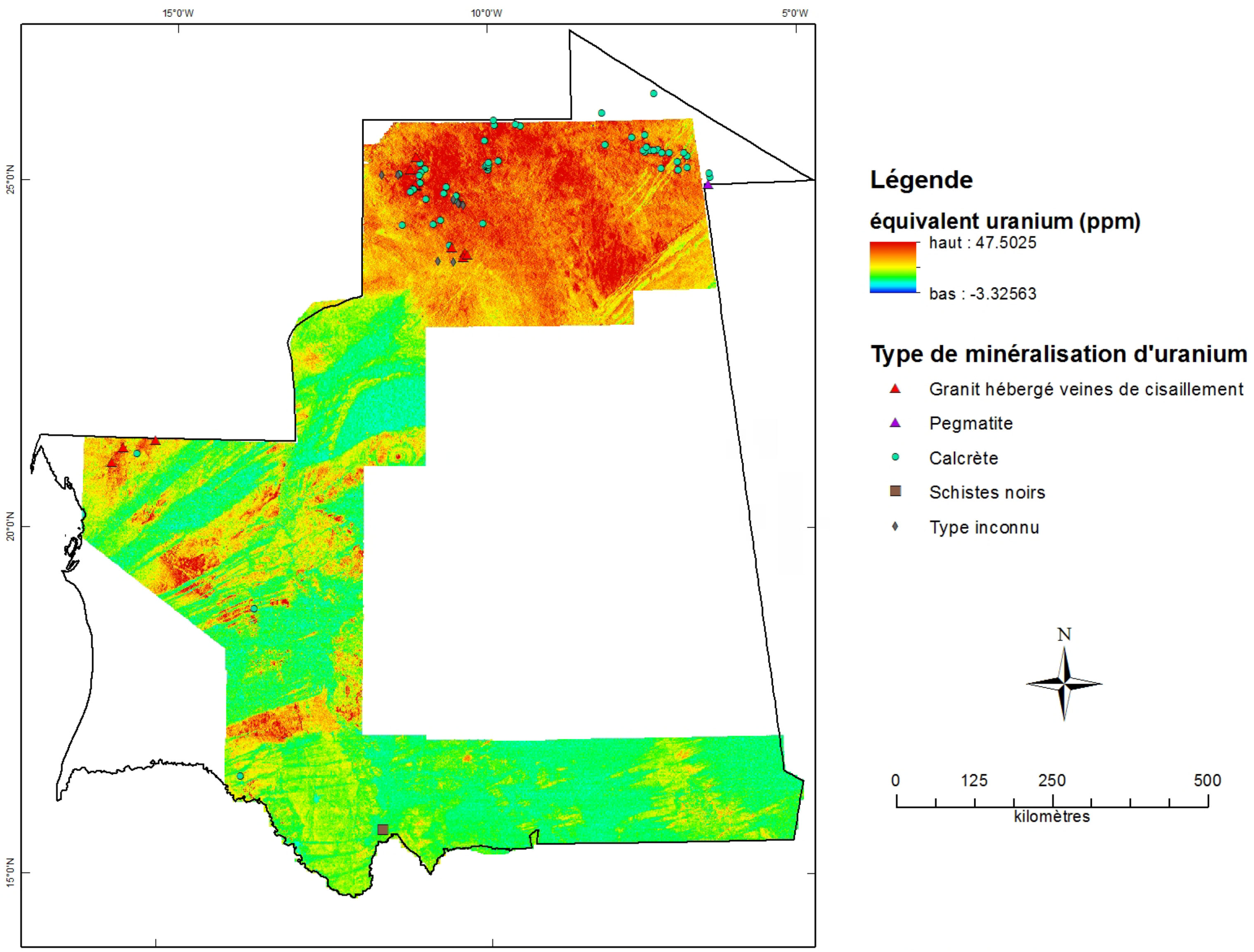

Figure 13. PRISM Airborne radiometric data - uranium channel and uranium occurrences in Mauritania.

5.2.1 Calcrete Uranium Deposits

Twelve tracts were drawn to define areas considered permissive for calcrete uranium deposits (fig. 14).

Tract MU-01 Rgueïbat 1. The tract is defined by the area of >4 ppm eU in the PRISM radiometric data and the limit of the Paleoproterozoic Rgueïbat Shield. It extends outside the Paleoproterozoic rocks in two areas which show >4 ppm eU in airborne radiometrics. The radiometric anomaly mainly corresponds to the Cortege de Yetti, the Complexe de Tmeïmichatt Ghallamane and the Complexe d'Adam Esseder and includes within its area most of the known uranium occurrences in Mauritania. The tract is considered permissive based on the presence of uranium-rich source rocks as indicated by the radiometric anomaly and favorable geomorphic, climatic and hydrologic conditions as seen by the presence of large areas of calcrete (Hamada) and numerous sabkhas.

Tract MU-02 Rgueïbat 2. Defined by a group of 11 calcrete uranium deposits and prospects and a coherent >4 ppm eU radiometric anomaly which includes several areas of >20 ppm eU. The tract is entirely underlain by Cortegee de Yetti. The tract is considered permissive based on the presence of the same critical regional geologic features as in Tract MU-01 as well as a cluster of calcrete deposits and prospects and strong radiometric anomalies.

Tract MU-03 Rgueïbat 3. The tract is drawn to cover an area of strong (>10 ppm and >20 ppm eU) radiometric anomalies which correspond to northeast trending Hamada units. In the southwest part of the area there are seven calcrete uranium prospects or occurrences. Another calcrete uranium occurrence is located in the central part of the tract. In the southcentral part of the tract there are several samples of unconsolidated material which contain between 10 and 50 ppm uranium. Bedrock in the tract is the Complexe de Tmeïmichatt Ghallamane. The tract is considered permissive based on the presence of the same critical regional geologic features as in Tract MU-01 as well as a cluster of calcrete uranium deposits and prospects and strong radiometric anomalies.

Tract MU-04 Rgueïbat 4. The tract is drawn around a north trending 10–20 ppm eU radiometric anomaly. Within the tract there are two calcrete uranium occurrences and three anomalous (5–10 ppm uranium) unconsolidated geochemical samples. The tract is considered permissive based on the presence of the same critical regional geologic features as in Tract MU-01 as well as the presence of a calcrete uranium occurrence and prospects, anomalous geochemical samples and a strong radiometric anomaly.

Tract MU-05 Rgueïbat 5. Tract MU-05 is drawn around two >20 ppm eU radiometric anomalies associated with two calcrete uranium deposits; Umm Ferkik K and L. The geophysical anomalies are located on the western edge of a distinctive light colored intrusive within the Complexe d'Adam Esseder. The tract is considered permissive based on the presence of the same critical regional geologic features as in Tract MU-01 as well as the presence of strong radiometric anomalies and calcrete uranium deposits.

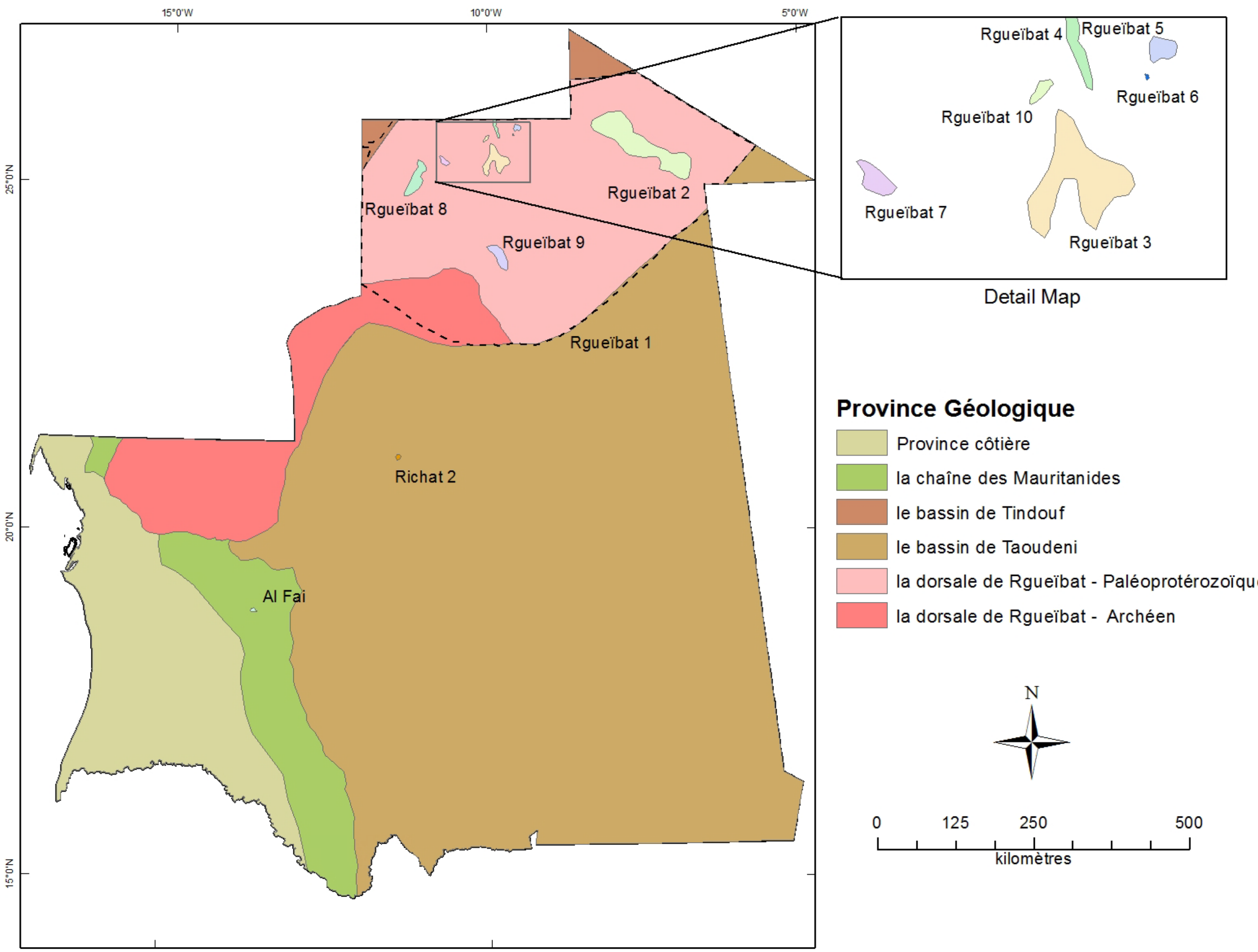

Figure 14. Permissive tracts for calcrete uranium deposits.

Tract MU-06 Rgueïbat 6. The tract is drawn around the limit of a sabkha. A soil sample collected at the edge of the sabkha contains 10.2 ppm uranium and 355 ppm vanadium. The tract is considered permissive based on the presence of the same critical regional geologic features as in Tract MU-01 as well as the presence of a favorable depositional environment and a geochemical sample anomalous in uranium and vanadium.

Tract MU-07 Rgueïbat 7. The tract is drawn to cover a >10 ppm eU radiometric anomaly and ten PRISM soil samples containing 5–10 ppm uranium. The area of the tract is underlain by granitic intrusive rocks of the Complexe d'Adam Esseder. The tract is considered permissive based on the presence of the same critical regional geologic features as in Tract MU-01 as well as a cluster of anomalous geochemical samples and a strong radiometric anomaly.

Tract MU-08 Rgueïbat 8. Tract MU-09 is drawn to cover a northeast-trending group of strong (>10 pp eU) radiometric anomalies and a group of eight calcrete uranium occurrences, prospects and deposits. The radiometric anomaly and uranium occurrences are broadly distributed along irregular areas mapped as Hamada (calcrete) and cailloutis de reg (desert pavement) which overlie granitic rocks of the Complexe d'Adam Esseder. The tract is considered permissive based on the presence of the same critical regional geologic features as in Tract MU-01 as well as the presence of strong radiometric anomalies and calcrete uranium occurrences.

Tract MU-09 Rgueïbat 9. The tract is drawn to cover a uranium anomaly in PRISM soil samples where fifteen samples contain 5–8 ppm uranium and 80–120 ppm vanadium. The anomaly occurs on a north-northwest trending fault zone which cuts granitic rocks of the Complexe d'Adam Esseder, gneiss of the Complexe d'Aguelt abd el Maï and tonalite of the Cortège de Gleïbat Tenebdar. This fault zone hosts several bedrock uranium occurrences along strike. A number of the anomalous samples occur in a sabkha. The tract is considered permissive based on the presence of the same critical regional geologic features as in Tract MU-01 as well as the presence of a uranium-vanadium geochemical anomaly.

Tract MU-10 Rgueïbat 10. This tract covers a group of three radiometric anomalies with >10 ppm eU and a calcrete uranium occurrence in an area underlain mainly by cailloutis de reg (desert pavement) and Hamada (calcrete). The tract is considered permissive based on the presence of the same critical regional geologic features as in Tract MU-01 as well as the presence of the calcrete uranium occurrence and cluster of geophysical anomalies.

Tract MU-11 Al Fai. Tract MU-11 covers a 4 km wide airborne radiometric anomaly with values of >20 ppm eU and the Al Fai calcrete uranium prospect. The area is underlain by cailloutis de reg (desert pavement). The area is considered permissive based on the presence of calcrete uranium mineralization and a strong geophysical (eU) anomaly.

Tract MU-12 Richat 1. This tract is drawn to cover the center of the Richat Dome which overlies the Richat complex. The center of the complex has a eU radiometric anomaly that is >10 ppm. The anomaly is interpreted to be over sediments accumulated in the valley. The sediments are described by Lahondère, Thieblemont, Goujou, and others (2003) as a small circular basin containing porous analcime bearing limestone with fossil roots in the lower part. The unit is interpreted as fluvial sediments overlain by lake sediments. The area is considered permissive for calcrete uranium based on the surficial geologic environment (sabkha), uranium source rocks (alkaline intrusive rocks) and the radiometric anomaly.

5.2.2 Granite-Hosted Shear/Vein Uranium Deposits

Eight tracts were drawn to define areas permissive for granite-hosted vein-shear type uranium deposits. These are shown on figure 15.

Tract MU-13 Rgueïbat 11. The tract is drawn to cover an east-west trending fault zone with four 10–20 ppm eU radiometric anomalies which cuts a light colored intrusive body within the Complexe d'Adam Esseder. The area is considered permissive based on the presence of a major fault zone coincident with airborne radiometric anomalies.

Tract MU-14 Rgueïbat 12. Tract MU-14 is drawn to cover a major north northwest-trending lineament which cuts the Paleoproterozoic intrusive and metamorphic rocks of the Cortège de Zednes and the Cortège de Gleïbat Tenebdar in the Rgueïbat Shield. Along strike to the north the same lineament hosts the Bir en Nar, A238 and A238 NW uranium deposits. The tract is considered permissive based on the presence of a major fault zone which hosts uranium deposits along strike to the northwest.

Tract MU-15 Rgueïbat 13. Tract MU-14 is drawn to cover a major north northwest-trending lineament which cuts the Paleoproterozoic intrusive and metamorphic rocks of the Complexe d'Adam Esseder in the Rgueïbat Shield. There are a number of weakly anomalous (5–10 ppm uranium) PRISM soil samples scattered along the length of the tract. The tract is considered permissive based on the presence of a major fault zone within an area which hosts uranium occurrences.

Tract MU-16 Rgueïbat 14. The tract is drawn to cover a west northwest-trending fault zone which cuts the Paleoproterozoic intrusive and metamorphic rocks of the Complexe d'Adam Esseder, the Cortège de Gleïbat Tenebdar and the Complexe de Tmeïmichatt Ghallamane in the Rgueïbat Shield. Along strike to the north the same lineament hosts a number of uranium occurrences. The tract is considered permissive based on the presence of a major fault zone which hosts uranium occurrences along strike to the northwest.

Tract MU-17 Rgueïbat 15. Tract MU-17 is drawn to cover a major northwest trending lineament cuts the Paleoproterozoic intrusive and metamorphic rocks of the Complexe d'Adam Esseder in the Rgueïbat Shield. This structure hosts seven granite-hosted shear/vein type uranium deposits or prospects. Also within tract MU-17 are four calcrete uranium prospects and one occurrence of unknown type. The tract is considered permissive based on the presence of a major crustal-scale fault zone which hosts uranium deposits.

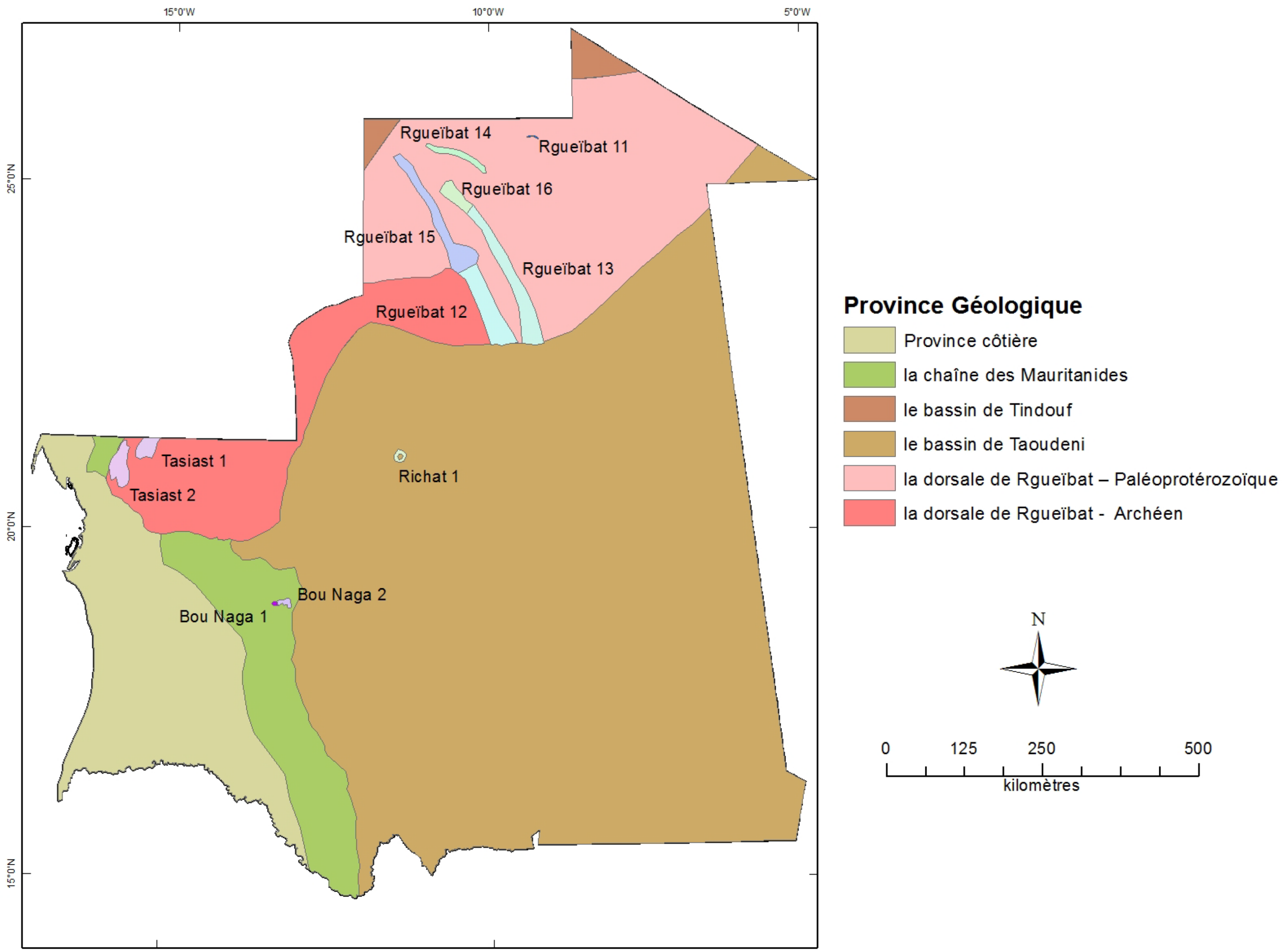

Figure 15. Permissive tracts for uranium deposits associated with intrusive rocks.

Tract MU-18 Rgueïbat 16. This tract is drawn on a major northwest-trending lineament which cuts rocks of the Complexe d'Adam Esseder in the Rgueïbat Shield. Within the tract there are eleven uranium occurrences: one granite-hosted shear/vein type, four calcrete type and six of unknown type. PRISM rock samples collected at two of the occurrences of unknown type contain 249 and 500 ppm uranium. In the northwestern part of the tract there are a number of airborne radiometric anomalies in the range of 10–20 ppm eU. The tract is considered permissive based on the presence of a major fault zone which hosts uranium occurrences, several of which have high uranium values in rock samples.

Tract MU-19 Tasiast 1. Tract MU-19 is drawn over an area of migmatite gneiss of the Archean Complex de Çtel Ogmâne and tonalite of the Cortège de Tasiast. Both rock units show strongly anomalous potassium and thorium in airborne radiometric data. There are irregular also a 4–10 ppm eU radiometric anomalies over most of the eastern part of the tract which is underlain by tonalities. There is one uranium occurrence of probable granite-hosted type in the northeast part of the tract and a calcrete occurrence in the southwest part. The calcrete uranium occurrence is along an east northeast-trending fault zone marked by large quartz veins which is visible in the PRISM aeromagnetic data for the area. The tract is considered permissive based on the presence of uranium occurrences, eU radiometric anomalies and possible presence of peralkaline rocks based on the strong potassium and thorium radiometric anomalies.

Tract MU-20 Tasiast 2. This tract, located southeast of Tract MU-19 is also underlain by migmatite gneiss of the Archean Complex de Çtel Ogmâne and tonalite of the Cortège de Tasiast. Irregular 4–10 ppm eU radiometric anomalies are present over most of the tract with four small areas of 10–20 ppm eU at the north end of the tract and one in the south central part.

The tract is also underlain by the Complex de Çtel Ogmâne and shows the same light colored signature on the K-Th-U grid as the bedrock in tract Tasiast 1. This tract also has irregular uranium radiometric anomalies throughout and two granite related uranium occurrences. Strongly anomalous potassium and thorium radiometric anomalies are present over both rock units. The southernmost of the uranium occurrences is the calcrete uranium occurrence that is along the same east northeast-trending fault zone marked by large quartz veins, the calcrete uranium occurrence in Tract MU-19. The tract is considered permissive based on the presence of uranium occurrences, eU radiometric anomalies and possible presence of peralkaline rocks based on the strong potassium and thorium radiometric anomalies.

5.2.3 Alkaline Intrusive-Hosted Uranium Deposits

Four tracts were delineated for areas permissive for alkaline intrusive-hosted uranium deposits. These tracts are also shown on fig. 14.

Tract MU-21 Richat 2. Tract MU-21 is drawn on the interpreted limit of the Richat intrusive as interpreted from aeromagnetic data. The tract is considered permissive based on the presence of alkaline intrusive rocks (carbonatite).

Tract MU-22 Bou Naga 1. The tract is drawn to cover the western part of the Bou Naga alkaline intrusive complex which hosts rare earth element bearing veins. Much of tract MU-22 has >4 ppm eU in airborne radiometric data. There are also with two areas of >10 ppm eU and one area at >20 ppm eU. The radiometric data for the entire tract are also strongly anomalous in potassium and thorium. Also within the tract are 11 PRISM rock samples with >10 ppm uranium and two samples with >50 ppm uranium. The tract is considered permissive based on the presence of alkaline intrusive rocks, strong (>10 and >20 ppm eU) uranium, potassium and thorium radiometric anomalies and a relatively large number of rocks samples with anomalous uranium contents.

Tract MU-23 Bou Naga 2. This tract is drawn to cover the eastern part of the Bou Naga alkaline intrusive complex. Most of the tract is underlain by rhyolites of the Formation de l'Oued Tidoumaline and shows anomalous uranium (>4 ppm eU), potassium and thorium in the PRISM airborne radiometric data. The tract is considered permissive based on the presence of alkaline intrusive rocks and strong (>10 and >20 ppm eU) uranium, potassium and thorium radiometric anomalies.

Tract MU-24 Tabatanate. The tract is drawn around the outcrop of the Tigsmat el Akhdar alkaline complex. Marot and others (2003) report an occurrence of alluvial rare earth minerals on the eastern edge of the complex. There are four PRISM rock geochemical samples that were collected within the complex that contain 16–20 ppm uranium. The intrusive is permissive for the occurrence of uranium minerals based on its lithology, tectonic setting and the presence of threshold uranium values in rock samples.

Tract MU-25 Gara el Hamoueid. The tract is drawn around the outcrop of the Gara el Hamoueid syenite intrusive which hosts two occurrences of barite-fluorite veins (Marot and others; 2003, Marsh and Anderson, 2015). The intrusive is permissive for the occurrence of uranium minerals based on its lithology and tectonic setting.

5.2.4 Unconformity-Associated Uranium Deposits

Two tracts were defined which are considered permissive for unconformity-associated uranium deposits (fig. 16).

Tract MU-26 Taoudeni 1. Tract MU-26 is drawn over the unconformity between the Rgueïbat Shield and the Taoudeni Basin in eastern Mauritania. Within the tract there is 4–10 ppm eU radiometric anomaly over the Paleoproterozoic Cortege de Yetti which indicates that the basement in the area is anomalous in uranium. There are also 4–10 ppm eU radiometric anomalies over the Groupe d'El Mreiti and the Groupe de Jbielat within the Taoudeni sedimentary section. Within the area of the tract there are three major lineaments in the basement which pass beneath the basin sediments. The tract is considered permissive based on the presence of an unconformity between Paleoproterozoic basement rocks which are enriched in uranium with Mesoproterozoic sediments in an area of major structures within the basement rocks.

Tract MU-27 Taoudeni 2. The tract is drawn over the unconformity between the Rgueïbat Shield and the Taoudeni Basin where the unconformity covers three major crustal lineaments, one of which hosts the granite-hosted shear/vein type Bir en Nar, A238 and A238 NW uranium deposits. The tract is considered permissive based on the presence of an unconformity between Paleoproterozoic basement rocks and Mesoproterozoic sediments in an area of major structures within the basement rocks.

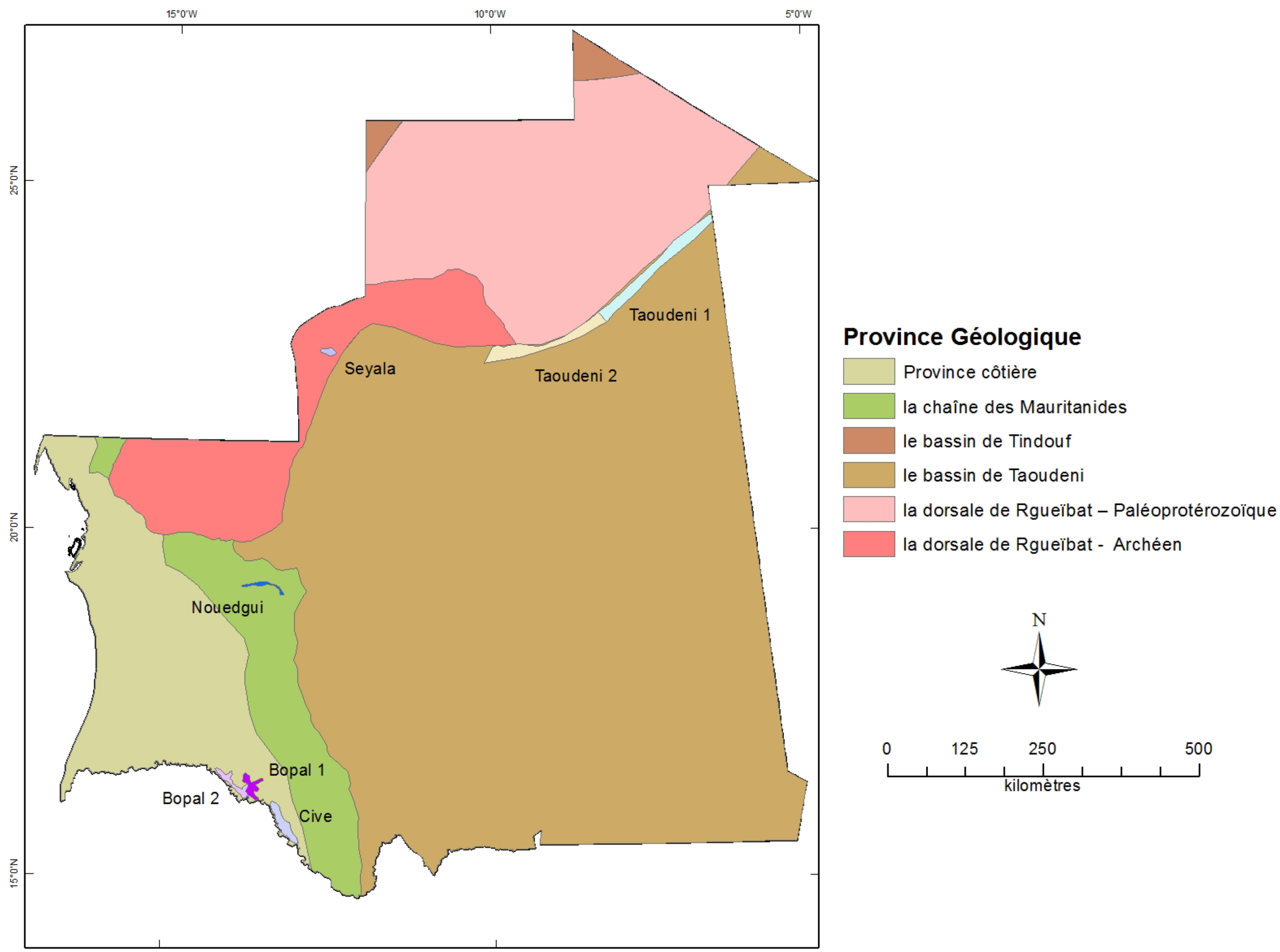

Figure 16. Permissive tracts for phosphate hosted, quartz pebble conglomerate, and unconformity associated uranium deposits.

5.2.5 Quartz-Pebble Conglomerate Deposits

One tract was drawn which is considered permissive for quart pebble conglomerate-hosted uranium deposits (fig. 16).

Tract MU 28 Seyala. Tract MU-28 is drawn to cover the outcrop area of the Paleoproterozoic Seyala Formation. The Seyala Formation is made up of conglomerate and ferruginous quartzite. The tract is considered permissive based on the lithology and age of the Seyala Formation.

5.2.6 Phosphorite Deposits

Four tracts were defined which are considered permissive for phosphorite-hosted uranium deposits (fig. 16).

Tract MU-29 Bofal 1. The tract is drawn around a part of the outcrop area of the Bopal Formation which includes the Bofal, Boubou Aoudi and the Debai Doubel phosphate deposits and one other phosphate occurrence. The Bofal deposit is reported to contain 80 ppm uranium by Boujo and Jiddou (1989). In the northern part of the tract, near the Bofal deposit, 44 rock samples were collected by the PRISM Project (Gunn and others, 2004, Eppinger and others, 2015). All of the samples have detectible uranium and seven of the samples contain >50 ppm uranium with a maximum value of 108 ppm. The anomalous samples were collected from several units including the Tertiary Rinndiao and Mbidane Formations and Cenozoic laterite. In the eastern part of the area there are irregular >4 ppm eU radiometric anomalies. The tract is considered permissive based on the presence of phosphate deposits and their host unit and of rock samples anomalous in uranium.

Tract MU-30 Bofal 2. The tract is defined by the outcrop area of the Bofal Formation. Within the tract there is the Bagoudinie-Ferrala phosphate deposit and five phosphate prospects or occurrences. The tract is considered permissive based on the presence of phosphate occurrences and their host rock.

Tract MU-31 Cive. Tract MU-31 is drawn to cover an area which includes the Cive phosphate occurrence and several small 4–10 ppm eU radiometric anomalies. The area is mainly covered by Cenozoic dunes and the radiometric anomalies correspond to outcrops of ferruginous laterite. The tract is considered permissive based on the presence of phosphate occurrences weak radiometric anomalies.

Tract MU-32 Nouedgui. Tract MU-32 tract is drawn around part of the outcrop area of the Hofret el Jenna Formation. The tract includes the Nouedgui phosphate occurrence and a >4 ppm uranium radiometric anomaly. There is one PRISM rock sample in the tract which contains 32 ppm uranium, 38 ppm vanadium and >10,000 ppm phosphorous. The Hofret el Jenna Formation is composed of a transgressive sequence of conglomerate, sandstone and siltstone which rests unconformably on migmatitic tonalite gneiss. Phosphate is recorded widely in this sequence, particularly in the basal 20 m of quartz-pebble conglomerate and fine sandstones and siltstones (Gunn and others, 2004). The tract is considered permissive based on the presence of a phosphorite occurrence with weakly anomalous uranium content.

5.2.7 Sandstone-Hosted Deposits

Five tracts were identified as permissive for sandstone-hosted uranium based on criteria outlined above. Tracts one through four are located within the Taoudeni Basin and tract five is within the Coastal Basin (fig. 17).

Tracts MU-33 to MU-36 Sandstone 1a–1d. These tracts are drawn with a buffer around the mapped outcrop area of the Mesoproterozoic Agueni Formation of the Char Group. This is the lowermost unit of the Char Group and in the Taoudeni Basin. It consists of fluvial conglomerate and sandstone which discordantly overlie Paleoproterozoic rocks of the Rgueïbat Shield. The tracts are considered permissive based on the tectonic setting, lithology and depositional environment of the Agueni Formation and the presence of petroleum source rocks in the Taoudeni Basin.

Tract MU-37 Sandstone 2. Tract MU-37 is composed of the mapped area of the Foum Chor Formation of the Atar Group of Mesoproterozoic age. The unit consists of ~100 m of fluvial and deltaic sandstones, conglomerate, silt and clay. The tract is considered permissive based on the tectonic setting, lithology and depositional environment of the Foum Chor Formation and the presence of petroleum source rocks in the Taoudeni Basin.

Tracts MU-38 to MU41 Sandstone 3a through3d. These tracts are defined by the mapped limits plus a buffer of the Cambro-Ordovician Gujaft Formation of the Nouatil Group. The unit consists of ~200 m of sandstone and feldspathic sandstone. The tract is considered permissive based on the tectonic setting, lithology and depositional environment of the Gujaft Formation and the presence of petroleum source rocks in the Taoudeni Basin.

Tract MU-42 Sandstone 4. This tract is drawn with a buffer on the mapped limit of the Cretaceous Continental Intercalair in the central Taoudeni Basin. This unit consists of terrigenous sandstones containing petrified wood. The tract is considered permissive based on the tectonic setting, lithology and depositional environment of the Continental Intercalair and the presence of petroleum source rocks in the Taoudeni Basin.

Tract MU-43 Sandstone 5. Tract MU-43 is drawn by the mapped extent plus a buffer of the Middle Tertiary Gorgol Formation of the Bababe Group. The unit, which outcrops along the eastern edge of the Coastal Basin Province, is made up of brown-red, cross bedded terrestrial sandstone with minor conglomerate. The tract is considered permissive based on the tectonic setting, age, lithology and depositional environment of the Gorgol Formation.

5.2.8 Sediment-Hosted (Red Bed) Copper ± Uranium Deposits

Tracts MU-45 to MU-51 Red Bed 1 through 8. Taylor and Giles (2015) delineated eight tracts which were considered permissive for sediment-hosted red bed type copper deposits. Sediment-hosted copper deposits may also contain economic amounts of uranium. Therefore, all of these tracts can be considered permissive for uranium associated with red-bed type copper deposits (fig. 18). The reader is referred to Taylor and Giles (2015) for details on the geologic character of these tracts.

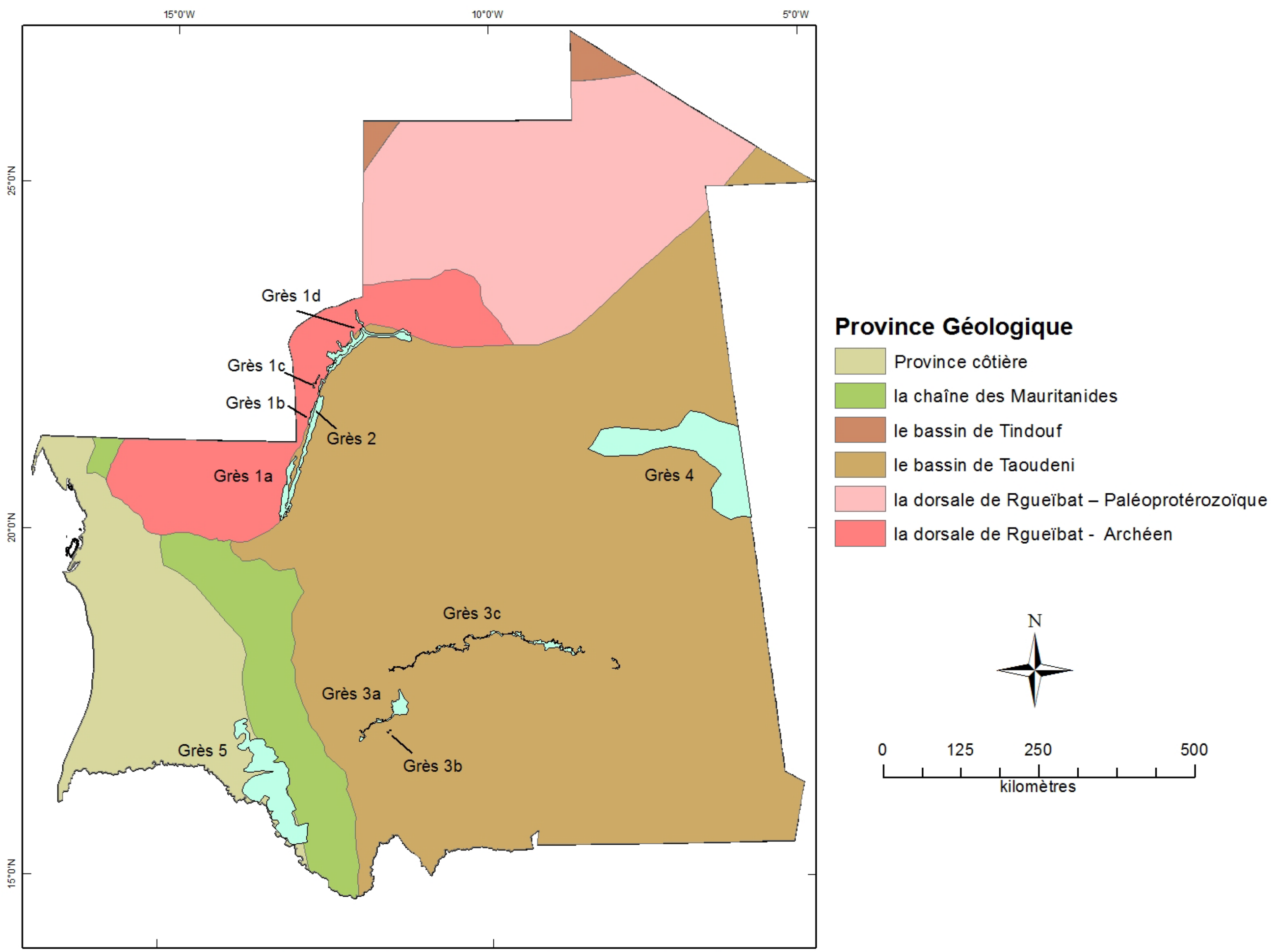

Figure 17. Permissive tracts for sandstone-hosted uranium deposits.

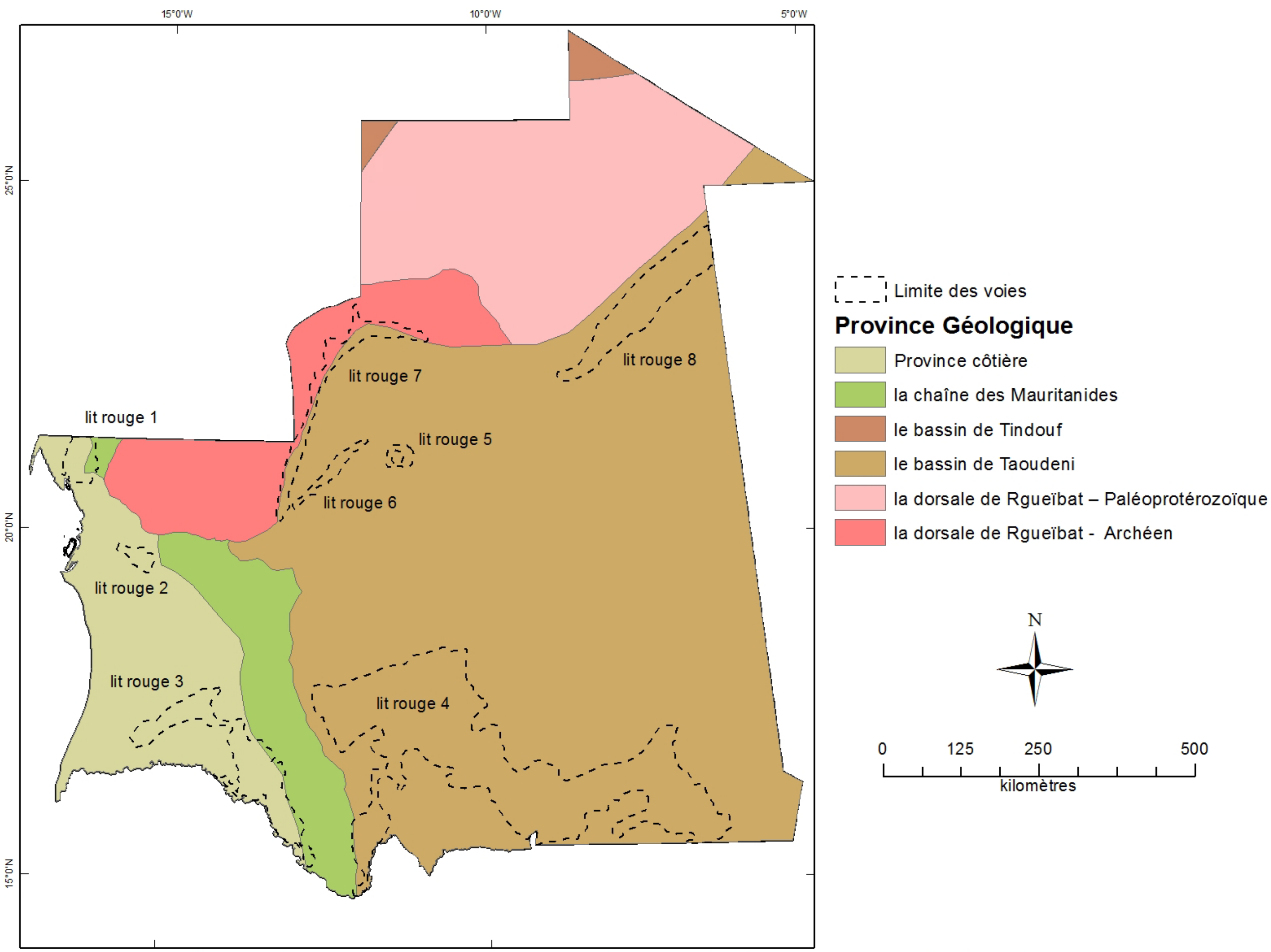

Figure 18. Permissive tracts for red-bed uranium deposits.

6 Conclusions

Mauritania is the site of active uranium exploration where new discoveries are being made. Of the 80 known uranium occurrences most are calcrete-type and most are located in the Paleoproterozoic Rgueïbat Shield. Much of the northern Rgueïbat Shield is anomalous in uranium as shown by the widespread >4 ppm eU anomalies in airborne radiometric data. The anomalous granitic rocks provide the source for the uranium in the calcrete deposits. Three granite-related deposits and a number of prospects are also found in the same area. The granite-related deposits and prospects are all within or proximal to major northwest trending fault zones.

In addition, there are permissive environments for a number of other deposit types including phosphate-hosted, alkaline intrusive and carbonatite-related, unconformity-associated, sandstone-hosted, and uranium associated with “red bed” sediment-hosted copper deposits.

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Appendix 1: List of Company Reports

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