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Case studies and testing of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009

Application of UNFC-2009 for monitoring the project maturity of the Central Jordan Uranium Project

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Summary

This document provides a case study that looks at the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) to uranium resources in the Central Jordan Uranium Project (CJUP), Jordan. The uranium deposits in the CJUP are primarily hosted by the Muaqar Chalky Marl (MCM) Formation of upper Maastrichtian age, part of the Upper Cretaceous to lower Tertiary Belqa Group. Uranium exploration and resource estimation was performed over two phases in this project, Phase 1 (2009-2014) and Phase II (2015). This case study demonstrates the advantages of using UNFC-2009 to monitor the project maturity of CJUP over different phases of exploration. The project progressed from a "Potentially Commercial Projects/Development on Hold" project in Phase I to a more mature "Potentially Commercial Projects/Development Pending" in Phase II. The application of UNFC-2009 to the CJUP study in Jordan clearly demonstrates the advantage of tracking the project from a lower maturity level of assessment to a higher level. Therefore, classification and reporting of uranium project results using UNFC-2009 have clear advantages for policy makers in Jordan, as well as for internal company requirements for monitoring the progress of a project over time. UNFC-2009 is thus an effective tool for taking decisions on whether or not to make further financial commitments in order to demonstrate the continued viability of the project.

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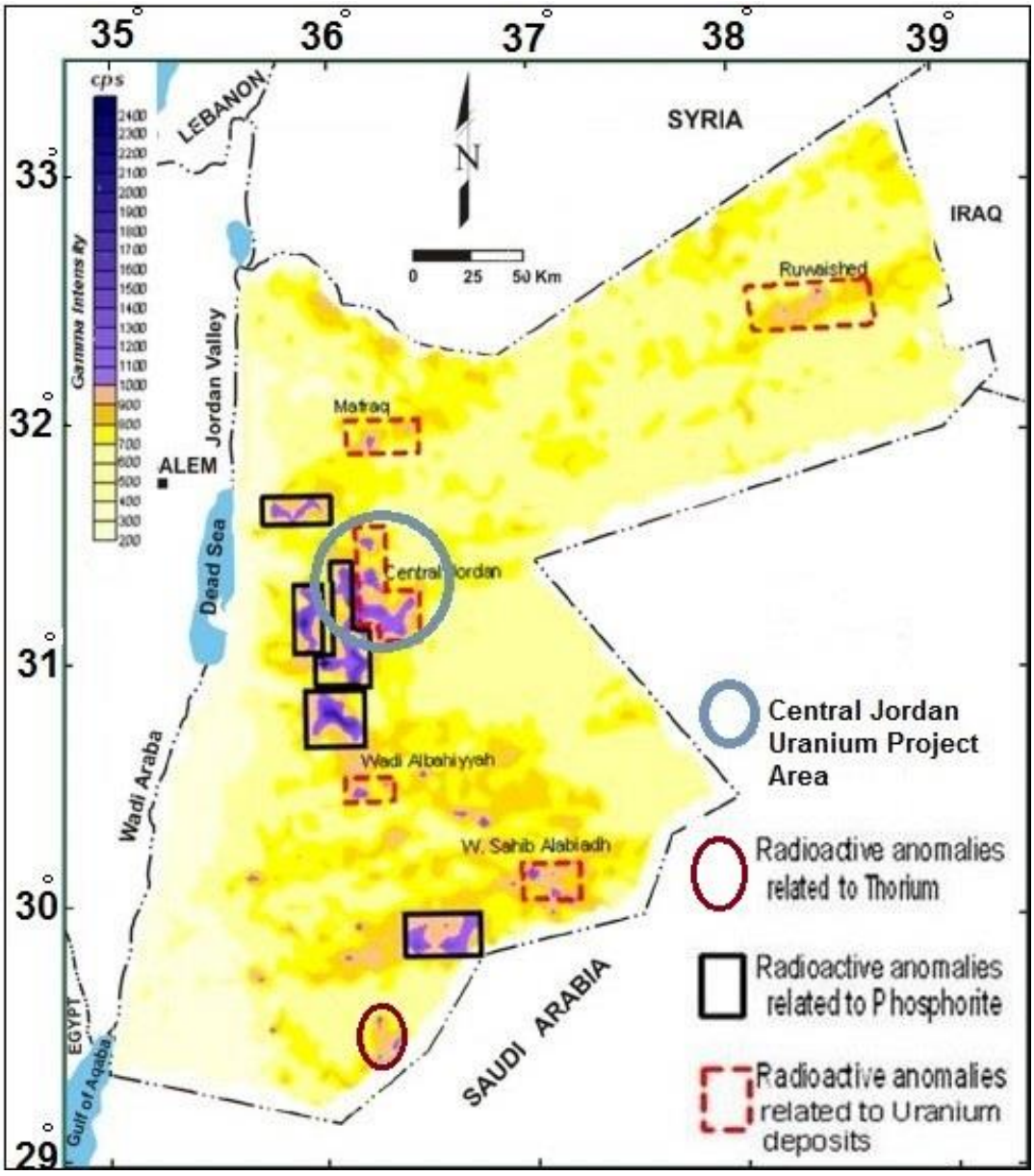
I. Introduction

1. This case study was prepared by Mr. Ahmad Al Dajani and Mr. Hussein Allaboun, Jordan Uranium Mining Company (JUMCO), Jordan, with technical input from Mr. Harikrishnan Tulsidas of the secretariat of the United Nations Economic Commission for Europe (ECE).

2. Since 1992, uranium ore deposits have been discovered in several locations in Jordan by the Jordanian Natural Resources Authority (NRA) (Figure 1). Discoveries relied on measurements obtained from several data resources, including airborne radiometric surveys, geological surveys, radiation measurements collected by car and by foot, radon gas measurements, and from the results of sample analyzes obtained from drilled boreholes and excavated trenches.

Figure 1
Airborne Radiation Survey, Jordan

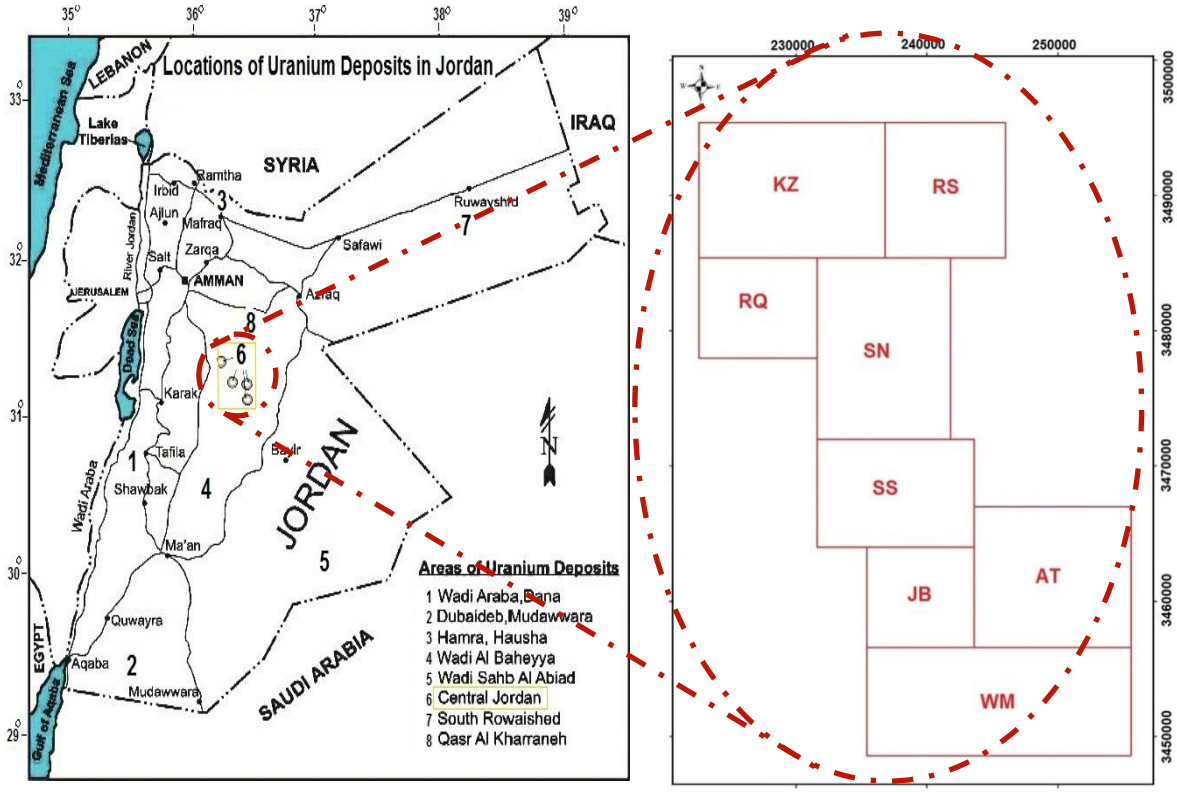


3. The Central Jordan Uranium Project (CJUP) is located some 60 km south of Amman along the Amman-Aqaba highway and occupies an area of 875 km² (Figure 2, left). The project's licensed area was divided into several zones as shown in (Figure 2, right) to facilitate planning and monitoring of exploration activities.

4. Uranium exploration and resource estimation was performed over two phases. In Phase I, the uranium mineralization in the CJUP that is hosted in the Muaqar Chalky Marl (MCM) Formation was estimated and reported as an Inferred Resources according to the 2012 Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves ('the JORC Code') principles (JORC 2012). Intense exploration activities were continued in Phase II with the objectives of further increasing the uranium resource base and upgrading the existing resource to the Indicated Category.

5. This case study demonstrates the advantages of using UNFC-2009 to monitor the project maturity of CJUP over different phases of exploration [1] [2]. The project progressed from a “Potentially Commercial Projects/Development on Hold” project in Phase I to a more mature “Potentially Commercial Pro-jects/Development Pending” in Phase II.

Figure 2
CJUP within Jordan and its exploration zones



KZ: Khan AZ Zabib
RS: Rujm Al Sheed
RQ: Rujm Qiyal
SN: Siwaqa North
AT: Attarat
WM: Wadi Maghar
JB: Jabal Al Bayda
SS: Siwaqa South

II. Regional Geology

6. The general geology of Jordan can be summarized as follows:

(a) Precambrian rocks, south-western part of Jordan, comprise metavolcanic, metasedimentary, gneiss and migmatite belts.

(b) Palaeozoic rocks, southern Jordan, comprise limestone, dolomite and fine-grained sandstone.

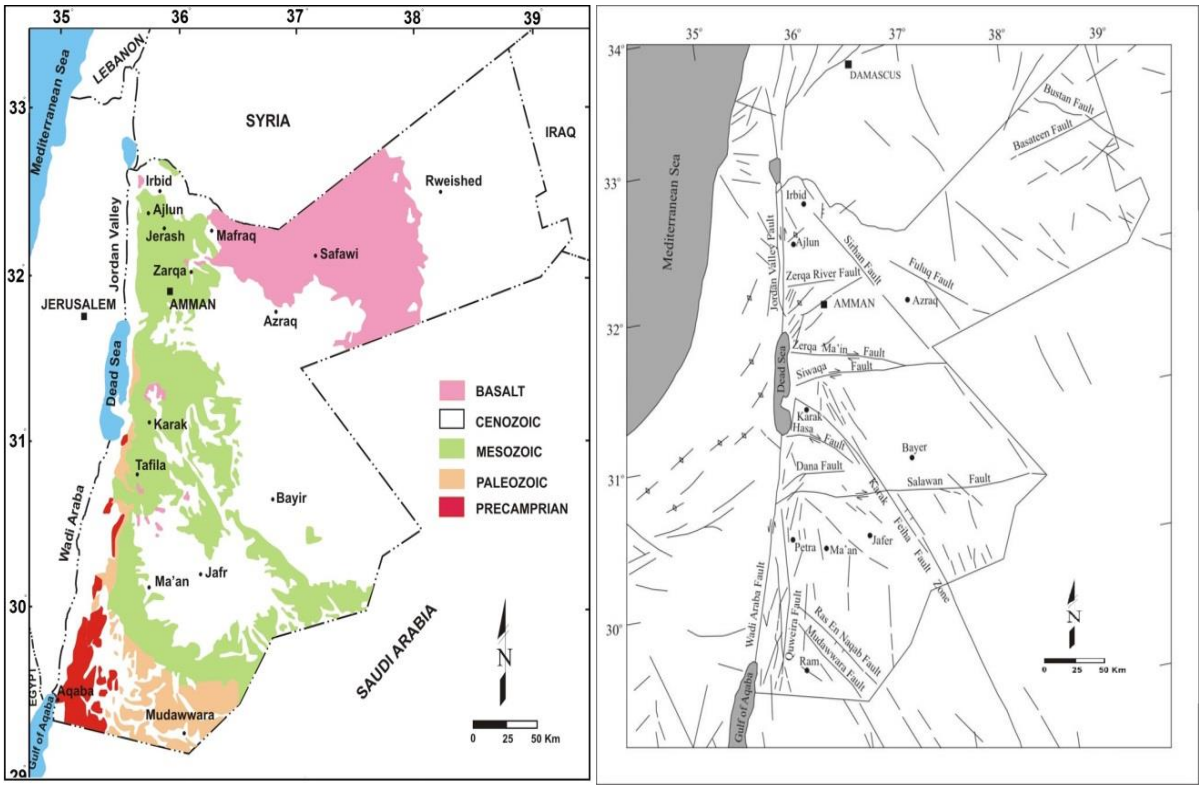
(c) Mesozoic rocks, the western and southern margin of Jordan. Upper Cretaceous rocks have the dominant distribution; they are considered sources of oil shale, phosphate, limestone, and marble.

(d) Cenozoic rocks, northeastern Jordan. These are shallow marine deposits, mainly composed of chert, limestone, chalk, marl, conglomerate and evaporates.

(e) Neogene basalts.

7. The general dip direction of strata in Jordan is to the north-east. The overall trend is rock formations towards the north-east (Figure 3, left) [3].

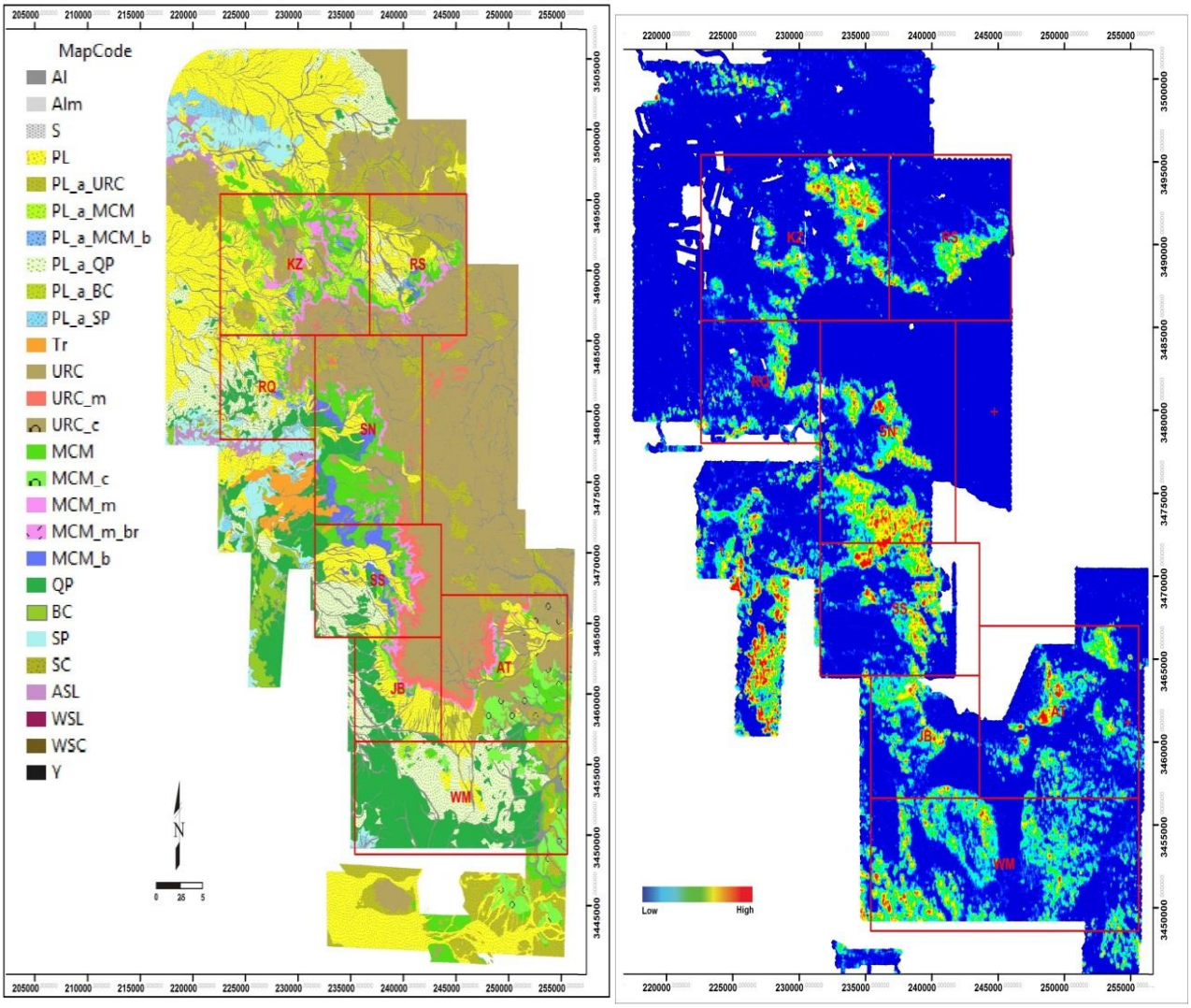
Figure 3
General geology and structural trends of rock units in Jordan



III. Geology of Central Jordan

8. In Central Jordan, the sedimentary sequence is composed of rocks of Upper Cretaceous (Turonian) to Paleogene in age (Figure 4, left). Locally, these rocks are overlain by beds of travertine and alluvial sediments of the Pleistocene age. The area of the CJUP was surveyed by a car-borne radiometric study (Figure 4, right).

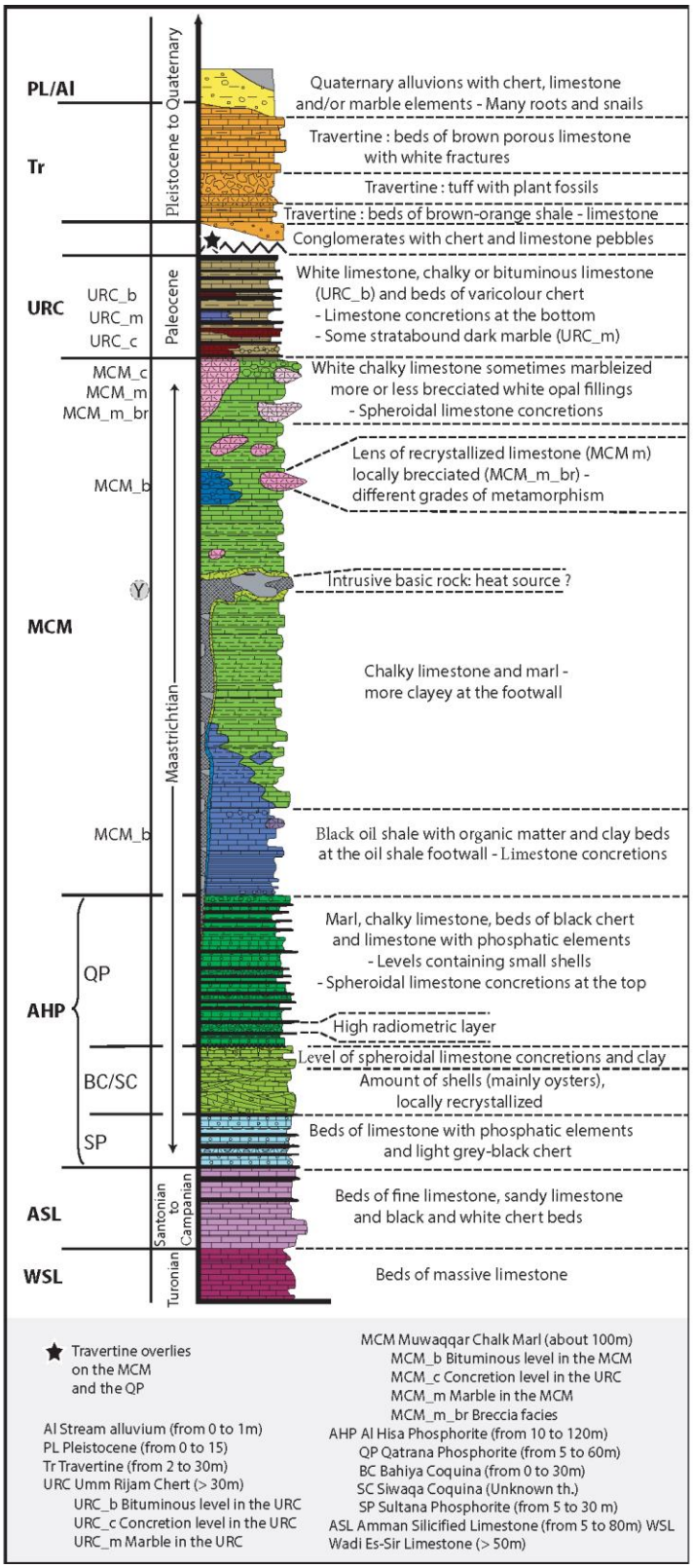
Figure 4
Geology (left) and gamma-ray intensity (right) maps of the Central Jordan Uranium Project area (see Figure 5 for explanation of rock units in the legend on the left)



IV. Lithology and stratigraphy of the mineralized zone

9. The uranium deposits in the CJUP are primarily hosted by the Muaqar Chalky Marl (MCM) Formation of the upper Maastrichtian age, part of the Upper Cretaceous to lower Tertiary Belqa Group (Figure 5).

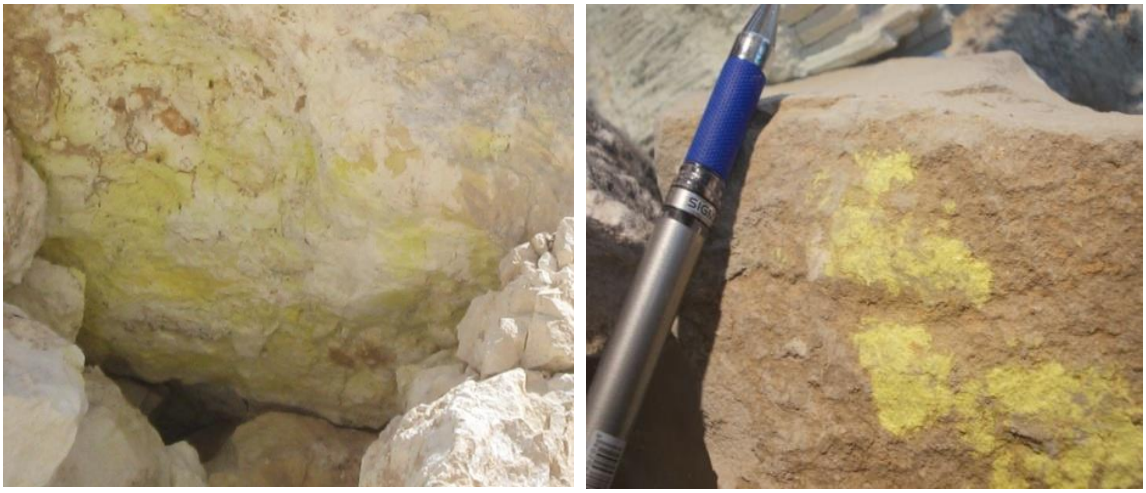
Figure 5
Litho-stratigraphic section of Central Jordan



10. Uranium mineralization occurs in two zones. Surficial uranium mineralization occurs as a thin layer from near surface to a depth of around 4 to 5 m, and an underlying interval of mineralization occurs from 5 m to 20 m depth. The upper part of the surficial mineralization layers tends to be weathered and fractured chalky limestone (saprolite), while the lower part is more intact but constitutes fractured rock [4].

11. Yellow secondary uranium minerals are the dominant uranium phases, which are mainly fine-grained uranium vanadates (carnotite group). These include the minerals strelkinite and tyuyamunite [5], which occur as thin discontinuous layers on fractures and joints and as irregular patches and disseminations that impregnate the most porous and friable sediments (Figure 6).

Figure 6
Shows of uranium mineralization (uranium vanadate minerals)



12. The main features of uranium mineralization in the area are:

(a) The uranium deposits are surficial (average overburden is about 0.5 m) and can be mined by shallow open-pit methods, hence at relatively low cost and with less technological complications. Uranium mineralization is amenable for mining using free digging technologies while excavating trenches.

(b) Infrastructure is already well established, including roads, power lines, water and energy.

(c) The uranium ore requires minimal crushing due to the friable nature of the host rock.

V. Estimation History and Application of UNFC-2009

13. Uranium quantities for the Central Jordan Uranium Project were estimated using two sets of data generated during two phases of exploration. The surficial mineralization was estimated based on the channel sample data set, and for deep mineralization, downhole gamma logs were used [5].

14. Quantities were estimated originally with JORC 2012 compatible standards and then transferred to UNFC-2009 using the Bridging Document between the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) Template and UNFC-2009.

15. UNFC-2009 is a project-based classification system in which quantities are classified by three fundamental criteria: (1) socio-economics; (2) project feasibility; and (3) geological knowledge. Hence, UNFC-2009 provides a more granular data categorization of the quantities reported. The aforementioned Bridging Document was used to transfer quantities from the CRIRSCO Template to UNFC-2009, together with an independent evaluation of the information based on UNFC-2009 principles (Table 1) [1].

Table 1
Mapping of CRIRSCO Template to UNFC-2009 [2]

CRIRSCO Template		*UNFC-2009 "minimum" Categories*			*UNFC-2009 Class*
Mineral Reserve	Proved	E1	F1	G1	Commercial Projects
	Probable			G2	
Mineral Resource	Measured	E2	F2	G1	Potentially Commercial Projects
	Indicated			G2	
	Inferred			G3	
Exploration Results / Exploration Target		E3	F3	G4	Exploration Projects

E: Social and economic viability
F: Technical feasibility
G: Geological knowledge

A. Channel samples data

16. Starting in 2013, the Jordanian Uranium Mining Company (JUMCO) initiated a detailed exploration programme for uranium mineralization in the CJUP area using excavated trenches and chemical analysis of collected samples. These samples were the main set of data to estimate the surficial uranium mineralization (0 m to 5 m depth). By using chemical analysis for the surficial layers a higher accuracy level was obtained and the effects of the secular disequilibrium on the assayed results were eliminated.

B. Borehole data

17. Equivalent uranium (eU) assays obtained from the down-hole gamma logs were used in the estimation of the resources below 5 m, referred to as the deep mineralization layers within the CJUP (5 m to 20 m depth). The database for this deep mineralization contains 5,691 drilled holes carried out by the Jordanian French Uranium Mining Company (JFUMC) during 2009 through 2012.

C. Phase I Estimation

18. In Phase I (April 2014) of the project [5], the resource estimation was based on the data of 1,967 trenches and 19,685 channel samples. These trenches were excavated in several zones of the central JCUP area at grid distances of 200 m by 200 m. The surficial

mineralization (0 m to 5 m depth) was constrained and separated from the deep mineralization (5 m to 20 m depth) by wireframe and the two mineralization styles were estimated separately.

19. Based on the study by the international team of Competent Persons, the mineralization in CJUP was estimated and reported as an inferred mineral resource category. Central Jordan was estimated to contain approximately 269 Mt of uranium ore containing 30,857 tU at an average grade of 114 ppm U. This was estimated using a cut-off grade of 78 ppm U applied to Selective Minable Unit (SMU) blocks of dimensions 50 m x 50 m x 0.5 m. This estimate is classified as an Inferred Resource of the JORC Code (JORC 2012). These quantities are classified as G3 in UNFC-2009.

Table 2
Data grid spacing (m) for G axis classification of uranium resources in the central Jordan resource study area

	Measured (JORC) / G1 (UNFC-2009)	*Indicated (JORC) / G2 (UNFC-2009)*	*Inferred (JORC) / G3 (UNFC-2009)*
Central Jordan Area	25-50 x 25-50 m	100 x 100 m	200 x 200 m

20. To assess and categorize project feasibility, the extraction by a defined development project or mining operation was subject to further evaluation in Phase I. During this phase, preliminary studies have demonstrated the existence of a deposit in such form, quality and quantity that the feasibility of extraction by a mining operation can be evaluated. However, further data acquisition and studies may be required to confirm the feasibility of extraction. Thus, this project can be classified as UNFC-2009 category F2.

21. Since 2009, the Jordan Atomic Energy Agency has conducted an International Atomic Energy Agency (IAEA) supported Technical Cooperation project (TC project code, JOR2009) to develop the uranium deposits of the country. This project was carried out in parallel with a nuclear energy programme that is envisaged for Jordan. It was intended that the supply of uranium fuel could be procured locally and surplus uranium, if any, could be sold on the international market. Several studies on ore characterization and extraction from a surficial carbonate ore were investigated at laboratory level during this phase [6] [7] [8]. Since the project activities are at an early stage, justification as a commercial development will require more data and investigations, especially bulk ore testing and pilot scale experiments focused on the efficiency of uranium extraction. The F axis sub-category was hence designated as F2.2 in this phase.

22. Since Jordan foresees demand for domestic utilization of uranium and also possible exports internationally, further studies would be addressed to determine the extraction and sale feasibility, which are expected to become economically viable in the predictable future. Hence, an E axis criteria of E2 has been assigned to this project in Phase 1.

23. In summary, the project in Phase I could be designated as E2, F2.2, G3 with calculated resources of 30,857 tU, at an average ore grade of 114 ppm U (Table 3). This project will fall in the Class of a Potentially Commercial Project and Sub-class of Development on Hold.

Table 3
Uranium resource in the CJUP area as reported in Phase I Estimation (Effective date 2014)[a]

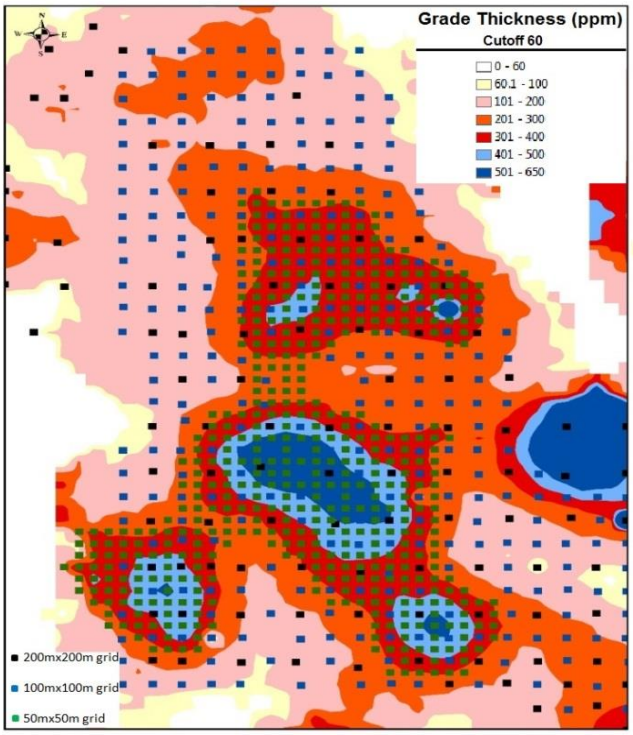
Region	*UNFC-2009 Criteria*	*Ore tonnage (Mt)*	*Grade (ppm U)*	*Metal (tU)*
Surficial Mineralization		67.5	135	9,100
Deep Mineralization	E2,F2.2,G3	201.7	108	21,757
Total		269.2	114	30,857

[a] Cut-off grade of 80 ppm U.

D. Phase II Estimation

24. To improve the categorization of the Potentially Commercial Project/Development on Hold project, JUMCO continued an intense exploration programme with the aim to further increase and refine the resource base and upgrade inferred portions of its resources to the indicated category. By the end of 2015, over 5,000 trenches had been excavated and sampled by JUMCO [9]. Detailed metallurgical tests of bulk samples, density tests, coordinate measurements, and other special studies were carried out by JUMCO.

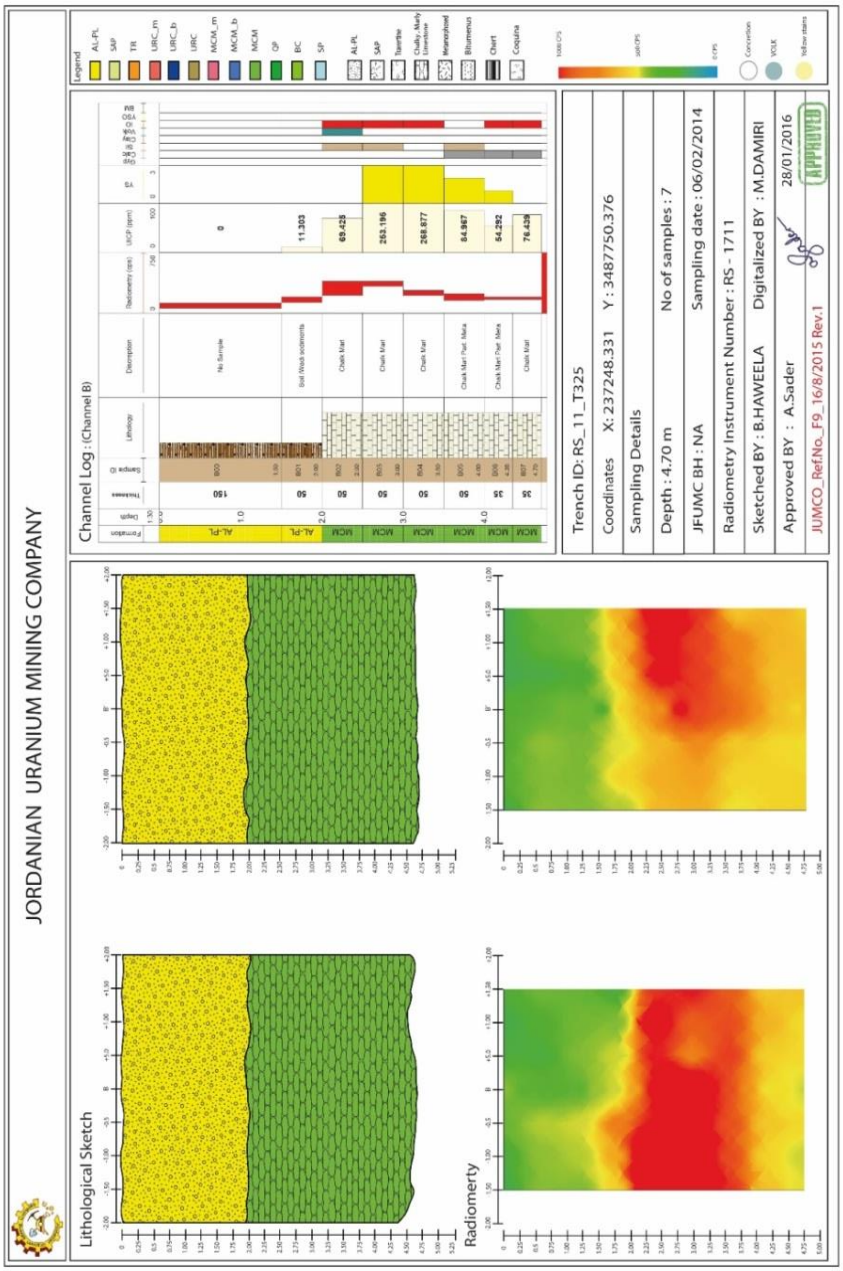
Figure 7
Trenching grid at the Khan Az Zabib uranium deposit



25. As shown in Figure 7, in selected parts of the deposits (for example, Khan Az Zabib (KZ), see Figure 2) the exploration trenching grid was infilled from 200 m x 200 m to 100 m x 100 m grids. Subsequently, additional more dense 50 m x 50 m grids were adopted. However, the 50 m x 50 m infill trenches were not included in the revised mineral resource estimation.

26. All the data records collected for each excavated trench were compiled into one final digitized layout to represent individual trench data in a comprehensive way. These data include lithology, radiometry, as well as general information and details for the collected channel (Figure 8).

Figure 8
Example of digitalized trench data



27. Uranium resources for the CJUP deposit, according to JORC 2012, are estimated and reported as mineral resources in both the Indicated and Inferred categories [9]. The deposit was estimated to contain approximately 289 Mt of uranium-bearing mineralization at an average grade of 115 ppm U (136 ppm U_3O_8) containing 33,398 tU (Table 4). The estimate is based on a cut-off grade of 80 ppm U (94 ppm U_3O_8). Since the resource estimation included data from trenches excavated at grids spaced at 100 m x 100 m and 200 m x 200 m, the resource estimate was upgraded to G2, G3 quantities according to UNFC-2009. Some of the remaining quantities were designated to G3. Currently, selected areas within the KZ exploration zone are being infilled with trenches at a grid of 50 m x 50 m as an attempt to upgrade the quantities to the G1 category.

28. Extraction of uranium from the ore is being tested by an alkaline leaching process by the principle of irrigation in six-metre long columns (Figure 9). The leaching agent consists of sodium carbonate and bicarbonate. Temperature, flow and slump are monitored daily. The samples collected daily are sent to the Jordan Atomic Energy Commission for analysis. Following the conclusion of a given test, the recovery of the uranium is calculated together with any other needed elements. Metallurgical studies so far have shown that uranium is easily recovered by conventional alkaline leaching. Uranium recovery of 80 per cent to 90 per cent was achieved during the metallurgical test [10] [11] [12].

29. Because the feasibility of extraction by a defined development or mining operation is subject to further evaluation, the project can be designated as F2. In Phase II, project activities continue to evaluate and justify development in the foreseeable future; thus, the F axis Sub-category has been designated as F2.1.

Figure 9
Columns used in the metallurgical testing

30. The uranium resources are located close to the surface and hosted by soft, friable sediments. The resource can be effectively mined using free gigging techniques with relatively low mining costs. A preliminary economic evaluation, based on extraction and sales estimates, suggests that uranium mineralization of the Central Jordan Uranium Project is expected to become economically viable in the foreseeable future. Hence the project can be designated as E2.

31. In summary, the classification of CJUP in Phase II has been upgraded to an E2, F2.1 and G2, G3 project, which falls in the UNFC-2009 class of Potentially Commercial Project and the Sub-class of Development Pending. The estimated quantities of uranium are 33,398 tU (39,380 tonnes $U_3O_{8)}$ from ore with an average grade of 115 ppm U (Table 4) [9].

Table 4
Uranium resource classification of Phase II Estimation (Effective date 15 December 2015)[a]

UNFC-2009 Class	*UNFC-2009 Sub-class*	*UNFC-2009 Criteria (E,F,G)*	*JORC 2012 Category*	*Surficial Mineralization*			*Deep Mineralization*			*Both Mineralizations*		
				Tonnage (Mt)	*Grade (U ppm)*	*Metal (tU)*	*Tonnage (Mt)*	*Grade (U ppm)*	*Metal (tU)*	*Tonnage (Mt)*	*Grade (U ppm)*	*Metal (tU)*
Potentially Commercial Project	Development Pending	2,2.1,2	Indicated	20.5	148	3,058	34	113	3,830	54.5	126	6,888
Potentially Commercial Project	Development Pending	2,2.1,3	Inferred	67.2	127	8550	167.7	107	17,960	235.0	113	26,510
Total quantities				87.8	132	11,608	201.7	108	21,790	289.5	115	33,398

[a] Using cut-off of 80 ppm U (94 ppm U_3O_8)

VI. Conclusions

32. In Phase I of the Central Jordan Uranium Project, the uranium quantities were estimated with a low level of confidence; thus, all of the calculated resources of 30,857 tU were designated as G3 quantities. Project feasibility studies were initiated at this stage at a laboratory level, indicating the F criteria as F2.2. Since Jordan has embarked on a nuclear energy programme that envisages domestic demand for uranium as well as the sale of excess uranium on the international market, extraction and sale are expected to become economically viable in the foreseeable future. Hence a category of E2 was designated for the project. Under UNFC-2009, the project was classified as a “Potentially Commercial Project” with Sub-class “Development on Hold”.

33. Since the initial exploration and laboratory investigation data were encouraging, the project was pursued with greater vigour in Phase II. More exploration data based on closer-spaced sampling intervals were generated in Phase II. Further, bulk ore testing was initiated on a pilot scale by JUMCO.

34. In Phase II of the study of uranium resources in the CJUP, the results of the exploration operations and the development of extraction processes are classified according to UNFC-2009 as E2 F2.1 G2, G3. On the G axis, separate quantities are designated as G2

and G3, reflecting that the estimates have moderate and low levels of confidence, respectively. Further investigations are ongoing to designate part of the quantities with a high level of confidence, i.e., G1. With regard to the project feasibility criteria, the project is designated as F2.1, where extraction is being evaluated with a pilot-scale study. Further data acquisitions and studies are required to confirm the visibility of study.

35. The project is now designated as E2 because extraction and sale are expected to become economically viable in the foreseeable future on the basis of current market conditions and realistic assumptions about future market conditions. The uranium price at which the project breaks even at a 7 per cent discount rate, i.e., a net present value (NPV) of zero, is US$ 45.4 /lb U_3O_8 (US$ 118 /kgU), which is a realistic forecast of uranium prices in the foreseeable future. Utilizing the estimated 88 Mt of ores reserves in surficial mineralization containing 11,617 tU, the capital expenses could be fully repaid during seven years of production [9]. According to UNFC-2009, CJUP can be classified as a "Potentially Commercial Project" with Sub-Class "Development Pending" (E2 F2.1 G2, G3).

36. The application of UNFC-2009 to the CJUP study in Jordan clearly demonstrates the advantage of tracking the project from a lower maturity level of assessment (Phase I) to a higher level (Phase II). Therefore, classification and reporting of uranium resources using UNFC-2009 have clear advantages for policymakers in Jordan, as well as for internal company requirements for monitoring the progress of a project over time. UNFC-2009 is thus an effective tool for taking decisions on whether or not to make further financial commitments in order to demonstrate the continued viability of the project.

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