Iraqi Bulletin of Geology and Mining *Vol.10, No.2, 2014* *p 157 – 172*
Papers of the Scientific Geological Conference *Part 1*

IMPACT OF SHARP CHANGES IN SOURCE ROCKS ON THE GEOCHEMISTRY OF TANJERO FORMATION IN DOKAN DISTRICT, NORTHEAST IRAQ

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Received: 22/ 08/ 2013, Accepted: 28/ 10/ 2014
Key words: Tanjero Formation, Source, Tectonic, Rare earth elements, Dokan, Iraq

ABSTRACT

Analysis of major, trace and rare earth elements, in 17 samples, some are composite of 3 samples, collected along a vertical section of Tanjero Formation (Upper Campanian – Maastrichtian) exposed at Dokan district in northeast Iraq, have shown that sharp changes in the geochemical characteristics of the formation occur at certain level in the section. These changes involved a sharp increase in the content of elements (Cr, Ni, Co, Sc and V) that are known to be concentrated in mafic and ultramafic rocks and an obvious decrease in content of elements (Y, Rb, Zr, Hf, Th, ..etc.) known to be relatively concentrated in felsic rocks. These changes reflect sharp changes in the nature of the source rocks supplying clastics to the basin of deposition of the formation. The changes involved the emplacement of island arc volcanics and ophiolites onto the ridge separating the foreland basin to the west and southwest from the Neo-Tethys to the east and northeast. The emplacement of these mafic and ultramafic rocks is undoubtedly related to the tectonic activity associated with the different stages of the collision of the Arabian Plate with Eurasian Plate.

On the bases of these chemical and mineralogical characteristics, it is found necessary to divide the Tanjero Formation into lower and upper parts. It is even suggested that a new formation name should be given for the lower part, in support of previous suggestions by early geologists working on the formation.

تأثير التغيرات الحادة في الصخور المصدرية على جيوكيميائية تكوين تانجيرو في منطقة دوكان، شمال شرقي العراق

مجاهد عبد الواحد النقيب و هشام يحيى ذنون

المستخلص

أظهرت تحاليل العناصر الرئيسة والأثرية والأرضية النادرة في 17 عينة البعض منها مركب من ثلاث عينات، ملتقطة على امتداد مقطع عمودي لتكوين تانجيرو (الكمباني الأعلى – الماسترختيان) منكشف في منطقة دوكان في شمال شرقي العراق أن هنالك تغيرات حادة في الخصائص الجيوكيميائية للتكوين عند مستوى معين في المقطع. تضمنت هذه التغيرات ازدياد حاد في محتويات العناصر (Cr، Ni، Co، Sc و V) المعروف أنها تتركز في الصخور المافية وفوق المافية ونقصان واضح في محتوى العناصر (Y، Rb، Zr، Hf، Th ..... الخ) المعروف أنها تتركز نسبيا في الصخور الفلسية، وهذه التغيرات عكست تغيرات حادة في طبيعة صخور المصدر المزودة لحوض ترسيب تكوين تانجيرو بالفتات. وتضمنت التغيرات توضع صخور بركانية لجزر قوسية وكتل من الاوفيولايت على الحافة الفاصلة بين حوض الأرض الأمامية (foreland) الواقع إلى الغرب والجنوب الغربي عن بحر النيوتيثس الواقع إلى الشرق وشمال شرق الحافة. وتوضع الصخور المافية وفوق المافية ارتبط بدون شك مع النشاط التكتوني الذي رافق

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المراحل المختلفة من ارتطام الصفيحة العربية مع الصفيحة الأوربي – أسيوية. وعلى أساس هذه الخصائص الكيميائية والمعدنية وجد من الضروري تقسيم تكوين تانجيرو إلى جزء سفلي وجزء علوي. لا بل اقتراح إعطاء أسم تكوين جديد للجزء السفلي تأييدا لمقترح سابق وضع من قبل الجيولوجيون الأوائل الذين عملوا على هذا التكوين.

INTRODUCTION

The Tanjero Formation was deposited in a quickly sinking trough in front of the Arabian Plate margin, filled by flysch-type clastics. The source rocks of these sediments are believed to be originated from the elevated areas formed due to obducted sheets that accompanied the collision of the Arabian Plate with the Eurasian Plate, which started in the Late Campanian and continued through Maastrichtian (Jassim and Goff, 2006 and Fouad, 2010). The formation was deposited in a continuous belt along Balambo – Tanjero Zone in northeastern Iraq. It crops out in the Imbricate Zone and also in the High Folded Zone (Fig.1).

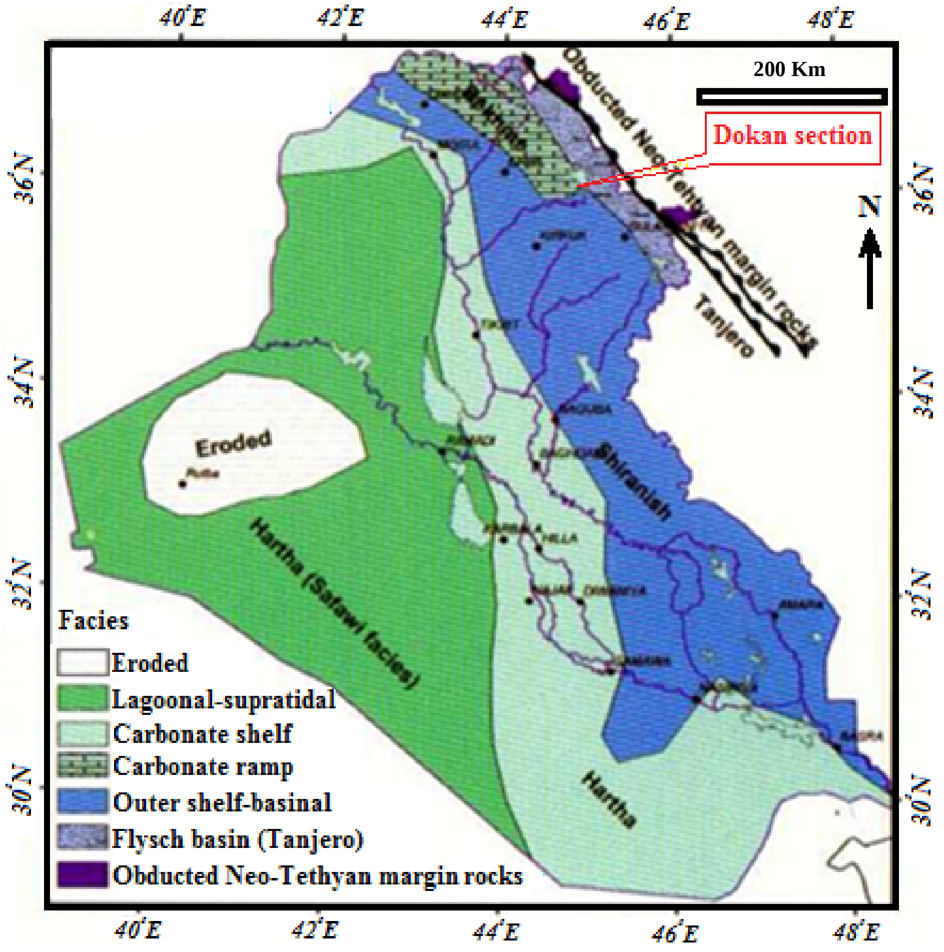


Fig.1: The paleogeography of the depositional basin of
Late Campanian – Maastrichtian
(after Jassim and Goff, 2006)

The type locality of the formation lies in the Sirwan Valley, southeast of Sulaimaniyah city, and belongs structurally to the Imbricate Zone. The formation had been divided, in the type section, into two divisions: The lower division occupying one quarter of the total thickness, consists of pelagic marls, and rare marly limestone with silt. The silt content diminishes downwards (Belen *et al.*, 1959, p. 282). The upper division consists of silty marls, siltstones, conglomerates, and sandy or silty organic detrital limestones.

The age of the formation is Upper Campanian – Maastrichtian, the upper-flysch-part is Maastrichtian throughout, the lower part is Maastrichtian at top, Upper Campanian at the base (Buday, 1980). According to Kassab (1972, p. 20; 1975) the Tanjero Formation contains at its top the youngest Maastrichtian rocks in Iraq. Bellen *et al*. (1959) indicated that the lower boundary of the formation is marked by the first appearance of clastic influx. However, they admitted that identical lithologies to the Shiranish Formation exist as intervals, which are clastic free. It is evident that the two divisions are tectonically very different (Buday, 1980). In many sections, which have been studied in details, e.g. at Bekhme and Balambo (Ditmar *et al*., 1971), the lower part of the formation was regarded essentially as open sea, marly limestone units with occasional influx of silty terrigenous clastics. According to Buday (1980) the upper part of the formation is a typical orogenic flysch. Buday (1980) wrote "therefore in our opinion, the connection of two, greatly different units into one single formation had been an unfortunate event". He recommended either to include the lower part of the formation into the Shiranish Formation, or to define a new formation. He indicated the former proposal might be the more appropriate one. However, he stressed that the proposed re-arrangement of the stratigraphical column needs further sedimentological and petrological investigations.

The Tanjero Formation is well studied in most aspects of sedimentology and paleontology by many researchers (Bellen *et al*., 1959; Kassab, 1972, p. 20; 1975, Buday, 1980; Al-Rawi, 1981; Buday and Jassim, 1987; Saadallah and Hassan, 1987; Jaza, 1992; Lawa *et al*., 1998; Al-Rawi and Al-Rawi, 2002; Karim, 2004; Karim and Surdashy, 2005a and b; Jassim and Goff, 2006). Karim (2004) studied sedimentary structures, lithology, and environment of deposition of the formation. On the basis of the main lithological distribution, he divided the formation into three parts (lower, middle and upper), both lower and upper parts are regarded as being deposited in shallow marine environment, while the middle part is deposited in deep marine.

Many authors (Aswad, 1999; Aswad *et al*., 2011 and Ali *et al*., 2012) have related the lithological constituent of the formation to the elevation of obducted sheets of mixed provenance (old sedimentary rocks, e.g. Qulqula radiolarian chert, and ophiolitic mélange and other ultramafic masses). However, the effects of these provenances on the geochemical development of the formation begin with the lowermost bed and end in the Kolosh Formation, and hence the tectonic development of these provenances are not well studied.

The element composition of clastic sedimentary rocks can give accurate information on provenance type as well as other information related to intensity of weathering and distance of transportation of the product to basin of deposition. Fine grained clastic rocks (e.g. shale and siltstone) better reflect the provenance chemistry than coarse grained clastics (sandstone), because the fine grained rocks represent well-mixed source rocks (Taylor and McLennan, 1985).

Due to their relatively immobile nature during sedimentary processes, the contents of selected trace elements, such as the high field strength elements e.g., Th, Zr, Hf, Nb, Y and the ferromagnesian related trace elements e.g., Cr, Ni, Co, Sc, and REE (rare earth elements) are best suited for provenance and tectonic setting determination studies (Cullers *et al*., 1979; McLennan *et al*., 1983; Taylor and McLennan, 1985 and 1991; Bhatia and Crook, 1986; Roser and Korsch, 1986; Ronov *et al*., 1990; Cullers, 1994; Cox *et al*., 1995; Nesbitt *et al*., 1996; Cullers and Berendsen, 1998; Cullers, 2000).

The aim of the present paper is to follow up the variation in the type of the provenance of the Tanjero Formation and its reflection on the tectonic developments of the source area of the sediments of the formation.

SAMPLING AND ANALYTICAL METHODS

A total of 17 rock samples were collected from outcrop section of the Tanjero Formation in Dokan locality at the southwest flank of Sara anticline in the High Folded Zone in northeastern Iraq at the cross line between longitude 44° 65' 9.9" E and latitude35° 56' 45" N, (Fig.1). The samples were collected along a perpendicular line to the strike of the bedding plane. The first samples were taken at the lower contact with the Shiranish Formation, based on the first appearance of 0.5 m thick bed of sandstone. Some samples of similar lithology that are close to each other were collected as composite samples of equal weight, e.g. CT4 (consists of 3 samples), CT6 (consists of 2 samples), CT7 (consists of 2 samples), CT8 (consists of 2 samples) (Fig.2). The rock chips were powdered using TEMA swing mill to – 200 µm mesh size. The powder was used for XRD analysis and for chemical analyses. The major elements (except Si) and trace elements including REE were analyzed employing Inductively Coupled Plasma Mass-Spectrometry (ICP – MS; Perkin Elmer) at Acme analytical laboratories/ Canada. Small part (0.2 gm) of the sample was subjected to standard acid digestion with HF – HNO_3 – $HClO_4$. The accuracy and precision was ± 1 – 3% for major oxides and for trace and REE was ± 1 – 5%. Loss on ignition (LOI) was determined by weight loss, and the acid insoluble residue (IR.) content also determined using routine procedure. The results of the chemical analysis and ratios of elements are shown in Table (1).

PETROGRAPHY AND MINERALOGY

Twelve thin sections were selected for detailed petrographic study. The samples of the lower part (T1 to T9) of the formation contain abundant carbonate rock fragments and chert with olive green chlorite grains, which increase upwards in the samples of the section. On the other hand, the upper part, from sample T10 to T17, the chlorite form a major constituent of the rocks, also abundant metamorphic rock fragments are observed, these are represented by serpentine minerals. Unusual abundance of chromite and plagioclase feldspar is also identified. Powdered bulk and insoluble residue samples were analyzed by XRD, at Iraq Geological Survey, Baghdad. The XRD diffractograms of 10 insoluble residue samples (3 representative samples) are shown in Fig. (3). The diffractograms clearly show difference in bulk mineral compositions across the lithological section of the formation, sample T2, which represent the lower portion of the section, shows predominant non carbonate mineral constituents including quartz, chlorite and feldspar. While samples T14 and T17, which represent the upper portion of the section, clearly show distinctive mineralogy where serpentine appears strongly and the chlorite content increases distinctly (as shown by the increase of the highest peak intensity). The samples also show the appearance of analcime {$Na\ Al\ (SiO_3)_2.H_2O$} and distinct increase of the plagioclase feldspar content (Fig.3). The carbonate present in bulk samples consists mainly of calcite, which represents rock fragments of the Qulqula Formation.

The mineralogical characteristic of the lower and upper portions of the section are well reflected in the differences in the contents of MgO, Fe_2O_3, Cr and Ni. This relation clearly reflects the increased contribution of ultramafic clastic constituents along the section from the lower part upwards. This undoubtedly indicates the increased volume of the exposed ultramafic rocks in the provenance area in going up the section.

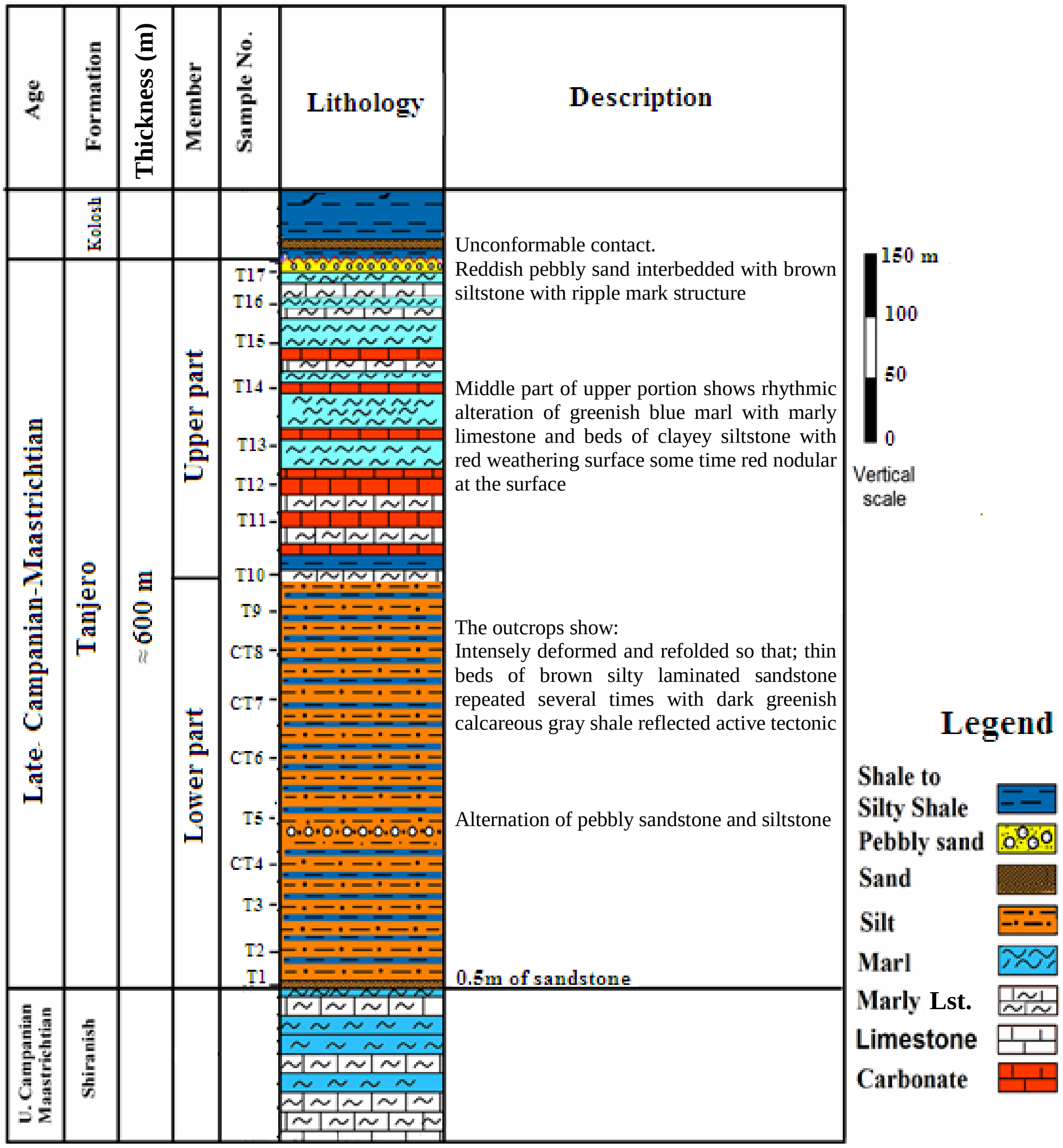


Fig.2: The lithological section of Tanjero Formation in the studied area

GEOCHEMISTRY

▪ Major Oxides

The major element composition of the Tanjero Formation is quite variable. Although there is little or no variation in insoluble residue content along the section, it is clear that there is enrichment of MgO and Fe_2O_3, and depletion in K_2O and P_2O_5 in the samples from T10 to T17, which represent the upper part of the formation, relative to its lower part (samples T1 to T9), with the exception of samples T1 and CT7, where the content of some elements are higher than the mean. For this reason, samples are exempted from the lower part of the section (Table 2). The unusual higher content of MgO and Fe_2O_3 and other ferromagnesian related elements, in these two samples, is undoubtedly a reflection of the higher contribution of mafic and ultramafic submarine weathered clastics during the deposition of the sediments represented by these samples. This probably happened as pulses of weathered mafic and ultramafic rocks supplied from the still elevated ridge of the northeast part of the Foreland basin, but under the surface of the sea. No serpentine clastics were found in these samples.

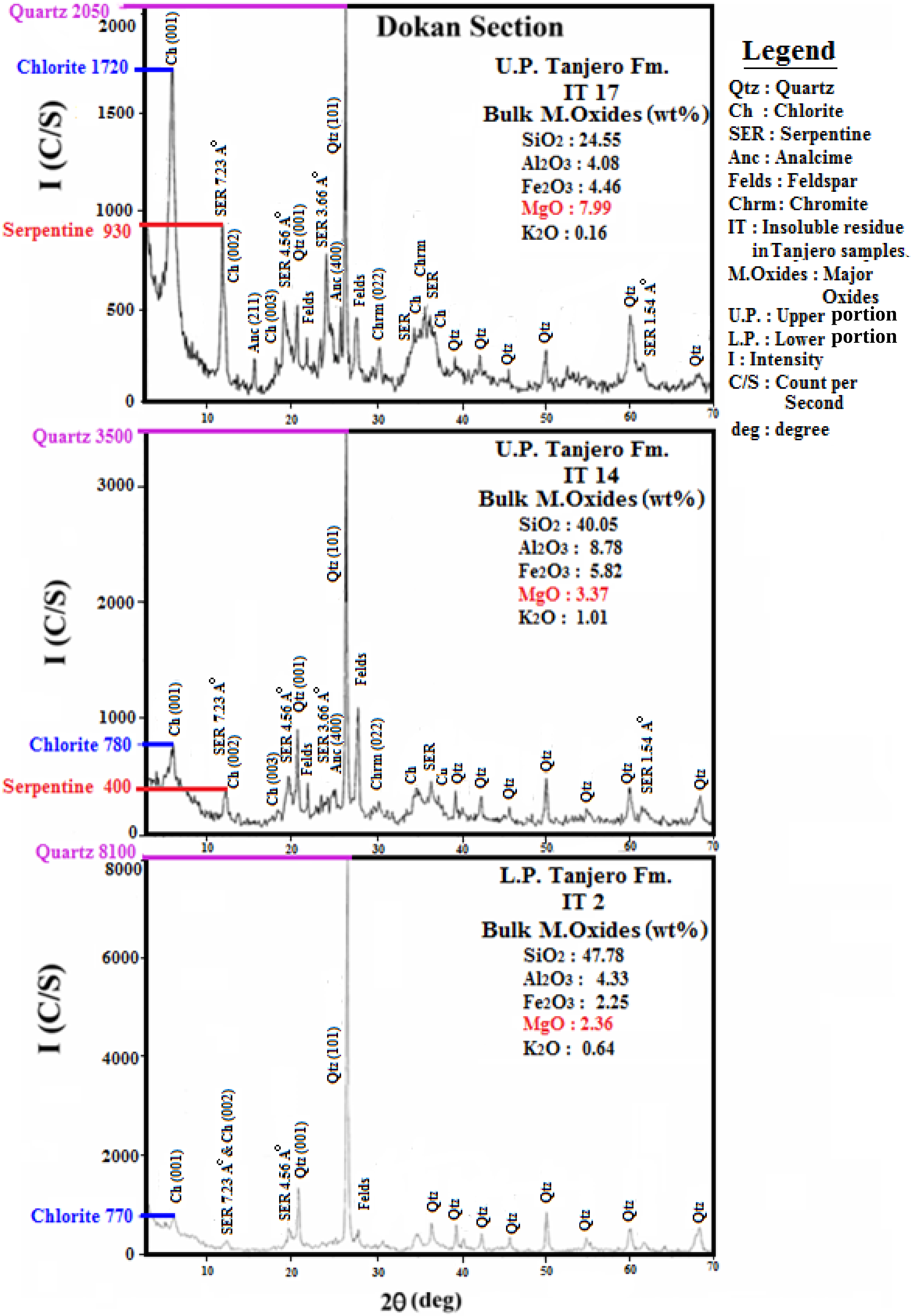


Fig.3: XRD of the non-carbonate fraction of the samples from lower and upper parts of the Tanjero Formation

Table 1: Major oxides' contents recalculated to a total of 100%, IR., LOI (%), trace and rare earth elements contents (ppm), and ratios in rocks of the Tanjero Formation

Sample No.	T1	T2	T3	CT4	T5	CT6	CT7	CT8	T9	T10	T11	T12	T13	T14	T15	T16	T17
Major Oxides (wt%)																	
SiO_2	51.9	47.8	54	58.7	44.6	57.3	54.42	55.48	46.8	44.14	47.9	60.1	40.1	38	39.7	24.6	27.8
TiO_2	0.2	0.18	0.18	0.35	0.16	0.32	0.25	0.33	0.22	0.15	0.17	0.42	0.46	0.37	0.28	0.12	0.07
Al_2O_3	4.69	4.33	5.16	8.52	4.42	7.5	5.86	7.86	5.06	4.25	4.63	8.05	8.78	7.56	5.31	4.08	3.89
Fe_2O_3	5.03	2.25	1.92	3.72	2.12	3.76	4.12	4.46	3.4	3.18	4.18	4.59	5.82	5.68	5.52	4.46	3.8
MgO	6.14	2.36	1.54	2.29	1.41	3.07	7.36	5.92	4.2	5.7	8.27	6.62	3.37	9.92	10.8	7.99	4.68
CaO	15.1	21.4	18	11.7	22	12.4	12.55	11.05	19.6	20.09	14.2	6.63	19.3	16.7	13.5	28.8	29.8
K_2O	0.17	0.64	0.75	1.34	0.69	1.1	0.53	1.1	0.84	0.43	0.53	1.24	1.01	0.77	0.58	0.16	0.12
Na_2O	0.35	0.28	0.24	0.37	0.3	0.34	0.44	0.36	0.31	0.21	0.25	0.36	0.79	0.38	0.25	0.37	0.43
P_2O_5	0.05	0.08	0.1	0.12	0.07	0.11	0.08	0.11	0.08	0.04	0.05	0.11	0.09	0.09	0.07	0.03	0.03
L.O.I.	16.4	20.8	18.1	12.9	24.2	14.1	14.39	13.33	19.4	21.81	19.8	11.9	20.4	20.5	24	29.4	29.4
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
I.R.	70.7	58	64	78.1	57	77	75.5	79.7	62.1	59.5	64.1	83.3	64.9	67.4	57.7	42.4	40.9
C-Org.	_	_	_	0.01	_	0.05	_	0.24	_	_	_	0.15	0.18	0.34	_	_	_
Trace Elements (ppm)																	
Cr	467	84	58	69	102	94	364	135	134	469	632	234	359	325	314	641	615
Ni	690	98	68	101	66	132	309	218	216	281	575	416	268	432	542	675	733
Co	41	10	11	16	12	17	35	23	28	26	38	38	27	39	26	39	44
Sc	11	5.4	5.3	10	5.7	9.3	9.3	9.9	7	8.9	11	12.2	19.1	16.3	11.7	12.6	10.4
V	61	32	35	69	32	67	56	69	47	47	60	92	115	90	67	50	42
Zr	22	28	29	55	27	55	33	49	35	23	27	62	41	35	28	7	5
Th	1.3	2.4	3	5	2.3	4.2	2.4	4.4	2.9	1.7	1.9	4.9	1.7	1.5	1.4	0.3	0.2
Hf	0.6	0.88	0.89	1.32	0.55	1.3	0.81	1.36	0.99	0.53	0.57	1.67	1.15	0.89	0.73	0.17	0.15
Ta	0.3	0.3	0.3	0.5	0.3	0.4	0.4	0.4	0.4	0.3	0.3	0.6	0.3	0.3	0.3	0.1	0.1
Nb	3.25	3.68	3.79	7.31	3.37	6.86	4.55	6.96	4.4	3.13	3.37	8.85	5.97	5.76	4.98	1.16	0.58
U	0.5	0.8	0.9	1.1	0.7	0.9	0.7	0.9	0.8	0.5	0.6	1.1	0.8	1.2	1.5	0.3	0.3
Y	6.6	13	14.5	15.4	16.7	13.7	11.6	14.1	14.9	9.5	7.4	12.9	10.5	9.3	7.9	2.9	3.6
REE (ppm)																	
La	5.9	14.7	14.8	17.1	18.7	14.4	12.5	16	16	11.8	8.3	14.8	7.1	7.7	6.7	2.4	2.5
Ce	11.7	27.2	29.4	36	34.3	32.2	24.79	33.71	30.8	20.69	16.3	31.6	12	15.9	13.4	3.96	4.11
Pr	1.4	2.9	3.2	4.1	3.4	3.4	2.7	3.6	3.1	2	1.8	3.4	1.8	1.8	1.6	0.4	0.6
Nd	5.8	11.1	14.1	18.2	13.6	14.7	11.3	15.1	13	8	7.7	14.6	7.6	7.5	6.2	1.9	2.2
Sm	1.1	1.9	2.6	3.3	2.6	2.8	2.1	2.8	2.2	1.4	1.1	2.6	1.5	1.6	1.1	0.3	0.5
Eu	0.3	0.5	0.6	0.7	0.5	0.6	0.5	0.6	0.5	0.3	0.3	0.5	0.5	0.4	0.3	0.1	0.1
Gd	1	1.8	2.2	2.9	2	2.5	1.7	2.6	1.9	1.2	1.2	2.1	2.2	1.4	1.1	0.4	0.4
Tb	0.2	0.3	0.4	0.5	0.3	0.4	0.3	0.4	0.3	0.2	0.2	0.4	0.3	0.2	0.2	0.1	0.1
Dy	1.3	2.1	2.4	2.7	2.7	2.3	1.6	2.5	2	1.4	1.3	2.4	2.1	1.7	1.3	0.5	0.6
Ho	0.2	0.4	0.5	0.6	0.6	0.5	0.4	0.5	0.4	0.3	0.2	0.5	0.4	0.3	0.3	0.1	0.1
Er	0.7	1.2	1.5	1.5	1.7	1.3	1.2	1.4	1.3	0.9	0.7	1.3	1.2	1.1	0.7	0.4	0.4
Tm	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Yb	0.6	1	1.1	1.8	1.3	1.1	1	1.3	1.2	0.7	0.6	1.2	1.2	0.9	0.7	0.3	0.4
Lu	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1
∑REE	30.4	65.4	73.2	89.8	82.1	76.6	60.49	80.91	73.1	49.09	39.9	75.8	38.2	40.7	33.8	11.1	12.2
LREE	25.9	57.8	64.1	78.7	72.6	67.5	53.39	71.21	65.1	43.89	35.2	67	30	34.5	29	8.96	9.91
HREE	4.2	7.1	8.5	10.4	9	8.5	6.6	9.1	7.5	4.9	4.4	8.3	7.7	5.8	4.5	2	2.2

(-) undetermined value

Continue Table 1:

Sample No.	T1	T2	T3	CT4	T5	CT6	CT7	CT8	T9	T10	T11	T12	T13	T14	T15	T16	T17
Ratios																	
LREE /HREE	6.17	8.14	7.54	7.57	8.07	7.94	8.09	7.83	8.68	8.96	7.99	8.07	3.89	5.94	6.44	4.48	4.5
$(La/Yb)_n$	6.65	9.94	9.08	6.92	9.72	8.84	8.45	8.32	9.01	11.4	9.35	8.33	4	5.78	6.48	5.41	4.23
$(La/Sm)_n$	3.38	4.87	3.58	3.26	4.53	3.24	3.75	3.6	4.58	5.31	4.75	3.58	2.98	3.03	3.84	5.03	3.14
$(Gd/Yb)_n$	1.35	1.46	1.62	1.31	1.25	1.84	1.38	1.62	1.28	1.39	1.62	1.42	1.49	1.26	1.28	1.08	0.81
Eu_n/Eu^*	0.87	0.83	0.77	0.69	0.67	0.69	0.81	0.68	0.75	0.71	0.8	0.65	0.84	0.82	0.83	0.88	0.68
Ce_n/Ce^*	0.91	0.89	0.92	0.95	0.89	1.02	0.93	0.97	0.92	0.86	0.91	0.98	0.95	0.95	0.93	0.79	0.77
La/Sc	0.54	2.72	2.79	1.71	3.28	1.55	1.34	1.62	2.29	1.33	0.75	1.21	0.37	0.47	0.57	0.19	0.24
Th/Sc	0.12	0.44	0.57	0.5	0.4	0.45	0.26	0.44	0.41	0.19	0.17	0.4	0.09	0.09	0.12	0.02	0.02
Zr/Sc	2.02	5.2	5.47	5.46	4.74	5.91	3.57	4.91	5.03	2.6	2.41	5.11	2.16	2.17	2.39	0.56	0.47
La/Co	0.15	1.46	1.33	1.07	1.6	0.85	0.35	0.71	0.58	0.45	0.22	0.39	0.26	0.2	0.26	0.06	0.06
Th/Co	0.03	0.24	0.27	0.31	0.2	0.25	0.07	0.19	0.1	0.06	0.05	0.13	0.06	0.04	0.05	0.01	0.01
La/Ni	0.01	0.15	0.22	0.17	0.28	0.11	0.041	0.073	0.07	0.042	0.01	0.04	0.07	0.02	0.01	0	0
Y/Ni	0.01	0.13	0.21	0.15	0.25	0.1	0.038	0.065	0.07	0.034	0.01	0.03	0.04	0.02	0.02	0	0.01

- **Ferromagnesian-related Trace Elements (Cr, Ni, Co, Sc)**

The ferromagnesian-related trace elements (Cr, Ni, Co, Sc) are well known to be enriched in ultramafic and mafic rocks, in comparison with felsic rocks, due to being highly compatible in minerals of mafic and ultramafic rocks. These elements show different degree of mobility during weathering and transportation process. Cr is the least mobile, while Co and Ni are slightly more mobile (Nesbitt *et al*., 1996). Therefore, abnormal content of these elements in sedimentary rocks, in particular, clastic rocks indicate mafic and ultramafic source contributing to the sediments. In the Tanjero Formation, these elements are exceptionally enriched when compared with PAAS (Post Archean Australian Shale) (Fig.4), which represents sediments derived from the upper continental crust (Granodiorite). Generally speaking, the Tanjero Formation contains ferromagnesian elements higher than PAAS content. However, their content in samples T1 to T9, with the exception of samples T1 and CT7, as explained earlier, are distinctly lower than their content in samples T10 – T17. There is a very distinct increase in the ferromagnesian related trace elements and a parallel increase in MgO and Fe_2O_3 contents, in the samples beginning with T10 and ending in sample T17 (Table 2). Moreover, the distinct change in mineralogy, which is indicated by obvious appearance of serpentine, and distinct increase in the chlorite content, and the increase in the plagioclase feldspar content in these samples, reflect change in the provenance components and the type of weathering of source rocks. Superimposed upon the obvious increase of the ferromagnesian related elements and MgO, Fe_2O_3 content in samples T10 – T17 are the anomalous content of these elements in samples T16 and T17, which represent the closure of the sedimentation period of the Tanjero Formation. Looking at the relation between MgO, Fe_2O_3 and Cr, Ni and Co contents in the Tanjero rocks, it was found that in the group of samples T1 to T9 the Cr, Ni and Co are well positively correlated with MgO (r = 0.98, 0.99 and 0.99, respectively) and with Fe_2O_3 (r = 0.94, 0.98 and 0.99, respectively). However, in samples group T10 to T17 both Ni and Co are well positively correlated with MgO (r = 0.91, 0.90, respectively) and negatively correlated with Fe_2O_3 (r = – 0.51, – 0.53, respectively), but the correlation of Cr with MgO showed no or even negative correlation (r = – 0.26), while Cr is well correlated with Fe_2O_3 (r = 0.99). There is no doubt that the difference in the behavior of Cr in the samples groups is related to change in the provenance nature. During the deposition of the sediments represented by samples of the lower group, the main minerals holding Cr was chlorite, which was most probably derived from pyroxene or hornblende. While in the upper group, Cr was present as chromite grains which is supported by the positive correlation between Cr and Fe_2O_3.

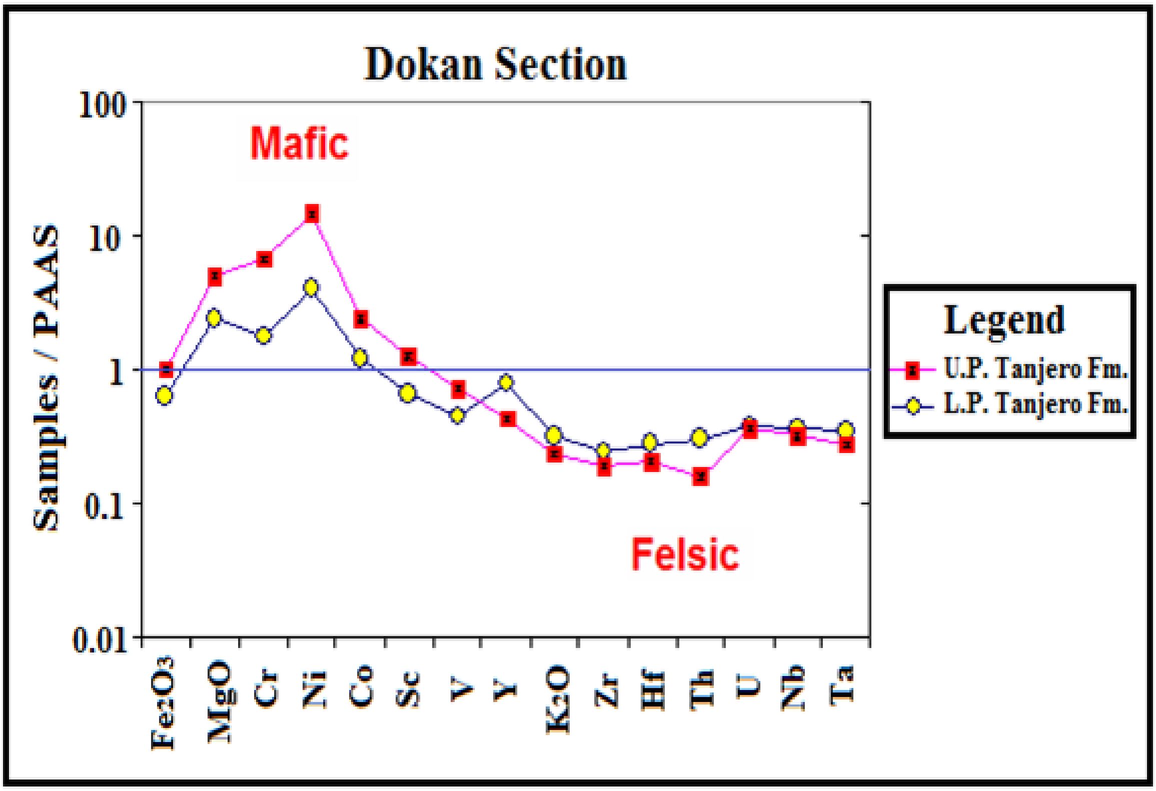
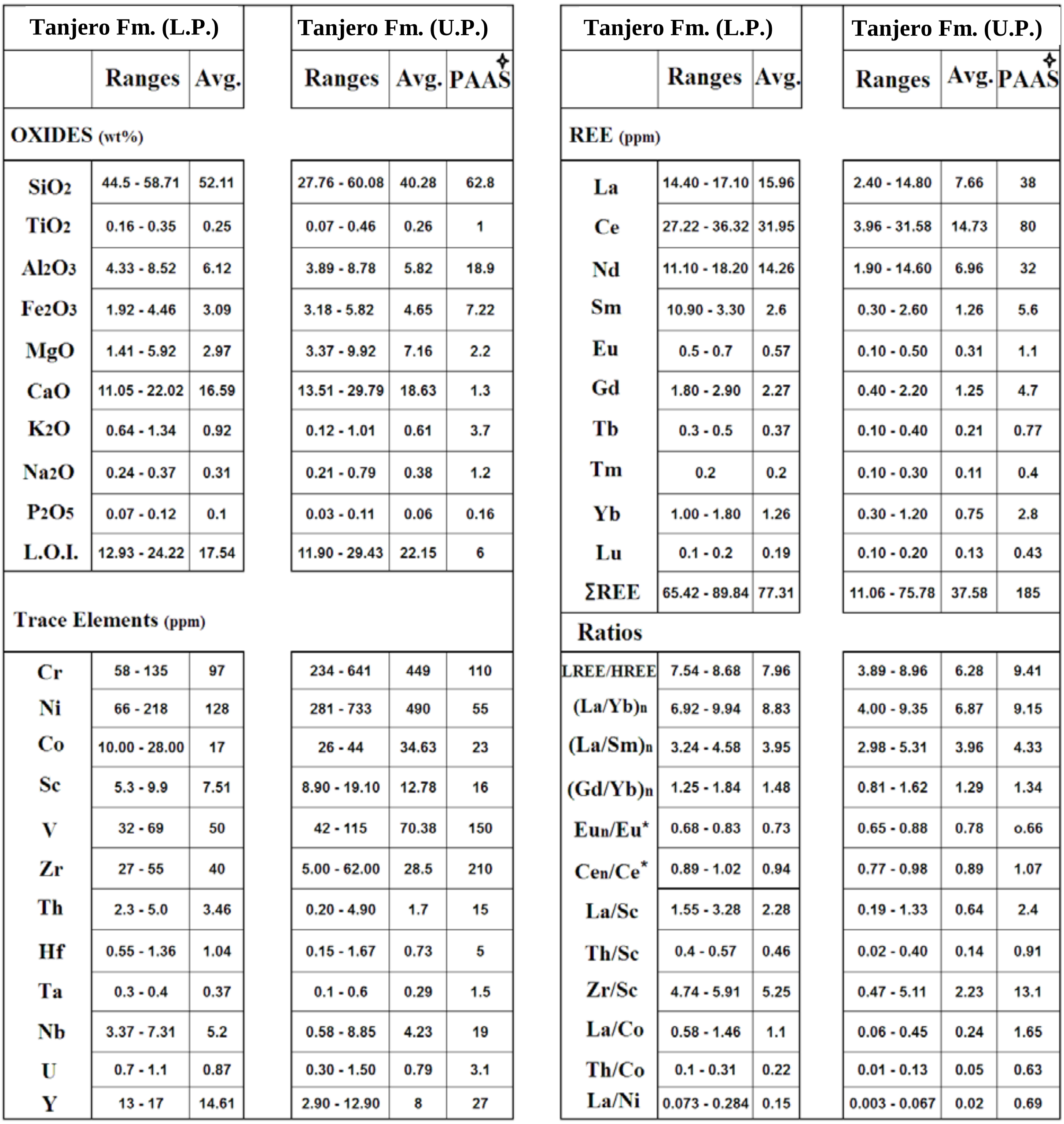


Fig.4: Spider plot of the content of some oxides and trace elements in carbonate free fractions of Tanjero Formation normalized to PAAS (normalization data from Taylor and McLennan, 1985)

- **High Field Strength Elements (HFSE)**

The elements Zr, Nb, Hf, Ta, Y, Th and U are preferentially partitioned into melts during fractional crystallization of magma (Feng and Kerrich, 1990), and as a result, these elements are enriched in felsic rather than mafic rocks. Additionally, these high field strength elements are considered to reflect provenance composition as a consequence of their immobile behavior (Taylor and McLennan, 1985). In the Tanjero Formation, the HFSE in the lower group of samples (T1 to T9) are notably higher than it is in the upper group of samples (T10 to T17) (Table 2). The content of the HFSE of both groups of samples are lower than the PAAS (Fig.4). However, the lower values are most distinct in the upper samples group, where values are almost one sixth when compared with PAAS, suggesting significant mafic and ultramafic input from the source area.

Table 2: The range and average contents of elements and ratios of both lower and upper parts of the Tanjero Formation compared with PAAS



	Tanjero Fm. (L.P.)		Tanjero Fm. (U.P.)		
	Ranges	Avg.	Ranges	Avg.	PAAS✧
OXIDES (wt%)					
SiO_2	44.5 - 58.71	52.11	27.76 - 60.08	40.28	62.8
TiO_2	0.16 - 0.35	0.25	0.07 - 0.46	0.26	1
Al_2O_3	4.33 - 8.52	6.12	3.89 - 8.78	5.82	18.9
Fe_2O_3	1.92 - 4.46	3.09	3.18 - 5.82	4.65	7.22
MgO	1.41 - 5.92	2.97	3.37 - 9.92	7.16	2.2
CaO	11.05 - 22.02	16.59	13.51 - 29.79	18.63	1.3
K_2O	0.64 - 1.34	0.92	0.12 - 1.01	0.61	3.7
Na_2O	0.24 - 0.37	0.31	0.21 - 0.79	0.38	1.2
P_2O_5	0.07 - 0.12	0.1	0.03 - 0.11	0.06	0.16
L.O.I.	12.93 - 24.22	17.54	11.90 - 29.43	22.15	6
Trace Elements (ppm)					
Cr	58 - 135	97	234 - 641	449	110
Ni	66 - 218	128	281 - 733	490	55
Co	10.00 - 28.00	17	26 - 44	34.63	23
Sc	5.3 - 9.9	7.51	8.90 - 19.10	12.78	16
V	32 - 69	50	42 - 115	70.38	150
Zr	27 - 55	40	5.00 - 62.00	28.5	210
Th	2.3 - 5.0	3.46	0.20 - 4.90	1.7	15
Hf	0.55 - 1.36	1.04	0.15 - 1.67	0.73	5
Ta	0.3 - 0.4	0.37	0.1 - 0.6	0.29	1.5
Nb	3.37 - 7.31	5.2	0.58 - 8.85	4.23	19
U	0.7 - 1.1	0.87	0.30 - 1.50	0.79	3.1
Y	13 - 17	14.61	2.90 - 12.90	8	27

	Tanjero Fm. (L.P.)		Tanjero Fm. (U.P.)		
	Ranges	Avg.	Ranges	Avg.	PAAS✧
REE (ppm)					
La	14.40 - 17.10	15.96	2.40 - 14.80	7.66	38
Ce	27.22 - 36.32	31.95	3.96 - 31.58	14.73	80
Nd	11.10 - 18.20	14.26	1.90 - 14.60	6.96	32
Sm	10.90 - 3.30	2.6	0.30 - 2.60	1.26	5.6
Eu	0.5 - 0.7	0.57	0.10 - 0.50	0.31	1.1
Gd	1.80 - 2.90	2.27	0.40 - 2.20	1.25	4.7
Tb	0.3 - 0.5	0.37	0.10 - 0.40	0.21	0.77
Tm	0.2	0.2	0.10 - 0.30	0.11	0.4
Yb	1.00 - 1.80	1.26	0.30 - 1.20	0.75	2.8
Lu	0.1 - 0.2	0.19	0.10 - 0.20	0.13	0.43
ΣREE	65.42 - 89.84	77.31	11.06 - 75.78	37.58	185
Ratios					
LREE/HREE	7.54 - 8.68	7.96	3.89 - 8.96	6.28	9.41
$(La/Yb)_n$	6.92 - 9.94	8.83	4.00 - 9.35	6.87	9.15
$(La/Sm)_n$	3.24 - 4.58	3.95	2.98 - 5.31	3.96	4.33
$(Gd/Yb)_n$	1.25 - 1.84	1.48	0.81 - 1.62	1.29	1.34
Eu_n/Eu^*	0.68 - 0.83	0.73	0.65 - 0.88	0.78	o.66
Ce_n/Ce^*	0.89 - 1.02	0.94	0.77 - 0.98	0.89	1.07
La/Sc	1.55 - 3.28	2.28	0.19 - 1.33	0.64	2.4
Th/Sc	0.4 - 0.57	0.46	0.02 - 0.40	0.14	0.91
Zr/Sc	4.74 - 5.91	5.25	0.47 - 5.11	2.23	13.1
La/Co	0.58 - 1.46	1.1	0.06 - 0.45	0.24	1.65
Th/Co	0.1 - 0.31	0.22	0.01 - 0.13	0.05	0.63
La/Ni	0.073 - 0.284	0.15	0.003 - 0.067	0.02	0.69

✧ Data from Taylor and McLennan (1985)

▪ Rare Earth Elements (REE)

The results of the REE analyses are summarized in Table (1). The chondrite – normalized REE distribution patterns (Fig.5A) for the seventeen analyzed samples display LREE (light REE) enrichment La_n/ Sm_n range between 2.98 – 5.31 and flat HREE (heavy REE) Gd_n/ Yb_n with values ranging between 0.81 – 1.84 and variable, but mostly slightly negative Eu-anomalies Eu/ Eu° varies between 0.57 – 0.88. Looking at the patterns one can see a separation of lower group of samples (yellow colored T1 – T9) from the upper group of samples (red colored T10 – T17). Figure (5B) shows the patterns of the average of lower and upper group of samples. When the patterns of average contents of REE of the two groups of Tanjero Formation are normalized to PAAS pattern (Fig.5C), notable differences can be seen: The first is that the total REE contents in both groups which are 77.31 and 37.58 respectively are much lower than that in the PAAS (185 ppm); secondly, the Eu-anomalies in both groups (0.73 and 0.78) show more positive values as compared with the PAAS (0.66); thirdly, the ratio of LREE/ HREE (7.95 and 6.28) in both the lower and upper groups respectively is much lower than PAAS (9.41) (Table 2). All these differences indicate the contribution of mafic and ultramafic components in the Tanjero sediments, as compared with PAAS provenance (upper continental crust). Such differences are attributed by McLennan (1989) to local contribution of mafic and ultramafic source rocks in the post-Archean sediments. However, the contribution of mafic and ultramafic clastics to the sediments of the upper part of the Tanjero Formation was much more than it is in the lower part. The upper part of the Shiranish rocks in Dokan are comparable with both groups of the Tanjero Formation (Fig.5C). The REE-pattern of the Shiranish Formation (Al-Nakib, 2013) is closer to the lower part of the Tanjero Formation, but the upper part of the Tanjero Formation is far away from the pattern of the Shiranish Formation, but closer to the Kolosh Formation (Al-Nakib, 2013).

▪ Elemental Ratios

Elemental ratios are used by many researchers dealing with provenances of clastic sedimentary rocks, to avoid possible influences of the contents of trace elements by dilution effects of some constituents, which are known to be devoid of any significant trace or rare earth elements, such as quartz, chert and carbonate minerals. Ratios are usually chosen of two elements; one found enriched in felsic source, and the other in mafic and ultramafic source, e.g. La/ Sc, Th/ Sc, Th/ Co, La/ Co, Zr/ Sc, La/ Ni, Y/ Ni. Table (1) shows the values of such ratios in both the lower and upper groups of the Tanjero Formation as compared with PAAS. It can be seen that there are distinct differences in such ratios between the two groups of samples and the PAAS. The upper group shows sharp difference from the lower group and the PAAS. These differences reflect the substantial contribution of mafic and ultramafic source rocks in the sediments of the upper group. This is reflected in the obvious low values of all ratios without any exception.

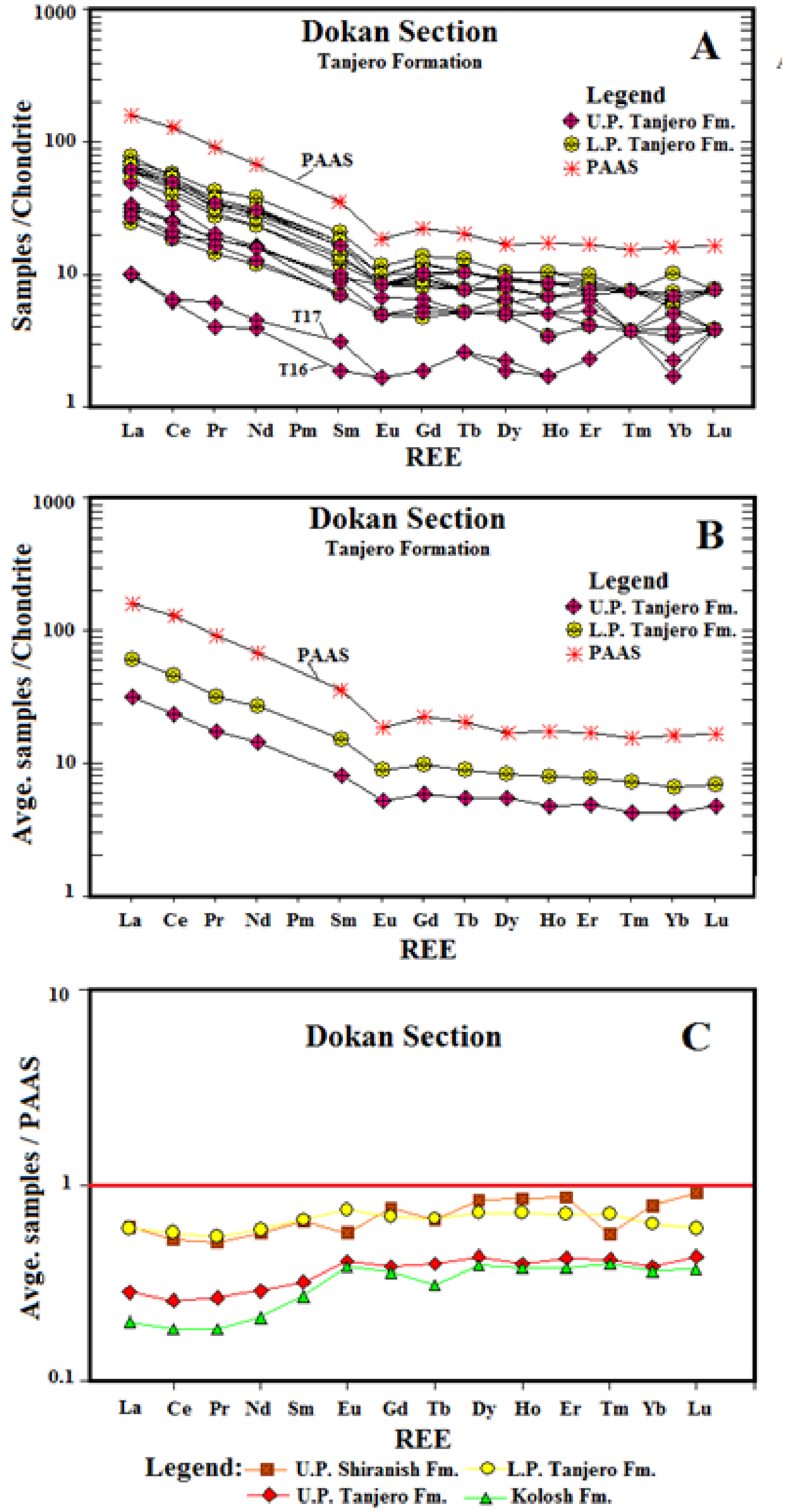


Fig.5: Chondrite and PAAS normalized REE in lower and upper parts of the Tanjero Formation. Upper Shiranish and Kolosh formations patterns are shown for comparison (after Al-Nakib, 2013)
Chondrite normalizing values (after Sun and McDonough, 1989)
PAAS normalizing values (after Taylor and McLennan, 1985)

EVOLUTION OF PROVENANCE

Geochemical and mineralogical characteristics of the Tanjero rocks involved in the present study leave little doubt that the upper part of the formation is strongly and clearly distinguished from the lower part. This is due to changes in nature of the source rocks of the formation. The rocks of the lower part include clastics of carbonate and chert derived from Qulqula Formation and a variable minor contribution of clay seized particles mainly chlorite derived from mafic source laying probably to the east and northeast of the basin of deposition. This source was probably in the form of island arc which Ali *et al*. (2012) identified as Hassan Beg. The transportation of particles was achieved through upwelling currents across the northeast and east ridge separating the Neo-Tethys from the foreland basin. This ridge at that time was below sea level.

Oceanic upwelling currents were suggested by Al-Bassam and Al-Allak (1985) to explain the high concentration of Cr, Ni, V, Cu and Zn in the Late Cretaceous to Eocene phosphorites and associated rocks exposed in the Western Desert of Iraq. The source of metals is believed to have been supplied by submarine volcanic activities, which were active in the Tethyan region during the Late Cretaceous to Eocene time. Bjorlykke (1974) working on the shales of Early Paleozoic age in the Oslo region, attributed the increase in the content of chlorite in going from lowermost Ordovician to Late Ordovician as evidence of transport of clastic chlorite from developing Island arc system to where sedimentation was in progress in the adjoining continental basin in the Trondheim region. The transporting medium was upwelling oceanic currents. This was related to Taconic Orogenic Phase during the same period. The increase in the chlorite content was paralleled by increase in the content of Mg, Fe, Ni and Cr from lower to Middle and Late Ordovician beds.

In Dokan area, the geochemical facies of the lower part of the Tanjero Formation lies between the upper part of the Shiranish Formation and the upper part of the Tanjero Formation (Al-Nakib, 2013). The slight differences in the chemistry of the lower part of the Tanjero Formation and the Shiranish Formation reflect variable pulses of mafic clastics introduced into the basin of deposition of the lower part of the Tanjero Formation (Buday, 1980, p. 193). The most important observation in the mineralogy and chemistry of the Tanjero samples is the clear introduction of serpentine minerals, analcime and plagioclase feldspar starting from sample T10 to the upper part of the formation ending in sample T17, and the increased content of chlorite, as shown by XRD.

When the samples of the Tanjero Formation are plotted in the triangle La-Th-Sc diagram (Taylor and McLennan, 1985) it is obvious that most samples of the lower part of the Tanjero Formation lies in the field of ACM (Active Continental Margin) and most of the samples of the upper part lies in the field of OIA (Oceanic Island Arc) (Fig.6).

All the chemical and mineralogical characteristics described above indicate that during the Late Maastrichtian and with the beginning of the deposition of the sediments represented by sample T10 a major changes occurred in the nature of the source rocks, which point out the increased outcrop areas of the ultramafic rocks. It can be deduced now that with beginning of the deposition of the upper part of the formation the island arc volcanics (Ali *et al*., 2012) and the associated ultramafic rocks (ophiolites) mentioned in Jassim and Goff (2006) were uplifted above sea level and become available for contributing ultramafic clastics to the upper part of the formation.

Buday (1980) indicated from, lithological studies, that the lower part of the Tanjero Formation represents pelagic marls, and rare marly limestone unit that were deposited in open sea with occasional influx of fine clastics, but the upper part of the Tanjero Formation represents a typical orogenic flysch. Bolton (1958d, p. 54 – 55; in: Buday, 1980) reported the presence of beds that could be regarded as Shiranish – Tanjero facies lying between the Tanjero and Shiranish formations at Ganav village. This is in agreement with the name Smaquli given by Sharbazheri (2010) for the red beds, which represents transitional facies change between Shiranish and Tanjero Formations in Smaquli area, west of Koisanjaq.

As mentioned earlier, Buday (1980) pointed out that the connection of two greatly different units into one single formation had been an unfortunate event. He suggested either to include the lower part of the Tanjero Formation with the Shiranish Formation, or to give a new formation name for the lower part. The present study based on geochemical characteristics support the idea of giving a new formation name for the lower part of the Tanjero Formation. Before doing so, it is suggested that further geochemical and lithological studies should be carried out in other areas.

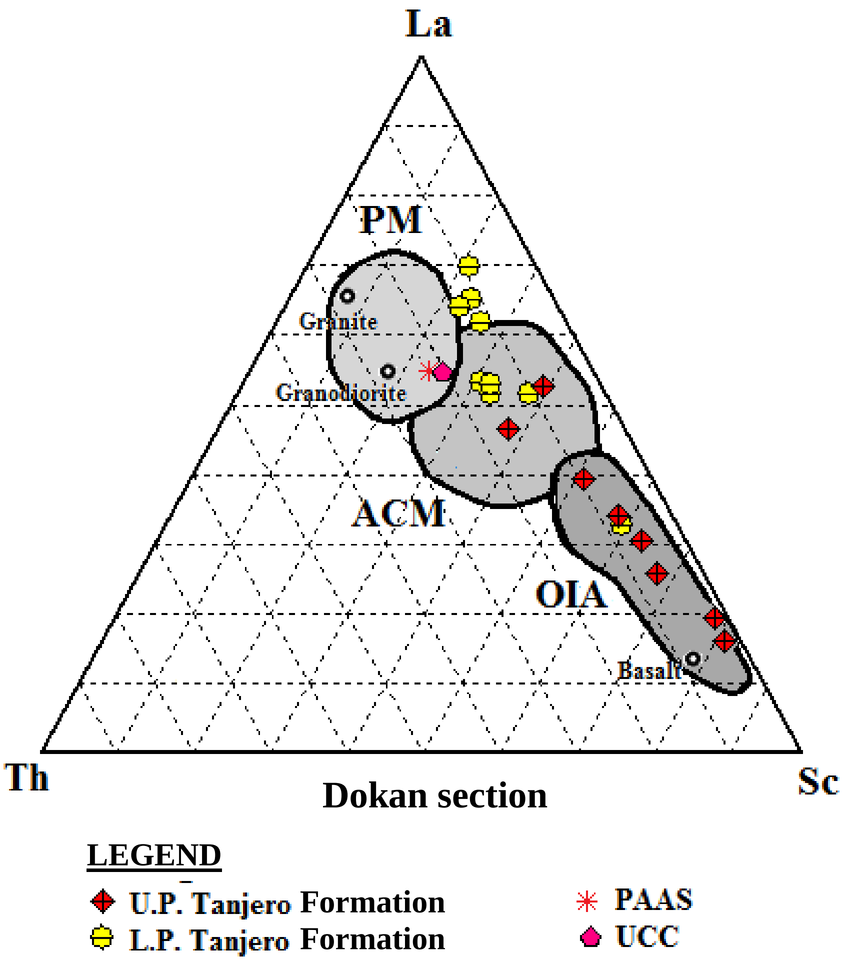


Fig.6: Plots of samples collected from Tanjero Formation in La-Th-Sc Triangular diagram showing the tectonic fields of provenance: PM (Passive Continental Margin), ACM (Active Continental Margin), OIA (Oceanic Island Arc), UCC (Upper Continental Crust), (after Bhatia and Crook, 1986)

CONCLUSIONS

Geochemical and mineralogical studies of samples collected from the Tanjero Formation across a section in Dokan area northeast Iraq pointed to significant differences in the natures of source rocks of the lower part as compared with the upper part of the formation. The lower part was deposited in a deep marine basin in continuation with the deposition of the Shiranish Formation but with minor contribution, through upwelling currents, of fine clay size particles derived from mafic sources laying to the northeast and north of the ridge separating the foreland basin from Neo-Tethys and across a slightly elevated ridge above sea floor. This ridge was developed in the early stages of the collision of the Arabian Plate with the Eurasian Plate. The upper part of the formation, however, was deposited in shallower basin where clastics derived from outcrops elevated above sea level along the same ridge mentioned earlier consisting mainly of mafic and ultramafic rocks (ophiolite) and older sedimentary rocks obducted on the uplifted ridge. The lithological, chemical and mineralogical differences between the lower and upper parts and the ability of delineating the two parts in the field warranted giving a new formation name for the lower part. This conclusion should be supported by further geochemical and lithological work in other outcrops elsewhere.

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