Africa Geoscience Review, Vol. 15, No.2, 56-68, 2008
Printed in France

Flaky minerals in the recent sediments of the Tigris River, Northern Iraq: provenance and paleogeographic approaches

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Abstract - Mineralogical, chemical, and morphological characteristics of the flaky minerals in the Tigris River sediments, northern Iraq, were determined by using standard petrographic, scanning electron microscope and electron microprobe analyses. The objective is to elucidate the provenance and environmental changes affecting these minerals. Flaky minerals such as muscovite, biotite and chlorite, can constitute up to 60% of the total heavy mineral fraction from recent sandy sediments of the Tigris River at certain locations in northern Iraq. Chemical analyses of the studied white mica indicate that they are of late to post-magmatic and hydrothermal types with close affinities to the mica composition in mica-schist. The studied biotite component was derived from metamorphic rocks rather than from igneous rocks, (i.e. they are not phlogopitic or Mg-rich biotites). Chlorites are of the chamosite type and were derived from metamorphic rocks (mainly schist and slates). The mineralogical and geochemical indicators suggest that these flaky minerals were mainly derived from metamorphic rocks of the Nappe Zone of Turkey and partly from rocks of the Iraqi Nappe Zone as well as from the disintegration of older clastic sedimentary formations within the valley of the Tigris River.

Key words: Flaky minerals, chemistry, morphology, provenance, Tigris River, northern Iraq.

INTRODUCTION

Many factors control the occurrences of light and heavy minerals in the river deposits. The mineral composition of these deposits is dependent on the type, amount and size of the minerals in the source rocks, the way in which the source rocks have disintegrated absolute and relative rates of mechanical wear and chemical disintegration during transport, and the hydraulic conditions that existed at the place and during the time of deposition. Moreover, it is concluded experimentally that the distribution of heavy minerals in river deposits is largely dependant on the hydraulic conditions and the hydraulic equivalent size of the heavy minerals, as well as on the relative availability of various sizes of each heavy mineral in the stream load (Rittenhouse, 1943; Morton and Hallsworth 1999).

The flaky minerals (muscovite, biotite and chlorite) are hydrous aluminum silicates with varying amounts of iron, potassium, magnesium, lithium and other cations (Bateman, 1981). These flaky minerals are commonly present as detrital components in sandstones. Because of their flaky shape, and despite of their higher density and large size, they tend to collect with finer sands and silt (Pettijohn, 1975). Studies of modern sands contribute to our understanding of the effects of processes controlling the composition of sand-sized sediments. This information can be useful for better paleogeographic interpretations of ancient source area and basin systems (Zuffa, 1987; Dickinson, 1988). Detrital heavy minerals (including the flaky minerals) have been widely used to study the weathering processes, provenance and diagenesis of siliciclastic rocks (Mange and Maurer 1992; Dill, 1998; Morton and Hallsworth 1999; Fornelli and Picacarreta 1997). Such provenance studies may include all aspects of the drainage area, including source lithology, topographic relief, climate, transport energy and hydrodynamics of the sedimentary environments (Suttner, 1974; Johnsson, 1993). The recent sediments of the Tigris River contain abundant flaky minerals when compared with older sediments in the same region (Philip, 1968; Jawad Ali, 1977; Hussein, 1981; Al-Juboury *et al*., 2001) and may comprise about 60% of the heavy fraction at some localities in northern Iraq. The micaceous minerals (muscovite, biotite and chlorite) are also common in the Pliocene molasses and Euphrates fluvial sediments in Iraq. It is unlikely that these minerals suffer complete breakdown during weathering (Jawad Ali, 1983).

Studying the mineralogy and chemistry of flaky minerals is a useful method for obtaining a better understanding of the provenance of recent sediments in the Tigris River. Thus, this study aims to evaluate the distribution of the flaky minerals along the Tigris River in northern Iraq and to use their mineralogical and chemical indications to elucidate the provenance and paleogeographic setting of the region.

GEOLOGICAL SETTING

The regional geology of Iraq is divided into three zones; a thrust (nappe) zone, folded zone and unfolded zone (Dunnington, 1958). The area of study (northern Iraq) is a part of the folded zone that has a NW-SE structural trend (parallel to the Zagros Mountains) in the northeastern part and an E-W trend (parallel to the Taurus Mountains) in the north and northwestern parts (Fig. 1). The former consists of folded Late Paleozoic and Mesozoic limestones and a nappe zone of metamorphosed Early Paleozoic rocks along the borders with Iran in northeastern Iraq. Northern Iraq is also situated in the low-competent and foot hills belts according to the geomorphologic divisions proposed by Bolton (1958).

The Tigris River initiates from the Taurus Mountains in Turkey. The river crosses the southeastern part of Turkey, which consists of a very complex igneous and metamorphic region (Nappe Zone; Figure 2), while most of its tributaries rise from the northeastern part of the nappe zone of Iraq (i.e. across the Mawat-Chuwarta Ophiolite Complex area; Abdul-Wahab, 1983). The nappe zone includes the area of northern and northeastern Iraq, forming the high and tectonically complex Zagros Mountains which trend northwest-southeast. This area forms the headwaters of a number of rivers which drain southwestward to the Tigris River.

In Iraq, the Tigris River, in its upper reaches receives a number of tributaries, principally the Greater and Lesser Zab Rivers. These drain the highly folded and faulted igneous and metamorphic thrust zone (Dunnington, 1958) in extreme northeastern Iraq, where the Tigris River cuts through the low-competent fold mountains and foot-hills belt. It exposes Paleocene to Eocene rocks (Pilaspi, Jaddala and/or Gercus Formations) in the cores of the anticlines, surrounded by younger Miocene and Pliocene rocks that occupy the relatively low synclinal areas. The Quaternary sediments, including the Pleistocene Tigris River terraces, lie unconformably on these folded rocks (Figure 3). Lithologically, most of the exposed successions along the river channel are composed of carbonate and clastic rocks.

MATERIALS AND METHODS

Samples were collected from nine localities on cross-profiles along the river and in abandoned meanders in northern Iraq (Figure 3). A total of twenty samples were collected from these locations. The samples were carefully washed by using distilled water on a 0.063 mm sieve to decant the clay-sized particles. The sand samples were then dried and subjected to heavy mineral separation. Five grams from the 0.25-0.063 mm size fraction were separated into heavy and light fractions using bromoform ($CHBr_3$ specific gravity, 2.89). This size fraction was selected in order to avoid the negative effects of the varying density, shape and size of different heavy minerals in caused by hydraulic differentiation (Hubert, 1971; Jeans *et al.*, 1993). The weights of the heavy mineral fractions were noted after drying and the magnetic minerals were removed with a hand

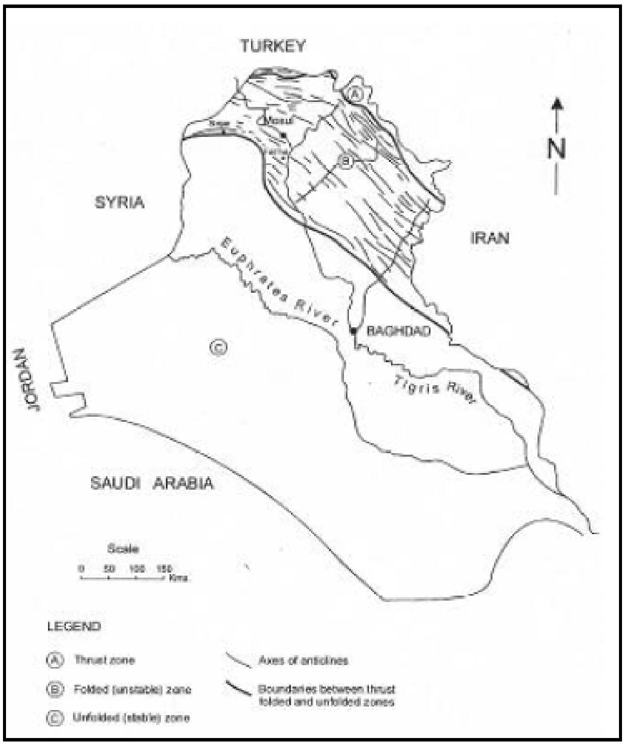


Figure 1. Tripartite tectonic subdivision of Iraq (modified after Dunnington, 1958).

bar magnet. The weights of the light minerals were calculated by deducting the weights of the heavy minerals from the sieve fraction weight (Table 1). The grains were mounted on glass slides with canada balsam and each slide was systematically studied to identify all the minerals present. Heavy minerals were

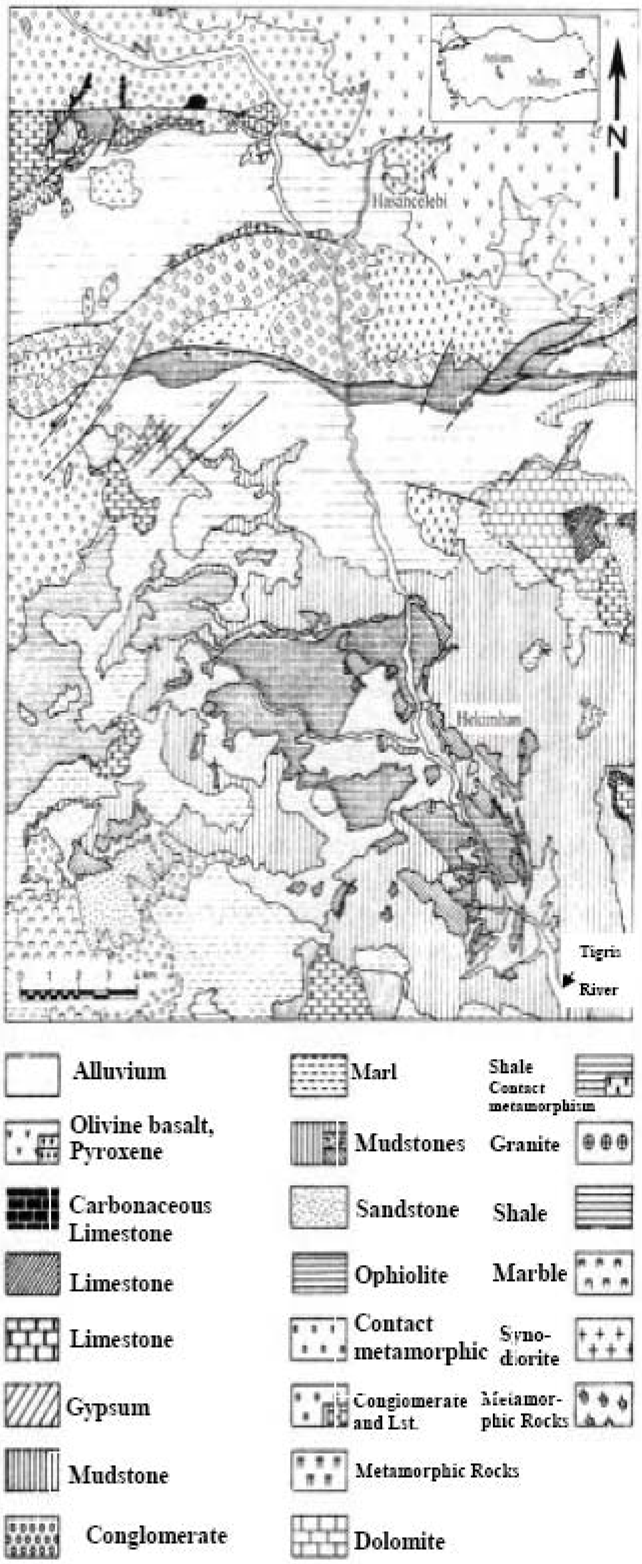


Figure 2. Geology of the southeastern part of Turkey from which the Tigris River initiates. (modified from Gürer, 1994).

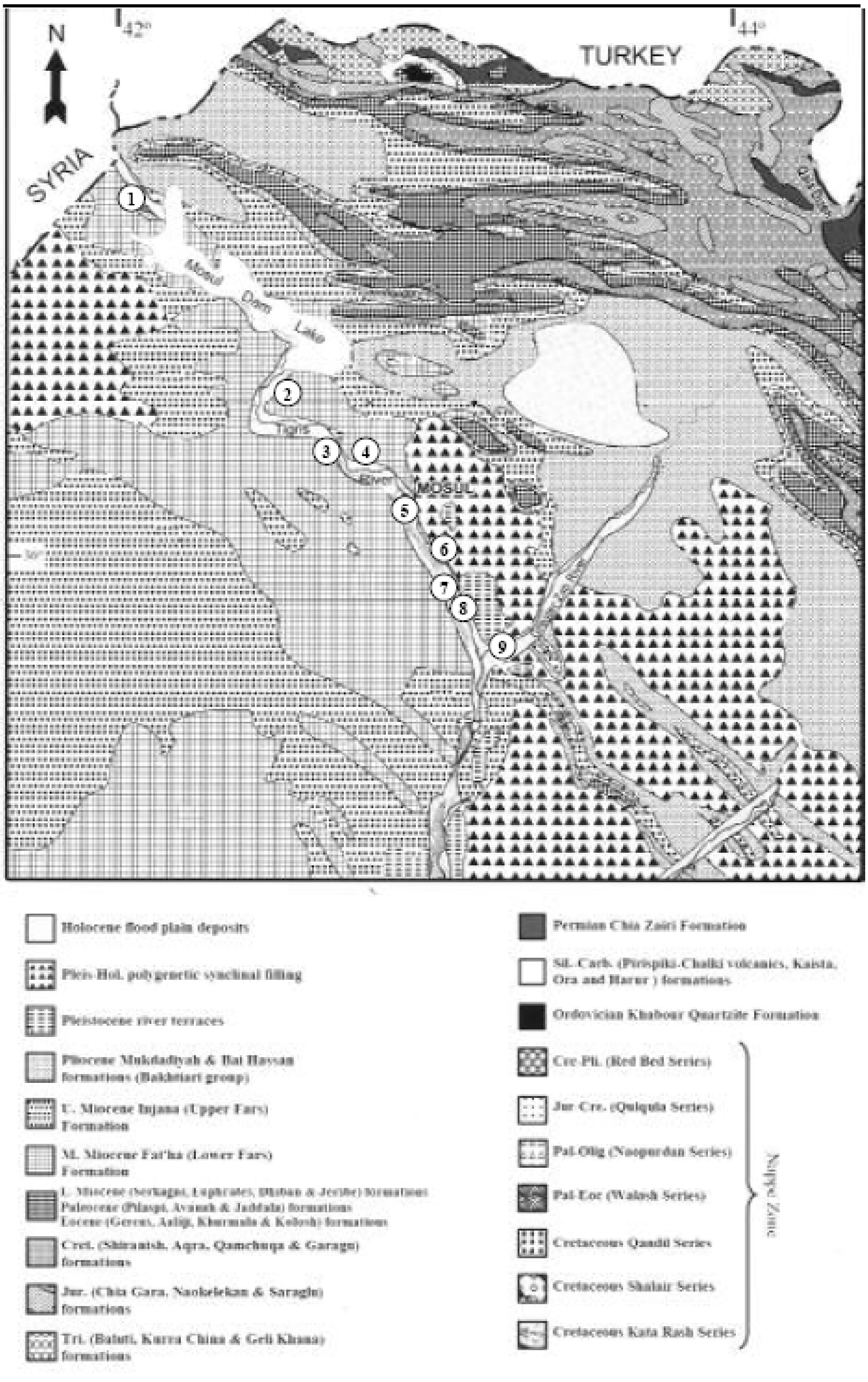


Figure 3. Geological map of northern Iraq showing the geological formations of the Ordovician to Recent age, and sample locations (modified from the Geological map of Iraq ,1986). Open circles are samples location.

identified using standard petrographic procedures – 300 grains from each sample were counted (Table 2) as described by Mange and Maurer (1992).

The morphologies of the flaky minerals were examined using scanning electron microscopic analysis with a Cam Scan MV 2300 at the Paleontological Institute, Bonn University, Germany, and equiped with a calibrated energy dispersive X-ray analysis system.

Table 1. Illustrates the geographic and environmental location from which samples were taken and the mean percentage of the heavy and light minerals in the studied locations.

Sample No.	Location Geographic/Environmental	Heavy minerals %	Light minerals %	Carbonate Fraction %
1	Sehayla/ River channel	4.9	63.7	31.4
2	Wana/ River channel	6.8	62.7	30.5
3	Badoosh/ abandoned channel	9.1	61.5	29.4
4	Rashidiya/ Ox-.bow	6.1	58.7	35.2
5	Mosul/ River channel	10.4	71.0	18.6
6	Al-Qasr/ abandoned channel	11.2	72.5	16.3
7	Hammam Al-Alil/ Ox-.bow	11.2	50.9	37.9
8	Namroud/ River channel	10.7	69.1	20.2
9	Makhlat/ River channel	9.5	82.3	8.2

Table 2. Average relative percentages of the heavy minerals in the studied Tigris River sediments (see Figure 3 for sample locations)

Minerals / Sample No.		T1	T2	T3	T4	T5	T6	T7	T8	T9
Opaques		31.2	38.3	35.5	33.7	46.4	47.1	54.1	52.3	52.1
Amphiboles		4.8	3.9	4.4	2.3	4.3	2.9	2.7	3.0	2.8
Pyroxenes		6.1	6.2	5.8	2.6	5.1	4.8	7.4	7.6	6.8
Epidotes		9.4	18.4	18.1	12.7	18.6	19.2	22.1	24.2	25.1
Garnet		6.3	3.5	5.7	2.4	10.0	14.2	2.2	3.9	6.8
Flaky	**Muscovite**	16.2	11.2	13.1	18.0	8.3	6.4	5.4	5.1	3.4
	Biotite	10.1	5.3	5.8	10.5	1.4	1.7	0.7	0.4	1.1
	Chlorite	13.2	10.1	9.8	15.8	2.7	3.2	3.0	1.9	0.3
Zircon		0.7	1.0	0.5	0.3	0.7	0.3	0.5	0.3	0.6
Tourmaline		1.0	1.2	0.7	0.4	0.9	0.6	0.9	0.8	0.9
Rutile		0.4	0.1	--	--	0.2	0.1	--	--	0.5
Kyanite		0.4	1.2	0.5	0.4	0.6	--	--	--	0.7
Staurolite		0.1	0.1	0.2	--	--	--	--	--	0.1
Spinel		--	0.1	--	--	--	0.2	--	--	--
Sphene		--	0.1	--	--	--	--	--	0.2	--
Apatite		--	0.1	--	--	--	0.1	--	--	--
Olivine		--	--	--	--	0.2	--	--	0.2	--

Chemical analyses of the flaky minerals were carried out at Bonn University, Germany using a CAMEBAX electron- probe microanalyzer. Five analyses of each biotite grain and three for each muscovite and chlorite grain were made, in the center and near the rims of each of the examined grains (Figure 4). Representative chemical analysis of these minerals is shown in Table 3.

MINERALOGICAL AND GEOCHEMICAL ANALYSES

Occurrences of Detrital Flaky Minerals

Most of the flaky minerals are separated from the light fractions of the recent (late Quaternary) sediments of the Tigris River of northern Iraq. Due to their relatively low density and flaky nature, they were already found as minor accessories. Detrital flaky minerals of muscovite, biotite and chlorite form up to 60% of the heavy mineral fractions in recent sandy sediments taken from locations in northern Iraq (Figure 5). The samples studied are fine to medium-grained, moderately sorted sands and their mineralogical maturity increases downstream (Al-Juboury *et al*., 2001).

The light fraction of the sediments studied consists of sub-angular to sub-rounded quartz grains; both mono- and polycrystalline, with minor amounts of opal, chert and feldspar in addition to rock fragments. The latter comprise sedimentary, igneous and metamorphic fragments indicating the diversity of their provenance. The mineralogical data of the sand fractions show significantly higher percentages of detrital carbonate grains, which is mainly due to the fact that the sediments were admixed with material derived from the neighboring Eocene and Oligocene limestone in northern Iraq.

The heavy mineral assemblage contains opaque minerals, including magnetite, chromite and/or chromian spinels, hematite, ilmenite, goethite, pyrite, and non-opaque minerals such as epidote, pyroxene, amphibole, garnet, zircon, tourmaline, rutile, kyanite, staurolite, olivine, sphene, apatite, white mica, biotite, and chlorite (Table 2).

Flaky minerals tend to concentrate in medium-sized sand, while other heavy minerals are more abundant in the finer sand fraction. Generally, they are recorded as irregular and angular grains. The enrichment of mica may be a result of sampling from the meandering part of the river, which permits these flaky minerals to accumulate in pockets or in lenses. Furthermore, the presence of the Mosul Dam reservoir (Figure 3) leads to settlement of the heavy minerals in the lake and permits the light flaky minerals to be transported beyond the lake along the river channel, especially for locations 3 and 4 (Figure 3).

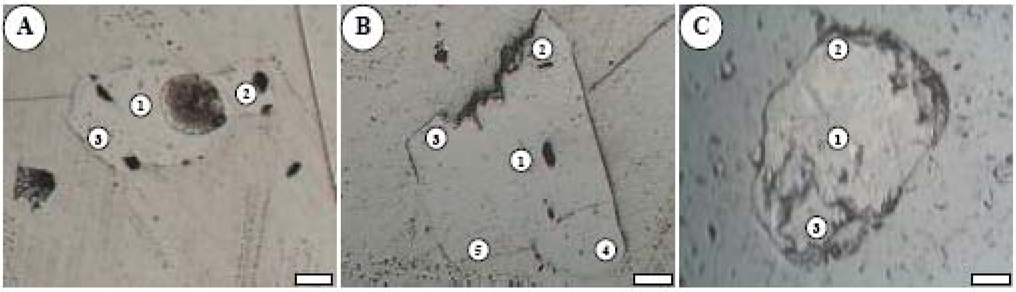


Figure 4. Electron microprobe photographs of detrital flaky mineral grains. A, muscovite; B, biotite and C, chlorite. The numbers show the location of the single analyses. Scale bar= 0.2 mm.

Table 3. Representative chemical compositions of selected flaky minerals (muscovite, biotite and chlorite) in the recent sandy sediments of Tigris River, northern Iraq.

Oxides	**Biotite**					**Chlorite**			**Muscovite**		
Sample N	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**1**	**2**	**3**
SiO_2	37.38	36.56	37	39.81	38.83	24.98	24.13	25.01	45.3	46.01	45.66
Al_2O_3	18.34	18.04	17.76	20.34	19.25	20.86	21.25	21.08	36.69	36.32	36.45
TiO_2	3.9	3.92	3.69	1.36	2.79	0.07	0.08	0.06	0.1	0.21	0.17
Cr_2O_3	0	0	0	0	0	0	0	0	0.01	0	0
FeO	20.21	20.84	20.84	16.58	19.45	29.39	29.42	29.25	1.39	1.65	1.72
MnO	0.13	0.07	0.12	0.07	0.09	0.29	0.21	0.27	0.02	0.03	0.02
MgO	9.66	9.65	9.31	9.82	9.27	11.15	10.68	11.1	1.28	0.94	0.84
CaO	0.16	0.41	0.18	0.11	0.15	0	0	0	0.15	0.01	0.03
Na_2O	0.04	0.1	0.04	0.06	0.02	0.03	0	0.01	0.15	0.03	0.2
K_2O	8.2	8.08	8.07	9.63	7.98	0.03	0	0.01	9.31	8.89	9.51
T	**98.02**	**97.67**	**97.01**	**97.78**	**97.83**	**86.8**	**85.77**	**86.79**	**94.4**	**94.09**	**86.79**
	Cation % on basis of 22 O					Cation % on basis of 28 O			Cation % on basis of 22 O		
Si	5.486	5.417	5.51	5.743	5.646	5.446	5.335	5.444	6.042	6.133	6.088
Al	3.172	3.15	3.117	3.458	3.298	5.36	5.537	5.408	5.767	5.705	5.727
Ti	0.43	0.437	0.413	0.148	0.305	0.011	0.013	0.01	0.01	0.021	0.017
Cr	0	0	0	0	0	0	0	0	0.001	0	0
Fe	2.48	2.582	2.595	2	2.365	5.358	5.439	5.324	0.155	0.184	0.192
Mn	0.016	0.009	0.015	0.009	0.011	0.054	0.039	0.05	0.002	0.003	0.002
Mg	2.114	2.132	2.067	2.112	2.009	3.624	3.52	3.602	0.255	0.187	0.167
Ca	0.025	0.065	0.029	0.017	0.023	0	0	0	0.021	0.001	0.004
Na	0.011	0.029	0.012	0.017	0.006	0.013	0	0.004	0.039	0.008	0.052
K	1.535	1.527	1.533	1.772	1.48	0.008	0	0.003	1.584	1.511	1.617
Fe/Fe+Mg	0.5398	0.5477	0.55662	0.48638	0.54069						

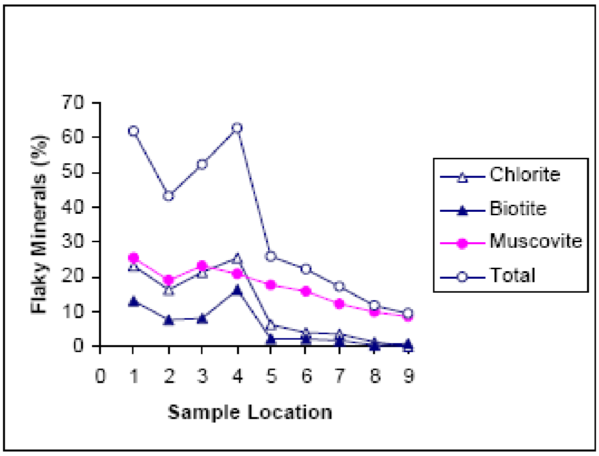


Figure 5. Distribution of the studied flaky minerals along the Tigris River channel of northern Iraq illustrating the downstream decrease in the content of flaky minerals.

Petrography of the Flaky Minerals

The studied flaky grains have an average size of 0.4 mm. optically; muscovite occurs as colorless flakes, with common inclusions of iron oxides, and frequently shows undulose extinction denoting stress. Biotite is present as reddish brown plates with most flakes having strong to intense pleochroism and a small optic axial angle. Some biotite has been chloritized. Chlorite occurs as green to dark green flaky grains with faint pleochroism but they are distinct in all cases (Figure 6). In occasional chlorite flakes, some oxidation has occurred, resulting in a change of color from green to greenish-brown or brown with a distinct rise in the refractive index and birefringence.

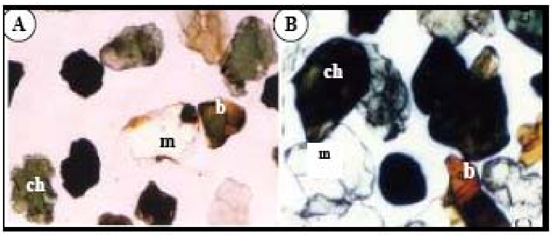


Figure 6. Photomicrographs of detrital flaky minerals showing white mica muscovite (m); brown biotite (b) and green to dark green chlorite (ch).

The morphology of the studied flaky minerals is shown in Figure (7). The important property of the flaky minerals is their perfect basal cleavage, which permits them to be split into sheets or films. Muscovite splits into thicker sheets than biotite (Bateman, 1981). This characteristic is shown in the present work as thick sheets of muscovite (Figure 7A) and thinner sheets of biotite (Figure 7C&D), whereas, the sheets of chlorite are partly undulose (Figure 7E). Generally, the small broken flakes are softer in chlorite than in the other detrital flaky minerals (Figure 7E&F). The flaky minerals are unlikely to suffer complete breakdown during weathering (Jawad Ali, 1983).

Chemistry of the Flaky Minerals

Muscovite The microprobe analyses of three muscovite grains from this study (Table 3; Figure 4A), show that they have 45.3-46.01 wt% SiO_2, 36.32-36.69 wt% Al_2O_3, 8.89-9.51 wt% K_2O as essential oxides, with low contents of FeO (1.39-1.72 wt%) and MgO (0.84-1.28 wt%). They are restricted to the di-octahedral muscovite. Ideal muscovite has Si content of 3.0 per formula unit (p.f.u, calculated on the basis of 11 O). Whereas another di-octahedral white K-mica with Si content considerably higher than 3.0 p.f.u is termed phengitic mica and ideal phengite has Si equal to 3.5 p.f.u and (Mg, Fe) equal to 0.5 p.f.u (Deer *et al.*, 1992; Figure 8A). The Si content of these white micas in the present study is very close to 3.0 (3.02-3.06 p.f.u, on the basis of 11O). The low Si and Mg contents (0.08-0.12 p.f.u, on the basis of 11 O) of these micas classify them as muscovite. These values are also very close to the corresponding values for muscovite from the regionally metamorphosed quartzite and mica-schist at Sivrihisar in Turkey (Si = 3.03 and Mg = 0.06; Whitney, 2002).

Other plots of Si versus Al_{tot}; K versus Na; and Al versus Si (Fig. 8B&C respectively) show a great coincidence with mucovite from Turkey (mean of n = 4) given by Whitney (2002). By comparing the analyses of the muscovite from the present study with those of Turkey (Whitney, 2002), it is clear that they both have very close chemistry, especially the Mg+Fe content and Si p.f.u (on the basis of 11 O) as shown in Figure **(**8D). The triangular plot (Figure 9) of Monier et al. (1984) shows that the muscovite in both the present study and Turkey are of late- to post-magmatic and hydrothermal type (i.e. not magmatic due to their lower content of TiO_2), therefore, they are of metamorphic origin. This interpretation is coincident with that mentioned by Pettijohn *et al*. (1987) who noted the white K-mica is considered to be a common detrital mineral in the sandstones, especially those derived from metamorphic rocks.

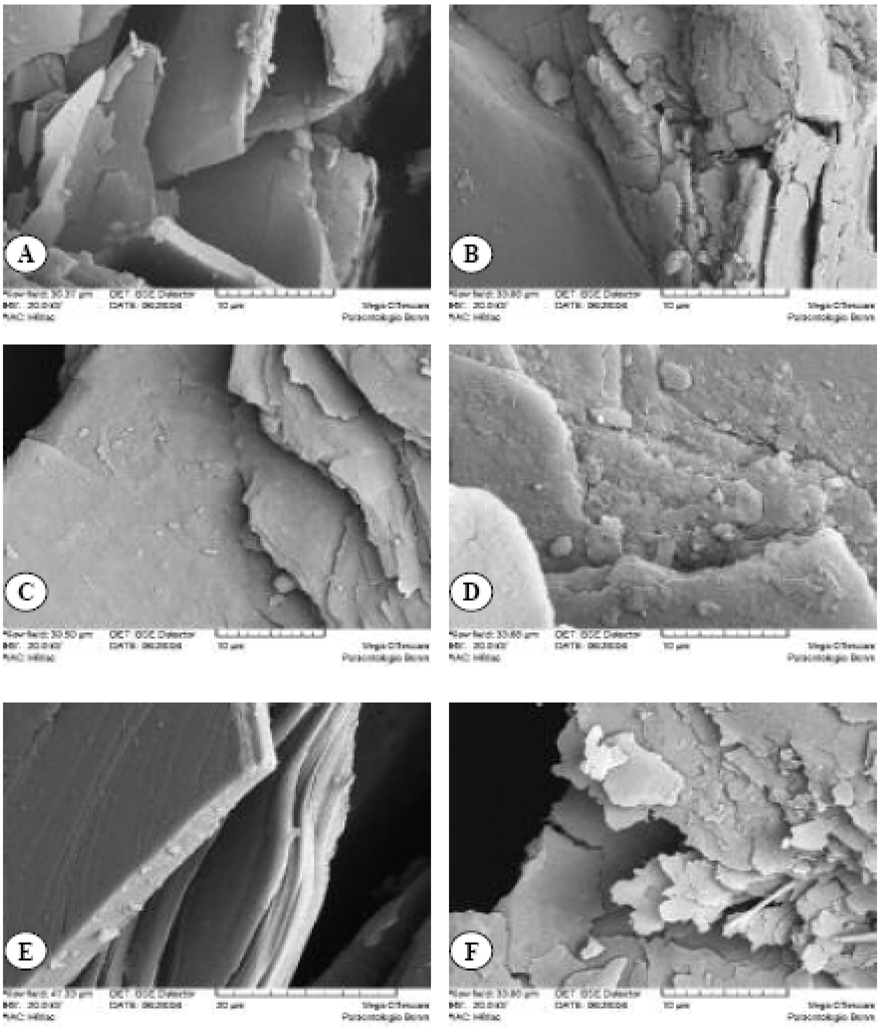


Figure 7. Scanning electron micrographs showing the morphology of the studied flaky minerals. A&B) muscovite thick and broken flakes; C&D) broken fine flakes of biotite; E&F) chlorite thick and undulated flakes as well as fine thin broken small flakes.

Biotite Microprobe analyses of five biotite samples from the present study (Table 3; Figure 4B) have essentially 37.38-39.81 wt% SiO_2, 17.76-20.34 wt% Al_2O_3, 16.58-20.84 wt% FeO, 9.27-9.82 wt% MgO and 7.98-9.63 wt% K_2O, with lesser amounts of TiO_2 (1.36-3.92 wt%) and CaO (0.11-0.41 wt%; Table 3). The plot of Aliv versus Fe/Fe+Mg (p.f.u. based on 11 O) shows that the biotites in the present study, as well as the biotite (n = 1) given by Whitney (2002), are classified as biotite due to their high values (>0.4) of Fe/Fe+Mg (Figure 10A; Deer *et al*., 1966, Thorpe *et al*., 1990). Moreover, the triangular plot of Foster (1960) shows that these biotites are Fe-rich biotites (Figure 10B).

There is a great similarity between the chemistry of the biotite from the recent sediments in the present study and the chemistry of biotite of from the Sivrihisar quartzite and mica-schist in Turkey (Whitney, 2002). Thus, this leads to the conclusion that the biotite in the present work was derived from metamorphic rocks rather than from an igneous or magmatic origin, especially since they are not phlogopitic or Mg-rich biotite.

Chlorites in the present study contain 24.13-25.01 wt% SiO_2, 29.25-29.42 wt% FeO, 20.96-21.25 wt% Al_2O_3 and 10.68-11.15 wt % MgO as essential constituents. Other constituents are very low (less than 1%). They

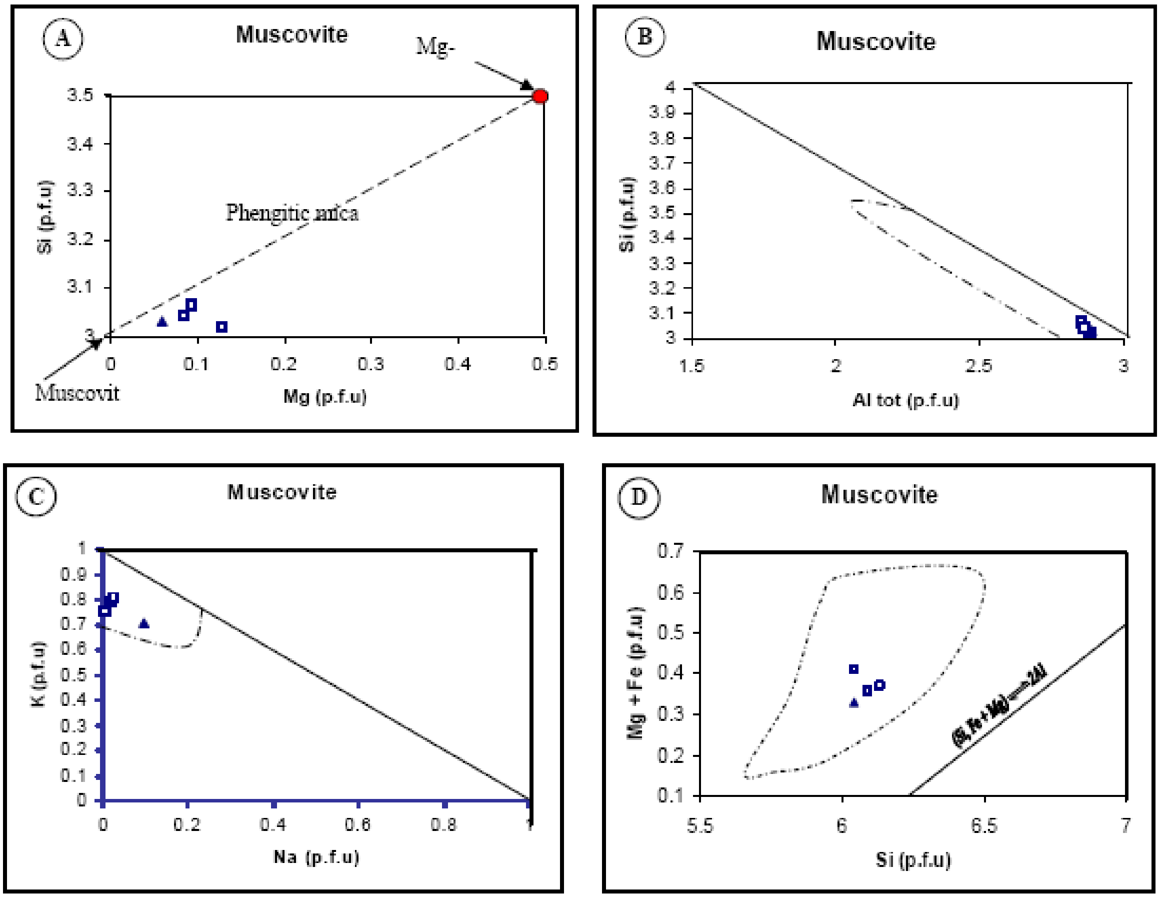


Figure 8. Chemistry of the analyzed white mica (muscovite) grains illustrated in the Si vs. Mg (A); Si vs. Al $_{tot}$ (B); K vs. Na (C) and Mg+Fe vs. Si (D). Stippled line indicates 1:1 substitution of Si and Mg (replacing 2 Al). Dotted dashed line represents the field of 202 analyzed white mica of Von Eynatten and Gaupp (1999). Dotted dashed shape of (D) represents the plot of white mica in Gadlağ Al_2SiO_5-bearing schists and quartzite from Turkey (Whitney, 2002). Open squares represent three analyzed muscovite of the present work, solid triangle represents mean of four analyzed muscovite from Turkey (Whitney, 2002). All calculations are based on 11 O. The studied samples are classified as muscovite.

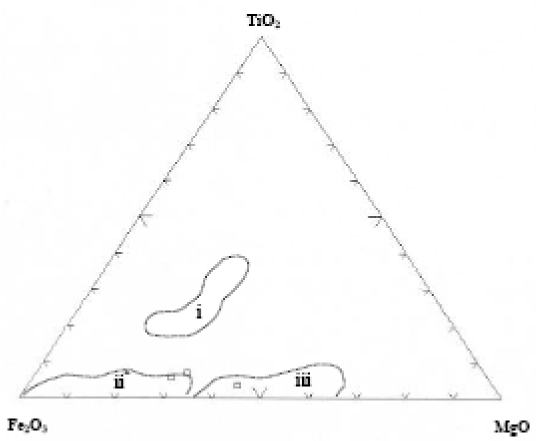
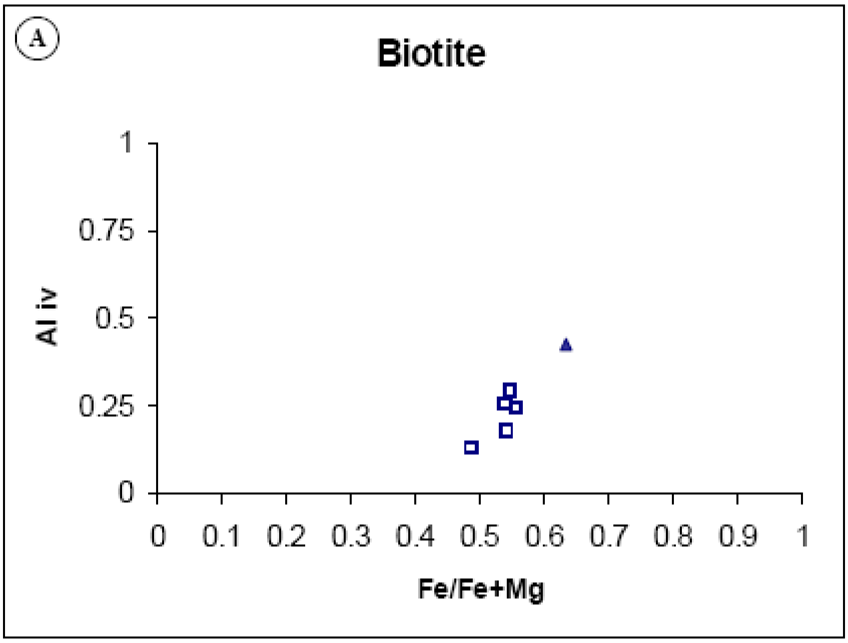


Figure 9. TiO_2-Fe_2O_3-MgO triangular diagram for white mica (muscovite) showing the fields: (i) magmatic, (ii) late-to post- magmatic and (iii) hydrothermal muscovite (according to Monier et al., 1984). Open squares = muscovite of the present work and solid triangle = muscovite from Turkey (Whitney, 2002).

are of a chamosite type, especially ripidolite according to Hey (1954) nomenclature (Figure 11). The provenance of these chlorites is from metamorphic rocks (mainly schists and slates). Alternatively, they could be derived from igneous rocks as an alteration of ferromagnesian minerals such as pyroxenes, amphiboles, biotite and garnet.

DISCUSSION

The study of the flaky minerals (muscovite, biotite and chlorite) in the recent sediments of the Tigris River, northern Iraq, is quite important for several reasons. First; they occur together with finer sand and silt sizes despite their relative lower density as compared with heavy minerals. Secondly; they specially occur in some localities as lenses or pockets near the meandering parts of the river. Third; they are important in paleogeography, where they reflect a clear relationship in some places between their accumulation and enrichment and the nature of transportation and river channel on one hand, and the geography of the weathered older igneous, metamorphic and sedimentary rocks on the other. As a special case, the flaky minerals in the present study give a good conception of the role of the Mosul Dam reservoir in settling heavy minerals and permitting lighter flaky



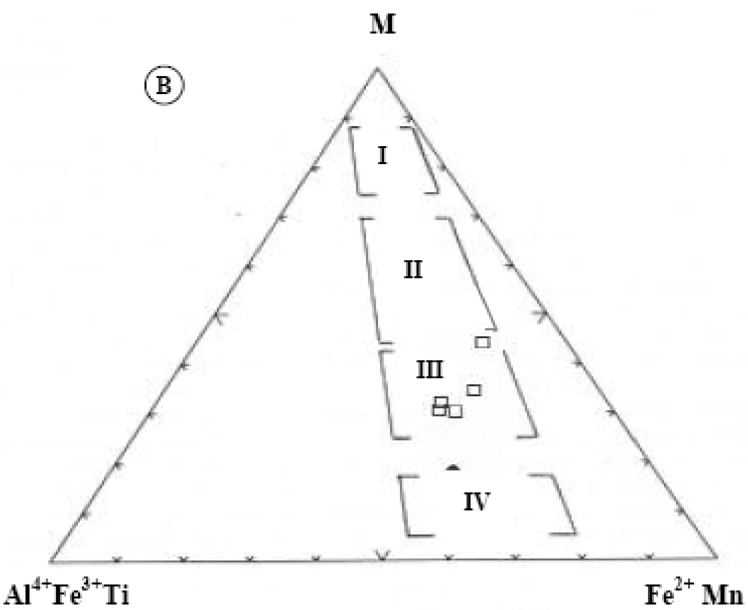


Figure 10. A, Composition of biotite represented on modified version of Deer et al. (1966) after Thorpe et al. (1990). Open squares = biotite of the present work and solid triangle = biotite from Turkey (Whitney, 2002); B, Foster's triangular diagram illustrating the composition of biotite in the fields: (i) phlogopite, (ii) Mg-rich biotite, (iii) Fe-rich biotite and (iv) lepidomelanes and siderophyllites. Open squares = biotite of the present work and solid triangle = biotite from Turkey (Whitney, 2002).

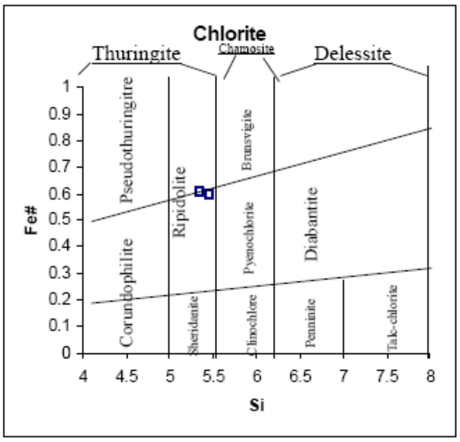


Figure 11. Nomenclature of chlorites (after Hey, 1954). Open squares are the chlorites analysed during the present study (ripidolites).

minerals to travel beyond the lake along the river channel, especially to localities 3 and 4 (Figure 3). Moreover, the flaky minerals reflect the paleogeography of the higher topography through which the river crosses and it is obvious from the concentrations of flaky minerals downstream (Figure 4). Fourth; they are important in elucidating the provenance depending on their chemistry.

The decreasing amount of flaky minerals downstream (Figure 5) may reflects their short term response to environmental energy conditions that affect their transportation and depositional characteristics. Generally, the heavy minerals from the downstream sections of the river have a greater degree of roundness due to abrasion along the length of the river, which coincides with the overall well rounded nature of the stable light fractions (quartz and chert) and mineral maturity downstream (Al-Juboury *et al*., 2001).

Density is not the only control on settling velocity of the heavy minerals and thus on hydraulic/settling equivalence (Morton and Hallsworth, 1999). Experimental work by Briggs *et al*. (1962) showed that grain shape can be as important as density in controlling the hydraulic behavior of heavy minerals. Mica shows the most extreme manifestation of the effect of the shape factor on hydraulic equivalence. Although mica is a heavy mineral, with a density at about 2.8 to 3.0 gm cm^{-3}, sand-sized mica particles are hydraulically equivalent to silt-sized light minerals (Doyle *et al*., 1983). This highly anomalous hydraulic behavior results from the flaky (platy) habit of detrital mica (Morton and Hallsworth 1999).

Doyle *et al*. (1983) have shown that mica in the coarse silt, very fine-sized sediments is the hydraulic equivalent of silt and very fine sand-sized quartz spheres. They showed that mica grains most often do not orient themselves perpendicular to the flow field as they settle but they tend to settle at some orientation between broadside and edgewise. As a result of the transportation and depositional characteristics of mica, its areal distribution in sediments reflects short term responses to environmental energy conditions. The presence of mica flakes indicates possible deposition from older parent sources or that winnowing and/or by-passing are not being carried out efficiently (Doyle *et al*., 1968).

The most probable source of the flaky minerals is the disintegration of metamorphic and igneous rocks of the Nappe Zone in southern Turkey with additions from the Iraqi Nappe Zone through the tributaries of the Tigris River (Greater Zab River and seasonal tributaries). The plots drawn in the present work reveal that the chemical analysis of individual muscovite flakes has close affinities with the mica composition from mica-schists (Fornelli and Picacarreta 1997). Mica-schists are common in the Nappe Zone of southern Turkey (Tüysüz, 1993) and are probably the source of the studied micas. Muscovite also is common in the fluvial sediments of Turkey (Gültekin, 1991), and indicates that muscovite was derived from the metamorphic basement rocks of Turkey which are composed mostly of garnet mica- schist and quartz muscovite schist. This source is also approved by other works like Ghazal (2005) and Ghazal and Al-Juboury (2006).

The clinochlore-chamosite solid-solution of chlorite grains studied by Zimák (1999) are hydrothermal chlorites from three regions in the NE part of the Bohemian Massif. The studied chlorites of the present work are similar to those called by Zimák typical post-metamorphic veins and veinlets of the "Alpine-type", which contains green, dark green to almost black chlorite in metamorphic amphibolites and gneisses especially of the Sobotin region. That means the chlorites are more expected to be of metamorphic origin related to Alpine-type orogeny. This orogeny was affirmed in the area by many workers (e.g. Al-Juboury *et al*., 1999).

CONCLUSIONS

The flaky minerals (muscovite, biotite and chlorite) were studied from the recent sediments of the Tigris River at selected locations in north

Iraq. Micas are enriched in some localities as pockets and lenses, especially at meander bends along the river. Chemically, the minerals were analyzed using microprobe analysis and the representative plots of each mineral were drawn in order to classify and name them properly. The studied white mica (muscovite) indicates that it is of late- to post-magmatic and hydrothermal type and has close affinities with the mica composition from mica-schist. The studied biotite was derived from metamorphic rocks rather than from magmatic origin, especially it is not phlogopitic or Mg-rich biotite, whereas chlorites are of chamosite type.

The data reveal mostly the suggestion of their source from the metamorphic and igneous rocks of Taurus Range in Turkey, as well as from the disintegration of the older sedimentary formations that the Tigris River crosses and passes through.

Acknowledgments - The authors would like to thank the Paleontological and Mineralogical Institutes of the Bonn University, Germany, for providing access to facilities including the scanning electron microscopy and microprobe analyses during the research fellowship of the fist author granted by the (Deutscher Akademischer Austauschdienst DAAD).

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Table 2. Average relative percentages of the heavy minerals in the studied Tigris River sediments (see Figure 3 for sample locations)

Sample No.	Opaques	Amphiboles	Pyroxenes	Epidotes	Garnet	Mica			Zircon	Tourmaline	Rutile	Kyanite	Staurolite	Spinel	Sphene	Apatite	Olivine
						Mus.	Bio.	Chl.									
T1	31.2	4.8	6.1	9.4	6.3	16.2	10.1	13.2	0.7	1.0	0.4	0.4	0.1	--	--	--	--
T2	38.3	3.9	6.2	18.4	3.5	11.2	5.3	10.1	1.0	1.2	0.1	1.2	0.1	0.1	0.1	0.1	--
T3	35.5	4.4	5.8	18.1	5.7	13.1	5.8	9.8	0.5	0.7	--	0.5	0.2	--	--	--	--
T4	33.7	2.3	2.6	12.7	2.4	18.0	10.5	15.8	0.3	0.4	--	0.4	--	--	--	--	--
T5	46.4	4.3	5.1	18.6	10.0	8.3	1.4	2.7	0.7	0.9	0.2	0.6	--	--	--	--	0.2
T6	47.1	2.9	4.8	19.2	14.2	6.4	1.7	3.2	0.3	0.6	0.1	--	--	0.2	--	0.1	--
T7	54.1	2.7	7.4	22.1	2.2	5.4	0.7	3.0	0.5	0.9	--	--	--	--	--	--	--
T8	52.3	3.0	7.6	24.2	3.9	5.1	0.4	1.9	0.3	0.8	--	--	--	--	0.2	--	0.2
T9	52.1	2.8	6.8	25.1	6.8	3.4	1.1	0.3	0.6	0.9	0.5	0.7	0.1	--	--	--	--

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As there are too many data do in 2 parts Sample No., Opaques – Mica

And Sample No., zircon - olivine