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# Geochemical variations in heavy minerals as provenance indications: application to the Tigris river sand, northern Iraq

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ABSTRACT - Heavy mineral assemblages of the Holocene sediments from the Tigris River in northern Iraq include opaque minerals such as magnetite, chromite and/or chromian spinels, hematite, ilmenite, goethite and pyrite, and non-opaque minerals including epidotes, pyroxenes, amphiboles, garnet, zircon, tourmaline, rutile, kyanite, staurolite, olivine, sphene, apatite, white mica, biotite and chlorite. Mineralogical and chemical characteristics of the heavy minerals were determined using standard petrographic and electron microprobe analyses. Opaque minerals and epidotes increase in content downstream, mica decreases, whereas amphiboles, pyroxenes and garnet show irregular distributions. Chemical characteristics of selected heavy minerals suggest their derivation from a complex of metamorphic and igneous source rocks. Based on the mineralogical and geochemical signatures, heavy minerals closely reflect mafic and ultramafic igneous rocks, metamorphites, and the ophiolitic complexes of northeastern Iraq and southern Turkey.

KEY WORDS: provenance; heavy minerals; mineral chemistry; Tigris River; Iraq

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## INTRODUCTION

Heavy 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 and Arribas et al., 2000). The study of the chemistry of some heavy minerals is a useful tool for better discrimination of the source rocks. Significant information of provenance and tectonic settings can derive from analyses of heavy mineral suites (Morton, 1985; Basu and Molinaroli, 1989; Arai and Okada, 1991; Cookenboo et al., 1997; von Eynatten and Gaupp, 1999; Hisada et al., 2002). Heavy mineral assemblages in river sediments closely reflect the nature of the source area, although their composition is affected by a number of other processes occurring during the sedimentary cycle, such as weathering in the source area, the effects of the transportation process, the hydraulic selection at the depositional environment and the diagenetic processes (Morton and Johnsson, 1993).

The general pattern of the source rocks of the Tigris and Euphrates rivers sand is well constrained upon study of heavy mineral assemblages (Philip, 1968; Jawad Ali, 1977). Al-Juboury et al. (2001a and b) studied the texture and mineralogy of the Holocene sediments of the Tigris River and its tributaries in northern and northeastern Iraq and explained the distribution of these heavy minerals as a consequence of different grain size in the Holocene sediments in addition to the source areas. They also found that the sandy sediments of the Tigris River are finer than those of the Greater and Lesser Zab Rivers and other seasonal tributaries. These sediments show different sorting due to the composition of source rocks and different modes of transportation. Mineralogically, they are composed of quartz, feldspars, mica, rock fragments (mainly sedimentary) and heavy minerals.

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The chemistry of the heavy minerals is used in order to provide new information on provenance area (Morton, 1991; Acquafredda et al., 1997). Based on mineralogical and geochemical characteristics of the heavy minerals, the present work attempts to investigate provenance and transport mechanism of the Holocene Tigris River sand in the northern sector of Iraq.

## GEOLOGY AND GEOMORPHOLOGY

The regional geology of northern Iraq consists of the Zagros Mountain Range with a NW-SE structural trend in the northeastern part, and the E-W trending Taurus Range in the

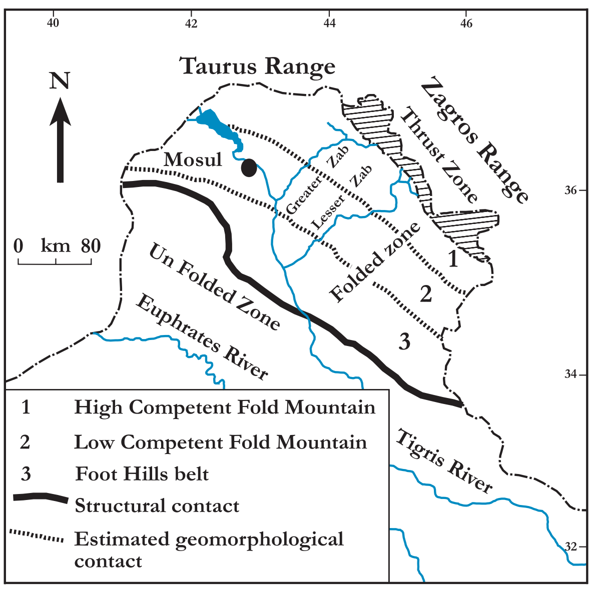



Fig. 1 - Structural framework on Northern Iraq, after Dunnington (1958) and Bolton (1958).

northern part. The structural framework of Iraq was divided by Dunnington (1958) into Thrust Zone, Folded Zone and Unfolded Zone. The Folded Zone was divided geomorphologically by Bolton (1958) into the high competent fold mountains, low competent fold mountains and the foothills belt (Fig. 1). The Tigris River cuts through the latter two morphstructural zones. The zone of low competent fold mountains comprises Tertiary formations and forms gentle though mountainous country with wide valleys and fairly imposing folds structures. The foothills belt mainly consists of Upper Miocene and Pliocene coarse-grained detrital sediments which are gently folded along a NW-SE axis parallel to the structural trend of the Zagros Range with wide synclinal areas.

The Tigris River crosses the southern parts of Turkey, which is a complex igneous and metamorphic region (Nappe Zone), (Gürer, 1994) while most of its tributaries have risen from NE Nappe Zone (i.e. across the Mawat-Chuwarta Ophiolite Complex area) of northern and northeastern Iraq. The Nappe Zone includes the high and tectonically complex Zagros Mountains which trend northwest-southeast. In this area the headwaters of a number of rivers that drain southwestward to the Tigris River may be found. The main sedimentary units outcropping in the area range in age from Jurassic to Quaternary (Fig. 2). This zone has undergone widespread igneous activity including the intrusion of dolerite, gabbro and granite, and the extrusion of andesite and basalt (Jawad Ali, 1977; Buday, 1980) as well as explosive pyroclastics and tuff. Rocks in this zone show a low grade of metamorphism (e.g. slates, phyllites, schists and spilites).

The Zagros Mountains to the north consist of NW-SE trending parallel ridges of folded Upper Paleozoic and Mesozoic age limestones, and a Nappe of metamorphosed Lower Paleozoic rocks along the Iranian border. In this area headwaters of a number of rivers are present; these rivers drain southwestward to the Tigris River. The main drainage system in the area of the Tigris River is discontinuous, whereas it is perennial and subsequent for the region of the Greater and Lesser Zab rivers (Jawad Ali, 1977). The Foothills province mainly consists of Upper Miocene and Pliocene coarse-grained detrital sediments, which are gently folded along the NW-SE axis parallel to the structural trend of the Zagros Mountains. To the west, the Jezira province consists of relatively undisturbed Miocene and Pliocene limestone and evaporites (gypsum), and poorly consolidated Pleistocene detrital rocks (Berry et al., 1970).

The Holocene sediments of the Tigris River consist mainly of unconsolidated to fairly well-indurated deposits of sands, silts and mud. Minor deposits of pebbles are present in some upstream areas; they are mostly of local origin and eroded from the adjacent sedimentary formations (Al-Juboury et al., 2001a). Heavy mineral distribution in these Holocene sediments is compared with older sediments cropping out along the main channel of the Tigris River in the area under study; these include the upper part of the Middle Miocene Fat'ha Formation and the sandstone units of the Late

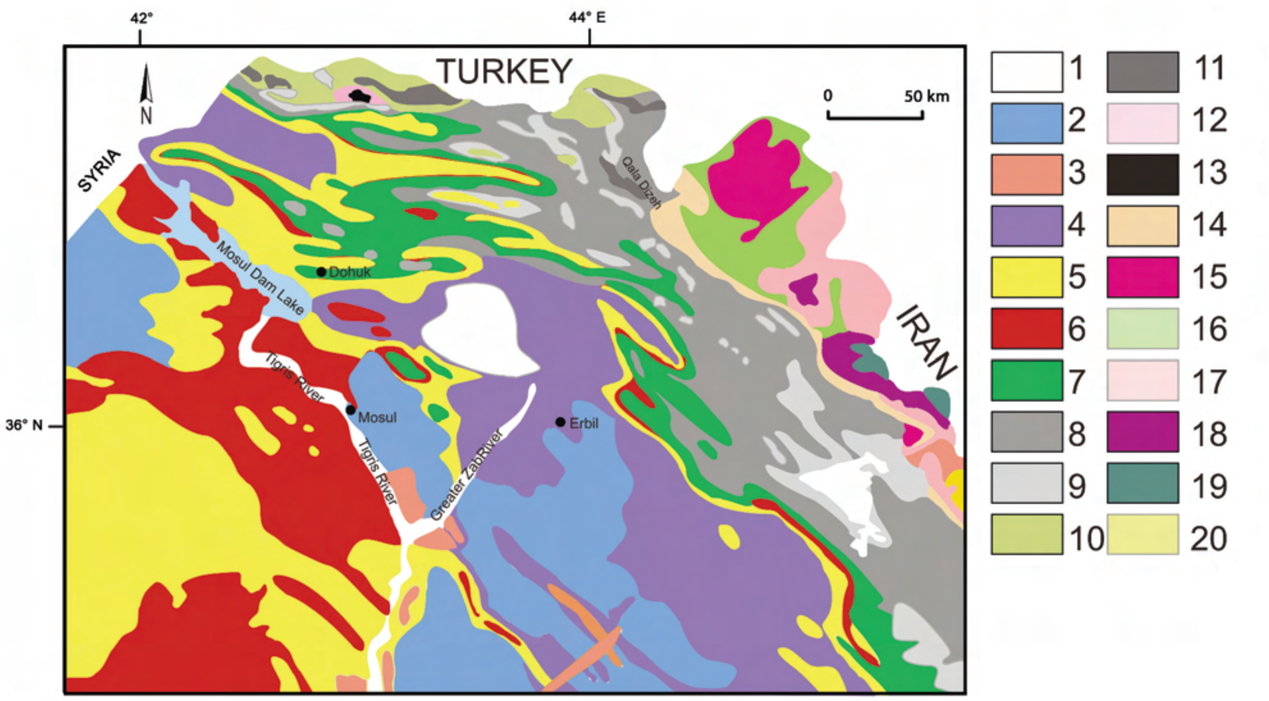



Fig. 2 - Geological map of northern Iraq showing the geological formations from Ordovician to Recent. Modified from the Geological Map of Iraq (1986). 1- Holocene flood plain deposits; 2- Pleistocene-Holocene polygenetic synclinal filling; 3- Pleistocene river terraces; 4- Pleistocene Mukdadiya and Bai Hassan Formations (Bakhtiari group); 5- U. Miocene Injana (U. Fars) Formation; 6- M. Miocene Fatha (L. Miocene) Formation; 7- L. Miocene (Serikagni, Euphrates, Dhiban and Jeribe) Formation. Paleocene (Pila Spi, Avanah and Jaddala) Formations and Eocene ( Gercus, Aaliji, Khurmala and Kolosh) Formations; 8- Cretaceous (Shiranish, Aqra, Qamchuqa and Garagu) Formations; 9- Jurassic (Chia Gara, Naokelekan and Sargelu) Formations; 10- Triassic (Baluti, Kurra China and Geli Khana) Formations; 11- Permian Chia Zairi Formation; 12- Silurian-Carboniferous (Pirispiki chalki volcanics, Kaista, Ora and Harur) Formations; 13- Ordovician Khabour Quartzite Formation; 14- Cretaceous-Pliocene (Red Bed Series); 15- Jurassic-Cretaceous (Qulqula Series), mudstone, shale, and chert; 16- Paleocene-Oligocene (Naopurdan Series), shale, greywacke, and limestone; 17- Paleocene-Eocene (Walash Series), basalt, andesite, and tuff;. 18- Cretaceous (Qandil Series), metamorphic (phylite); 19- Cretaceous (Shalair Series), metamorphic (calcphylites and schists); 20- Cretaceous (Kata Rash Series), volcanic group mainly andesites, dacites, and rhyolites. 14-20 = Nappe Zone successions.

Miocene Injana Formation respectively.

The clastics of the upper member of the Fat'ha Formation are comprised of sandstone, silty claystone and claystones characterized by red coloration and represent two main coarsening-upward cycles. These cycles have been interpreted as having formed within a fluvial-dominated deltaic depositional system (Al-Juboury and McCann, 2008). The Injana Formation is basically a clastic sequence that consists of fining upwards cyclothems of carbonate-rich sandstones, siltstones and claystones and was deposited dominantly in fluvial, coastal and near-shore river environments (Al-Juboury, 1994).

## SAMPLING AND ANALYTICAL METHODS

### Sampling

In the present study, ten localities (Fig. 3) were selected from the Tigris River flood plain area in northern Iraq. The samples were collected from the cross profiles along the river and in abandoned meanders starting from the Turkish

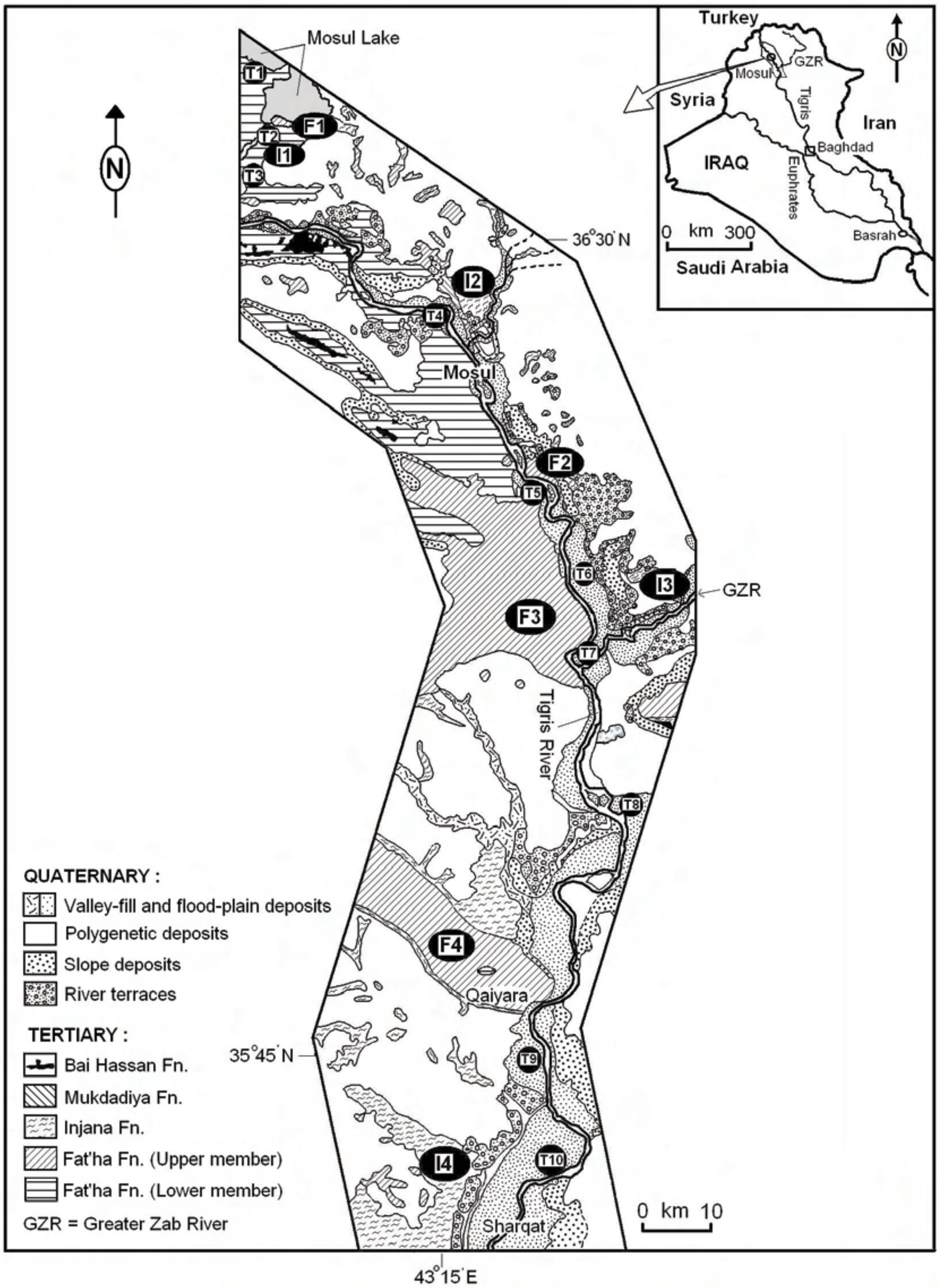



Fig. 3 - Topographic map and surficial geology of the area under study showing the Quaternary to Holocene and some of older formations along the Tigris River with sample locations.

borders to Sharqat town. They were taken during summer season at a depth of 10-cm in each location and were spaced over 250 km.

A quantitative mineralogical study was performed on 20 samples (12 of Holocene and 8 of Miocene sediments) to determine changes in the mineralogical composition. The Holocene sediments consist of 10 samples collected from the main channel of the Tigris River and other two samples from the Greater Zab and Khoser tributaries. The older sediments are represented by 4 samples from the upper clastic unit of the Middle Miocene Fat'ha Formation and 4 samples from the Late Miocene Injana sandstones.

### Heavy mineral analysis

Twenty samples of sands and sandstones were selected from the Holocene and Miocene clastics for the heavy mineral analysis. Heavy minerals from the 0.25-0.063 mm size fraction were separated in order to avoid the effects of the density, shape and size of different heavy minerals in causing hydraulic differentiation (Hubert, 1971). High-density liquid, bromoform and $CHBr_3$ (specific gravity, 2.85) were used to concentrate the heavy minerals. Heavy minerals were identified using standard petrographic procedures. Three hundred grains from each sample were counted as described by Mange and Maurer (1992).

### Chemical analysis

Chemical analyses of the constituent minerals were carried out at the University of Bonn, Germany. A CAMEBAX electron-probe microanalyzer was used. The analyses were carried out on the sand samples of Tigris River. The main mineral phases that are common in the studied samples and dominate in amount are chromian spinel, epidote, amphibole, pyroxene and garnet, and their compositions are summarized in the next section.

Three polished thin sections were prepared from these detrital grains in order to apply electron probe microanalysis (EPMA) techniques to determine the major and minor oxides using wavelength dispersive CAMEBAX microprobe. Analytical error by this technique is < 0.5 wt% for major oxides and < 0.001 wt% for minor oxides.

## RESULTS

### Dense mineral characterization

Opaque minerals represent an important constituent of all heavy mineral suites and usually comprise more than one third of the heavy fraction examined. These opaque minerals are represented by magnetite, chromite and/or chromian spinels, hematite, ilmenite, goethite and pyrite. Non-opaque transparent minerals include epidote, pyroxenes, amphiboles, garnet, zircon, tourmaline, rutile, kyanite, staurolite, olivine, sphene, apatite, white mica, biotite and chlorite (Tab. 1; Fig. 4).

The chromian spinel grains are generally fresh and range from sharply euhedral octahedra to subrounded forms. The mineral is opaque and appears smooth, brilliant and jet-black to deep brown in color.

The recent sandy sediments of Tigris River in northern Iraq are also characterized by a higher proportion of flaky minerals (muscovite, biotite) and chlorite with dominance of white mica (muscovite) comprising about 40% of the heavy fraction at medium grain size sand while other dense minerals are more abundant in the finer grain size. This enrichment of mica may be a result of the sampling method from the meandering part of the river where flaky minerals in pockets or lenses may accumulate. Furthermore, the presence of the Mosul Dam reservoir (Fig. 3) leads to settlement of the dense minerals in the lake and permits the light flaky minerals to be transported beyond the lake along the river channel, especially for the localities T3 and T4 (Fig. 3). Chemical analysis of individual muscovite grain shows similar composition to micaschists (Al-Juboury, 2002; Al-Juboury and Ghazal, 2008). Micaschists are one of the common constituents of the metamorphic complexes of southern Turkey (Gürer, 1994) and are probably the source of the studied muscovite.

The metamorphiclastic (e.g. Le Pera and Critelli, 1997; Critelli and Le Pera, 2004) origin of Tigris River sediments is evidenced by the presence of epidotes and amphiboles,

| Sample No. | Apat. | Sphene | Spinel | Staur. | Kyanite | Rutile | Tourm. | Zircon | Mica | | | Garnet | Epidotes | Pyroxenes | Amphiboles | Opaque | Oliv. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Mus. | Bio. | Chl. | | | | | | |
| T1 | -- | -- | -- | 0.1 | 0.4 | 0.4 | 1.0 | 0.7 | 16.2 | 10.1 | 13.2 | 6.3 | 9.4 | 6.1 | 4.8 | 31.2 | -- |
| T2 | 0.1 | 0.1 | 0.1 | 0.1 | 1.2 | 0.1 | 1.2 | 1.0 | 11.2 | 5.3 | 10.1 | 3.5 | 18.4 | 6.2 | 3.9 | 38.3 | -- |
| T3 | -- | -- | -- | 0.2 | 0.5 | -- | 0.7 | 0.5 | 13.1 | 5.8 | 9.8 | 5.7 | 18.1 | 5.8 | 4.4 | 35.5 | -- |
| T4 | -- | -- | -- | -- | 0.4 | -- | 0.4 | 0.3 | 18.0 | 10.5 | 15.8 | 2.4 | 12.7 | 2.6 | 2.3 | 33.7 | -- |
| T5 | -- | -- | -- | -- | 0.6 | 0.2 | 0.9 | 0.7 | 8..3 | 1.4 | 2.7 | 10.0 | 18.6 | 5.1 | 4.3 | 46.4 | 0.2 |
| T6 | 0.1 | -- | 0.2 | -- | -- | 0.1 | 0.6 | 0.3 | 6.4 | 1.7 | 3.2 | 14.2 | 19.2 | 4.8 | 2.9 | 47.1 | -- |
| T7 | -- | -- | -- | -- | -- | -- | 0.9 | 0.5 | 5.4 | 0.7 | 3.0 | 2.2 | 22.1 | 7.4 | 2.7 | 54.1 | -- |
| T8 | -- | 0.2 | -- | -- | -- | -- | 0.8 | 0.3 | 5.1 | 0.4 | 1.9 | 3.9 | 24.2 | 7.6 | 3.0 | 52.3 | 0.2 |
| T9 | -- | -- | -- | 0.1 | 0.7 | 0.5 | 0.9 | 0.6 | 3.4 | 1.1 | 0.3 | 6.8 | 25.1 | 6.8 | 2.8 | 52.1 | -- |
| T10 | -- | -- | 0.1 | -- | 0.4 | -- | 0.8 | 0.6 | 3.8 | 1.0 | 0.4 | 7.5 | 25.7 | 6.0 | 2.5 | 50.8 | -- |
| G1 | -- | 0.1 | -- | -- | -- | -- | 0.5 | 0.2 | 4.5 | 0.8 | 0.9 | 0.7 | 30.3 | 7.6 | 2.6 | 52.3 | -- |
| K1 | -- | -- | -- | 0.2 | 0.3 | 0.5 | 0.7 | 1.9 | 3.8 | 1.8 | 0.7 | 2.7 | 31.1 | 1.9 | 1.3 | 51.6 | 0.3 |

Tab. 1 - Average relative percentage of the heavy minerals in the studied Tigris River sediments. T (1-10) = Samples from the sand of the main river channel; G1 = Sample from the Greater Zab sediments; K1 = Sample from the Khoser stream sediments; see Figure 3 for sample locations.

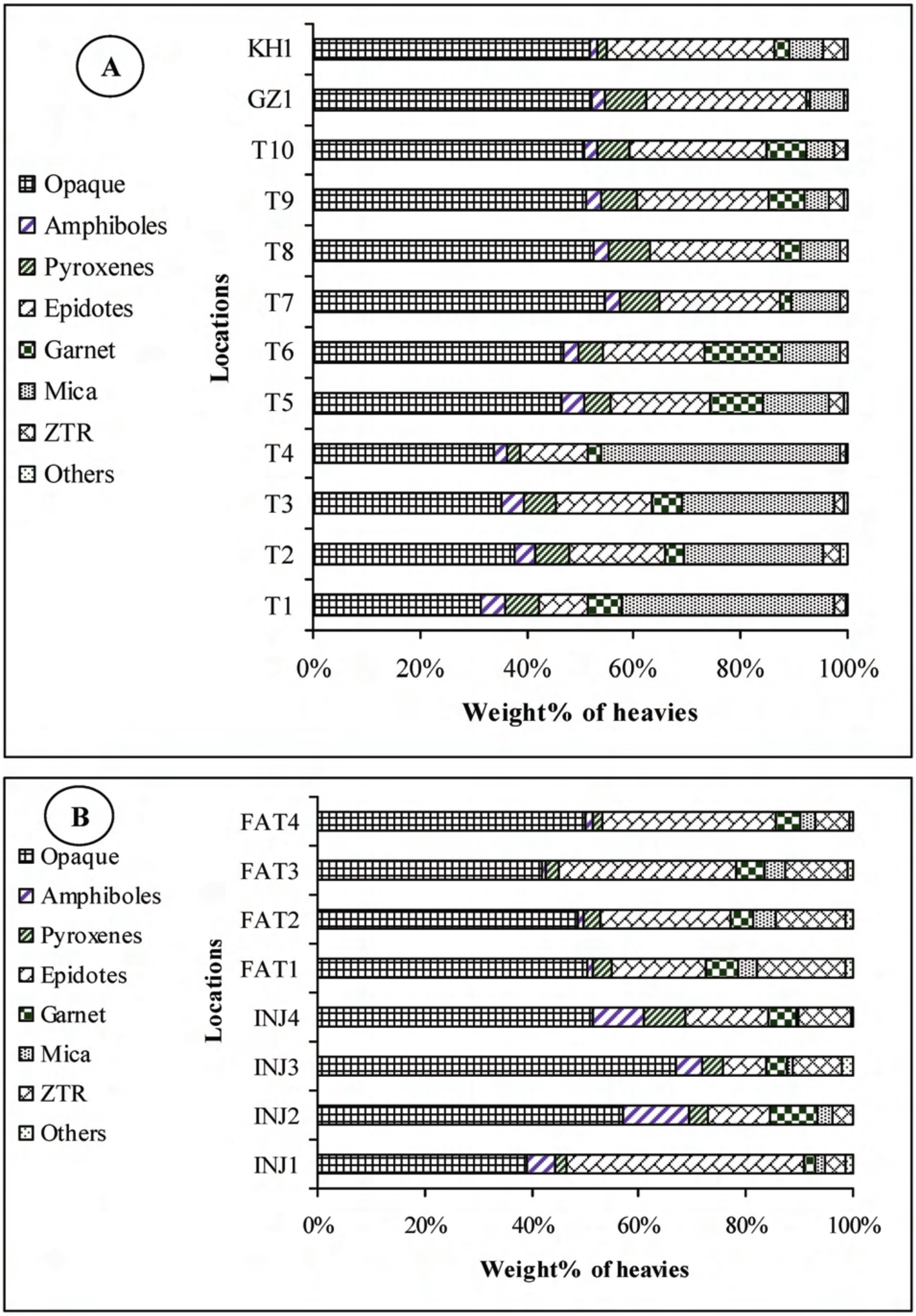



Fig. 4 - Distribution of heavy minerals along the Tigris flood plain deposits A; and from the older Miocene sediments B. Sample locations as in Tables (1 and 2). ZTR= zircon, tourmaline and rutile; others= kyanite, staurolite, sphene, spinel, apatite and olivine.

| Sample No. | Chltd. | Apat. | Sphene | Staur. | Kyanite | Rutile | Tourm. | Zircon | Mica | | | Garnet | Epidotes | Pyroxenes | Amphiboles | Opaque | Oliv. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Mus. | Bio. | Chl. | | | | | | |
| I1 | 0.8 | 0.2 | -- | 0.3 | 0.2 | 0.4 | 0.3 | 3.2 | 0.2 | 1.1 | 0.2 | 2.1 | 44.0 | 2.0 | 5.3 | 38.7 | -- |
| I2 | -- | -- | -- | -- | -- | 0.8 | 1.2 | 1.7 | -- | 1.8 | 1.0 | 8.7 | 11.6 | 3.5 | 12.2 | 56.4 | -- |
| I3 | -- | -- | -- | 1.5 | 0.7 | 1.5 | 2.5 | 3.1 | -- | -- | 1.0 | 4.2 | 8.2 | 4.0 | 4.9 | 68.5 | -- |
| I4 | 0.5 | -- | -- | -- | -- | 2.2 | 3.5 | 4.0 | -- | -- | 0.3 | 5.1 | 15.1 | 7.3 | 9.1 | 49.5 | -- |
| F1 | -- | -- | 0.1 | 1.2 | 0.2 | 8.2 | 1.0 | 5.8 | 1.1 | 0.7 | 1.5 | 6.2 | 17.5 | 3.4 | 1.1 | 50.3 | -- |
| F2 | -- | -- | -- | 1.2 | 0.1 | 6.1 | 0.9 | 5.0 | 0.9 | 0.7 | 2.9 | 4.3 | 24.7 | 3.0 | 1.0 | 49.5 | -- |
| F3 | -- | -- | -- | 1.1 | -- | 4.5 | 1.3 | 4.8 | -- | 0.5 | 3.5 | 5.4 | 33.5 | 2.6 | 0.8 | 42.5 | -- |
| F4 | -- | 0.1 | -- | 0.7 | -- | 3.9 | 1.5 | 5.9 | -- | 0.4 | 2.2 | 4.3 | 30.0 | 1.9 | 1.3 | 46.5 | -- |

Tab. 2 - Average relative percentages of the heavy minerals in the studied Miocene sediments. I (1-4) = Samples from Late Miocene Injana sandstones; F (1-4) = Samples from Middle Miocene Fat'ha sandstones (upper unit), see Figure 3 for sample locations.

such as diagnostic garnet, staurolite and kyanite, which together form more than 25% of the entire dense sedimentary budget. Contributions from basic igneous rocks are testified by the presence of pyroxene minerals (enstatite, diopside, augite and hypersthene), olivine and apatite. Such source rocks occur widely in Turkey, Iran and northeast of Iraq.

Downstream increase in opaque minerals and epidotes is observed especially in sample T6 (near the conjunction with the Greater Zab River) and downward river channel (Fig. 4), whereas mica decreased along this course. This may reflect contributions of sediment supply from the Greater Zab River, which drains the Nappe Zone of northern and northeastern Iraq. This zone has undergone widespread igneous activity including the intrusions of dolerites, gabbro and granites, and the extrusions of andesite and basalt (Jawad Ali, 1977). These rock types commonly contain high amounts of opaque iron ore minerals. Epidote group minerals probably originated from metamorphosed basic rocks in the Nappe Zone where rocks of greenschist facies and hydrothermally altered basalts are common (Buda and Al-Hashimi, 1977). Tigris River tributaries and seasonal streams drain from the folded zone and the headwaters of a number of them rise and cross the Cretaceous and Tertiary clastic formations (Cretaceous Tanjero, Paleocene Kolosh, Eocene Gercus, Upper Miocene Injana, Pliocene Mukdadiya and Bai Hassan) which are rich in both opaque and epidote minerals.

The decreasing of micas may reflect their short-term response to environmental energy conditions that affect their transportation and depositional regime. Generally, the transparent heavy minerals from the downstream sections of the river have a greater degree of roundness that coincides with the overall well roundness of the stable light fractions (quartz and chert) and mineral maturity downstream (Al-Juboury et al., 2001 a).

Amphiboles, pyroxenes and garnet show irregular distributions (Fig. 4). These unstable and moderate stable heavy minerals are not stable under transportation; this is confirmed by the total lack of olivine, apatite and sphene. The decrease of these minerals may relate to their abrasion during transport and/or loss during chemical weathering at the source area.

By comparison with the heavy minerals separated and investigated from the Miocene (Upper part of the Fat'ha Formation and Injana Formation) sediments (Tab. 2), the same heavy mineral suites were observed from these older sediments but in different frequencies, indicating the same source rocks for the Holocene sediments and the older Miocene clastics (Al-Juboury et al., 2009a).

## Chemical characterization

The provenance study has been emphasized using amphiboles, pyroxenes, epidotes and garnets. Detrital chromian spinels are found as one of the accessory heavy minerals from fluvial Miocene to Holocene sediments from northern Iraq, They also exist in older alluvial, deltaic and turbiditic sandstones of Late Tertiary and Cretaceous ages. The provenance and tectonic significance of this mineral were studied by Al-Juboury et al. (2009b). The results indicate that most chromian spinels have interrelated ranges of Cr# or Cr/(Cr+Al) and rather low values of Fe and Ti contents (Tab. 3), suggesting their derivation from ultramafic provenance (Press, 1986; Cookenboo et al., 1997; Lee, 1999; Hisada et al., 2002).

Alpine-type peridotites characterize plate boundaries of all types, and emplaced tectonically rather than by magmatic intrusion (Lee, 1999). Chromian spinels from Alpine-type peridotites exhibit a wide range of Cr# from 0.08 to 0.95 and those near the harzburgite–lherzolite boundary (Cr#≈ 0.5) are predominant.

Higher $Al_2O_3$ and lower Fe values in Chromian spinels are comparable to disseminated chromian spinels in harzburgite Cocherie et al. (1989). Harzburgite with subsidiary dunite and pyroxenite are suggested to be the main intrusive facies of the ultramafic rocks of Iraqi ophiolitic complexes (Al-Jawadi, 1980). He states also that the serpentinized peridotites and the associated chromites from northern Iraq are texturally, mineralogically and chemically similar to Alpine-type peridotites, and are generally rich in Al and more akin to those of podiform alpine-type. In Alpine type peridotites, $Cr^{3+}$ increases with increasing $Fe^{3+}$, but $Fe^{3+}$ concentrations overall remain quite low (Lee, 1999). These results suggest the Alpine-type peridotites as the source rocks of the studied chromian spinels (Fig. 5). All lines of evidence support the derivation of sandstones from the ophiolite-radiolarite belt of the Taurus-Zagros besides the uplifted Cretaceous strata of northern and northeastern Iraq.

The analyzed amphiboles are calcic and ferromagnesian in composition (Tab. 4). The color diversity is mainly due to the variation in the Ti content. $TiO_2$ content in brown hornblende varies from 1.2 to 3.9 wt%, while in the green ones it approaches zero (<0.5%). The FeO content varies from 5.9 to 20.8 wt%. The brown calcic amphiboles are most probably

| ChromianSpinels | 1 | 2 | 3 | 4 | Iraq.1 | Iraq.2 | Iraq.3 | Tr.1 | Tr.2 | Tr.3 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.00 | 0.01 | 0.01 | 0.01 |
| $Al_2O_3$ | 19.06 | 21.68 | 20.14 | 20.01 | 16.21 | 13.40 | 14.81 | 16.99 | 14.90 | 16.15 |
| $TiO_2$ | 0.19 | 0.04 | 0.08 | 0.02 | 0.10 | 0.09 | 0.10 | 0.10 | 0.10 | 0.14 |
| $Cr_2O_3$ | 45.37 | 46.84 | 49.35 | 48.28 | 51.79 | 47.68 | 52.84 | 52.89 | 53.12 | 54.54 |
| FeO | 22.29 | 17.84 | 18.19 | 18.31 | 16.67 | 23.06 | 17.05 | 14.67 | 18.20 | 14.87 |
| MnO | 0.26 | 0.24 | 0.26 | 0.27 | 0.17 | 0.16 | 0.18 | 0.15 | 0.13 | 0.18 |
| MgO | 10.39 | 11.00 | 11.29 | 10.98 | 14.99 | 14.96 | 15.24 | 14.64 | 12.94 | 14.44 |
| Total Oxygen | 97.57 | 97.66 | 99.32 | 97.88 | 99.94 | 99.37 | 100.22 | 99.45 | 99.40 | 100.33 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Al | 0.74 | 0.81 | 0.75 | 0.76 | 0.60 | 0.52 | 0.55 | 0.63 | 0.57 | 0.60 |
| Ti | 0.005 | 0.001 | 0.002 | 0.000 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 |
| Cr | 1.17 | 1.18 | 1.23 | 1.23 | 1.29 | 1.23 | 1.32 | 1.32 | 1.35 | 1.35 |
| $Fe^{2+}$ | 0.49 | 0.47 | 0.46 | 0.47 | 0.29 | 0.27 | 0.27 | 0.31 | 0.37 | 0.32 |
| $Fe^{3+}$ | 0.125 | 0.006 | 0.020 | 0.024 | 0.150 | 0.366 | 0.178 | 0.077 | 0.116 | 0.070 |
| Mn | 0.007 | 0.006 | 0.007 | 0.007 | 0.005 | 0.004 | 0.005 | 0.004 | 0.004 | 0.005 |
| Mg | 0.51 | 0.52 | 0.53 | 0.53 | 0.71 | 0.73 | 0.72 | 0.69 | 0.62 | 0.67 |
| Cr# | 0.61 | 0.59 | 0.62 | 0.62 | 0.68 | 0.70 | 0.71 | 0.68 | 0.71 | 0.69 |
| Mg# | 0.51 | 0.53 | 0.54 | 0.53 | 0.71 | 0.73 | 0.72 | 0.69 | 0.62 | 0.68 |
| Cr3# | 0.58 | 0.59 | 0.62 | 0.61 | 0.63 | 0.58 | 0.64 | 0.65 | 0.67 | 0.67 |
| Al3# | 0.36 | 0.41 | 0.37 | 0.38 | 0.29 | 0.24 | 0.27 | 0.31 | 0.28 | 0.30 |
| Fe3# | 0.061 | 0.002 | 0.010 | 0.012 | 0.073 | 0.173 | 0.086 | 0.038 | 0.057 | 0.034 |

Tab. 3 - Representative chemical composition of chromian spinels of recent sediments of the Tigris River and from the ophiolitic complexes from Iraq and Turkey. (Iraq 1-3) = massive chromites from Mawat and Penjwin complexes, Iraq (Al-Jawadi, 1980); (Tr. 1-3) = massive chromites from Turkey (Tüysüz, 1993).

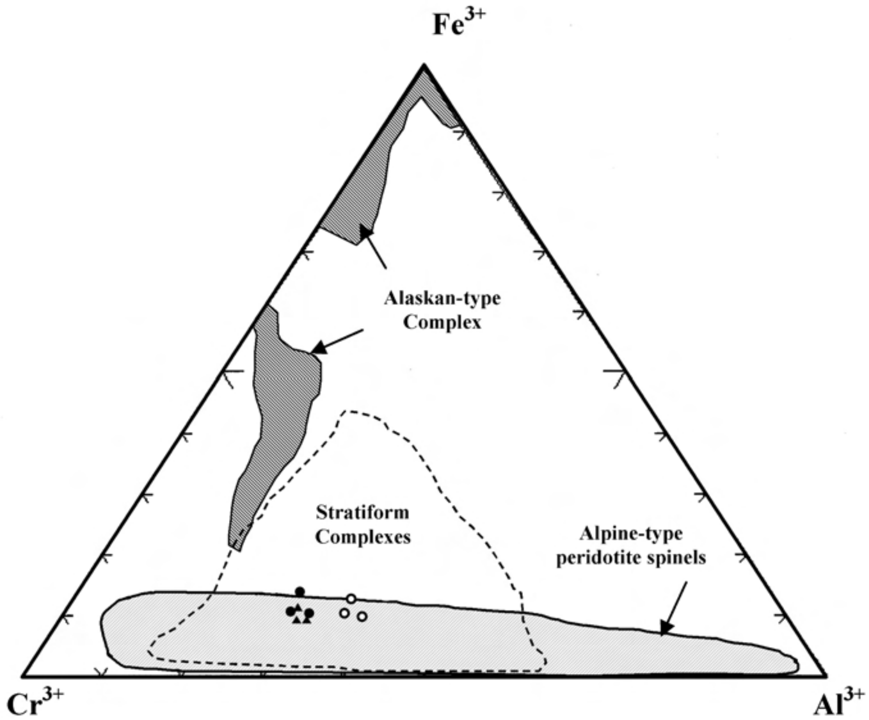



Fig. 5 - Ternary plot of the major trivalent cations in chromian spinels for discriminating types of ultramafic source (after Cookenboo et al., 1997), illustrating the position of the studied chromian spinels and those taken from the ophiolitic complexes from Iraq and Turkey within the alpine-type peridotite field; open circles=present study, solid circles= chromian spinels from Iraqi ophiolite (Al-Jawadi, 1980), solid triangle = chromian spinels from Turkish ophiolite (Tüysüz, 1993).

| Sample No. | 1 | 2 | 3 | 4 | KH-3 | 221 | N-4Amph. | N-7 | N-16 | 1 | 2 | 3 | 4 | KH-4 | KH-10 | 221 | 304 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mineral | Amph | Amph | Amph | Amph | Amph | Amph | Amph | Amph | Amph | Pyrx. | Pyrx | Pyrx | Pyrx | Pyrx | Pyrx | Pyrx | Pyrx |
| $SiO_2$ | 44.38 | 46.81 | 46.51 | 44.81 | 42.83 | 42.34 | 42.90 | 41.79 | 42.11 | 52.96 | 57.02 | 53.07 | 48.38 | 47.95 | 48.64 | 51.59 | 49.93 |
| $Al_2O_3$ | 11.34 | 10.34 | 12.93 | 9.94 | 11.10 | 12.07 | 12.98 | 14.00 | 12.45 | 2.45 | 1.54 | 1.94 | 5.81 | 5.80 | 5.23 | 2.49 | 4.03 |
| $TiO_2$ | 3.99 | 4.36 | 3.56 | 4.24 | 4.55 | 4.34 | 3.36 | 3.81 | 4.01 | 0.34 | 0.18 | 0.37 | 1.07 | 1.86 | 1.88 | 0.56 | 1.50 |
| $Cr_2O_3$ | 0.04 | 0.00 | 0.04 | 0.06 | 0.05 | 0.005 | 0.07 | 0.38 | 0.15 | 0.31 | 0.20 | 0.48 | 0.28 | 0.23 | 0.27 | 0.30 | 0.28 |
| FeO | 11.21 | 12.58 | 10.09 | 8.66 | 12.81 | 13.27 | 7.35 | 7.40 | 8.65 | 4.15 | 5.92 | 4.45 | 6.10 | 7.11 | 7.63 | 8.64 | 6.48 |
| MnO | 0.13 | 0.07 | 0.36 | 0.16 | 0.24 | 0.25 | 0.26 | 0.09 | 0.13 | 0.19 | 0.09 | 0.03 | 0.01 | 0.11 | 0.14 | 0.41 | 0.23 |
| MgO | 12.66 | 11.82 | 12.81 | 15.06 | 12.65 | 12.62 | 15.36 | 14.70 | 14.24 | 16.59 | 21.52 | 15.97 | 13.80 | 14.05 | 13.90 | 14.32 | 14.02 |
| CaO | 12.16 | 10.11 | 10.53 | 11.77 | 11.13 | 11.04 | 11.69 | 11.82 | 11.48 | 22.46 | 12.42 | 23.82 | 23.70 | 22.58 | 22.40 | 21.05 | 22.70 |
| $Na_2O$ | 2.04 | 2.06 | 2.07 | 1.29 | 2.38 | 2.49 | 2.51 | 2.79 | 2.72 | 0.25 | 0.06 | 0.25 | 0.51 | 0.35 | 0.44 | 0.37 | 0.67 |
| $K_2O$ | 0.50 | 0.63 | 0.35 | 0.13 | 0.77 | 0.58 | 0.55 | 0.46 | 0.40 | 0.00 | 0.08 | 0.02 | 0.01 | 0.00 | 0.01 | 0.00 | 0.03 |
| Total Oxygen | 98.45 | 98.78 | 99.25 | 96.12 | 98.51 | 99.01 | 97.03 | 97.24 | 96.34 | 99.70 | 99.03 | 100.4 | 99.67 | 100.04 | 100.54 | 99.73 | 99.87 |
| | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Si | 6.439 | 6.734 | 6.578 | 6.547 | 6.287 | 6.192 | 6.227 | 6.070 | 6.201 | 1.940 | 2.039 | 1.941 | 1.808 | 1.790 | 1.809 | 1.927 | 1.860 |
| Al | 1.938 | 1.753 | 2.155 | 1.712 | 1.919 | 2.029 | 2.219 | 2.396 | 2.160 | 0.106 | 0.065 | 0.084 | 0.256 | 0.225 | 0.228 | 0.108 | 0.176 |
| Ti | 0.435 | 0.472 | 0.379 | 0.466 | 0.502 | 0.477 | 0.367 | 0.416 | 0.444 | 0.009 | 0.005 | 0.010 | 0.030 | 0.052 | 0.053 | 0.016 | 0.042 |
| Cr | 0.005 | 0.000 | 0.004 | 0.007 | 0.006 | 0.001 | 0.008 | 0.044 | 0.017 | 0.009 | 0.006 | 0.014 | 0.008 | 0.007 | 0.008 | 0.009 | 0.008 |
| $Fe^{2+}$ | 1.360 | 1.513 | 1.193 | 1.058 | 1.572 | 1.622 | 0.892 | 0.898 | 1.064 | 0.127 | 0.177 | 0.136 | 0.290 | 0.222 | 0.237 | 0.269 | 0.201 |
| Mn | 0.016 | 0.009 | 0.043 | 0.020 | 0.030 | 0.031 | 0.032 | 0.011 | 0.016 | 0.006 | 0.003 | 0.001 | 0.000 | 0.003 | 0.004 | 0.013 | 0.007 |
| Mg | 2.738 | 2.535 | 2.701 | 3.281 | 2.768 | 2.751 | 3.324 | 3.183 | 3.126 | 0.906 | 1.147 | 0.871 | 0.769 | 0.782 | 0.774 | 0.798 | 0.779 |
| Ca | 1.890 | 1.558 | 1.595 | 1.842 | 1.750 | 1.730 | 1.818 | 1.839 | 1.811 | 0.881 | 0.476 | 0.933 | 0.949 | 0.903 | 0.892 | 0.842 | 0.906 |
| Na | 0.574 | 0.427 | 0.351 | 0.365 | 0.163 | 0.116 | 0.112 | 0.142 | 0.159 | 0.018 | 0.004 | 0.018 | 0.037 | 0.025 | 0.032 | 0.028 | 0.048 |
| K | 0.093 | 0.116 | 0.063 | 0.024 | 0.144 | 0.108 | 0.102 | 0.085 | 0.075 | 0.000 | 0.003 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| | | | | | | | | | | Fs6.70 | 9.80 | 7.00 | 10.0 | 11.6 | 12.5 | 14.1 | 10.7 |
| | | | | Calcic | | | | | | En47.3 | 63.7 | 44.9 | 40.3 | 41.0 | 40.5 | 41.8 | 41.3 |
| | | | | | | | | | | Wo46.0 | 26.5 | 48.1 | 49.7 | 47.4 | 47.0 | 44.1 | 48.0 |

Tab. 4 - Representative chemical composition of selected amphiboles and pyroxenes in the recent sandy sediments of Tigris River (samples 1-4) and of other amphiboles and pyroxenes. Amph. KH-3; Pyrx. KH-4 & KH-10 = amphibole and pyroxene samples from Bulfat gabbro, NE Iraq (Ghazal, 1980), Amph. 221; Pyrx 221 & 304 = amphibole and pyroxene samples from Qala Dizeh area, NE Iraq (Buda and Al-Hashimi, 1977), N-4, N-7 & N-16 = amphibole samples from Herro (Qala Dizeh), NE Iraq (Sofy, 2003). Fs = Ferrosilite; En = Enstatite; Wo = Wollastonite.

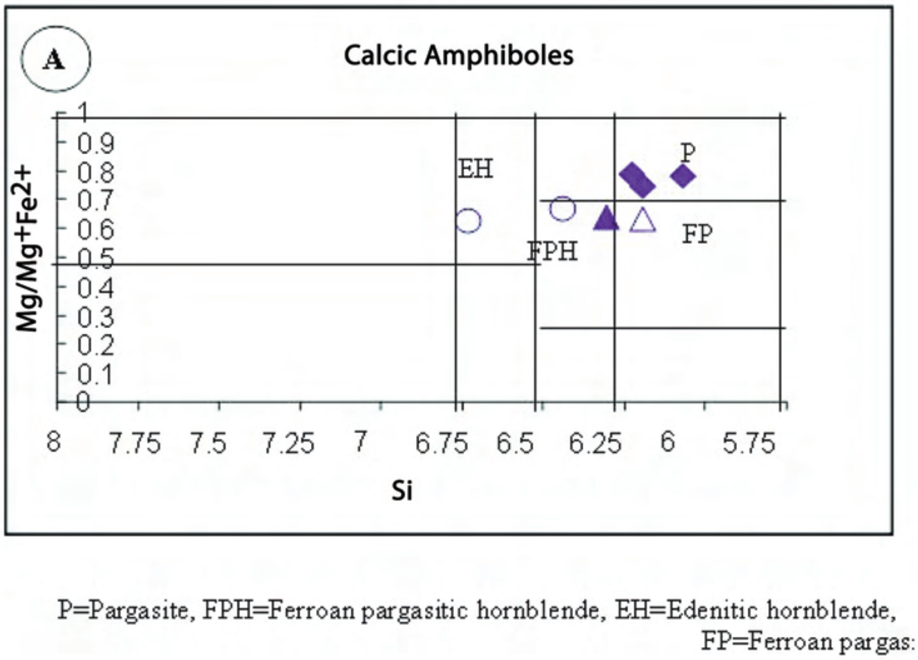
derived from basic/intermediate magmatic rocks, whereas the green calcic and Mg-actinolite and tremolite hornblende may originate from low-grade regionally metamorphosed ultrabasic rocks (Deer et al., 1992).

These rocks are common in northeastern Iraq and southern Turkey. Using the classification diagrams of Leake (1978), the amphiboles of the present work are shown to be of calcic amphiboles (ferroan pargasite and silicic ferro-edenite) and are similar to those amphiboles from the crystalline rocks at Bulfat, northeastern Iraq, (Fig. 6A; Tab. 4) which are believed to be a source of the studied amphiboles.

Pyroxenes analyzed are classified as clinopyroxene, including diopside, augite and Ti-augite (Fig. 6B; Tab. 4). In Table (4), the clinopyroxenes in general are rich in CaO (12.4-24.0%), MgO (13.5-21.5%) and poor in FeO (4.1-6.1%). The calculation of their constituents clearly revealed that they have enstatite ($en_{40}$-$en_{48}$), wollastonite ($wo_{45}$-$wo_{50}$) and ferrosilite ($fs_{6.0}$-$fs_{10}$) in their chemical formulae.

The pyroxene composition ($En_{47-40}Fs_{10-6}Wo_{49-45}$) straddles the diopside–augite fields according to Morimoto's (1988) classification. The chemistry of detrital clinopyroxenes studied is near to the clinopyroxenes of the Paleogene Bulfat layered gabbroic plutons in northeastern Iraq (Ghazal, 1980) and to the pyroxenes of the Penjwin ophiolitic complexes in northeastern Iraq (Al-Hassan and Hubbard, 1985). Recently, Sofy (2003) studied the petrogeochemistry of Bulfat mafic layered igneous intrusions from northeastern Iraq and concluded that they were composed mainly of trectolite, olivine gabbro, pyroxene and amphibole gabbros. Geochemical analysis of the studied amphiboles and pyroxenes are closely related to these crystalline sources (Fig. 6).

Detrital garnet analyzed in this study is usually almandine rich (> 40% up to 60%). Pyrope and grossular components generally range from 10% to 34% with maximum values of 34% and 27%, respectively (Tab. 5). Garnet group minerals are common in heavy minerals of siliciclastic sediments and indicate metamorphic source rocks (Mange and Maurer 1992). The garnets of the Tigris River sands are pyrope-bearing almandine; therefore, they are not typical garnets of granitic and aplitic igneous rocks (Deer et al., 1992), otherwise of metamorphic origin. In comparison with the available garnets from the crystalline rocks of Turkey, it is



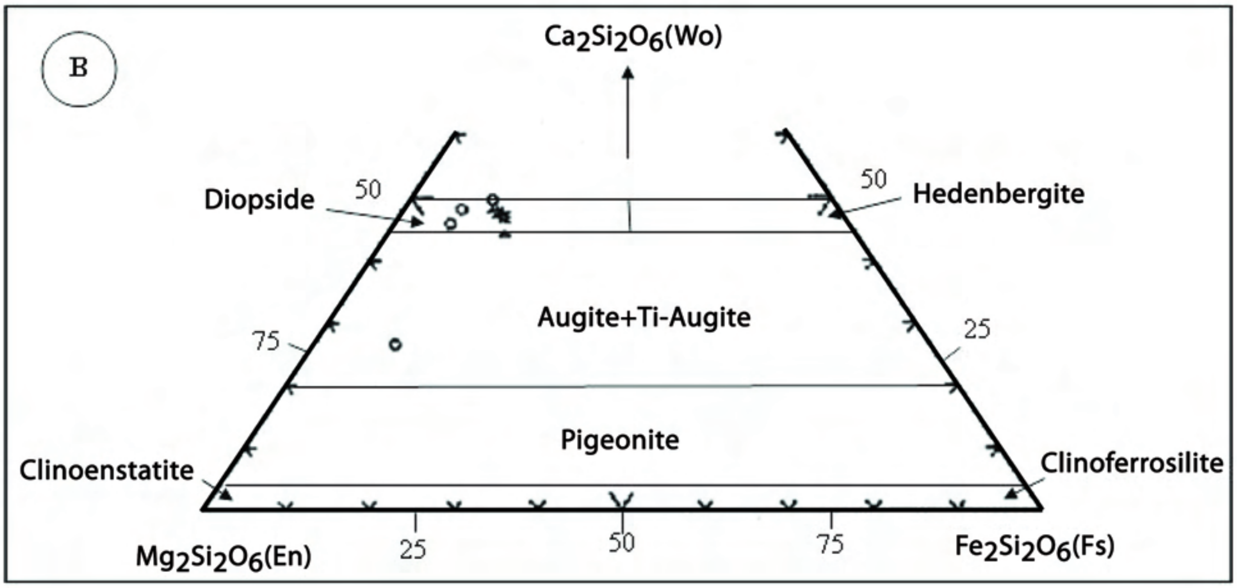




Fig. 6 - (A) Classification of the studied amphiboles and from Bulfat gabbroic rocks, NE Iraq. Fields after Leake (1978); open circles = present study, solid triangle = Ghazal (1980), open triangle = Buda and Al-Hashimi (1977), solid diamonds = Sofy (2003).
(B) $Ca_2Si_2O_6$-$Mg_2Si_2O_6$-$Fe_2Si_2O_6$ plot of analyzed clinopyroxenes and from Bulfat gabbroic rocks, NE Iraq. Fields after Morimoto (1988); open circles = present study, stars = Ghazal (1980), solid triangle = Buda and Al-Hashimi (1977).

believed that the present garnets were derived from these crystalline rocks since these crystalline rock garnets are mainly of almandine type, but with different varieties (Tab. 5; Fig. 7). The chemical analysis of detrital epidotes (Tab. 5) shows a highly Ca-rich composition pointing to clinozoisite in both garnet bearing micaschist and blue amphibole micaschist grains (Fornelli and Piccarreta, 1997). Epidote minerals are dominantly epidote (synonym pistachite) with smaller amounts of zoisite and clinozoisite derived from metamorphic rocks including metamorphosed igneous rocks. These rock types occur in the Zagros and Taurus Ranges of Iraq and Turkey respectively. Moreover, recycling of older clastic formations (Tanjero, Kolosh, Injana, Mukdadiya and Bai Hassan) and river terraces, which have relatively high content of detrital epidotes, have probably affected the high content of epidote in the recently studied sandy sediments.

## DISCUSSION

The Holocene sandy sediments from the Tigris River in northern Iraq are fine- to medium-grained with moderate to poorly sorted texture. The most significant constituents in addition to quartz are rock fragments (predominantly sedimentary), micas, feldspars and heavy minerals. They are classified as litharenites (Al-Juboury et al., 2009a) according to Folk (1974).

| Sample No. | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | TR.1 | TR.2 | TR.3 | TR.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mineral | Epid. | Epid. | Epid. | Epid. | Gar. | Gar. | Gar. | Gar. | Gar. | Gar. | Gar. | Gar. |
| $SiO_2$ | 34.97 | 35.78 | 35.98 | 36.00 | 38.69 | 38.18 | 38.09 | 39.37 | 36.95 | 37.27 | 37.15 | 37.23 |
| $Al_2O_3$ | 18.77 | 19.12 | 19.29 | 19.47 | 22.33 | 22.22 | 21.70 | 22.81 | 21.11 | 21.08 | 21.07 | 21.10 |
| $TiO_2$ | 0.63 | 0.02 | 0.27 | 0.01 | 0.01 | 0.05 | 0.16 | 0.04 | <0.03 | <0.03 | 0.31 | 0.04 |
| $Cr_2O_3$ | 0.00 | 0.00 | 0.01 | 0.00 | 0.09 | 0.00 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| FeO | 2.92 | 3.03 | 3.26 | 2.85 | 26.53 | 26.72 | 22.81 | 20.29 | 17.05 | 21.98 | 28.62 | 32.82 |
| MnO | 0.00 | 0.07 | 0.02 | 0.00 | 0.68 | 0.55 | 1.25 | 0.40 | 22.75 | 17.29 | 9.98 | 5.57 |
| MgO | 1.08 | 1.55 | 1.12 | 1.05 | 8.04 | 8.04 | 6.03 | 9.26 | 2.25 | 2.26 | 1.35 | 1.57 |
| CaO | 34.24 | 34.34 | 34.87 | 34.81 | 4.52 | 4.26 | 10.20 | 9.47 | 0.25 | 0.24 | 1.87 | 2.46 |
| $Na_2O$ | 0.07 | 0.06 | 0.06 | 0.02 | 0.04 | 0.06 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| $K_2O$ | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total Oxygen | 92.68 | 93.98 | 94.88 | 94.21 | 100.93 | 100.09 | 100.31 | 101.66 | 100.35 | 100.12 | 100.35 | 100.79 |
| | 13 | 13 | 13 | 13 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Si | 3.138 | 3.161 | 3.164 | 3.169 | 2.965 | 2.953 | 2.951 | 2.945 | 2.99 | 3.01 | 3.00 | 3.00 |
| Al | 1.985 | 1.991 | 1.993 | 2.020 | 2.017 | 2.026 | 1.981 | 2.011 | 2.01 | 2.01 | 2.01 | 2.00 |
| Ti | 0.043 | 0.001 | 0.018 | 0.001 | 0.001 | 0.003 | 0.009 | 0.002 | 0.0 | 0.00 | 0.02 | 0.00 |
| Cr | 0.000 | 0.000 | 0.001 | 0.000 | 0.005 | 0.000 | 0.002 | 0.001 | 0.0 | 0.0 | 0.0 | 0.0 |
| $Fe^{2+}$ | 0.219 | 0.224 | 0.289 | 0.210 | 1.700 | 1.728 | 1.478 | 1.269 | 1.15 | 1.49 | 1.94 | 2.21 |
| Mn | 0.000 | 0.005 | 0.001 | 0.000 | 0.004 | 0.036 | 0.082 | 0.025 | 1.56 | 1.18 | 0.68 | 0.38 |
| Mg | 0.149 | 0.204 | 0.146 | 0.138 | 0.918 | 0.927 | 0.696 | 1.033 | 0.27 | 0.27 | 0.16 | 0.19 |
| Ca | 3.292 | 3.250 | 3.275 | 3.283 | 0.371 | 0.353 | 0.847 | 0.759 | 0.02 | 0.02 | 0.16 | 0.21 |
| Na | 0.012 | 0.010 | 0.010 | 0.003 | 0.006 | 0.009 | 0.005 | 0.001 | 0.00 | 0.00 | 0.00 | 0.00 |
| K | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | Pyr30.3 | 30.5 | 22.4 | 33.5 | 9.00 | 9.00 | 6.00 | 6.00 |
| | Clinozoisite | | | | Sp 1.50 | 1.20 | 2.60 | 0.80 | 52.0 | 40.0 | 22.0 | 13.0 |
| | | | | | Gro12.2 | 11.6 | 27.3 | 24.6 | 1.00 | 1.00 | 6.00 | 7.00 |
| | | | | | Alm56.0 | 56.8 | 47.6 | 41.1 | 38.0 | 50.0 | 66.0 | 74.0 |

Tab. 5 - Representative chemical composition of selected epidote and garnet in the recent sandy sediments of Tigris River, and some garnet samples from Turkey (GTR 1-4; Whitney, 2002), Pyr = Pyrope; Sp = Spessartine ; Gro = Grossular; Alm = Almandine.

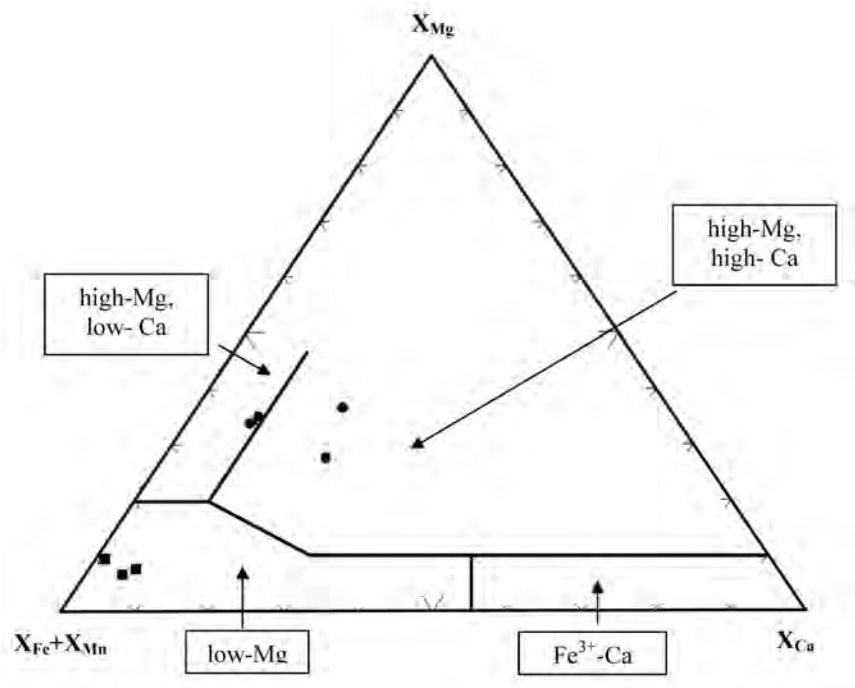



Fig. 7 - Ternary diagram illustrating the classification of the studied garnet, and those from Turkey. Fields after Morton et al. (2003); open circles = present study garnets, stars = garnets from the crystalline rocks of Turkey. Whitney (2002).

The heavy mineral suites observed in samples taken from recent and older Miocene deposits contain nearly the same minerals but in varying frequencies. Most of the minerals observed, fall into four groups: opaque, epidotes, amphiboles and pyroxenes which form more than 80% of the heavy minerals in the majority of samples studied, (Fig. 4). On the basis of heavy minerals distribution, the provenance of Tigris river sandy sediments suggests metamorphic and igneous rocks of the Nappe Zone of Iraq and the highlands of southeastern Turkey, whereas those of the Greater Zab river were derived from igneous and metamorphic terrain especially Walash and Qandil series as well as older clastic formations of northern and northeastern Iraq. The source areas of the Tigris River and its tributaries are the highlands in Turkey, Iran and the Nappe zone of Iraq, which consists mainly of metamorphic and basic igneous rocks.

Opaque minerals generally form more than one-third of the heavy fraction and are composed of chromian spinels as well as magnetite, ilmenite, goethite, pyrite and hematite. Chromian spinel is the dominant opaque mineral and reaches up to two-thirds of the studied opaque at some localities from northern Iraq (Al-Juboury et al., 1999). Most of the opaque minerals of Tigris River sediments show well-developed crystals as they have been originated from the relatively nearby source rocks in the highlands of southern Turkey. The Iraq-Nappe Zone is composed of basic igneous and metamorphic terrains which may be the source of the opaque minerals in the studied sediments.

The high concentration of opaques in many samples from the present study indicates that these stations had experienced erosion and high-energy conditions. Erosion leading to the concentration of these opaques involves the selective removal and transportation of the light minerals.

By comparison with the heavy minerals taken from the older sediments, it is evident that the recent sediments of the Tigris River, which are presumably derived from similar sources, contain several times as much heavy minerals (average content of more than 7%, Philip, 1968; and about 5.5%, the present work). Along with many features of alteration and dissolution discussed above, this fact indicated that intrastratal alteration has caused a reduction in the heavy mineral content of the older Fat'ha and Injana formations.

Several factors control the enrichment of chromites and chromian spinels in Tigris River Holocene sediments and its tributaries in northern Iraq. These factors include the following: the location of study area, which is not far from the main ophiolitic complexes of Iraq and Turkey (these complexes are rich in chromites and chromian spinel; Buda and Al-Hashimi, 1977; Engin et al., 1986); recycling of chromian spinels from the older clastic formations (mainly the Eocene Gercus Formation) which contain more than 60% of chromian spinels and chromites in the opaque fractions of the heavy minerals (Al-Rawi, 1980); and the morphology of the river which may represent another factor for such enrichment. In fact, most of the studied samples are taken from the meandering part of the river where heavy minerals can be accumulated.

The chromite and chromian spinels have a specific gravity of 4.6 and show small mean grain sizes, which may be responsible for the concentration of mineral grains in the finer rather than coarser-sized detritals. This conclusion coincides with an increase in the overall content of smaller grain size heavy minerals from medium to fine detrital varieties Osovetskii (1974).

The facts that opaque minerals have specific gravity within the range of 4.3-5.2, are largely restricted to the finer size grades 0.125-0.063 mm (3Ø-4Ø) and microscopically show comparable shape and specific gravities led Leupke (1980) to conclude that such characteristics effectively eliminate any differential sorting of these minerals and promote its better accumulation in the Recent fluvial and beach sediments.

The presence of common sharply euhedral shapes of chromian spinel grains indicates short transportation distance. Intensive weathering of the ophiolites of the Zagros thrust zone under highly oxidizing and alternating wet and dry conditions resulted in unique composition of the weathering products. A suite of heavy minerals, consisting essentially of chromian spinel grains, was flushed away during the wet seasons to be deposited in various local environments along nearby elongated troughs that included deltas, floodplains and alluvial fans and even shallow marine environments (Dhannoun and Al-Dabbagh, 1990).

The amphiboles are calcic, ferromagnesian and partly sodium-rich, whereas pyroxenes are typically of clino-pyroxene type diopside, augite and Ti-augite. Chemical analyses of the amphiboles and pyroxenes from the Tigris River sands show closer affinities to those taken from the crystalline source rocks from Bulfat (Qala Dizeh) in northeastern Iraq (Fig. 6).

Garnet is mainly almandine-rich with variable content of pyrope and grossular. This garnet shows some similarity to the garnet from the crystalline rocks of Turkey (Tab. 5, Fig. 7). Epidotes generally are of clinozoisite Ca-rich type with subordinate pistachite for all the analyzed samples.

Chromian spinels have a value of Cr# or Cr/(Cr+Al) generally over 0.5 with low Fe and $TiO_2$ content suggesting that the sand hosted chromian spinels were derived from ultramafic provenance. These chemical variations indicate the derivation of the studied heavies from the ophiolitic complexes in northeastern Iraq as well as the Nappe Zone of southern Turkey. These geochemical results support the Alpine-type peridotites source rocks of the studied chromian spinels.

The source of the heavy minerals in these sediments is believed to be from the northern and northeastern parts of Iraq and is composed of metamorphic and igneous complexes of Zagros-Taurus belt as well as the Cretaceous and Paleocene–Eocene clastic rocks (Al-Juboury, 2001; Al-Juboury et al., 2001c).

## CONCLUSIONS

1. The study documents the heavy mineral composition of the Tigris River sediments in northern Iraq and compares their distribution with the older Miocene sediments cropping out along the river channel and concludes on the provenance of the heavy minerals.
2. The recent sandy sediments along the Tigris River and the older sedimentary rocks from northern Iraq show similar heavy mineral suites but in different frequencies, indicating similarity in their source rocks.
3. The heavy mineral assemblage is dominated by opaque minerals (mainly chromian spinel) as well as non-opaque minerals represented by epidotes, pyroxenes, amphiboles, garnet, zircon, tourmaline, rutile, kyanite, staurolite, olivine, sphene, apatite, biotite, muscovite and chlorite, which are derived from metamorphic and to a minor extent igneous (basic to ultrabasic) sources.

4. Opaque minerals and epidotes increase in content downstream, mica decreases, whereas, amphiboles, pyroxenes and garnet show irregular distributions. This may reflect the contribution of the source rocks, the resistance to weathering and hydraulic conditions. The decrease of mica may also reflect environmental and fluvial conditions that influenced their transportation and deposition.

5. Chemical analysis of epidote, amphibole, pyroxene, garnet and chromian spinels suggests their derivation from a complex of metamorphic and igneous terrain.

6. Based on the mineralogical and geochemical indicators, the probable provenance of the heavy minerals from the recent sandy sediments of the Tigris River is the basic, ultrabasic and metamorphic rocks and the ophiolitic complexes of northeastern Iraq and southern Turkey.

7. The present study can be regarded as a modern analogue of a fluvial system with a geologically well-studied hinterland and known drainage network.

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