Tectonostratigraphy of the Khoy Complex, northwestern Iran

Emile A. Pessagno, Jr.1, A. Mohamad Ghazi2, Mohsen Kariminia1, R. A. Duncan3, and A. A. Hassanipak4

1Department of Geological Sciences, The University of Texas at Dallas, PO Box 830688, Richardson, TX 75083-0688
2Department of Geology, Georgia State University, Atlanta, GA 30303
3COAS, Oregon State University, Corvallis, OR 97331-5503
4Department of Mining Engineering, University of Tehran, Iran

ABSTRACT: Previous studies suggested that only one ophiolite, the “Khoy ophiolite”, existed near Khoy, northwestern Iran. This thesis is no longer tenable.

Combined investigations (biostratigraphic, chronostratigraphic, geochronologic, and geochemical) demonstrate that there are at least two and perhaps three ophiolite remnants in the Khoy area:

(1) A Late Jurassic (early to middle Oxfordian: 156 Ma to 159 Ma 40Ar-39Ar on gabbro) remnant;
(2) A Late Cretaceous (early Coniacian: Radiolaria) remnant (~N-MORB geochemistry); and, possibly,
(3) A Late Cretaceous (latest Campanian) remnant (E-MORB geochemistry).

Because it is impossible to use the term “Khoy ophiolite” in this report, we refer the ophiolitic rocks in the Khoy area to the “Khoy Complex” (sensu International Stratigraphic Guide).

The sedimentary contact between Late Cretaceous (early Coniacian) red manganiferous ribbon chert lacking calc-alkaline volcanic contributions and overlying pyroclastics (tuff and tuff breccia) in the far northwestern part of the Khoy complex is of great tectonostratigraphic significance. This interface represents a sudden change from pelagic to pyroclastic sedimentation. Field evidence indicates that the contact is disconformable and is associated with a hiatus of unknown magnitude. Red ribbon chert (lacking calcalkaline contributions) in the same area overlies and is interbedded with N-MORB pillow basalt; early Coniacian Radiolaria were recovered from interpillow siliceous mudstone. We postulate that by the early Coniacian oceanic crust (covered with a veneer of Radiolarian ooze) had moved close enough to an island arc system to receive calc-alkaline pyroclastics.

Tectonic mélange in the Khoy Complex represents a subduction complex probably associated with the island arc noted above. Micrite (pelagic limestone) knockers in the tectonic mélange belt contain Early Cretaceous (late Albian: Vraconian) planktonic foraminifera; Late Cretaceous (early Campanian and early Maastrichtian) planktonic foraminifera; Late Cretaceous (late Maastrichtian) planktonic foraminifera; and early Middle Eocene planktonic foraminifera. The age of the micrite knockers in the tectonic mélange, suggests that subduction associated with island arc volcanism continued from the Early Cretaceous (latest Albian) to the Early Tertiary (early middle Eocene).

INTRODUCTION

The geological evolution of southern and western Iran can, in part, be characterized by accretionary tectonics where tectonostratigraphic terranes of different origins are now juxtaposed. Although the origin of most of these terranes can be traced back to continental margins of Eurasia or the Afro-Arabian plate, other terranes contain numerous ophiolites (text-figures 1-2) of oceanic affinity and represent fragments of accreted Tethyan ocean crust on continental margins (e.g., Dewey and Bird 1970; Moores and Vine 1971; Coleman 1981; Nicolas and Boudier 1991).

Iranian ophiolites have been divided into four groups (Takin 1972; Stocklin 1974; see text-figure 2):

1) Ophiolites of northern Iran along the Alborz range;
2) Ophiolites of Bitlis-Zagros Suture Zone including the Neyriz and the Kermanshah ophiolites which appear to be an extension of the Oman ophiolite abducted onto the Arabian continental mass;
3) Ophiolites and colored tectonic mélanges of Makran which are located to the south of the Sanadaj-Sirjan microcontinent including unfragmented complexes such as Sorkhband and Rudan; and
4) Ophiolites and colored mélanges that mark the boundaries of the internal Iranian microcontinental block including some of those in the Makran region (e.g., Band-e-Zyarat, Dar Anar, Ganj) and those inside of the Sanadaj-Sirjan microcontinental block (Baft, Nain, Shar-Babak, Sabsevar and Tchehel Kureh).

The Khoy area is situated near an important junction where the Iranian ophiolites connect with the Turkish and Mediterranean ophiolites (text-figs. 1-3). Curiously, the ophiolites of the Khoy area have been entirely overlooked in the widely accepted tectonic model for the origin of Middle Eastern ophiolites and the closure of the Tethyan Ocean (Moores et al. 1984; Dilek and Delaloye 1992; Dilek and Moores 1990; Sarkarinejad 1994).
According to this model the ophiolites of the Bitlis-Zagros Suture Zone [Troodos (Cyprus), Baer-Bassit (Syria), Hatay, Kizildag and Cilo (Turkey), Kermanshah, Neyriz and Esphandagheh (Iran) and Samail (Oman)] may represent ridge segments of an ancient “ridge-transform fault” oceanic spreading axis that was located in the southern Tethys and was connected to what are now the Troodos and Samail ophiolites. Previous analysis of radiolarian chert samples by the senior author of samples (Paragon Oil Company) from the Kermanshah Ophiolite yielded the same Upper Cretaceous (lower Coniacian) radiolarian assemblage as that which occurs in the northwest part of the Khoy area associated with N-MORB pillow basalt (Localities Kh-01-D3-S22 and Kh-01-D3-S24, Table 1; Figure 3, “E”). It is tempting to suggest that this ophiolitic remnant within the Khoy is closely related to the Kermanshah Ophiolite. Geochemical studies by Ghazi (in progress) may be useful in confirming this relationship.

Earlier reports (e.g., Ghorashi and Arshadi 1978) suggested that only one ophiolite, the “Khoy ophiolite”, occurred in the area near Khoy, northwestern Iran. This thesis is no longer tenable. Our preliminary studies of the Khoy region indicate that this area is complicated structurally and contains remnants of ophiolitic and island arc rocks of different ages and different origins. Hence, the term “Khoy ophiolite” can not be accurately applied in the Khoy area. In this report the term “Khoy Complex” (sensu International Stratigraphic Guide) is applied to the rocks in the area of study.

Previous investigations dealing with the “Khoy complex” (e.g., Ghorashi and Arshadi 1978) contained sparse biostratigraphic and chronostatigraphic data. An initial objective of the present investigation was to obtain radiolarian and planktonic foraminiferal biostratigraphic and chronostatigraphic data from volcanic rocks that have been mapped as ophiolite within the “Khoy complex” as well as from strata that occur in contact (sedimentary or fault) with ophiolitic rocks within the “Khoy complex”. Where possible, we have integrated the new biostratigraphic and chronostatigraphic data with both new and existing geochronometric and geochemical data. Samples for geochemical analysis were collected in conjunction with micropaleontological sampling. All new samples were located using a handheld global positioning unit (GPS).

REGIONAL GEOLOGY

The “Khoy complex” is bounded to the west and north by the Iran-Turkey border and to the east by a northwest-southeast trending fault (text-fig. 2). To the south the “Khoy complex” is in contact with the northern edge of the Sirjan-Sanandaj Zone. The Cretaceous rocks, which include the “Khoy complex”, constitute two-thirds of all the outcrops in the area. Our investigations, thus far, have produced biostratigraphic, chronostratigraphic, geochronometric, geochronologic, and geochemical data from four areas within the “Khoy complex” (text-figs. 3-4):

Area 1: A Lower Cretaceous (early Albian) amphibolite closely associated with an Upper Jurassic (lower Oxfordian
to middle Oxfordian) ophiolite remnant with gabbro, diabase, and ultramafics (Figure 4, “A”). No sedimentary rocks known.

a. Lower Cretaceous (Albian) amphibolite (Figure 4, Area 1,”A”).
A large mass of amphibolite occurs in the eastern part of the Khoy Complex (text-fig. 4, Area 1 "A"). The western portion of the amphibolite is in tectonic contact with the ultramafic rocks and some of the lower gabbros units of the Upper Jurassic ophiolite whereas the eastern portion of the amphibolite unit is in contact with the Pre-Cambrian rocks (Kahar Formation). The rocks of the metamorphic zone show the effect of an inverse thermal gradient from amphibolite facies (e.g., hornblendite, gneiss and calc-silicate marble) immediately adjacent to the basal tectonized ultramafic rocks, to green schist facies (e.g., quartzite, phyllites, mica and chlorite-epidote schist) in contact with the Precambrian rocks.

The amphibolite is generally laminated, some having schistose and gneissic texture that show compositional layering consisting largely of brown-green hornblende and lesser amounts of plagioclase and quartz. Grain size ranges from less than 1mm to 10-15mm in finer-grained rocks to 1cm to 2-5cm in coarser-grained rocks. The highest grade amphibolites have gneissic texture and contain deformed layers, augen, and pods of coarse-grained plagioclase.

The Early Cretaceous (early Albian) amphibolite unit needs further investigation. It may represent an exotic slab that is unrelated to the adjacent Upper Jurassic ophiolite. It is probably too extensive to represent the metamorphose sole of the Upper Jurassic ophiolite.

b. Upper Jurassic (lower Oxfordian to middle Oxfordian) ophiolite remnant with gabbro, diabase, and ultramafics:

The Upper Jurassic gabbro is interpreted as cumulate gabbro and occurs as a small mapable unit adjacent to the basal amphibolite-gneiss. In general, the cumulate gabbro is massive, fine- to coarse-grained, and consists of clinopyroxene, plagioclase and olivine. Coarse-grained gabbros commonly contain large pegmatoid segregations and veins, up to 3-5cm grain size, which have contacts with the finer-grained host rocks that range from diffused and gradational to sharp and cross-cutting. The mineralogy of the pegmatoid gabbro consists of hornblende and plagioclase. In some areas, the gabbro contains patches of finer grained leucogabbro and diorite which have been mostly altered to greenschist facies assemblages of uralite; saussuritized plagioclase, epidote, and chlorite.

A diabase dike complex occurs within the Upper Jurassic remnant (text-figure 4, Area 1). The diabase dike complex within the Jurassic remnant is not as extensive as dike complexes in Semail or Troodos ophiolites, and because of extensive weathering it is difficult to identify any geometric relationships among individual dikes. The primary minerals of the dikes are of calcic plagioclase, clinopyroxene and Fe-Ti oxide. However, in most areas, the primary minerals have been completely replaced by alteration minerals that include actinolite, chlorite, epidote, prehnite, pumpellyite, quartz, and calcite.

The ultramafic sequence consists of two main rock types, harzburgite (70-80%) and dunite (20-30%), which have been variably serpentinized and tectonized. Harzburgite consists of olivine (70-80%); orthopyroxene (20-30%); and Cr-spinel (1-2%).

Area 2: Tectonic mélange containing knockers of pelagic limestone (micrite with Radiolaria and planktonic foraminifera), serpentinite, and basalt.

Lower Cretaceous (upper Albian) to Lower Tertiary (lower middle Eocene) micritic limestone knockers occur in the tectonic mélange.

It should be noted that this area was mapped as a fault bounded block comprised mostly of pink pelagic limestone, basaltic lava flows, and colored shales by Radfar and Amini (Khoy Sheet, Geologic Map of Iran 1:100,000 Sheet 4967).

Text-figure 5 shows a panoramic view of hills along the western margin of Area 2 with knockers of pink pelagic limestone (micrite) and basalt in the mélange.
Area 3: Basalts with E-MORB AND N-MORB affinities.

E-MORB basalt with interbedded pelagic limestone (micrite) containing Upper Cretaceous (latest Campanian) planktonic foraminifera occurs at “D” in Area 3. (See Figure 4 and Geochemistry herein). Basaltic andesite-subalkaline basalt pillow lava (N-MORB affinity) with interpillow siliceous mudstone and red chert containing Upper Cretaceous (lower Coniacian) Radiolaria at “E” in Area 3 (See text-figure 4 and Geochemistry herein). Text-figure 6 shows spectacular pillow basalt near “E”. Note the red chert overlying the basalt.

Area 4: Upper Cretaceous red, manganiferous ribbon chert overlain disconformably by conglomerate with well rounded chert clasts followed by medium to thick bedded pyroclastics (tuff).

To date, only lower Coniacian Radiolaria have been recovered from chert exposures adjacent to and below the pyroclastics. Text-figure 7 shows the disconformable contact between the red ribbon chert unit and the overlying pyroclastic unit.

These four areas form a framework for the discussion of and the interpretation of all data presented below.

BIOSTRATIGRAPHIC AND CHRONOSTRATIGRAPHIC DATA

New biostratigraphic and chronostratigraphic data resulting from our studies of Radiolaria and planktonic Foraminifera comes from Areas 2-4 above (see text-figure 4).

Area 2 (text-fig. 4): Tectonic mélange belt.

To date, we have recovered uppermost Albian (Vraconian); lowermost Cenomanian; lower Campanian to lower Maastrichtian; upper Maastrichtian; and lower Middle Eocene microfossil assemblages from micritic limestone knocker in the unnamed tectonic mélange belt. The results from our investigations are as follows:

(1) A Lower Cretaceous (uppermost Albian) to Upper Cretaceous (lower Cenomanian) planktonic foraminiferal assemblage with Thalmanninella evoluta, Hedbergella planispira, and Hedbergella delrioensis occurs in micrite samples from Locality KH 99-46.3 (See Table 1; Area 2, “C” in text-fig. 4). This assemblage is assigned to Superzone 7 to Superzone 6D of Pessagno (text-figure 9).

(2) An Upper Cretaceous (lower Cenomanian) radiolarian assemblage with Pseudodictyomitra pseudomacrocephala, Archaeodictyomitra sliteri, Holocryptocanium astensis, Thanarla praevenera, Patelula spp., and Alievium spp. also occurs in micrite samples from Locality KH 99-46.3 (See Table 1; Area 2, “C” in Figure 4). The radiolarian assemblage is assignable to Zone 10, Subzone 10A (base) of Pessagno (1976, 1977; see Table 1 and text-figure 11 herein). The combined radiolarian and planktonic foraminiferal biostratigraphic data from Locality KH 99-46.3 indicate that micrites are assignable to the Upper Cretaceous (lower Cenomanian) and possibly the Lower Cretaceous (uppermost Albian).
Radiolaria were originally extracted from a micrite sample using concentrated HF (see Pessagno 1977, p. 7). One year after this sample was processed in concentrated HF co-author S. M. Kariminia developed his new acetic acid technique for extracting calcified radiolaria and other calcareous microfossils from micrites (Kariminia et al., 2003; Kariminia in press).

(3) Upper Cretaceous (lower Campanian to lower Maastrichtian) planktonic foraminifera including *Globotruncana linneiana*, *Globotruncana bulloides*, and *Globotruncana* spp. were identified from thin-sections of micrite from Locality Kh-01-D3-S19-b (Area 2. “C” in text-figure 4; Table 1). GPS coordinates are given for this locality in Table 1. This assemblage is broadly assigned to Zone 2 F (lower Campanian) to Zone 2A, Subzone 2A1 (lower Maastrichtian) of Pessagno (text-figure 10A). Planktonic foraminifera were identified from thin-section analysis of a micrite sample.

(4) Upper Cretaceous (upper Maastrichtian) planktonic foraminifera occurring in micrite from Locality Kh-01-D4-S29 were identified both from thin-section analysis and from matrix free specimens extracted from the rock using the acetic acid method (Kariminia et al. 2003; Kariminia in press). Taxa include *Globotruncanita conica*, *Globotruncanita elevata*, *Globotruncanana navarroensis*, *Globotruncanella havanaensis*, and *Racemiguembelina fructicosa* (Area 2. “C” in Figure 4; Table 1). GPS coordinates are given for this locality in Table 1. This assemblage can be precisely assigned to Superzone K1, Zone 1B, base of Subzone 1B1 to Zone 1A. Both *Globotruncanita conica* and *Racemiguembelina fructicosa* (sensu
KEY

++ = First occurrence of single keeled, trochspherical Globigerinacea with curved, raised sutures umbilically.
YY = First occurrence of double or single keeled, trochspherical Globigerinacea with curved, raised sutures umbilically.
* = sensu Pessagno 1967.

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Stage

Superzone

Zone

PRIMARY MARKER TAXA

TEXT-FIGURE 9
Planktonic foraminiferal zonation for Cretaceous (part). Pessagno in prep. Note that K7 includes the Vraconian of older literature.

Smith and Pessagno (1972) make their first appearance at the base of part Subzone 1B1 in North America (e.g., Corsicana Formation, Texas: Pessagno 1967, 1969; Smith and Pessagno 1972. Text-figures 10A and 10B herein). It should be noted that Subzone 1B1 is equivalent to the *Racemiguembelina fructicosa* Zonule of Smith and Pessagno (1972, Figure 3).

(5) Lower Tertiary (Lower Middle Eocene) planktonic foraminifera were identified in thin-section analysis of micrite samples from Locality KH-99-21-1-2 (Area 2. “C” in text-figure 4; Table 1). Taxa from Locality KH-99-21-1-2 include *Acarinina densa* and *Acarinina* spp. In Trinidad *Acarinina densa* occurs in the *Hantkenina aragonensis* and *Globigerapsis kugleri* Zones of Bolli (1957).

Illustrations of some of the microfossils from the samples noted above and in Table 1 are shown in text-figure 8.

Area 3: (text-fig. 4). E-MORB basalt with interbedded pelagic limestone. See “D” in text-figure 4.

At Locality Kh-01-D3-S6 Upper Cretaceous (Zone 2B, uppermost Campanian) planktonic foraminifera were recovered from interbedded indurated micrites in this unit using the Kariminia method of microfossil extraction (Kariminia et al. 2003; Kariminia, in press. See Table 1 and text-figure 10 herein). The follow taxa occur in micrite samples from Locality Kh-01-D3-S6: *Globotruncanella fornicata*, *G. hilli*, *G. lapparenti*, *G. linneiana*, *G. ventricosa*, *Globotruncanita elevata*, *Globotruncanella havanensis*, *Archaeoglobigerina* sp., and *Heterohelix* spp. Analysis of samples from Texas, Arkansas, Mexico, and Puerto Rico indicate that *Globotruncanella hilli* and *Globotruncanella havanensis* both make their first appearance at the base of Zone 2B and *Globotruncanella ventricosa* makes its final appearance at the top of Zone 2B. (See text-figure 10A). Zone 2B is equivalent to the *Globotruncanella calcarata* Zonule of Pessagno (1967, 1969).

Area 3 (text-fig. 4): Basaltic andesite-subalkaline basalt (N-MORB affinity) with interpillow siliceous mudstone. See “F” in text-figure 5.

At localities Kh-01-D3-S22 and Kh-01-D3-S24 the following Upper Cretaceous (lowermost Coniacian) Radiolaria were extracted from interpillow siliceous mudstone samples utilizing the HF Technique of Pessagno and Newport (1972): *Pseudoaulophacus putahensis*, *Allevium prae-gallowayi*, *Dictyomitra formosa*, *Dictyomitra torquata*, *Pseudodictyomitra* sp., *Xitus*
sp., *Patellia* sp., and *Orbiculiforma quadrata* (?). This assemblage is assigned to the base of Zone 12, Subzone 12A (Pessagno, 1977; see Figure 11 herein). In the California Coast Ranges Pessagno (1977) determined that *Dictyomitra formosa* and *Alievium praegallowayi* made their first appearance at the base of his Subzone 12A whereas *Pseudodictyomitra* sp. and *Pseudoaulophacus putahensis* make their final appearance at the top of Zone 11, Subzone 11B. In Oman Tippit et al. (1981) found *Pseudodictyomitra* sp. to range into the lower part of Subzone 12. It is likely that the range of *Pseudoaulophacus putahensis* extends into the lower Coniacian although the possibility of reworking can not be ignored.

Text-figure 13 illustrates lowermost Coniacian Radiolaria from this locality.

**Area 4 (text-fig. 4): Upper Cretaceous reddish brown, manganiferous ribbon chert overlain (sedimentary contact) by medium to thick bedded pyroclastics (tuff and tuff breccia).**

The Radiolarian assemblage from localities Kh-01-D5-S34 and Kh-01-D5-S35 in Area 4 is essentially the same as that in Area 3 ("E") (See Table 1). This assemblage is characterized by the presence of *Dictyomitra formosa* Squinabol, *Dictyomitra torquata* Foreman, and *Pseudodictyomitra* Pessagno. Moreover, it is assignable to Zone 12, lowermost part of Subzone 12: Upper Cretaceous: lowermost Coniacian. See text-figures 11-12 herein.

**GEOCHRONOMETRY**

**40Ar-39Ar ages**

The result from incremental heating 40Ar-39Ar age determinations on four hornblende mineral separates from two pegmatitic gabbro (text-figure 4, "B") and two hornblende amphibolite samples (text-figure 4, "A") from rocks in ophiolitic remnants within the “Khoy complex “ is presented in Table 2 and text-figures 14-17. Age determinations were calculated in three ways. We first examined age spectra (step ages versus temperature, represented by %39Ar released) for evidence of concordant step ages for a majority of the Ar released from the sample (so-called plateau ages). Good plateaus were apparent in all samples, defining a narrow age range from 156 to 159 Ma for the gabbros and 107-110 Ma for the amphibolite samples. We also calculated total fusion ages obtained by summing all the step compositions, as if the sample had been heated to fusion in one step. These total fusion ages range from 153 to 160 Ma for the gabbro, and from 107 to108 for the amphibolites which are
TEXT-FIGURE 13
Upper Cretaceous (lowermost Coniacian) Radiolaria from the Khoy Complex, northwestern Iran.
Emile A. Pessagno et al.: Tectonostratigraphy of the Khoy Complex, northwestern Iran

TEXT-FIGURE 14
Late Jurassic (middle Oxfordian) age for gabbro in Area 1. Note that we use the Geologic Society of America 1999 Geologic time scale for geochronologic interpretation of the geochronometric data. Oregon State University sample MG99-4.

156.21 ± 1.40 Ma

TEXT-FIGURE 15
Late Jurassic (early Oxfordian) age for gabbro in Area 1. Note that we use the Geologic Society of America 1999 Geologic time scale for geochronologic interpretation of the geochronometric data. Oregon State University sample MG99-2.

159.62 ± 1.56 Ma
comparable to plateau ages. The third age calculation was derived from the correlation of the step Ar compositions ($^{36}$Ar/$^{40}$Ar versus $^{39}$Ar/$^{40}$Ar isochrons). These correlations allow us to determine the initial composition of Ar in the sample at crystallization, assumed to be atmospheric ($^{40}$Ar/$^{36}$Ar = 295.5) in the age spectra calculations. The isochron ages range from 155 to 157 Ma for the gabbro and from 107 to 108 for the amphibolite which are also comparable with both plateau and total fusion ages. Furthermore, for all the samples, the isochrons revealed initial compositions close to the atmospheric values, confirming the reliability of the plateau ages. The isochron ages are concordant with, but have slightly larger fitting uncertainties than, the plateau ages.

GEOCHEMISTRY

Fifteen samples of extrusive rock from the “Khoy complex” were analyzed for geochemical signatures. In general, these volcanic rocks have suffered extensive secondary changes due to sea-floor alteration and low-grade hydrothermal metamorphism. This alteration typically results in losses or gains of most of the major elements. In this report we have focused our attention on the analysis of the ten samples from the extrusives with the least amount of alteration. In this report we have focused our attention on the analysis of the ten samples from the extrusives with the least amount of alteration. Based on a Nb/Y vs. Zr/Ti diagram (Winchester and Floyd 1977) the extrusive rocks from the ophiolitic rocks in the “Khoy complex” can be divided into at least three different types (text-figure 18):

1. Andesite-trachyandesite;
2. Basaltic andesite-subalkaline basalt; and
3. Alkalic basalt.
Selected minor and trace elements (e.g., Ti, Zr, Y, Hf and Nb) believed to be relatively immobile under conditions of metasomatism and low-grade hydrothermal metamorphism are used to characterize extrusive rocks with respect to their original composition and possible tectonic environment of formation (e.g., Pearce and Cann 1973; Winchester and Floyd 1977; Jenner 1996). In a Zr-Nb-Y discrimination diagram (Meschede 1986), the results from all the extrusive rocks show three distinct chemical affinity. The basaltic andesite-subalkaline groups show N-MORB chemical affinity, whereas the alkaline basalts show within-the-plate type chemical affinity, and the trachyandesite samples plot in the field of within-plate alkalic basalt.

Primitive mantle-normalized incompatible element patterns and chondrite-normalized rare earth patterns (REE) for these extrusive rocks are illustrated in text-figures 19 and 20. For the purpose of comparison the patterns from ocean island basalt (OIB), E-MORB and N-MORB are plotted (Sun and McDonough, 1989). In general, the patterns for these extrusives form three recognizably different semi-parallel envelopes. Patterns for the trachyandesite group have the highest relative abundances, are light REE-enriched and show very good similarities with ocean island basalt. However, the large trough at Nb is a characteristic feature of extrusive rocks influenced by continental lithosphere which has been explained in terms of fractionation and retention of this element in the source during partial melting of the subducting plate (Pearce, 1996). The basaltic andesite-subalkaline basalt have elemental signatures that are similar to those of N-MORB and the samples which were identified as alkalic basalts clearly show E-MORB origin (text-figures 19-21). In general, the preliminary geochemical data show three distinct geochemical signatures (OIB, E-MORB and MORB) for the extrusive rocks from the Khoy ophiolite Complex.

**DISCUSSION AND CONCLUSIONS**

(1) Biostratigraphic, chronostratigraphic, geochronometric, geochronological, and geochemical data resulting from our investigations indicate that there are at least two and possibly three remnants of oceanic crust within the "Khoy complex": A Late Jurassic (early to middle Oxfordian) remnant (Area 1, "A"); an early Coniacian remnant (Area 3 "E": N-MORB affiliated geochemistry); and, possibly, and, a latest Campanian remnant (Area 3 "D": E-MORB geochemistry) (See text-figure 3-4).

(2) Amphibolite closely associated with the Late Jurassic remnant has been dated as Early Cretaceous (early Albian: 107-110 Ma 40Ar-39Ar). The amphibolite needs further study. It may be an exotic slab which is totally unrelated to the other ophiolites or may represent a metamorphosed part of the adjacent Late Jurassic remnant.

(3) The crystallization ages of 159.6±1.56 Ma and 156.2±1.4 Ma for the gabbros suggest that ophiolite formation in that part of Neotethys which is now present-day northwestern Iran (in the vicinity of the Caspian sea) began in the Late Jurassic (early to middle Oxfordian). As a consequence, this ophiolite formed much earlier than other ophiolites along the Zagros suture zone. For example, total gas 40Ar-39Ar ages for hornblends from ophiolitic rocks at the Neyriz ranging from 77±2.4 Ma to 104±1.0 Ma were interpreted by Lanphere and Pamic (1983) to indicate Late Cretaceous age of crystallization for the formation of the Neyriz ophiolite. Similarly, Delaloye and Desmons (1980) obtained K/Ar ages of 86 Ma and 81 Ma for diorite and diabase samples from the Sahneh (Kermanshah) ophiolite of western Iran. The geochronometric age for the Kermanshah Ophiolite is relatively compatible with the early Coniacian determination that the senior author obtained from the analysis of
Kermanshah radiolarian chert associated with the ophiolite. The Neyriz and Sahneh (Kermanshah ophiolite) possibly were coeval with the Semail and other Neotethyan ophiolites of the Bitlis Zagros suture zone (e.g., Sengor 1990).

(4) The assumption by previous workers (e.g., Ghazi and Hassanipak 1996; Ghazi et al. 1997) that the Khoy represents a single ophiolite is invalid because at least two and possibly three different ophiolite remnants are present. These rocks should be included under the term “Khoy complex” (sensu International Stratigraphic Guide).

(5) Our preliminary analysis of remote sensing data indicates that the latest Campanian ophiolite remnant (E-MORB geochemistry) has been juxtaposed against an early Coniacian ophiolite remnant comprised of basaltic andesite-subalkaline basalt (N-MORB) affinity) with radiolarian-rich interpillow mudstone and red ribbon chert (Area 3: See text-figure 4: “E”). It is tempting to suggest that the latest Campanian E-MORB basaltic is part of the same volcanic sequence that disconformably overlies the red ribbon chert in Area 4 (see below).

(6) The early Coniacian red ribbon chert characteristic of Area 4 represents pelagic strata deposited at or near an oceanic spreading center (See text-fig. 4: F). The contact between the lower Coniacian red chert and overlying pyroclastics (tuff and tuff breccia) represents a disconformity and an associated hiatus of unknown magnitude (text-figure 7). This contact indicates that oceanic crust topped by radiolarian ooze lacking any sort of calc-alkaline island arc components had arrived in the vicinity of an island arc by the early Coniacian or later.

(7) Tectonic mélangé present in Area 2 (text-figs. 4, 22) is interpreted to represent a subduction complex associated with an island arc. Biostratigraphic and chronostratigraphic data acquired thus far indicate that subduction was active from the Early Cretaceous (late Albian: Vraconian) until the early Middle Eocene.

(8) Finally, we suggest that the oceanic spreading center, subduction complex, and island arc complex depicted in Figure 22 were abducted on to the craton during post early Middle Eocene time.

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REFERENCES


TABLE 1
New planktonic foraminiferal and radiolarian biostratigraphic and chronostratigraphic data from the Khoy Complex.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>CHRONOSTRATIGRAPHIC DETERMINATION</th>
<th>BIOSTRATIGRAPHIC DETERMINATIONS, SEE FIGURES 7-8</th>
<th>Taxa</th>
<th>type of microfoss</th>
<th>Area &amp; GPS data (where available). See Figure 4.</th>
<th>Rock type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kh-01-D3-S19-b</td>
<td>lower Campanian - lower Maastrichtian</td>
<td>Zone 2F to Subzone 2A</td>
<td>Globotruncanina linneana, Globotruncanina bulloides, Globotruncanina spp.</td>
<td>Planktonic Foraminiferida</td>
<td>AREA 2. “C” in Figure 4. N38°46′, 24.1′′ E44°30′, 58.3′′</td>
<td>Pelagic Limestones (micrite)</td>
</tr>
<tr>
<td>Kh-01-D4-S29</td>
<td>upper Maastrichtian</td>
<td>Subzone 1B to upper part of Zone 1A</td>
<td>Globotruncanina conica, Globotruncanina elevata, Globotruncanina navarroensis, Globotruncanella havanensis, Racemiguembelina fructosa</td>
<td>Planktonic Foraminiferida*</td>
<td>AREA 2. “C” in Figure 4. N38°52′, 57.1′′ E44°33′, 52.5′′</td>
<td>Pelagic Limestones (micrite)</td>
</tr>
<tr>
<td>KH 99-46.3</td>
<td>lower Cenomanian</td>
<td>base Subzone 10A</td>
<td>Pseudodictyomitra pseudomacrocephala, Archaeodictyomitra sitleri, Holocryptocanium astensis, Thanaria praeveneta, Patiula spp., Alleivum spp.</td>
<td>Radiolaria</td>
<td>AREA 2. “C” in Figure 4.</td>
<td>Pelagic Limestones (micrite)</td>
</tr>
<tr>
<td>KH 99-46.3</td>
<td>uppermost Albian to lower Cenomanian</td>
<td>Zone 7 to Superzone 6, Zone 6D of Pessagno, in prep.</td>
<td>Thalassinella evoluta, Hedbergella planispira, Hedbergella delrioensis</td>
<td>Planktonic Foraminiferida</td>
<td>AREA 2. “C” in Figure 4.</td>
<td>Pelagic Limestones (micrite)</td>
</tr>
<tr>
<td>KH 99-21-1.2</td>
<td>lower middle Eocene</td>
<td>Equivalent to Bolli’s (1957) Hantkenina aragonensis and Globigerapris kugleri zones of Trinidad.</td>
<td>Acarinina densa, Acarinina spp.</td>
<td>Planktonic Foraminiferida</td>
<td>AREA 2. “C” in Figure 4.</td>
<td>Pelagic Limestones (micrite)</td>
</tr>
<tr>
<td>Composite Kh-01-D3-S22 and Kh-01-D3-S24</td>
<td>lowermost Coniacian</td>
<td>Zone 12, lowermost part of Subzone 12A</td>
<td>Pseudouolaphacys putheinis, Aleiwm praeoffloyvi, Dictyomitra formosa, Dictyomitra torquata, Pseudo dictatoria sp., Xitus sp., Patiula sp., Orchibifurca quadrata?</td>
<td>Radiolaria</td>
<td>Area 3.”E” in Figure 4. N38°41′, 45.5′′ E44°25′, 09.1′′</td>
<td>Siliceous mudstone</td>
</tr>
<tr>
<td>Kh-01-D5-S34 and Kh-01-D5-S35</td>
<td>lowermost Coniacian</td>
<td>Zone 12, lowermost part of Subzone 12A</td>
<td>Same fauna as Kh-01-D3-S22, 24 above</td>
<td>Radiolaria</td>
<td>AREA 4. “F” in Figure 4. N38°58′, 45.9′′ E44°12′, 9.6′′ and N38°59′, 7.3′′ E44°12′, 10.2′′ respectively</td>
<td>Medium to thin-beded reddish brown chert</td>
</tr>
</tbody>
</table>


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