Afghan Geological Survey

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Abstract

As part of U.S. Geological Survey assistance in the reconstruction effort in Afghanistan funded by the U.S. Agency for International Development, the U.S. Geological Survey is working with the Afghanistan Ministry of Mines and Industries and the Afghan Geological Survey in conducting a mineral resource assessment of Afghanistan. In the early stage of this assessment, we are evaluating Afghanistan's gemstone deposits. Afghanistan is rich in gemstone deposits including emeralds, rubies, lapis lazuli, and pegmatite-hosted semiprecious gems. This report presents a preliminary assessment of the geologic setting and origin of emerald deposits in the Panjsher Valley in the Hindu Kush Mountains of northeastern Afghanistan. Existing geologic maps and reports published by Soviet and Afghan geologists in the mid-1970s have been translated and are discussed. These maps and reports are used in conjunction with our new field and petrographic data to allow us to critically evaluate the Soviet geologic and tectonic interpretations for the northeastern part of the country. We also discuss the character of the emerald deposits and present a working hypothesis on the origin of the emeralds.

Introduction

The U.S. Geological Survey is funded by the U.S. Agency for International Development to help in the Afghan reconstruction effort. Of significant importance in this effort is to provide knowledge and training that can be used to rebuild a healthy economy. Afghanistan is rich in mineral resources such as copper, chromium, iron, and gold and also has extensive gemstone deposits including emeralds, rubies, lapis lazuli, and pegmatite-hosted semiprecious gems. The safe, economical development of these deposits will be a critical component in the stabilization of the Afghan economy. Because of the years of conflict that have plagued the country, the mineral industry infrastructure has been seriously damaged and no modern mineral resource assessment studies have been conducted. The most recent report, *Geology and Mineral Resources of Afghanistan*, was published in 1995 by the United Nations. The report concluded that, among other efforts to rebuild the economy, "gold and gas exploration and the rehabilitation of the gemstone industry are critical because all are good sources of foreign exchange earnings with quick cash flow returns". In the longer term, copper, iron, chromium, lead, zinc, and industrial mineral deposits should be brought on line to develop the economic base of Afghanistan.

Although published as recently as 1995 and seemingly current, the conclusions of *Geology and Mineral Resources of Afghanistan* are based on geologic work carried out by Soviet Union and Afghan geologists in the 1960s through the 1980s. These studies are dated, but they provide a geologic foundation that can be used for modern assessment approaches. The earlier work produced maps of the geology, magmatic belts, tectonics, and mineral resources of the entire country. Even though the production of these maps was strongly controlled by V.V. Beloussov's (for example, Beloussov and others, 1982) fixist ideas in opposition to plate tectonics, they clearly show that the geology of Afghanistan is a mosaic of crustal terranes of various sizes juxtaposed against each other and separated by large-scale faults (fig.1). This mosaic likely formed during the collision of India with Asia about 50 million years ago and is part of the larger Himalayan geologic story. Younger magmatic belts also extend across much of the country. Each of these terranes as well as the magmatic belts has unique geologic characteristics that control the nature of associated mineral resources (figure 1). Crossing from one crustal block into another may result in entirely different geology and mineral resources reflecting differing geologic affinities of each.

As one of the first field studies associated with the mineral-resource-assessment task of the USGS effort in Afghanistan, a group of USGS and Afghan geologists visited the Panjsher Valley, Parwan Province, northeastern Afghanistan in July, 2004 to examine the geology of the valley and the emerald deposits within the valley. The known emerald deposits of the Panjsher Valley lie along the valley's southeastern side near the village of Khenj (Kazmi and Snee, 1989; Bowersox and others, 1991), although emeralds have also been reported on the northwest side of the valley (Tawach area; Sabot and others, 2001). The Panjsher Valley follows a major northeast-trending tectonic structure that has been thought to be a continental scale fault zone between different crustal plates. The field party also visited the Ghowr Band Valley, which extends to the west from the village of Towtamdarreh-ye Olya (a few kilometers north of Charaikar). The Ghowr Band Valley apparently follows the western extension of the structural zone that defines the Panjsher Valley. The purpose of these trips was multifaceted. We wanted to determine the feasibility, in terms of logistics and safety, of conducting field work in Afghanistan. (These feasibility results are described in a previously submitted trip report, which is attached to this report as Appendix 1.) With the expert guidance of our Afghan colleagues, Abdul Wasay and Mohammed Omar, we were able to assess the regional geology of Panjsher Valley, conduct preliminary geologic investigation of the geology of the Panjsher emerald deposits, and collect numerous samples for future detailed geochemical, geochronologic, and petrographic study. We also obtained a detailed report that resulted from Russian and Afghan field studies conducted in the Panjsher Valley in 1975 and 1976 (Samarin and Akkermantsev, 1977); this report published in Russian has been translated into English. Herein we provide a preliminary overview of the geology and structure of the Panjsher Valley and the geologic framework of the Panjsher emerald deposits.

Regional Geologic Setting

In 1977, the Soviet Union and the Afghan Ministry of Mines and Industries published the geologic map of Afghanistan at a scale of 1:500,000 (Abdullah and others, 1977). Figure 2 (Lindsay and others, 2005a) is the section of this geologic map for the Pulkhamri and Charikar quadrangles (Quadrangle 3568), which includes the southwestern part of the Panjsher Valley, overlain at a 1:250,000 scale on topography derived from Shuttle Radar Topography Mission (SRTM) 90-meter digital data. Figure 3 (Lindsay and others, 2005b) is a similarly derived map for the Tagab-Munjan and Samar-Kamdes quadrangles (Quadrangle 3570), directly east of the area of Figure 2, and including the northeastern extension of the Panjsher Valley. The Explanation of Map Units for both maps has been converted from the origin Soviet terminology to a standard international format. However, no attempt has been made at this stage to modify or reinterpret the original geologic dataset. The geology displayed on these two figures, which cover the region between 35° to 36° north latitude and 68° to 72° east longitude, clearly illustrates that Afghanistan is a mosaic of crustal terranes each with unique geology.

From the maps, at least two major crustal structures cross east-west through Quadrangle 3568 and join together near the Anjoman Pass at the northeastern end of the Panjsher Valley in Quadrangle 3570 forming a single structural zone that continues northeastward. The southern of these two crustal structures, named the Tectonic Zone Hindu Kush by the Soviet geologists, trends westward through the Ghowr Band Valley, westward to Bamyan, and onward to the west to and beyond Herat (Figure 3). This entire structure that crosses Afghanistan is one of the most significant and complex in Afghanistan, and has been called the Middle Afghanistan Geosuture (Chmyriov and others, 1976; United Nations, 1995) among other names. This structure largely divides the platform sedimentary rocks of northern Afghanistan from structural blocks of rocks of various origins to the south. This division is well defined across this structure to the west of Bamyan, but to the east of Bamyan into the Ghowr Band Valley, this relationship becomes less clear. In the Panjsher Valley high-grade metamorphic rocks (Precambrian-age gneisses in the Soviet nomenclature) on both sides of the structure are separated from each other by a thin, up to 5-km-wide, fault belt of low-grade metasedimentary rocks consisting of graphitic schists and metacarbonates. The northern of the two fault zones follows the Andarab Valley. This northern structure separates the largely Precambrian and Mesozoic plutonic and metamorphic rocks and Mesozoic and Paleozoic sedimentary rocks to the south from predominantly Mesozoic sedimentary and plutonic rocks north of the Andarab Valley.

Scattered throughout the wedge-shaped terrane between the Andarab and Panjsher Valleys are fault-bounded lozenges of ultramafic rocks. Even though the Soviets mapped these bodies as intrusive bodies of presumed Carboniferous age, their map reveals that most are fault bounded placing their age and affinity in question. Similar fault-bounded ultramafic bodies are exposed in the Tectonic Zone Hindu Kush in both the Panjsher and Gowr Band Valleys (fig. 4). The presence of these bodies has significant implications for the tectonic history and affinity of the terrane(s) between the Andarab and Panjsher Valleys; these bodies and their age of emplacement must be studied in detail to understand the tectonic history of this region. These bodies, if not intrusive, may be

dismembered fragments of oceanic crust, like those exposed within the continental collision zone in Pakistan (Kazmi and Snee, 1989), or slivers of deep-seated crustal rocks brought up from great depth during tectonic activity. In either case their presence indicates the deep crustal character of this tectonic zone.

Structure and Geology of the Panjsher Valley

Structure

The geologic map of the Panjsher area originally compiled at a 1:500,000 scale by Abdullah and others (1977) is shown in Figure 2. A more detailed geologic map of this area at the 1:100,000 scale is shown in Figure 5 in the original Russian, which has not yet been translated into English. Both maps show that the Panjsher Valley is defined by a complex fault system, named the Tectonic Zone Hindu Kush by the Soviet and Afghan geologists. This fault system juxtaposes sedimentary rocks of presumed Paleozoic age that have been metamorphosed to upper greenschist facies against high-grade metamorphic schist and gneisses of presumed Precambrian age to the northwest. Ultramafic rocks both of presumed Carboniferous age and Precambrian age form fault-bounded lozenges within the tectonic zone. Another major fault zone discussed in Samarin and Akkermantsev (1977) is the Panjshersky fault, which lies a few miles to the southeast of the Tectonic Zone Hindu Kush and parallels it. Samarin and Akkermantsev (1977) report that the Panjshersky fault zone, as defined by Schadchinev and others (1975), is a major structural break between Precambrian rocks of the "East Afghanistan median massif" to the southeast in Nuristan and the sedimentary rocks in Panjsher Valley (figs. 6 and 7). Schadchinev and others (1975) and Chmyriov and others (1976) believed that the structural zone between the Panjshersky fault zone and the Tectonic Zone Hindu Kush are Hercynian in age (that is, about 300 Ma). The emplacement of granitoid plutons of presumed Oligocene age (Laghman Intrusive Complex; Schadchinev and others, 1975) was apparently controlled by the Panjshersky fault zone.

Metamorphic rocks

A significant difficulty in using the Russian and Afghan geology maps is the lack of certainty and confidence in the ages assigned to metamorphic and plutonic rocks and to assumed ages of tectonic activity. No where in Afghanistan is this more troublesome than in the northeastern part of Afghanistan, especially in the Hindu Kush. Very few isotopic ages existed during the Russian mapping effort. As a result the ages that were assigned appear to be based to some extent on metamorphic grade—the higher the grade, the older the rock. In the Hindu Kush are large regions of presumed Proterozoic and Archean age. However, across the border in Pakistan (Chitral area), and to some extent in some areas of Afghanistan (Ghorband Valley; Siah Koh and Safed Koh, also known as Caper Ghar and Spin Ghar), the Indian Geological Survey (for example Hayden, 1913, 1915; Griesbach, 1887 a,b, 1892) and later geologists including Calkins and others (1981) identified fossils in lower metamorphic grade-equivalent rocks. These fossils confirmed ages ranging from Cretaceous to Devonian for rocks shown as Precambrian on Abdullah and others (1977). Both careful review of existing published age

determinations and the acquisition of modern geochronology will be fundamental contributions in unraveling the geologic history of Afghanistan.

At the southwestern terminus of the Panjsher Valley, the Panjsher River flows through a gorge of metamorphic rocks (fig. 8 a-d) of presumed Precambrian age (Abdullah and others, 1977), but of Tertiary age, at least in part, on figure 4 (Schadchinev and others, 1975). These rocks are strongly foliated, high-grade layered gneisses; the general orientation of the foliation at this location (35° 09' 33.2" N, 69° 17' 20.9" E) at the entrance into the valley is 60° 60°NW. However, as shown in figures 8 a and b, the orientation of the foliation is variable, and it is folded and affected by boudinage in places. Color banding is evident (fig. 8 c) and reflects compositional variation from felsic to mafic. Amphibolite and augen gneiss are present (fig. 8 d). In thin section the augen gneiss (fig. 9) is quartzo-feldspathic with biotite and garnet. The garnets were rotated showing a strong shear deformation. Compositionally these rocks are similar to gneisses shown on Abdullah and others (1977) southeast of the Panjshersky fault zone. This belt of gneisses extends northeastward from the Panjsher River gorge, and along the Hazara River at 35° 21' 17.3" N, 69° 35' 40.4" E, it is in fault contact with metasedimentary rocks to the northwest (fig. 10). Similar composition gneisses are exposed along the road to the Salang Tunnel, just to the northwest of the Panjsher River gorge (fig. 2) and extend in a belt northeastward, just west of the Panjsher Valley. The nature of the contact between these two belts near the Panjsher River gorge is unclear, although it is likely a fault contact between two distinct belts of gneiss. The uncertainty in the nature of this contact is amplified by figure 5 (Schadchinev and others, 1975), on which a strong foliation developed in Tertiary crystalline rocks, which trend east-west, is cut off by the TZHK**.**

Sedimentary units

Sandwiched in between these two belts of gneisses, and exposed in the Panjsher River Valley, are metasedimentary rocks that are generally of low metamorphic grade (figs. 2, 5, 6, and 7). Disparity exists among these 4 maps in the age and stratigraphic relationship of the metasedimentary units. On the map by Abdullah et al. (1977; fig.2), clastic Ordovician sedimentary rocks are the oldest units exposed in the valley. Silurian to Devonian age limestones and dolomites form a younger sedimentary unit. In Samarin and Akkermantsev (1977), the oldest rocks are reported to be Silurian to Lower Carboniferous in age based on mapping by Schadchinev and others (1975); and in this report the oldest rocks are carbonates. Clastic rocks consisting of quartzite, metamorphosed shale (schist and phyllite), sandstones and conglomerates, ranging in age from Carboniferous and Permian to Triassic form the younger sedimentary sequence.

We examined these metasedimentary units during our visit to the Panjsher Valley. The sedimentary units are extensively faulted but seem to form two sedimentary packages, one clastic and the other carbonatic. Metamorphic grade is variable from very low grade to upper greenschist facies. No fossils were noticed, but it is possible that careful investigation of the lower grade layers would be fruitful. Maximum disruption and segmentation of the sedimentary units occurs within the Tectonic Zone Hindu Kush (TZHK), which is a few kilometers wide, defines the valley, and faults the northwestern margin of the sedimentary units against presumed Precambrian-age gneisses. The TZHK

is well exposed at the confluence of the Hazara and Panjsher Rivers at 35° 23' 37.2" N, 69° 40' 54.1" E. A panoramic view looking south at the TZHK is displayed in figures 11 a-e progressing westward from generally southeastward.

The sedimentary units are also well displayed on Landsat imagery (fig. 12). On this image, which is tilted from vertical with a view to the south-southwest along the Panjsher Valley, dark gray carbonaceous phyllites define a northeast-trending band on the image. Lighter colored rocks on both sides of the dark layer are generally carbonates. Older gneisses are the brown rocks to the left (east) and the light brown rocks to the right (west). Near the center of the image, the dark-colored unit appears to be duplicated; this disruption occurs in the TZHK. The dark gray unit at lowest examined metamorphic grade is carbonaceous phyllite (fig. 13 a, b, c). Fine-grained thinly laminated phyllite is interbedded with massive, up to 1-meter thick discontinuous sandstone layers. In thin section the low grade carbonaceous phyllite exhibits angular quartz fragments in a fine-grained dark matrix dominated by graphite (fig. 14). At higher metamorphic grade, this rock underwent prograde metamorphism from spotted phyllite (figure 15 a) to schist (fig. 15 b). The more massive lenses in figures 13 b and c are carbonate-cemented quartz-rich sandstone blocks (fig. 16). According to Samarin and Akkermantsev (1977) the clastic rocks lie in apparent disconformity over the older carbonate rocks. They assign a Lower Carboniferous age to the lower sequence of clastic rocks, but the clastic units range in age up to the lower Permian. No justification for these age designation is given in the report.

The lighter colored sedimentary units indicated on figure 12 are primarily carbonates. Their composition ranges from massive limestone to dolomite, and grades into carbonate-cemented bedded sandstone. As like the clastic sequence, the degree of metamorphism varies from low grade to completely recrystallized marble. In Samarin and Akkermantsev (1977) these carbonates are described as the oldest (Silurian to Carboniferous) Phanerozoic sedimentary rocks in the area. (Again, no justification for these age designation is given in the report.) These authors describe the carbonate rocks as "essentially monomineralic of very variable calcite-dolomite ratios, with gradual transitions from limestone to dolomite. The amount of mineral\admixtures is 1 – 5%, not exceeding 10% (Schadchinev, 1975). The admixed components are quartz, pyrite, clay (sericite), and a coal-like non-transparent matter" (fig. 17 a, b). "The thickness of the carbonate series in the area does not exceed 2000 m."

Intrusive rocks

Samarin and Akkermantsev (1977) describe three complexes of intrusive rocks that intrude same or all of the sedimentary units. The oldest are presumed to be part of a middle-Carboniferous to early-Permian gabbro-diorite complex. These rocks generally occur as veins or dikes that cross-cut the presumed Silurian to Carboniferous limestones and dolomites and the Carboniferous to Permian clastic units. The dikes are most common in zones of tectonic disturbance, and are common in emerald-mineralized areas. The mafic rocks are generally altered, not greater than five meters wide, up to 300 meters long, and northeast trending (figs. 5 and 6). During our field visit we sampled several of these dark gray to black-colored bodies throughout the emerald-mineralized area. In thin

section (figs. 18 a, 18 b), the mafic body in the Rewat stream drainage at 35° 30' 07.8" N, 69° 50' 49.0" E consists primarily of plagioclase, pyroxene, and hornblende; the hornblende is both primary and an alteration product of pyroxene. Similar bodies are exposed along the Hazara River (figs. 18 c and d).

A second complex of igneous rocks is of presumed late Triassic age and consists of quartz porphyry veins and dikes that are relatively common in the carbonate rocks (Samarin and Akkermantsev, 1977; figs. 5 and 6). These light-gray- to yellowish brown-colored dikes also are most common in tectonically disturbed zones and they trend parallel to the northeasterly structural grain. In thin section (fig. 19 a, b), one of these dikes exposed at 35° 29' 07.8" N, 69° 49' 28.9" E shows phenocrysts of quartz, plagioclase, and potassium feldspar in a fine-grained quartzofeldspathic groundmass.

The third major group of intrusive rocks exposed in the Panjsher Valley is granites, granodiorites, and syenogranites of the Laghman Intrusive Complex (Samarin and Akkermantsev, 1977; figs 5, 6). Abdullah and others (1977; fig. 3), Samarin and Akkermantsev (1977; fig.5) and Schadchinev and others (1975; fig. 6) agree that the intrusive complex is Oligocene in age, but none presents geochronology to support this contention. In detail between Abdullah and others (1977; fig. 3) and Samarin and Akkermantsev (1977; fig.5), a significant difference exists in the mapped extent of the Laghman complex and the Precambrian gneisses. Some of this difference is likely a result of the high degree of overprinting caused by metamorphism and shearing of both the groups of rocks. Rocks mapped as Laghman Complex granites at 35° 13' N, 69° 26' E, which is just east of the Panjsher River gorge, are highly sheared, and exhibit a well-developed east-west-trending cleavage (fig. 20 a). In addition, in some locations, intrusive rocks and gneisses are intimately intermingled (fig. 20 b), and could cause difficulties for accurate mapping. However, in other places, such as at 35° 28' 13.5" N, 69° 47' 04.4" E, intrusive rocks are massive and show no evidence of significant metamorphic overprint. In thin section (fig. 21), the primary minerals of this granodiorite also show no evidence of later metamorphism or deformation.

Surficial deposits

Surficial deposits of presumed Quaternary age are well developed throughout the Panjsher Valley (figs. 22 a, b, and c). These deposits include alluvium consisting of pebbles, laminated sandstone, and clay-rich layers distributed along the Panjsher Valley floor. Several levels of alluvial terraces are exhibited in the valley; alluvial fans are developed on some mountain slopes. Alluvial material is also perched on lower ridge tops. Side streams and rivers, which flow into the Panjsher River, commonly flow rapidly through steep valleys, but in areas of widened stream floors, alluvial deposits also exist.

Geology and Character of the Panjsher Emerald Deposits

The emerald-bearing zone occupies an area about 3-km wide and 20-km long in Panjsher Valley that extends from southwest near the northwest-flowing tributary Khenj

to northeast near the northwest-flowing tributary Riwat, and is confined to the southeastern side of the Panjsher River. The mountain ridge that parallels the Panjsher River rises steeply in elevation from about 7000' at the river near Khenj to over 17,000' (fig. 23) within seven miles to the southeast. This ridgeline is dissected by several fast-flowing tributaries, which from south to north are the Khenj (fig. 24), Mikeni (fig. 25), Buzmal, and Rivat streams. The primary emerald-bearing zones are a few miles to the east of the Panjsher River at about 10,000' elevation but as high as 12,500' (fig. 24). Access to the mineralized areas is by footpaths generally following the streams (figs. 25, 26), but also cutting across the steep terrain (figs. 27, 28).

The geology of the 3-km wide by 20-km long emerald-bearing belt in the Panjsher Valley is shown on figure 4 (Samarin and Akkermantsev, 1977). The rocks in this belt consist of highly faulted carbonate and clastic sedimentary rocks, which are variably metamorphosed to phyllites, schists, and marbles. Intruded into these units are mafic gabbro-diorites and felsic quartz porphyry bodies. Within this belt, seven emerald-bearing zones (figs. 4 and 6) were defined by Samarin and Akkermantsev (1977); three of these occurrences, Khenj (western zone) (fig. 29), Buzmal (figs. 30, 31), and Rivat, are in carbonate host rocks, and the other four, Khenj (eastern zone) (figs. 32, 33), Mikeni I, Mikeni II, and Darun, and are in clastic host rocks. However, all of these occurrences are found within the fractured and altered contact between the carbonate and clastic units (fig. 34). To date the best emeralds have been found in the Khenj and Mikeni occurrences. Yearly emerald production values are unknown but estimates range up to $50 million for production in year 2000.

A broad description of the emerald mineralized area as given in Samarin and Akkermantsev (1977):

> In the course of geological mapping on the scale of 1:100,000, conducted in 1974 on the left(southeast) bank of Panjsher River the following exploration indications for emerald have been established.
>
> In the given area, a favorable geological pre-condition is the presence of the granites of the Laghman complex which appear to be specialized in rare metals. With this complex there are genetically connected the rare metal occurrences of this rayon, as well as the genesis of the emerald mineralization.
>
> The emerald mineralization is localized in linear zones of slight fracturing and brecciation of hydrothermally altered gabbro-diorite dikes, marbles, schists and quartz porphyry. The emerald mineralization occurs in two zones: in the north-western zone (locality Buzmal) and in the south-eastern zone (the other occurrences), associated with the contact between the carbonate series of Silurian-Lower Carboniferous age, and the Upper-Carboniferous-Permian flysch suite (sketch drawing No.1, 2T). Along the contact extends a series of closely spaced steep dipping faults, complicated by zones of little folding, fracturing, brecciation, boudinage and cataclasis, as well as of an intensively hydrothermal rock alteration (biotitization, phlogopitization, epidotization, albitization, potasium feldspatization, silicification , tourmalinization, sulfidization, carbonatization, chloritization, muscovitization, and other).

The beryllium mineralization with emerald sections is superimposed in a

complex system of fractures upon hydrothermally altered (carbonate-sulfide) rocks (gabbro-diorites, marbles, schists).

As a favorable factor apparently providing the source of chromium, which is needed to give the green color to beryl, was the presence of hydrothermally altered biotitized (phlogopitized) and chloritized diorite dikes (gabbro-diorites)…

special attention was given to reveal local indications within the beryl-mineralized dikes of gabbro-diorites and the rocks hosting them, and in the zones of brecciation and fractures penetrating the black quartz-biotite schists away from their apparent association with the gabbro-diorite dikes. The following observations have been assembled.

The emerald mineralization is locally controlled, usually not extending beyond the area of hydrothermally altered gabbro-diorite dikes. It is typical that the emeralds do not occur in all the dikes, only in the largest ones, essentially belonging to the south-eastern zone, close to the contact between the schist and carbonate series. Neither all the zones of slight fracturing and hydrothermal alteration of the schists are beryl mineralized, only those occurring close to the main contact structure - according to A.S. Schadchinev and others (1975). The locality Buzmal, occurring aside of the main structure, is an exception. However, its structural position is, in many respects, identical with the above description. At Buzmal, the beryl-mineralized dike of gabbro-diorites and the hosting rocks (marbles) located near the contact with the dike, occur in the vicinity of black shales, although in a separate monocline block. The separation of this block from the south-eastern zone can be explained, evidently, by a band-block structure [approximate translation of "cheshue-blokovoe stroyenie"] of the whole rayon on the left-bank of Panjsher River.

Within the gabbro-diorite dikes, the emerald mineralization occurs, at individual places in diagonal, or more often transverse zones of albitization and carbonatization where they are cut by veins with quartz-potassium feldspar-carbonates with pyrite (or tourmaline) and veins with green beryl, in places of a complicated dike structure or a change of its strike. Not rarely, the zones tend to follow the contact of the dike with the country rocks, mostly developed at the sahlbands (contact zone?) and sometimes deviating into the hosting marbles in a distance from 1-2 to 5-10 meters, even more. In some places the beryl-bearing veins are restricted to zones of schistosity (location Khenj) which occur in the footwall and hanging wall of the dike. In the quartz porphyry an occurrence of a light blue (strongly fractured) beryl was noted in individual quartz-potassium feldspar-carbonate veins with pyrite.

In the schist, quartz- potassium feldspar - iron-carbonate mineralization with pyrite and beryl is developed, following directions transverse to the schistosity, but in close-spaced parallel fractures with an intensive albitization and sericitization of rocks.

The beryl mineralization occurs in hydrothermally altered rocks in the form of small inclusions, individual crystals or aggregates, usually metasomatically replacing yellow coarse-grained vein dolomite, or quartz, K-feldspar or an Fe-carbonate present in veinlets in the gabbro-diorites, marbles, schists and, rarely, in quartz

porphyry at the contact with gabbro-diorites. As a rule, all these beryls are strongly fractured, non-transparent, in size no greater than 3.5 x 0.6 cm, usually 1.0 – 1,5 x 0,2 – 0.1 cm or smaller. Their color variations are mostly bluish-green, in some cases blue or colorless, and rarely emerald-green.

The factors playing a favorable role in the formation of low-fractured and very rarely unfractured emerald crystals is the presence of small slit-like [transl of 'shchelevidnyi'] remnants of cavities in the quartz-K-feldspar-carbonate veins which appear to be the principal carrier of the emerald mineralization. These veins appear to be the latest (not cut by any other), transecting the zones of albitization and carbonatization in the gabbro-diorite dikes, marbles and shales. …

Within the deposit of Panjshir, there are distinguished three types of emerald mineralization: [1] Associated with the dikes of gabbro-diorites within the zones of tectonic disturbance (locality Khenj – western zone; Buzmal', and Rivat); [2] Associated with shear fractures in the schists which appear to be feather fractures of the tectonic disturbances (locality Khenj – Eastern zone, Mikeni I and II, Darun); [3] Associated with hydrothermally altered and albitized dikes of quartz porphyry.

Emerald miners generally excavate into the contact zone between carbonate and clastic host rocks; dynamite is commonly used to the detriment of the crystals. Currently mining is being conducted in the Khenj and Mikeni localities. Favorable horizons are highly sheared and/or intruded by gabbro-diorite dikes (fig. 35). The gabbro-diorites are normally strongly altered and sheared. The presence of quartz porphyry dikes is also favorable. Miners follow yellow hydrothermal alteration zones and veins in search of emeralds (figs. 36, 37). Some tunnels extend only a few meters into the hillside; however, we followed a few for more than 200 meters underground. None of the tunnels that we explored showed evidence of structural reinforcements. Veinlets of carbonate (with specular hematite in places; figs. 38, 39), quartz, quartz-carbonate, pyrite-carbonate, quartz-tourmaline-carbonate are common. Tourmaline-albite-carbonate-iron oxide alteration is common (figs. 40, 41, 42). Microcline, white mica, and biotite or phlogopite also form alteration products. Beryl forms in clusters (figs. 43, 44, 45) within the alteration and in veinlets. Evidence for post-depositional fracturing is exhibited by some beryl crystals (fig. 45).

During geological-exploration studies of the Khenj locality in 1976 (Samarin and Akkermantsev, 1977), 3,360 gm of emerald crystals were recovered. Most of this quantity (3,125.4 gm) was recovered from the western zone (carbonate host rocks) of the Khenj deposit; the remainder was recovered from the eastern zone. Samarin and Akkermantsev (1977) report that of this recovered quantity, 591.2 gm (2,950.8 carat) were below gem quality, 32.3 gm (161.5 carat) were suitable for face cutting, and 557.9 (2789 carat) were suitable for convex cutting (cabochon). Samarin and Akkermantsev (1977) estimate that the gemstone-grade quantity of emerald crystals in the western zone within the productive area is 7.5 carat per cubic meter; in the eastern zone it is 0.6 carat per cubic meter. These authors also estimate that as of January 1, 1977 the reserves of emerald resources in the ground at Khenj (both eastern and western zones) was 439.9 kg for all emerald crystals of which 324,625 carats (65.0 kg) were of gemstone-grade

quality; of the gemstone-grade quality emeralds, 17,860 carats (3.6 kg) are suitable for face cutting and 306,765 carats (61.4 kg) for convex cutting (cabochon).

Panjsher emeralds have been described by Bowersox (1985), Kazmi and Snee (1989; and articles therein), and Bowersox and others (1991), as well as Samarin and Akkermantsev (1977). The quality of the emerald crystals varies from mine to mine. Most miners feel that the highest quality crystals come from Mikeni and Khenj localities. Crystals are transparent to translucent or opague and generally range from 4 to 5 carats, although a 190-carat crystal was reported by Bowersox (1985). Crystals are normally euhedral and prismatic although in some cases crystals were naturally etched by later reactive fluids. Color zoning is common and where present interiors are paler; exteriors are darker green. The green color of all emeralds is the result of the substitution of a small amount of chromium or vanadium for aluminum in the beryl crystal structure (Deer and others, 1986). In Panjsher emeralds, chromium contents of up 19180 ppm and vanadium up to 690 ppm were measured by instrumental neutron activation analysis (Snee and others, 1989). Hammarstrom (1989) measured chromium contents of up to 13700 ppm and vanadium up to 3100 ppm by electron microprobe. Hammarstrom (1989) also showed that the green brightly colored areas of emerald are enriched in chromium (fig. 46). Chemically Panjsher emeralds fall within the range for natural emeralds (Snee and others, 1989), but appear to be most similar to Colombian emeralds. They can be easily distinguished from Pakistan emeralds (Hammarstrom, 1989; Snee and others, 1989) and other world emerald deposits (Groat and others, 2002) by differences in trace element content.

As do other emeralds of the world, Panjsher emeralds contain inclusions. Seal (1989; and Seal in Bowersox and others, 1991) described numerous primary, three-phase, and other multiphase inclusions with distinct morphologies and crystallographic orientations (fig. 47; and figures in Seal, 1989, and Bowersox and others, 1991). Some tabular inclusions are oriented parallel to the c-axis and range up to 1000 µm in length. Other tabular inclusions formed perpendicular to the c-axis and are less than 250 µm in length. A third group of inclusions is subhedral and equant and generally less than 150 µm in length. Multiphase inclusions contain up to eight daughter minerals, H_2O-rich brine, and CO_2-liquid and gas. Although not all solid inclusions are identifiable, some of the most abundant solids are halite and sylvite, and Seal estimated salinity (NaCl+KCl) of approximately 37 weight percent. The salinity of Panjsher emeralds is high and makes them distinct from all other emeralds except those of Colombia (Seal, 1998; Ottaway and others, 1994; Giuliani and others, 1997; Sabot and others, 2001). Heating and freezing experiments conducted on three Panjsher emeralds with daughter mineral-bearing inclusions allowed Seal (1989) to determine vapor-homogenization-to-liquid temperatures between 147° and $201^{o}C$. However, in this experiment, not all daughter minerals dissolved; therefore these temperatures must be considered minima. Corresponding minimum calculated entrapment temperatures at an estimated 900 bars confining pressure fall between 247° to $301^{o}C$ (Potter, 1977). Similarly, Giuliani and others (1997) estimated Panjsher emerald formation temperatures between 200° and $350^{o}C$, but did not comprehensively define why their temperature estimate covers a broader range with both lower and higher temperature limits. Although in the lower range of emerald formation temperatures for many other deposits (Groat and others,

2002), both of these estimates are similar to formation temperature estimates for Colombian emeralds (Ottaway and others, 1994; Giuliani and others, 1992; Cheilletz and others, 1994).

Origin of the Panjsher Emerald Deposits

Emerald is one of the rarest and most precious gemstones because unusual circumstances are necessary to bring chromium and beryllium together in the natural environment. Emerald is the result of the substitution of a small amount of chromium (or vanadium) for aluminum in the beryl crystal structure (Sinkankas, 1981; Deer and others, 1986; see also Farm, 1975 for an alternative definition of emerald). Beryllium and chromium are geochemically incompatible. Beryllium has a very small atomic radius (0.3 Å; Shannon and Prewitt, 1969). Thus, it is excluded from the crystal structure of most minerals, and it remains in fluid or magma until the latest, most evolved magmatic processes. Beryllium also has a small crustal abundance (5ppm or less; Wedepohl, 1978; Beus, 1965; Krauskopf, 1955). Therefore beryllium-bearing minerals are generally only found in late-stage igneous rocks, such as pegmatites, or form from beryllium scavenged from beryllium-bearing source rocks by hydrothermal processes. Chromium, on the other hand, is found in significant amounts in ultramafic and some "primitive" mafic rocks. Ultramafic rocks crystallize early in magmatic processes and are at the opposite end of the geological spectrum from those that carry beryllium. Chromium is also found in significant amounts, up to 5000 ppm (Krauskopf, 1955), in some black shales; vanadium contents in some black shales can be as high as 14,000 ppm. The source of the high concentrations of chromium and vanadium in black shales is uncertain, but Krauskopf (1955) recognizes the importance of provenance and Snee and Kazmi (1989) suggested that high chromium content could reflect the presence of ultramafic and chromium-rich mafic rocks in the source area of the shales. Thus, the presence of emerald in nature represents the unusual geologic circumstance that brought these incompatible elements together. Many authors (Kazmi and Snee, 1989; Ottaway and others, 1994; Schwarz and Giuliani, 2001; Groat and others, 2002; among many others) have described these conditions in known world emerald deposits, and several authors (Snee and Kazmi, 1989; Schwarz and Giuliani, 2001) categorize and classify emerald deposits based on geologic environment.

Samarin and Akkermantsev (1977) recognized the favorable conditions for the formation of Panjsher emeralds including:

- Nearby occurrence of the rare-metal-enriched granites of the Laghman complex;
- Zones of tectonic disturbance and shearing;
- Hydrothermally altered biotitized (phlogopitized) and chloritized gabbro-diorite dikes, marbles, schists and quartz porphyry;
- The contact between the carbonate and clastic sedimentary rocks.

Samarin and Akkermantsev (1977) also clearly understood the necessity for having distinct sources for both chromium and beryllium. They concluded that the chromium source for Panjsher emeralds is mafic (gabbro-diorites) igneous rocks, although no chemical analyses of these rocks was presented by them. They also concluded that beryllium was transported along faults and fractures to the chromium-bearing host rocks

by hydrothermal fluids that were derived during magmatic processes associated with the emplacement of the Laghman Complex. Again, no chemical analyses of the alteration assemblages were presented by them. In addition, no isotopic ages for the time of hydrothermal alteration were presented; furthermore, only a broad understanding of the age of evolved plutonic rocks in the Laghman Complex was defined. Aside from quartz porphyry dikes, no chemically evolved igneous rocks or pegmatites exist in the mineralized area. Laghman Complex granitoids are located to the east in Nuristan. There they are the host and likely source for numerous rare-metal pegmatites, some of which bear beryl. The alteration assemblage associated with the Panjsher emeralds includes colorless and blue beryl, albite, and tourmaline, among other minerals. This assemblage is consistent with a derivation from evolved magmatic/hydrothermal fluids, perhaps derived from the Laghman Complex. Fluid inclusions in the emeralds are saline and of a composition that could transport beryllium; according to Renders and Anderson (1987), beryllium is transported in hydrothermal fluids as hydroxyl- chloride-, and fluoride-complexes. Therefore, the conclusion on the origin of the Panjsher emeralds by Samarin and Akkermantsev (1977) is a valid working hypothesis, but more data are needed to test their conclusion.

In recent years, work done on Colombia emeralds by Beus (1979), Ottaway (1991), Ottaway and Wicks (1991), Ottaway and others (1994), Giuliani and others (1992, 1995, 1997), and others has resulted in an alternative hypothesis for the source of beryllium and chromium in Colombian emerald deposits. In the Colombian model, beryllium and chromium are both derived from organic-rich black shales, which are exposed within the sedimentary units that host the emeralds. As noted above, black shales in some parts of the world contain significant abundances of chromium and vanadium, but near the Colombian emerald deposits the chromium abundances are only on the order of 30 to 40 ppm. Beryllium content in most shales is low; in the shales at Muzo, Colombia, it is on the order of 3 ppm (Ottaway, 1991; and Ottaway and others, 1994), which is near crustal abundance level (Wedepohl, 1978; Beus, 1965). In the Colombian model, hydrothermal brines derived from the dissolution of evaporates transported sulfate to the black shales along fractures and faults. Beus (1979) noted that there are a number of salt domes within the Colombian Cordillera Oriental, near the location of the emerald deposits. The sulfate reacted with the organic matter in the shales and released chromium, vanadium, and beryllium, which ultimately precipitated as emerald. Considering the very low concentrations of chromium, beryllium, and vanadium in the host rock shale, this process must have been highly efficient.

Sabot and others (2001) have proposed a similar model for the formation of the Panjsher emeralds. In their study of Panjsher emeralds they report, as did Seal (1989) and Bowersox and others (1991), the presence of high-salinity inclusions. The inclusions in Panjsher emeralds are very similar to those of Colombia emeralds. Experimental analysis of Panjsher inclusion fluids showed them to be highly saline with chlorine over 200,000 ppm, sodium over 73,000 ppm, potassium nearly 20,000 ppm, and very low bromine abundance indicating derivation from the dissolution of halite. Their stable isotope analyses suggested to them that sulfur and boron were derived from an evaporite source. They also described natural organic compounds and graphite in the emeralds,

and these were linked to thermochemical reduction of sulfate by organic matter in shales. Presumably, then, beryllium, chromium, and vanadium were released effectively from the wall rocks by the reaction of the sulfate with organic matter, a process similar to that proposed for the formation of Colombian emeralds.

Currently we are collecting geochemical, isotopic, geochronologic, and fluid inclusion data on samples collected from the Panjsher Valley emerald deposits and host rocks to better constrain the origin of the emeralds. However, our new field data combined with observations and data published by Samarin and Akkermantsev (1977), Kazmi and Snee (1989), Bowersox and others (1991), Giuliani and others (1997), Sabot and others (2001), and Schwarz and Giuliani (2001) allow us to generally constrain the origin of Panjsher emeralds. Some of the critical observations include the following. Altered mafic/ultramafic rocks, a potential source of chromium, are commonly directly associated with emeralds. Some quartz porphyry intrusions, a potential source of beryllium, are present in the vicinity of the emerald zones, but these intrusions are not ubiquitous. Variably metamorphosed graphitic shales are exposed throughout the emerald zone. Emerald-bearing host rocks are extensively sheared and faulted as a result of structural activity along the continental-scale Tectonic Zone Hindu Kush. Hydrothermal alteration is present in all emerald-bearing zones. Stable isotopes and fluid inclusions suggest a metamorphic or magmatic source, and the fluid inclusions were highly saline (Seal, 1989; Bowersox and others, 1991; and Giuliani and others, 1997). Beryllium-bearing hydrothermal fluids, derived from magmatic fluids associated with emplacement of evolved granitoids of the Laghman Complex, may have gained access to chromium-bearing ultramafic/mafic rocks along shear zones. Alternatively, according to Sabot and others (2001), beryllium (and presumably chromium, also) was derived from the interaction of saline-rich fluids of uncertain origin with black shales associated with the emerald deposits.

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Appendix 1

Trip Report: Afghanistan Reconstruction Effort, Kabul, Bagram, Panjsher Valley, Ghowr Band Valley; June 30-July 14, 2004

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In support of the US-AID-funded, USGS reconstruction efforts in Afghanistan, I was part of a group that traveled to Afghanistan through Baku, Azerbaijan in June and July, 2004. The group included Robert Bohannon, Roy George, and Jared Abraham, all from the USGS in Denver, Colorado. The purpose of this trip was multiple: We were to make contact with members of the Afghan Geological Survey. We were to establish a working relationship with staff of the US Embassy and US AID in Kabul. We were to work closely with Said Mirzad (Senior Adviser to the American Ambassador to Afghanistan) in support of the USGS efforts in Afghanistan. We were to attempt to conduct field work in the Panjsher Valley, in particular, in northeastern Afghanistan to assess emerald deposits and study geology. This trip was highly successful and highlights are described below. Additionally, some observations and assessments are presented.

- Travel by US government employees into and in Afghanistan requires close coordination with the US Embassy in Kabul. Upon arrival in Kabul on June 30, 2004, from Azerbaijan, I met with Dr. Said Mirzad and representatives of the U.S. Embassy and U.S. AID at the Embassy. Arrangements had already been completed for field work in the area of the Panjsher Valley. Two 5-day long visits to the Panjsher were planned, and initial contact with governmental officials of Panjsher had been made. Security arrangements were in place. Two members, Dr. Abdul Wasay and Mohammed Omar, of the Afghan Geological Survey were prepared to accompany us to the field area. Abdul Wasay is the acting Director General of the Afghan Geological Survey; he does not speak English, but he has done extensive work in the area of the emerald deposits. Mohamed Omar is also a geologist, and he speaks English. Neither Afghan had field equipment or adequate boots for the work. Neither received adequate pay from the Afghan government to dedicate their time to day-to-day work at the Afghan Geological Survey. Arrangements were made in advance to provide both with field equipment, boots, sleeping bags, and a stipend to cover expenses in the field.
- On July 1, 2004, three US geologists, Bob Bohannon, Roy George, and Lawrence W. Snee, along with the two Afghan geologists, Abdul Wasay and Mohammed Omar, departed Kabul in mid morning under heavy security for Bagram to drop supplies at the Parwan PRT at the air base 60-km north of Kabul. It had been decided before our arrival that we would travel daily approximately 100 km into the Panjsher Valley to emerald localities near Khenj from Bagram by ground convoy under heavy security. The convoy for this first trip included five reinforced, armored Toyota Land Cruisers, one Toyota pickup truck to transport guards, and two Toyota pickup trucks with bed-mounted machine guns and gunner's seats. Sixteen heavily armed American Embassy guards and 2 translators accompanied us. Travel to Bagram was uneventful, and we continued into the Panjsher Valley. Travel into the Panjsher was very slow over a poorly maintained, albeit primary road along the bank of the Panjsher River. The machine gunners were severely battered in the gun trucks from the roads and this slowed our progress. We examined the geology along the way and collected samples for geochemical analysis. The geology is complex and includes crystalline rocks of possible Proterozoic age, a major tectonic feature, named the Tectonic Zone Hindu Kush by the Russians, and sedimentary rocks with low metamorphic grade adjacent to the crystalline rocks. We arrived at Bazarat at 3 PM, and we met with the Governor of the Province, Engineer Wasel. He was polite and cordial, almost to a fault. We relied on Mohammed Omar to translate. Although the Governor was obviously excited about the help being offered by the USGS to work with Afghan emerald miners, he was clearly concerned about the number of weapons that we carried into the Panjsher. The people of the valley are self sufficient and very suspicious of armed foreigners. The Russians had attempted to invade the valley 11 times during the Russian occupation of Afghanistan, and 11 times the Panjsheris under Mohammed Shah Massoud had repelled their attacks. The Governor was insistent that we would not be harmed. After extensive discussion, he was reluctantly willing to let us take our guns into the valley. He offered lodging at a guest house/government office at Khenj. We

told him that we wanted to work in the valley for five days. Clearly he was concerned about us being in the valley Friday July 2, the next day. He was too polite to tell us his concern, or our translation from Omar was incomplete. We realized he was concerned and asked if we should not be in the valley on Friday. Clearly he was relieved when we offered to leave the valley that evening and begin work on Saturday. As it turned out, many people from outside the valley were expected to vacation in the valley that weekend. We returned to Bagram.

- July 2, the convoy traveled up the road towards the Salang tunnel from Bagram. We examined the geology and collected samples for geochemical analysis. We crossed into the Tectonic Zone Hindu Kush, but were unable to cross out of it to the north because the police would not allow us to travel all the way to the tunnel. The valley was filled with vacationers, many of whom were picnicking and playing along the river.
- July 3, the convoy traveled from Bagram to Khenj. We were able to assure the Embassy that we would be safe if we stayed in the Panjsher Valley for the next few nights under our and Panjsheri security. The Embassy gave permission for us to stay at Khenj. If we had had to drive into the valley every day from Bagram, we would not have been able to accomplish any significant field work. Travel time from Bagram to the Governor's residence at Bazarat was 2 ½ hours with no stops. Another meeting with the Governor, who was grateful that we had not worked in the valley on Friday. We drove from Bazarat through Khenj to Dashte Rewat, the northeastern extent of the emerald zone. The emerald zone extends from Peshgor, northeastward to Dashte Rewat; the highest quality emeralds are found near Khenj and Mikeni. Emeralds are primarily found on the eastern side of the Panjsher River in carbonates and graphitic schists of very low metamorphic grade. The schists are in the Tectonic Zone Hindu Kush and are generally accompanied by pods of ultramafic rocks and granitic intrusive bodies. We made a short hike into the emerald zone at Dashte Rewat to examine the geology. In this area, pale green emerald is found in quartz and carbonate veinlets that cut through diabase and aplite. Host rocks are sericitic carbonate, marble, mafic rocks, and sandstone.
- July 4 we hiked from Khenj at an elevation of 7700' up the Dar Khenj to the lower Khenj emerald mines in the vicinity of 35° 24.72'N and 69°46.04'E, at an elevation of about 9000'. Good trails follow the stream and provide easy access to the lower, inactive mines in the cliffs to the north. Mines are found both in carbonate hostrock and in graphitic schist host. Some mines extend 10s of meters into the host rocks. These mines have no visible reinforcements or support and could be extremely unstable. Some mafic rocks are present, as are granitic intrusive rocks. Emeralds are found in quartz, carbonate, limonite veinlets cutting across the host rocks, and are likely hydrothermal in origin. Questions still remain on the origin of the chromium and the beryllium, two chemically incompatible elements essential for the formation of emerald. Emerald is the green-colored mineral beryl, whose coloration results from the presence of a few hundred ppm or more chromium in the crystal structure. Chromium is commonly present and derived from ultramafic rocks like those observed in the Tectonic Zone Hindu Kush. Beryllium is possibly derived from hydrothermal fluids that

traveled from granitic intrusions along fractures in the host rocks. Samples were collected of the host rocks, granitic rocks, and ultramafic rocks for geochemical analysis.

- July 5 we hiked up the Darya Mikeni beginning at 35° 27.15'N and 69°46.45'E at the village of Degak. Similar geology here as east of Khenj. Hiked to Mikeni village but were unable to reach any of the emerald mines due to the distance and elevation. Collected samples of host rocks for geochemical analysis.
- July 6 and 7, we returned to Kabul and visited the Afghan Geological Survey in Kabul. We toured the Survey building, which is in terrible condition from the war. We visited with some of the geologists, who spend limited time at the Survey because they are paid inadequately. For example Abdul Wasay, the acting Director General, must drive taxi to make his living. These individuals are highly motivated but we must provide them with salary, training, equipment, and books. We heard numerous requests for these things. We discussed the desire of both sides to train them in the field in Afghanistan, to bring some to the US for training, to teach courses for them in Kabul, to have some attend American universities.
- July 8 and 9, we traveled into the Ghowr Band Valley both days to study geology and collect samples for geochemical analysis. To get permission to make the trip we visited with the governor of Parwan Province in Charikar before entry into the valley. The valley trends east-west and follows the western extension of the Tectonic Zone Hindu Kush. The valley extends to Shebar Pass, just east of Bamiyan. Access into the valley is also along poorly maintained roads but travel was without risk even with fewer security guards than during the previous trip. Several secondary roads extend off the main road and could provide access to other parts of the valley and the geology. In parts of the valley are thick surficial deposits with evidence of young (Neogene) structural activity. The bedrock is similar to that in the Panjsher with carbonates and graphitic schists, some mafic rocks and granites. Travertine deposits occur. There are exposures of mylonites near the road that we did not visit but should be visited in the future in order to understand the structural history of the Tectonic Zone. Apparently, according to Wasay, the mylonites show evidence of strike-slip translation.
- July 10, we traveled into Panjsher from Bagram. We visited with the governor again for his permission; he was pleased that we had not worked in the valley on Friday, again. We drove up the Panjsher road to 35° 29.65'N and 69°49.65'E and hiked into the Buzmal emerald mining area. These mines are now inactive, but produced some fine stones. Some of the adits drift 300 meters into the mountain and have no structural support. The adits were drifted along the contact between ultramafic rock and carbonate host rock. Wasay described the mined emeralds as having been very clear, with few inclusions, and bright green. Veinlets of albite and limonite carried the emeralds. Emeralds were found in "nests" of albitized carbonate. We collected samples for geochemical analysis. We found some poor quality pieces of emerald in quartz with pyrite. Specular hematite is also present.
- July 11 we were to hike to the Mikeni mines. However, the previous day there was a murder in the small village of Degak that we were to hike through. The police did not give us final permission to start our hike until 9 AM. I decided to

cancel our trip because I thought the potential for conflict was too great. Instead we began our transit back to Bagram and Kabul. We collected additional samples along the Panjsher road. We traveled approximately 10 km southeastward along a road that follows the Hazara River. Here we crossed through the Tectonic Zone Hindu Kush collecting samples. We had a tense encounter in a village along this road where a traffic jam resulted. The villagers were upset with the presence of our weapons. We returned to the Panjsher road, visited Massoud tomb, visited with the governor in Buzarat to give him our thanks, and returned to Bagram and on to Kabul that evening.

- July 12, I visited the Afghan Geological Survey again. I toured the museum. Wasay showed me a copy of a Russian report on the Panjsher emerald deposits. This report is comprehensive and includes 7 maps of the mining area. I was able to copy the report at the Embassy, but I could not get full copies or scans of the maps. Instead I copied the maps on the Embassy page-format copier. This report must be translated to understand better the emerald deposits, including developing a deposit model of these emerald deposits, and to determine where additional effort should be focused. The report clearly shows five areas of emerald mining interest. Three of these areas are still in operation. Although we observed no active mining during our visit, evidence of miners' tents was present higher in the mountains.

Observations and suggestions:

This was a short but highly successful trip. Although travel to field areas such as the Panjsher is difficult, it is possible. Roads are in poor condition. Much time is used to meet with local officials. The logistics of coordinating 5 to 8 vehicles in tribal areas is a challenge. We had clear requests from the officials in the Panjsher area to cut back on our weapons. It is in my mind as dangerous to have as many guards and weapons as we did, as it is to rely on local security. The governor of the Panjsher offered us local security. In the future this option should be explored. Clearly, additional work must be done in Panjsher and Nuristan. Pack trips or helicopter support will be essential. Working closely with the governors of these regions can only bring us into their trust. Organizing a pack trip, for example, along the Hazara River from Panjsher to Nuristan could be attempted with the support of local leaders.

Our Afghan Geological Survey counterparts are extremely important. We all know the training needs, the needs for modern geologic literature, the importance of rebuilding the AGS building. They also critically need a solid organizational and salary structure so they can focus on the critical work of the Afghan Geological Survey in its role as the nation's earth science organization. I strongly encourage the USGS in its efforts to bring some of these folks to the U. S. for onsite training.

The geology of the Panjsher is complex. Details on the genesis, or deposit model, of the emeralds are still uncertain. However, this trip provided much first-order geologic information to begin to develop a better understanding of these deposits. In addition, the Russians have mapped this area and have studied the emerald deposits. Abdul Wasay is a great asset for work in this area. He has visited all the deposits and understands the geology. Russian literature exists on this area, and I have obtained a copy of a

comprehensive report with extensive maps. The report is in Russian and needs to be translated. This report was unknown until Abdul Wasay mentioned it to me.

An important consideration that must be addressed is the future of the Panjsher emerald deposits. This concern applies to several aspects. First, mining in the Panjsher uses primitive techniques that endanger the stones as well as the miners. Explosives are indiscriminately used; mines are holes intot he earth that are unreinforced. The miners need training in gemstone mining techniques and mine safety. The miners need adequate mining equipment. Consideration should be given to developing an exploitation plan that allows the primary interests to remain with the Afghan miners, themselves, but with professional consideration of the resources themselves and the world market. The preparation and export of the gemstones needs to be carefully considered. Currently, most emeralds leave the country through the back door. Afghanistan could benefit from developing a cutting and export industry within Afghanistan.

Appendix 2

Original title: **Geologicheskaya karta i karta poleznykh iskopaemykh**.

Geological Map

and
Map of Mineral Resources

Basins of rivers Gorband, Salang, Panjshir*
[Russian spelling: Pandzhsher]
Parts of sheets 503-F, 504-C,D,E,F

Compiled by:
A.S. Shadchinev, N.V. Khandozhko, V.S. Drannikov,
Said Yakub Matin, Zul'mad Salikhi, Abdul Kadyr Gemat

Scale: 1: 100,000

1975

Instructions for printing the English version of the map:

Please, print what is shown in black. Words in red are just instructions.

Words in parentheses (…) keep what was in parentheses in the Russian text.

Words in brackets [……] show the Russian words which were translated.

Stratigraphic column
for scale 1: 25,000

Please follow the section numbers and a,b,c,… as used on the attached two xerox pages.

Section No.1
Vertical print:
a. Time/Era b: Period c: Section d: Symbol e: Thickness in meters

Horizontal print: Rock types

Section No.2
Vertical print
a Cenozoic b: Paleogen-Neogen c: Oligocene-Miocene d: P_3 N_1 e: 600

Horizontal print red conglomerates, gritstones [gravelity], sandstones, siltstones [aleurolites]

Section No.3
Vertical print
a Mesozoic b: Triassic c: Lower d: T_1 e: 1200

Horizontal print grey conglomerates, gritstones [gravelity], sandstones, siltstones [aleurolites] with horizons of boulders and blocks of mainly carbonate rocks. In limestone fragments are found crinoids–Cupressocrinites sp.-D

Section No.4

Vertical print:

a Paleozoic b: Permian d: $C_2P_1^a$ e: 2800

b Carboniferous

Horizontal print: To be printed in the upper part of section 4 across the boundary separating Permian and Carboniferous (see the attached xerox page);

quartz-sericite-chlorite, quartz-biotite, and biotite-quartz schists, polymict sandstones, siltstones [aleurolites] with separate horizones and blocks of gritstones [gravelity] and conglomerates with different detritus. In carbonate fragments of conglomerates occur fauna remnants of crinoids: Pentagoncyclicus sp., Cupressocrinites sp.-D

---

c: Lower d: C_1^b e:700

Horizontal print Siliceous (jasper-schist) rocks, microquartzites with layers of breccia-looking carbonate rocks and their fragments. In some areas of the lower section occur albite-actinolite and micaceous-albite schists (after volcanites of basic composition), in other places basal conglomerates with carbonate fragments containing crinoids – Cupressocrinites sp., Pentagonocyclicus sp.-D.

C_1^a

Section No.5

Vertical print

a: Paleozoic (continues from Section 4) b: Devonian c: e: 2000

b: Silurian

Horizontal print: Limestones, dolomites and intermediate composition varieties. In the neighboring area to the west, remnants of the following fauna was found:

Leptaena rhomboidalis (Phillips); Atrypa reticularis (Linne) – D_1-D_2 e; Douvillina interstrialis (Phillips); Productella cf. subaculeata (Murchinson); Schizophoria striatula (Schlotheim); Gruzithyris inflata (Schnur)-D_2 e; Spinatrypa sp.ex gr.explanata (Schlotheim) – D_2 e gv);

Rhynochonella cuboides Sow; Spirifer verneuli Murch: D_3 ;
Gnaiodus cf. texanus (Hass); Mindeodeila germana (Holmes);
Zaphrentis sp. , Siringopora sp.- C_1 v

Section No.6
Vertical print
a: Precambrian d: include symbol for Precambrian. e: 3000

Horizontal print garnet-sillimanite-biotite, cordierite-garnet-biotite, biotite, biotite-amphibolite gneiss, amphibolites, crystalline schists, marbles, quartzite.
In the marbles: Conophyton sp.

LEGEND on the right side of the map:

A. Inscriptions on the left side of the boxes with symbols.
including names, some printed vertically and some horizontally:

Quaternary (vertically)
Neogene (horizontally)
Triassic (horizontally)
Carboniferous (vertically)
Precambrian (horizontally)
Next inscriptions are not readable.

B. Legend on thr right side of the boxes with symbols (printed horizontally):

Q^2_{IV} Alluvial floodplain deposits, and lower part of the terraces above the floodplain (up to 10 meters); talus [deluvial] and slopewash [proluvial] deposits; coarse gravel [galechniki]; sands; loam [suglinki]; detritus [shcheben'].

Q^1_{IV} Alluvial deposits of the terraces above the floodplain (up to 30 meters); glacial material and travertine; pebble; sand; loam [suglinki]; detritus; calcareous tufa.

Q_{III} Upper Quaternary alluvial terraces (100 – 200 meters); landslide deposits; coarse gravel; sands; loam; detritus; boulder; rock block.

Q_{II} Middle Quaternary deposits. Loess, loam.

Note: Combine the above four Q groups by a vertical bracket and name Quaternary.

P_I N_I Oligocene-Miocene deposits. Red conglomerates, sandstones, clays, siltstones (aleurolites).

Note: Put name Neogene (horizontally) before the symbols $P_I N_I$

T_I Lower section. Grey conglomerates , gritstones [gravelity], sandstones, siltstones (aleurolites) with boulders and blocks of mostly carbonate rocks.

Note: Put name Triassic (horizontally) before the box with symbol T_I

Symbol in the box not readable, map is folded in that place. Try to read the symbol on computer.

Horizontal text is also hard to read:

Quartz - …… -.chlorite, quartz-biotite schists, sandstones, siltstones (aleurolites) with layers of……. and conglomerates.

C_I^b Siliceous jaspers, schistose rocks, microquartzites with layers of breccia-looking carbonate rocks and their separate fragments. At the bottom albite-actinolite and micaceous albite schists (after volcanites of basic composition).

$S - C_I^a$ Limestones, dolomites and intermediate composition varieties

Combine the above three groups by a vertical bracket and put, also vertically, the name of……..[not readable, please try to focus on it]

Put symbol of Precambrian in the box .

Write horizontally to the left of the box: Precambrian

Horizontal text to the right of the box:

Garnet-sillimanite-biotite, cordierite-garnet-biotite, biotite-amphibole gneiss, amphibolite, crystalline schists, marbles, quartzites.

$\chi_2 P_3$ Second phase. Coarse χ……. Cannot read the symbol in the box. grained pegmatoid granites.

First phase. Medium-coarse grained sometimes porphyric tonalites, granodiorites, granites, gneiss-granites.

Combine the above two groups by a vertical bracket on the left side of the two boxes, and add, also vertically, Late Paleogene……. not readable

On the right side of the box, there should be a few words, vertically, before the horizontal text starting "First phase'. These words I could not read either. Please, try to focus on them.

Box with symbols not readable.

Horizontal text: Early Mesozoic gabbro-diorites, diorites.

$\chi\ \pi\ T_3$ Late Triassic subvolcanic quartz porphyry intrusives

$\sigma\ P_2 - T_1$ Pegmatites

$\chi_3\ P_2 - T_1$ Third phase. Medium-coarse grained sometimes porphyric biotite granites

$\chi_1\ P_2\ T_1$ Second phase. Small-medium grain biotite-amphibole granites, granodiorites.

$\rho\ \ \delta_1\ P_2\ T_1$ First phase. Quartz diorites.

Combine the above four groups (starting with that with Pegmatites) by a vertical, brackets on the left side of the boxes and leave space for a text which, at the moment, is not readable.
On the right side of the four boxes should be written, vertically: Hindukush Complex

---

…..$\delta\ C_2\ P$ Middle-Early Permian intrusives of gabbro-diorites, diorites and gabbro.

$\sigma\ C_{1\text{-}2}$ Early-Middle Carboniferous ultrabasic intrusives (serpentinites)

Follow boxes with graphic patterns:
Box: Hornfels alteration
Box: Skarn alteration
Box: Injection alteration (migmatitization of amphibolites after gabbro diorites).
Box: Biotite quattz schists
Box: Hematitization
Box: Albitization
Combine the above six boxes by a vertical bracket on the left side of the boxes, adding, again vertically: not readable, please try to focus.

Box: Pegmatoid granites
Box: Coarse grained and porphyric granites
Box: Medium- and small-grained granites, granodiorites
Box: Gneiss-granites, granites with gneissy-texture
Combine the above four boxes by a vertical bracket on the left side of the boxes, addnig: Acid rocks

---

Box: Diorites
Box: Gabbroids
Box: Ultrabasics
Box: Pegmatites
Combine the above eight (four and four) boxes, starting with "Pegmatoid granites" and extending through "Pegmatites" by an "outer bracket" to the left of the bracket covering the first four boxes, and adding: Intrusive rocks

---

Box: River deposits

Box: Glacial deposits
Box: Aeolian-stream deposit
Box: Slope and valley talus [deluvial], talus -slopewash [proluvial], and slopewash deposits
Box: landslide [opolznevye] deposits
Box: travertines (limestone tufa)
Combine the above six boxes by a vertical bracket on the left side of the boxes,adding again vertically: Genetic types of Quaternary deposits

---

Box: Siliceous rocks (a – on the map; b – on the profiles; v – in the column)
Box: Boulders and blocks of carbonate rocks.

ATTENTION. Continuation of boxes from the upper right, above the table of mineraal deposit types: - see next page.
Box: Boundaries between formations of different ages
Box: Facial and lithologic subdivisions of one and the same age
Combine the above two boxes by a vertical bracket on the left side of the boxes, adding word (again vertically): boundaries.

Box: a: reliable; b: supposed
Box: Below Quaternary deposits: a: reliable; b: supposed
Combine the above two boxes by a vertical bracket and add, vertcally: Geological contours.

Box: Chaotic accumulation of blocks and boulders of carbonate, siliceous terrigenous rocks, tufs and effusives of basic composition. Ultrabasics and serpentines. The blocks show signs of mutual displacement.
Add the following words , horizontally, on the left side of the box: Melange of the Hindukush fault zone.

Follows explanation to symbols used on the map:

Dip
Prevailing dip
Vertical
…….not readable, please focus. Probably Russian word for “overturned”
Horizontal
Banding [poloschatost’] of gneiss-granites and its dip
Combine the above six symbols and explanations by a vertical bracket to the left of the symbols, and add, vertically: Bedding and structure
Location of organic remnants

Major table of ore deposits with symbols:

Deposits and manifestations of mineral resources

Names of horizontal columns at the top of the table:

Mineral Resources	Economic deposits	Non-economic deposits	Manifestations	Spots of mineralization

Names in the first column:

Iron
Manganese
Copper
Lead
Zinc
Tin
Arsenic
Silver
Lithium
Tantalum
Niobium
Pegmatite (ceramic)
Mica (muscovite)
Rock salt
Cement resource (limestone)
Plastic clays
Emerald
Piezo-quartz

Two paragraphs at the bottom, beneath the large table of Mineral Resources

To the right of the 'curved' symbol:

149 – aureole number; Pb – symbol of the element; ZN-15.0 - threshold content of a mineral (element) in the schlich (metallometric sample), corresponding to g/m^3 (symbol [znak]) or percents.

Note: The map does not show minor schlich and secondary lithochemical aureoles. All deposits, manifestations and aureoles are given in **Attachment No.1-a**.

Next two tables on the right:

Heavy minerals aureoles

Copper-containing minerals
Lead-containing minerals
Cassiterite
Scheelite and wolfram
Tantalite and columbite

Mercury
Bismuth and basobismutite
Uranium-thorium minerals

Secondary litho-geological aureoloes

Copper
Lead
Zinc
Tin
Molybden
Wolfam

Title of a small table above the long geological profiles:
Scheme of the position of individual map sheets.

Four long vertical geological profiles:

Profile along line A – B
Introduce orientation: NW (on the left) and SE on the right.
Names inside the profile (from left to right): river Gorband, Pagman [?] Range

---

Profile along line V – G It is below profile A-B

Introduce orientatio NW on the left, and SE on the roght
Names in the profile (from left to right): river Ko..lami [not readable], river Salang ; river Panjshir

---

Print translation of the scale beneath the above profile:

Scale horizontal 1:100,000
vertical

please adjust as on the map

Profile along line D - E
Introduce orientation: NW (on the left) and SE (on the right)
Names in the profile (from left to right): river And….man (not readable), river Panjshir

---

Pofile along line Zh – Z (it is below profile D-E):
Introduce orientation: NW (on the left) and SE (on the right)
One name in the profile: river Panjshir

Insciption in he upper right corner of the whole map (above a major stamp):

Attachment No.1
to the report by the Gel'mend Party,
1975

Names on the stamp (only partly readable):
Ministry of ……..and Industries.

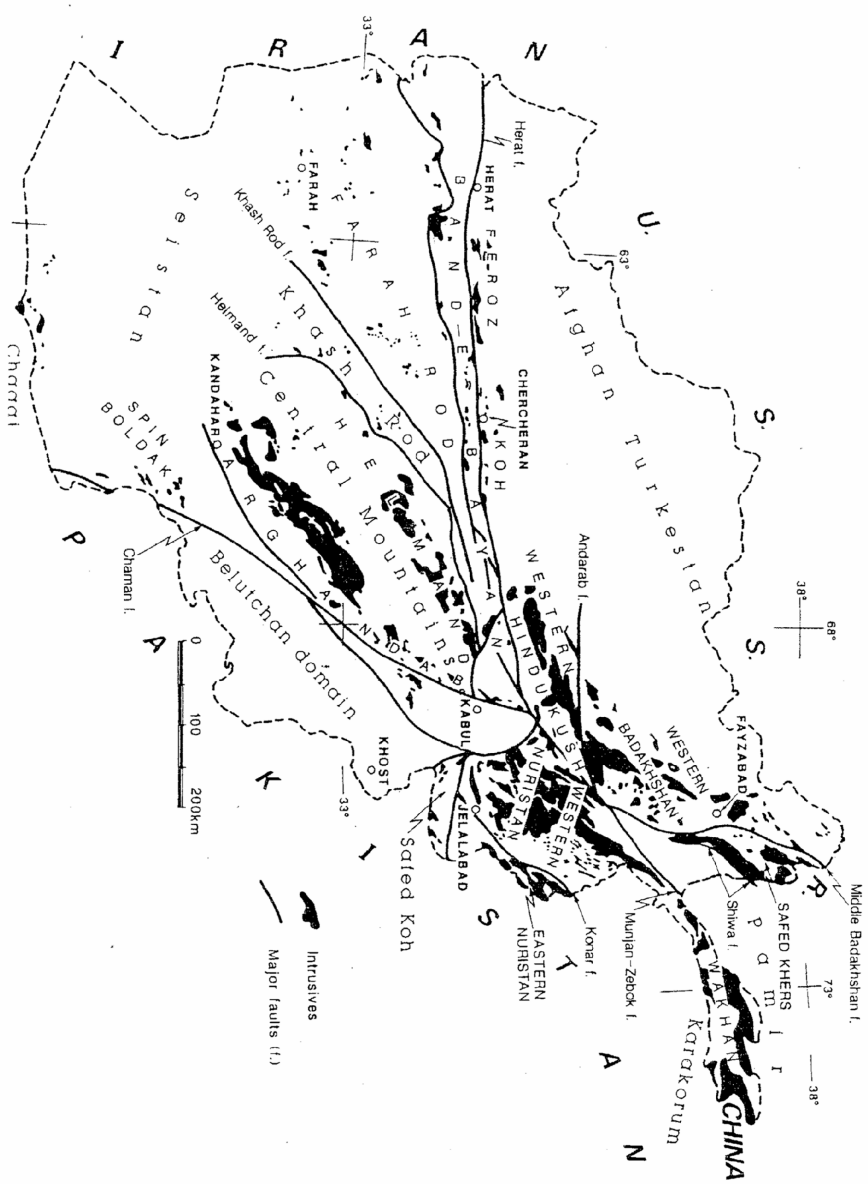


Figure 1. Sketch map of Afghanistan showing major structures and zones of intrusive rocks from Debon and others (1983) after Stazhilo-Alekseev and others (1973).

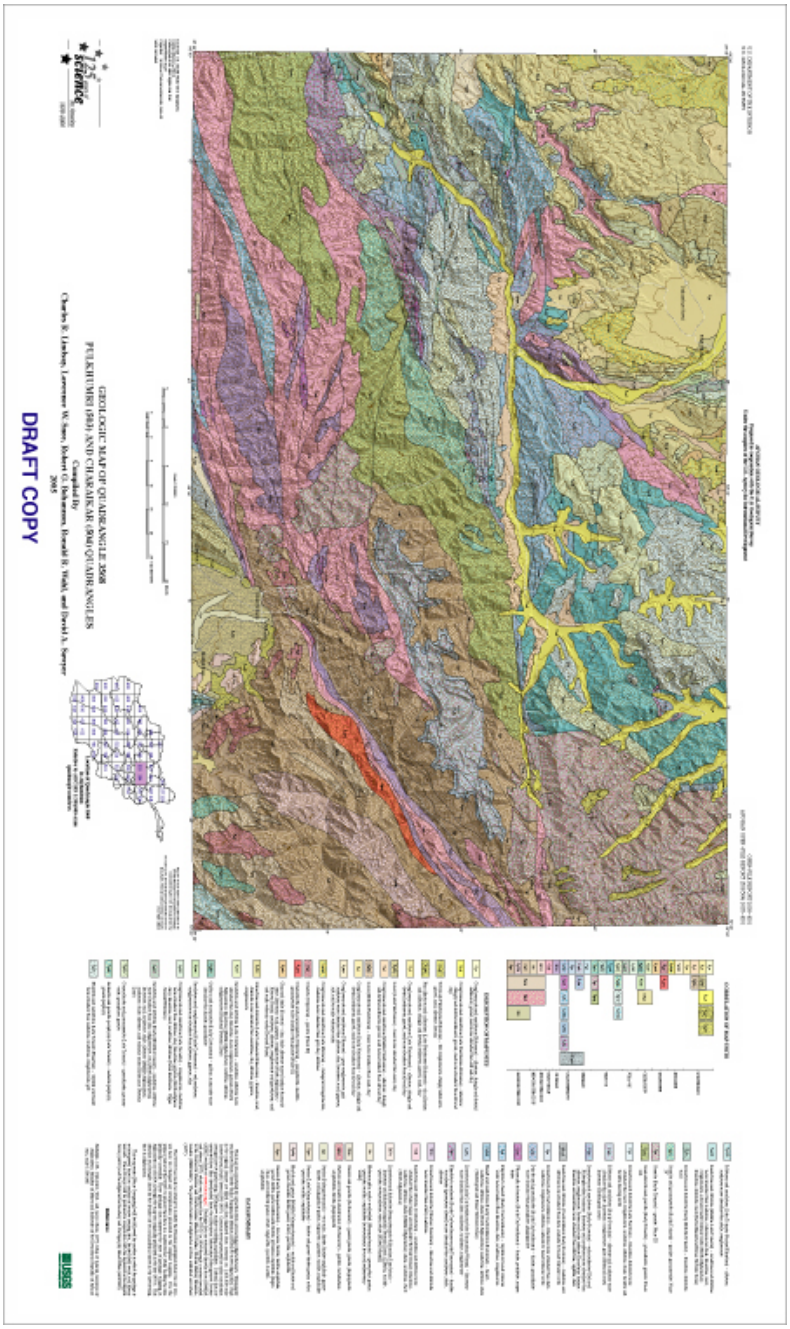


Figure 2. Geologic map of quadrangle 3568, Pul-e-Khomri (503) and Charaikar (504) quadrangles, Afghanistan.

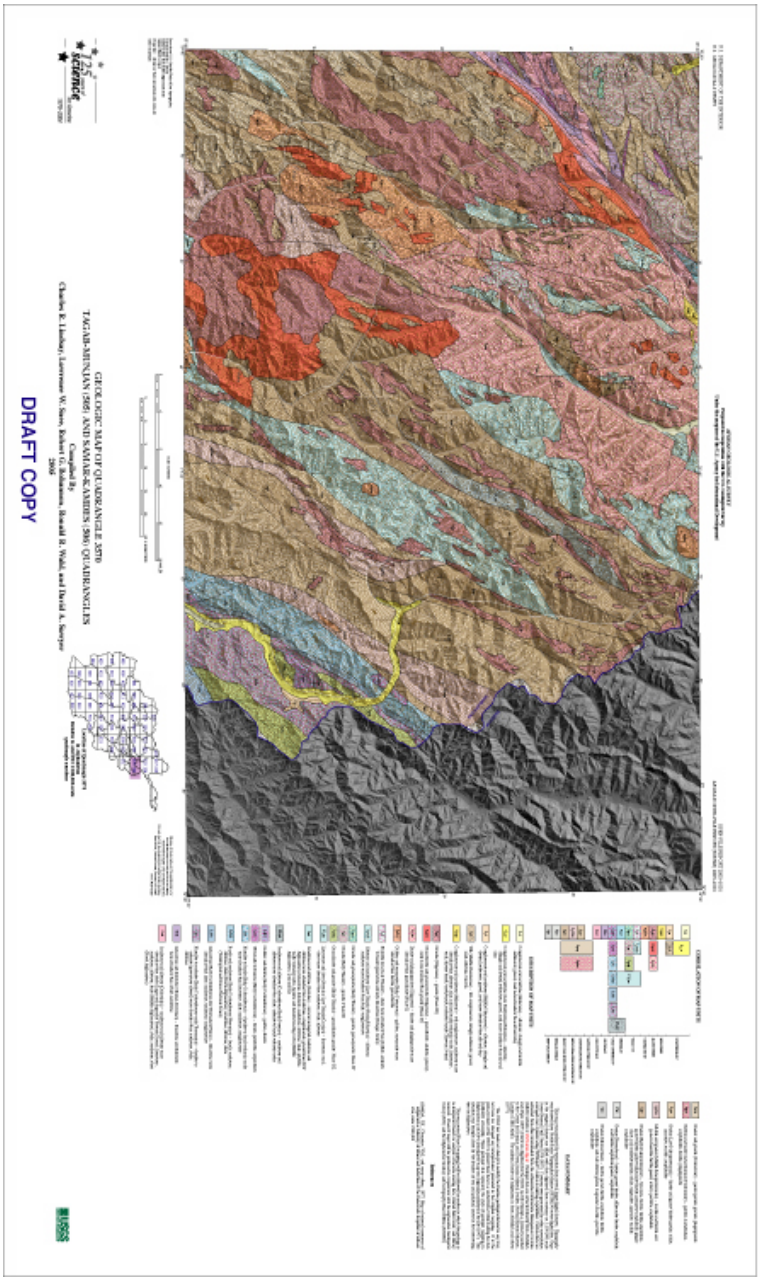


Figure 3. Geologic map of quadrangle 3570, Tagab-e-Munjan (505) and Asmar-Kamdesh (506) quadrangles.

Figure 4. An aerial view of a fault sliver of ultramafic rocks in the Tectonic Zone HinduKush in Ghowr Band Valley. Fault is exposed along the southern side of the Ghowr Band River. View to the east.

Figure 5. Russian geologic map at scale of 1:100,000 of Ghor Band, Salang, and Panjsher Valleys (Schadchinev and others, 1975).

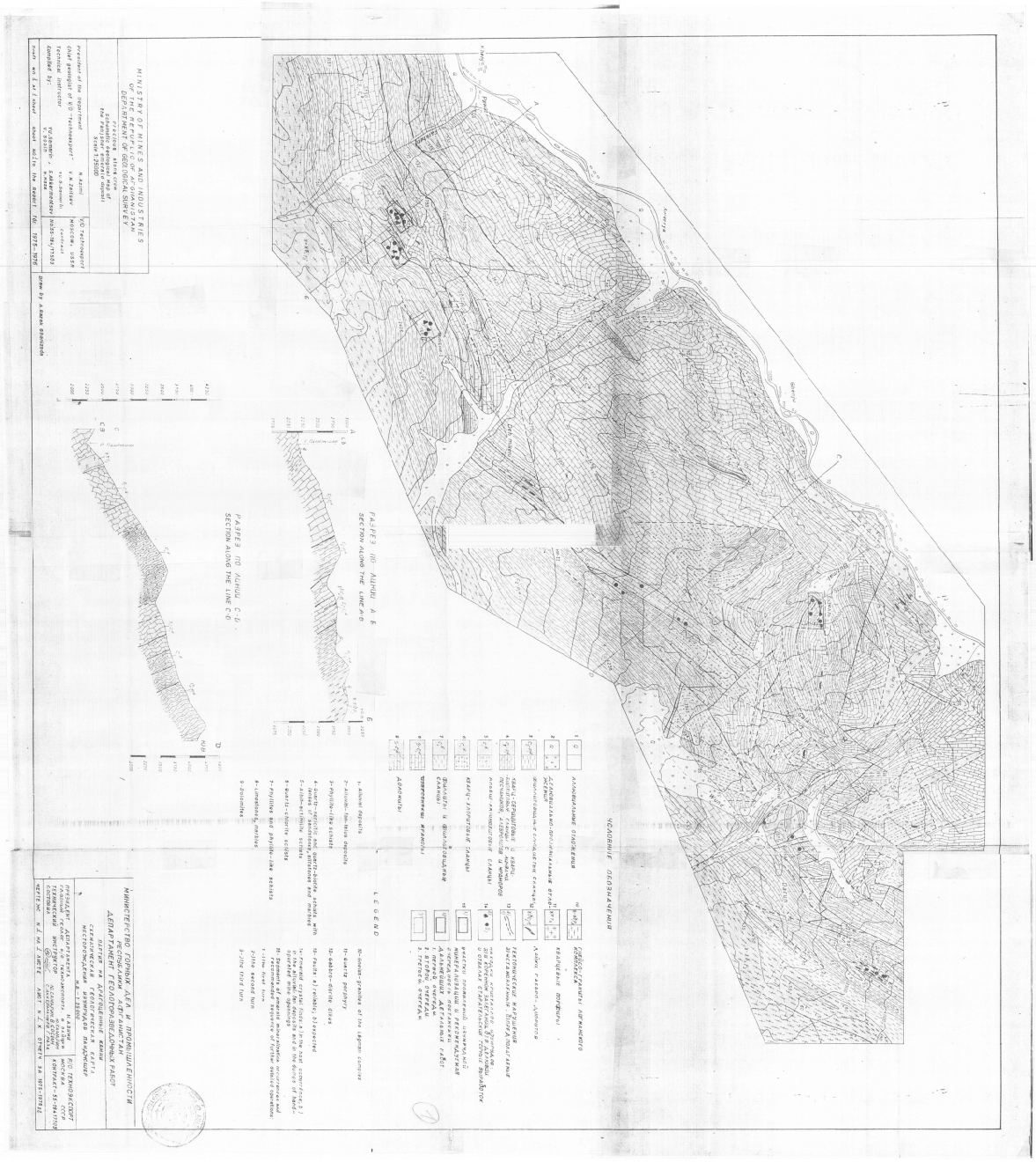


Figure 6. Russian geologic map of Panjsher emerald deposits from Samarin and Akermantsev (1977).

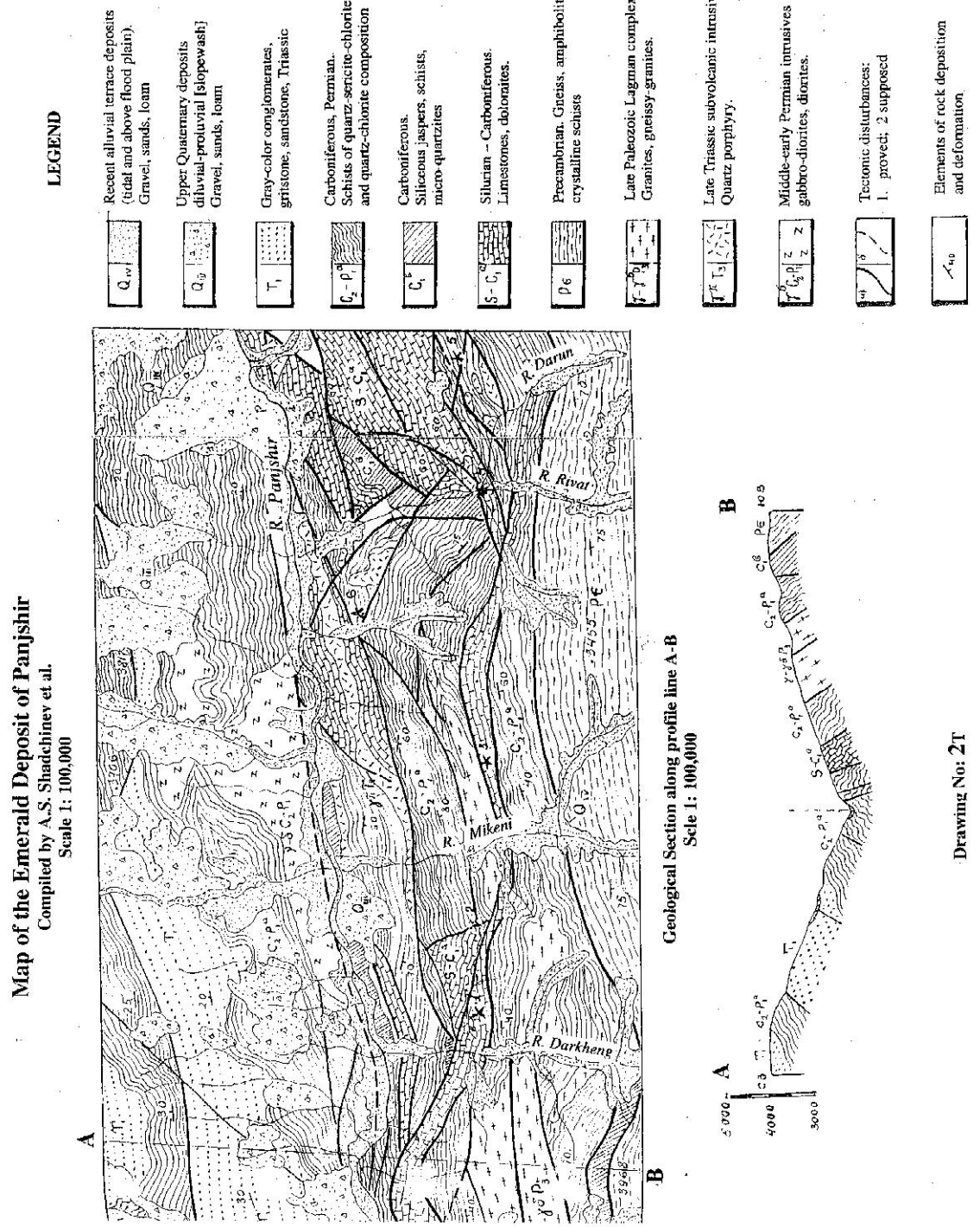


Figure 7. Sketch geologic map with cross section of the Panjsher emerald deposits adapted from Schadchinev and others (1975) and included in Samarin and Akkermantsev (1977).

Figure 8a-d. Photographs of layered high-grade Precambrian (?) gneisses at Panjsher River gorge.

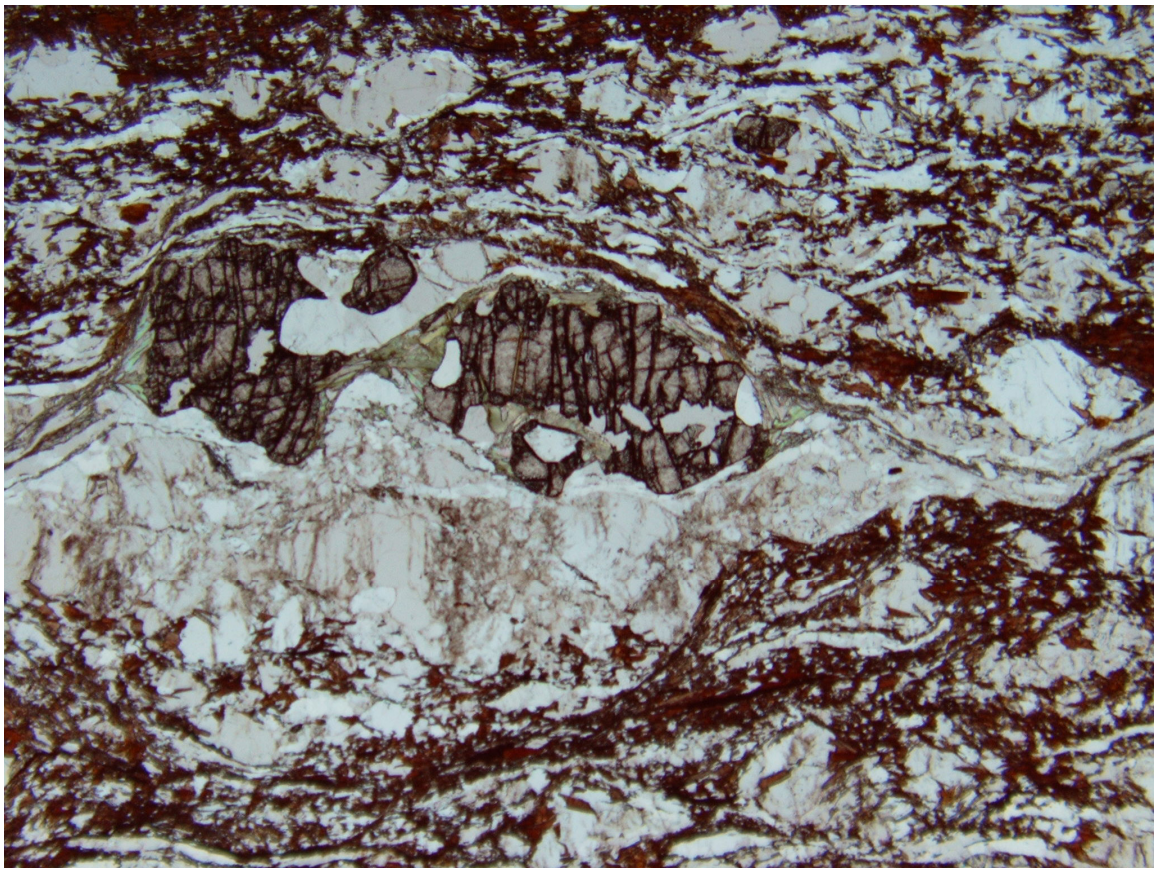


Figure 9. Photomicrograph of rotated garnets in high-grade Precambrian (?) gneiss from Panjsher River gorge.

Figure 10. Faulted contact between Precambrian (?) gneisses to the east (left) and Paleozoic (?) metasedimentary rocks to the west (right). View to the northwest from south bank of Hazara River.

Figure 11a. Sequence of five panoramic photographs of the Tectonic Zone Hindu Kush looking south across the Hazara River near its confluence with the Panjsher River. 10a to 10e from east to west.

Figure 11b. Sequence of five panoramic photographs of the Tectonic Zone Hindu Kush looking south across the Hazara River near its confluence with the Panjsher River. 10a to 10e from east to west.

Figure 11c. Sequence of five panoramic photographs of the Tectonic Zone Hindu Kush looking south across the Hazara River near its confluence with the Panjsher River. 10a to 10e from east to west.

Figure 11d. Sequence of five panoramic photographs of the Tectonic Zone Hindu Kush looking south across the Hazara River near its confluence with the Panjsher River. 10a to 10e from east to west.

Figure 11e. Sequence of five panoramic photographs of the Tectonic Zone Hindu Kush looking south across the Hazara River near its confluence with the Panjsher River. 10a to 10e from east to west.

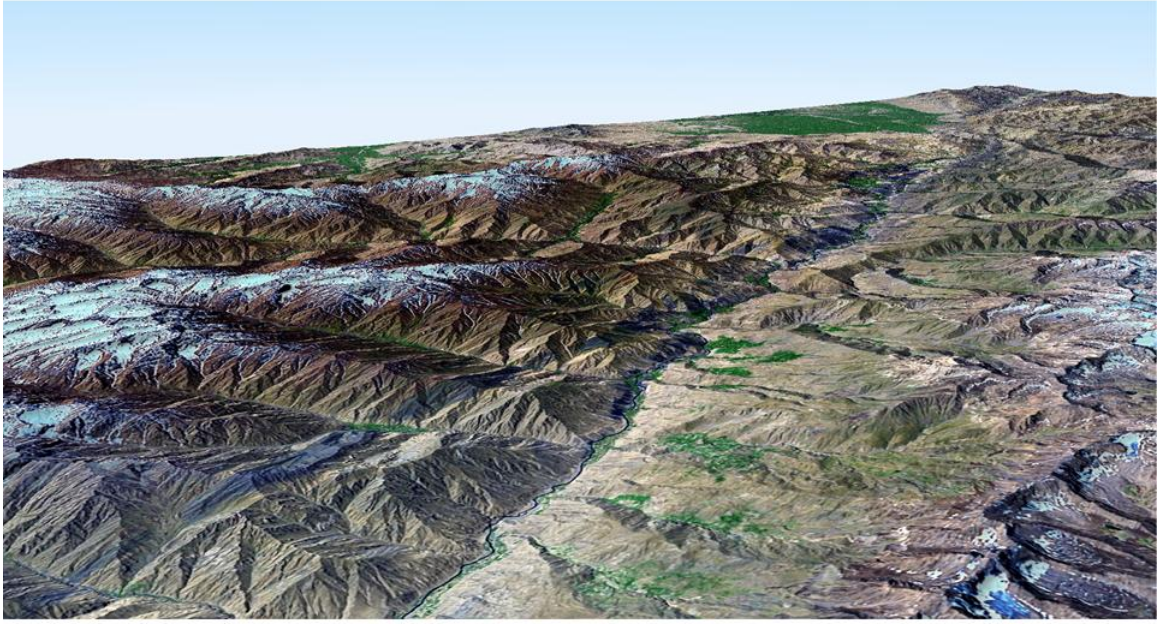


Figure 12. Landsat image of Panjsher Valley draped over DEM looking southwestward giving an appearance of 3-D. Dark gray northeast-southwest-trending band of rocks is graphitic phyllite.

Figure 13a. Dark gray carbonaceous phyllite of the Panjsher Valley.

Figure 13b. Dark gray carbonaceous phyllite of the Panjsher Valley.

Figure 13c. Dark gray carbonaceous phyllite of the Panjsher Valley.

Figure 13d. Dark gray carbonaceous phyllite layers in Panjsher Valley walls.

Figure 13e. Closer view of D.

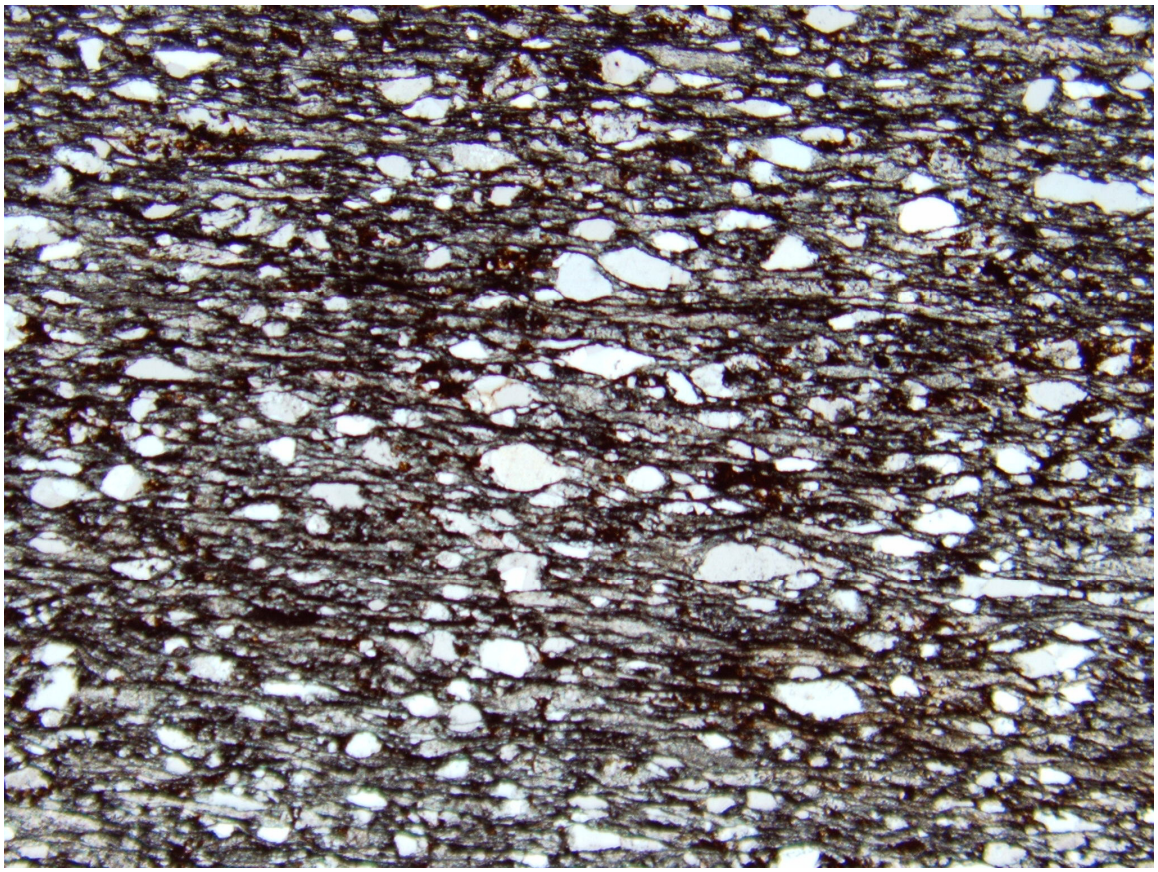


Figure 14. Photomicrograph of low-grade dark gray carbonaceous phyllite of the Panjsher Valley.

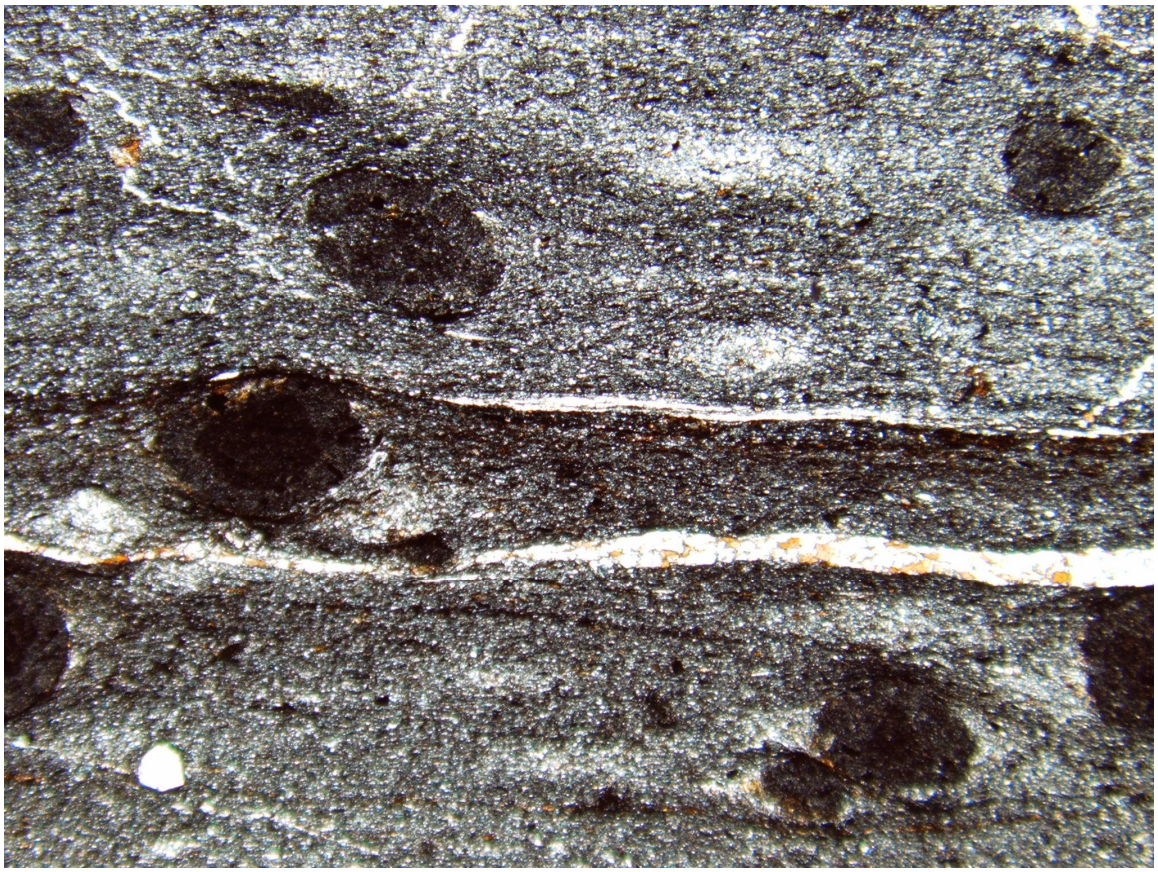


Figure 15a. Photomicrograph of dark gray spotted carbonaceous phyllite of the Panjsher Valley. This sample is at slightly higher metamorphic grade than figure 13.

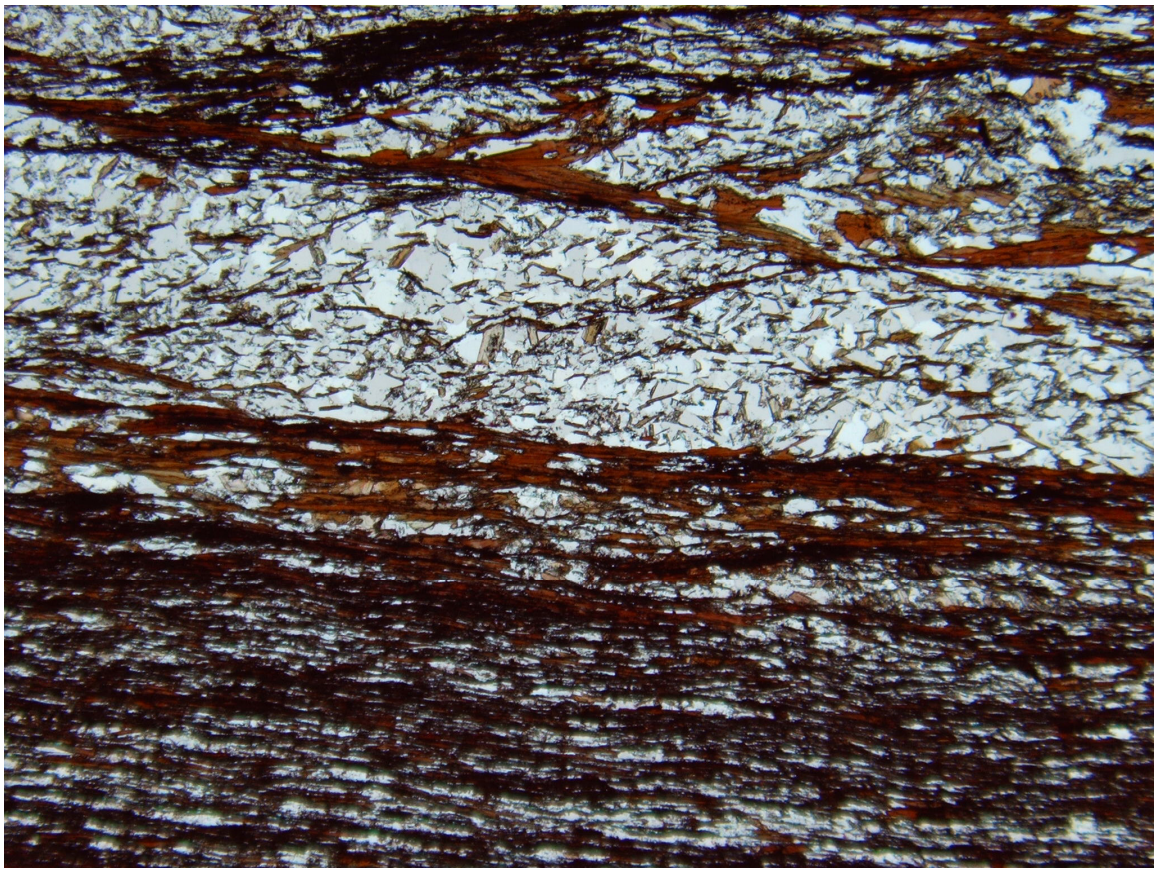


Figure 15b. Photomicrograph of dark gray carbonaceous schist of the Panjsher Valley. This sample is at higher metamorphic grade than figure 14a.

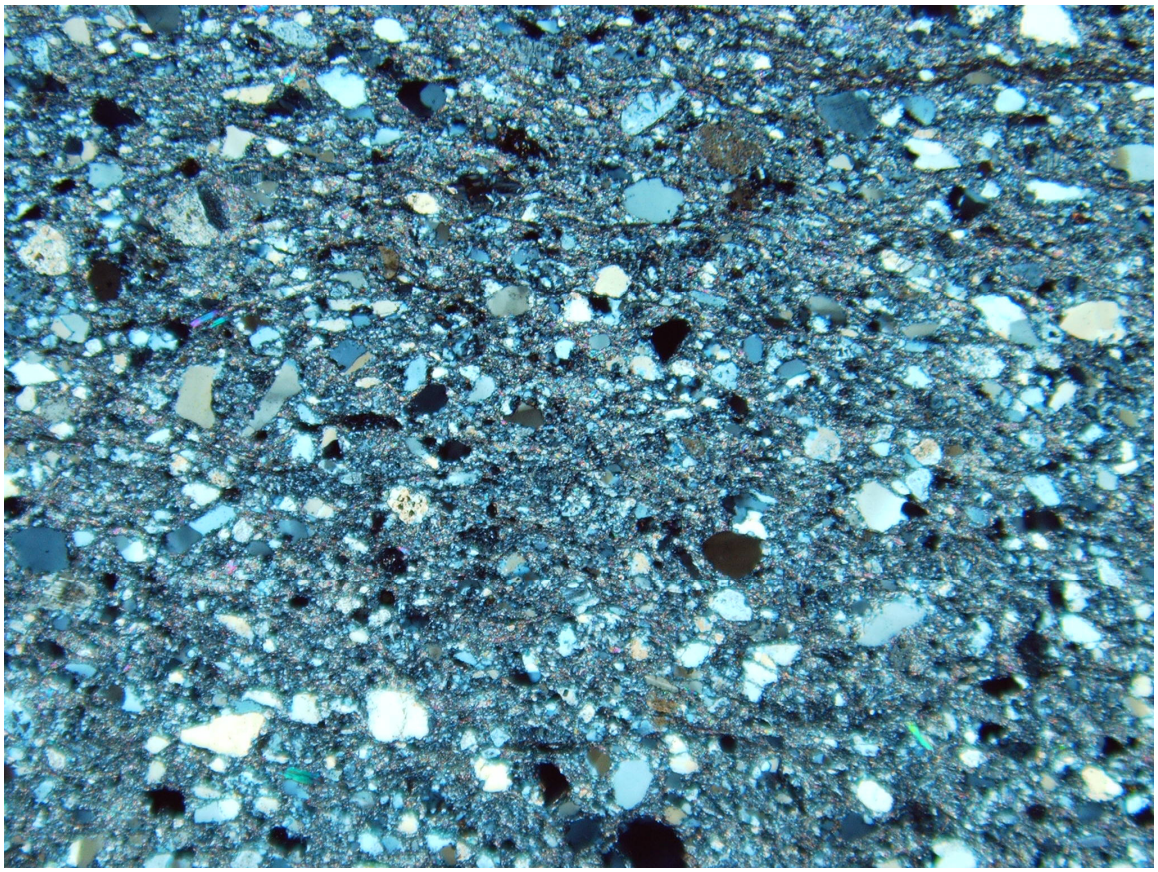


Figure 16. Photomicrograph of carbonate cemented sandstone. Angular grains of quartz, feldspar, iron oxides and mica in fine-grained carbonate matrix.

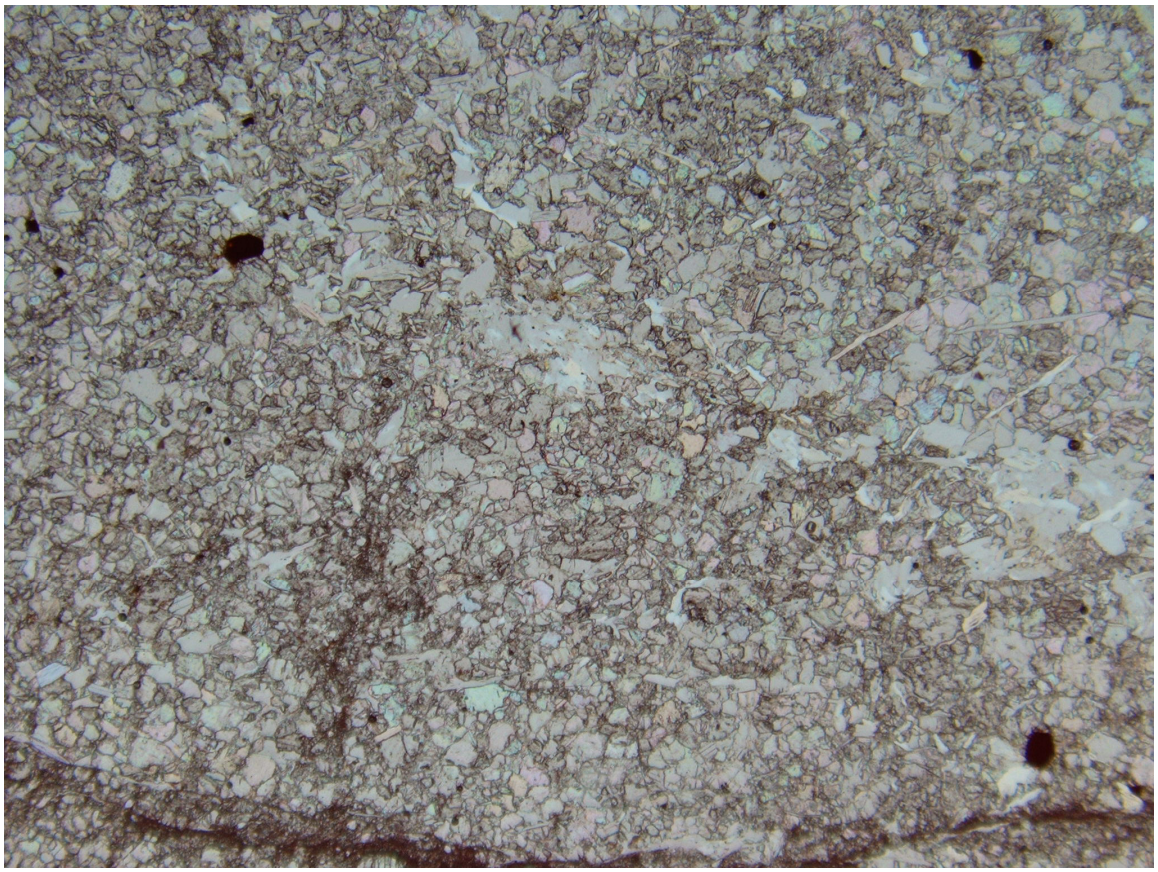


Figure 17a. Photomicrograph in plain polarized light of micaceous carbonate.

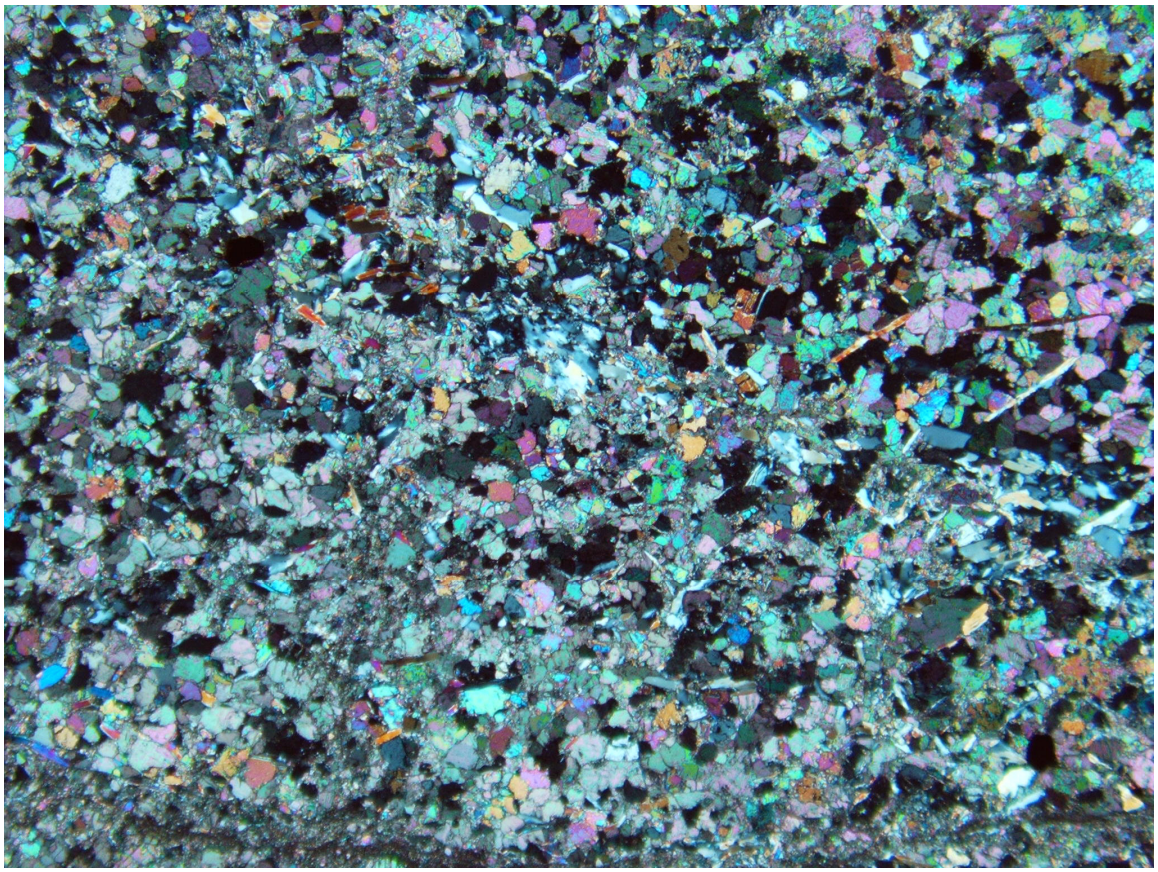


Figure 17b. Photomicrograph in crossed polarized light of micaceous carbonate.

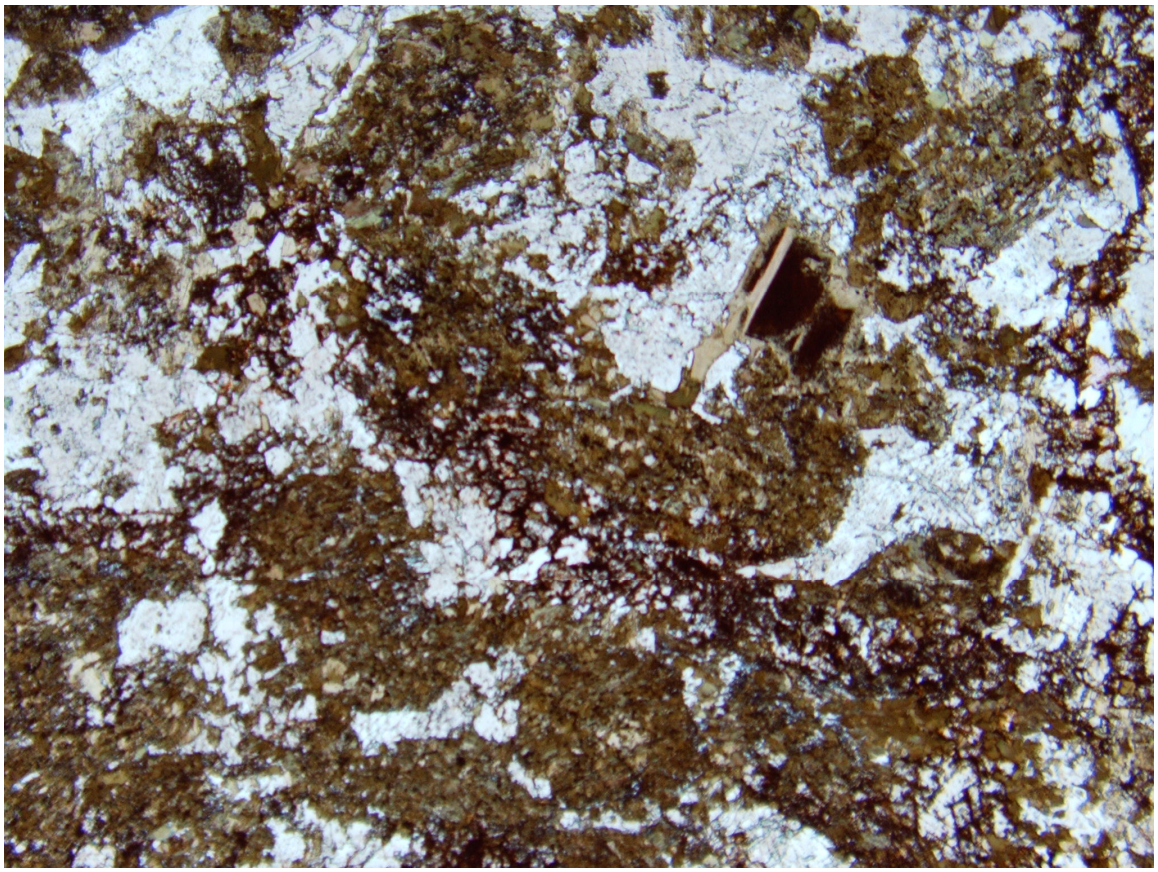


Figure 18a. Photomicrograph of hornblendite in plain polarized light.

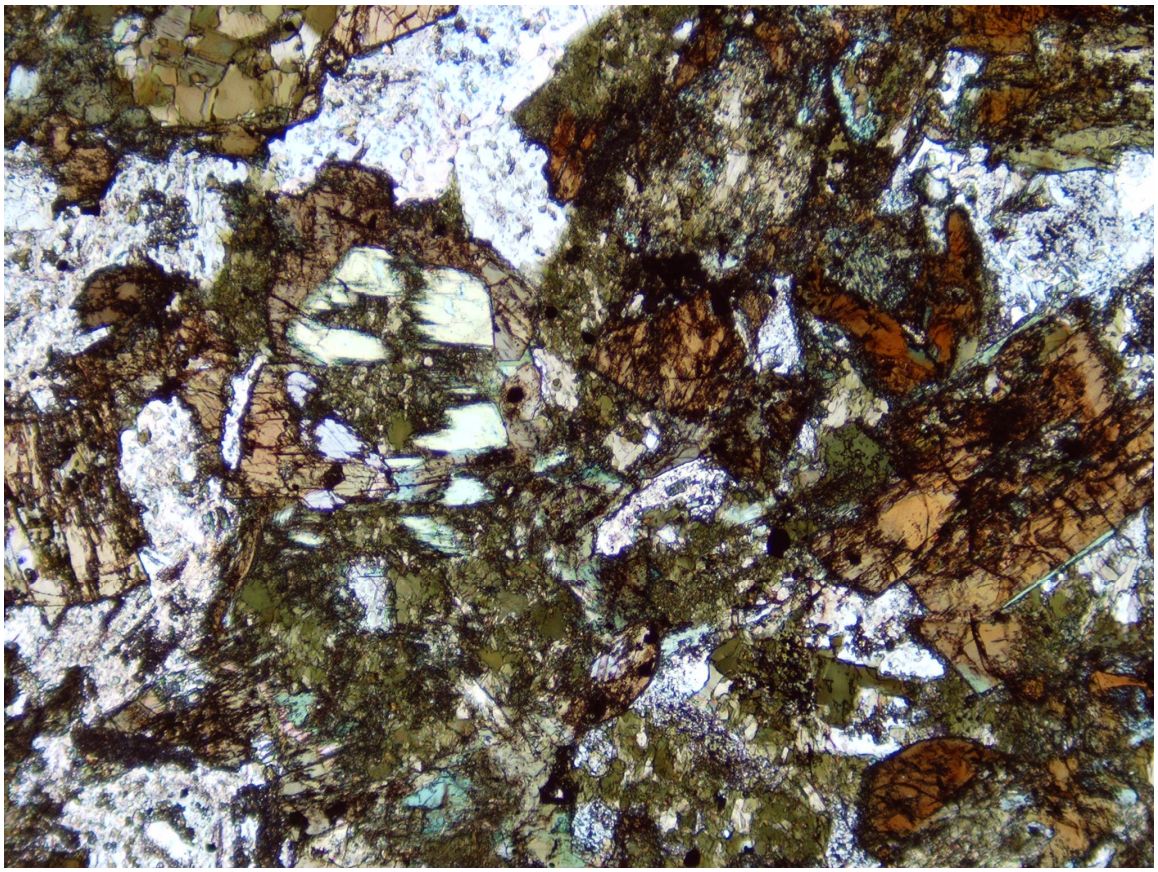


Figure 18b. Photomicrograph of pyroxene-hornblende gabbro under plain-polarized light.

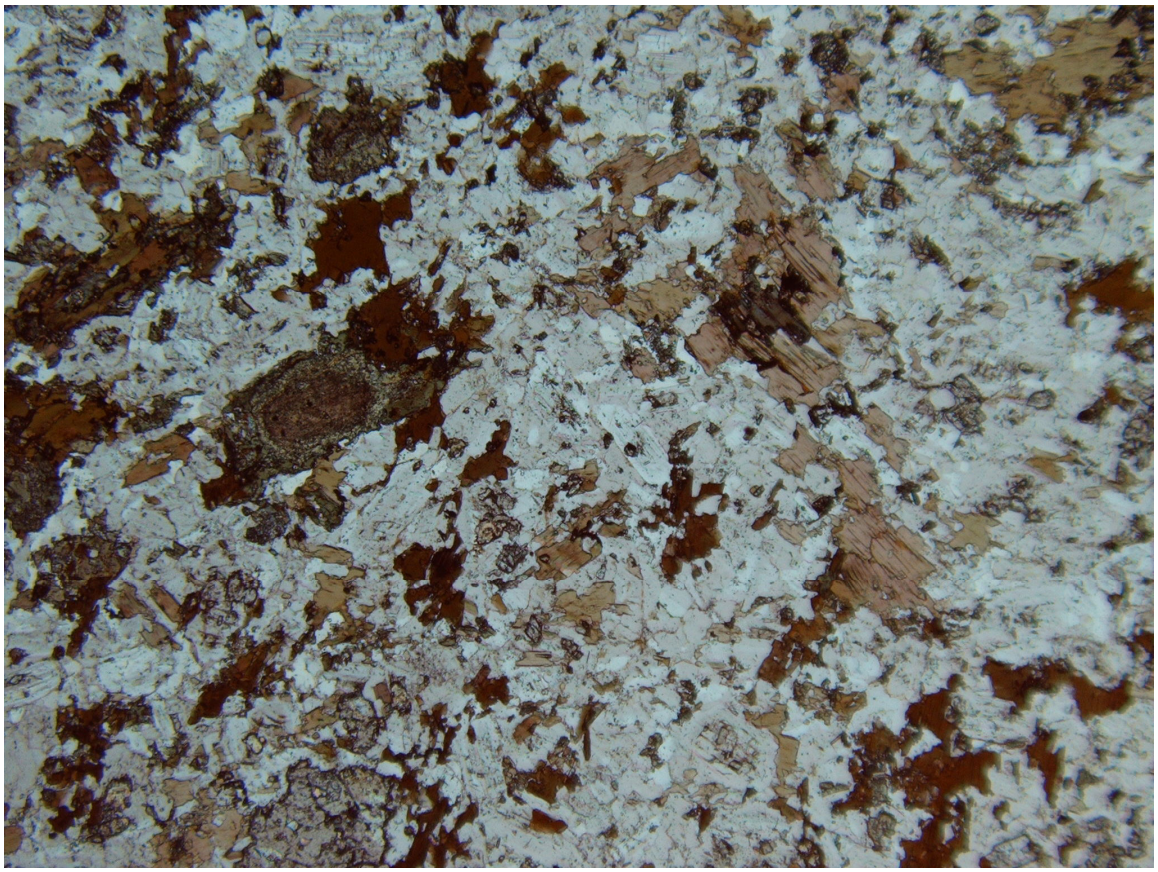


Figure 18c. Photomicrograph of hornblende diorite along Hazara River in plain-polarized light.

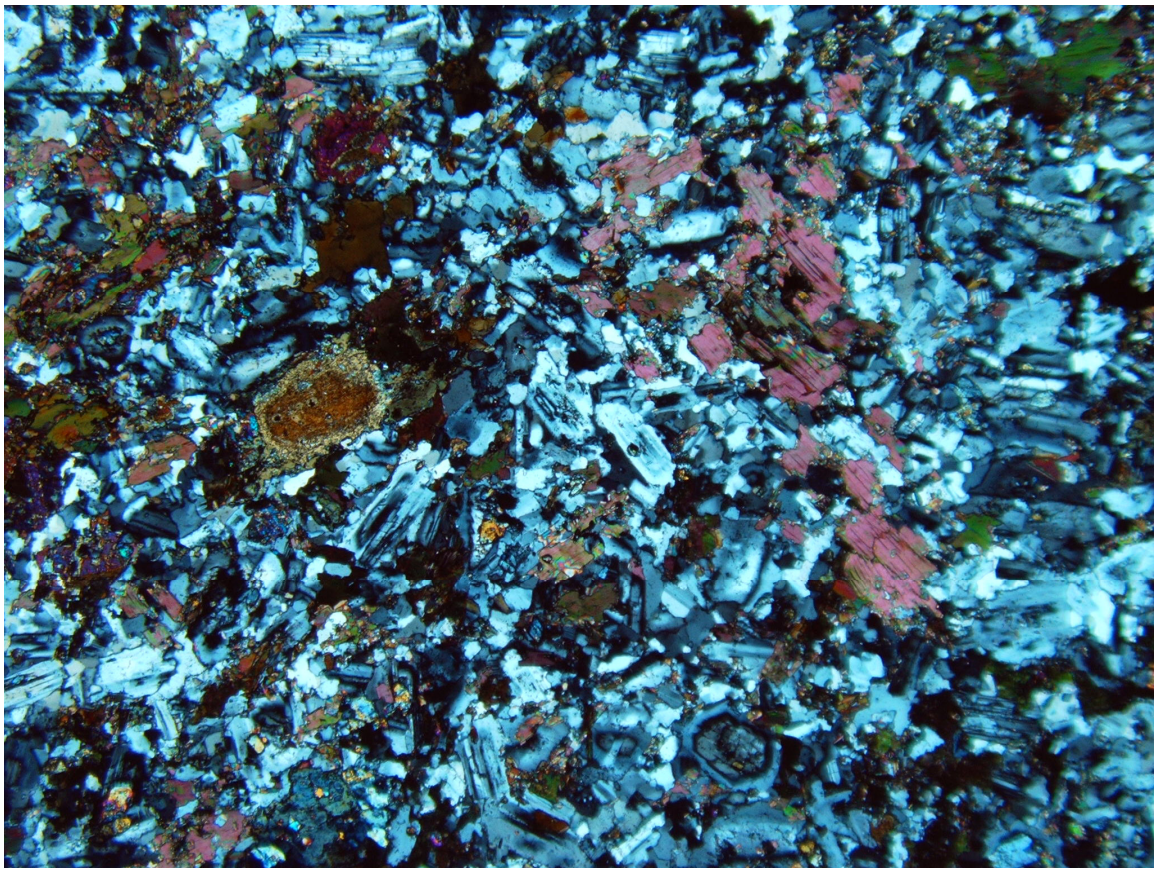


Figure 18d. Photomicrograph of hornblende diorite along Hazara River in crossed-polarized light.

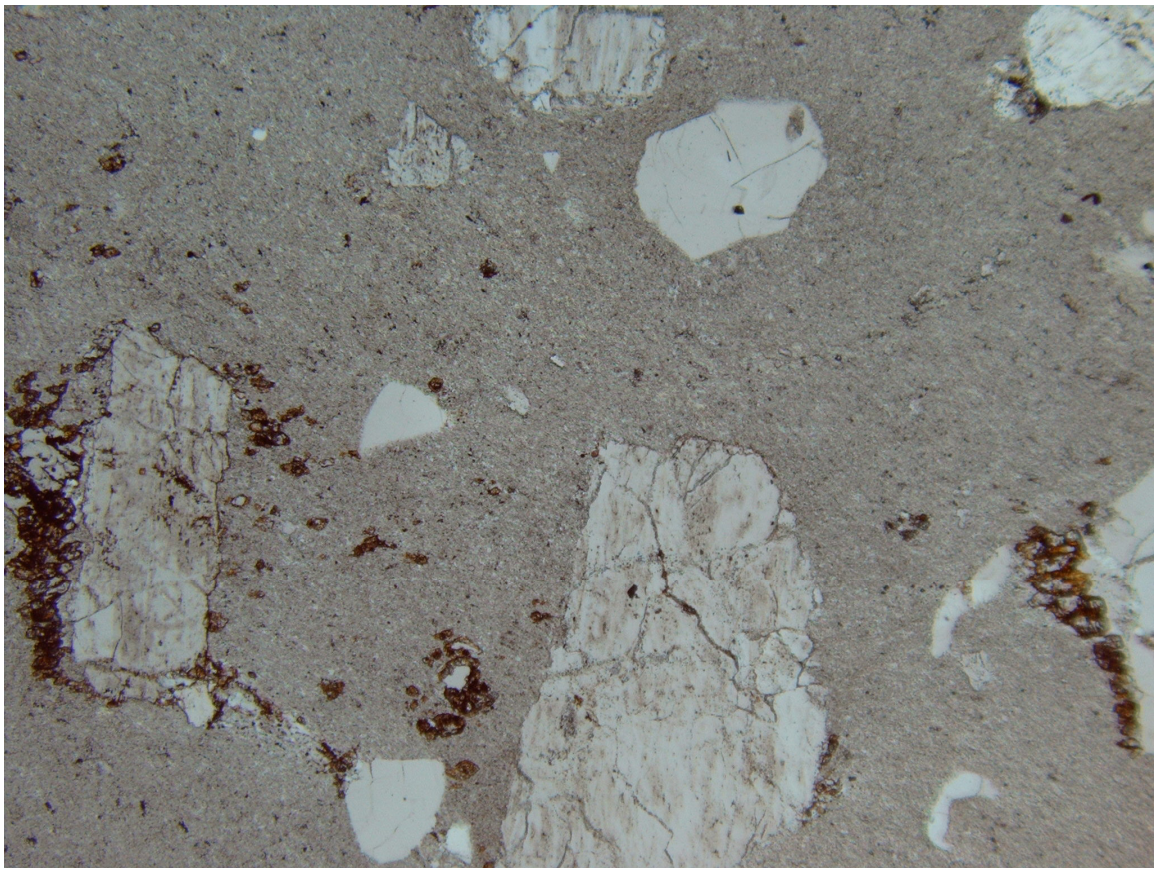


Figure 19a. Photomicrograph of quartz porphyry dike under plain-polarized light.

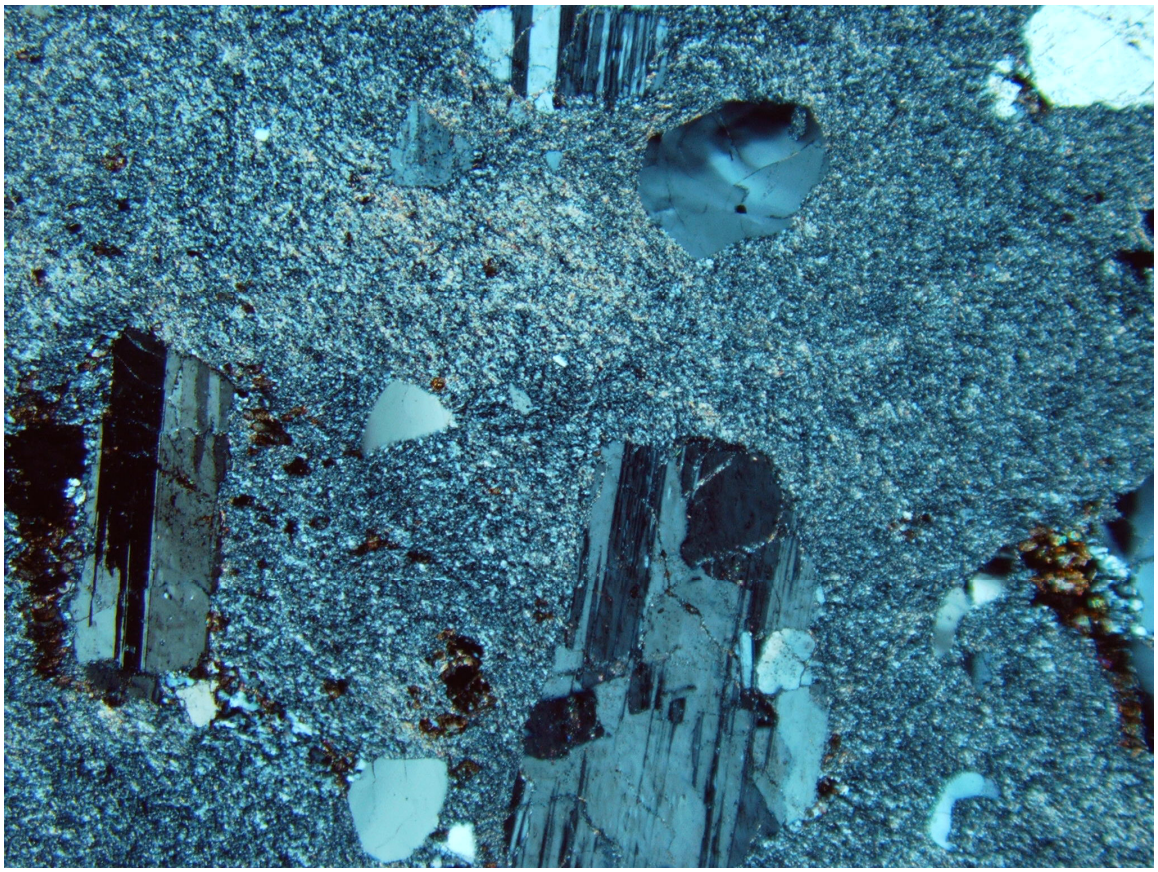


Figure 19b. Photomicrograph of quartz porphyry dike under crossed-polarized light. Phenocrysts of plagioclase, quartz, and sanidine are present.

Figure 20 a. Highly sheared granitic rock mapped as part of the Oligocene-age Laghman Complex (Abdullah and others, 1977),

Figure 20 b. Granites and gneisses are commonly intermingled in area east of Panjsher River.

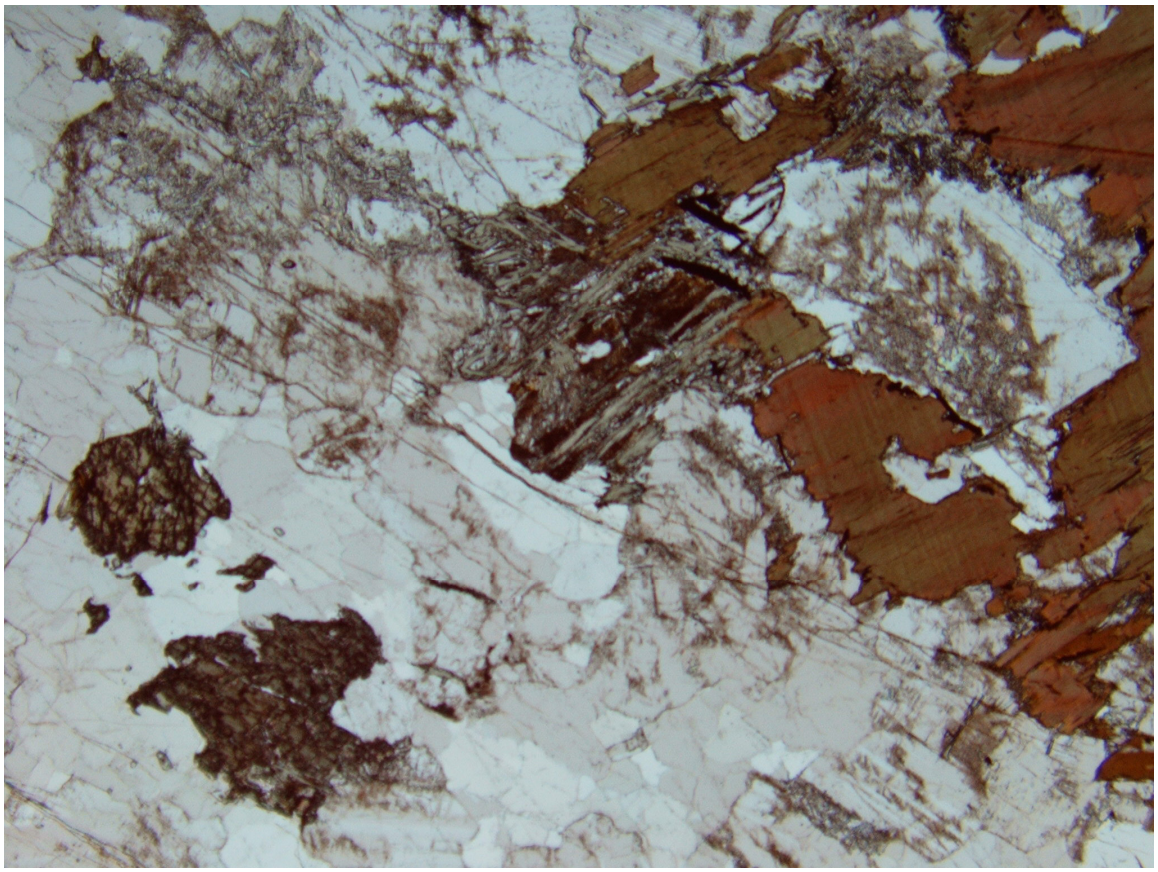


Figure 21. Photomicrograph of hornblende biotite granodiorite exposed along the Panjsher River northeast of Khenj.

Figure 22a. Terrace deposits in Panjsher Valley overlapping phyllite.

Figure 22b. Lower terraces used for cultivation.

Figure 22c. Surficial deposits in Panjsher Valley near Bazarat.

Figure 23. An unnamed 17,000-ft high mountain to the east of Khenj.

Figure 24. Khenj Village on the west side of the Panjsher River from the east in Khenj Stream valley.

Figure 25. Mikeni Stream and buildings just west of Mikeni Village.

Figure 26. Footpath along Mikeni Stream.

Figure 27. Trails along the ridges in the Panjsher Valley near Khenj mining area.

Figure 28. Trails along the ridges in the Panjsher Valley near Khenj mining area.

Figure 29. Trails and workings along the ridges in the Panjsher Valley near Khenj eastern zone.

Figure 30. Buzmal emerald workings from below.

Figure 31. Buzmal emerald mine drifting into sheared contact between carbonate rock and mafic dike. Abdul Wasay for scale.

Figure 32. More Khenj mines in the high peaks in the western zone.

Figure 33. Khenj mines high in the ridge in the western zone.

Figure 34. Well-developed contact between clastic and carbonate rocks in the mountains east of Khenj near the emerald mines.

Figure 35. Sheared contact zone between carbonate and mafic with typical reddish-brown iron oxide stain from hydrothermal fluids.

Figure 36. Hydrothermal alteration and quartz-carbonate veins that commonly carry emerald.

Figure 37. Hydrothermal alteration and quartz-carbonate veins that commonly carry emerald.

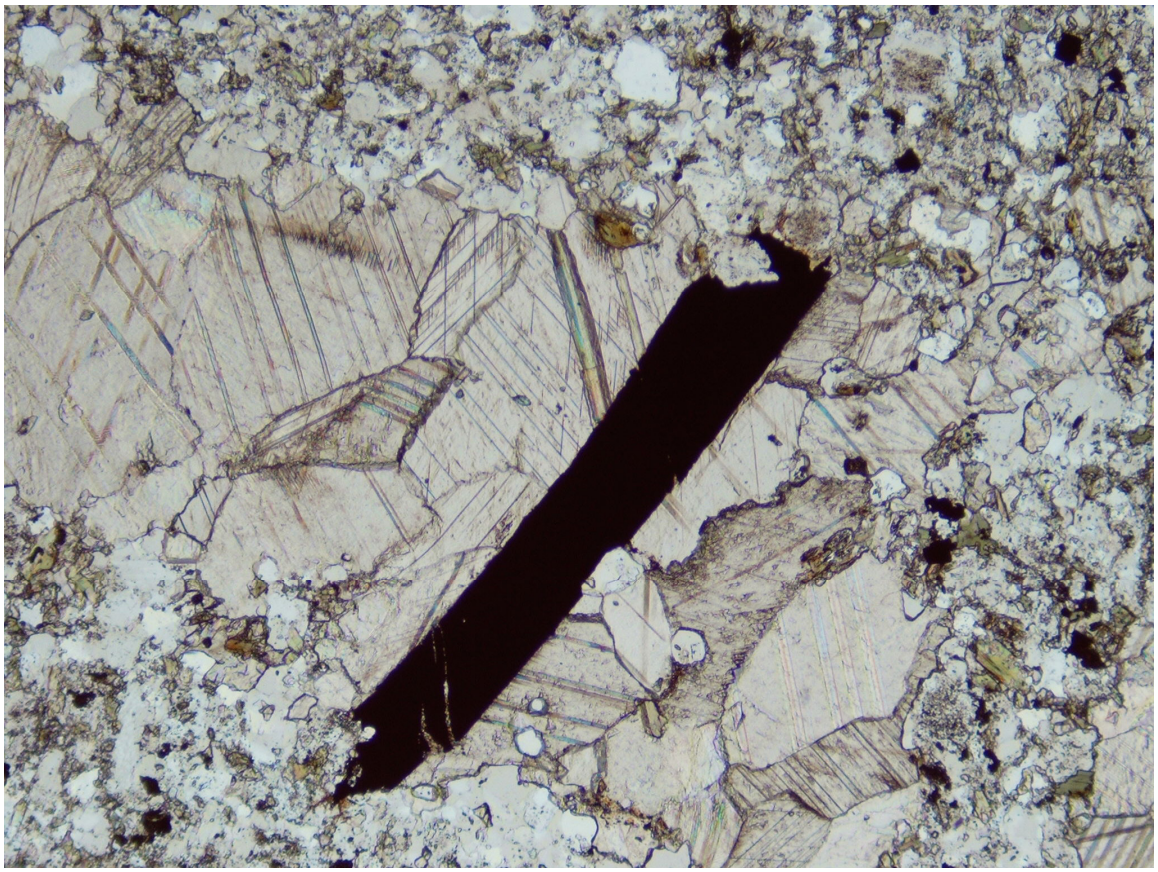


Figure 38. Photmicrograph of specular hematite in carbonate veinlet cutting carbonate host rock in plain-polarized light.

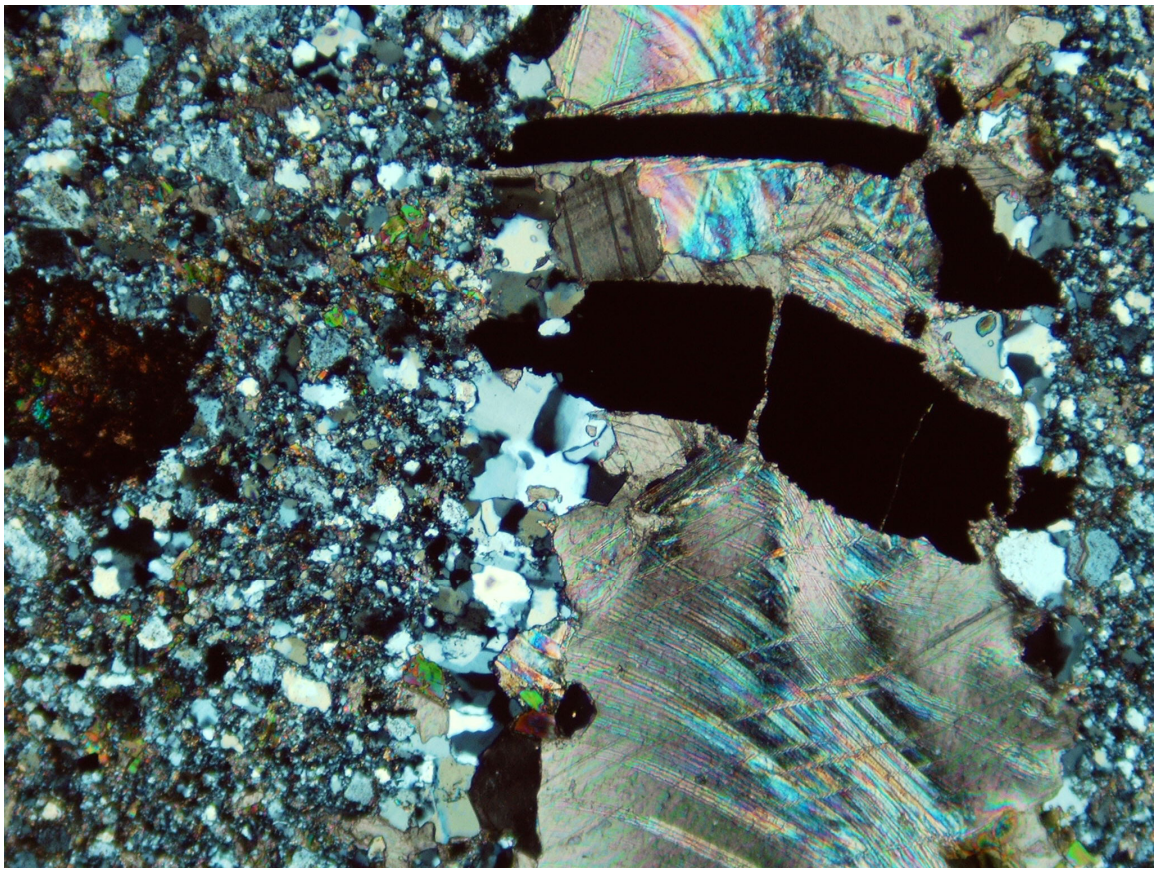


Figure 39. Photmicrograph of specular hematite in carbonate veinlet cutting carbonate host rock in plain-polarized light.

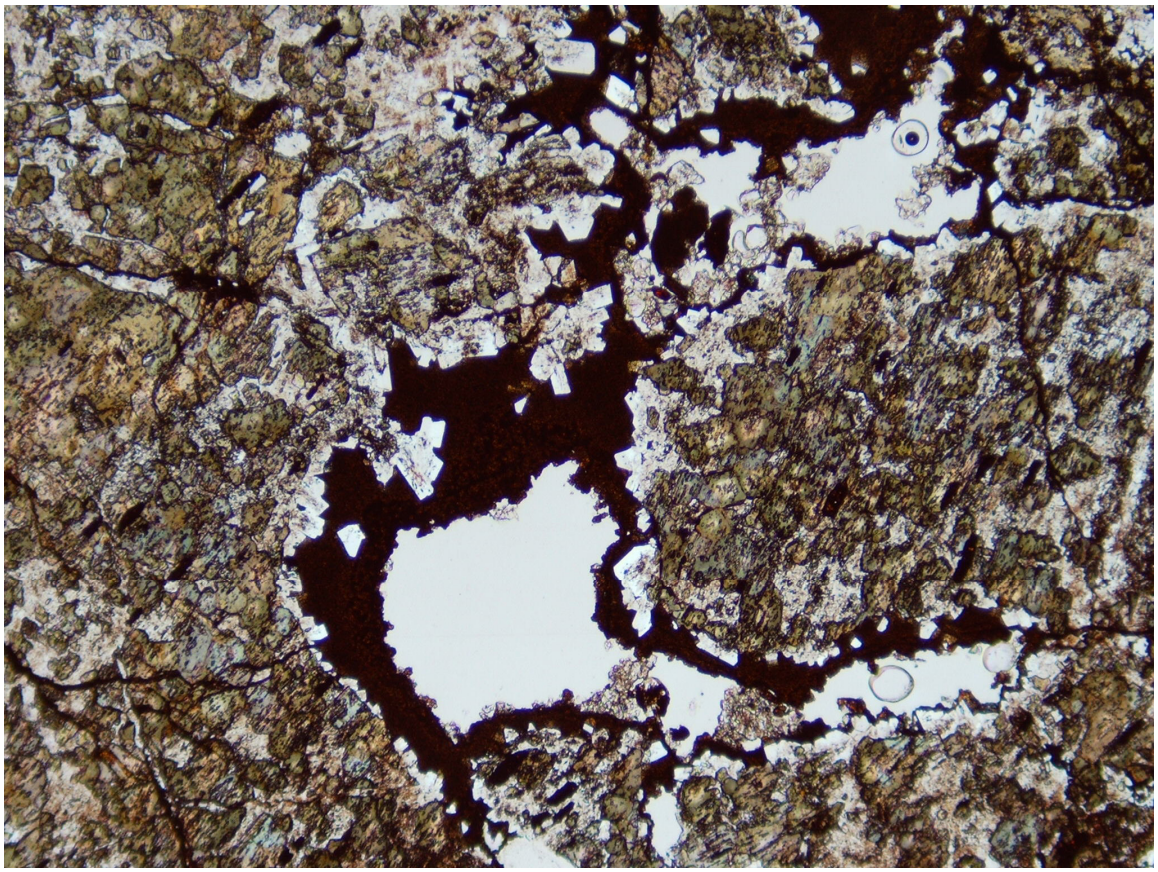


Figure 40. Alteration phases including albite, iron oxide, tourmaline, and carbonate in plain polarized light.

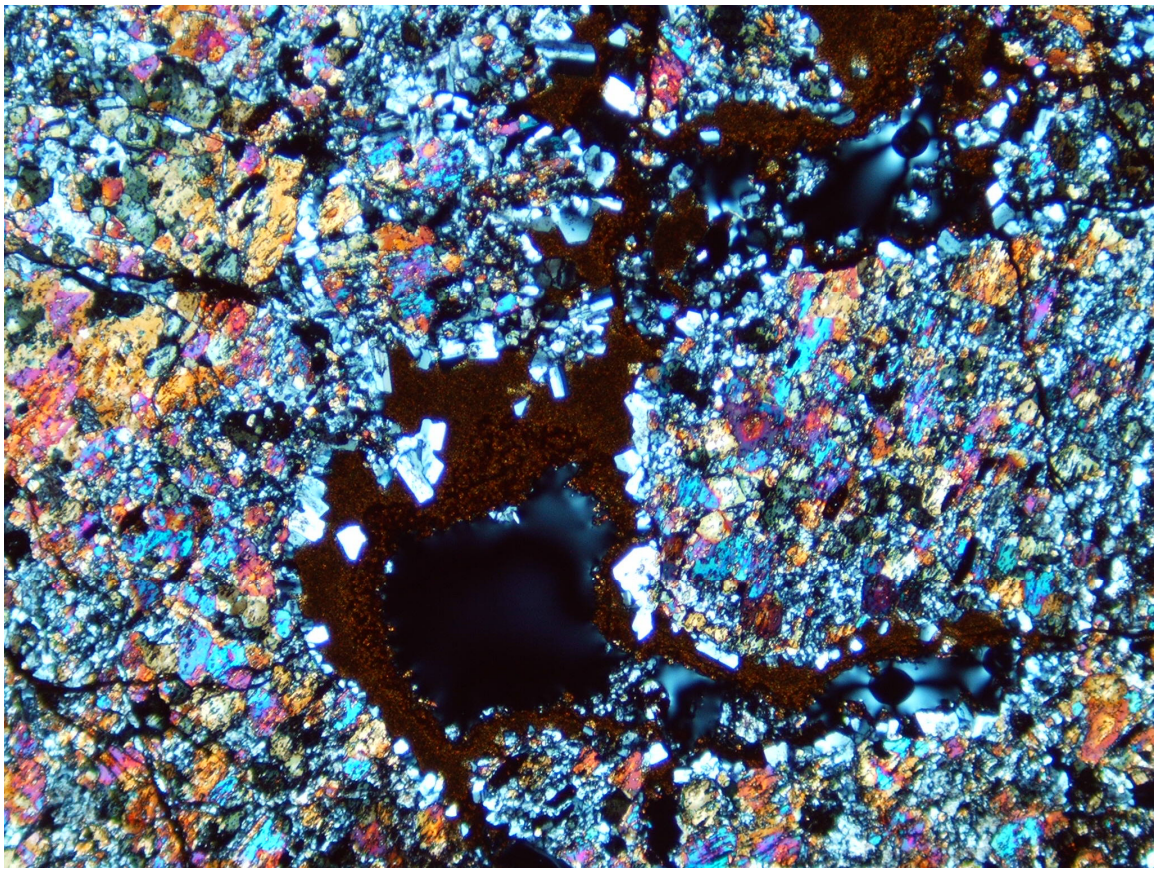


Figure 41. Alteration phases including albite, iron oxide, tourmaline, and carbonate in cross-polarized light

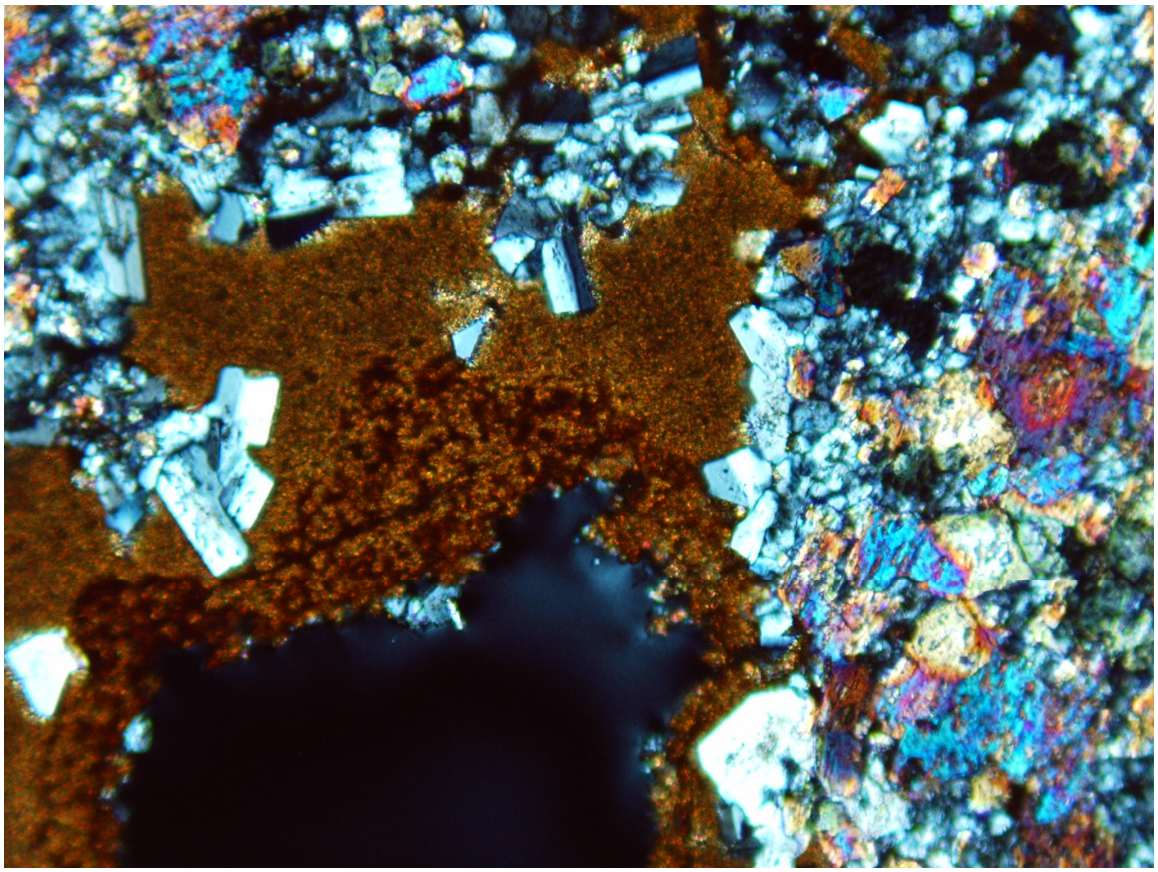


Figure 42. Close up of alteration phases including albite, iron oxide, tourmaline, and carbonate in cross-polarized light.

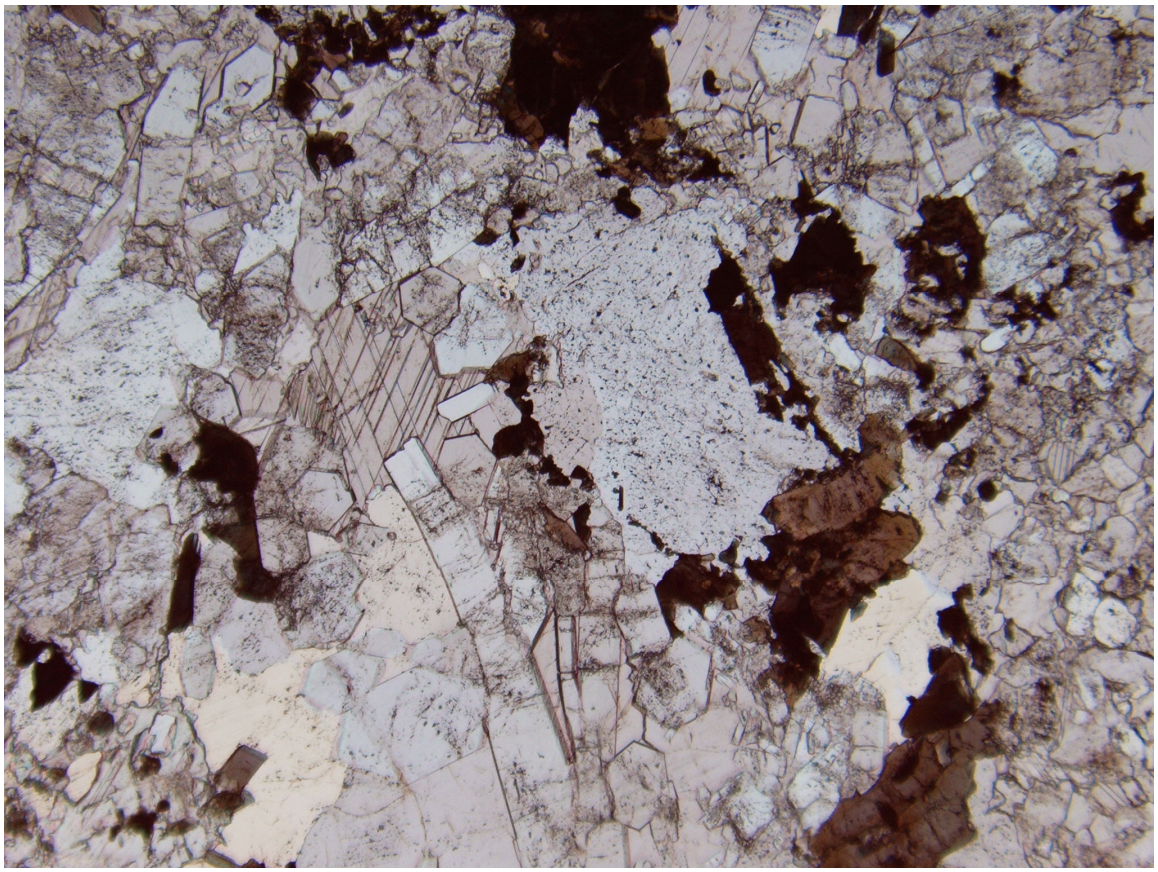


Figure 43. Hydrothermal beryl crystals in plain polarized light.

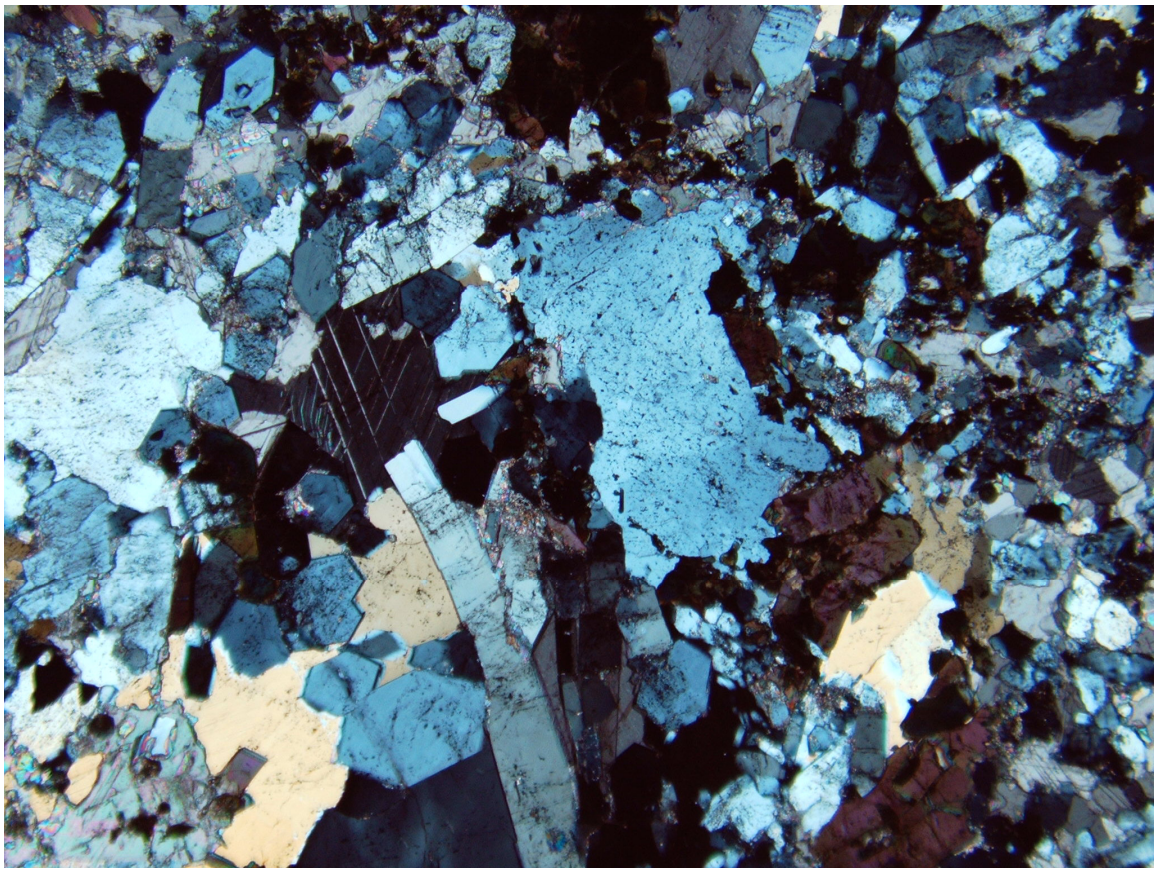


Figure 44. Hydrothermal beryl crystals in cross-polarized light.

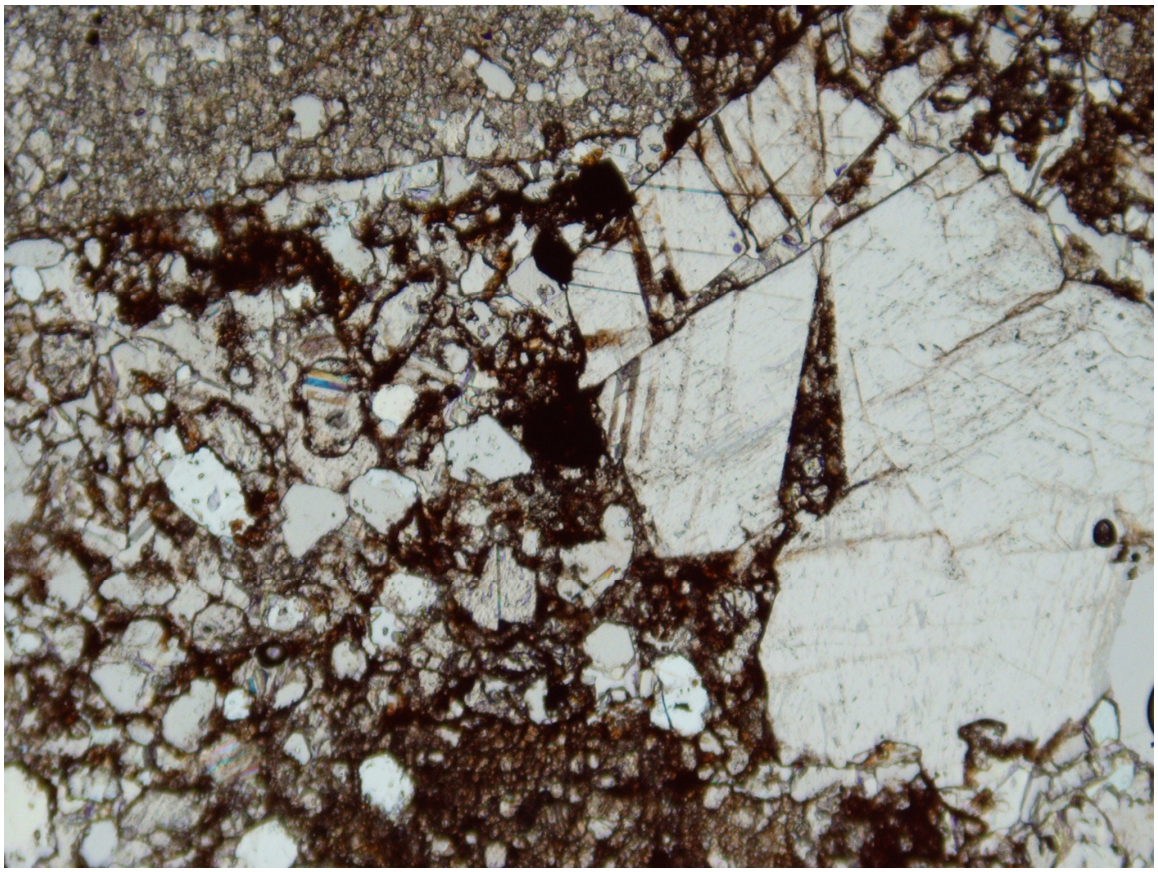


Figure 45. Cracked hydrothermal beryl crystals in cross-polarized light.

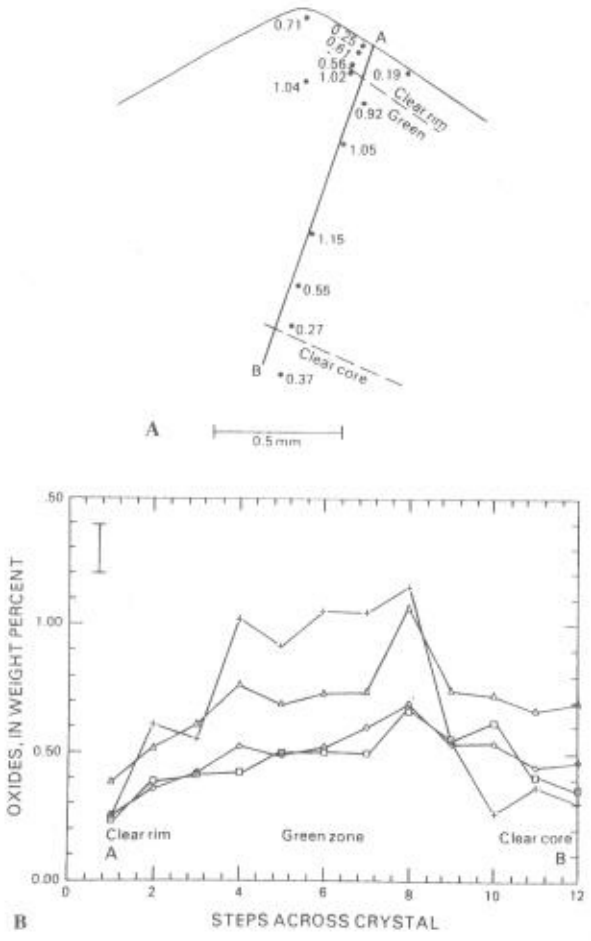
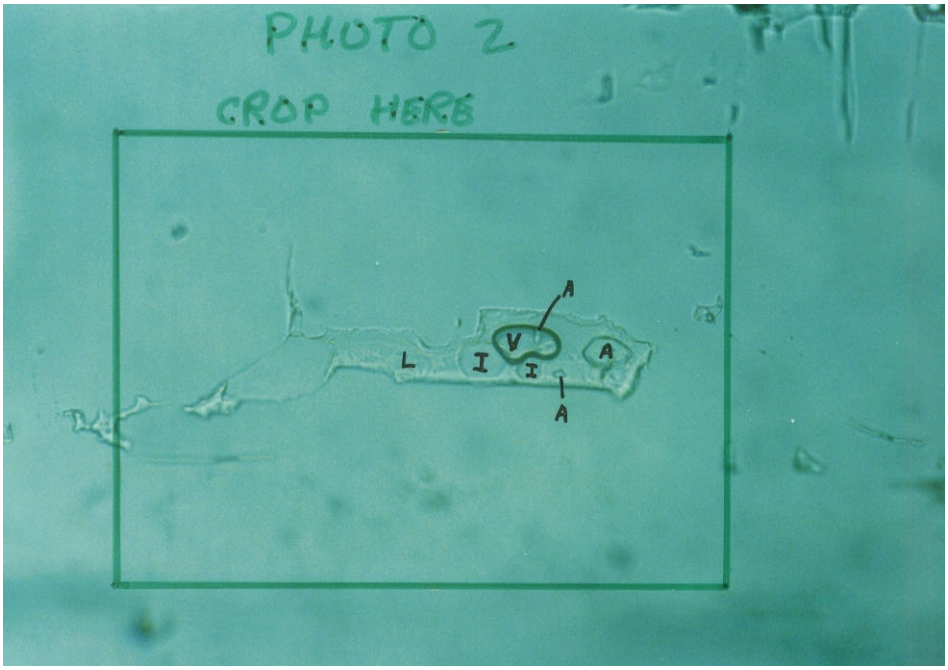


Figure 46. Microprobe traverse across Panjsher emerald, from Hammarstrom (1989).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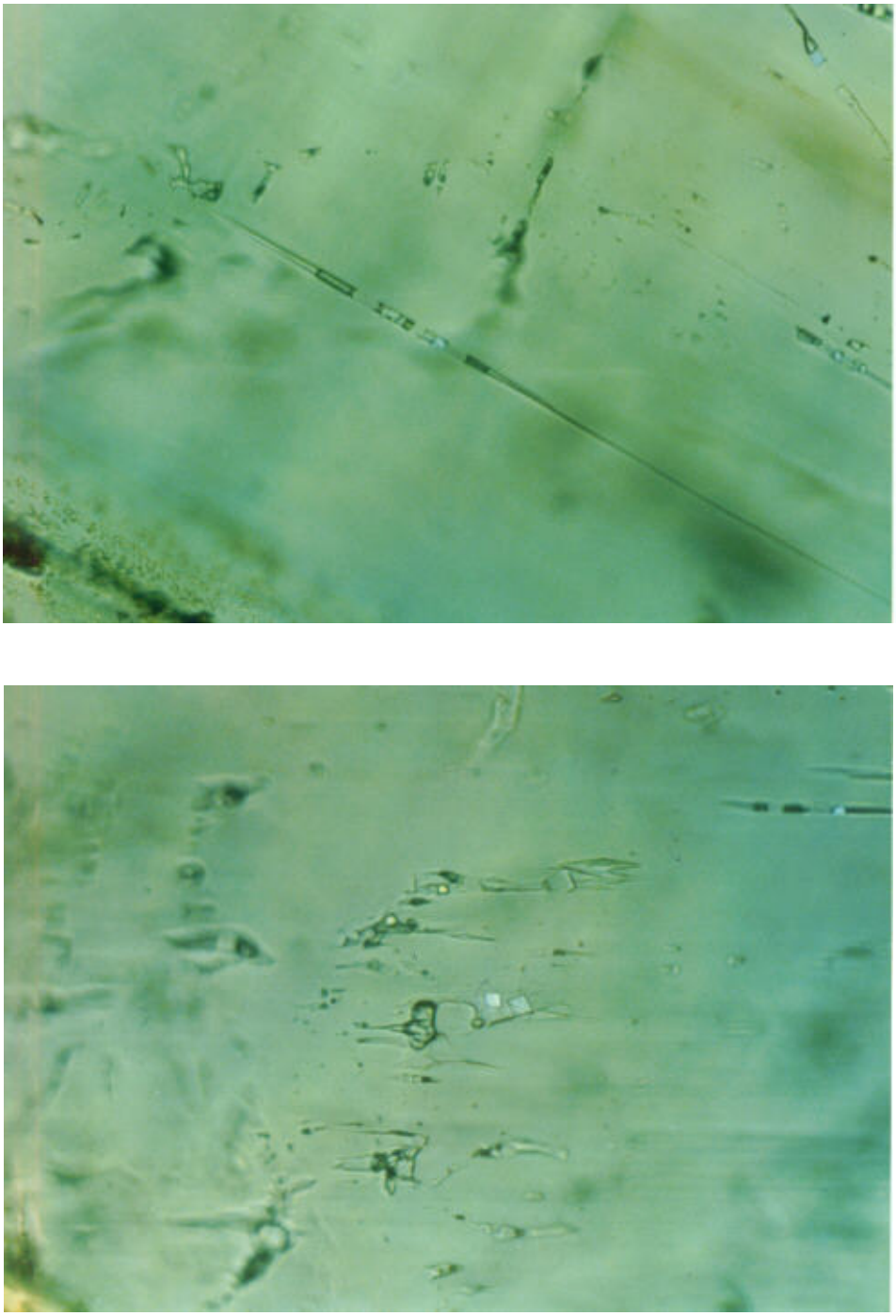

Figure 47 a-d. Fluid inclusions in Panjsher emeralds.