RESURGENT CAULDRONS AND THEIR MINERALIZATION BETWEEN NARIGAN, ESFORDI, KUSHK, AND SEH CHAHOON, CENTRAL IRAN

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Abstract The metamorphic basement consists of ortho-and paragneisses, micaschists, and some marble (Precambrian CHAPEDONY Formation). It is overlain by green graywackes, quartzitic shales, calcareous graywackes and arcoses, bituminous thinly bedded limestone, thin black siliceous shale, and some fine-grained tuffite (Precambrian TASHK Formation, formerly also designated as Morad Follows the Darkuh-Facies). By a pronounced angular unconfirmity follows the ESFORDI Formation (rhyolites, rhyolitic tuffs and ignimbrites, black bituminous shale, siliceous limestone, dolomite, and magnetitites; also called Rizu or Desu Formation). We found in the shales near Kushk a new fossil: Persimedusites chahgazensis, a member of the Infracambrian subclass Scyphomedusae. The rocks of the Esfordi and Tashk Formation are intruded by leucocratic granites, biotite syenites, and pyroxenites (NARIGAN Granite). The Narigan Granite is the subvolcanic equivalent of the Esfordi rhyolites. In the area studied, the ignimbrites have a volume of at least 100 km^3. Such volumes are typical for epicontinental ring structures. It is difficult to map the caldera (or calderas) due to overlaying Cambrian to Quaternary formations and tectonic disturbances. However, the center of the caldera complex seems to be the resurgent dome of the Narigan Granite. A ring of small intrusions marks a caldera rim of 16 by 22 km diameter. The iron ore deposits (e.g. Barbara, Lak-e-siah) are considered as magnetite flows emitted from vents close to the ring fracture. The manganese Jaspilites are atrributed to early volcanic activity.

The synsedimentary-exhalative lead-zinc-deposits of Kushk, jaspilites and dolomites point to a moat-like lake (or sea) surrounding the caldera complex. The Narigan resurgent cauldron will be discussed in the context of the genetic models proposed by ELSTON (1976) and SILLITOE (1980) and compared to well studied cauldrons from other parts of the world.

چکیده در منطقه مورد مطالعه سنگهای دگرگونی قدیمی شامل اورتوگنایس‌ها ، پاراگنهایسها ، میکا شیست‌ها و مقداری مرمر (سازندچا بدونی پره‌کامبرین) است . این سنگها بوسیله گراواکه‌های سبز رنگ ، شیلهای کوارتزیتی ، گراواکه‌های آهکی و آرکوزلایه‌های نازک آهکهای بیتومینی ، شیلهای سیاه رنگ سیلیسی نازک و توفیت‌های دانـــه‌ریز (پره‌کامبرین سازند تاشک که قبلا " بنام سازند مرا دیا رخساره‌دار کوه نامیده شده بود) پوشیده شده است . بوسیله یک دگرشیبی زاویه‌ای که کاملا " مشخص است ، سازنداسفوردی (ریولیت‌ها ، توفهای ریولیتی و ، Ignimbrite ، شیلهای سیاه رنگ بیتومینی ، سنگ آهک سیلیسی ، دولومیت و مانیتیت که سری ریز و یادسو نیز نامیده‌شده‌اند)روی آنها رامی‌پوشاند . این محققین در نزدیکی کوشک فسیل جدیدی بنام (Persimedusites chahgazensis) یک عضو از زیر رده اسکی فومدسا انفراکامبرین پیدا نمودند . در سنگهای اسفوردی وسازندتا شک گرانیت‌های لوکوکراتیک ، بیوتیت سینیت و پیروکسنیت نفوذ نموده‌اند (گرانیت ناریگان) . گرانیت ناریگان معادل ریولیتهای اسفوردی است . در ناحیه مورد مطالعه Ignimbrite ها حجمی معادل یکصدکیلومتر مکعب را دارد . چنین حجمی مشخصه اصلی ناحیه ساختهای حلقوی اپی کنتنتال‌می‌باشد . تهیه نقشه از دهانه‌های آتشفشان (یا دهانه‌آتشفشان) بعلت پوشیده شدن آن بوسیله سازنده‌های کامبرین تا عهد حاضر و اثرات تکتونیکی مشکل است . بهرحال مرکز دهانه آتشفشان بنظر میرسد که یک گنبد تجدید حیات کرده از گرانیت نا ریگان باشد . یک حلقه از توده‌های نفوذی کوچک لبه دهانه آتشفشان را با قطری ۱۶ تا ۲۲ کیلومتر مشخص میکند . کانسارهای کانه آهن (بطور مثال باربارا ، لکه سیاه ،) بعنوان جریان مانیتیتی ملاحظه شده‌اند که از منافذ نزدیک به شکافهای حلقه خارج شده‌اند . وجود ژاسپلیت‌های منگنزدار به فعالیتهای اولیه آتشفشانی نسبت داده شده است . کانسارهای سرب و روی کوشک ، شبه رسوبی ــ بالا رونده ژاسپلیت و دولومیت از وجود یگ دریاچه (یا دریا) خندق مانند که دهانه آتشفشان را احاطه نموده ، حکایت می‌کند .

INTRODUCTION

The most important iron ore deposits of Iran are located in the area of Bafq in Central Iran. The total reserves of the 14 deposits that have been explored to date amount to at least 1 billion metric tons of high grade magnetite ore (TAGHIZADEH, 1976; BASSIR, 1976). Several massive sulfide ore deposits are located in the same area (Kushk, Zarigan).

The origin of the ore deposits and their host rocks, the age of the mineralisations and the possible genetic relations between the various kinds of ore deposits and their host rocks have been subject of controversy (see HUCKRIEDE et al., 1962; BORUMANDI, 1973; FORSTER & KNITTEL, 1979). Since the area is quite remote and largely difficult to access, most students of the area were not able to carry our extensive field studies, thus their conclusions were based on mere reconnaissance surveys. This picture is changing, since large efforts were started to evaluate the economic potential of the area in the early seventies.

The senior author (H. F.) and several co-workers have studied various parts of this mineral district. Their work benefited greatly from the exploration efforts, since drill core samples became available.

The present paper deals with the central part of the mineral district of Bafq. It summarizes the informations, obtained by several studies, made by the author's and others. Finally it is attempted to synthesize the facts to draw conclusions on the relations between ores and their host rocks and on the volcanotectonic development of the area in the period of ore formation.

STRATIGRAPHY

1. Precambrian

1.1 The metamorphic basement (Chapedony Formation)

The oldest rocks found in the area studied are exposed about 21 km northeast of Bafq. These exposures consist mainly of ortho-paragneisses, which are overlain by mica-schists and in places by marbel.

These metamorphics, which were already known to STAHL (1911) and KUMEL (1941), were studied in some detail by HUCKRIEDE et al. (1962). All these authore assigned a precambrian age to this formation, while other students of Central Iran considered them to be of Mesozoic age (for discussion see HUCKRIEDE et al., 1962, p. 127 f). FORSTER et al. (1973) on the basis of similarities of the stratigraphgic position and the lithology correlated the metamorphics with the Chapedony formation (STOCKLIN, 1971; HAGHIPOUR, 1977).

According to BORUMANDI (1973) the gneisses are medium graines rocks, composed of quartz, feldspars, biotite and muscovite. Feldspars in places occur as porphyroblasts, giving the rocks the appearance of augengneisses. The orthogneisses, which have a granitic composition, grade into migmatites by destruction of their metamorphic fabrics.

The mica-schists are rather fine grained, muscovite-schists having a smaller grain size biotite-schists. Commonly the mica-schists contain garnet and accessory tourmaline, zircone, rutile and sphene.

The marbels are composed of calcite porphyroblasts, set in a matrix of very fine grained calcite, Twinning is very common in the porphyroblasts. Subordinate amounts of quartz are usually present. The marbles in places contain some chert lenses.

1. 2 Tashk Formation

Large areas in the southwest and northeast, of the area studied are occupied by a monotonous clastic series, which was named by HUCKRIEDE et al. (1962). They described this series as a sequence of thin layered shales with mica on bedding planes, alternating with thick beds of quartzite, quartzic arcose and graywacke. Since, in their opinion, this series was lacking black siliceous shales and slump structures, they did not correlate it with the "Morad Seies", a monotonous sequence of sandstone and argillaceous shale with typical intercalations of black siliceous shales of late precambrian age, exposed in the core of the Morad anticline NW of ab-e-Morad. Instead they considered the Darkuh-Facies to be a special facies of the Ordovician-Devonian Old Red.

BORUMANDI (1973), who studied the graywackes found in the southwestern part of the area shown in the map, correlated it with the precambrian Tashk Formation, a monotonous series of dark green phyllites, quartzites and slates with rare ryholite layers, exposed at the Kuh-e-Tashk east of Saghand (STOCKLIN, 1971). This series is comparable in lithology and stratigraphic position to the Morad Series. From a reconnaissance survey of the northeastern graywacke sequence, BORUMANDI (1973) concluded that these graywackes too can be correlated with the Tashk-Formation, which implies, that the Darkuh-Facies of HUCKRIEDE et al. (1962) is identical with the Tashk-Formation.

BAILEY et al. (1978) described in the Kushk area a lithologic unit, composed of green sandstone and shale with lenses of limestone and dolomite. Minor volcanic intercalations were also noted ("a single lense of purpose tuff indicates minor volcanic activity during a long period of sedimentation"). The thickness of the sequence was estimated to be more than 3000m. The writers of the CENTO-report however did not, discuss the age of this sequence.

Detailed field work by KRUGER & SENNEWALD (1979) in the area between Kushk and Seh Chahoon has shown that the sequnce comprises

- green chlorite and sericite bearing graywacke,
- quartzitic shale,
- calcareous graywacke and arcose,
- thick sequences of bituminous thinly bedded limestone,
- subordinate fine grained tuffite and
- ubiquitous thin beds of black siliceous shale.

The observation of these siliceous shales shows, that the age assignement of HUCKRIEDE et al. (1962) was based on unsufficient knowledge of the area. KRUGER & SENNEWALD (1979) and BAILEY et al. (1978) observed, that these rocks unconformably underly the Esfordi Formation (see below) in the area N of Kushk. It thus may be concluded, that it is of Infracambrian age. A similar observation was made by BORUMANDI in the area to the southwest.

Thus KRUGER & SENNEWALD concluded, that all areas mapped as Darkuh-Facies, Morad Series or Tashk Formation are essentially the same strtigraphic and lithologic Unit.

In the contact zone of the Narigan Granite in the southern part of the studied area the graywackes of the Tashk Formation were subjected to contact metamorphism, which converted them to cordierite bearing hornfelses. Since the unmetamorphic graywackes grade into the hornfelses and since both are the same stratigraphic unit they are not shown separately on the map.

INFRACAMBRIAN

2.1 Esfordi Formation

The Esfordi Formation (named after Kuh-e-Esfordi, the highest mountain north of the "Barbara-iron ore deposit") is a volcanosedimentary sequence of rhyolite, rhyolite tuff, siliceous limestone, dolomite and magnetitites (FORSTER et al., 1973). It overlies the Precambrian Tashk Formation, from which it is separated by a pronounced angular uncomformity (BORUMANDI, 1973).

HUCKRIEDE et al. (1962) attributed the rocks comparable to the Esfordi-Rhyolite and

Esfordi-Dolomite to two different Lowest Paleozoic series, the "Rizu-" and "Desu-Series" and assigned a Combrian age to them. They also observed a transgressive contact between the Rizu Series and the Morad (Tashk) Formation. FORSTER et al. (1973) rejected this subdivision and stated, that both series are different facies of the same formation.

Outside of the mappes area at Zarigan, Shaitur, Buhabad and north of Zarand the Esfordi Formation is overlain without uncomformity by a red sandstone, the Dahu-Sandstones (HUCKRIEDE et al., (1962), which correlates with the Cambrian Lalun-Sandstone (STOCKLIN, 1971), spread over the whole Iran. The base of the Lalun-Sandstone marks the boundary between Infracambrian and Lower Cambrian (STOCKLIN, (1971). The Lalun-sandstone itself is conformably overlain by a trilobite bearing limestone of Lower to Middle Cambrian age (HUCKRIEDE et al., 1962), which occurs north of Zarand. It is also exposed in the Kushk Valley 5 km W of Kushk (See below).

Thus the Esfordi Formation represents the uppermost Precambrian, that is the upper infracambrian. This has been confirmed by KRUGER & SENNEWALD (1979), who found fossils of medusa approx. 3 km NW of Kushk in the shales of Kushk, a member of the Esfordi Formation. These medusae were identified by HAHN & PFLUG (1980) as Infracambrian Scyphozoa.

Large areas, covered by the Esfordi Formation, were mapped by HUCKRIEDE et al. as metamorphics. Detailed petrographic studies by BORUMANDI (1973) and KRUGER & SENNEWALD (1979) however have shown, that these rocks are not metamorphic. A study of n-alkanes in the black shale of Kushk shows, that during the past 600 m.y. temperatures never exceeded 60 C (FLEKKEN & LEYTHAEUSER, 1975, cited by FORSTER, 1987).

On the basis of identical lithology and stratigraphic position BORUMANDI correlated the Esfordi-Dolomite with the Soltanieh-Dolomite (named after the town Soltanieh in NW Iran; STOCKLIN et al., 1964. STOCKLIN, 1971), which is spread over large areas of North-, Central and East-Iran.

BAILEY et al. (1978) found some fossil plants of possibly Triassic age and tentatively considered them as part of the dolomite-rhyolite sequence. They stated however, that this assignement is more or less speculation, since they were not able to study the field relations of the fossil locality in detail.

2. 1. 1 Rhyolites

Rhyolites are volumetrically the most important member of the Esfordi formation. They are a group of volcanice, which very texturally and structurally in high extend. All transitions between very fine grained and nearly "plutonic" varieties are to be found (BORUMANDI, 1973). A few km north of the Kushk mine actually rhyolite intrusions were observed: Two of Them "appear to be plugs that have shouldred aside the intruded strata" (BAILEY et al., 1978).

In the surroundings of Lak-e-Siah (a magnetite deposit NW of Kushk) KRUGER & SENNEWALD (1979) observed ignimbrites of rhyolitic composition., Stratification of rhyolite sequences and fluidal textures may be observed in many places. BORUMANDI (1973), who was able to distinguish eight different types of rhyolite, stated that all varieties occur as massive lava and as tuff. From the studies of KRUGER & SENNEWALD (1979) it may be concluded that tuffs are most abundant.

The Rhyolites are porphytitic. Phenocrysts are quartz and feldspars, potassic feldspar usually dominating over plagioclase with the exception of sodic rhyolites, where albite is more abundant than microcline. Myrmecitic intergrowths between feldspars and quartz are frequently observed. Usually only minor quantities of mafic minerals occur, among these biotite, rutile and ore, Hydrothermal alteration is ubiquitous. Silification and sericitification of feldspars seem to be most prominent. Alunite and tourmaline (schorl), which forms often spherolitic aggregates, are also common. Epidote also seems to be a common alteration product of plagioclase.

FORSTER & KNITTEL (1979) compared the alteration at the deposit of Mishdovan, which lies farther to the NW, with the greisenitization of granites.

Most of the rhyolites are highly potassic with K_2O/Na_2O ratios of 4.1-5.1 or higher., The other rhyolites are however distinctly sodic with K_2O/Na_2O ratios of about 0.3-0.4.

2. 1. 2 The "Kushk-Shales"

The Kushk-Shales, named after the village of Kushk, consist of dark gray to black coloured bituminous shales which contain Pb-Zn mineralisations. Two massive sulfide ore bodies hosted by the Kushk-Shales are worked at the Kushk Mine.

The thickness of the sequence was estimated by SCHMITZ (1973) to be approximately 40 m, while BAILEY et al. (1978) state, that it is in excess of 100 m. As already stated, the shales show no sign of metamorphism.

At Chahgaz, 2 km north of the Panhu Ore Body of the Kushk Mine, KRUGER & SENNEWALD (1979) found the already mentioned medusae according to HAHN & PFLUG (1980) they are a so far unknown species, which they named Persimedusitis chahgazensis n. sp., They consider this species to be of late Precambrian age, since it is well comparable with medusae known from the Late Precambrian Ediacara Fauna of Australia. Of all genera of the Ediacara fauna, rugoconites (GLAESSNER & WADE, 1966) show the closest similarities with Persimedusitis. Accordingly HAHN & PFLUG (1980) ascribe-Persimedusitis to the sub-class Scyphomedusae.

The identification of these fossils and their age assignement confirm the common lead model age of 595-715 m.y. for the Kushk ores, reported by HUCKRIEDE et al. (1962).

2. 1. 3 Soltanieh-Dolomite and-Limestone

The dolomites overlying the rhyolites are fine graines, layered rocks. individual layers attaining thicknesses of several meters. In places they contain abundant fragments of quartz, sanidine, microcline and albite (BORUMANDI, 1973), but they are remarkably pure elsewhere (BAILEY et al., 1978, FORSTER & KNITTEL (1979). At Mishdowan FORSTER & KNITTEL (1979) observed thin layers of volcanics, intercalated in the dolomites, these volcanics were indentified as latite, trachyte and rhyolitic (?) ignimbrite.

A characteristic feature of the dolomite are chert lenses or layers. These cherts usually are red coloured due to their high content of hematite (jasper). In thin sections colloidal textures may be observed.

The Soltanieh-Dolomite is widespread. It overleis all the precambrian formations, occuring in the area mostly with sharp-angular unconformity. In many places it shows intensive folding, while underlying formations may be completely unfolded. In other places unfolded Soltanieh-Dolomite overleis folded strata.

HUCKRIEDE et al. (1962) considered the contact of the dolomite and underlying formations to be an overthrust with a direction of the tectonic movement from N to S. BAILEY et al. (1978) report the basal surface of the dolomite to be "clearly almost flat lying on folded beds" (p. 23), being "therefore a thrust fault of unknown, but necessarily large, displacement" (p. 26). Since the youngest formation overthrown by the Soltanieh-Dolomite are Jurassic strata, the overthrust must have occured in post-Jurassic time.

KRUGER & SENNEWALD (1979) presented two models dealing with the origin and extent of the thrust faults. Model A is based on the assumption, that the rhyolites and dolomites are of different competence. While the rhyolites reacted to stress by deformation the dolomites only in the first stage reacted by folding, but were faulted as the stress increased. If this model is correct, overthrusting would be of small scale. Model B assumes that the dolomites were deposited somewhere north of their present position, druing an orogenic phase they were overthrusted over the rhyolites, forming a large nappe. The distance of tectonic transport would be in the range of 15km.

The limestone occurs predominantly in the northern part of the studied area. It is of dark gary to black colour, usually bituminous and siliceous. It contains no fossils. Locally it is replaced by dolomite. The limestones overlay the Esfordi-Rhyolites and the Tashk Formation respectively without unconformity.

2.2 Intrusives

The Narigan Granite was already known to STAHL (1897), BOHNE (1928), BAIER (1940), KUMEL (1941) and WALTHER & KURSTEN (1958). It was described as a magmatic complex, which intruded Jurassic sediments in Jurassic time. Petrographical studies by BACHTIAR (1973) have shown, that this magmatic complex is composed of rocks most probably solidified under subvolcanic conditions. Two varieties of granite are present, one has a porphritic texture, the other is equigranular. The equigranular granite is rather coarse grained.

The main components of the granites are pertitic orthoclase (about 50%), quartz (30-40%), plagioclase (7-15%) and biotite (2-3%). In the equigranular granite myrmekitic intergrowths of quartz and orthoclase are Common. Locally the granite contains secondary tourmaline. In place of biotite some granites contain riebeckite.

The chemical analyses published by BACHTIAR (1973) show, that most granites are highly potassic. The K_2O contents vary from 3.7 to 5.3%, the ratio K_2O/Na_2O varies from 1.4 to 1.9. Minor quantities are even more potassic. On the other hand there are also sodic granites having K_2O/Na_2O ratios of 0.6-0.13. No intermediate types were found.

HUCKRIEDE et al (1962) have proven a pre-Jurassic age of the Narigan Granite, since they found boulders of this granite in Lower Cretaceous and Dogger conglomerates. From the similarity of the petrochemical characteristics of the Narigan Granite and the rhyolites of the Infracambrian Esfordie Formation BACHTIAR (1973) concluded, that the granite is the subvolcanic equivalent of the rhyolites and consequently assumed, that it is also of Infracambrian age.

Syenites, which were already recognized by BAIER (1940), form numerous stocks and dikes in the area under investigation, They are medium to coarse grained, equigranular rocks. Besides orthoclase and plagioclase the syenites contain biotite or biotite and amphibole or biotite and augite, biotite-rich varieties tend to be relatively mafic, their colour index may be as high as 40. Only in one locality quartz was found to be a constituent of the syenites. Apatite is a common accessory mineral of the syenites.

Other intrusive stocks are composed of

amphibole-gabbro, amphibole-diorite or pyroxenite. The pyroxenites predominantly are composed of diopside and apatite, Secondary amphiboles (tschermakite and aktinolite) sometimes are very abundant.

3. Cambrian
Trilobite-Limestone

Three km southwest of the Kushk Mine a small occurrance of trilobite bearing limestone is exposed. The trilobites have been determined by Dr. HAMMANN (Wurzburg) as redlichidae of Lower to Middle Cambrian age.

In the area studied the Trilobite-Limestone represents the formation overlying the Esfordi Formation. Outside of this area at Zarigan, Shaitur and Buhabad the Esfordi Formation is conformably overlain by a typical red sandstone, named by HUCKRIEDE et al. (1962) "Dahu-Sandstone", which is equivalent to the Lalun-Sandstone (STOCKLIN, 1968), widespread over whole Iran (BORUMANDI, 1973). At the aboue mentioned exposures the Lalun-Sandstone is overlain by the Trilobite-Limes stone, determined by HUCKRIEDE to be of Lower to Middle Cambrian age.

The Lalue-Sandstone is not exposed in the area studied, however boulders of it have been found in the upper Kushk Valley. The contact between the Trilobite-Limestone and the underlying formation is covered by alluvial gravel, thus one can only speculate about the nature of its footwall. In addition, there must be expected tectonic disturbances, since the authors assume that the Kushk Valley represents a tectonic graben, accompaied by fractures and faults, which are exposed on both sides of the valley parallel to it. The tectonic disturbances are illustrated by the direct neighbourhood of Jurassic, Cambrian and side of the Kushk Valley.

4. Jurassic

Jurassic sediments are exposed in the Kushk Valley and in the Mugirt Valley in the southernmost part of the mapped area. They consist of thin bedded graywackes and sandstones.

Near Kushk a fossil find of Lepidodendron sp. is reported by SCHMITZ (1973) and BAILEY et al. (1978). SCHMITZ assigns a possible Jurassic age to it, while BAILEY et al. consider it to be of questionable Triassic age, SCHMITZ considers these rocks to be either erosional remnants or imbricate wedges of the Jurassic Shemshak Formation (STOCKLIN, 1971). In the Mugrit Valley Liassic beds are overthrown by rocks of the Esfordi Formation, Both units are overlain by transgressive Cretaceous limestone (HUCKRIEDE et al., 1962).

The Jurassic strata in the Mugirt Valley in contrast to the Infracambrian formation show no sign of volcanic activity. They contain small coal seams and thin intercalations of yellow dolomite layers. Carbonate sediments are of minor importance in comparison to green and brown sandstones (HUCKRIEDE et al., 1962).

5. Cretaceous

The southwestern part of the area studied is covered by transgressive strata of Cretaceous age. Lower Cretaceous strata (Aptian) are composed of greenish marls. They are overlain by a basal conglomerate of variablae thickness, that separates Lower and Upper Cretaceous sediments. The conglometate is overlain by fossiliferous limestone beds. In general the limestone beds dip about 35 SW (BORUMANDI, 1973).

6. Tertiary

The only Tertiary rocks exposed in the area under consideration are a sequence of conglomerates, composed of coarse limestone clasts, named Kerman-conglomerate by HUCKRIEDE et al. (1962). According to these authors these sediments mark the boundary between the Cretaceous and Tertiary systems.

7. Quarternary

Large areas are covered by alluvial gravel, the thickness of which increases to the west and may attain several 100 m under the salt lake of Bafq.

II. MINERALISATION

1. Iron ores

The occurrence of iron ores in the area east and northeast of Barq is known since long. STAHL (1911) mentioned the Chogart, a hill 150 m in hight, compsoed almost entirely of magnetite ore.

BOHNE (1929) already recognized the high phospior content of the ores. He assumed, that the ores originated by replacement of Upper Crteaceous limestone at the contact to syemite.

DIEHL (1944) and LADAME (1945) gave short descriptions of the deposits of the deposits of the Chogart, the Narigan Valley and Lak-e-Siah. Like BOHNE both considered the ores to be of pyrometasomatic origin. Based on their genetic concept they assumed a Cretaceous age of the mineralisation ("1'age mesozolque .... est etabli de facon sure", LADAME, P. 259).

To BANFIELD & CLARKE (1960) the iron ores appeared to be only of Eocene age. They also considered them as replacements "mostly along fissures in Jurassic and Cretaceous limestone" (P. 78), but admitted, that at the Chogart "the contacts were not sufficiently exposed to show the relationship between the ore and the country rock of carbonates, altered Volcanics and possibly other rock types" (P. 80). These early genetic interpretations were based mainly on the observation of the association of igneous acid rocks, limestones or dolomites and iron ores. The idea that the ores are monadnocks, intercalated in acid rocks, which were covered much later by cretaceous limestons (SEEGERS, 1976), did not occur to them.

WALTHER & KURSTEN (1958) also concluded that the ores are of metasomatic origin, but also considered the possibility, that the ores found of the Narigan Granite are of synsedimentary origin.

They subdivided the magnetite ores into phosphorous-rich types and phosphorous-poor types. The authors noted, that the chemistry of most of the ores was quite uncommon for metasomatic magnetites.

WILLIAMS & HUSHMAND (1966) for the first time included pertrographic studies of the host rocks in their investigation and found, that no granite that could be responsible for the ore is present at Chogart. They considered this deposit to have originated by the intrusion of a magnetite melt (Kirunea-type), since they observed disoriented angular inclusions of country rock in the magnetite and flow structures of apatite and magnetite. Also the presence of large amounts of apatite, the high Vanadium-contents of the ore and the scarcity of sulfides seemed to them to be incompatible with a metasomatites origin. BEHAIN (1970) however again referred to the Chogart ores as metasomatites. He claimed to have been able to map the transitions limestone --- dolomite --- siderite.

FORSTER & BORUMANDI (1971) observed, that the ores in small deposits are conformably intercalated between rhyolite and dolomite. Since the dolomite did not show any signs of metasomatic aleration. they concluded, that the ores originated as lava flows.

This assumption was supported by the observation of volcanic ash, composed of magnetite, magnetitite lapilli and magnetite bombs. BORUMANDI (1973), BACHTIAR (1973), FORSTER et al. (1973), SEEGERS (1976), KRUGER & SENNEWALD (1979) and FORSTER & KNITTEL (1979). The iron ore deposits in the area studied are part of the iron ore district of Bafq. Besides the three major occurrences of iron ore in the area under investigation (Lak-e-siah, Esfordi (Barbara), Seh-Chahoon), described bu FORSTER et al. (1973), BACHTIAR (1973), BORUMANDI (1973), SEEGERS (1976), there are numerous small and occurrences were subdivided into three categories:

– deposits in contact to dolomites, jaspilites, shale
– deposits in contact to pyroclastics and lavas and
– deposits in contact to intrusives.

Deposits of the last two categories prove, that magnetite ores occur independently from the occurrence of carbonates.

Deposits of the various types do not show a certain spatial arrangement, which is to be expected from metasomatic ores but are found scattered all around.

Small and smallest deposits offer a much better opportunity than the large deposits to study details of the structures and textures of ores and host rocks. Layered jaspilites concordant to thin ore beds, thin layered magnetite tuffs, bedded volcanics with Japilli and bombs of magnetite ore indicate a volcano-sedimentary origin of the ore.

Breccias, composed of rhyolite fragments, set in a magnetite matrix, schlieren-textures of the ore and euhedral apatite crystals in magnetite ore cannot be explained but by the assumption of a magnetite melt into very thin fissures indicate, that this melt had a very low viscosity.

2. Manganese ores

In the volcano-sedimentary sequence to the north of the Narigan Granite there occur several deposits of jasperous manganese-rich ironstones. The largest deposit, which is located NW of the village of Narigan, can be traced over a distance of more than 1000 m. The total thickness of the deposit varies from 3-15 m. It is composed of thin (0.1-2 mm) beds of ore and chert. Besides chert it also contains some dolomite and baryte, The Mncontent usually is in the range of 6.0-8.5%, while the Fe-content usually is higher than 40%.

The ores close to the Narigan Granite have been subjected to contact metamorphism.

3. Lead-Zinc ores

The lead-zinc deposit of Kushk was mentioned already by BOHNE (1929), DIEHL (1944) AND LADAME (1945). They considered it as a vein deposit, situated in a fracture zone, characterized by the intimate intergrowth of fine grained galena, pyrite, chalcopyrite and little sphalerite (BOHNE, 1929).

Modern mining of the ores started only in 1957. HUCKRIDE et al. (1962), SCHMITZ (1973), SCHMITZ & SCHMITZ WIECHOWSKI (1975) and BAILEY et al. (1978) describe the deposit in more detail.

The ore beds are part of a sequence of gray-green, thin bedded tuffs and the black bituminous shales of Kushk, to which they are bound. This sequence, the "ore-sequence"

(BAILEY et al., 1978), has an aggregate thickness of almost 600 m. The maximum thickness of the ore body itself is about 25-30 m.

SCHMITZ (1973) considered the deposit to be of a synsedimentary-submarine-hydrothermal origin, since the ore is stratiform, always associate with the shales of Kushk, thoroughly accompanied by concordant volcanics. It has a layered structure and is extremely fine grained.

The ore is composed of tne following minerals (SCHMITZ & SCHMITZ-WIECHOWSKI, 1975; BAILEY et al., 1978): sphalerite, locally making up as much as 75% of the ore. It occurs thinly banded or laminate, intercalated with melnicovite bands about 3 mm wide or as fine grained fillings between clastic shale particles.

Galena, much less abundant than sphalerite, in places makes up 33% of the ore, usually fine grained, it is interstitial to sphalerite.

Iron sulfides like melnikovite and pyrite "are sparsely present in unmineralised shale and increase in almount as the shale approaches ore" (BAILEY et al., 1978, p. 30).

Small amount of chalcopyrite are reported by WRIGHT (1965), "but most ore is copper free" (BAILEY et al., 1978, p. 30).

III. DISCUSSION

The Esfordi Formation is most important in the area studied, since it covers the largest areas (with the exception of the alluvial planes) and contains numerous ore deposits.

Rhyolites are the most abundant rock types of this volcano-sedimentary sequence. In the area shown in the map they cover approx. 200 km^2. The aggregate thickness of the rhyolite layers of the formation is about 500 m, as can be seen from the profiles described by BACHTIAR (1973) from the northern margin of the Narigan Granite, by FORSTER & KNITTEL (1979) from Mishdovan and by SEEGERS (1976) from Seh-Chahoon. Thus a conservative estimate of the volume of extruded rhyolites in the area covered by th present study is 100 km^3. Since large rhyolite complexes also exist in the north and the south of the area, dealt with in this paper, the total volume of acid extrusives must be much larger.

Extensive rhyolite deposits in many places of the world, like the Bozen Quarzporphyr, Lake Toba in Sumatra or in the southwestern United States and Northern Mexico, are known to have been emplaced largely as ignimbrites (WESTERVELD, 1942; van BEMMELEN, 1939; ROSS & SMITH, 1961; ELSTON, 1976). FORSTER & KNITTEL (1979) and KRUGER & SENNEWALD (1979) were able to prove, that also in the Bafq area at least a part of the rhyolite was emplaced as ignimbrites.

Extrusion of large volumes of rhyolitic ignimbrites in many cases were succeeded by caldera formation (SMITH & BAILEY, 1968). SMITH (1979) has stated, that caldera formation may occur after the extrusion of volumes of 1-10 km^3. Volumes of 100 - 1000 km^3, a dimension that may be applicable to the area under consideration, are considered to be typical for epicontinental ring structures, while even larger Volumes are associated with calderas found in epicontinental areas as well as in island arcs (SMITH, 1979, p. 6). Thus it seems to be reasonable to assume, that the extrusion of the Esfordi-rhyolites also was connected with caldera formation.

To trace outlines of the caldera or calderas in the Bafq area seems to be a difficult task, especially if one takes into consideration, that despite of many years of intense studies the outlines of many of the calderas in the Mid-Tertiary volcanic fields of Southern New Mexico are only tentatively known or only suspected (ELSTON, RHODES, CONEY, DEAL, 1976). Topographic expression of old calderas in the Bafq region of course is destroyed by erosion since long and important parts of the structures possibly are already eroded. Large areas are covered by younger sediments and are thus not accessible to inspection. Hydrothermal alteration and diagenesis may have obliterated diagnostic features. Tectonic disturbance such as low angle overthrusts, as observed by the authors at the Mishdovan deposit, have at least in place destroyed the spatial relationships of various units.

The features that still may help to trace the outlines of ancient calderas are related to a resurgent phase in the course of the volcano-tectonic evolution of the caldera (SMITH & BAILEY, 1968). In many caldera complexes igneous activity continues after the caldera collapse by intrusion of subvolcanics, which lift the caldera center (resurgent doming) and by ring fracture volcanism or plutonism (SMITH & BAILEY, 1968). The intrusions, namely theone, causing the resurgent dome, are a possible tool for locating the sites of former calderas, provided, that the caldera collapse was followed by a resurgent phase, An intrusion of the approximate size for a resurgent dome is the Narigan Granite. It's textures point to a high-level emplacement. BACHTIAR (1973) already noted the chemical similarities of this granite and its rhyolitic host rocks and concluded, that both were derived from the same source. The presence of highly potassic and of sodic rhyolites and granites could point to a more complicated history of caldera formation, possibly an earlier cycle was followed by a second magmatic cycle, as in the Jemez Mountains of New Mexico, where the Toledo Caldera was in part obliterated by the later collapse of the Vallez Caldera.

The outdrops pattern of smaller plugs, which could have intruded the ring fractures, is more difficult to interprete, since the study of their distribution is hampered by the fact, that (especially south of the Narigan granite) the area is covered by younger sediments. Thus the pattern observed may reflect the present exposure and may not be an original feature. However there seems to exist a concentration of subvolcanic intrusions about 8 to 10 km north of the Narigan Granite, which could-if interpreted as trace of the old ring fractures-delineate a caldera about 16 x 22 km wide. This size is quite comparable with other calderas such as the Vallez Caldera (SMITH & BAILEY, 1986).

The occurrence of extrusive or intrusive iron ores (FORSTER & BORUMANDI, 1971; FORSTER & KNITTEL, 1979; SEEGERS, 1976) probably fits into this picture. On the myps of the El Laco Deposits in Chile, published by FRUTOS & OYARZUN (1975), it can be seen, that the magnetite flows were emitted from vents close to the calders rims, thus their extrusion seems to be related to the ring fracture volcanism, that followed the caldera collapse.

A similar relationship can be observed in the Durango deposits of Mexico (SWANSON et al., 1978).

If one accepts the model of a caldera with its center in the vicinity of the Narigan Granite, then the extrusion of the iron ores of the Barbara Deposit (BORUMANDI, 1973) and Lak-e-Siah can be related to ring fracture magmatism.

North of the large Lak-e-Siah Deposit KRUGER & SENNEWALD (1979) observed numerous small iron deposits, which appear to be of synsedimentary origin. In part they were interpreted as tuffs of magnetite lapilli and magnetite ash, while others are redeposited ores, emplaced in a matrix of carbonates. Their distribution conforms with the assumption, that the debris was transported downslope the caldera shoulders (that is to the north, away from the center of the caldera at Narigan). The presence of jaspilites and thick dolomite sequences indicates, that the area, surrounding the caldera, was a shallow sea or lake, where deposition of evaporites just started (KRUGER & SENNEWALD, (1979). Dolomite deposition might have taken place predominently at the elevated shoulders of the caldera. The manganese -rich iron jaspilites, described by BACHTIAR from the sequence of volcanics, that lies just north of the outcrop of the Narigan Granite, are of synsedimentary-exhalative origin. Since their host rocks the roof of the Narigan Granite and since they have been metamorphosed by the latter, they must be related to earlier volcanic activity.

The occurrence of the Kushk-Shales and their mineralisations are compatible with the model proposed, if they are considered as moat deposits, SILLITOE (1980) has summarized evidence, indicating, that resurgent calderas are favourable sites for the formation of massive sulfide deposits. Metal-bearing solutions can rise along the ring fractures and circulate in the highly fractured collapse zone.

The ultimate source of these huge volumes of acid volcanics and of the large amounts of iron remain to be identified, ELSTON (1976) concluded from a survey of the literature and from field evidence, obtained in the New Mexico sector of the Mid-Tertiary Volcanic Province of Southwestern North America, which contains thick sequences of acid ash-flow tuffs, that high-silica alkali rhyolite could from by partial melting of silicic crust, wherever tectonic extension causes masses of basaltic magma to rise. These basaltic diapirs are thought to rise the temperature of lower crustal levels above the solidus of granite or rhyolite.

Accordingly the volcanism simply transfers material from the lower part of the crust to the top ("overplating"). This mechanism may operate not only in areas of back-arc-basin setting, as in the Mid-Tertiary Volcanic Province of SW America, but also in the interior of plates as in Tibesti.

FORSTER (1981) has suggested, that the iron of magnetite deposits is derived from the rising basalt diapir underlying the silicic crust. The iron is released at pressure relieve from pyroxenes and separates from silicate melt hematite liquid due to liquid immiscibility.

The melt is Patially reduced and release of oxygen will result in a foaming-up of the melt. The lowered density of this melt will facilitate the rise of the melt to the earth's surface (FORSTER, 1980).

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