GEOTECTONIC ENVIRONMENT OF Au QUARTZ LODES OF MESOZOIDS IN NORTHEASTERN ASIA

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ABSTRACT

The main type of gold mineralization in northeastern Asia are Au-quartz veins. They are confined to folded belts that formed during Late Mesozoic accretion of discrete, mostly sialic, blocks into the passive margin of North Asia. The length of folded belts with Au-quartz veins correlates to granitoid occurrences. They are bounded by maximum compression zones that define the accretionary collision front. A succession of Au-quartz deposits develop during the formation of collisional zones: 1) regional metamorphism, 2) metamorphogenic syntectonic Au-quartz veins, 3) early collisional I-type granitoids, 4) magmatogenic Au-quartz late syntectonic veins, 5) late collisional granitoids, 6) Au-rare metal-quartz and rare metal late syntectonic veins. The formation of the highest grade Au-quartz veins is closely related to early collisional I-type granitoids. A metallogenic and geotectonic model for the formation of collisional Au-quartz veined belts is developed. The Late Jurassic-Early Cretaceous accretion of tectonic blocks to the North Asia continental margin terminated with a number of collisional events. The folding and thrust faulting processes resulted in regional metamorphism of terrigenous rocks and the formation of metamorphgenic syntectonic veins. The granitoid intrusion stage is genetically related to the formation of late syntectonic Au-quartz and Au-rare metal-quartz veins, terminating the collisional cycle. Au-quartz veined belts in northeastern Asia formed because of the regional sialic substratum and its geodynamic environment during a single collisional cycle during the late Mesozoic.

INTRODUCTION

A Mesozoic gold-bearing province in northeastern Asia is the major Phanerozoic gold province in the world. Here the production of gold has been about 200 t of gold from lode deposits and more than 3500 t from placer deposits. Au-quartz veins are the most important deposit type and a source for placer deposits in this area. Their geologic and mineralogic properties are well known (Firsov, 1985; Gamyanin, 1991). Nevertheless, the geotectonic environment of major gold belts in this area needs to be studied further, especially in consideration of modern accretionary tectonics theory.

GENERAL DESCRIPTION OF MESOZOIC COLLISIONAL ZONES

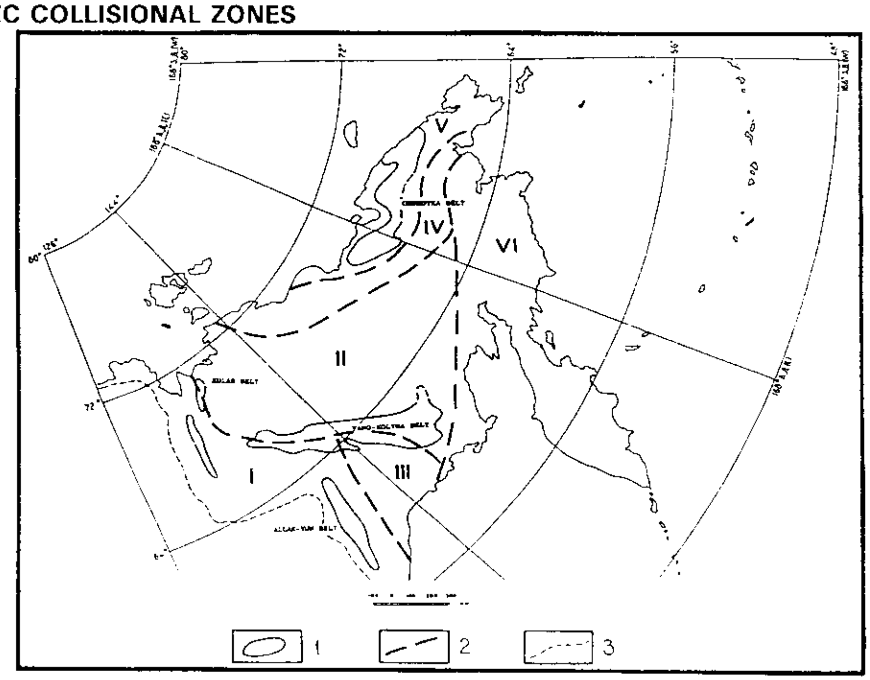

Fig.1. Major Au-quartz vein belts of northeastern Asia.
1 - boundaries of Au-quartz belts; 2 - boundaries of major tectonic blocks (after L.M.Parfenov, 1994); 3 - eastern boundary of the Siberian platform.

According to Parfenov (1994), the modern tectonic pattern of Mesozoic rocks in northeast Asia consists of five major tectonic blocks: (1) the North Asia craton including the Siberian platform and the Verkhoyan miogeoclinal folded belt, (2) the Okhotsk microcontinent, (3) the Kolyma-Omolon superterrane, (4) the South-Anyui zone, (5) the Chukotka shelf terrane. The main Au-quartz belts are confined to the boundaries of these blocks (Fig.1). At present, most researchers interpret these as collisional zones marked by folded belts, metamorphic zones and belts of granitoid intrusions (Zonenshain et al., 1990; Bogdanov and Tilman, 1992; Parfenov, 1994).

Table 1. Comparison of major collisional zones of Northeastern Asia.

Features	Allakh-Yun zone	Yana-Kolyma zone	Chukotka zone
Character and intensity of folding	Linear and locally intense folding; large linear box and arch structures complicated by minor folds; cross faults are present	Intense areal folding; linearly squeezed folds, large box anticlines and U-shaped synclines complicated by minor folding; zones of complete folding	Locally intense folding; large linear horst anticlines and graben synclines; zones of compressed folds and thrusts alternate with zones of brachyform folds
Main vector of compression	West to northwest (J_3 -K_1)	Southwest (J_3 - K_1)	Southwest (J_3 - K_1)
Faulting	Deep upthrown displacements, outside thrusts	Deep faults and thrusts; several parallel systems of faulting are distinguished	Structure-bounding thrusts and faults
Regional metamorphism	Dislocational metamorphism; a narrow linear zone of greenschist facies (T over 500°C, P=3-6.5 kb)	Dislocational metamorphism; linear zones and areas of regional plutonic greenshist metamorphism (T=450-620°C, low pressure)	Local domal greenshist and amphibolite metamorphism (gedrite paragenesis)
Granitoid magmatism	Zoned intrusions of I-type early orogenic granitoids (140-95 Ma): post-orogenic S-type granite-leucogranite intrusions (110-80 Ma), east of the belt	Intrusions are abundant, including early and late orogenic deep I-type granodiorites (150-130 and 130-115 Ma), orogenic shallow peraluminous two-mica granites (140-120 Ma) and post-orogenic S and A-type granite-leucogranite intrusions (less than 110 Ma)	A combination of early orogenic I-type granitoids (sometimes zoned) and post-orogenic S-type granites
Location of gold mineralization	Mostly linear zones of mineralization combined with zones of regional metamorphism; ore fields are less widespread and occur in association with diorite-granodiorite I-type granitoids	Linear-node zones and ore fields in combination with diorite-granodiorite intrusions and plutonic metamorphic areas	Mineralization occurs in nodes; ore fields are a result of a combination of structural geologic, metamorphic and magmatic factors

Compiled from Bogdanov and Tilman, 1992; Fedorova, 1991; Gelman, 1963; Gelman et.al., 1980; Goryachev, 1992; Goryachev et.al., 1994; Gusev et.al., 1985; Nenashev, 1979; Nenashev and Zaitsev, 1987; Parfenov, 1994; Shkodzinsky et. al., 1992; Simanovich and Andrianov, 1994.

These collisional zones have characteristic features, despite differing spatial positions and the age of their terrigenous complexes (Table 1). The appearance of these features is dependent on the size of the collisional zones, and probably the level of their erosional truncation.

AU QUARTZ BELTS

The *Yana-Kolyma* Au-quartz belt (Fig.2) is related to the most significant and well-defined collisional zone. Over 2500 t of gold has been produced from this belt (Gorodinsky et. al., 1994). Granitoids are the most widespread in this zone (Shkodzinsky et. al., 1992) and coincide with the Au-quartz belt. This belt occurs along the boundary between the Verkhoyan miogeoclinal belt and the Kular-Nera terrane, along the Adycha-Taryn collisional suture (Parfenov, 1994). Host sediments consist of terrigenous sandy-shaly flyshoids of Permian to mid-Jurassic age. They are usually subject to low-grade regional dislocational, plutonic and contact metamorphism of greenschist chlorite and biotite facies (Gelman et.al., 1980; Krutous, 1991; Fedorova, 1991). Terrigenous rocks that underwent regional metamorphism have many granitoid intrusions in an extensive belt, partially coinciding with the gold-bearing zone (see fig.2). Two-mica high-alumina granites are widespread and make up large (up to 7000 sq. km) batholith-like S-type intrusions at relatively low depths (Shkodzinsky et.al., 1992). They are associated with percalcareous I-type granitoids of high temperature deep magmas, which are close to them in age (Shkodzinsky et.al., 1992). They divided in two groups of plutons: (1) early diorite-granodiorite and (2) late granodiorite-leycogranite (Gamyanin et.al., 1991). Late post-tectonic granite-leycogranite intrusions contain rare metals.

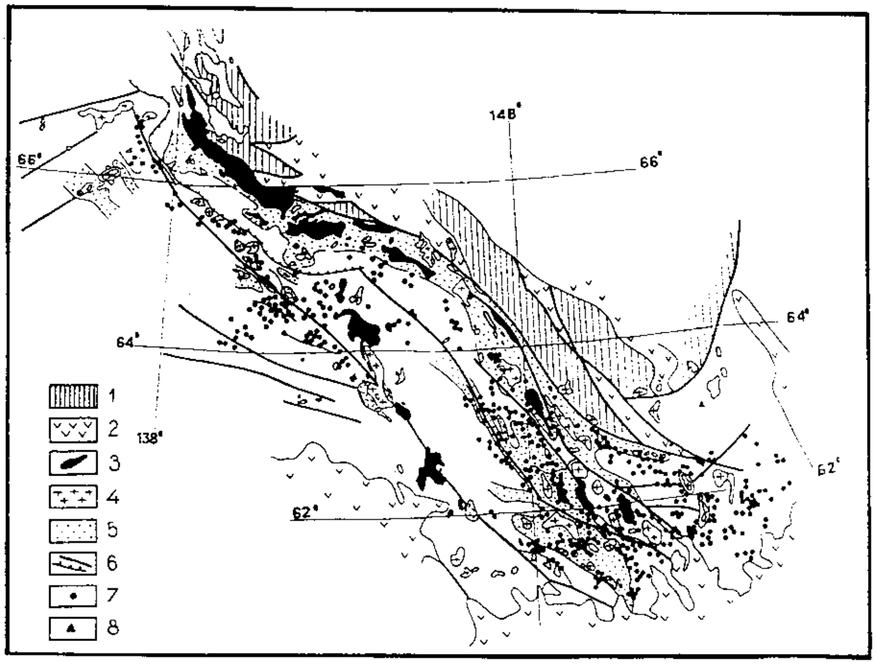

Fig.2. Schematic simplified map of the Yano-Kolyma Au-quartz vein belt.
1 - Paleozoic carbonate tectonic blocks; 2 - Late Jurassic and Cretaceous volcanic belts; 3 - peraluminous granitoid intrusions; 4 - percalcareous granitoid intrusions; 5 - zones of regional metamorphogenic rocks of the Verkhoyan sequence; 6 - faults; 7 - Au-quartz vein deposits; 8 - Au-rare metal quartz vein deposits.

Au-quartz mineralization occurs as several bands, where regional plutonic metamorphism is widespread; it is the most compositionally diverse. Metamorphogenic syntectonic Au-quartz veins are scarce and not of commercial grade. Late syntectonic magmato-genic Au-quartz and Au-rare metal quartz veins occur with I-type granitoids in ore-magmatic fields (Gamyanin, et.al., 1991). They differ by the composition and typomorphic properties of their minerals (Gamyanin et.al., 1991). These veins are 135-115 m. y. old (Firsov, 1985; Nenashev, 1979) and formed under constant horizontal pressure (Kalinin, 1989). The Yano-Kolyma Au-quartz belt disappears to the northwest, due to a belt of transverse "concealed" basement faults tending far southwest to the Siberian platform (Mokshantsev, 1968). These faults have an unknown nature and control the transverse granitoid intrusions, which are younger than granites of the Mainly collisional belt (Parfenov, 1994). These granites are similar to granitoids of the Northern batholith belt (Bakharev et.al., 1988; Trunilina, 1992), but therefore they are classified as belonging to the same collisional granitoid belt (Zonenshain et.al., 1990; Bogdanov and Tilman, 1992; Parfenov, 1994) seems doubtful. Granitoids of the Northern batholith belt may be Late Jurassic (Natapov, Stavsky, 1985) or Early Cretaceous zonal markers of displacements. These deep faults could be a result of the rotation of the Kolyma-Omolon superterrane (block) during its collision with the North Asia craton (Kuznetsov, 1990). In the southeast, the Yana-Kolyma Au-quartz belt is overlain by the Okhotsk-Chukchi post-accretionary volcanic belt. It is here that post-tectonic Au-quartz veins are the most widespread. These veins usually occur in older granitoid stocks under tensional conditions and are confined to deep fault zones. These veins also cut granitoid dikes and stocks of Late Cretaceous age (Gamyanin and Goryachev, 1988).

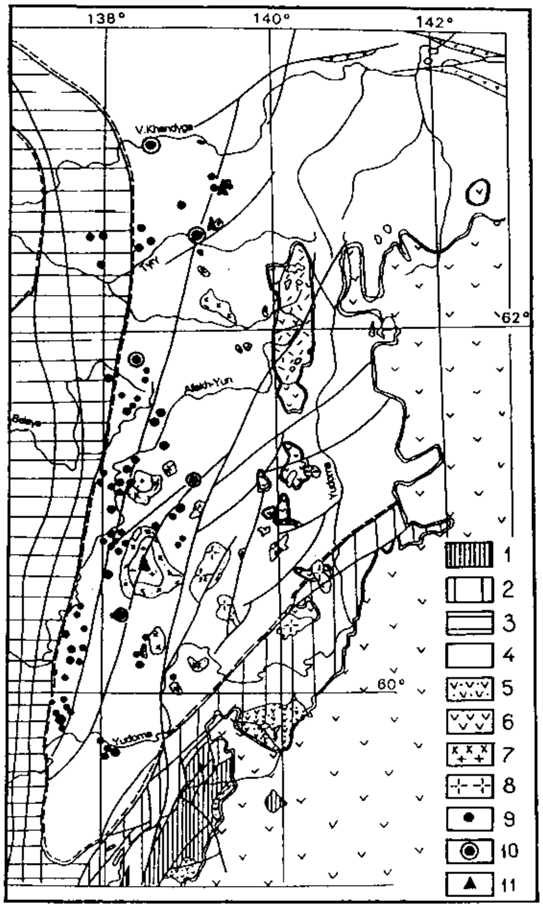

Fig.3. Schematic simplified map of the Allak-Yun Au-quartz vein belt.
1 - the Okhotsk microcontinent; 2 - terrigenious rocks of the Bilyakchan zone (PZ-MZ_1); 3 - carbonate rocks of the Sette-Daban zone (PZ_{1-2}); 4 - terrigenious rocks of the Yuzhno-Verkhoyan zone (PZ_3-MZ_1); 5 - Late Triassic volcanic rocks; 6 - Okhotsk-Chukchi volcanic belt; 7 - accretionary granitoid intrusions; 8 - post-accretionary granitoid intrusions; 9 - metamorphic Au-quartz vein deposits; 10 - magmatic Au-quartz vein deposits; 11 - Au-rare metal vein deposits.

The *Allakh-Yun* Au-quartz belt is a well-defined structure that occurs along the South Verkhoyan collisional zone, the collisional boundary between the Okhotsk microcontinent and the North Asia craton (Table 1). Several hundred tons of gold have been produced from here. It is hosted by structures of the Verkhoyan miogeoclinal folded belt. This Au-quartz belt coincides with areas of regional dislocational and granitoid magmatism (Fig. 3). The South Verkhoyan collisional zone features an intense but local regional metamorphism of greenschist to amphibolite facies (Simanovich and Andrianov, 1994). Metamorphism occurred prior to the formation of granitoids and Au-quartz veins. Another peculiarity is that syntectonic granitoid magmatism was less intense here compared to other zones. It is represented here by intruding dikes of mostly intermediate composition and major zonal intrusions of granitoids. This zoning is expressed in a higher silicic content of rocks toward the center of the massif, a result of the successive development of crystallization phases (Grinberg et.al., 1970). These granitoids are compositionally similar to I-type granitoids, and their age is 140-95 m. y. (Nenashev, Zaitsev, 1987). They form a long narrow belt in the axial portion of the folded zone and are replaced to east, toward the Okhotsk microcontinent, by an extensive area of Cretaceous post-tectonic leucocratic granites and subvolcanic granites related to the formation of the post-accretionary Okhotsk-Chukchi volcanic belt. Au-quartz veins occur as a linear zone along the western side of the belt of zonal intrusions and dikes (see fig. 3). They are divided into two groups of veins (Ivensen and Levin, 1975; Gamyanin et.al., 1985): (1) stratified pre-dike and pre-granitoid Au-quartz veins of metamorphogenic origin; examples are the Yur, Duet, Finn and other gold deposits (Buryak et.al., 1990), and (2) cross-cutting veins and stringers of magmatogenic origin; examples are the Nezhdanin, Lazurnoye, Zaderzhnoye, Voskhod, Novinka and other gold deposits ("syngranitoid"). The first group of veins is mostly present at the southern end of the metallogenic belt and forms a set of on echelon bands tending northeast; these veins are closely related in space to the dislocational metamorphic zone. The second group of veins is relatively regular throughout the entire belt. Veins are different both in morphology and composition. Magmatogenic post-dike veins have a more diverse mineralogy. They contain up to 5% sulphides, as well as sulphosalts. In the north, the Au-quartz belt seems to be bounded by a fault zone including the Bryungadin and Suntar faults, which marks the joint of the South Verkhoyan younger collisional zone and the Yana-Kolyma collisional zone. In the south, it is bounded by the closure zone of the folded belt.

The *Chukotka* Au-quartz belt has produced 700 t of gold (Gorodinsky et.al., 1994), and occurs on the passive margin of the old North America continent (Parfenov, 1994). This belt enters the Arctic Ocean, and is in part overlain by extrusive rocks of the Okhotsk-Chukchi post-accretionary volcanic belt. This belt may be a part of the major Chukotka-Steward belt. It features discontinuous, clustered Au-quartz occurrences confined to horst-anticlines, where greenschist and amphibolite metamorphism is intense, age 146 m. y. (Gelman, 1963; Gelman et.al., 1980). Nevertheless, it is noteworthy that Au-quartz deposits are confined to domes featuring biotite greenshist metamorphism, which are surrounded by early orogenic granitoid intrusions of varied composition (Fig. 4).

Au-quartz veins include syntectonic metamorphogenic low-gold veins and zones, which are the oldest occurrences and are related to areas of regional metamorphism, late syntectonic magmatogenic Au-quartz veins like the Karalveem deposit (Goryachev et.al.,1994), which are of the most commercial interest, and post-tectonic veins resulting from the overlying Okhotsk-Chukchi volcanic belt. The Au-quartz mineralization is Early

Cretaceous in age, and post-tectonic mineralization seems to have taken place during the Late Cretaceous (Goryachev et.al., 1994).

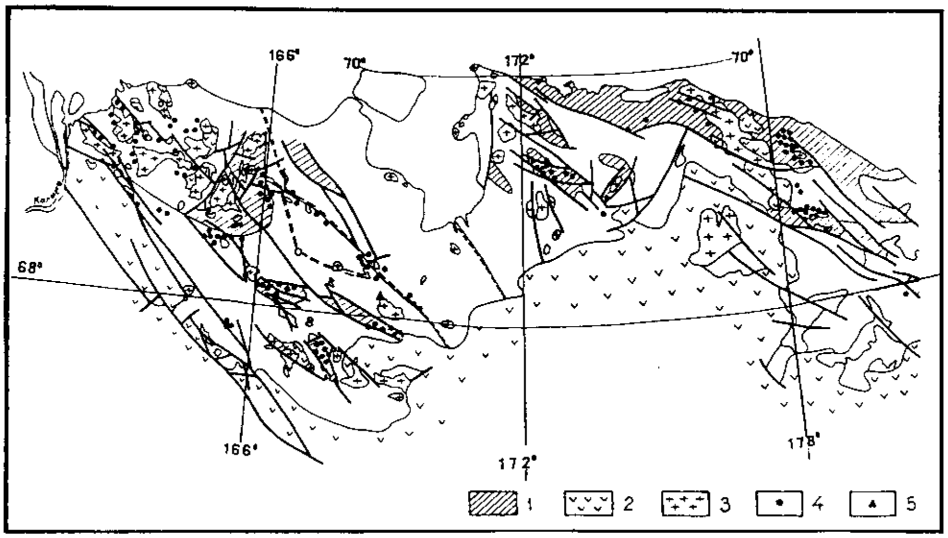

Fig.4. Schematic simplified map of the Chukotka Au-quartz belt.
1 - horst-anticlinal uplift with Paleozoic and early Mesozoic cores; 2 - late Mesozoic volcanic rocks; 3 - granitoid intrusions; 4 - Au-quartz vein deposits; 5 - Au-rare metal quartz vein deposits.

METALLOGENIC MODEL FOR AU QUARTZ BELTS

Au-quartz mineralization typical of all three metallogenic belts was closely related to the processes of metamorphism and granitoid magmatism caused by the accretionary and post-accretionary development of Mesozoic rocks. The gold occurrences of these belts have the following features in common: (1) a regular distribution of Au-quartz occurrences with regard to regional metamorphism and granitoid magmatic zones (see Figs. 2-4); (2) the same succession of processes of metamorphism, magmatism and Au-quartz mineralization in terms of interrelations (Goryachev, 1992; Goryachev et.al., 1994; Gamyanin and Goryachev, 1991), and also in absolute age dates (Firsov, 1985; Nenashev, 1979; Nenashev and Zaitsev, 1987). This succession is as follows: (1) regional dislocational metamorphism (the final folding stage); (2) metamorphic syntectonic Au-quartz veins; (3) regional-plutonic metamorphism, early orogenic I-type granitiods; (4) magmatic late syntectonic Au-quartz veins; (5) late orogenic (late collisional) I-type granitoids; (6) Au-rare metal quartz veins and tungsten deposits. All of these occurrences are overlain by post-accretionary granitoids and post-tectonic Au-quartz veins (Goryachev et.al., 1994).

Au-quartz veins of major lode belts have similar structural, mineralogic, and geochemical properties (Gamyanin, 1991; Goryachev, 1992; Goryachev et.al., 1994; Firsov, 1985), whereas non-contemporaneous veins are definitely different (Table 2). A general succession and separation of veins with regard to timing may serve as a basis to relate them to accretionary (collisional) and post-accretionary developmental stages in northeastern Asia.

A general geotectonic and metallogenic model of the formation of collisional Au-quartz lode belts is as follows: Late Jurassic to Early Cretaceous accretion of major tectonic blocks to the North Asia continental margin terminated with a set of collisional events. During the collisional cycles, the processes of folding and thrust-faulting were followed by regional metamorphism and the related formation of metamorphic Au-quartz veins. The formation of Au-quartz and Au-rare metal quartz mineralization are genetically related to the stage of granitoid intrusions. Au-rare metal quartz mineralization ended the collisional cycle.

CONCLUSION

The major Mesozoic Au-quartz belts in northeastern Asia formed due to the accretion of discrete blocks to the Siberian continental edge, as a result of the collision between the continental passive margin and microcontinents or large mosaic blocks (superterranes). These belts result from endogenic processes associated with collision, and their size depends upon the intensity of such processes. The formation of Au-quartz veins in northeastern Asia was closely related to an insignificant regional metamorphism and intense granite-forming processes there. They differ in this from gold-bearing belts of active continental margins, which were related to collision (Koons and Craw, 1991) or subduction processes (Kerrich and Wyman, 1990). These differences are due to a sialic continental crust in this area and the regional geodynamic environment corresponding to a single late Mesozoic collisional cycle, that was a result of the simultaneous movement of the Arctic and Pacific plates.

Table 2. Classification of Au-quartz vein deposits of the Northeastern Asia

Lode deposits types and ages	Host rocks	Metamorphism-related occurrences	Lode deposits structural-morphologic types	Magmatism-related occurrences	Sulphides (%)	Geochemical composition	Mineral deposit examples
Au-quartz metamorphogenic syntectonic (162-175 m.y.)	Permian and Carboniferous sandstones and shales, Ordovician limestones, Triassic and Jurassic terrigenous rocks	In areas of regional dislocational greenshist metamorphism	Mostly interlayer subconformable veins	Pre-granitoid	1 - 2	Au (As, Pb)	Duet, Yur, Finn, Nekur
Au-quartz magmatogenic late syntectonic (115-136 m.y.)	The Verkhoyan terrigenous complex (C_2-J_2), intermediate and felsic dikes and small intrusions (J_3- K_1)	In areas of regional plutonic greenschist-to-amphibolite metamorphism	Both interlayer (peaked) and cross-cutting veins and stockworks in sandstones and dikes	Associated with early orogenic I-type intrusions; post-dike	1 - 5	Au, As, Pb, Sb, (W)	Imtachan, Utin, Zhdannoye Svetloye, Karalveem, Yukhondzha, Nezhdanin Zaderzhnoye
Au-rare metal quartz magmatogenic late syntectonic (110-133 m.y.)	Hornfels after the Verkhoyan complex rocks, the apical portions of felsic intrusions (K_1)	In areas of contact metamorphism	Mostly complex cross-cutting veins and systems of veins and, more seldom, stockworks	Associated with late orogenic I-type granite intrusions	5- 10	Au, As, W, Bi, Te	Ergelyak, Levo-Dybin, Chistiye, Basugun'in, Kurum
Au quartz post-tectonic (less than 100 m.y.)	Permian, Triassic and Jurassic sandstones and shales, felsic and intermediate dikes and stocks (J_3-K_2)	Unrelated	Fault-feathering cross-cutting tabular veins and systems of veins	Associated with complexes of dikes and I-type granitoid small intrusions, post-orogenic (K_2)	1 - 5	Au, Ag, Sb, (Pb, As)	Shkol'noye, Sypuchee, Shurick, Ichuveem, Kysylga
Au-rare metal quartz post-tectonic (less than 100 m.y.)	Granite intrusions (K_2) and, less commonly, hornfels along the exocontact	In areas of contact metamorphism	Stockworks and lenticular veins in shear zones	Associated with Late Cretaceous granites	5 - 10	Au, Bi, Te, As	Pel'vuntykoinen, Khalali, Okhot-Kuhtui

* Dates from Nenashev, 1979 and Firsov, 1985.

The distribution of major Au-quartz belts is well-controlled by granitoid occurrences and bounded by compression zones, which define the collision front. Therefore, it seems valid to state that, in northeastern Asia, the widespread Au-quartz veins mark the collisional zones and do not occur outside of them.

The major Yana-Kolyma gold belt in northeastern Asia is related to the most significant and well-defined collisional zone, where I and S-type granitoids are the most widespread, and include two-mica peraluminous ones not found in other structures.

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