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Results of pilot Re–Os dating of sulfides from the Sukhoi Log and Olympiada orogenic gold deposits, Russia

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ABSTRACT

The pilot study with Re–Os dating of sulfides from Sukhoi Log and Olympiada gold deposits revealed early Paleozoic ages of the auriferous sulfides from the two largest orogenic gold systems in the Neoproterozoic orogens of the Baikalides framing the Siberian craton. The age-dating results indicate that gold mineralization is therefore epigenetic. The formation of the dated orogenic gold deposits is synchronous with some regional metamorphic events in the Baikalides, at least in case of the Sukhoi Log deposit. The metamorphic events occurred in the rear parts of the early Paleozoic magmatic arcs, where coeval subduction-related magmatism produced porphyry copper–(molybdenum) mineralization.

1. Introduction

Sukhoi Log and Olympiada are the two largest orogenic gold deposits in Eurasia and some of the largest in the world, with resources of 96 Moz Au (Migachev et al., 2008) and 60 Moz Au (Wardell Armstrong, 2011), respectively. Both deposits occur within the Neoproterozoic orogens at the southern and western periphery of the Siberian craton (Fig. 1; Yakubchuk et al., 2005).

The opinion on age of gold mineralization at Sukhoi Log is currently ranging from Neoproterozoic (Buryak, 1982; Buryak and Khmelevskaya, 1997) to middle Paleozoic (Goldfarb et al., 2001; Laverov et al., 2000). Rundqvist et al. (1992) and Laverov et al. (2000) showed that the main metamorphism is early Paleozoic (516 ± 22 Ma), whereas their Rb–Sr dating of quartz from Sukhoi Log gave a middle Paleozoic (320 ± 16 Ma) age. Dating of granitoids (Rundqvist et al., 1992) and alteration (Goldfarb et al., 2001) revealed an age for both of 370–350 Ma. These ages are similar to the age of the large Barguzin batholiths, occupying most of Transbaikalia (Kuz'min et al., 2006).

At the Olympiada deposit in the Yenisei Ridge, previous attempts to date the mineralization employed K–Ar and Rb–Sr techniques. Novozhilov and Gavrilov (1999) dated muscovite from quartz-vein selvages of the earliest (pre-ore) alteration as 890 to 842 Ma (K–Ar ages). However, the sericite–quartz–carbonate altered rocks yielded ages of 794 ± 15 Ma (Rb–Sr) for early hydrothermal alteration, and 615 ± 15 Ma for late stage events (Novozhilov and Gavrilov, 1999). Serdyuk (2002) reported 754, 765, 811 Ma ages based on K–Ar data. The results of dating using the K–Ar and Rb–Sr methods appear to be controversial. These dates are complemented by similar Neoproterozoic estimates for some smaller Sb–Au deposits nearby (Distanov et al., 1975; Novozhilov and Gavrilov, 1999), generally believed to be 847 to 605 Ma old (Sazonov et al., 2010). The age of >3 Moz Sovetskoye orogenic gold deposit, another large deposit in the Yenisei Ridge, is constrained based on $^{40}Ar–^{39}Ar$ data on 900–850 Ma metamorphic slate micas and 830–820 Ma to 730–720 Ma for ore-related metasomatism (Tomilenko et al., 2008).

These uncertainties are a critical problem when attempting to establish a genetic model for the deposits and, specifically, in determining how mineralization relates to regional tectono-magmatic evolution. In order to resolve some of the uncertainties of the previous geochronological work, we collected samples from Sukhoi Log and Olympiada gold deposits to assess whether the Re–Os technique could provide a more robust estimate of age of mineralization (e.g., Stein et al., 2000). Sulfides are principal hosts of gold and are considered to be coeval with gold at Sukhoi Log (Buryak, 1982) and Olympiada (Genkin et al., 1994). This provides an opportunity of direct dating the mineral event. However, several generations of sulfides have been reported for both deposits (Buryak, 1982; Distler et al., 2004; Genkin et al., 1994; Large et al., 2007; Novozhilov and Gavrilov, 1999), suggesting a potentially complex isotopic history.

2. Geological setting

2.1. Sukhoi Log deposit

The Sukhoi Log deposit is hosted within the more than 15,000-m-thick deformed and metamorphosed Meso- to Neoproterozoic passive

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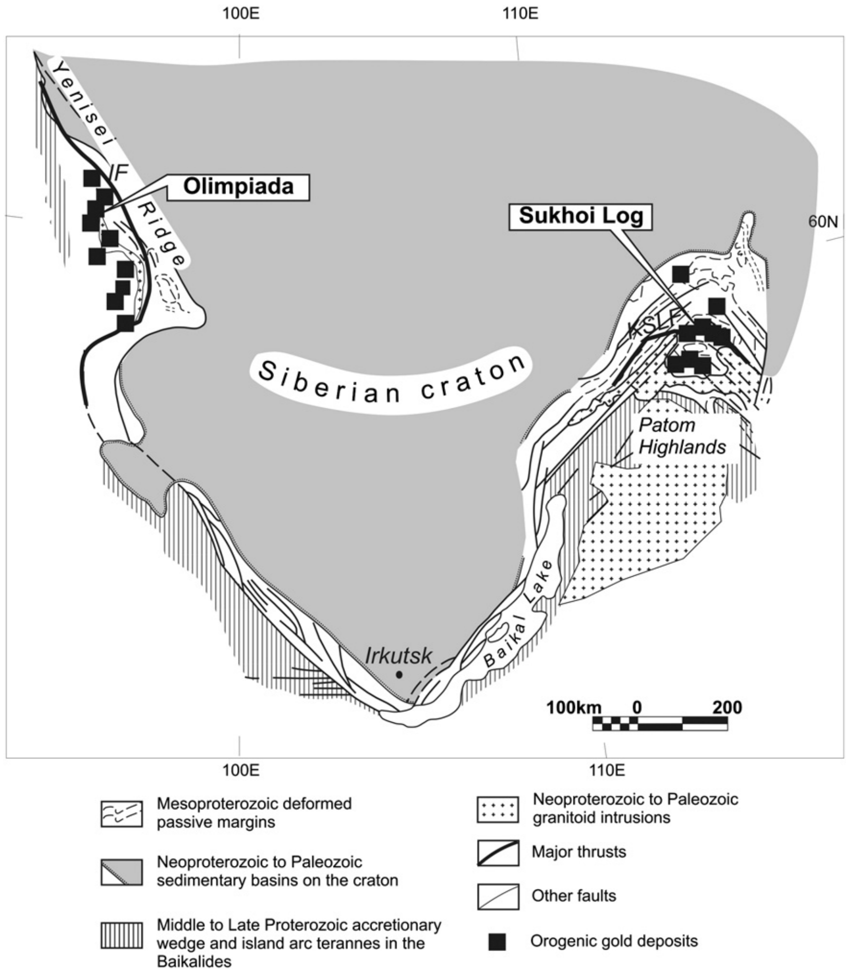

Fig. 1. Position of the Sukhoi Log and Olympiada orogenic gold deposits in the Neoproterozoic orogens of the Patom Highlands and Yenisei Ridge relative to the Siberian craton (modified after Yakubchuk et al., 2005). IF—Ishimba fault, KSLF—Kadali–Sukhoi Log fault.

margin rock sequences in the Patom Highlands (Buryak, 1982; Buryak and Khmelevskaya, 1997; Distler et al., 2004). Lithologically, gold mineralization of Sukhoi Log occurs within carbonaceous shales (Khomolkho Formation), part of the 1500-m-thick carbonate–shale sequence of the Nigry Group (Distler et al., 2004), forming most of the Chuya–Tonoda anticlinorium whose core occurs several dozen kilometers to the north of the deposit towards the Siberian craton. In the core of the anticlinorium is the exposed Paleoproterozoic basement (Buryak and Khmelevskaya, 1997).

The Nigry Group package is overturned to the south and thrust along the Kadali–Sukhoi Log fault onto the 2500-m-thick predominantly clastic-shale sequence of the Bodaibo Group, part of the Mama–Bodaibo synclinorium (Fig. 2A), suggesting that the Kadali–Sukhoi Log fault zone can be viewed as a major structural divide in the Patom Highlands. The fault zone also seems to control position of the middle Paleozoic granitoids of the Konkuder–Mamakan Complex that intruded the already deformed package (Rundqvist et al., 1992). Near Sukhoi Log, it is represented by the Konstantinovskiy stock, exposed just 6 km southwest of the deposit (Fig. 2B). On the basis of the geophysical data, it is interpreted as an exposed part of the larger and deeper intrusion (Distler et al., 2004).

At the deposit level, the shales of the Khomolkho Formation, sandwiched between otherwise marble–carbonate formations of the Nigry Group, form a parasitic anticlinal fold on the southern limb of the Chuya–Tonoda anticlinorium. Locally, gold mineralization outcrops as the discrete Zapadnoye and Sukhoi Log orebodies (Fig. 2C), which however merge at depth. Within the anticlinal fold, gold distribution is controlled by an axial cleavage (Fig. 2C, D).

Owing to the complex geological history, Buryak (1982) proposed that the Sukhoi Log deposit has a metamorphogenic origin, with remobilization of auriferous fluids from syngenetic sulfides and their entrapment into the anticlines. Buryak (1982) and Buryak and Khmelevskaya (1997) recognized the earliest sulfides at Sukhoi Log as syngenetic. Syngenetic sulfides were partly to completely recrystallized in the ore zones, often with fibrous-columnar quartz pressure-fringes during metamorphism. The post-metamorphic mineralization in the form of quartz and quartz–calcite veinlets was proposed to link genetically with the Konstantinovskiy stock, as part of a third introduction (or remobilization) of gold into steeper-dipping Au–quartz veins and additional recrystallization of cleavage-controlled disseminated sulfide minerals.

Buryak's three main sulfide events were confirmed by Large et al. (2007), who, however, identified six sulfide phases, further subdividing the three phases of Buryak (1982).

2.2. Olympiada deposit

The Olympiada gold deposit also occurs within the Neoproterozoic (Late Riphean) quartz–mica carbonaceous schists, but in the Yenisei Ridge on the western flank of the Siberian craton (Fig. 3A). In its west is the Isakov island arc terrane (700–630 Ma), which is tectonically transposed eastward along the Yenisei thrust fault onto the Central Angara terrane (Vernikovsky et al., 2003). The latter consists of the Ribnaya–Panimba ophiolite belt in the east, with 1050–900 Ma Ar–Ar ages of amphibole and plagioclase from gabbro–amphibolite. This is inferred to reflect the time of their accretion to the Siberian craton

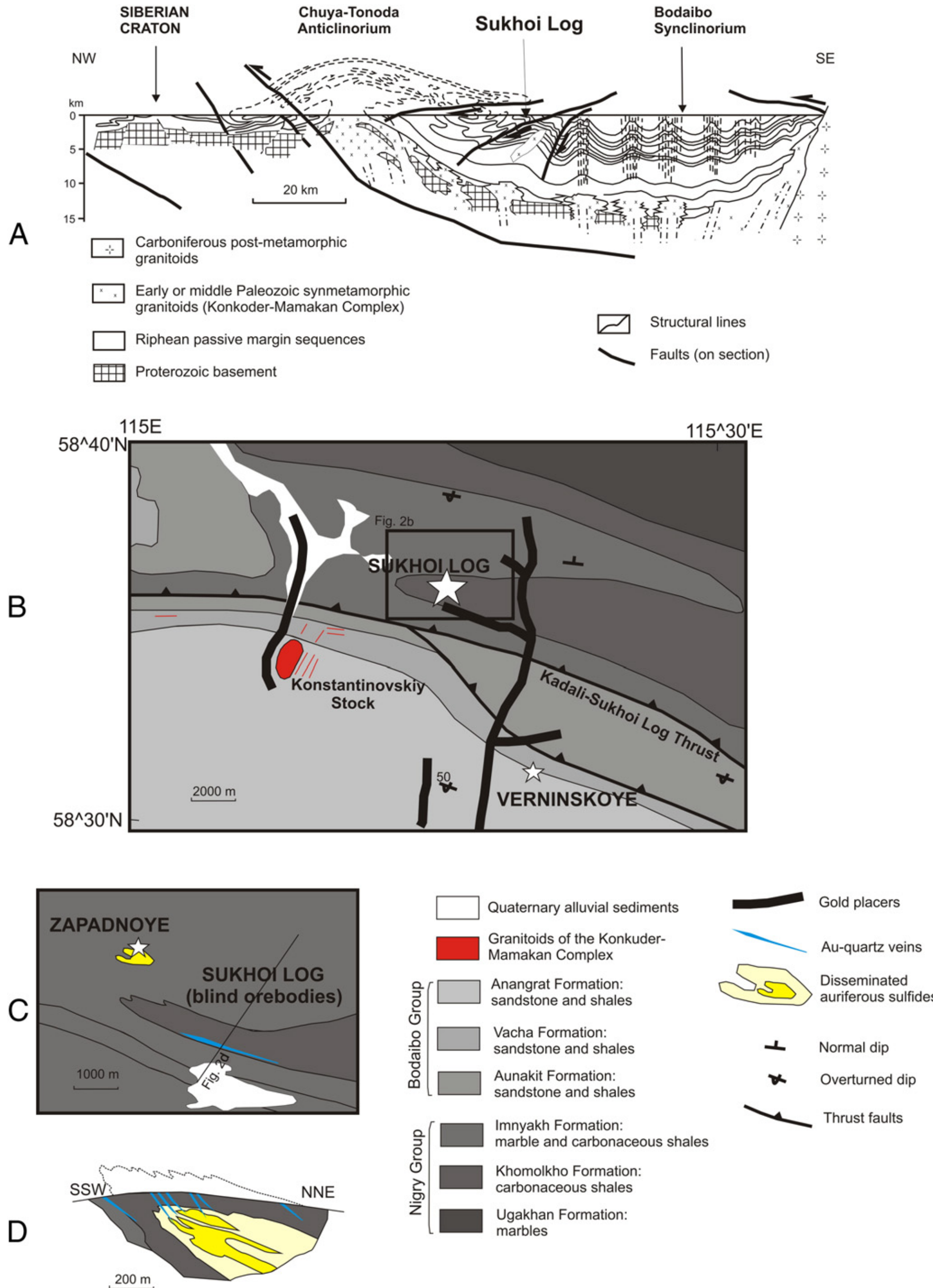

Fig. 2. Schematic cross-section of the Patom Highlands (A) modified after Yakubchuk et al. (2005). Geological map (B), orebodies (C) and cross-section (D) of the Sukhoi Log deposit (simplified after Buryak and Khmelevskaya, 1997). Stars on Fig. 2B show location of the Sukhoi Log and Verninskoye gold deposits. Star on Fig. 2C shows location of the samples AW07-001 and AW07-002 for this study.

(Vernikovsky et al., 2003). In other words, their age is not younger than 1000 Ma. The bulk of the Central Angara terrane consists of Neoproterozoic shale, carbonate and mollase sequences, all intruded by the post- or late-metamorphic granites of the Tatarka–Ayakhta complex. This complex was previously dated as 850 Ma (Nozhkin et al., 1999; Volobuev, 1993), but more recent zircon dating of Chirimba granite, located just 2 km from the Olympiada deposit, revealed the 720–760 Ma age (Vernikovskaya et al., 2002). These granites were followed by emplacement of small 710–690 Ma (Romanova et al., 2012) and 640–680 Ma alkaline mafic and ultramafic intrusions, as well as 620–625 Ma alkaline granitoids (Vernikovskaya et al., 2007).

The Central Angara terrane is thrust eastward along the Ishimba fault onto the East Angara terrane, also consisting of the Neoproterozoic sequences, but with greater role of the carbonates and complete absence of Neoproterozoic granites. The East Angara terrane can be therefore viewed as part of the Siberian craton. Its continuation to the south of the River Angara can be correlated with the Kan terrane, consisting of Paleoproterozoic metamorphic rocks, representing the exposed basement of the Siberian craton (Vernikovskaya et al., 2004).

The continuation of the Ishimba fault south of the River Angara can be proposed between the Neoproterozoic Predivinskiy island arc terrane and the Kan terrane. However, the Predivinskiy terrane is considered as equivalent of the Isakov terrane in the north of the Yenisei Ridge, and therefore the equivalents of the Central Angara terrane are absent in the south of the Yenisei Ridge. In this part of the ridge, Vernikovskaya et al. (2004) revealed 455 to 510 Ma zircons in the Posolnenskiy and

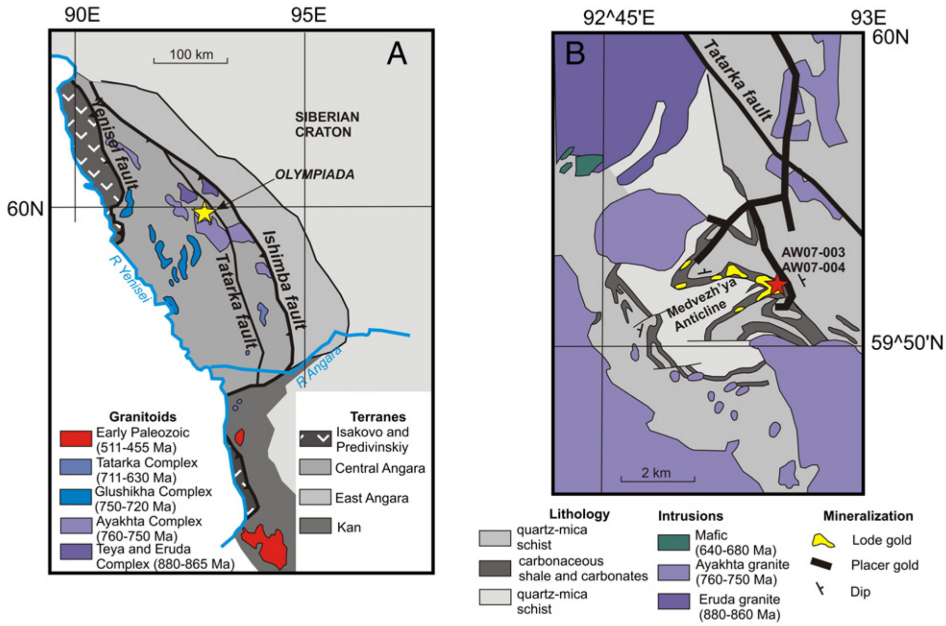

Fig. 3. (A) Tectonic scheme of the Yenisei Ridge (Vernikovsky et al., 2003) and (B) geological map of the Olympiada deposit (simplified after Kruglov and Li, from Serdyuk, 2002) showing collection points of AW07-003 and AW07-004 samples. Note preferential setting of lode gold mineralization in the carbonaceous shale.

Nizhnekansk granitoid massifs in the immediate vicinity to the proposed continuation of the Ishimba fault, apparently postdating the suturing. Regional geological maps of the Yenisei Ridge show that the northwest-trending regional faults offset the Neoproterozoic granitoid intrusions, unconformably lying Cambrian carbonates, and even Ordovician to Carboniferous overlap assemblages, indicating active post-metamorphic tectonic history of the Yenisei Ridge. Some of the recumbent folds can be considered as paragenetic structural assemblages with the regional faults, which postdate the youngest recorded (Neoproterozoic) igneous events.

The Ishimba fault must be therefore viewed as a major structural divide in the Yenisei Ridge. Interestingly, almost all gold deposits of the Yenisei Ridge occur on the western limb of this fault and also along the Tatarka fault to the west, which reveals some evidence of westward thrusting (Fig. 3A).

In the Olympiada camp, the gold mineralization does not seem to be in direct contact with the granitoid intrusions, although they outcrop just 2 km from the deposit (Fig. 3B) and hence genetic links have been proposed (Serdyuk, 2002). The host rocks are quartz–mica–carbonate schists, comprising the northwest-trending linear folds. The rocks have undergone intricate and numerous metamorphic transformations, including both prograde and retrograde regional metamorphism, as well as contact metamorphism and hydrothermal alteration. Regional prograde metamorphism is related to the biotite stage of the greenschist facies, but close to the granites the metamorphism reaches the epidote–amphibolite facies. Retrograde metamorphism is observed along faults, and is expressed by replacement of high temperature paragenetic assemblages with chlorite and sericite.

The linear folds are additionally deformed into the recumbent cleavage folds of west–east strike, with cleavage of the Medvezh'ya Anticline controlling the disseminated gold-bearing metasomatic sulfide minerals (Wardell Armstrong, 2011), mainly arsenopyrite, pyrite, antimonite and pyrrhotite. It cannot be excluded that the recumbent folding can be structurally related to the movements along the Tatarka fault, located just 3 km east from the closure of the Medvezh'ya Anticline that hosts the Olympiada deposit. Genkin et al. (1994) identified several paragenetically distinct generations of fine-grained sulfide with complex intergrowth, whose separation in time is unknown.

3. Sample description, sample preparation and methodology

3.1. Sukhoi Log samples

The Sukhoi Log samples were collected during site visits by the principal author from the Zapadnoye open pit (Fig. 2B). Pyrite is hosted by greenschist facies, fine-grained, chlorite-rich phyllite derived from organic-rich carbonaceous shale. The pyrite is coarse-grained with cubic euhedral form, and smaller grains are subhedral, enclosed in bedding parallel, vein-like lenses and aggregates of carbonate (Fig. 4). Microscopic study showed that coarse, euhedral to subhedral pyrite (up to 6 mm across) is narrowly rimmed by fibrous quartz and chlorite, with associated finer grained vein. The pyrite contains small inclusions of pyrrhotite and occasionally chalcopyrite. Finer grained, irregularly-shaped bodies of pyrrhotite, with intergrown pyrite, chalcopyrite and rare sphalerite, occur adjacent to the coarse pyrite euhedra. Rare flames of pentlandite were observed in the pyrrhotite.

The studied pyrite occurs in knobby quartz veins that pinch and swell along the cleavage. Rather than quartz as strain fringes, the quartz–pyrite forms boudinaged veins or porphyroblastic clots, interpreted to be syndeformational. According to the classification of pyrites presented in Large et al. (2007), it is likely that they represent Py_4 and Py_5 generations, formed during the metamorphic event of Buryak (1982). Py_4 commonly exhibits quartz strain fringes, which become more pronounced in the strongly deformed zones of the ore body.

For dating, samples of the Sukhoi Log sulfide were obtained by drilling out several hundred milligrams of material, targeting what appear to be homogeneous sulfide crystals of a single event. Given the observations of Large et al. (2007), it is possible that we obtained mixtures of pyrite generations. Nonetheless, if generations were only briefly separated in time, this may not be critical.

3.2. Olympiada samples

Samples from Olympiada (Fig. 5) are quartz–carbonate–mica schist (AW07-003). Schistosity in the host rock is defined by crystallographically aligned concentrations of sericite occurring throughout a fine grained (averaging 0.065 mm across), granoblastic mass of carbonate and quartz. Accessory rutile occurs throughout the schistose masses. Subparallel, elongate bodies of interstitial pyrrhotite, measuring up to

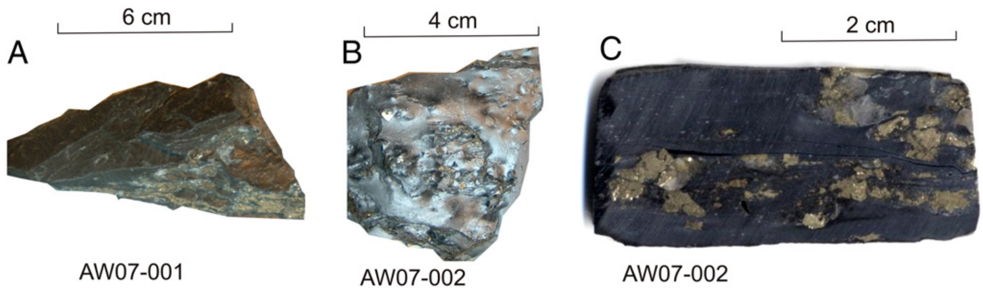

Fig. 4. Samples of studied phyllites from the Zapadnoye orebody of the Sukhoi Log deposit. Coarse pyrite crystals can be seen in AW07-001 (A). Metamorphic foliation and cubic pyrite can be seen in AW07-002 (B) and its polished section (C).

0.6 mm in length and rimmed by fine flakes of chlorite, lie within the foliation. Pyrrhotite occurs as massive clots in irregular and discontinuous quartz veins. The foliation is cut by a coarse grained, vein-like body of quartz, carbonate, pyrrhotite and sphalerite, containing minor stibnite, pyrite and chalcopyrite. Pyrrhotite is always associated with clear, secondary quartz. Coarse grained sphalerite, minor stibnite and rare chalcopyrite are peripherally intergrown with pyrrhotite. The sample does not contain arsenopyrite, which is a common ore mineral in the deposit. This mineral assemblage reflects the retrograde alteration of pre-existing higher grade metamorphic schist.

Sample AW07-004 is more quartzose schist, which reflects flooding by hydrothermal quartz and pyrrhotite. Pyrrhotite is disseminated as 0.5 mm or smaller crystals.

Pyrrhotite was extracted from these samples by drilling under a high-power binocular scope. It is possible that some quantities of micron-sized arsenopyrite and pyrite were present in the extracted pyrrhotite. A magnet covered with Kim wipe was used in an attempt to eliminate any non-magnetic grains of pyrite and arsenopyrite.

The sulfide samples were equilibrated with single ^{185}Re and ^{190}Os spikes using a Carius tube digestion. Re–Os analysis was performed at the Colorado State University at Fort Collins, USA. Four separate analyses from the two samples were conducted (Table 1). Blanks were carefully monitored throughout the study.

4. Results

Results are presented in Table 1. Normally, for a pilot study, a couple of samples is analyzed, expected to be LLHR (low level, highly radiogenic; Stein et al., 2000), yielding a single mineral age on much the same principle as molybdenite.

The Sukhoi Log and Olympiada samples have notable common osmium; and, as a result, selection of the initial ratio has a profound effect on the calculated age. Samples from both deposits had similar and easily measurable Re and Os concentrations at the hundreds of ppb and tens of ppt levels, respectively. It is also important to have some knowledge of the initial Os ratio given that the mineralization is hosted in black shale. While marine shales do vary with the isotopic composition of seawater through geologic time, it would be very reasonable to assume an initial Os of 0.6 to 1.0 if the origin of the metals is assumed to be directly associated with the black shale.

4.1. Sukhoi Log deposit

Table 1 shows results of five separate analyses from the two pyrite-bearing Sukhoi Log samples (AW07-001 and AW07-002). As generally happens on the first try, the first run was poorly spiked, but nevertheless supports the results from the subsequent four runs. There were no issues with Re and Os levels and mass spectrometric measurements.

As expected, the obtained Re–Os data reflect complexities of six generations of syngenetic, diagenetic, and metamorphic pyrite at Sukhoi Log (Large et al., 2007). Three very poorly constrained regressions suggest an age for the Re–Os systematics between 590 and 470 Ma, with very large overlapping errors. The initial Os ratios derived from the regressions suggest a value of 0.6 to 0.8, again with very large uncertainties. The younger age (480 Ma) has the higher initial ratio (0.8) which would make sense if the metals were “reworked” and “upgraded” under near in situ conditions.

For AW07-001, two runs agree, even though the first was very overspiked (LL-404). If we assume an initial Os ratio of 0.65, then the age for this sample converges on 493 ± 27 (LL-404) and 500 ± 29 Ma (LL-414). Assumption of higher initial Os ratios drives the age lower, including late Paleozoic ages when the assumed initial ratio reaches 0.8–0.9. However, if plutonism is a factor, depending on its source, it is more likely that the initial ratio might be lower than 0.6, not higher.

For AW07-002, three runs from three different mineral separates have yielded moderately good agreement. The initial Os ratio, where the ages for the three runs converge, is 0.75. In this case, the ages are 508 ± 33 (LL-415), 477 ± 20 (LL-423), and 505 ± 19 (LL-424) Ma. To illustrate the sensitivity of the initial ratio assumption, the age for LL-423 moves from 477 to 524 Ma with a shift in the initial ratio from 0.75 to 0.70.

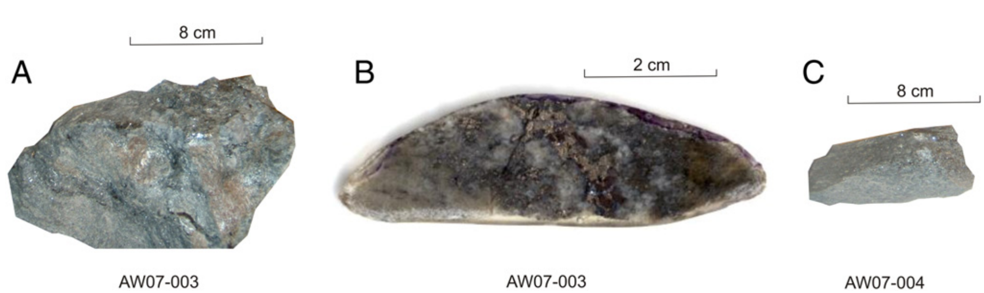

Fig. 5. Olympiada deposit. Samples of studied AW07-003 quartz–carbonate–mica schist (A) and its polished section (B). Quartz–mica schist of AW07-004 (C). Both samples were collected from the main pit of the deposit.

Table 1
Re–Os data for Sukhoi Log and Olympiada gold deposits, southern Siberia, Russia.

AIRIE run #	Sample, mineral, replicate	Re, ppb	Os, ppb	$^{187}Re/^{188}Os$	$^{187}Os/^{188}Os$	^{192}Os, ppb	Sam Wt (mg)
Sukhoi Log							
LL-404	AW007-001, Pyrite, A	0.298 (12)	0.0353 (2)	45.5 (1.6)	1.025 (3)	0.0033	0.15678
LL-414	AW007-001, Pyrite, B	0.269 (1)	0.0353 (2)	40.9 (2)	0.992 (4)	0.0106	0.50176
LL-415	AW007-002, Pyrite, A	0.475 (1)	0.0726 (4)	35.3 (1)	1.051 (4)	0.0216	0.50296
LL-423	AW007-002, Pyrite, B	0.447 (6)	0.0395 (3)	62.5 (8)	1.248 (5)	0.0118	0.51662
LL-424	AW007-002, Pyrite, C	0.469 (4)	0.0412 (3)	63.1 (5)	1.283 (5)	0.0123	0.51807
Olympiada							
LL-405	AW007-003, Pyrrhotite, A	0.596 (4)	0.0528 (4)	72.1 (5)	2.615 (6)	0.0055	0.20648
LL-416	AW007-003, Pyrrhotite, B	0.752 (2)	0.0939 (6)	52.0 (2)	2.79 (1)	0.0237	0.51222
LL-417	AW007-004, Pyrrhotite, A	0.269 (1)	0.0295 (2)	48.7 (2)	0.966 (4)	0.0043	0.24508
LL-425	AW007-004, Pyrrhotite, B	0.212 (1)	0.0377 (3)	29.5 (2)	0.803 (4)	0.0132	0.57366

Runs LL-404 and LL-405 were poorly spiked.
All runs represent uniquely drilled mineral separates.
For AW007-004, both separates had 20–30% silicates.
Common Os component indicated by ^{192}Os (ppb).
Carius tube digestion using single ^{185}Re and ^{190}Os spikes.
For all runs, Re blank = 9.07 ± 0.05 pg, Os blank = 0.267 ± 0.001 pg, and $^{187}Os/^{188}Os$ blank composition = 0.127 ± 0.002.

4.2. Olympiada deposit

For AW07-003, the first run was overspiked (LL-405; Table 1), but a repeat analysis with correct spiking (LL-416; Table 1) still yielded ages that were unreasonably old (scattered in the Paleoproterozoic). This is a clear evidence that either the Re–Os systematics are disturbed beyond the volume of the mineral separate that we extracted, or we are dealing with more than one generation of sulfide and the generations formed at distinctly different times. Also, the somewhat different Re and Os concentrations for the two runs support a more complex history than observed at the hand-specimen scale.

For AW07-004, we had moderately good results. We analyzed this sample twice (LL-417 and LL-425; Table 1) obtaining fairly similar Re and Os concentrations for both runs. The lower Re contents, relative to AW07-003, reflect 20–30% silicate in the drilled pyrrhotite separate. As in Sukhoi Log, a strong component of common Os in the sample means that the calculated age is highly dependent on the selection of the initial ratio. The Os initial ratio, where the ages agree for this sample, is 0.55, which provides imprecise model ages of 511 ± 24 (LL-417) and 513 ± 40 (LL-425) Ma.

5. Discussion

5.1. Age of Sukhoi Log gold mineralization

Our results suggest that the metamorphogenic mineralization at Sukhoi Log was formed between 470 and 508 Ma. Somewhat close results were received by Meffre et al. (2008) using the LA-ICPMS age determinations for the cores of large monazite crystals at this deposit, which predate obvious tectonic fabric development in the host rocks and began growing at 573 ± 12 Ma. The U, Th and Pb isotopic systematics indicate the rims of the same monazite crystals formed at 516 ± 10 Ma (Meffre et al., 2008), during peak metamorphism and deformation, e.g., very close to our Re–Os dates.

Regionally, this and our ages are only slightly older than the 470 Ma metamorphic event recorded at Sukhoi Log (Rytsk et al., 2001) and 480–468 Ma metamorphic ages obtained in the nearby Baikal–Muya region, immediately southeast from the Patom Highlands (Rytsk et al., 2009). Furthermore, the regional metamorphism in the Baikalide orogen on the island of Olkhon at lake Baikal, to the southwest of the Patom Highlands, was dated at 500–460 Ma by Donskaya et al. (2000) and then at 507 to 473 Ma by Gladkochub et al. (2008), defining peak metamorphism at 507 to 498 Ma, principally overlapping with our Re–Os data. This event seems to be part of longer metamorphic event in the suture zone between the Siberian craton and the Barguzin terrane, defined by Zhmodik et al. (2006) as 550–490 Ma. Rytsk et al. (2009) concluded that the Early Ordovician was an epoch of collision involving Late Riphean juvenile crust.

We therefore conclude that there is a growing evidence, supporting a possibility of the early Paleozoic age of Sukhoi Log. The above-mentioned late Paleozoic ages are likely to be due to a younger overprint, possibly related to the emplacement of the giant late Paleozoic Barguzin batholith (Kuz'min et al., 2006).

5.2. Age of Olympiada gold mineralization

Our early Paleozoic sulfide dates from Olympiada are much younger than previous age estimates. The nearest dated coeval 455 to 510 Ma granitoids occur some 300 km to the south from Olympiada (Vernikovskaya et al., 2004). However, they may be also controlled by the Ishimba–Tatarka fault system (Fig. 3A). It is therefore possible that the mineralization at Olympiada, while not related to the documented magmatic events near the deposit itself, may be related to post-collisional structural events, such as post-intrusive strike–slip or thrust faulting.

Obviously, a much more thorough dating of the other gold deposits in the Yenisei Ridge is necessary.

5.3. Implications for regional tectonic setting

This pilot study of sulfides from the Sukhoi Log and Olympiada gold deposits revealed different than previously reported ages for these orogenic gold deposits, indicating their epigenetic nature, most likely unrelated to the Neoproterozoic orogenic events in the Baikalides. Instead, they seem to represent a Cambrian to Early Ordovician superimposed event, which is also coeval with formation of the Zun–Kholba orogenic gold deposit at 480–440 Ma at the southern tip of the Siberian craton (Goldfarb et al., 2014; Yakubchuk et al., 2005).

The most obvious correlation of the pilot Re–Os ages can be drawn to the metamorphic events in Transbaikalia for the Sukhoi Log gold deposit and, with lesser certainty, to the post-metamorphic events in the Yenisei Ridge for the Olympiada deposit. In case of Sukhoi Log and Zun–Kholba deposits, the early Paleozoic ages can be correlated with the metamorphic event in the suture zone between the Siberian craton and the Barguzin terrane, extending for 1200 km from the southern tip of the Siberian craton to the Patom Highlands (Donskaya et al., 2000; Fedorovsky et al., 1995; Gladkochub et al., 2008). This suture zone and gold deposits occur in the rear part to the nearest coeval early Paleozoic subduction-related magmatic arcs in Central Mongolia (Fig. 6). Similar correlation can be drawn for the Yenisei Ridge relative to the Altai–Sayan area (Fig. 7).

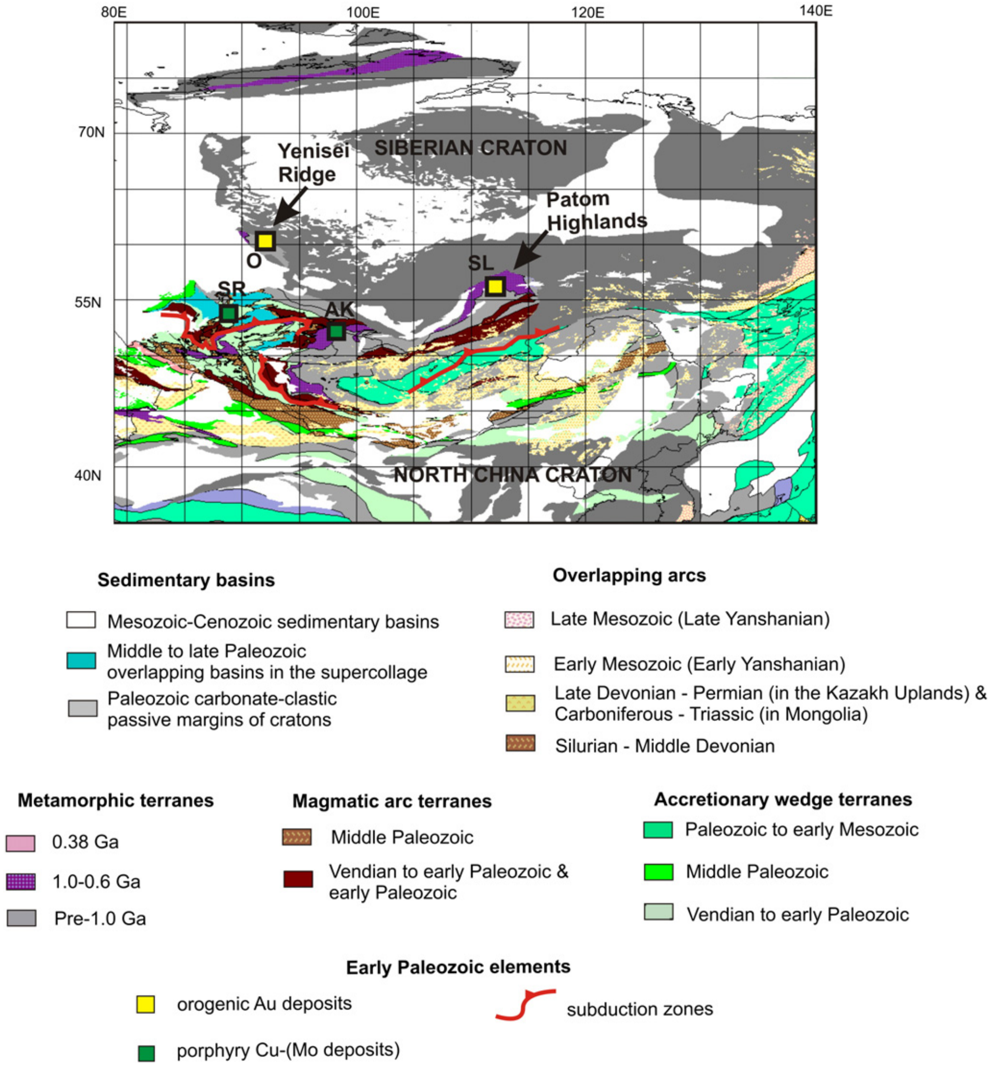

Fig. 6. Terranes of the Central Asian supercollage on the southern periphery of the Siberian craton, Orogenic gold deposits: O—Olympiada, SL—Sukhoi Log. Porphyry copper–(molybdenum) deposits: AK—Aksug, SR—Sora.

The new ages suggest that both Sukhoi Log and Olympiada deposits do not reveal any genetic relation to the accretionary wedges in the frontal parts of the magmatic arcs in the Baikalides, as proposed elsewhere in the orogenic gold deposit models (Groves et al., 2003). Instead, they seem to be epigenetic. The orogenic gold deposits are broadly coeval with some early Paleozoic porphyry Cu–(Mo) deposits of Aksug and Sora (Berzina et al., 2003; Yakubchuk et al., 2012) in the early Paleozoic magmatic arcs in the Altai–Sayan area inside the Central Asian supercollage. The porphyries occur some 500 to 600 km away from the Baikalide orogen and the margin of the Siberian craton, being close in age with numerous granitoid intrusions (Vladimirov et al., 2008), scattered across the Altai–Sayan area (Fig. 6).

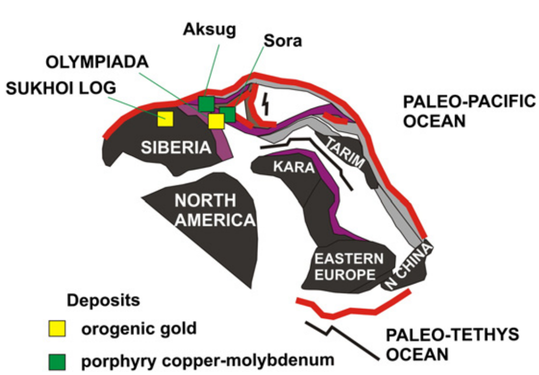

Fig. 7. Early Paleozoic reconstruction and position of the porphyry copper and orogenic gold deposits in the Siberian craton and adjacent Central Asian supercollage (modified after Yakubchuk et al., 2012).

6. Conclusions

The new Re–Os age data for sulfides from the Sukhoi Log and Olympiada orogenic gold deposits should be seen as preliminary. Reasonable assumptions have been made to acquire these data. With a larger, targeted and generation-confined sample suite, the assumptions would be reduced or even disappear. Since the $^{187}Re/^{188}Os$ ratios are not particularly high, the initial Os ratio could be constrained by a well-formed isochron. This pilot study revealed that there is plenty of Re and Os for the measurements and, not surprisingly, that analyzing paragenetically constrained samples is critically important.

The obtained early Paleozoic ages of the sulfides from the two largest orogenic gold deposits in the Baikalides indicate that their mineralization is epigenetic and can be correlated with the early Paleozoic metamorphic event around the Siberian craton (Donskaya et al., 2000; Fedorovsky et al., 1995; Rytsk et al., 2009; Sukhorukov et al., 2005; Zhmodik et al., 2006). The synchronism with some regional metamorphic events, at least in case of the Sukhoi Log deposit, which took place in the rear of the adjacent early Paleozoic magmatic arcs, as well as synchronism with porphyry deposits of Aksug and Sora (Berzina et al., 2003), suggests formation of the Sukhoi Log, Olympiada and Zun–Kholba orogenic gold deposits in the rear of the early Paleozoic magmatic arcs.

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