Platinum-group minerals from alluvial placer of the Kitoy river (East Sayan, Russia)

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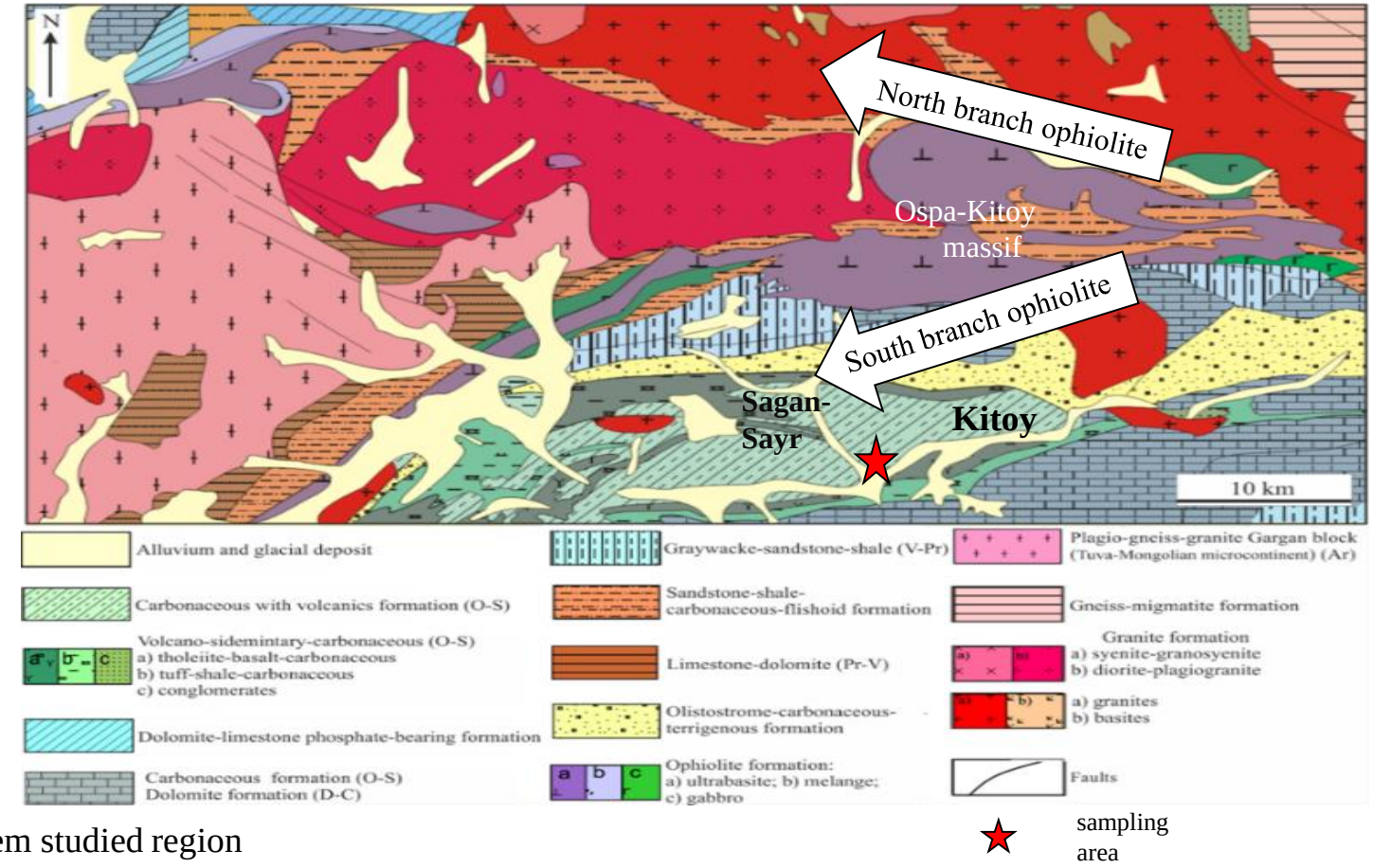

Figure 1. Geological chem studied region

The studied platinum group minerals were taken (or extracted) from the alluvial deposits of the right bank of the Kitoy River, 10 km below the mouth of the Sagan-Sayr River. The Sagan-Sayr River, with all its temporary tributaries, crosses the largest Ospa-Kitoy ophiolite massif in the Eastern Sayan.

Platinum group assemblage of the south-east part Eastern Sayan region

Chromitite south branch of the Ospa-Kitoy massif

Chromitite north branch of the Ospa-Kitoy massif

Kitoy alluvial placer

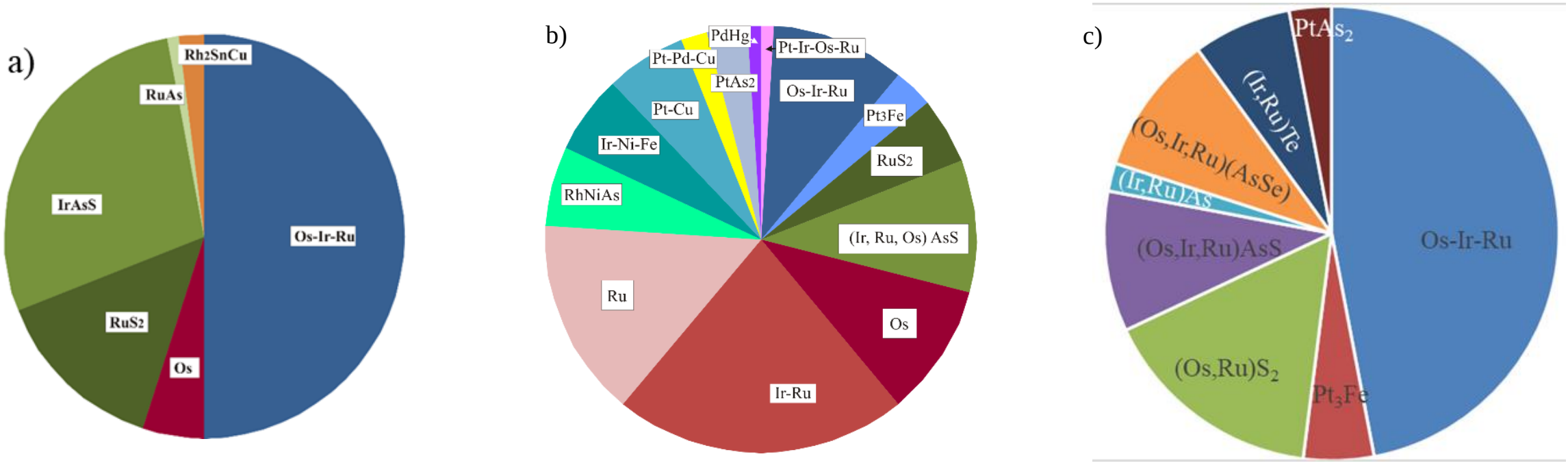

Figure 2. PGE assemblage from: a) chromitites south branch of the Ospa-Kitoy massif, b) chromitites north of the Ospa-Kitoy massif, c) Kitoy alluvial placer.

The platinum group minerals are mainly represented by magmatic high-temperature Os-Ir-Ru alloys, sulfides, sulfoarsenides, arsenselenides in the Os-Ir-Ru system. The mineral assemblage is identical to the mineral associations from the chromitites of the Ospa-Kitoy ophiolite massif.

Chemical composition and BSE images of the Os-Ir-Ru alloys

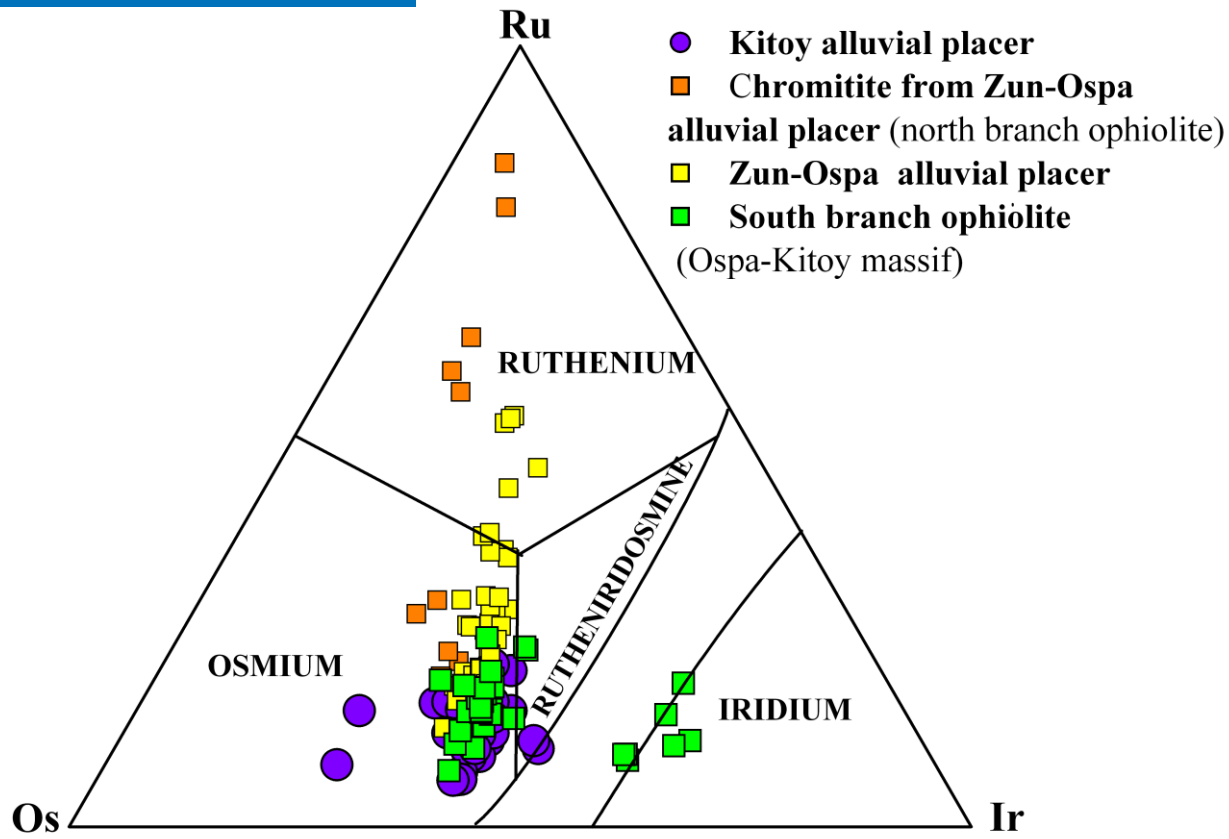

Figure 3. Diagram of the composition of Os-Ir-Ru alloys from alluvial placer and podiform chromitites from the Ospa-Kitoy massif

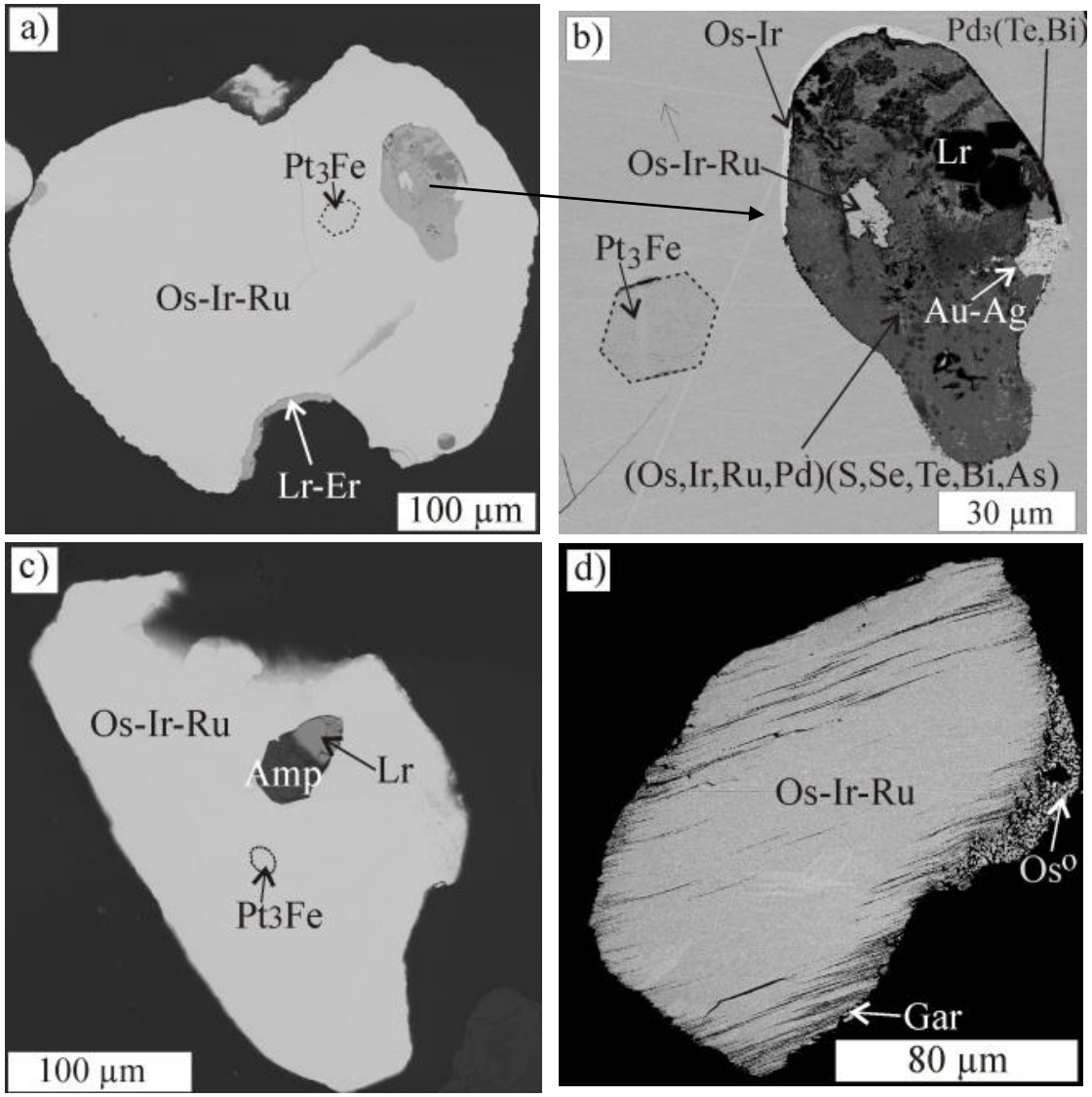

Figure 4. BSE images of the platinum group minerals from the Kitoy alluvial placer

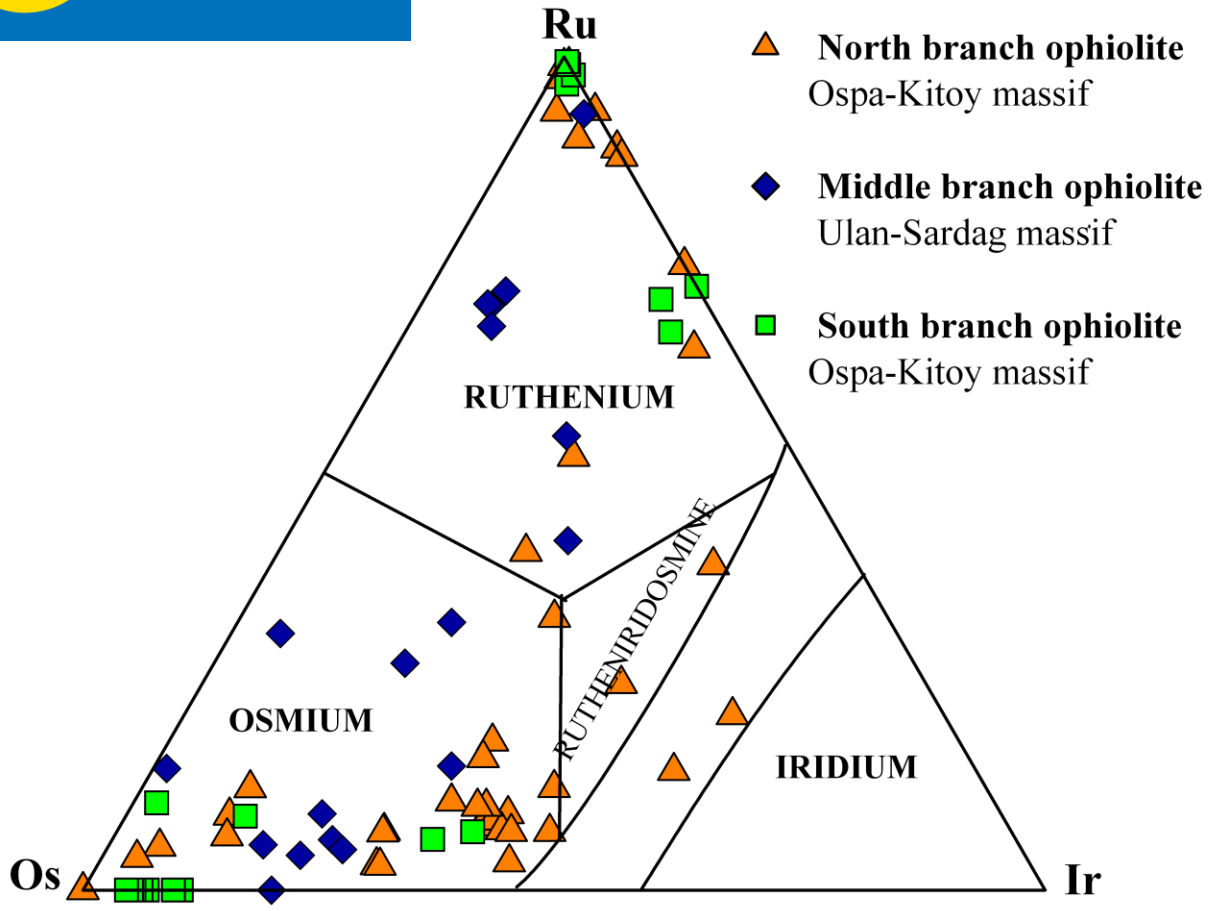

Figure 5. Diagram of the composition of Os-Ir-Ru alloys from the podiform chromitites north, middle and south ophiolite branches

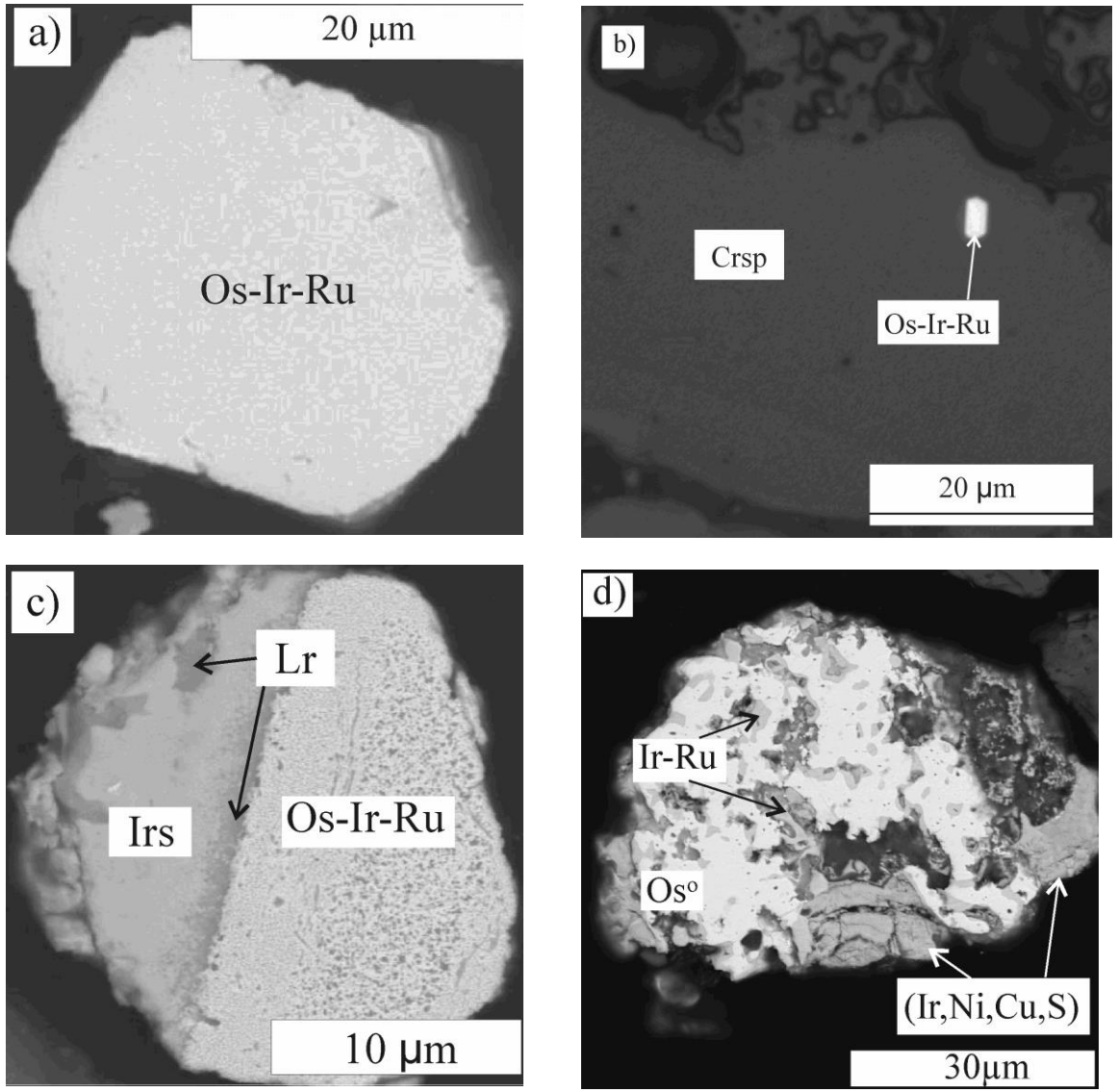

Figure 6. BSE images of the platinum group minerals (a, b) from chromitites of the south branch ophiolite; (c, d) from chromitites of the north branch ophiolite

- High-temperature magmatic Os-Ir-Ru alloys. According to the Cabri classification diagram, high-temperature alloys from the alluvial placer of the Kitoy River belong to osmium and rutheniridosmine. They are identical in composition to the high-temperature alloys from chromitites of the southern branch of the ophiolites (Ospa-Kitoy massif) (fig. 3, 5). For comparison, the compositions of high-temperature osmium alloys from chromitites and the Zun-Ospa river alluvial placer, that crossing the northern branch of the ophiolites were drawn on the diagrams. The diagrams show that the high-temperature alloys of the northern branch of ophiolites (Fig.3, 5) have a higher Ru content and a ruthenium trend, and remobilized platinum group minerals are widely distributed: native osmium, ruthenium and (Ir-Ru) alloys (рис. 3, 5-6). The grains from the Kitoy alluvial placer are isometric, euhedral and partly rounded in shape. Some grains contain inclusions of Pt3Fe, $(Ru,Os)S_2$, amphibole and polyphase assemblage consist of RuS_2, RhNiAs, Pd_3Te,Bi, flogopite (fig. 4a-d).

Chemical composition and BSE images of the sulfides from the Kitoy alluvial placer

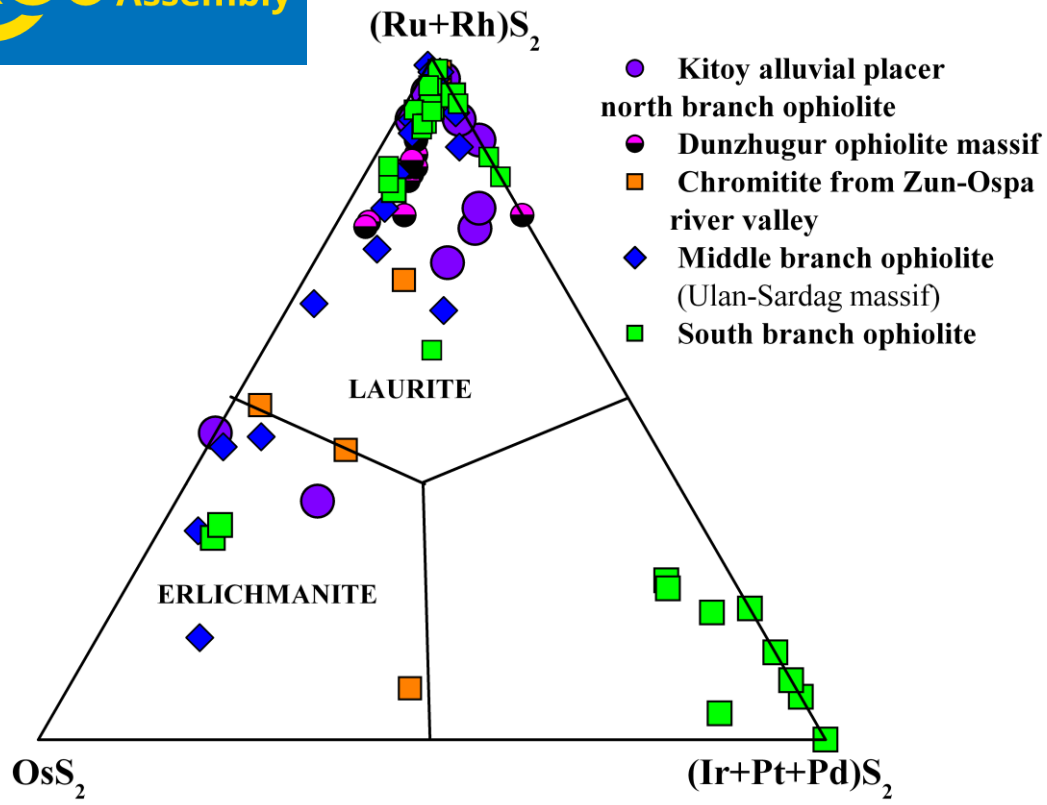

Figure 7. Diagrams of the composition of sulfides in Os-Ir-Ru system.

Among the sulfides from the alluvial placer Kitoy river, laurite predominates and is identical in composition to the sulfides (Os, Ir, Ru) of the composition from chromitites of the southern branch of ophiolites (Ospa-Kitoy massif) and from chromitites of the middle branch ophiolite (Ulan-Sardag massif) (fig.7-8). In the northern branch of the ophiolites, sulfides are not widely distributed.

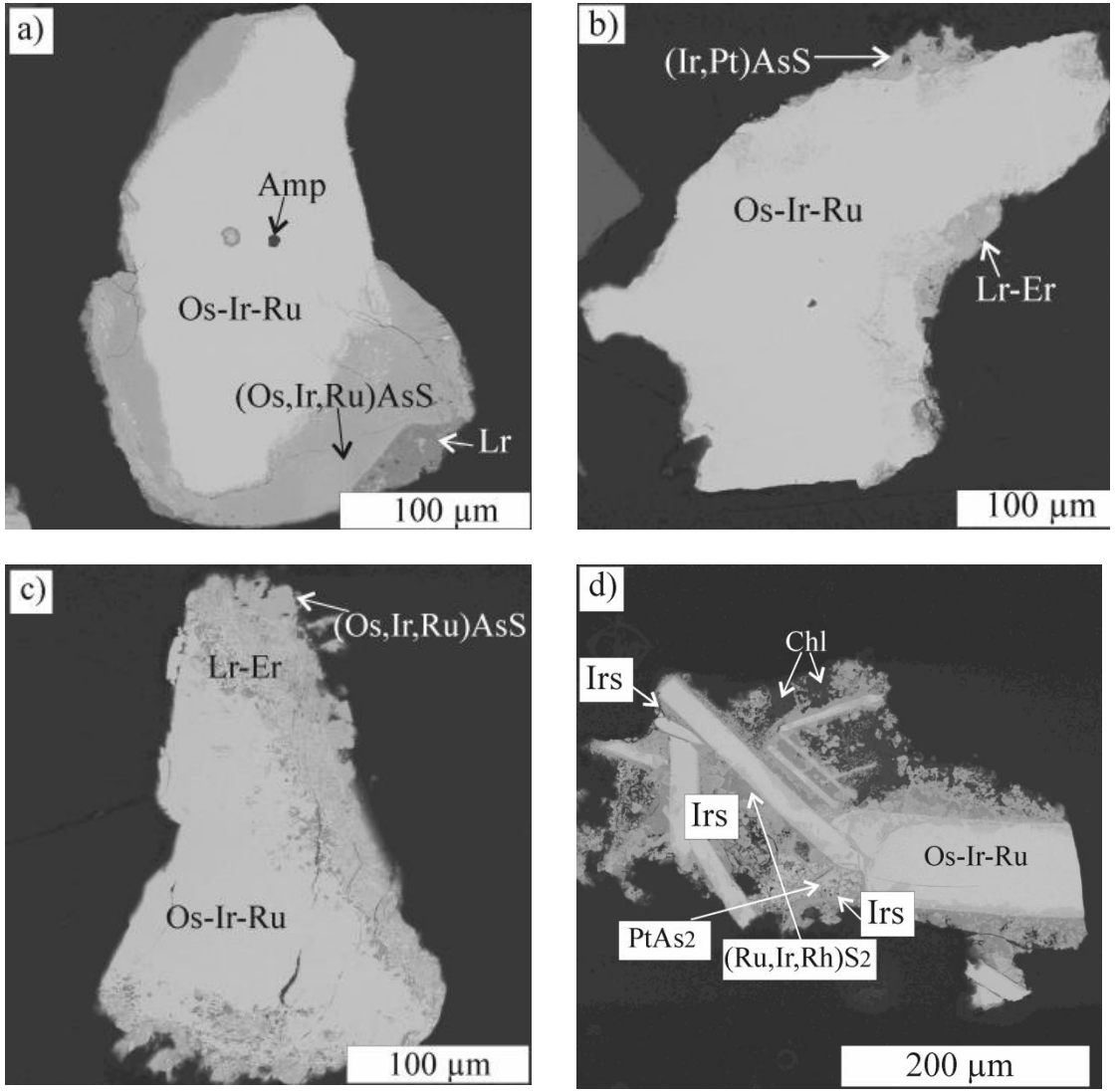

Figure 8. BSE images the platinum group minerals from the Kitoy alluvial placer

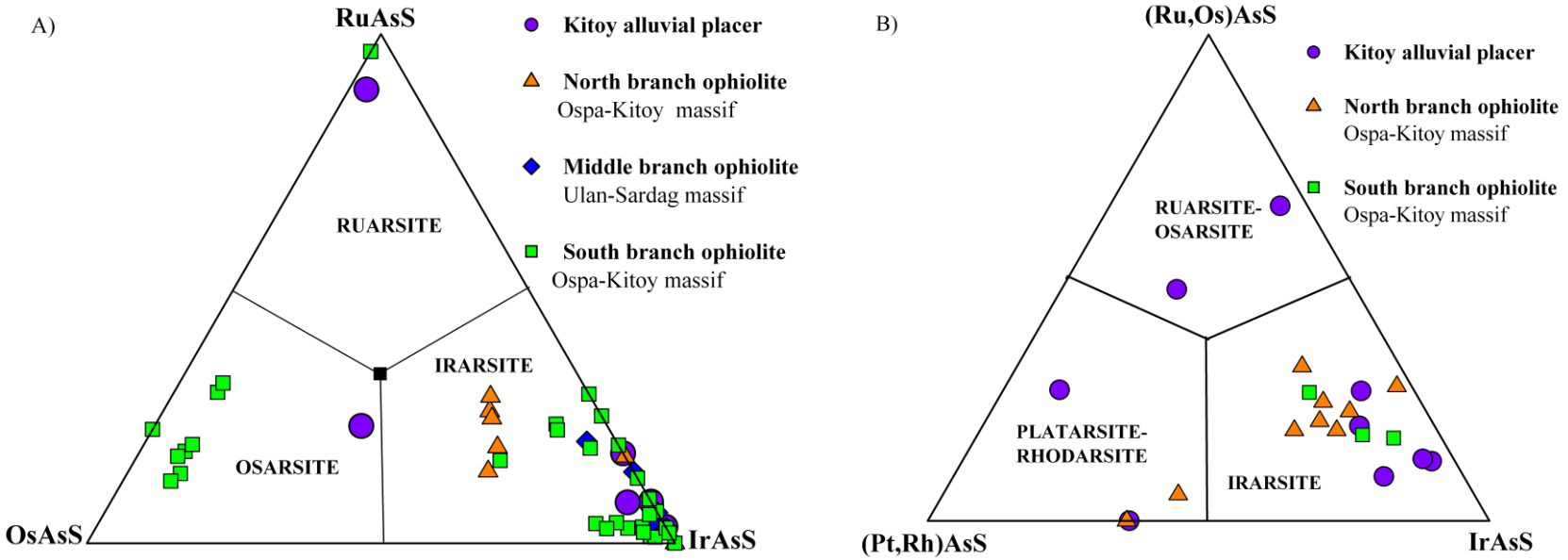

Figure 9. Diagrams of the composition of sulfoarsenides in Os-Ir-Ru-Rh-Pt system.

Sulfoarsenides are widely distributed as replacement products of (Os-Ir-Ru) alloys. Sulfoarsenides are represented by irarsite, as well as in chromitites from the ophiolites of the Eastern Sayan, in addition, platarsite and rhodarsite are present (fig. 9-10).

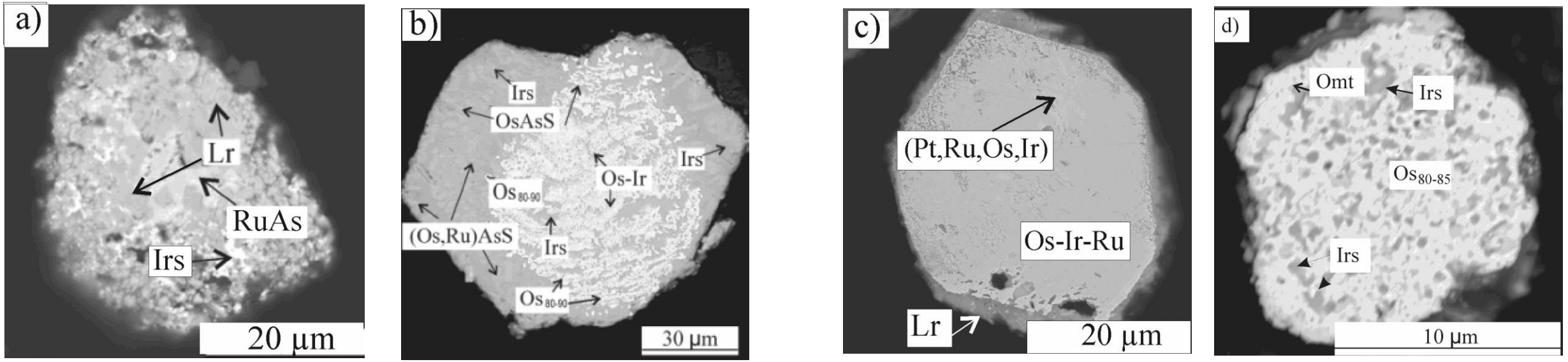

Figure 10. BSE images of the platinum group minerals:
a-b) from the chromitite of the south branch ophiolite;
c-d) from the chromitites of the north branch ophiolite

Chemical composition selenides, arsenselenides, tellurides in Os-Ir-Ru system

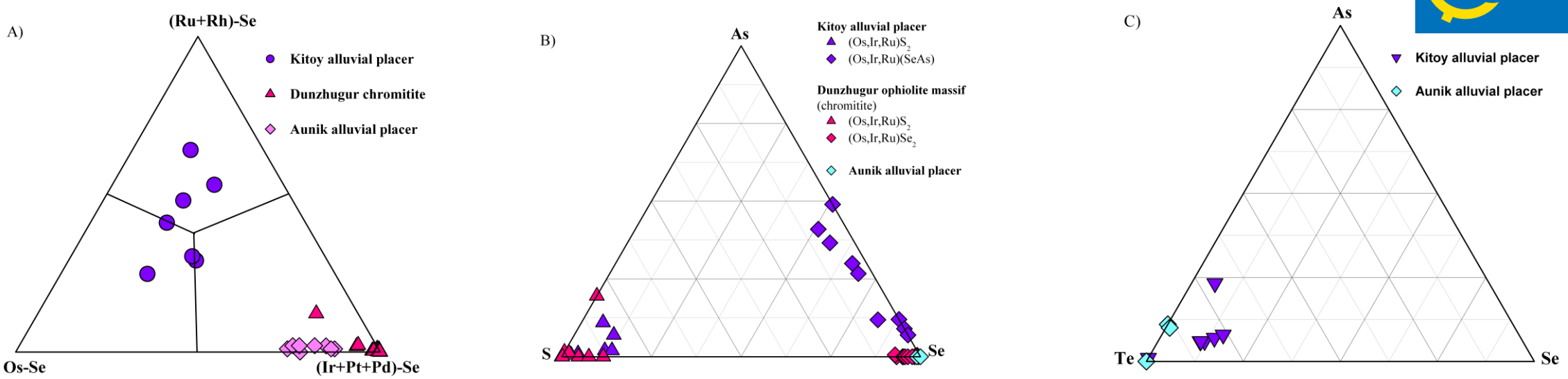

Figure 11. Diagrams of a) kations and b, c) anions composition for selenides, arsenselenides and tellurides

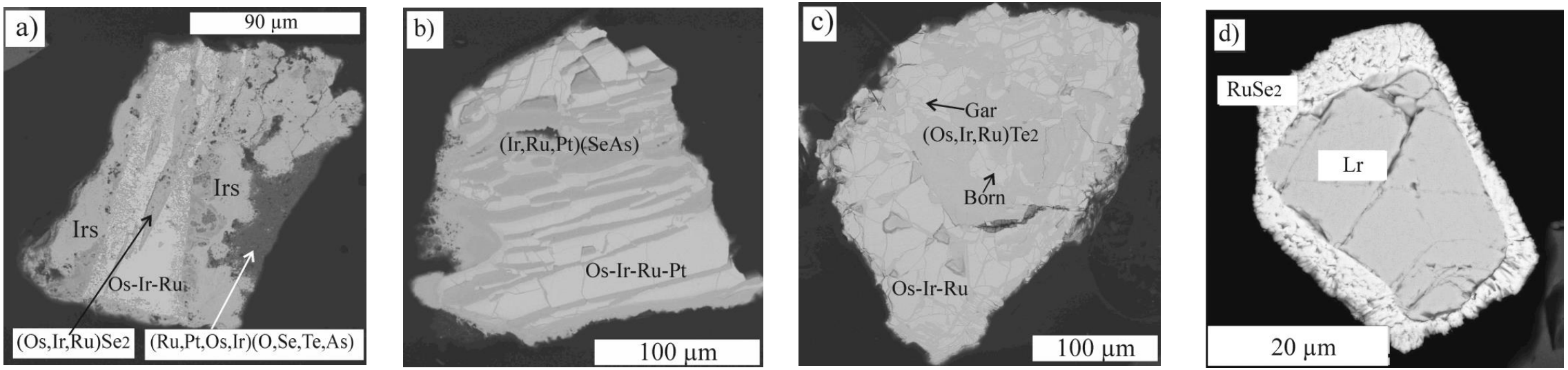

Figure 12. BSE images Se-, Te-ferous platinum group minerals: a-c) from the Kitoy alluvial placer; d) from the chromitites of Dunzhugur ophiolite massif

- A distinctive feature of Os-Ir-Ru alloys from the Kitoy alluvial placer is that the sulfides, sulfoarsenides of PGE are replaced by seleniferous PGE. Cracks in the crushed grains of PGM are filled with selenides, arsenoselenides, and tellurides of these metals. PGE selenides of the Os, Ir, and Ru groups are extremely rare in natural objects. Three synthesized compounds Os, Ir, and Ru are known (Dey and Jain, 2004). In the Eastern Sayan, we found ruthenium selenides in the podiform chromitites of the Dunzhugur ophiolite massif (north branch ophiolite). Selenoarsenides of iridium, arsenotellurides of Ir, Os, and ruthenium telluride were found in placers of the Zolotoy River crossing the Kurtushubinsky ophiolite complex (Tolstykh et al., 1997). Also, iridium selenides ($IrSe_2$) with Os and Te admixtures were found in the gold placer of the Aunik River (Western Transbaikalia) (Ayriants et al., 2020). The diagrams show the cationic and anionic composition of PGE compounds with Se, As, and Te (Fig. 11). For comparison, the diagrams show selenides from the chromitites of the Dunzhugur massif and the alluvium of the Aunik River. The cationic composition of the Dunzhugur massif chromitites is dominated by Ru, which is consistent with the Ru trend for PGE mineralization of the northern branch of ophiolites. In the alluvial placer of the Kitoy River, Os, Ir, Ru, and Pt are present in the cationic composition, and in the placer of the Aunik River – it is Ir (fig. 11). In the anionic composition of the PGM from the alluvial placer of the Kitoy River, arsenoselenides are characteristic, with a small proportion of selenides and tellurides (fig. 11). In the selenides from the chromitites of the Dunzhugur massif and the alluvial placer of the Aunik River, the anionic copmposition is represented by Se with a very small proportion of As, Te.

CONCLUSION

The platinum group minerals from the alluvial placer Kitoy river are identical in composition and microstructural features to the PGE minerals from the chromitites of the southern branch of the Ospa-Kitoy massif, with the exception of selenarsenides and tellurides. The source of the platinum-group minerals from the Kitoy river placer is the Ospa-Kitoy ophiolite massif, and primarily chromitites.

Platinum-group minerals were formed in several stages:

1. At the magmatic stage, high-temperature Os-Ir-Ru alloys with the magmatic ratio Os:Ir:Ru and homogeneous grain microstructure are formed under mantle conditions.
2. Late magmatic stage. The fluid-saturated residual melt enriched with S, As, and Sb interacts with early platinum group minerals. The high-temperature Os-Ir-Ru alloys are replaced by sulfides and PGE sulfoarsenides in the Os-Ir-Ru ± Pt system.
3. The stage of remobilization and re-deposition of PGE in mantle conditions. The most intense changes in the platinum group minerals occur during the processes of fluid action on ultrabasites and podiform chromitites in mantle conditions. The fluid-rock interaction occurs with the participation of gases (H2, CH_4) and H_2O, which is typical for subduction environments. At this stage, native osmium, ruthenium, (Ir-Ru) alloys, garutite (Ir,Ni, Fe), and zaccarinite RhNiAs are formed.
4. The metamorphic stage is accompanied by a change in the early associations of PGM in the conditions of the change of reducing conditions to oxidizing ones. We assume that in the process of obduction of ophiolite complexes, the reduction conditions change to the oxidizing ones. The formation of selenides, PGE arsenides may be associated with a low S/Se ratio, which may be caused by effective removal of S, which is more mobile than Se in a fluid-saturated environment, especially where the sulfur is oxidized to sulfate. These processes can also occur at the subduction stage, in which case the selenides will replace the previously formed sulfides and sulfoarsenides of PGE. The crushed grains filled with selenarsenides and tellurides of PGE were probably formed at the stage of obduction of ophiolites and tectonic deformations. At the stage of obduction and orogeny, gold deposits were formed on the territory of the Eastern Sayan, in which telluride mineralization was established.


Thank you for attention !