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**PREDICTIVE ESTIMATE OF Ti-Zr PLACER DEPOSITS
IN MESOZOIC AND CENOZOIC SEDIMENTS AT NW MARGINS
OF THE ZAYSAN BASIN, EAST KAZAKHSTAN**

Abstract. During the research of orographic, geological and geomorphological characteristics of the Zaysan basin area aiming to identify targeting factors of Ti-Zr alluvial deposits it has been established that the following special favourable conditions are required for their formation: neighbouring occurrence of magmatic rocks with Ti-Zr credit; well-formed deep chemical weathering crust, which has facilitated the release of ore minerals; alluvial, proluvial limnic hydrodynamic conditions for transportation, segregation and concentration of Ti and Zr minerals; availability of local structural particular qualities (tectonic layers, basins), which have prevented the deposits from washing out during transgression and regression of the Zaysan paleo-lake. It has been established that well-known Ti-Zr deposits in the north-west margin areas of the Zaysan basin are geomorphologically located in gentle slope, non-segmented plains of subaerial denudation of 400–700m altitude, within the littoral zone of the Zaysan paleo-lake. The orographic representation of modern relief of the region have been established, stratigraphic positions of Mesozoic and Cenozoic placer deposits were determined, and an area for prospecting of new Ti-Zr deposits was identified.

Keywords: Ti-Zr deposits, plains of subaerial denudation, geomorphological regionalization, Zaysan basin, East Kazakhstan, placer deposit, titanium, zirconium, area orography, geological-geomorphological analysis, prospecting characteristics.

1. Introduction. Over the last years, the efficiency of research and prospecting works for placer deposits in Kazakhstan has severely declined due to the limited number of easily-discoverable deposits. Therefore, scientific forecast becomes important, whereas its absence leads to unproductive investment and work output of geological prospecting becomes inefficient.

The objectives of this paper include: 1) to define prospecting characteristics to determine Ti-Zr mineralization of placer deposits within Mesozoic and Cenozoic sediments of the Zaysan basin in East Kazakhstan, and 2) to study characteristic features of the geological and geomorphological development of the area.

Research carried out and presented in this paper allowed to clarify the role of area relief and to constrain development of surface substrate during the formation of placer deposits in Mesozoic and Cenozoic sediments, and to determine indicators for Ti-Zr prospecting within the Zaysan basin.

2. Research methods. Studies of geological-geomorphological and morphotectonic evolution of the Zaysan basin area with subsequent predictive estimation of Mesozoic-Cenozoic Ti-Zr placer deposits were carried out in two stages as follows:

1. During the first stage, the morphology of modern relief of the Zaysan basin was investigated, including detailed research on geology, morphology and morphotectonic processes; construction of regional orographic layout and sections using Global Mapper geo-information system based on terrain data of modern relief (SRTM Worldwide Elevation Data, 1-arc-second resolution). Research results allowed determining the position of modern faults, amplitude of new displacements and nature of plicative deformations. An orographic scheme with cross-section of modern relief of the area has been also constructed.

2. During the second stage and within the boundaries of the Zaysan basin area, the proposed bank line of the Zaysan paleo-lake was determined by way of alignment of determined Ti-Zr alluvial deposit locations and altitude horizontals of the constructed orographic layout. It is suggested that Ti-Zr minerals were concentrated and sorted under coastal hydrodynamic conditions within local geological structures (tectonic layers, basins, etc.). Detailed research of particular features of the geological and geomorphological development has been performed on the identified territory.

Therefore, the research methods included the following: construction of orographic layout and sections of modern relief of the studied area; research of stratigraphic positions of sediments containing known Ti-Zr placer deposits in the area, and determining their geomorphological positions; research of geomorphological and geological development of north-west margins of the Zaysan basin, identifying plains of subaerial denudation and determining local forecasting areas for research of Ti-Zr placer deposits.

3. Assessment of Ti-Zr placer maturity within the Zaysan basin area. Ti-Zr placer deposits formed in the Mesozoic-Cenozoic sediments in different parts of the Zaysan basin due to the rewashing and segregation of sandy-clay material. Sources for these deposits include older sedimentary-volcanic and igneous rocks.

The following Ti-Zr placer deposits are known in the area of the Zaysan basin [1-4]:

1. **Karaotkel deposit** is confined to river valleys embedded in the Mesozoic weathering crust and made by Paleogene and Neogene proluvial-alluvial deposits. The weathering crust is developed over calc-alkaline and subalkaline granitoids of the Karaotkel intrusion. Ore minerals include: ilmenite, leucoxene and zircon.

Three ore horizons are distinguished at the deposit: the lower horizon in the Upper Cretaceous weathering crust (K_2ma) composed of 55 % clay and 45 % sandy components; the middle horizon in the sediments of the North Zaysan series ($Pg_1^{2-3}sz$) of Paleogene, represented by outwashed sandy-clayey rocks; and the upper horizon in the sediments of the Aral suite ($N_1^{1-2}ar$) of Neogene, consisting of 62–64 % clay and 36–33 % sandy components.

2. **Satpaev deposit** is geomorphologically associated with the area of transition from the accumulative plain (the north-western border of the Zaysan basin) to the slightly dissected low-hill terrane (the piedmont of the Kalba highland) and localized in the alluvial (stream-bed) deposits of the Aral suite ($N_1^{1-2}ar$) of Neogene. The placer deposit stretches within the Preobrazhensk intrusion of granitoids and is represented by sandy clays, unsorted coarse, medium-grained and uneven-clayey arcose sands. The main ore mineral is ilmenite, whereas zircon is observed in insignificant quantities.

3. **Peschanka deposit** is represented by an alluvial valley placer. The mineralised bed consists of homogeneous sand-gravel-pebble sediments with insignificant fluctuations of pebble content from 20 to 39 %. The main ore minerals are ilmenite, magnetite, cassiterite, scheelite, zircon, rutile, pyrite and apatite.

In general, Ti-Zr placer deposits within the Zaysan basin are localised in three different stratigraphic levels as follows [5, 6]:

Upper Cretaceous weathering crust (K_2ma) – it occurs everywhere at the base of the Cenozoic section of the Zaysan trough with a thickness of up to 20m and is exposed in small areas within the relics of the plains of subaerial denudation. The chemical composition of the weathering crust depends on the initial composition of the source rocks. In terms of composition and structure, the weathering crust is close to modern tropical and subtropical areas.

North Zaysan Paleogene Series ($Pg_1^{2-3}sz$) – it is represented by variegated sediments at the base of the section of the Zaysan basin and lies with weakly-expressed ravinement on the Upper Cretaceous weathering crust. The rock mass is dominantly represented by variegated red spotted clays, siliceous mudstones and siltstones with rare interlayers and lenses of quartz sand. The middle part and the base of

the upper part of the series section contain signs of the Paleocene flora [7]. The thickness of the series is relatively constant at 190–210 m, but gradually decreases to 10 m within the anticlinal structures.

Aral suite of Neogene ($N_1^{1-2}ar$) – it is represented within the Zaysan basin by a monotonous gray-green silty clays with rare layers and aleurite lenses, red-brown clays and marls. In some areas there are white calcareous concentrations, druses and gypsum crystals. Sands and siltstones corresponding to the coastal-delta part of the paleo-basin are dominant in the northern part of the Zaysan basin. The thickness of these sediments is 30–90 m.

4. Results of orographic, geological and geomorphological analysis of the Zaysan basin area: implications for prognostic area for Ti-Zr placer deposits. The Zaysan basin area formed as the result of a prolonged and complex geological development. The most important factors, which influenced the genesis and morphology of the relief of the area include [8, 9]: (1) the activation of intrusive magmatism; (2) subsequent tectonic activity during the Alpine orogenesis; (3) transgressive-regressive hydrodynamic regimes of the Zaysan paleo-lake; (4) development of denudation processes of physical and deep chemical weathering. The Ti-Zr placer deposits of Karaotkel, Satpaev, and Peschanka formed within close proximity to volcanic-sedimentary and intrusive source rocks [13, 14]. The degree of maturity of the rocks that were outwashed and transported into the Mesozoic and Cenozoic basins was very critical during the formation of mineral sands [10-16].

Identification of the bank line of the Zaysan paleo-lake (i.e., areas of favourable hydrodynamic conditions) is a very critical forecasting factor for the research of metal-bearing Ti-Zr placer deposits. A horizontal line of 450 m (+/- 50 m) is highlighted by a red line on the orographic layout of the Zaysan basin (figure 1) near the granitoids of the Kalba highland, which coincides with the location of known Ti-Zr placer deposits (Karaotkel, Satpaev, Peschanka), which probably was the bank zone of the Zaysan paleo-lake with the conditions favourable for the concentration of Ti-Zr minerals.

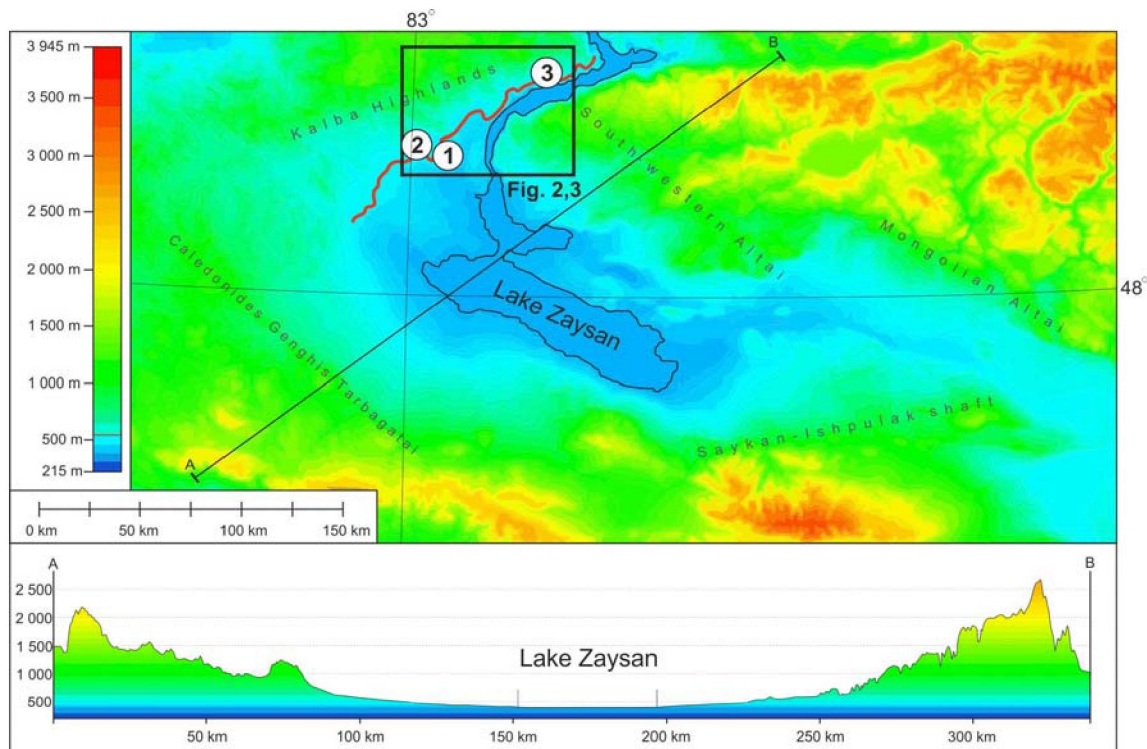


Figure 1 – Orographic layout of the Zaysan basin. Location of known Ti-Zr placer deposits in the area: 1 – Karaotkel; 2 – Satpaev; 3 – Peschanka. The red line indicates the proposed bank line of the Zaysan paleo-lake

The dedicated bank line of the Zaysan paleo-lake is proposed as a perspective for the discovery of new Ti and Zr placer deposits. It is important to note that location of the proposed bank line is in agreement with previous paleolimnological studies within the Zaysan sedimentary basin [17]. The region of the perspective area covers the south-east submontane part of the Kalba mountain chain, on the left bank of the Irtysh River (figure 2).

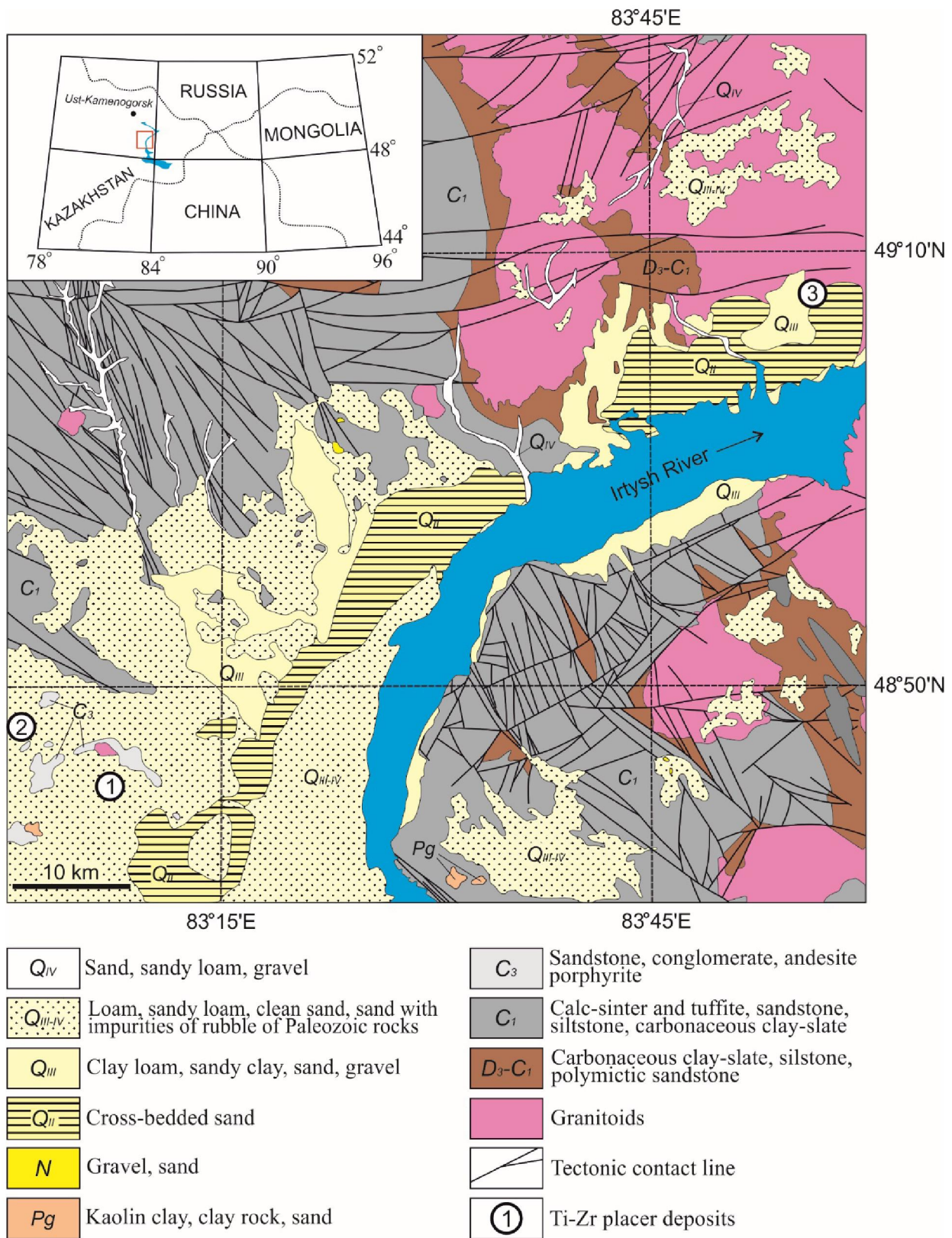


Figure 2 – Geological map of the north-west area of the Zaysan basin [18, 19]

A sharp asymmetry is observed in the morphological structure of the Kalba highlands in the perspective area (north-west frame of the Zaysan basin). Their northern slopes are steep and rocky, and the southern ones are relatively flat. The absolute elevations in the area vary from 864 to 1608 m, averaging 500–900 m with relative elevations from 20 to 700 m. At the watershed areas and gentle slopes of the ridges, there are almost flat areas that are remnants of an ancient peneplain. Along the left shore of the Irtysh River, dune ridge sands with areas of barchan sands are located within the band of 4–15 km.

Volcanic-sedimentary rock formations of the Middle and Upper Paleozoic and unconsolidated sediments of the Mesozoic and Cenozoic period are present in the geological structure of the area. The following rock formations are observed in the stratigraphic section of the Middle Paleozoic: Takyr (D_3-C_1tk), Baysum (C_1bs), Dalankar (C_1dk), and Arkaul (C_1v_2) suites. The Upper Paleozoic formations in the area are represented by the Maytyube ($C_{2,3mt}$) and Serzhikhinsk (C_3-P_1sr) suites. The following rock units are present in the Mesozoic and Cenozoic rock section: Upper Cretaceous weathering crust, Paleogene, Neogene and Quaternary sediments.

Sedimentary and volcanic rock formations of the Middle and Upper Paleozoic are crosscut by the granitoids of the Kalba and Zmeinogorsk intrusive complexes (C_1-P). Multiphase granites of the Kalba group of the left bank of the Irtysh River are characterized by relative homogeneity and common mineral composition. They are represented by plagioclase of albite-oligoclase and microcline perthite series, occurring in approximately equal proportions. The mineral content in granites is as follows: feldspar 60–70 %; quartz 20–25 %; dark mineral is represented by biotite in an amount of 5–15 % and more. An increased content of biotite is observed in granites of the endocontact areas of intrusions and in areas, where granites are enriched in xenoliths of host rocks. In some areas, granites show a complete or partial replacement of biotite with muscovite, primary feldspar with skeletal microcline, new growths of these minerals, as well as pneumatolytic changes of granites, manifested in greisenization.

In tectonic terms, the repeated deformations during the Hercynian the Hercynian tectogenesis, combined with igneous activity, led to the formation of complex tectonic forms, further complicated by the neotectonic (Alpine) discontinuous deformations. During the Alpine orogeny in the area, there was formed the Kalba-Narym highland (upheaval), complicated by numerous faults, which are represented by differently oriented faults of different age.

After active Alpine orogenesis, erosion-denudation processes, accompanied by intensive disruption of the ancient peneplain with the subsequent formation of a modern basin and range relief took place (figure 3).

According to morphogenetic features, two formation stages are distinguished in the area, namely a denudation relief of the (1) platform and (2) tectonic stages.

1. *Denudation relief of the platform stage of relief formation.* The relief of the platform stage includes ancient plains of subaerial denudation, identified in a number of places by kaolin residual soil and red-brown clay. The formation of this relief is associated with the relatively calm tectonic conditions that existed before the first signs of the Alpine orogenesis, when the processes of denudation dominated at the whole territory of Altai [18, 20–22]. It is generally accepted that peneplain formation began in the Upper Cretaceous. Plains of subaerial denudation are found on watershed spaces that have not yet reached regressive river erosion (at absolute elevations of 400–1600 m). In most cases, the plains of subaerial denudation have a slight slope (2–4°), which is probably associated with an arch pattern of the alpine orogenesis upheaval. According to morphological features, smooth slopes and poorly broken plains of subaerial denudation were established in the area at that time.

2. *Denudation-tectonic relief of the orogenic relief formation stage.* The relief of the orogenic stage is closely associated with the latest tectonic deformations, which first manifested in the area from the end of the Pliocene and continue until present. As a result of the arched nature of the upheaval associated with these deformations, two folds are formed in the area, corresponding to the Kalba and Narym Ridges, complicated by numerous faults and divided by the area of relative subsidence, to which the modern valley of the Irtysh River is related. Different amplitudes of tectonic movements within the areas of relative upheaval and the associated uneven activity of exogenous relief led to the formation of various types of mountainous relief in the area.

The products of denudation, brought into areas of relative subsidence, led to the formation of accumulative relief forms. According to leading relief factors, we can distinguish the lake, aeolian, gravitational, and river types of relief.

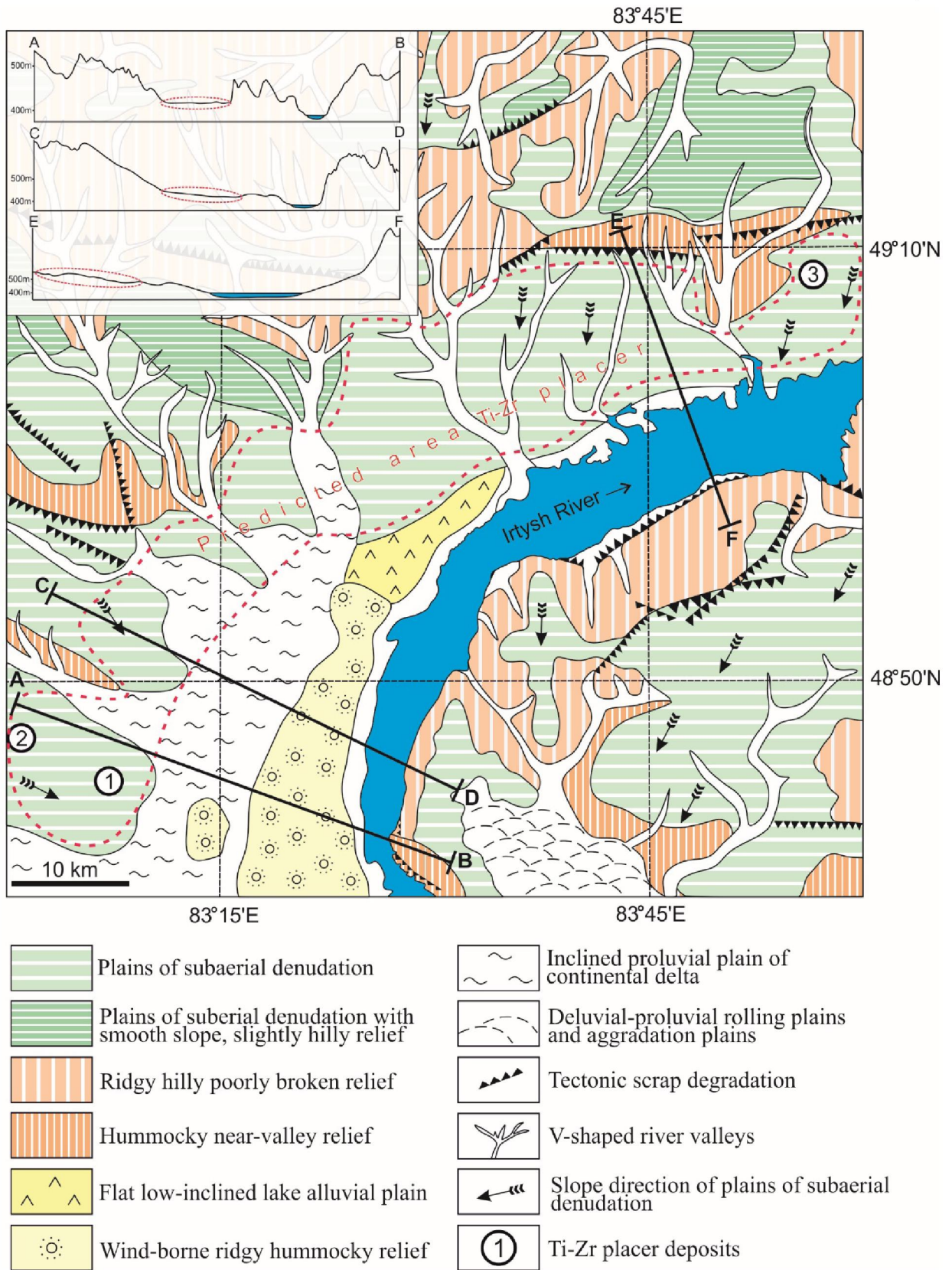


Figure 3 – Geomorphological layout of the north-west area of the Zaysan basin. Forecast area lies on the left bank of Irtysh River at the foot of the Kalba highland

5. Discussion of results.

1. In the history of geological and geomorphological development of the area during the Mesozoic-Cenozoic period the following factors had significant importance: tectonic movements of the Alpine orogeny, characterized by arched upheaval and subsidence; the widespread development of the processes of denudation of physical and deep chemical deflation; periods of transgression and regression of the Zaysan paleo-lake, periodically flooded large areas of continental land. Research of orographic pans and sections of the modern relief of the Zaysan basin established a presumably coastal zone of the paleo-basin, which hydrodynamic conditions could facilitate the transportation and segregation of Ti and Zr minerals, as well as accumulation in local geological structures (tectonic layers, basins, etc.).

2. The stratigraphic levels of known Ti-Zr placer deposits in the Zaysan basin area are characterized. Elevated concentrations of ore minerals are established in the following deposits: the Upper Cretaceous residual soil (K_2ma), the North Zaysan Paleogene series ($Pg_1^{2-3}sz$), and the Neogene Aral suite ($N_1^{1-2}ar$).

3. Prognostic characteristics of localisation of Ti-Zr placer deposits in sediments of plains of subaerial denudation were identified. In the morphogenetic aspect, the plains of subaerial denudation represent a rather flattened relief surface, which formation was promoted by the activity of various denudation processes: erosional surface waters, periods of transgression and regression of the Zaysan paleo-lake.

4. The prognostic area for more detailed exploratory research was determined to identify placer Ti-Zr deposits in the Zaysan basin. The prognostic area is confined to plains of subaerial denudation in the elevation range of 400-700 m in the coastal zone of the Zaysan paleo-lake of the north-west border of the Zaysan basin.

Therefore, favourable conditions for the concentration of Ti-Zr metal-bearing placer deposits in the area of the Zaysan basin were determined:

- availability of a substrate of igneous rocks of Karaotkel-Preobrazhensk, Kalbinsk and other complexes;

- availability of a deep chemical weathering crust, which contributed to the release of Ti and Zr ore minerals;

- availability of smooth sloping, poorly broken ancient plains of subaerial denudation with absolute elevations in the range of 400-700 m, located within the coastal zone of the Zaysan paleo-lake;

- availability of favourable structural features (tectonic layers, basins) that prevented placer deposits from erosion during periods of transgression and regression.

6. Conclusions. The paper highlights the importance of geological processes of tectonic activity, erosion activity, transgression and regression of the Zaysan paleo-lake during the formation of a contrasting modern relief of the Zaysan basin of East Kazakhstan. As a result, the role of geological and geomorphological development of the north-west margin of the Zaysan basin and surface substrate in the formation of metal-bearing Ti-Zr placer deposits in the area could be substantiated. Prospecting indicators are compiled serving to identify the prognostic area for the discovery of new Ti-Zr placer deposits in the region.

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ШЫҒЫС ҚАЗАҚСТАН ОБЛЫСЫНДАҒЫ ЗАЙСАН ОЙПАТЫНЫҢ СОЛТҮСТІК-БАТЫС ЖАҚТАУЫНДАҒЫ МЕЗО-КАЙНОЗОЙЛЫҚ ШӨГІНДІЛЕРДІҢ Ti-Zr ШАШЫРАНДЫ МЕТАЛДЫЛЫҒЫН БОЛЖАМДЫ БАҒАЛАУ

Аннотация. Ti-Zr шашырандыларын болжау факторларын анықтау мақсатында Зайсан ойпаты ауданының орографиялық және геологиялық-геоморфологиялық ерекшеліктерін зерттеу кезінде, олардың түзілуі үшін белгілі бір қолайлы жағдайлардың болуы қажет екендігі анықталды: Ti-Zr магматикалық жыныстарының ерекшеліктерге жақын орналасқан субстраты; кен минералдарын босатуға әсерін тигізетін, терең химиялық желге мүжілулерден пайда болған қыртыстар; Ti және Zr минералдарын тасымалдау, сұрыптау және концентрациялауға арналған аллювийлік-пролювиальдік-көл гидродинамикалық шарттар; шашыранды кендерді Зайсан палео-көлінің трансгрессиясы (тасуы) және регрессиясы (қайтуы) кезіндегі шайылып кетуден сақтайтын жергілікті құрылымдық ерекшеліктердің (тектоникалық баспалдақтардың ойыстардың) болуы. Зайсан ойпатының солтүстік-батыс жақтауы шегінде мәлім болған Ti-Zr кен орындары Зайсан палео-көлінің жағалаулық аймағында, 400-700 м биіктік диапазонындағы тегістікте геоморфологиялық қатынаста әлсіз бөлшектелген үстіңгі беттерде орналасқандығы анықталды. Ауданның қазіргі заманғы рельефінің орографиялық схема құрастырылған, шашыранды орналасқан мезо-кайнозойлік түзілімдердің стратиграфиялық орналасу жағдайы анықталған, және жаңа Ti-Zr кенорындарын іздеу үшін болжамды алаң бөлініп берілген.

Түйін сөздер: Ti-Zr ұсақ тау жыныстары, тегістелетін сыртқы беттер, геоморфологиялық аудандастыру, Зайсан ойпаты, Шығыс Қазақстан, аллювиалды кен орындары, аймақ орографиясы, геологиялық-геоморфологиялық талдау, барлау сипаттамалары.

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ПРОГНОЗНАЯ ОЦЕНКА Ti-Zr РОССЫПНОЙ МЕТАЛЛОНОСНОСТИ МЕЗО-КАЙНОЗОЙСКИХ ОТЛОЖЕНИЙ СЕВЕРО-ЗАПАДНОГО ОБРАМЛЕНИЯ ЗАЙСАНСКОЙ ВПАДИНЫ В ВОСТОЧНОМ КАЗАХСТАНЕ

Аннотация. При изучении орографических и геолого-геоморфологических особенностей района Зайсанской впадины с целью выявления факторов прогноза Ti-Zr россыпей было установлено, что для их образования необходимы определенные благоприятные условия: близ расположенный субстрат магматических пород Ti-Zr специализации; сформированная кора глубокого химического выветривания, способствовавшая высвобождению рудных минералов; аллювиально-пролювиально-озерные гидродинамические условия для транспортировки, сортировки и концентрации минералов Ti и Zr; наличие локальных структурных особенностей (тектонических ступеней, мульд), предохранившие россыпи от размыва в периоды трансгрессии и регрессии палеоозера Зайсан. Установлено, что известные Ti-Zr месторождения в пределах северо-западного обрамления Зайсанской впадины в геоморфологическом отношении локализируются в пологосклонных, слабодиссипированных поверхностях выравнивания в диапазоне высот 400-700 м, в береговой зоне палеоозера Зайсан. Построена орографическая схема современного рельефа района, определены стратиграфические положения россыпемещающих мезо-кайнозойских отложений, и выделена прогнозная площадь для поиска новых Ti-Zr месторождений.

Ключевые слова: Ti-Zr россыпи, поверхности выравнивания, геоморфологическое районирование, Зайсанская впадина, Восточный Казахстан, аллювиальные месторождения, орография области, геолого-геоморфологический анализ, поисковые характеристики.

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