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Dating of the Val'kumei Coastal-Marine Placer (East Siberian Sea)

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Abstract—This work is an attempt to determine the real time of formation of coastal-marine placers based on the modeling of placer-forming processes, present-day rates of lithodynamic processes, and recent parameters of placer sources. The result obtained shows that the real time of formation of the Val'kumei tin placer (Chaun Gulf, East Siberian Sea) significantly differs from its stratigraphic age. Possible reasons of this discrepancy are analyzed.

When working in the Chaun Expedition of the Sevvostgeologiya Industrial-Geological Association in 1982–1991, we studied geochemical features and lithological composition of alluvial and coastal-marine placers of Central Chukotka. Being involved in the modeling of sedimentation processes for the local prediction of placer parameters, we did not investigate the intensity of geological processes at that time, because such issues were beyond the scope of applied geology. An attempt to identify the time of formation of the Val'kumei coastal-marine tin placer (hereafter, Val'kumei placer) from calculations based on present-day sedimentation rates and ore component content in native sources showed that the time needed for placer formation is significantly less than its stratigraphic age. Since the recent lithodynamic conditions of placer formation mainly developed in the Pliocene, the available data allowed us to compare the real and geochronological times of placer formation.

The geology, geomorphology, hydrodynamics, lithodynamics, and structure of the sedimentary cover of the Val'kumei placer are scrutinized in several investigations (Lalomov, 2003b; Patyk-Kara and Ivanova, 2003). In this paper, we present only brief geological information needed for the calculation of the dating of placer accumulation.

GEOLOGICAL STRUCTURE AND LITHODYNAMICS OF THE VAL'KUMEI AREA

The Val'kumei placer is situated at the boundary of the zone of stable negative tectonic movements (Chaun Basin) and the uplifted Val'kumei granitoid massif. According to (Patyk-Kara *et al.*, 1980), development of the Chaun Basin and initiation of differentiated tectonic movements started in the Miocene. The placer material was derived from zones with vein mineralization and sectors with disseminated cassiterite–silicate ore association in the Val'kumei Massif. Outcrops of the native tin sources are observed both immediately in the abraded cliff and on the territory adjacent to the coastal zone (Lugov, 1965). Deluvial-proluvial (talus) sediments transported to the beach zone also contain tin. The zone located near the beach at the beginning of the stable alongshore debris flow (ADF) north of the Val'kumei Cape served as the main source of tin for the recent coastal-marine placer.

In the studied water area of the Chaun Gulf, the ADF is directed northward and starts from the extreme point of the Val'kumei Cape. The flow is unsaturated with debris and the coastal cliff is actively eroded (abrasion zone) within the main part of the placer near the cape. The coast becomes more stable further to the north (debris transit zone). The northern part of the placer is characterized by flow saturation, beach growth, and debris deposition (accumulation zone). The active debris transportation zone (pebbles, sands, and silts) widens from 100–200 m in the abrasion zone to 600 m in the accumulation zone. Bottom sediments beyond the active zone are composed of black organic-rich silty–pelitic muds.

Some definite conclusions about paleolithodynamic conditions in the Chaun Gulf area were made on the basis of the study of coastal geomorphology and drilling data. The presence of an approximately 4-km-long accumulative bar in the northern part of the placer testifies to a long-term stability of the ADF. Pebble deposits of the bar are recovered by wells even at the upper boundary of Pliocene sediments, indicating the existence of a stable unidirectional ADF in the Chaun Gulf as early as the initial Pleistocene. Grain size of the pebble material and other lithological features only slightly change over the entire Pleistocene–Holocene sequence. This suggests that the general (qualitative) pattern and intensity of lithodynamic processes almost did not change during the whole formation period of the Quaternary and Recent coastal-marine placer. Results of the geochemical study of the Val'kumei placer also indicate "the inheritance of lithodynamic conditions in the course of placer formation" (Patyk-Kara and Ivanova, 2003, p. 273) except for the Late Pleistocene regression period characterized by the formation of the Yedomas Complex.

The Sn-bearing apron extends from the native source toward the dominant debris flow in the unidirectional ADF area. Simultaneously, the Sn-bearing apron widens in accordance with parameters of the hydrodynamically active zone, whose outer (sea-facing) boundary coincides with the boundary of silty mud distribution.

The tin placer in the Val'kumei Cape area can be divided into two main structural-genetic stages. The lower (older) stage is mainly related to Miocene talus and alluvial sediments. The upper (younger) stage mainly includes Pliocene–Holocene coastal-marine sediments. In order to upgrade the reliability, the age of sediments was calculated only for the coastal-marine placer of the upper stage, because the application of quantitative recent data on the lithodynamics and parameters of native sources is less substantiated for the lower stage.

DATING OF PLACER

Time needed for the formation of the coastal-marine part of the Val'kumei placer was estimated using a simplified sedimentation model, which assumes that present-day geological conditions are approximately similar to those in the Pliocene–Recent period of coastal-marine placer formation.

The placer-forming component was transported downward from the provenance by the ADF through the section of an active sediment layer $L_{(x)}$ Z (figure) with a constant intensity corresponding to the recent one. Here, L is the width of the active layer of sediment transport in the ADF; Z is the thickness of the active layer, which does not exceed 1–1.5 m (according to different estimations); and X is the distance from the ADF origin. In order to calculate the time elapsed after the beginning of the placer formation, it is necessary to estimate the following parameters:

(1) Quantity of tin, $q_{(x)}$ (t/yr) passing in the active layer through an arbitrary section X:

$$q_{(x)} = L_{(x)}\, Z\, C_{(x)\mathrm{av}}\, v_{(x)} = V_{(x)}\, C_{(x)\mathrm{av}}, \qquad (1)$$

where $C_{(x)\mathrm{av}}$ (t/m^3) is the average Sn content in the active sediment layer in the ADF cross section $L_{(x)}$ Z 1 m at point X; $v_{(x)}$ (m/yr) is the average ADF velocity in the given section; $V_{(x)}$ (m^3/yr) is the volume of clastic Sn-bearing material passing through the ADF cross section at point X.

(2) The total quantity of Sn in the placer transported downward the ADF from the studied section equal to $Q_{(x)}$ (t).

Knowing these parameters, one can calculate the time $T_{(x)}$ elapsed after the origin of the placer area situated downward the ADF from section X using the formula

$$T_{(x)} = Q_{(x)}/q_{(x)}. \qquad (2)$$

In order to determine the value of $q_{(x)}$, let us estimate some dynamic characteristics of the ADF, as well as regime and volumes of clastic material and tin delivery to the ADF.

For the Val'kumei placer, the annual volume of clastic material delivered to the ADF was calculated by the following methods:

(1) Results of field works. They indicate that the volume of abraded slope material transported to the ADF is estimated at 3×10^3 m^3/yr.

(2) Indirect method. The area of the denudated provenance is equal to 3×10^6 m^2. The average denudation rate under these conditions is estimated at 1 mm/yr (Shumilov, 1980). Thus, the volume of material delivered to the ADF is equal to 3×10^3 m^3.

(3) Data on pebble material transportation. During the activity of waves oriented from south to north, the volume of coarse-clastic material passing through the cross section of the active zone in the ADF transit area can reach 150 m^3/day (Lalomov, 1986). Taking in account the material transported within the submarine slope, this value can be two times higher. The shore in the placer area is steep and wave breakers are generally absent in the submarine bar area. Wave energy release (consequently, material transport) mainly occurs in the beach zone. Therefore, the twofold increment of the total ADF thickness (relative to the beach) seems to be a quite reliable estimate. Considering that the southern winds (and, correspondingly, wave agitation) predominate over northern ones during the navigation period of 7–10 days, the ADF value can be estimated at ~(2–3) × 10^3 m^3/yr. The clayey constituent of friable slope sediments (30–40% of the sediments) delivered to the ADF practically immediately passes into suspension and leaves the ADF zone. Therefore, the volume of material entering the coastal zone can also be estimated at (3–5) × 10^3 m^3/yr.

An approximately similar value (~4.3×10^3 m^3/ yr) is obtained if we use data in (Kosheleva and Yanshin, 1999) concerning the abrasion of bedrock shores in the East Siberian Sea.

In this work, the total volume of material delivered to the entire abraded sector of the ADF is estimated at 3×10^3 m^3/yr. This material is gradually transported along the abrasion zone that stretches from the ADF origin (X) to the placer profile at X_A (~2500 m). Further downward the flow, abrasion gives way to transit and accumulation; i.e., the material input into the ADF ceases (Lalomov, 1986). At the same time, the intensity of abrasion (and, correspondingly, the rate of material delivery to the flow from the slope $U_{(x)}$) uniformly decreases from the maximal value at $X = 0$ to 0 at $X_A =$ 2500 m.

The total quantity of clastic material Sum$U_{(x)}$, which is delivered to the ADF in the abraded area upstream of the arbitrary point X, is an integral function of $U_{(x)}$:

$$\mathrm{Sum}U_{(x)} = \int_{x=0}^{x} U_{(x)} dx. \qquad (3)$$

As a first approximation, it is possible to dispense with linear approximation Sum$U_{(x)}$. However, let us assume for the sake of more precise calculation that $U_{(x)}$ rate is maximum in the intense abrasion zone at the flow origin and the rate decreases as the flow is saturated with debris. Correspondingly, the $V_{(x)}$ value (volume of clastic material passing through the ADF cross section at a distance of X from the ADF origin) grows intensely at the beginning and gradually in the flow saturation zone. At $X = 0$, the $U_{(x)}$ value is maximum, Sum$U_{(x)} = 0$ and, consequently, $V_{(x)} = 0$. At $X_A = 2500$ m, $U_{(x)} = 0$, Sum$U_{(x)}$ is maximum, and $V_{(x)}$ is proportional to the whole volume of clastic material delivered to the abrasion area upstream of the flow from point X. Coefficient k, which takes into consideration the removal of fine clayey fractions from the placer zone is calculated as follows:

$$V_{(Xa)} = k \int_{x=0}^{X_a} U_{(Xa)} dx = k\mathrm{Sum}U_{(Xa)}. \qquad (4)$$

It is assumed that the removal of fine fraction takes place almost simultaneously with the delivery of material to the ADF and precisely at the delivery point. Moreover, k is assumed constant over the entire abraded area. Proceeding from the fact that the removal of fine clayey fraction from the placer zone accounts for ~40% of the supplied material, k is taken to be equal to 0.6.

Let us approximate Sum$U_{(x)}$ by a quadric function. In this case, the equation has the following form:

$$\mathrm{Sum}U_{(x)} = \mathrm{Sum}U_{(Xa)} - K(X_A - X)^2, \qquad (5)$$

where K is constant coefficient depending on the ADF dynamics of and slopes erosion (abrasion) intensity; Sum$U_{(Xa)} = 3 \times 10^3$ m^3/yr; and $X_A = 2500$ m.

Let us calculate the K value at $X = 0$, Sum$U_{(0)} = 0$:

$$K = 4.8 \times 10^{-4} \text{ (m/yr)}.$$

$$\mathrm{Sum}U_{(x)} = 3000 \text{ m}^3\text{/yr} - 4.8 \times 10^{-4}(2500 \text{ m} - X)^2, \qquad (6)$$

$$V_{(x)} = k\mathrm{Sum}U_{(x)} = 0.6(3000 - 4.8 \times 10^{-4}(2500\text{m} - X)^2). \qquad (7)$$

One can obtain the $C_{(x)\mathrm{av}}$ value, which is needed for the calculation of $q_{(x)}$, from the factual data on the sampling of bottom sediments across the entire thickness of the active debris layer or the mathematical simulation data on the Sn content during its transport to the ADF. Originally, the mathematical model suitable for this purpose was developed for the local prognosis of placer parameters in geological prospecting. When its adequacy to real geological objects was proved (Lalomov and Tabolich, 1994), this model was also used for calculations of the placer formation time.

Thus, using $Q_{(x)}$ values known from geological reconnaissance and calculated $q_{(x)}$ values, it is possible to determine the real dating $T_{(x)}$ of the placer sector situated downward the ADF from any studied cross section.

In this paper, the time of placer formation has been calculated for two nodal points, namely the lower (downstream) point of Sn-bearing material input ($X = 500$ m) and the ADF saturation zone, where the abrasion regime gives way to the debris transit regime ($X = 2500$ m).

It should be noted that dating with the help of $C_{(x)\mathrm{av}}$, which is calculated in accordance with the above mathematical model, has a higher degree of reliability, because this method allows us to avoid errors caused by (1) discreteness of bottom sediments sampling; (2) inaccuracy of the Sn content determination in a small volume of samples from bottom sediments with a heterogeneous distribution of this element; and (3) laboratory (analytical) error.

Thus, the dating of placer based on modeling data is most preferable, because this allows us to eliminate errors caused by the use of direct factual data.

Results of the calculation of placer formation time $T_{(x)}$ based on factual and modeling data are shown in the table. They indicate that the real time of formation of the Val'kumei placer is approximately 2–4 ka. This value is equal to ~0.04–0.07% of the stratigraphic age of lower horizons of the Pliocene placer-hosting deposits (5.3 Ma, according to the generally accepted geochronological scale).

DISCUSSION

Dating based on Eq. (2) only yields the time needed for placer formation at the current rate of geological processes rather than its precise age. This is one of the possible disputable moments in the determination of real age by the proposed method. Except for a short and intense period of placer accumulation, the remaining period of the placer can theoretically be characterized by stagnant state (i.e., any processes of input and output of components are absent). However, the detailed study of the geological sequence showed that this supposition is invalid. Sedimentation in the Arctic region from the beginning of the Pliocene did not differ much from the recent one, except for the short-term Quaternary glaciation period. The total duration of Quaternary glaciations covers a time span of 600–20 ka ago (*Geologicheskii...*, 1960). This period is characterized by one local erosion boundary in the Pliocene–Quaternary placer section (Patyk-Kara and Ivanova, 2003; Fig. 71). Data on the specific lithological section of a placer and global paleosedimentary processes indicate that their intensity only slightly changed with time (Romanovskii, 1988). If the general contour of the sea is preserved, changes in the lithodynamic regime of

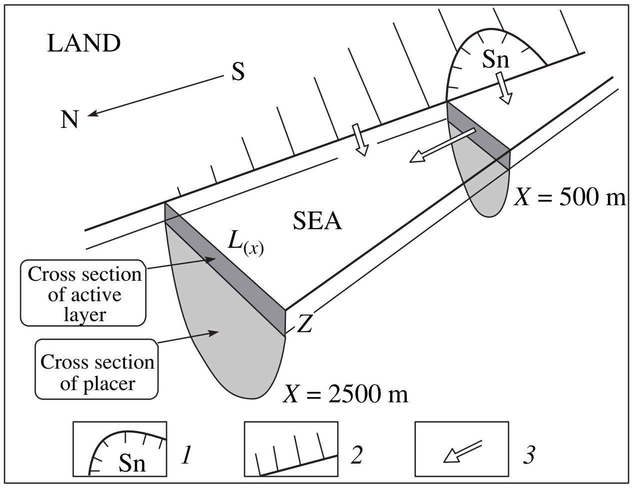
Calculation of the time of placer formation

X (m)	$V_{(X)}$ (m^3/yr)	$Q_{(X)}$ (t)	$C_{(X)av}$ (g/m^3)		$T_{(X)}$ (yr)	
			measured	calculated from the model	measured	calculated from the model
500	648	7000	5066	2854	2132	3785
2500	1800	2400	455	427	2930	3123

Note: Analysis of relative error in the calculations shows that the total relative error can be as much as 80–100% due to some uncertainty in the accepted data. Therefore, $T_{(av)}$ values given in the table (accurate to 1 yr) are **mean** values with a large relative error and one can speak only about the **order** of obtained values.

shores with time are generally insignificant and almost independent of climatic factors (Zenkovich, 1962). This is confirmed by investigations of the structure of the Val'kumei placer (Patyk-Kara and Ivanova, 2003).

The second important source of discrepancy between the calculated and stratigraphic ages is related to the possibility of cassiterite evacuation from the placer zone. This can lead to a significant reduction of the $Q_{(x)}$ value and the consequent proportional decrease of $T_{(x)}$. Nevertheless, the impact of this process on the dating of placer is negligible, because the recent placer contour at the level exceeding the local background value generally coincides with the zone of active debris lithodynamics (i.e., the boundary between silts and black organic-rich silty–pelitic muds). Results of the detailed geological prospecting made it possible to confidently outline the placer boundary on both offshore and ADF sides. The chemical analysis of bulk ore samples (without preliminary washing and separation of heavy fractions) yielded the total Sn content in sediments irrespective of the cassiterite grain size. The total Sn content in muds beyond the lithodynamically active zone does not exceed 2% of its total reserve in the placer.



Block-diagram illustrating the method for calculating the real time of placer formation. (Z) Thickness of the layer of active sediment transport under the influence of waves and currents; ($L_{(x)}$) width of the active zone in section X, X distance from the ADF origin. (*1*) Source of placer-forming component, (*2*) abrasion zone, (*3*) direction of clastic material transport.

Thus, the available data testify to a sufficiently complete settling of all cassiterite fractions within the placer boundary. Moreover, they indicate that the whole material delivered to the placer area (first of all, heavy fractions of sediments) settles in the proximal zone due to a low hydrodynamic activity in the water area of the Chaun Gulf.

Changes in parameters of the cassiterite provenance, which participated in the placer formation, were probably insignificant. Relative to the total vertical interval of mineralization (more than 200 m), the erosion level of ore zones of the Val'kumei Massif involved in the formation of the studied (coastal-marine) part of the placer does not exceed 10%. Consequently, we can suppose that parameters of the exposed cassiterite-bearing bedrocks did not change much during the development of the placer section involved in our calculations, and the influence of the value indicated above on the results of calculations is negligible.

Accuracy of the determination of placer formation duration can be disputed because of several assumptions in the calculations. It is worth mentioning that accuracy of the calculation of reserves used for the determination of placer age does not exceed 20–30% (*Metodicheskoe…*, 1982). Thus, accuracy of the dating of placers depends, first and foremost, on the accuracy of reserve calculation. The adopted assumptions might affect the final result. However, it is essential that the obtained placer formation duration is obviously several orders of magnitude less than the generally accepted age of Cenozoic geological boundaries.

CONCLUSIONS

Thus, it is unlikely that discrepancy between the real dating and stratigraphic age of the Val'kumei placer is provoked by the extrapolation of recent data to ancient processes or their oversimplification (Lalomov, 2003a).

Difference in notions "sedimentation rate" and "sediment accumulation rate" is widely discussed in recent geological publications (Baikov and Sedletskii, 2001). This difference is commonly related to injective sedimentogenesis when short periods of real sedimentation alternate with prolonged hiatuses. Such sedimentation conditions, most typical of turbidite accumulation, are also observed in coastal parts of basins. For example, sedimentation and accumulations rates are ten times different on the shelf adjoining the Yangtze River delta (Romanovskii, 1988); i.e., duration of latent hiatuses is ten times longer than that of the real sedimentation. Only a tiny share (0.01–0.001%) of the total time of sedimentation in shallow-water zones is usually documented because of the abundance of latent hiatuses (Meyen, 1989, p. 24).

Based on the analysis of tidal cycles, Kulyamin and Smirnov established that the pure deposition period of Cambrian–Ordovician sandstones in the Baltic region is surprisingly short (approximately 170 days, including a mere 133 days for Middle– Upper Cambrian Sablinsk sandstones and 40 days for Lower Ordovician Pakerort sandstones), because of an extremely poor preservation of sediments in the studied sequences with respect to the stratigraphic time range (Kulyamin and Smirnov, 1973, p. 699).

Study of analogous sediments in the Leningrad district also showed that the pure deposition time of Lower Paleozoic sands is estimated at 100–200 yr. The geological time of the Sablinsk sequence formation is 10–20 Ma (Tugarova *et al.*, 2001, p. 89). These authors explain the above paradox by the multiple rewashing of sediments in shallow-water zones with an active lithodynamics characterized by alternations of sedimentation and seafloor abrasion depending on the force of gales and currents.

We estimated duration of the Val'kumei placer formation based on the analysis of the recent rate of cassiterite input to the coastal zone and the total amount of tin in the placer. There are all grounds to suppose that the intensity of lithodynamic processes and Sn content in the provenance remained approximately constant during the coastal-marine placer formation. Signs of a significant removal of fine cassiterite fractions from the placer into the lithodynamically inactive zone are also lacking. We should carry out additional investigations in order to reconstruct specific paleoconditions of the accumulation of sediments in placers and elucidate processes that are responsible for the absence of erosion in the adjoining land and (or) accumulation of sediments within the Val'kumei placer.

This work has raised a number of issues that remain to be solved in the future. Therefore, we propose to discuss in press the possible reasons of the discrepancy between the real and stratigraphic age of placers (in particular, the Val'kumei placer) and the influence of the discrepancy on placer formation.

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