ГЕОМОРФОЛОГИЯ И ПАЛЕОГЕОГРАФИЯ, 2023, том 54, № 4, с. 226–237

ПАЛЕОЛИМНОЛОГИЧЕСКИЕ ИССЛЕДОВАНИЯ В РОССИИ: ОТ КАЛИНИНГРАДА ДО КАМЧАТКИ

УДК 551.89:551.4.04(-925.18)

GEOMORPHOLOGICAL PROCESSES IN THE CENTRAL KAMCHATKA DEPRESSION (THE KAMCHATKA PENINSULA, NE PACIFIC) DURING THE LAST 30 Ka#

© 2023 г. E. A. Zelenin[1,*], A. L. Gurinov[2,4,5], A. L. Zakharov[2], V. V. Ponomareva[3], and S. T. Garipova[1]

[1]Geological Institute, Russian Academy of Sciences, Moscow, Russia
[2]Institute of Geography, Russian Academy of Sciences, Moscow, Russia
[3]Institute of Volcanology and Seismology, Petropavlovsk-Kamchatsky, Russia
[4]National Research University Higher School of Economics, Moscow, Russia
[5]Peoples' Friendship University of Russia (RUDN University), Moscow, Russian Federation
*E-mail: egor.zelenin@ginras.ru; egorzelenin@mail.ru

Received April 17, 2023; revised August 10, 2023; accepted September 8, 2023

The paper presents a reconstruction of geomorphological processes in the Central Kamchatka Depression (CKD) since 30 ka, including the global LGM time. Major geomorphological processes of this period included the evolution of volcanic edifices accompanied by steady tectonic submergence. Glaciers that originated from volcanic edifices were greatly affected by both climatic forcing and the eruptive history of their host volcanoes.

The most prominent geomorphological feature of the studied time was a giant paleolake filled the CKD. The reassessed extent and timing of glaciation and volcanism provided the possible lake fill and discharge model due to the evolution of a piedmont glacier originating from the Old Shiveluch Volcano edifice. The lake discharge likely was gradual and started some 19 ka during the cold settings of LGM, and therefore did not have a climatic origin. The most possible trigger of the discharge is the change in ice supply from the highly active Shiveluch Volcano due to large sector collapses. During the Holocene, the ongoing tectonic submergence of the CKD have been preventing the complete drainage of this paleolake. Even now, an enormously wide floodplain of the Kamchatka River hosts a lacustrine system with a total area of water surface comparable to the largest lakes of the peninsula.

Keywords: Kamchatka Peninsula, Late Pleistocene, proglacial lake, active tectonics, volcanic landforms, Last Glacial Maximum

DOI: 10.31857/S2949178923040175, **EDN:** GLJFRD

INTRODUCTION

The Kamchatka Peninsula is located at the eastern active margin of NE Eurasia, above the northernmost portion of the Kuril-Kamchatka subduction zone (fig. 1, (a, c)). Its landmass has emerged due to the successive accretion of island arc blocks during the Cenozoic (e.g. Konstantinovskaya, 2003; Avdeiko et al., 2007; Lander, Shapiro, 2007). As a result, the Kamchatka Peninsula is much broader than the typical island arc, up to 400 km, and has a unique topography (fig. 1, (b, c)) comprising Sredinny Range and Eastern ranges, running for more than 500 km along the peninsula, with the Central Kamchatka Depression (CKD) between them. The sharp boundary of the CKD and Eastern Ranges is the East Kamchatka Fault Zone (EKFZ), a major zone of normal active faults (Kozhurin et al., 2006). This fault zone and the general pattern of mountains and lowlands were interpreted as a surface expression of arc-normal crustal extension due to subduction zone rollback (Kozhurin, Zelenin, 2017). The tectonics and volcanism have shaped the terrain of Kamchatka. Two volcanic belts, Sredinny Range (SR) and Eastern volcanic belt (EVB), comprising more than thirty active volcanoes, run along the peninsula.

Extensive geomorphological studies were conducted in the Kamchatka Peninsula in the 20th century (e.g. Kushev, Liverovsky, 1940; Braitseva et al., 1968; Kuprina, 1970; Kamchatka, Kurilskie ..., 1974). They have provided a general overview of the landforms and developed a chronological model of terrain development. However, due to the lack of absolute dates, these studies relied mainly on the global-scale chronology of glaciations and the relative age of landforms. The re-

For citation: Zelenin E.A., Gurinov A.L., Zakharov A.L. et al. (2023). Geomorphological processes in the Central Kamchatka Depression (the Kamchatka Peninsula, NE Pacific) since the global Last Glacial Maximum. *Geomorfologiya i paleogeografiya*. Vol. 54. No. 4. P. 226–237. https://doi.org/10.31857/S2949178923040175; https://elibrary.ru/GLJFRD

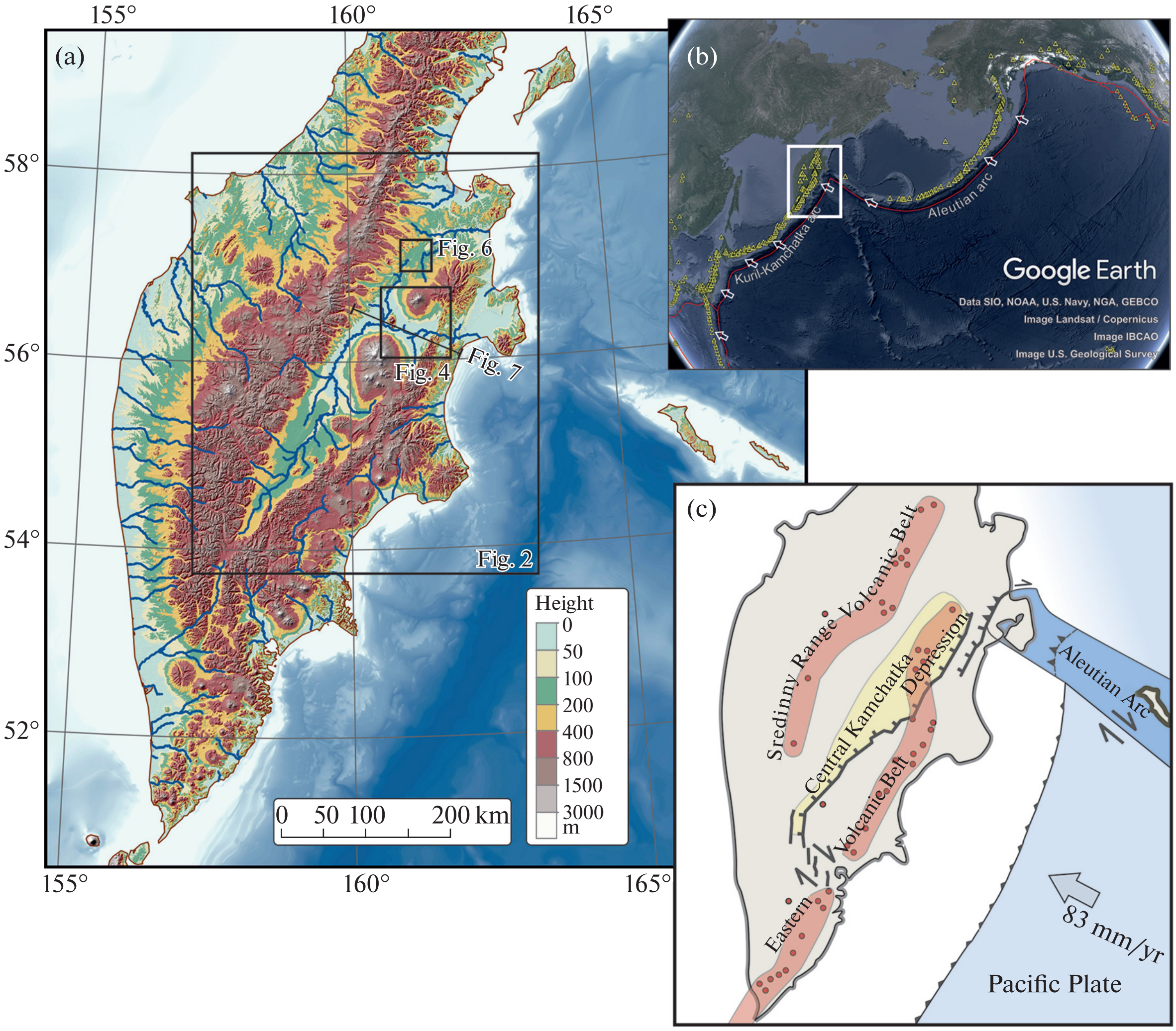

Fig. 1. (a) – The topography and drainage pattern of the Kamchatka Peninsula; (b) – The pattern of plate boundaries in the NW Pacific (yellow triangles, Holocene volcanoes (Smithsonian Global Volcanism Program, https://volcano.si.edu/), white arrows, relative direction of the Pacific Plate motion); (c) – Main tectonic features of the Kamchatka Peninsula. Volcanic belt of the Sredinny Range and the Eastern Volcanic Belt are outlined with red, Holocene volcanic centres (Ponomareva et al., 2007) are indicated with red points. Faults are black lines with hatches for normal faults, triangles for reverse and thrust faults, and one-sided arrows for strike-slip faults (Kozhurin, Zelenin, 2017).

Рис. 1. (a) – рельеф и речная сеть п-ова Камчатка; (b) – границы литосферных плит в северо-западной части Тихого океана (желтые треугольники – голоценовые вулканы (Smithsonian Global Volcanism Program, https://volcano.si.edu/), белые стрелки – относительное направление движения Тихоокеанской плиты); (c) – современная геологическая структура п-ова Камчатка. Вулканический пояс Срединного хребта и Восточный вулканический пояс показаны красной заливкой, голоценовые вулканы обозначены красными точками (Пономарева и др., 2007). Разломы – черные линии со штрихами (сбросы), треугольниками (взбросы и надвиги) или стрелками (сдвиги) (Кожурин, Зеленин, 2017).

sults of these studies included the model of the Late Pleistocene glaciations comprising two phases: Phase I, with an ice cap over most of the peninsula, and Phase II, which produced piedmont and valley glaciers (Braitseva, Melekestsev, 1974). A series of outcrops along the CKD that recorded a succession of lacustrine, fluvial and glacial deposits were described; however, the ages for various units remained unresolved, and their estimates ranged from the Early to the Late Pleistocene (Braitseva et al., 1968; Kuprina, 1970; Pevzner, 2019).

After that, only few studies focused on the geomorphology of the Kamchatka Peninsula. Most of the geomorphological studies in the Kamchatka Peninsula discussed the evolution of volcanic landforms (e.g., Ponomareva et al., 2006) and fluvial response to it (e.g., Lebedeva et al., 2020) or active tectonics (e.g., Kozhurin et al., 2006; Pedoja et al., 2013; Pinegina et al., 2020). Some data were provided for Holocene fluvial processes in the CKD (e.g., Pevzner et al., 2006, 20; Karimov et al., 2020). Few studies added to the Pleistocene geomorphology of the peninsula at some local sites: key outcrops of the Last Glacial Maximum (LGM) glacial facies in the Pakhcha valley (Krayevaya, Kuralenko, 1983), the largest Late Glacial sector collapses of the Shiveluch volcano (Pevzner et al., 2013; Ponomareva et al., 2014).

In recent years, the Holocene tephrochronological framework (Braitseva et al., 1997) was extended in the Late Pleistocene down to 30 ka (Ponomareva et al., 2021). Tephra correlations have integrated formerly disparate geomorphological studies and permitted the reconstruction of landscapes in the CKD during the global LGM time spanning 33–19 ka (Clark et al., 2009) and after that until the Holocene.

In this paper, the evolution of the CKD topography during the last 30 ka is discussed. The study is mainly based on published data that have been reviewed after creating the tephrochronological reference for the studied time (Ponomareva et al., 2021). These include paleovolcanological studies and studies of late Quaternary landscape dynamics, although the latter was conducted mainly in the mid-20th century. A GIS-based geomorphological mapping was conducted to provide the spatial background for the studied period. The mapping relies on SRTM 1-arc-second GDEM and ArcticDEM v.3 digital terrain model and their derivatives, supplemented by high-resolution satellite imagery and georeferenced maps from published studies (Braitseva et al., 1968; Braitseva and Melekestsev, 1974; Ponomareva et al., 2007; Barr, Solomina, 2014; Kozhurin, Zelenin, 2017). Extensive field geomorphological surveys have allowed us to verify the mapping results.

STUDY AREA

The Central Kamchatka Depression (CKD) is the largest sedimentary basin in the Kamchatka Peninsula and all the island arcs of the North Pacific with a size of 400×100 km. Its modern floor is ~2 km lower than the bounding ranges, and the thickness of its sedimentary fill reaches 600 m (Kamchatka, Kurilskie ..., 1974). As a tectonic structure, it is a half-graben – an asymmetric basin with a sharp eastern border created by the faults of the EKFZ. Due to the normal slip occurring at this fault zone, the CKD has been submerging at least since the Middle Pleistocene (Kozhurin, Zelenin, 2017). The age of the CKD is ambiguous, with estimates varying between the Eopleisocene (the Calabrian Age) (Ozornina, 2011) and the Miocene (Avdeiko et al., 2007).

CKD hosts the largest and most active volcanoes of the Kamchatka Peninsula. These include the composite Shiveluch Volcano in the north and the Kliuchevskoi volcanic group in the south. Some of these volcanoes, such as the Plosky volcanic massif, originated in the Late Pleistocene and were active until the early Holocene (Ponomareva et al., 2013). In addition, some CKD volcanoes that did not produce Holocene eruptions and are considered extinct were active in the Late Pleistocene within the period under study: these are Zarechny, Bolshaya Udina, and many monogenetic cones related to the Plosky volcanic massive and the zones near Kharchinsky Lake and north of the Shiveluch Volcano.

The geomorphological studies of Braitseva et al. (1968) and Melekestsev et al. (1974) revealed that the CKD was greatly affected by the glaciation of the Last Glacial Period with two distinctive phases sharply different in their extent. The glaciation of Phase I created an ice cap that covered most of the peninsula and smoothed the preexisting terrain. Phase II produced much less ice that was mostly constrained within the mountain valleys of the Sredinny range and volcanic edifices of the EVB and CKD, whereas few glaciers existed in the Eastern Ranges. The age of Phase II was then estimated to be some 25 ka, relying on the only dated mammoth skull (Krayevaya, Kuralenko, 1983).

After the deglaciation, the CKD has become an area of fluvial processes. The modern CKD is drained by the Kamchatka River and its tributaries. The general drainage pattern (fig. 2) follows the axis of the CKD, but in the north, the Kamchatka River turns eastward and flows between the Kliuchevskoi Volcanic Group and the Shiveluch Volcano and then incises through the Kumroch Range, the northernmost of the Eastern Ranges. Further north, the drainage divide between the Kamchatka River and the Ozernaya River basins traces the gradual northern termination of the CKD half-graben structure.

Sedimentary fill of the CKD comprises the succession of lacustrine, fluvial and glacial deposits. Among them, the most debatable is the age and origin of lacustrine deposits (Braitseva et al., 1968; Kuprina, 1970, Ponomareva et al., 2021). The lowermost deposits outcropping in the CKD are the "blue clays" sequence – an interbedding of bluish-grey loams and fine sands with a large number of tephra layers yet to be identified. The "blue clays" were interpreted as the deepwater sediments of a lake that once filled the CKD; its age was arbitrarily assigned to the Early Pleistocene on the basis of palynological and diatom analyses (Braitseva et al., 1968; Kuprina, 1970). However, recent reviews (Braitseva et al., 2005) argue the Middle Pleistocene age of this sequence. No evidence of possible coastlines or a dam location of the "blue clays" basin remained in the landscapes of the Kamchatka Peninsula. A more recent sedimentary unit is the "sand massif" dividing the basins of the Kamchatka River and the Karakovaya River (fig. 2) with a ~100 m high bar that runs for ~70 km. It was considered either an inland delta (Braitseva et al., 1968) or a subaqueous delta in a large lake (Kuprina, 1970) of the Middle to Late Pleistocene age. These data suggest that the CKD may repeatedly host vast water bodies interchanged with glacial and erosional periods.

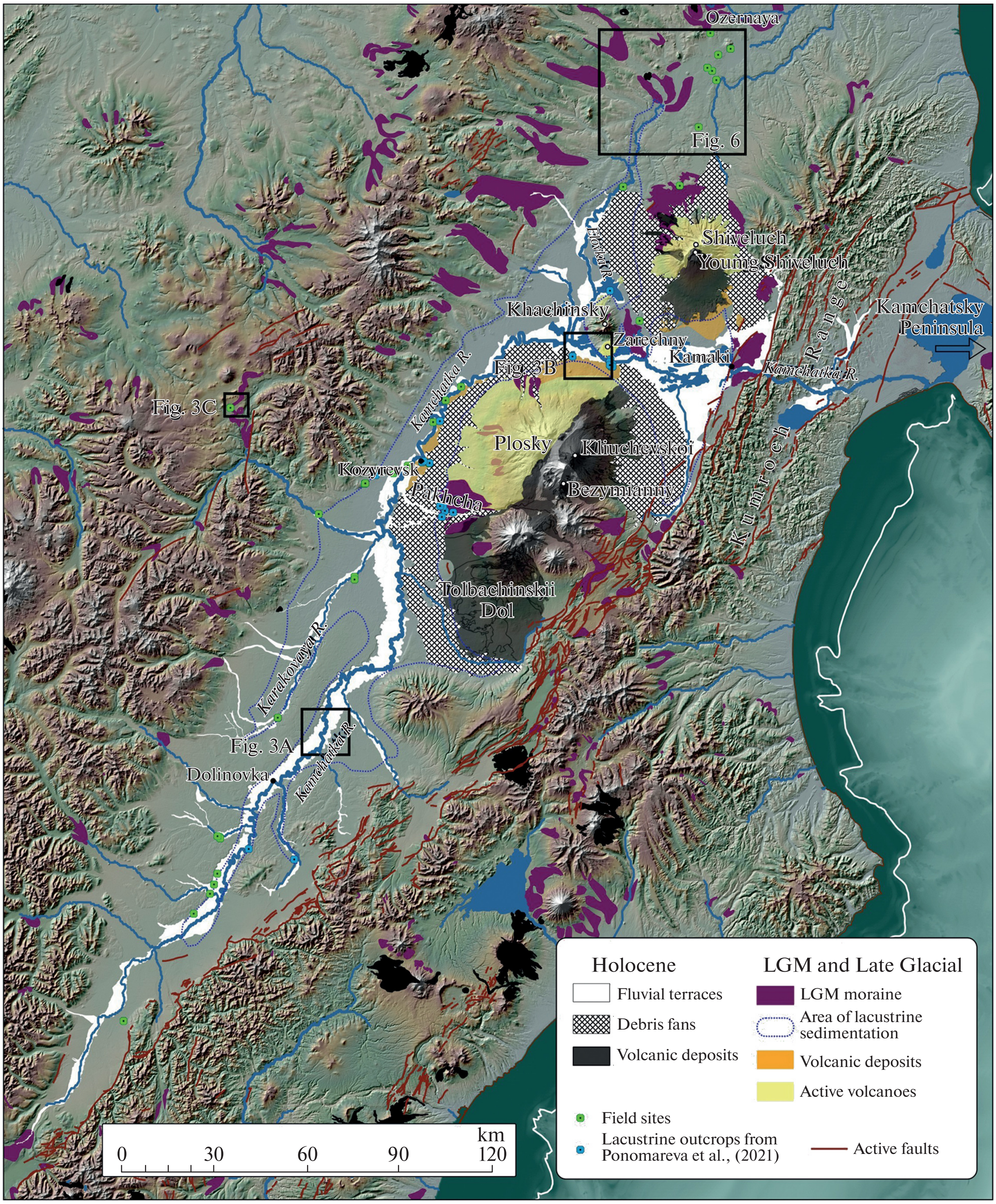

Fig. 2. The topography of the Central Kamchatka Depression. Note that the entire CKD belongs to the basin of the Kamchatka River with its modern channel crossing LGM moraine and the East Kamchatka Fault Zone. An isobath of 150 m is shown as a rough approximation of the coastline during the LGM.

Рис. 2. Рельеф Центральной Камчатской депрессии (ЦКД). Вся ЦКД относится к бассейну реки Камчатка с ее современным руслом, пересекающим морену максимума последнего оледенения и Восточно-Камчатскую зону разломов. Приблизительное положение береговой линии во время максимума последнего оледенения показано изобатой 150 (белая линия).

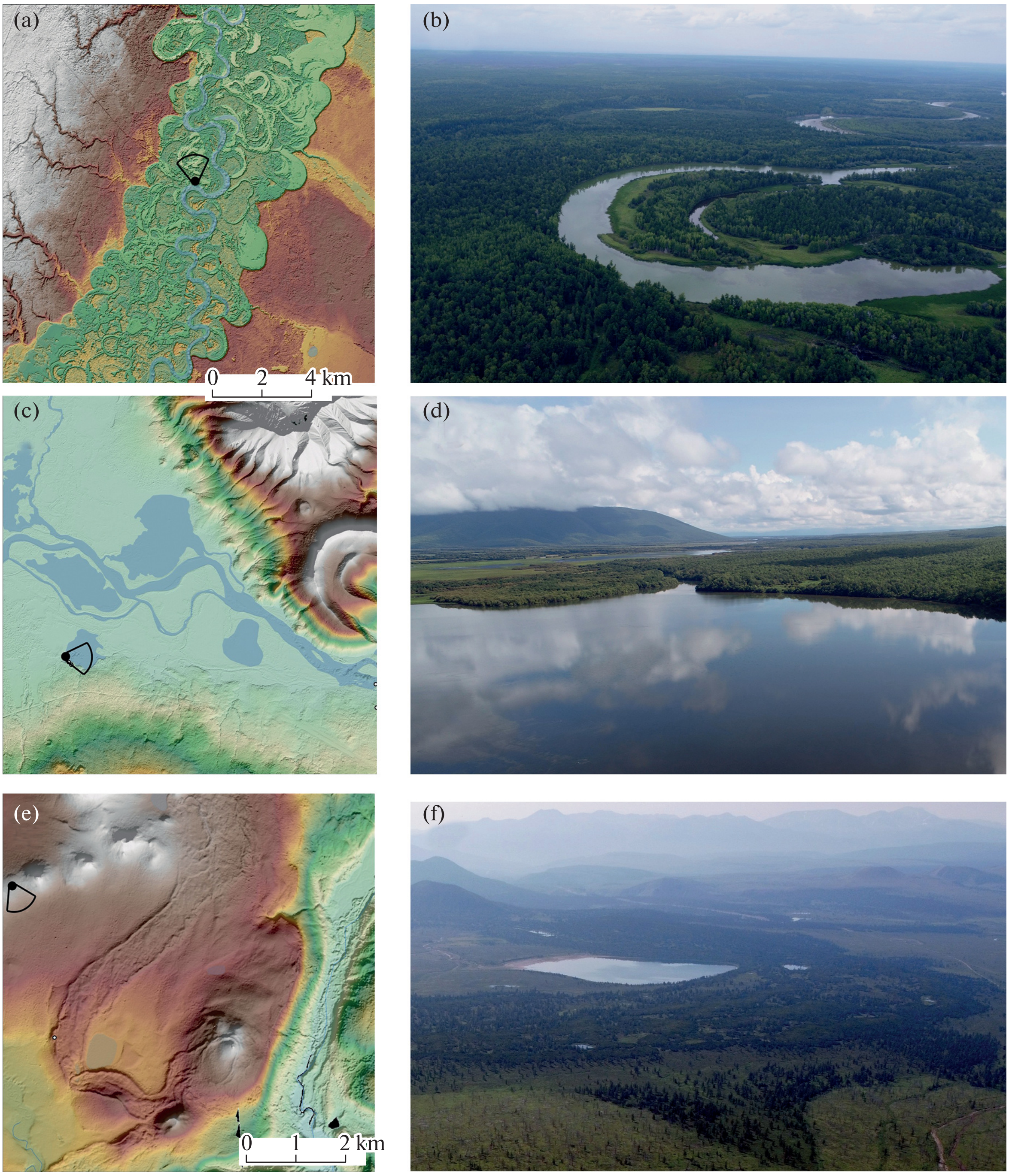

Fig. 3. Examples of interpretation of the ArcticDEM digital elevation model and oblique aerial photos (the view sector is shown on the DEMs). (a, b) – Kamchatka River meandering within floodplain; (c, d) – Braided channels and floodplain lakes in the lower reaches of the Kamchatka River. The right bank on (d) is a front of 30 ka lava sheets draped with lacustrine sediments; (e, f) – End moraine ridge bounding ground moraine of the Last Glacial Maximum.

Рис. 3. Примеры интерпретации цифровой модели рельефа ArcticDEM в сравнении со снимками с квадрокоптера (направление съемки показано на ЦМР). (a, b) – пойма и меандрирующее русло р. Камчатки; (c, d) – пойменная многорукавность и реликтовые озера в нижнем течении р. Камчатки. Правый борт долины на (d) сложен лавовыми потоками возрастом 30 тыс. л., перекрытыми озерными отложениями; (e, f) – конечно-моренная гряда, ограничивающая основную морену.

RESULTS

The LGM and the Late Glacial. During the entire Quaternary time, the general pattern of volcanic activity in the Kamchatka Peninsula (fig. 1, (c)) was similar to the modern (Avdeiko et al., 2007), whereas the individual volcanic centres may emerge or cease their activity. The greatest changes in the LGM and the

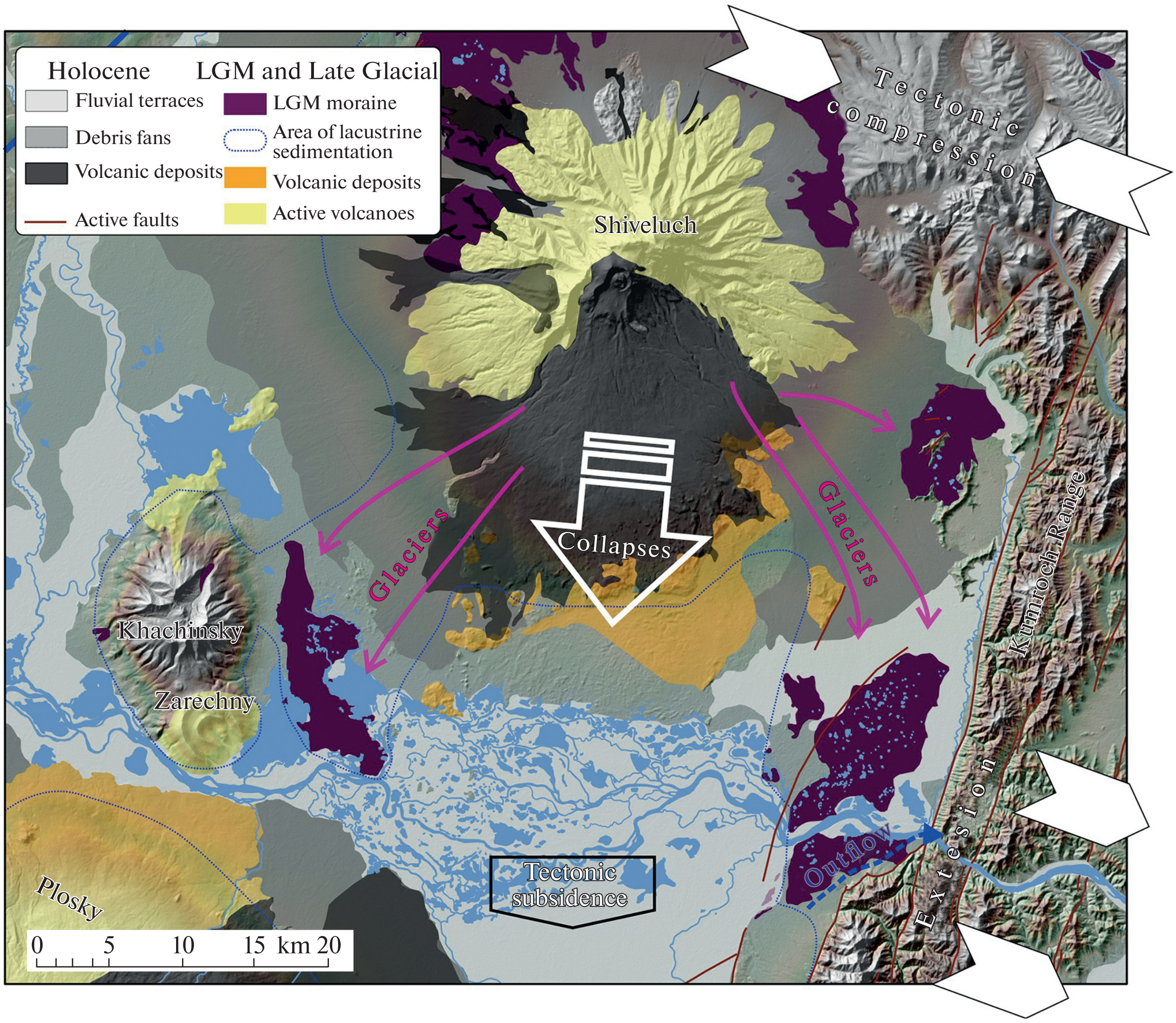

Fig. 4. The Kamchatka River valley at its outpour from the Central Kamchatka Depression. Arrows show major geomorphological processes during the LGM and the Late Glacial.

Рис. 4. Долина р. Камчатки на выходе из ЦКД. Стрелками показаны основные геоморфологические процессы, действовавшие в регионе начиная с максимума последнего оледенения.

Late Glacial happened in the Kliuchevskoi group of volcanoes (fig. 2). Here, the Plosky group of volcanoes and associated monogenetic vents were the main volcanic centres of the group during the LGM (Churikova et al., 2015). Lava sheets around the Plosky volcanoes, dated back to ca. 30 ka (Ponomareva et al., 2021), preserved the overlying tephra-bearing sediments from erosion, thus providing the older limit of study. North of the Kliuchevskoi group, the Zarechny and Kharchinsky volcanoes form an isolated massif, partially submerged below the CKD floor (fig. 3, (c, d)). Kharchinsky has been greatly eroded by Pleistocene glaciations (fig. 4) and overlapped with the Late Pleistocene zone of monogenetic vents (Volynets et al., 1999); no tephras of the Kharchinsky Volcano is known in the studied period, which indicates that it had ceased its activity before 30 ka. Its neighbour, the Zarechny Volcano, is a nested edifice with a lava dome in an open inner cone (Zarechny II) hosted in a collapse crater of older Zarechny I. They have not experienced glaciations and are little eroded (fig. 4). Zarechny II produced several explosions recorded in tephra sequences 21–19 ka (Ponomareva et al., 2021). Even though sector collapses repeatedly destroyed the eastern slope of the Zarechny Volcano, their deposits are now entirely buried below the Holocene floodplain. Further north, the Shiveluch Volcano is the northernmost active volcano in the Kamchatka Peninsula. It has been highly explosive throughout history and produced large sector collapses southward. The largest collapses happened in the Late Glacial, even though their accurate time is debatable (Pevzner et al., 2013; Ponomareva et al., 2006, 2014).

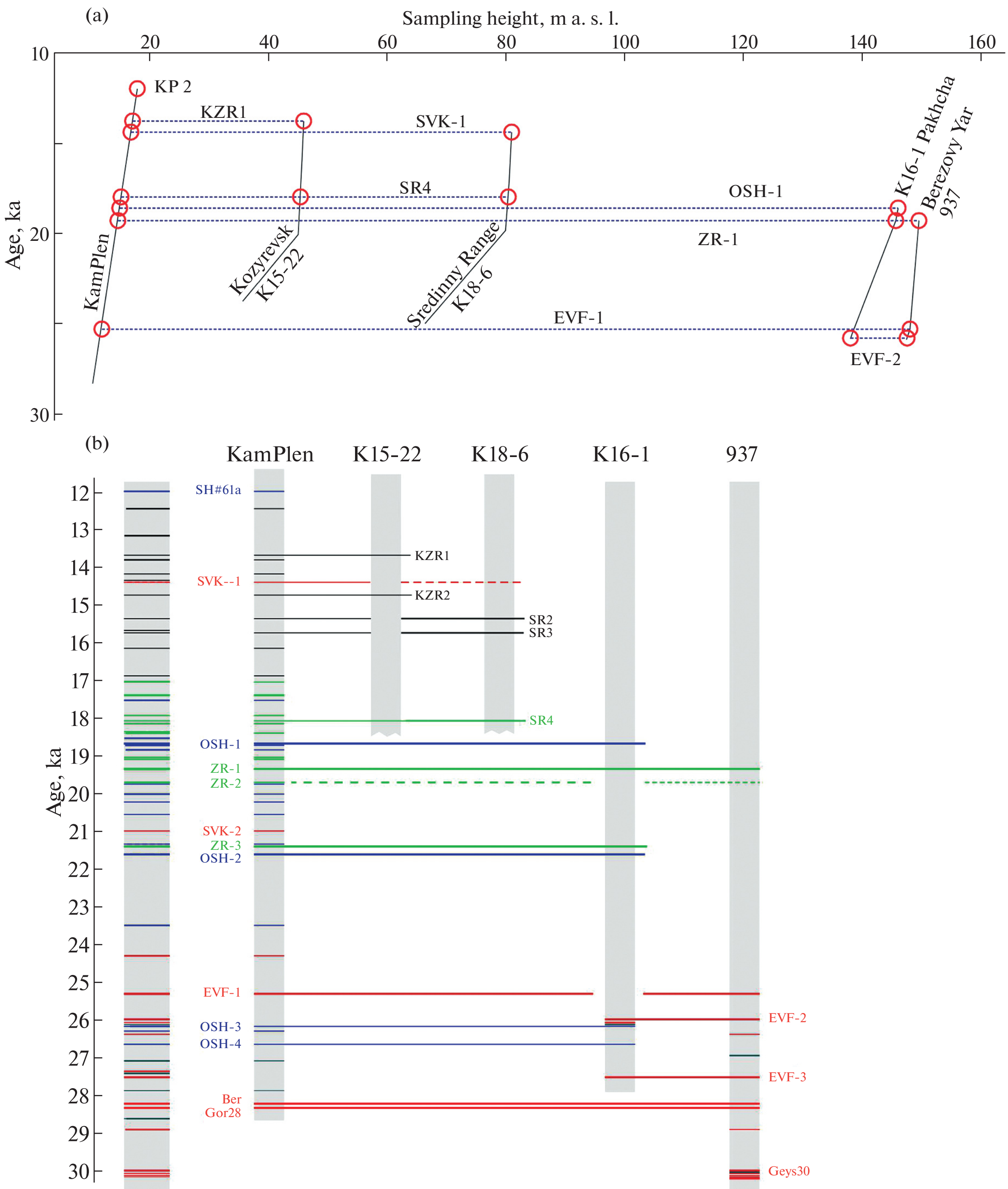

Fig. 5. Tephra sequences in the Late Pleistocene lacustrine deposits (Ponomareva et al., 2021). (a) – Major marker tephra layers found in individual sites aligned by the height of the outcrops. Tephra layers topping the studied sites are indicated and labeled in italics. Note that individual tephras may be absent in the outcrop due to ash-fall heterogeneities, but the overall trend marks the decrease of paleolake level. Source volcanoes are known for *KP2, KZR1, OSH-1* – Shiveluch Volcano and for *SR-4, ZR-1* – Zarechny Volcano. Tephras *EVF-1, EVF-2* originated from unknown volcanoes in the frontal zone of the Eastern Volcanic Belt and *SVK-1* – from unknown source in the Sredinny Range. (b) – A complete summary tephra sequence of the studied period and its correlation to the tephra sequences of individual sites. Tephras are color-coded according to their origin: Green – Zarechny Volcano, blue and black – Shiveluch Volcano (black for vents of the Baidarny Spur), red – distal sources. Sh#61a marks the beginning of the soil-pyroclastic sequence deposition.

Рис. 5. Тефростратиграфия позднеплейстоценовых озерных отложений ЦКД (Пономарева и др., 2021). (а) – основные маркирующие горизонты тефры, упорядоченные по высоте обнажений (Индексы горизонтов подписаны курсивом). Несмотря на то что отдельные горизонты тефры могут отсутствовать в разрезах, общая тенденция указывает на посте-

Even though LGM was a global event, its timing and extent varied greatly among regions. Glacial landforms of the most recent glaciation in the Kamchatka Peninsula were initially mapped by Braitseva et al. (1968) and Melekestsev et al. (1974) as Phase II of the Late Pleistocene glaciation and then reviewed by Barr and Clark (2012) and later by Barr and Solomina (2014). However, these studies lacked spatial detail and provided no data on the time of the glaciation onset and retreat. In the Kamchatka Peninsula, the age estimates of the LGM rely only on the glacial deposits outcropping in the Pakhcha River valley (Krayevaya and Kuralenko, 1983) dated using tephrochronology (Ponomareva et al., 2021). The two advances of glaciers have been identified there with a retreat at 26–18 ka; however, the moraine of the two advances is indiscernible in topography. The study of the LGM pollen spectra in the CKD (Mukhametshina et al., 2022) indicated that the steady warming established here some 12.5 ka.

The LGM moraines around the CKD are well-preserved hummocky terrain confined to mountain valleys or spreading at foothills as Malaspina-like piedmont glaciers (fig. 3, (c)). Its location and topography sharply differ from older moraines and landforms of other origins, allowing us to map LGM moraines and review the published small-scale maps with higher accuracy.

Among the piedmont moraines, the most prominent is the moraine that spread southward from the Shiveluch Volcano across the Kamchatka River at the former settlement of Kamaki. It has a relative height reaching 40 m above the valley floor just at the modern river channel. It was first interpreted as deposits of a lateral blast of the Shiveluch Volcano (Krayevaya, 1970). However, the provided field description was indiscernible from a glacial till with glaciofluvial facies, and such an interpretation was proposed by I.V. Melekestsev and O.A. Braitseva (personal communication). The latter studies of debris avalanches in the Kamchatka Peninsula pointed out that the transit distance of an avalanche does not exceed its drop height multiplied by 11 (Ponomareva et al., 2006), which makes a 45-km-long runoff unlikely to occur at the ~3-km-high edifice of the Shiveluch Volcano.

In the studied period, 10–30 ka, lacustrine deposits accumulated in the CKD across a vast area roughly bounded by a contour of 160 m (Ponomareva et al., 2021). These deposits imbricate the underlying topography with a cover up to 10 m thick. Most deposits were attributed to suspension-settling facies of fine-grained rhythmites with quasi-parallel bedding highlighted by tephra layers, whereas sandy gravel diamicts of subaqueous outwash fans were identified as well (Ponomareva et al., 2021).

A tephrochronological record in the studied outcrops cannot provide an exact age for the LGM paleolake discharge. However, when sorted by their elevation, the individual tephra sequences demonstrate that the hiatus in the lacustrine sedimentation started from the highest sites (fig. 5) some after ZR-1 tephra fall (19.3 ka) and then reached lower levels some after the ash-fall of SVK-1 (14.4 ka).

Holocene. Tephrochronological-based paleovolcanological studies provided data for the extent of Holocene volcanic deposits that completely bury the preceding landscape. In the area of study, those are the edifices of Kliuchevskoi and Bezymianny volcanoes (Melekestsev et al., 1974) with taluses sloping N and E from them, Young Shiveluch Volcano nested on the south slope of Pleistocene Shiveluch stratovolcano (Ponomareva et al., 2007), and monogenetic centres of Tolbachinsky Dol (Churikova et al., 2015) and of Plosky (Ushkovsky) Volcano (Ponomareva et al., 2013) with associated lava flows (fig. 2).

Kamchatka River and its tributaries significantly transform most of the CKD floor. The extent of their floodplain is indicated by a belt of free meandering and braided channels (fig. 3, (a, b)). Historical data for the 21st century (https://allrivers.info) provides maximum levels of flooding of 688 cm at the settlement of Dolinovka and 492 cm at the settlement of Kozyrevsk that support the morphological indicators. For some sites, Holocene fluvial terraces were dated by ^{14}C (Karimov et al., 2020) or tephrochronological dating (Pevzner et al., 2006).

DISCUSSION

The regional stage of lacustrine sedimentation was identified in the Late Glacial of the CKD since 30 ka (Ponomareva et al., 2021). During that time, the piedmont glaciers blocked the valley of the Kamchatka River (fig. 4) and caused the fill of a large lake reaching a depth of 150 m (Ponomareva et al., 2021). The period of its discharge, ca. 19–14 ka, falls within the cold period of the LGM (Mukhametshina et al., 2022) and therefore is unlikely to be caused by the retreat of glaciers. The sector collapse I at the Old Shiveluch volcano is estimated to occur ca. 16 ka; the age is extrapolated from a set of dates ca. 5 ka younger (Pevzner et al., 2013) and may have great uncertainty. However, the

пенное снижение высоты озерного осадконакопления. Источники пеплов *KP2, KZR1, OSH-1* – вулкан Шивелуч, *SR-4, ZR-1* – вулкан Заречный. Источники тефры *EVF-1, EVF-2* – неустановленные вулканы фронтальной зоны Восточного вулканического пояса, *SVK-1* – неустановленные вулканы в Срединном хребте; (b) – сводная тефростратиграфия изучаемого периода и вклад в нее отдельных разрезов. Цветом показано происхождение пеплов: зеленый – вулкан Заречный, синий и черный – вулкан Шивелуч (черный – Байдарный отрог), красный – прочие удаленные источники. Пепел SH#61a отмечает начало накопления субаэрального почвенно-пирокластического чехла.

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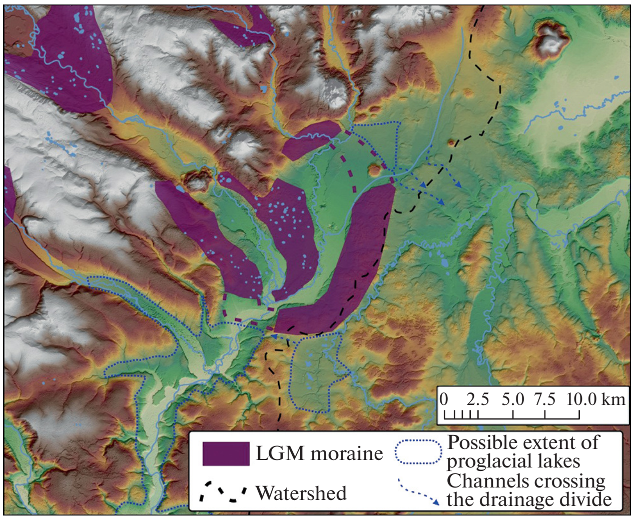

Fig. 6. The area of the drainage divide between the Kamchatka River and the Ozernaya River basins.

Рис. 6. Рельеф водораздела бассейнов рек Камчатка и Озерная.

glacier accumulation zone and transit pathways had to change dramatically after the collapse. Since then, Kamchatka River valley has been cutting through the moraine and lowering the lake water-level.

The narrow and morphologically young canyon of the modern outflow from the CKD suggests that there was another outflow during most of the Quaternary. I.V. Melekestsev (1974) first proposed the possibility of northward drainage but provided no age estimates for the changes in the drainage pattern. The maximum elevation of identified lacustrine deposits at 155 m a.s.l. reaches the northern drainage divide between the Kamchatka River and the Ozernaya River basins. However, the LGM moraine surpasses the possible overflow valley. With the height of a glacier added, the northern drainage required a much higher lake level to discharge northward. Indeed, no valleys comparable to the Kamchatka River valley have cut through the modern drainage divide (fig. 6), shaped by the pre-LGM Phase I glaciation some 50–30 ka (Barr and Solomina, 2014). Therefore, the drainage pattern of the CKD prior to the LGM was similar to the modern one, with an outflow eastward – across the Kumroch Range.

As the CKD has emerged and developed due to active tectonics (Melekestsev, 1974), the amount and distribution of deformations should be accounted for in any paleogeographic reconstructions. Known are the pattern of active faults and their sense (fig. 7), as well as the deformation rate estimate at the EKFZ further south (Kozhurin and Zelenin, 2017). Even though the fault zone topography on depth significantly affects the spatial distribution of surface deformations, it is still unknown. Moreover, the pattern of deformations rapidly changes above the northern tip of the subduction zone from slab rollback (Kozhurin, Zelenin, 2017) to arc-arc collision (Geist, Scholl, 1994). A belt of compression propagates westward from the Aleutians through the Kamchatsky peninsula (Kozhurin et al., 2014) and to the northern Kumroch and highlands north of Shiveluch. Submergence that created the CKD increases north and reaches its highest value somewhere at the lowest segment of Kumroch near the modern Kamchatka River valley, according to the model of Schellart et al. (2007).

The Kamchatka River valley is now cutting through the Kamaki moraine. Assuming the model of an LGM ice dam, the valley should be diverted by the front of the Kamaki glacier. The overflow might happen after the complete deglaciation when the base moraine becomes lower than the ridges of the end moraine. However, the deeply buried edifice of then-active Zarechny

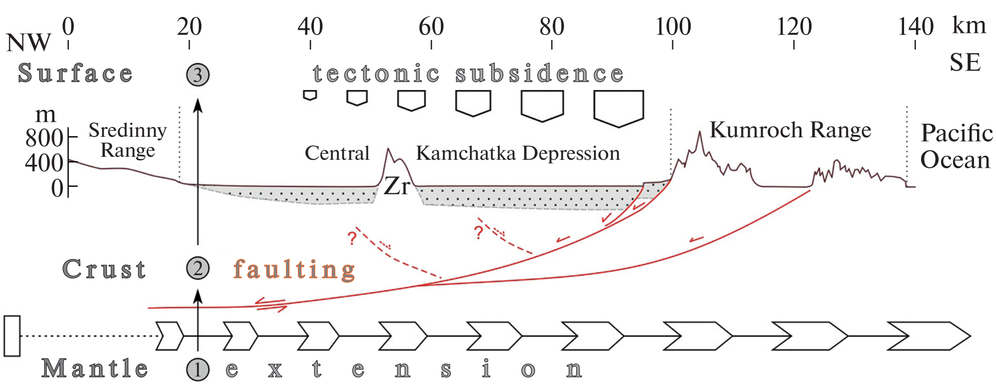

Fig. 7. A schematic cross-section of the CKD along the modern drainage through the Kumroch Range. (*Zr* – Zarechny Volcano. Modern tectonic processes affecting the topography are shown after Kozhurin, Zelenin (2017). No vertical scale is implied for the subsurface objects).

Рис. 7. Схематический геологический разрез ЦКД вдоль линии современного стока р. Камчатки (*Zr* – вулкан Заречный. Современные тектонические процессы показаны по (Kozhurin, Zelenin, 2017). Вертикальный масштаб для геологических структур показан условно).

suggests that the rapid submergence has been happening to the CKD during the LGM and since then. The pulses of glaciation and continuous tectonic submergence constantly changed the dam height. The constantly changing volume of the lake basin hampered the development of the coastline. Moreover, the glacial load may increase the local effect of submergence.

Remnants of a giant lake still exist on the CKD floor. At least 415 lakes and 128 large patches of wetlands were identified here by the OpenStreetMap project (https://www.openstreetmap.org), with a total area of water surface comprising 196 square kilometres. When considered together, it is the third largest lacustrine system in Kamchatka, after Nerpichye and Kultuchnoe lagoon lakes, with a total area of 552 sq. km and Kronotskoe Lake, 245 sq. km (Bonk, 2015).

CONCLUSION

The paper presents a reconstruction of landscapes during the global LGM and the Late Glacial based on the reviewed geomorphological data. Recently identified lacustrine outcrops suggested an existence of a giant paleolake in the CKD, which was the most prominent geomorphological feature of that time. The reassessed extent and timing of glaciation and volcanism provided the possible lake fill and discharge model due to the evolution of a piedmont glacier originating from the Old Shiveluch Volcano edifice. The lake discharge likely was gradual and started some 19 ka during the cold settings of LGM, and therefore did not have a climatic origin: as the accumulation zone of the Kamaki glacier was located at the highly active Shiveluch Volcano with known large sector collapses of that age, the changes in ice supply might be caused by the lowering of the volcanic edifice. The trend of the CKD tectonic submergence has been preventing the complete drainage of the paleolake. Even now, an enormous wide floodplain of the Kamchatka River hosts a lacustrine system with a total area of water surface comparable to the largest lakes of the peninsula.

ACKNOWLEDGEMENTS

The study was funded by the Russian Science Foundation, grant No. 21-77-10102.

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ГЕОМОРФОЛОГИЧЕСКИЕ ПРОЦЕССЫ В ЦЕНТРАЛЬНОЙ КАМЧАТСКОЙ ДЕПРЕССИИ (П-ОВ КАМЧАТКА, СЕВЕРО-ЗАПАДНАЯ ПАЦИФИКА) В ПОСЛЕДНИЕ 30 ТЫС. ЛЕТ[1]

Е. А. Зеленин[a,#], А. Л. Гуринов[b,d,e], А. Л. Захаров[b], В. В. Пономарева[c], С. Т. Гарипова[a]

[a] *Геологический институт РАН, Москва, Россия*
[b] *Институт географии РАН, Москва, Россия*
[c] *Институт вулканологии и сейсмологии ДВО РАН, Петропавловск-Камчатский, Россия*
[d] *Национальный исследовательский университет "Высшая школа экономики", Москва, Россия*
[e] *Российский университет дружбы народов, Москва, Россия*
[#] *E-mail: egor.zelenin@ginras.ru*

В статье представлена реконструкция геоморфологических процессов в Центральной Камчатской депрессии (ЦКД) в последние 30 тыс. лет, включая максимум последнего оледенения. В исследуемый период наиболее масштабными геоморфологическими процессами были рост и эволюция вулканических построек на фоне постоянного тектонического опускания ЦКД. Развитие ледников, спускавшихся с активных вулканов, зависело не только от общих климатических факторов, но и от истории извержений этих вулканов.

Наиболее заметной геоморфологической особенностью изучаемого времени являются формирование и спуск гигантского ледниково-подпрудного палеоозера. Накопленные данные о хронологии оледенений и вулканизма позволили предложить модель спуска палеоозера при постепенной деградации ледника, спускавшегося с вулкана Шивелуч. Спуск озера начался около 19 тыс. л. н., во время оледенения, и по всей видимости был связан не с климатическими факторами, а с секторными обрушениями, уменьшавшими ледоем вулкана Шивелуч. Продолжающееся тектоническое опускание ЦКД препятствовало полному осушению этого палеоозера. Даже сейчас на аномально широкой пойме реки Камчатка располагается система озер, сопоставимая по площади с крупнейшими озерами полуострова.

Ключевые слова: п-ов Камчатка, поздний плейстоцен, ледниково-подпрудное палеоозеро, активная тектоника, вулканические формы рельефа, максимум последнего оледенения

[1] *Ссылка для цитирования:* Зеленин Е.А., Гуринов А.Л., Захаров А.Л. и др. (2023). Геоморфологические процессы в Центральной Камчатской Депрессии (п-ов Камчатка, Северо-Западная Пацифика) в последние 30 тыс. лет // Геоморфология и палеогеография. Т. 54. № 4. С. 226–237. (на англ. яз.). https://doi.org/10.31857/S2949178923040175; https://elibrary.ru/GLJFRD