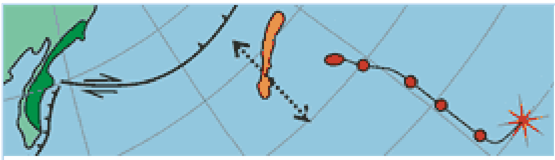

Is there any relation between the Hawaiian-Emperor seamount chain bend at 43 Ma and the evolution of the Kamchatka continental margin?

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Introduction and statement of the problem

The Hawaiian-Emperor volcanic chain is considered to be the trail of the Hawaiian hotspot, still active at the present day (Figure 1A). Based on deep-sea drilling data, the structure and evolution of the chain can be reconstructed from the early Campanian when the Meiji Seamount (also called the Obruchev Rise), representing northernmost terminus of the Emperor Seamounts, was formed [*Creager et al.*, 1973; *Rea et al.*, 1995; *Tarduno et al.*, 2002]. At that time the Hawaiian hotspot was located at ~5-10° to the north and somewhat to the east of its present position [*Shapiro*, 2005].

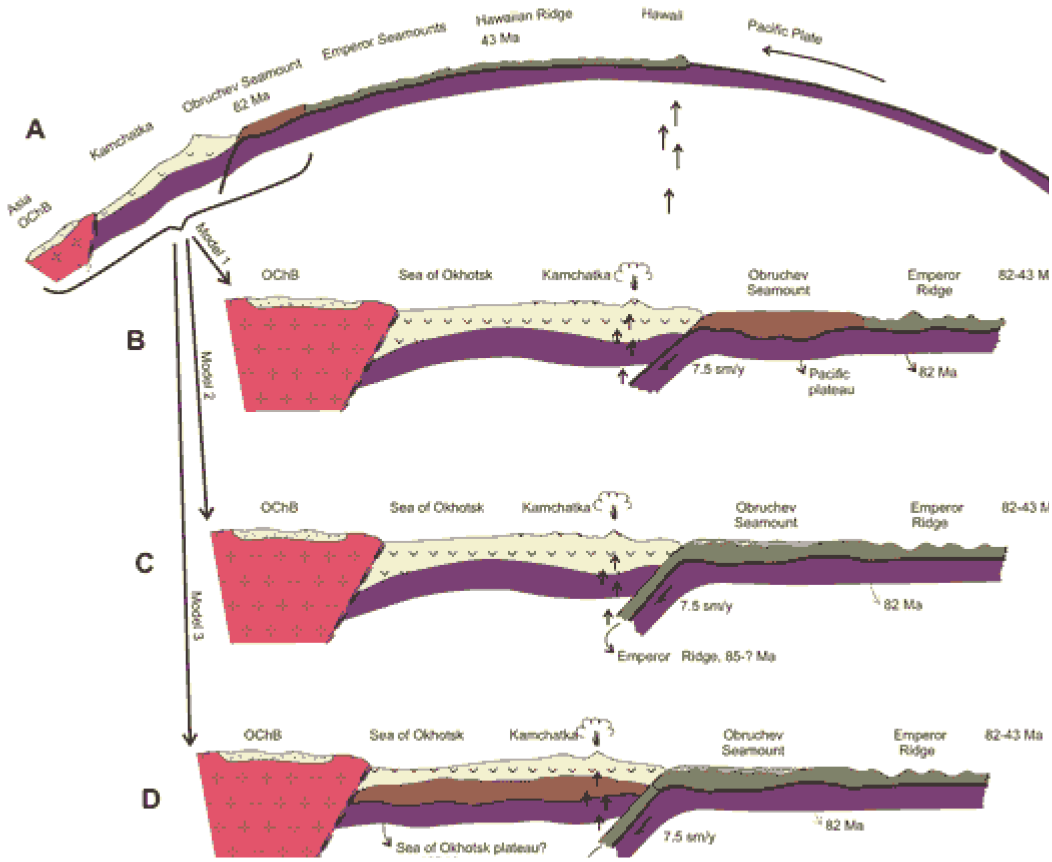

Figure 1 (Previous page): Profiles demonstrating possible relationships between the Emperor Seamounts and Eurasia.
Scheme A demonstrates the principal relationships between the main modern structures of the northwestern Pacific Ocean. The oceanic lithosphere (purple) and crust (thick black line) originated at the East Pacific Rise and then moved over the Hawaiian hotspot (plume), which resulted in formation of the Hawaiian-Emperor volcanic chain (vertical shading on green). In the northwest the chain is limited by the Obruchev Rise (also called the Meiji Seamount), which can be considered as the leading sector of the volcanic chain (lattice shading on brown). Structures of Kamchatka (yellow) presumably underlain by reworked oceanic crust are located further to the northwest. Kamchatka and the Obruchev Rise are separated by the active subduction zone. Another extinct subduction zone, which has been little studied, probably separates the structures of Kamchatka from continental structures overlapped by the Okhotsk-Chukchi subduction-related volcanic belt (OChB).
Schemes B, C and D (all corresponding to the northwestern fragment of Scheme A) show possible relationships between the Emperor Seamounts and Kamchatka structures, which are discussed in the text.

A peculiar feature of the Hawaiian-Emperor volcanic chain is its sharp 60° bend which is widely interpreted as the result of a major shift in the direction of movement of the Pacific plate at about 43 Ma [Ed: The most recent estimate of the age of the bend is 47 Ma. See also Hawaii page for discussion of the hypothesised change in Pacific plate motion at the time of the bend.] Alternatively, some researchers explain this bend as due to drift of the Hawaiian hotspot [*Norton*, 1995] or interaction of the oldest northernmost sections of the Emperor Seamounts with the northeastern Asian mainland [*Niu et al.*, 2003]. At present the northern terminus of the Emperor Seamounts is the Obruchev Rise, which only recently began subducting into the northern Kurile-Kamchatka Trench [*Seliverstov*, 1998].

Simplistic models of interaction of the Emperor Seamounts with the Asian mainland are as follows:

1. If the Hawaiian hotspot formed only in the early Campanian then the Obruchev Rise is the initial, plume-head plateau of the Emperor Seamounts (Figure 1B). *In this case, there was no collision of the Emperor Seamounts and the Obruchev Rise in particular with the Asian mainland and this collision could not result in a change in the direction of movement of the Pacific plate at ~43 Ma.*

2. If any former north continuation of the Emperor Seamounts was older than the Obruchev Rise, it might be subducted (Fig. 1C). *However, if subduction of these oldest chain sections did not meet with obstacles than this process could not have resulted in a change in direction of movement of the Pacific plate at ~43 Ma.*

3. A major change in the direction of motion of the Pacific plate is possible only if a ridge, most probably an oceanic plume-head plateau, was too buoyant to subduct (Fig. 1D). *According to this hypothesis the oldest section of the Emperor Seamounts drifted atop of the Pacific plate and later docked with the Asian mainland, but could not subduct. In this case, some of the oldest fragments of the Emperor Seamounts located between the Obruchev Rise and the northernmost terminus of the volcanic chain would be preserved on the northeastern Asian continental margin. Thus, this model can be tested by geological investigations.*

The main problem is locating where a possible continuation of the Emperor Seamounts would lie on the Asian mainland. The most promising area is Kamchatka, whose coast the Emperor Seamounts currently approach. Nonetheless, taking into consideration that at ~43 Ma the Obruchev Rise was located at 40°N and 140°W [*Engebretson et al.*, 1985] a structural relationship between the Hawaiian-Emperor volcanic chain and Kamchatka at 60°N and 180°W at that time is not so obvious (Figure 2).

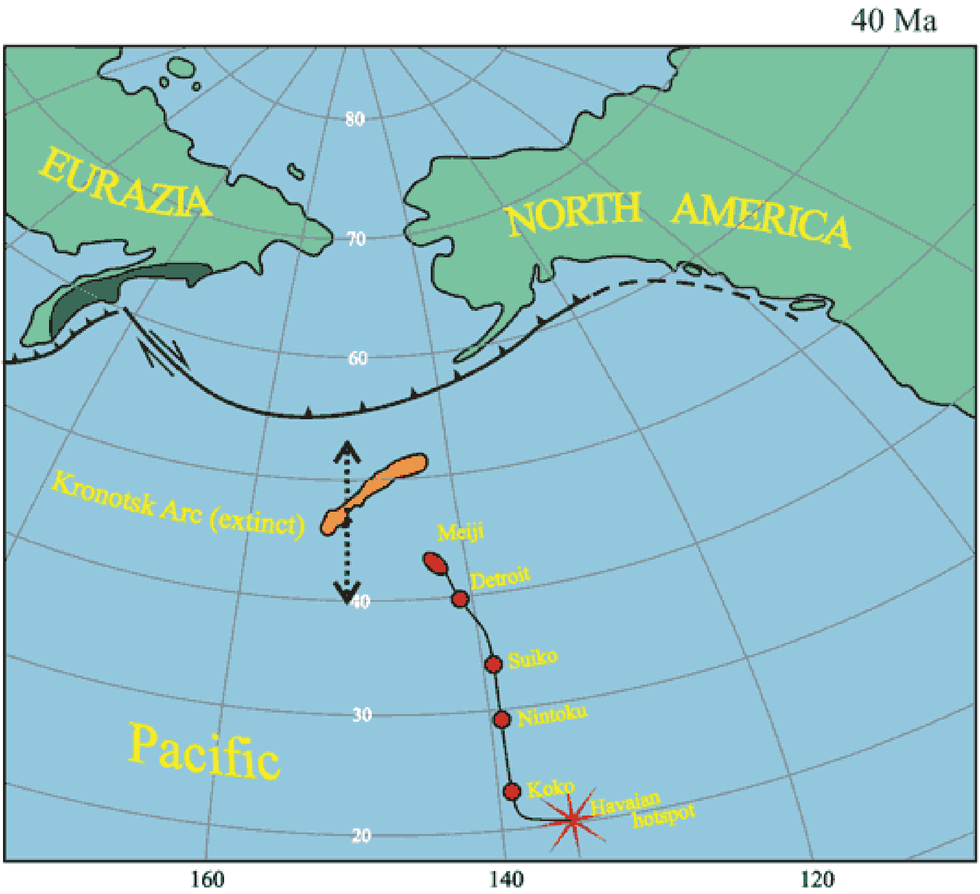

Figure 2: Northern Pacific at 43 Ma. The Achaivayam-Valaginsky arc accreted at the time to the mainland is shown in dark green. The extinct Kronotsky-Komandorsky arc (orange), which was located northwest of the Achaivayam-Valaginsky arc at the time, separated the Emperor Seamounts from Kamchatka. The position of the Hawaiian hotspot coincides with its modern position; the Emperor Seamount chain trended to the north of the Hawaiian hotspot (red circles). The average paleomagnetic latitude of the Kronotsky Arc in the Bartonian is shown by the arrow [Levashova et al., 2000].

If the Emperor Seamounts continue to the north-northwest, beyond the well-known chain that is preserved on the sea floor, than this continuation must have been subducted beneath the Aleutian arc and then transported along dextral strike-slip faults in the basement of the Aleutian arc after 43 Ma.

A continuation of the Emperor Seamounts can be found in Kamchatka only if the trend of the volcanic chain coincided with the trend of the Obruchev Rise. It should be emphasized that accreted fragments of the Emperor Seamounts should be located along the northwestern continuation of the Obruchev Rise strike because the Pacific plate south of the Aleutian arc has subducted orthogonally beneath the Kamchatka Trench since 43 Ma. Large strike-slip faults parallel to the trench, along which a continuation of the Emperor Seamounts could have been transported to the southwest or to the northeast of Kamchatka have not existed in the region since 43 Ma. Thus, the remnant of a hypothetical pre-Campanian section of the Emperor volcanic chain can only exist in the central Kamchatka Peninsula.

Are remnants of the Emperor chain preserved in Kamchatka or not?

The geological structure of Kamchatka and the Southern Koryak Highlands (Figure 3) is characterised by weakly deformed modern volcanic belts (a), depressions mainly filled with Cenozoic (middle Eocene – Pliocene) terrigenous sediments (b) and uplifts composed of strongly deformed pre-middle Eocene complexes (c). Pre-Campanian deposits of the Emperor volcanic chain could relate only to the uplifts. Based on the structure of these uplifts, four tectonostratigraphic terranes composing the basement of the Kamchatka Peninsula can be distinguished.

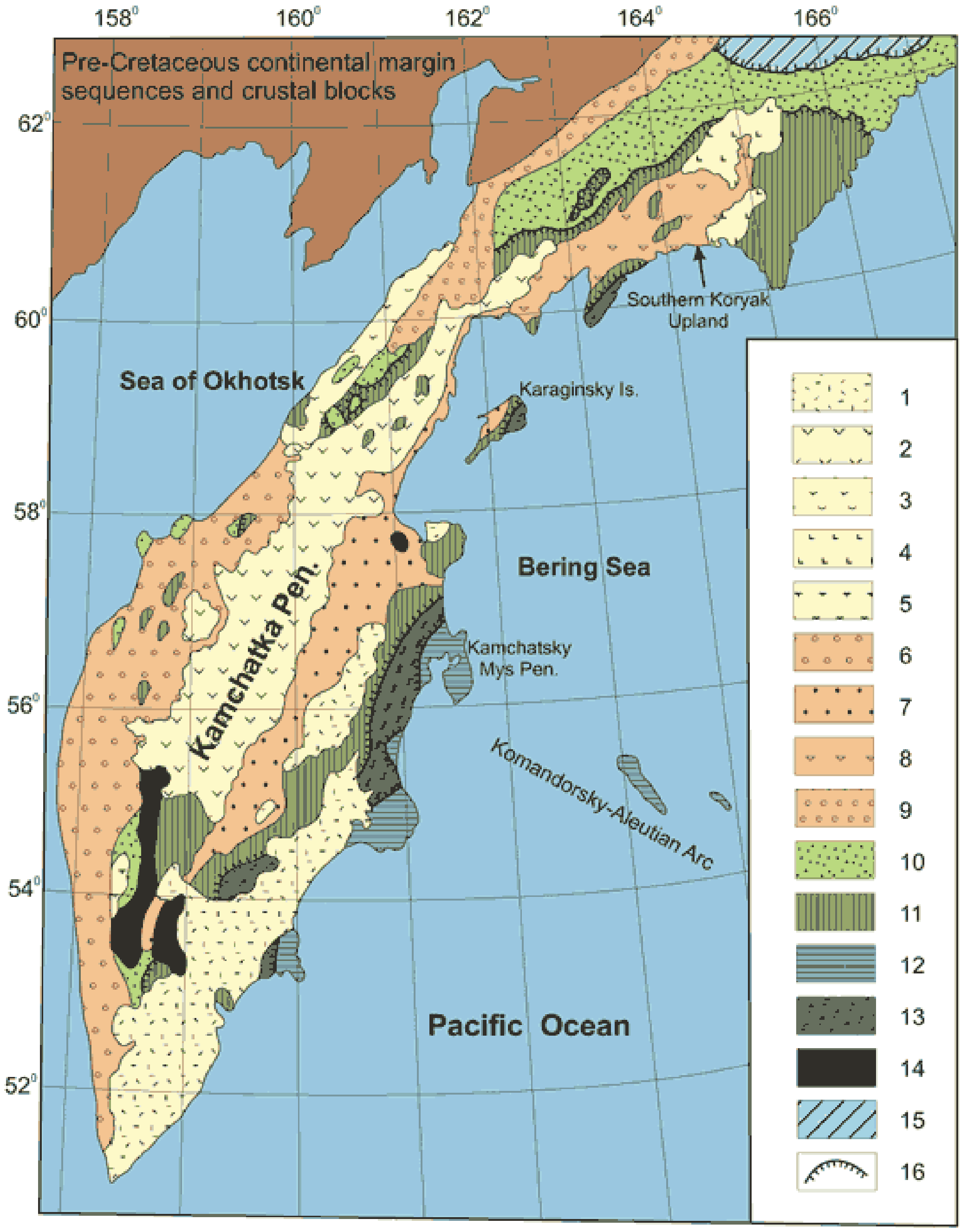

Figure 3: Sketch of the tectonic zoning of Kamchatka. Slightly deformed Cenozoic volcanic belts: 1 – Eastern Kamchatka, 2 – Central Kamchatka (Sredinny Range), 3 – Kinkil' (Western Kamchatka), 4 – Apuka and Vyvenka areas in the Southern Koryak Highlands, 5 – Cherepanovka area in the south of the Sredinny Range. Depressions, those filled with slightly and moderately deformed deposits of the middle Eocene – Pliocene: Western Kamchatka - 6, Central Kamchatka - 7, Ilpi-Pakhacha - 8, 9 – Pustoretsk-Parapolsk ones. Terranes exposed within uplifts: 10 – Omgon-Ukelayat, 11 – Achaivayam-Valaginsky, 12 – Kronotsky, 13 – Vetlovka, 14 – metamorphics after deposits of the Omgon-Ukelayat and Achaivayam-Valaginsky terranes, 15 – terranes of the northern Koryak Highlands. 16 – largest thrusts.

The Omgon-Ukelayat terrane occupies the northwest of the Olyutorsky - Kamchatka region and is dominated by strongly deformed sandy and flysch deposits dated at the middle Cretaceous to earliest middle Eocene [*Ermakov* & *Suprunenko*, 1975; *Garver et al.*, 2000; *Soloviev et al.*, 2006; in press]. The sediments are subarkosic in composition, reflecting derivation of terrigenous material from the Asian continental margin [*Shapiro et al.*, 1993, 2001]. These terrigenous sediments locally contain lenses of pillow MORBs. Sediments of the Omgon-Ukelayat terrane were deposited along the Asian continental margin, which bordered on a marginal sea basin to the southeast. This terrane did not experience significant movements relative to the Asian mainland. Neither deposits of the Omgon-Ukelayat terrane nor its section can be correlated with volcanics generated above a plume or with the sediments overlying an intraplate oceanic plateau.

The Achaivayam-Valaginsky terrane is located to the east of the Omgon-Ukelayat terrane [*Shapiro*, 1995]. It includes both large uplifts in Kamchatka (the Sredinny and Eastern Ranges), the Olyutorsky zone (the Vetvey and Olyutorsky Ranges, the Olyutorsky Peninsula) and small windows in the basement of western Kamchatka and the Ilpi-Pakhacha depression in the Olyutorsky zone. These uplifts are mainly composed of upper Cretaceous – lower Paleocene volcanic-sedimentary complexes that are locally dominated by medium-K and high-K calc-alkaline basaltic andesites, andesites and, less commonly, dacites that are geochemically similar to island-arc volcanics (Figure 4). These deposits are interpreted as proximal facies of the volcanic edifices of island arcs.

Other upper Cretaceous – lower Paleocene sequences both overlying and underlying the volcanic facies of island arcs are represented by bedded fine- and medium-grained tuffs of a mixed composition intercalated with cherty-silty sediments. Lavas associated with these sediments are island-arc tholeiites (Figure 4) indicating that these rocks were deposited in a volcanic arc environment. The sequences dominated by red-wax jaspers commonly contain intraplate tholeiites (Figure 4) that might represent the basement of the arc.

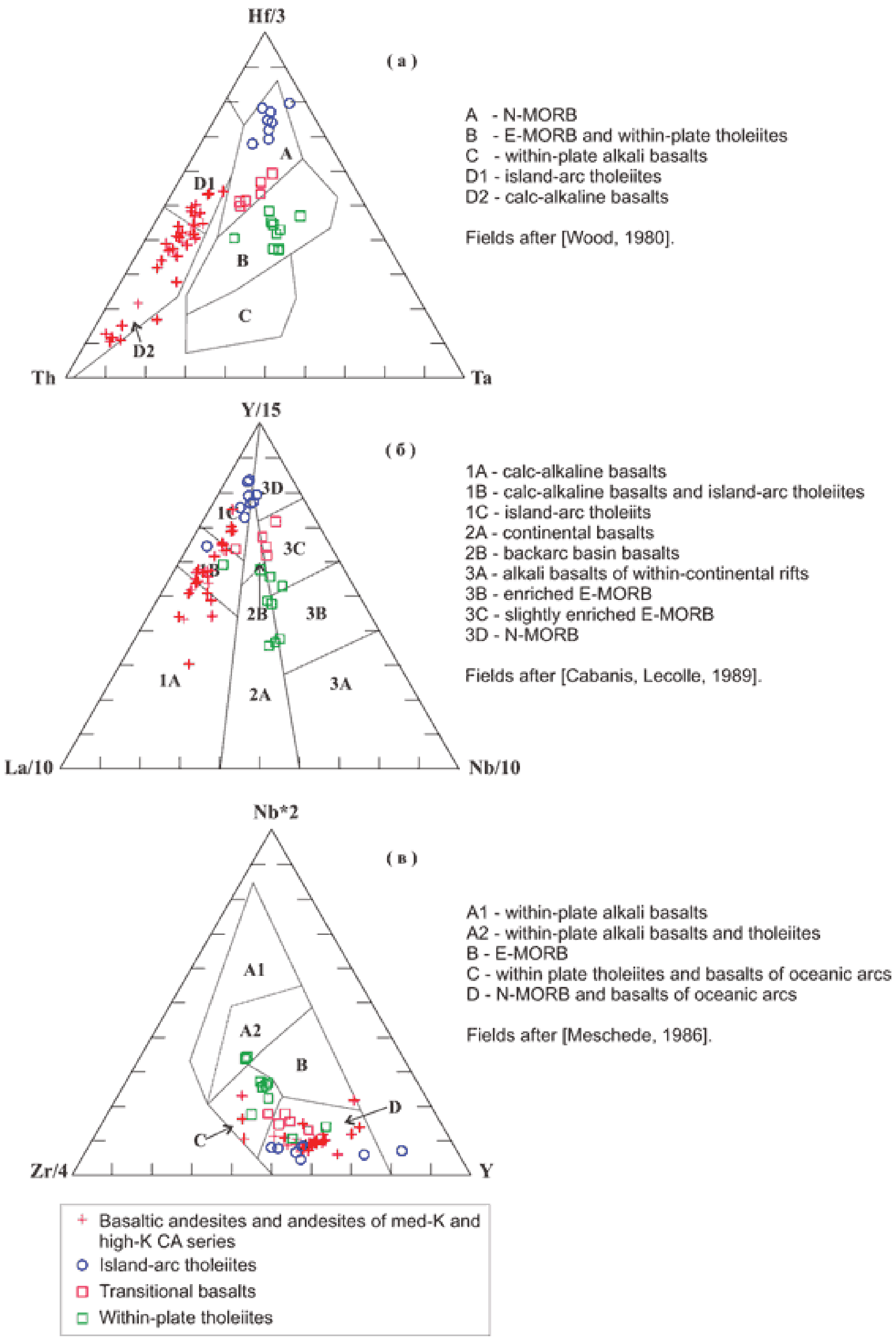

Figure 4: Discrimination diagrams for upper Cretaceous – lower Paleogene volcanics of the Achaivayam-Valaginsky terrane.

Pre-Campanian igneous and sedimentary rocks in the Achaivayam-Valaginsky terrane are quite rare. These deposits are either tuffs or silts resembling younger Campanian-Paleocene sequences of the same composition [*Bragin et al.*, 1986; *Sukhov & Kuzmichev*, 2005] or Jurassic-Maastrichtian radiolarites [*Kurilov*, 2005]. In Kamchatka Isthmus and the Olyutorsky Range island-arc complexes rest on tectonic nappes composed of pillow MORB-like aphyric basalts with lenses of Albian-Cenomanian red jaspers [*Bogdanov et al.*, 1987; *Soloviev et al.*, 2002a].

The Kamchatka Peninsula in its southern (the Ganaly Range, Malka Uplift) and central (the Havyvenka Uplift) parts is composed of metamorphic rocks that were until recently considered the basement of the Campanian-Paleocene island-arc complexes. These metamorphics were formed following terrigenous and volcanic deposits, whose composition differs drastically from the composition of Hawaiian-Emperor Seamount rocks. Moreover, SHRIMP dates of zircons indicate that most metamorphosed terrigenous rocks and volcanics of the Kamchatka Peninsula are early Cretaceous-Paleocene and Campanian-Maastrichtian in age, respectively [*Hourigan et al.*, in review; *Soloviev & Palechek*, 2004].

The Omgon-Ukelayat and Achaivayam-Valaginsky terranes are separated by a regional suture along which arc volcanics thrust over terrigenous deposits of the Asian continental margin. This suture resulted from arc-continent collision and formed at 50 Ma in the south and 45 Ma in the north [*Hourigan et al.*, in review; *Soloviev et al.*, 2002a, 2002b]. It is possible that this collision might have affected the kinematics of the Pacific plate. However, it occurred between the volcanic arc and the continent, and not between a continuation of the Emperor Seamounts and the continent. This arc-continent collision is not related to termination of volcanic activity in the Okhotsk-Chukchi volcanic belt, where arc magmatism ceased in the middle Campanian [*Filatova*, 1987]. The provenance of zircons with single-grain fission-track ages of 44 Ma and older [*Garver et al.*, 2000; *Niu et al.*, 2003] is still disputed but derivation from subduction-related arc volcanics of the Okhotsk-Chukchi belt is impossible.

The Eastern Kamchatka Peninsulas, including the Kamchatsky, Kronotsky and Shipunsky Peninsulas, are the fragments of the Kronotsky terrane and resulted from accretion of the relatively small Kronotsky arc. The Kronotsky terrane differs from the Achaivayam-Valaginsky terrane by the presence in its structure of an upper Paleocene – Eocene sequence dominated by thick island-arc deposits [*Khubunaya*, 1987]. Island-arc volcanic activity in both arcs had began almost simultaneously in the late Cretaceous (about 75-80- Ma) but ceased at different times, *e.g.,* 60 Ma in the Achaivayam-Valaginsky arc and 40 Ma in the Kronotsky arc.

The Kamchatsky Cape or Africa block is a key area within the Kronotsky arc. It is composed of upper Cretaceous siliceous tuffs, olistostome with blocks of middle Cretaceous cherts and limestones, pre-Cretaceous (?) ophiolites and quartz-feldspar greywacke of unknown age (presumably, Maastrichtian) [*Khotin & Shapiro*, 2006]. It is most probably a fragment of the accretionary wedge of the Kronotsky arc. In the light of the problem considered here, the most important is the Smaginskaya Formation: Albian – Cenomanian red jaspers, pink pelagic limestones and pillow oceanic tholeiites as blocks and slices among Campanian-Maastrichtian Pickezh tuffites as a matrix. The alkaline basalts that are mineralogically and geochemically similar to hypothesised plume-head oceanic volcanics occur even more rarely in this area [*Saveliev*, 2003].

The Achaivayam-Valaginsky and Kronotsky terranes are separated by a system of large nappes of the eastern vergence that are composed of terrigenous rocks varying in composition from poorly sorted breccia-conglomerates to black siliceous mudstones and turbidites of sandy mudstones. There are also common olistostromes and mélanges that are represented by blocks of arc deposits compositionally similar to rocks of the Achaivayam-Valaginsky terrane and MORBs associated with cherts and pelagic limestones cemented by sandy mudstones. The Vetlovka terrane is interpreted as accretionary wedge. This wedge was formed along the continental edge after collision of the Achaivayam-Valaginsky arc in late Eocene, up until collision of the Kronotsky arc in latest Miocene [*Konstantinovskaya*, 2003]. The analogues of these structures trend to the northeast up to the Govena Peninsula. This wedge includes both material derived from the continental margin and remnants of the upper oceanic crust that separated this mainland from the Kronotsky arc. Nonetheless, no pre-Campanian fragments of Hawaiian-Emperor Seamounts have been found in this accretionary wedge.

Thus, possible middle-Cretaceous plume-head volcanics and associated pelagic sediments occur only locally as small block in the Smaginskaya Formation deposits, which are interpreted as the accretionary wedge of Kronotsky arc. Comparison of these basalts with volcanics of the Emperor Seamounts requires additional work.

Spatial relations between the Cretaceous and early Paleogene island arcs of Kamchatka and Hawaiian-Emperor seamounts

Cretaceous and lower Paleocene island-arc sequences of the Achaivayam-Valaginsky arc as well as Cretaceous, Paleogene and Eocene sequences of the Kronotsky arc have gentle paleomagnetic declinations [*Kovalenko*, 2003; *Levashova et al.*, 2000]. This can be explained best by significant northward drift of these rocks after their deposition. The island-arc complexes became part of the Eurasian continent after collision of the arc with the mainland. This collision resulted in cesation of arc northward drift. The newly formed parts of the Eurasian continent are separated by large sutures coeval with collision that separate genetically different parts of the mainland. These sutures comprise the Vatyna-Vyvenka and Grechishkina thrust, that separates the Vetlovka and Kronotsky terranes.

The kinematic models developed for the evolution of the Olyutorsky-Kamchatka region are based on inaccurate but quantitative data. They take into account the known kinematics of the large lithospheric plates that existed in the northwestern Pacific Ocean [*Engebretson et al.*, 1984]. Although these models differ from one another, in all of them the Achaivayam-Valaginsky and Kronotsky arcs are located at about 45-40°N, south of where the Aleutian arc was built in the Eocene (Figure 5). The Kula-Pacific Ridge lay to the south of these arcs, and the Hawaiian hotspot and the earliest of the Emperor Seamounts on the Pacific plate lay even further to the south. In this reconstruction the Emperor Seamounts and Kronotsky arc lay on opposite sides of the Kula-Pacific Ridge. Nonetheless, the Smaginskaya Formation and the Obruchev Rise are suggested to have formed above the same plume.

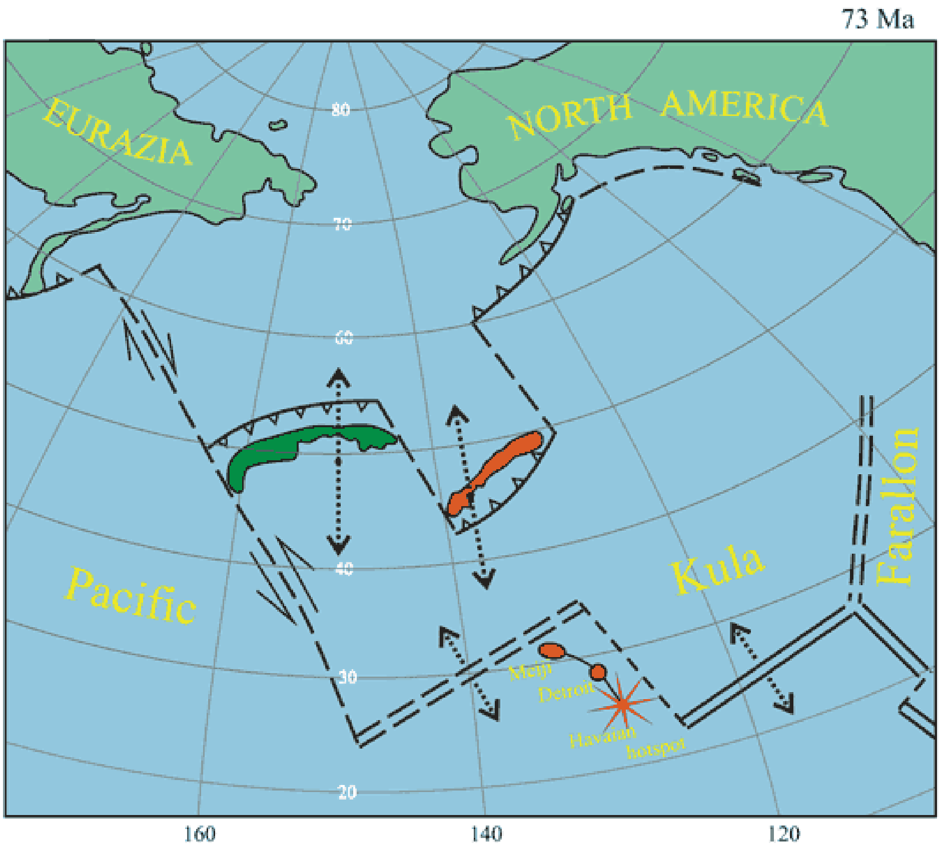

Figure 5: Northern Pacific Ocean at 73 Ma. The Achaivayam-Valaginsky arc is shown in dark green, and the Kronotsky-Komandorsky arc in orange.The northernmost section of the Emperor Seamounts, which had just started to form at 73 Ma, was separated from Kamchatka by a complicated system of ridges, arcs and transform faults. Although this system was changing all the time, it existed until collision of the Kronotsky arc with Kamchatka at ~5 Ma. Circles with arrows correspond to paleomagnetic latitudes of Kamchatka Isthmus in the Campanian and the Kronotsky Peninsula in the Campanian-Maastrichtian [Levashova et al., 2000]. See also caption of Figure 2.

43 Ma is the time at which the Hawaii-Emperor Seamount bend formed, activity of the hotspot essentially ceased for a while and the Kula-Pacific Ridge ceased to exist. The Kronotsky arc became extinct in the interval ~40-37 Ma. Since that time both the Emperor Seamounts and the Kronotsky arc have formed part of the Pacific plate and the distance between them has remained constant. Interaction of the Emperor volcanic chain with the Asian continent became possible only after collision of the Kronotsky arc with the mainland, and not earlier than ~10 Ma. However, this is a separate story that does not relate to events that affected the Emperor volcanic chain at 43 Ma.

Conclusions

Based on the overview given above, the least contradictory hypothesis is one where the Obruchev Rise is the first-formed of the volcanic plateaus of the Emperor Seamounts, and it indicates the initiation of the Hawaiian hotspot. In this case, the Emperor Seamounts never docked with the continental northwestern Pacific Ocean. Any rotation of the Pacific plate must then be unrelated to local geological events in Kamchatka.

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References

- Bogdanov N.A., Vishnevskaya V.S., Kepezhinskas P.K., Sukhov A.N., Fedorchuk A.V., *Geology of the Southern Koryak Highlands*, Moscow: Nauka, pp. 168, 1987. (in Russian).
- Bragin N.Yu., Zinkevich V.P., Lyashenko O.V., Politov A.G., Tsukanov N.V., Middle Cretaceous (Aptian – Turonian) deposits in the tectonic structure of the Eastern Kamchatka, *Essays on geology of the USSR Far East*. Moscow: Nauka, 21-34, 1986. (in Russian).
- Cabanis B., Lecolle M., Le diagramme La/10 – Y/15 – Nb/8: un outil pour la discrimination des series volcaniques et la mues en evidence des processus de mélange et/ou de contamination crustale, *C.R. Acad. Sci. Ser. II*., **309**, 2023-2029, 1989.
- Creager, J.S., Scholl D.W. et al., Initial Reports of the Deep Sea Drilling Project,**19**, Washington (U.S. Government Printing Office), pp. 913, 1973.
- Engebretson D.C., Cox A., Gordon R.G., Relative motions between oceanic and continental plates in the Pacific basin, *Geol. Soc. Amer. Special Paper*, **206**, 1-59, 1985.
- Ermakov B.V., Suprunenko O.I., Structure and conditions of formation of the upper Cretaceous and Miocene flysch deposits of the Koryak-Kamchatka region, *Soviet geology*, **12**, 53-65, 1975. (in Russian).
- Filatova N.I., Tectonic setting of Maastrichtian – Eocene basaltic magmatism of the northwestern sector of the Pacific belt, *Geotectonics*, **4**, 85-101, 1987. (in Russian).
- Garver J.I., Soloviev A.V., Bullen M.E., Brandon.M.T., Toward a more complete record of magmatism and exhumation in continental arcs, using detrital fission-track thermochrometry, *Physics and Chemistry of the Earth*, **A25**, 565-570, 2000.
- Hourigan, J.K., Brandon, M.T., Soloviev, A.V., Kirmasov, A.B., Garver, J.I., Reiners, P.W., Eocene arc-continent collision and crustal consolidation in Kamchatka, Russian Far East, Submitted to American Journal of Science.
- Khotin M.Yu., Shapiro M.N., Ophiolites of the Kamchatsky Mys (eastern Kamchatka): structure, composition and geodynamic settings, *Geotectonics*, **4**, In press, 2006.
- Konstantinovskaya E.A., Margins of the east seas: tectonics, structural evolution and geodynamic modeling, *Moscow: Scientific world*, pp. 224, 2003. (in Russian).

- Kovalenko D.V., Paleomagnetism of the geological complexes of Kamchatka and southern Koryakia, *Moscow: Scientific World*, pp. 255, 2003. (in Russian).

- Kurilov D.V., New findings of Jurassic and Cretaceous radiolarians on western Kamchatka, In *Western Kamchatka: geological evolution in Mesozoic*. Moscow: Scientific world, 55-76, 2005. (in Russian).

- Levashova N.M., Shapiro M.N., Beniamovsky V.N., Bazhenov M.L., Paleomagnetism and geochronology of the late Cretaceous – Paleogene island-arc complex of the Kronotsky Peninsula, Kamchatka, Russia: kinematics implication, *Tectonics*, **19**, 834 - 851, 2000.

- Meschede M., A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram, *Chemical Geology*, **56**, 207-218, 1986.

- Niu Y., O'Hara M.J, Pearce J.A., Initiation of subduction zones as a consequens of lateral compositional buoyancy contrast within the lithosphere: a petrological perspective, *Journal of Petrology*, **44**, 851-866, 2003.

- Norton I.O. Plate motion of the North Pacific: The 43 Ma nonevent, *Tectonics*, **14**, 1080-1094, 1995.

- Rea D.K., Basov I.A., Krissek L.A., and the Leg 145 Scientific Party, Scientific results of drilling of the North Pacific transect, Eds. Rea D.K., Basov I.A., Scholl D.W., Allan J.F., *Proc. ODP Sci. Results*, **145**, College Station, TX (Ocean Drilling Program), 577-596, 1995.

- Saveliev D.P., Within-plate alkali basalts of the Cretaceous accretionary complex (Eastern Kamchatka), *Volcanology and Seismology*, **1**, 14-20, 2003. (in Russian).

- Seliverstov N.I., Structure of near Kamchatka sea bottoms and geodynamics of junction of the Kurile-Kamchatka and Aleutian island arcs, *Moscow: Scientific world*, pp. 164, 1998. (in Russian).

- Shapiro M.N., Kinematics of the Campanian–Maastrichtian island arcs in northeastern Asia
in light of drilling results on the Emperor Seamounts, *Geotectonics*, **39**, 408-415, 2005. (Simultaneous English translation from Geotektonika).

- Shapiro M.N., Markevich P.S., Grechin V.I., Konstantinovskaya E.A., Cretaceous-Paleogene sandstones of Kamchatka: composition and provenance, *Lithology and Mineral Resources*, **1**, 36-49, 1993. (in Russian).

- Shapiro M.N., Soloviev A.V., Garver J.I., Brandon M.T., Sources of zircons from Cretaceous and lower Paleogene terrigenous sequences of the southern Koryak upland and western Kamchatka, *Lithology and Mineral Resources*, **36**, 322-336, 2001. (Simultaneous English translation from Litologiya i Poleznyie Iskopaemyie).

- Soloviev A.V., Shapiro M.N. Garver J.I., Lesnaya nappe, northern Kamchatka, *Geotectonics*, **36**, 469-482, 2002a. (Simultaneous English translation from Geotektonika).

- Soloviev A.V. Palechek T.N. New data on age of the Andrianovskaya Formation (Sredinny Range, Kamchatka): a problem of structure of the metamorphic complexes in accretionary zones, In: *Evolution of tectonic processes in Earth history*. Moscow: GEOS, 86-89, 2004. (in Russian).

- Soloviev A.V., Garver J.I., Ledneva G.V., Accretionary complex related to Okhotsk-Chukotka subduction, Omgon Range, western Kamchatka, Russian far east, *Journal of Asian Earth Science*, in press, available online 3 February 2006.

- Soloviev A.V., Shapiro M.N., Garver J.I., Shcherbinina E.A., Kravchenko-

Berezhnoy I.R., New age data from the Lesnaya Group: A key to understanding the timing of arc-continent collision, Kamchatka, Russia, *The Island Arc*, **11**, 79-90, 2002b.

- Sukhov A.N., Kuzmichev A.B., Upper Cretaceous deposits of western Kamchatka. In: *Western Kamchatka: geological evolution in Mesozoic*. Moscow: Scientific world, 121-162, 2005. (in Russian).
- Tarduno J.A., Dunkan R.A., Scholl D.W et al., Proc ODP. Init. Repts., **197**, 2002, online at http://www-odp.tamu.edu/publications/197-IR/197ir.htm.
- Wood D.A., The application of a Th–Hf–Ta diagram to problems of tectomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary volcanic province, *Earth Planet. Sci. Lett.*, **50**, 11-30, 1980.

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