Volcanism and Subduction: The Kamchatka Region

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Thermal Models Beneath Kamchatka and the Pacific Plate
Rejuvenation From a Mantle Plume Impact

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The Northwest Pacific area, comprising the Kamchatka peninsula, is a distinctive
area where a series of ongoing geodynamical processes like: plate rejuvenation
from a mantle plume impact, slab detachment, slab edge melting and exotic vol-
canism, take place. With the help of finite element modeling we infer the thermal
structure across Kamchatka in a series of 2D profiles normal to the trench. We
chose the location at these profiles based on seismicity, geochemical variation and
offshore heat flow measurements.

Assuming that the transition from brittle to ductile behavior inside the subduct-
ing slab corresponds to the 650°C isotherm, our thermal models predict a good
fit with maximum depth of seismicity (~500 km) for southern Kamchatka only
if the exothermic olivine-spinel phase transition is introduced. In the central part
of Kamchatka, a good fit is obtained if the hot mantle plume, located just beneath
Meiji Guyot seamount, thermally rejuvenates the subducting Pacific plate. Further
to the north, the seismicity shallows more (200–100 km) and slab rejuvenation
alone cannot provide a thermal structure with a good fit with seismically active
subducting slab. A good explanation for such shallow seismicity might be the slab
detachment due to cessation of subduction just north of Kamchatka-Aleutians junc-
tion. The thermal structure beneath the northernmost active volcano in Kamchatka,
Scheveluch, which exhibits a strong adakitic signature, shows that slab edge ex-
sposure to the hotter asthenosphere creates the favorable conditions for oceanic crust
melting at ~70 km depth, just beneath Scheveluch.

Our numerical models show that plate rejuvenation from a mantle plume, slab
edge exposure to hot upper mantle and probably slab detachment play an essential
role in subduction slabs thermal structure, seismicity down-dip extension and
geochemical variations of lavas in Kamchatka.

INTRODUCTION

One of the consequences of the motion of Earth’s tectonic
plates is the onset of subduction zones where one plate plunges
beneath another. Intense dehydration of the subducted plate
can induce partial melting in the mantle wedge, generating
thermo-chemical instabilities or plumes, which finally end
up in an intense arc volcanism (Gerya et al., 2003; 2003a).
Other mantle plumes, which are frequently assumed to come
from the transition zone or from the core-mantle boundary
(Hansen and Yuen, 1988; Helmlberger et al., 1998; Foulger
et al., 2000; Natof, 2000; Shen et al., 2002; Tan et al., 2002;
Zhao, 2003; Montelli et al., 2004), can affect the plate ther-
mal structure through a process called thermal rejuvenation.
(Crough, 1978; Nagihara et al., 1996; Moore et al., 1998), where an old plate behaves actually like a young plate. Such thermal discontinuities in a plate thermal structure, sometimes coupled with important variations in the subduction rates can produce an interesting phenomena, called slab detachment, where parts of the subduction slab separate and sink into the mantle (Von Blanckenburg and Davis, 1995; Davis and Von Blanckenburg, 1995; Wortel and Spakman, 2000; Xu et al., 2000; Levin et al., 2002; Rogers et al., 2002; Gerya et al., 2004). The Northwest Pacific area, comprising the Kamchatka peninsula, reassembles all of the above geodynamical processes. The old Pacific plate (PAC) subducts beneath Kamchatka at a fast convergence rate of ~7.5 cm/yr (Demets, 1992), producing one of the most active volcanic arcs in the world. A large positive bathymetric feature located at the northern end of the Emperor seamount chain, the Meiji Guyot seamount, is characterized by anomalously high heat flow (> 80 mW/m²) (Smirnov & Sugrobov 1979, 1980a,b) for the old (~90 Ma) Pacific plate. In this area, a non-linear iterative P-wave traveltime tomography of Gorbatov et al. (2001) has revealed a mantle plume rising across the 660 km discontinuity, and deflecting subhorizontally in the uppermost mantle.

Levin et al. (2002) imaged the upper mantle seismic structure beneath Kamchatka, and proposed two Quaternary episodes of slab detachment just north of the Aleutian-Kamchatka junction. Whereas extensive slab dehydration of the subducting Pacific slab beneath southern part of the eastern Kamchatka volcanic front (SEVF) is responsible for mantle wedge melting, the slab detachment, upwelling and southward flow of hot and fertile mantle are the main reason for the recent magmatism in southern Kamchatka central depression (SCKD) (Portnyagin et al., 2005). Although the convergence rate and the age of the Pacific plate show very little variation along the Kamchatka trench, the intraslab seismicity varies from ~500 km beneath SEVF to ~300 km in the central part of the peninsula (NEVF), and decreases to ~100–200 km further to the north (Gorbatov et al., 1997). The main goal of this paper is to infer the thermal structure beneath Kamchatka which satisfy simultaneously the seismic observations, type of volcanism and geodynamic background. We show that plate rejuvenation from a mantle plume and slab detachment plays an essential role in subduction slabs thermal structure, seismicity down-dip extension and geochemical variations of lavas along EVF and SCKD.

TECTONIC AND GEOLOGIC SETTINGS

Subduction is active only in the southern half of the Kamchatka peninsula, whereas past subduction in the north is indicated by an inactive volcanic arc (Kepezhinskas et al., 1997). The PAC subducts near-normal along the Kamchatka subduction zone (KSZ) with a highly variable dip angle, from ~55° in the south to ~35° in the north (G{}\textit{}orbatov et al., 1997). The Pacific plate age varies from 104 Ma to 87 Ma (Renkin and Sclater, 1988), and the converge rate from 7.8 cm/yr to 7.5 cm/yr (Gorbatov et al., 1997) (Fig. 1). The seismicity and structure of the KZS was studied in detail by Gorbatov et al. (1997). The subducting Pacific slab is seismically active down to ~450–500 km in southern Kamchatka. Further north, the seismicity shallows in steps, from ~300 km beneath NEVF to ~200 km beneath the Klyuchevskoy group and ~100 km under the Schevloch group, respectively (Fig. 2). The maximum depth of seismicity in subduction zones is controlled mainly by pressure and temperature. Goto et al. (1983), Spencer (1994) and Gorbatov and Kostoglodov (1997) proposed a cut-off temperature of 650°C for the maximum extent of intraslab seismicity. It is assumed that beyond this critical temperature the slab loses its brittle behavior, instead acting like a ductile material. Recent studies suggest that intermediate-depth intraslab earthquakes likely results from mineralogical changes within the subducting slab (Hacker et al., 2003). A recent study of Abers et al. (2006), advocates that a mineral reaction front controls the position of the earthquakes in the subducting slab. The linearity of the slab seismicity in the (p,T) space seen for the Alaska subduction zone (Abers et al., 2006), implies that the breakdown of lawsonite is responsible for the occurrence of seismicity located in the subducted oceanic crust. Beneath Kamchatka, the seismicity is too scatter within the subducting slab and consequently in the (p,T) space too. Therefore, we use in this study only the cut-off temperature (T_c =650°C) to constrain the thermal structure inside the subducting slab.

Offshore central Kamchatka heat flow data (Smirnov and Sugrobov, 1979; 1989a,b) show unusual high values higher than 80 mW/m² just above Meiji Guyot seamount, suggesting that the thermal thickness of the Pacific plate is much smaller in this area. Thus the effective age (thermally defined) is less than the geological age (Renkin and Sclater, 1988) (Fig. 3). In contrast, the Pacific plate offshore southern Kamchatka shows normal heat flow values (~40–60 mW/m²) for a ~100 Ma oceanic plate (Stein, 1995). Interestingly, Gorbatov et al. (2001) revealed a wide cylindrical shaped mantle plume (~2% δv anomaly) rising from ~900 km depth and being deflected by the Pacific plate motion toward the Kamchatka trench (Fig. 4). The superficial thermal effect of this plume seems to be reflected in the anomalously heat flow values recorded in the Meiji Guyot seamount area. In the northwestern Pacific the Aleutian and Kamchatka arcs collide at an angle of ~90°. At this junction, Levin et al., (2002) show that a large portal exists, exposing the slab edge to the hotter mantle and facilitating the production of high Mg andesites,
called adakites, through subducting oceanic crust melting. Also, Yogodzinski et al. (2002) provide strong geochemical evidence for the melting of subducting crust beneath northern Kamchatka and Aleutians. Levin et al. (2002) showed that two episodes of slab detachment occurred beneath northern Kamchatka in the last 10 Ma. The Klyuchevskoy volcanic group lies just above the slab edge itself, and its extraordinary volcanic productivity and high temperature of equilibrium of magmas (Ozerov, 2000) are attributed to slab-edge lofting (Park et al., 2002). Portnyagin et al. (2005) show a strong and opposite variation of Nb/Y, Ba/Nb and Dy/Yb ratios along the southern Central Kamchatka depression (SCKD) in the vicinity of the Kamchatka-Aleutian junction. For example, low NB/Y and Dy/Yb ratios and high Ba/Nb ratio for the SCKD suggest abundant slab dehydration which can contribute to extensive, high-degree mantle wedge melting. Also, the strong adakitic signature (i.e. high Sr contents and high Sr/Y ratios) of Sheveluch group is proposed to be the effect of thermal erosion of the subducting slab edge exposed to hot asthenosphere. In contrast, NCKD is characterized by high NB/Y and Dy/Yb ratios and low Ba/Nb ratio, advocate for a highly diminished fluid influx and therefore explaining the low degree melting beneath the northern volcanoes.

On the other hand, southern Kamchatka (SEVF and NEVF) is the place of a normal calc-alkaline arc volcanism, where the magmatism is proposed to be the result of the lowering of the melting point of peridotite through an influx of volatiles from the dehydration of subducting slab (Perfit et al., 1980). An important dissimilarity of southern Kamchatka is that no adakites were found, suggesting that in this region the subducting basaltic crust does not undergo melting.
In this study we divided the study area into four sub regions based on seismicity, geochemical variation and offshore heat flow measurements (Fig. 1). We assume a cut-off temperature of $T_{cr} = 650^\circ C$ for the maximum depth of seismicity. For each sub region, we build a series of 2D thermal models following the numerical scheme proposed by Manea et al. (2005). Then, we use MORB phase diagrams (Schmidt and Poli, 1998; Kerrick and Connolly, 2001; Hacker et al., 2003) and $(p,T)$ paths along the slab surface to investigate the dehydration variations along the oceanic crust beneath the volcanic arc. We also explore the circumstances for the oceanic basaltic crust and mantle wedge peridotite to undergo melting.

**MODELING PROCEDURE**

The numerical scheme of Manea et al. (2005) consists of a system of 2D Navier-Stokes equations and 2D steady state heat transfer equation. Strong temperature-dependence of viscosity is used in the present modeling.

\[
\eta = \eta_0 \cdot e^{\left(\frac{E_\eta}{RT_\eta}\right)},
\]

where the activation energy $E_\eta$ corresponds to diffusion creep of olivine (Karato and Wu, 1993). Other parameters used are: $\eta$ - mantle wedge viscosity (Pa s), $\eta_0$ - mantle wedge viscosity at the potential temperature $T_\eta (10^9$ Pa s), $T_\eta$ - mantle wedge potential temperature (1,450°C), $R$ - universal gas constant (8.31451 J/mol °K) and $T$-temperature (°C).

A finite-element grid extends from 25 km seaward of the Kamchatka trench up to 600 km landward of it, and consists of 15,000 triangular elements with an average resolution of 4 km. The model consists of five thermo-stratigraphic units as follows: upper continental crust, lower continental crust, oceanic lithosphere, oceanic sediments, and mantle wedge. The thermal parameters used for each layer are from: Peacock and Wang, 1999; Smith et al., 1979; Vacquier et al., 1967. The continental crust in Kamchatka is divided into two layers: the upper crust (0–15 km depth) and lower crust (15–35 km depth). These depths are consistent with values inferred by Gorbavitov et al. (2000) and Levin et al. (2002). The shape and dip of the subducting plate beneath the active volcanic arc are constrained by earthquake hypocenter distribution.

The upper and lower boundaries are maintained at constant temperatures of 0°C at surface and of 1,450°C in the asthenosphere, respectively. The left, landward vertical boundary condition is defined by a 22.5°C/km thermal gradient for the continental crust. Below the 35 km depth, the left boundary condition is represented by a low thermal gradi-
ent of 10°C/km down to the depth of 100 km. Beneath 100 km depth no horizontal conductive heat flow is specified. Underneath the Moho (35 km), for the left boundary, corresponding to the mantle wedge, zero traction is assumed. At the intersection between the subducted slab and the left boundary, the velocity of the subducting slab is assumed. The right, seaward boundary condition is a one-dimensional geotherm calculated for the oceanic plate using the GDH1 model of Stein and Stein (1992). We use plate age data and heat flow observation to obtain the oceanic geotherm using GDH1 (Fig. 3). In terms of displacement, the velocity of the oceanic plate is taken with respect to the continental plate. Thus the convergence rate of 7.4–7.8 cm/year between the PAC and Kamchatka is used (Renkin and Sciu, 1988). A long-term continuous sliding between the subducting and continental plates along the thrust fault should produce frictional heating. We introduce shear heating along the thrust fault from the trench down to the contact between the slab and continental Moho (35 km). Below Moho and above the slab we assume the presence of serpentinite, which exhibits rate-strengthening, stable-sliding and aseismic behavior (Reinen, 2000) and therefore decouples the subducting and overriding plates (Manea et al., 2004). We introduced in our models a small degree of volumetric frictional heating \( Q_{v} = \tau v / w \) where \( \tau \) represents the shear stress (\( \tau = 15 \) MPa on average, using Byerlee, 1978), \( v \) is the convergence rate and \( w \) is the thickness of the oceanic crust involved in friction (200 m).

Due to the deep seismicity (>500 km) for the southernmost profile we include the spinel – olivine exotermic phase transition at 410 km depth. The heat of exothermic reaction is \( L = 90 \) kJ/kg. For \( c_p = 1 \) kJ/Kg K, the heat released by this phase change increases the temperature inside the subducting slab by 90 K (\( \Delta T = L / c_p \)) (Turcotte and Schubert, 2001). We use the simplified phase diagram of olivine-spinel transition from Schmeling et al. (1999) (~0.3°C/MPa for T > 600°C) with a sharp transition from olivine to spinel.

For the northernmost profile, located just beneath the Schelovich group, we simulate the slab edge exposure to the hot mantle by constructing a series of 2D thermal models parallel with the Kamchatka trench at distances of 50, 100, 150, 200 and 250 km, and normal to the main thermal model. The boundary conditions for these models are: 0°C and 1450°C for the top and bottom, oceanic upper mantle geotherm for the northern boundary and the temperature profile through the main thermal model as southern boundary.
MODELING RESULTS

Thermal Models

The thermal models that correspond to the four sub-regions are presented in Fig. 5 through Fig. 8. Using as main constraints the geological age (~104 Ma), convergence rate (~7.8 cm/yr) and slab geometry (~55° slab dip), the first thermal model located beneath SEVF shows that the $T_{cr}$ is not consistent with the maximum extent of intraslab seismicity (450–500 km) (Fig. 5A). Alternatively, just introducing the exothermic olivine-spinel phase transition, a good agreement between the seismicity and the cut-off temperature is obtained (Fig. 5B).

The second area, where the seismicity shallows to 300–350 km beneath NEVF, shows little variation in age, convergence rate and slab geometry (91 Ma; 7.6 cm/yr; ~53° slab dip) compared with the neighbor region to the south. The thermal structure, and correspondingly the 650°C cut-off temperature, calculated with the above parameters, is not consistent with the maximum depth of seismicity (Fig. 6A). The mantle plume located just in front of this area seems to be the source for the anomalous heat flow above 80 mW/m². We argue that this high value of heat flow reflects a plate thermal rejuvenation, therefore the old 91 Ma Pacific plate behaves like a 35 Ma young oceanic plate (Fig. 3). Introducing this rejuvenation effect in our thermal models, we obtain a good fit between the seismicity and cut-off temperature of 650°C (Fig. 6B).

The third region corresponds to the inland jump of the volcanic front and an abrupt change of the seismicity from 300–350 km to ~200 km. The little variation in plate age and convergence rate compared with the previous area is not sufficient to explain such shallow seismicity. Even the oceanic plate rejuvenation cannot explain the maximum depth extent of ~200 km of the intraslab seismicity (Fig. 7). We discuss later an alternative mechanism which can explain this unusual shallow seismicity, inland shift of the volcanic front.

**Figure 5.** Thermal models for the southernmost study area located beneath SEVF (area A in Fig. 1). Notice the reasonable fit ($T_{cr} = 650°C$) with the maximum depth of seismicity when we introduced the olivine-spinel phase transition (B) compared with the model without this phase transition (A). The dashed line represent the 650°C isotherm, assumed here to be the transition from brittle to ductile behavior, and therefore a good indicator of the maximum depth of intraslab seismicity. The thick black line shows the surface of the subducting slab. Also, the thick dashed horizontal line represents the Moho (35 km depth).
and the extraordinary lava production of the Klyuchevskoy volcanic cluster.

The last section is located above the Aleutian - Kamchatka junction, where actually the edge of the Pacific slab comes in direct contact with the hot upper mantle material. Here, the seismicity shallows even more (~100 km) than in the previous area, despite the little variation in the slab age and convergence rate. Also the subducting slab dips at only ~33° beneath Schiveluch volcano, compared with ~52° just to the south below the neighbor Kluchevskoy volcanic cluster. The modeled thermal structure ($T_{cr}=650^\circ$C) shows no correlation with the shallow seismicity (Fig. 8). Nevertheless, despite this disagreement, the models which include the slab edge heating due to exposure to hot upper mantle, predict temperature above 750°C at ~70 km depth, enough to melt the oceanic basaltic crust (Fig. 9).

**Slab Dehydration and Melting**

The estimated variation of wt% H$_2$O content with depth along the subducting Pacific slab is presented in Fig. 10. We use both, computed (Kerrick and Connolly, 2001) and experimentally determined phase diagrams (Schmidt and Poli, 1998; Hacker et al., 2003). Using the computed phase diagram and weight percentages of H$_2$O in metabasalt of Kerrick and Connolly, 2001 (Fig. 10A), we see that complete and intense (~2.5 wt%) dehydration occur at depths of ~70–80 km just beneath Kluchevskoy group (KCKD) and NEVF when the slab reheating in taking into account. Experimentally phase relationships for basalt at water-saturated conditions of Schmidt and Poli (1998) (Fig.10B) show also intense dehydration (>3 wt%) beneath Kluchevskoy group (KCKD) and NEVF at depths of 70–90 km. On the other hand, the cold slab beneath SEVF retains ~0.5–1.0 wt% at greater depths (>100 km). Completely and progressively metamorphic devolatilization occurs beneath SCKD, where the subducted oceanic crust loses all its hydrous phases at shallower depths of ~60 km (Fig. 10A, B). Using the phase diagram of Schmidt and Poli (1998), the sequence of hydrous phases in the basaltic crust beneath SEVF, NEVF and KCKD might be as follows. At blueschist conditions, assemblages are composed of lawsonite-glaucophane-chlorite-garnet-clino.pyroxene-quartz (field G in Fig. 10B). Increasing the temperature lawsonite reacts to zoisite (field F). At depths greater than ~70 km, amphiboles decompose forming chloritoid at T<650°C (field D). Then, blueschist transforms to-lawsonite-eclogite (fields A and B) and amphibole-eclogite to zoisite-eclogite (fields C and D). At 90–100 km depth, zoisite breakdown produces an almost dry eclogite for T>700°C (field O). Beneath SCKD, the mineral assemblages are by lawsonite-amphibole-chlorite-albite-quartz at low (p,T) (field K in Fig. 10B). With increasing temperature lawsonite reacts with epidote (fields I and
J) and chlorite decomposes forming garnet (fields E and H). Other minor hydrous phase in the basaltic crust is represented by paragonite which forms at 20–30 km (at 500–650°C) and decomposes at ~70 km (500–700°C < fields E and F). At greater depths (>60–70 km), the oceanic crust beneath SCKD might undergo melting.

We also use the phase diagram for basalt of Hacker et al. (2003) (Fig. 10C) to reveal the metamorphic sequences in the subducted oceanic crust. Here the metamorphic structure is as follows: from jadeite-lawsonite-blueschist-ampibole-talc facies, the oceanic crust enters at a depth of ~65 km into the stability field of zoisite-ampibole-eclogite with strong dehydration (2.7–3.3% H₂O released). Another pulse of strong dehydration (0.3–2.3% H₂O released) occurs at 90–100 km depth, when the oceanic crust dehydrates completely and transforms into eclogite. Rigorous dehydration occurs through these phase changes, in total more than 5 wt% H₂O being released into the overlying mantle up to a depth of ~100 km. This process would hydrate and lower the melting point of the mantle wedge peridotite. In fact, using wet peridotite solidus from Wyllie (1979) (~1050°C at 100 km depth), the thermal models predict melting of mantle peridotite beneath the volcanic front only if the mantle wedge is subject to fluid hydration from the oceanic crust. Interestingly, the cold slab surface geotherm beneath SEVF does not intersect solidus, predicting no oceanic crust melting (Fig. 10C). On the other hand, the oceanic crust beneath NEVF and KCKD seems to approach the
Figure 9. A – 3D Thermal structure of the subducting slab edge exposed to the hotter asthenosphere beneath Aleutian-Kamchatka junction. B – cross-section normal to the main model (Fig. 8) where the Shiveluch volcano is located (A-A’). Note the high temperature (T>750°C) at ~70 km which represent the suitable conditions for the oceanic crust to undergo melting and producing adakitic magmas recorded at Shiveluch.
melting conditions at depth of 90–110 km (Fig. 10 B, C). Also, the model which incorporates the slab edge exposure to hotter mantle, clearly predicts oceanic crust melting (at ~70 km depth) just beneath Sheveluch, the northernmost active volcano in Kamchatka with a strong adakitic signature. Here, the oceanic crust shows a more complicated metamorphic structure: zeolite-prehnit-pumppellyite-actinolite-greenschist up to ~25 km depth, epidote-amphibolite up to ~35 km depth, then from zoisite-amphibole-eclogite the oceanic crust crosses the solidus at ~70 km depth and finally transforms into the anhydrous eclogite.

DISCUSSION AND CONCLUSIONS

The slab and mantle wedge thermal structure beneath Kamchatka is studied using numerical models of temperature developed using the numerical scheme of Manea et al. (2005). The thermal models are constrained by slab age, convergence rate, slab geometry, maximum depth of intraslab seismicity and offshore heat flow measurements. Four different areas are considered along Kamchatka, based on their difference in seismicity, volcanic front geometry and geochemical spatial variation (Fig. 1). Although the convergence rate and slab age varies slightly along the trench, the maximum depth of seismicity shows some considerable discontinuities. The seismicity shallows continuously from south (~500 km) to the north (~100 km) with a series of four main discontinuities (Fig. 2). The thermal structure beneath SEVF (section A in Fig. 1) which includes the exothermic olivine-spinel phase transformation shows a good correlation of maximal depth of slab seismicity with the cutoff temperature inside the subducting slab of 650°C. Pacific plate rejuvenation from ~91 Ma to ~35 Ma due to the mantle plume impact, provides a hotter thermal structure beneath NEVF (section B in Fig. 1) and a good fit of seismicity (300–350 km) with the position of the cutoff isotherm. Also, these models show strong slab dehydration (~5% wt H2O) down to depth of ~100 km. Such influx of fluids lowers the mantle peridotite melting point. Our models predict temperature in the mantle wedge beneath the entire EVF well above 1100°C, sufficient to melt hydrated peridotite, and therefore explaining the calcalkaline arc magmatism in this area.

The last two sections (C and D in Fig. 1) show a much shallower slab seismicity, from ~200 km beneath the Kluchevskoy volcanic cluster to ~100 km under the Sheveluch area. The slab thermal rejuvenation is not enough to explain such shallow seismicity. A recent study of Levin et al. (2002) revealed the seismic structure beneath northern Kamchatka, revealing that significant portions of the subducting slab detached and sank into the mantle. The active volcanism in the Kluchevskoy area lies just above the slab edge itself located at ~200 km depth, therefore explaining probably the lack of seismicity at greater depths. The ~200 km width of the Meiji Guyot seamount covers both the NEVF and SCKD, but only the Kluchevskoy group shows an unusual high magma output. The slab edge lithification proposed by Levin et al. (2002) seems to explain better the extreme volcanic activity at the Kluchevskoy cluster than an increased hydrous-fluid input from Meiji Guyot seamount proposed by Davies (2002). The northernmost active volcano in Kamchatka, the Sheveluch volcano, stands also above the slab edge where the Pacific plate ends and come in contact with the hotter upper mantle. The thermal models which integrate the lateral edge heating show that at a depth of ~70 km, just below Sheveluch, the temperature inside the oceanic crust exceeds 750°C (Fig. 9) and therefore the solidus for basalt (Fig. 10). This result is in good agreement with the strong adakitic signature recorded in magmas erupted from Sheveluch. This is not the only area across Kamchatka where adakites were identified. Recently, Maxim Pomyagin (personal communication 2005) identified adakitic signatures in Late Neogene dikes in central Kamchatka (Zhupanova area, see Fig. 1). Such adakitic signatures are in good agreement with the thermal structure beneath NEVF which takes into account the oceanic plate reheating due to Meiji plume impact, where the slab surface geotherm approaches the solidus at a depth of ~100 km (Fig. 10 B).

Recent numerical studies show that two types of plumes might form in the mantle wedge (Gerya et al., 2006). Such dual-type plumes can explain the presence of different magmas in volcanic arcs: magmas with adakitic signatures and magmas from peridotitic source. Rates of plumes or buoyant diapirs propagation vary from 0.1 to 3 My (Gerya et al., 2006; Manea et al., 2005), rates which are consistent with transfer times for fluids and slab melts from U-Th isotope measurements (Hawkesworth et al., 1997). Also, in these numerical models, intense melting of the mixed plumes (sediments and oceanic crust) occurs at low temperatures, therefore reconciling the cold slab geotherms beneath volcanic arc and the crust melting. The shallow seismicity (~100 km) beneath Sheveluch cannot be explained by the edge effect alone, and probably the slab detachment revealed by Levin et al. (2002) seems to be the reasonable explanation. We did not incorporate the slab detachment into our thermal models, and future studies will focus on the effect of such strong discontinuity in the slab thermal structure and mantle flow around the slab edge. Recent numerical studies of thermomechanical modeling of slab detachment (Gerya et al., 2004) show that the rapid detachment process takes place over a few million years, and the detachment occurs at depths of ~100–400 km (Gerya et al., 2004; Buiter et al., 2002; Houseman and Gubbins, 1997). The detached fragments of the slab are 300–500°C colder than the surrounding asthenosphere, therefore they might be seen in tomographic images (Levin et al., 2002). On the surface, the expression of slab breakoff might be represented by rapid topographic changes (i.e. uplift) and increasing volcanic activities due to melting of subducted oceanic crust. The vigorous volcanic activity at Sheveluch fits well in such scenario.

We conclude that the main effect of the slab rejuvenation from a mantle plume impact is the reducing of maximum depth extent of intraslab seismicity. The slab edge exposure to the upper mantle produces the favorable P-T conditions for oceanic crust melting at shallow depths.
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REFERENCES


The Kamchatka Peninsula and contiguous North Pacific Rim is among the most active regions in the world. Kamchatka itself contains 29 active volcanoes, 4 now in a state of semi-continuous eruption, and has experienced 14 magnitude 7 or greater earthquakes since accurate recording began in 1962. At its heart is the uniquely acute subduction cusp where the Kamchatka and Aleutian Arcs and Emperor Seamount Chain meet.

Volcanism and Subduction covers coupled magmatism and tectonics in this spectacular region, where the torn North Pacific slab dives into hot mantle. Senior Russian and American authors grapple with the dynamics of the cusp with perspectives from the west and east of it, respectively, while careful tephrostratigraphy yields a remarkably precise record of behavior of storied volcanoes such as Kliuchevskoi and Shiveluch. Towards the south, Japanese researchers elucidate subduction earthquake processes with unprecedented geodetic resolution. Looking eastward, new insights on caldera formation, monitoring, and magma ascent are presented for the Aleutians.

This is one of the first books of its kind printed in the English language. Students and scientists beginning research in the region will find in this book a useful context and introduction to the region’s scientific leaders. Others who wish to apply lessons learned in the North Pacific to their areas of interest will find the volume a valuable reference.