# Thermal Modeling of the Cascadia Subduction Zone

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Program Element I.2

## Investigations Undertaken

This project is designed to develop thermal models to examine the thermal structure of the Cascadia subduction zone and is aimed at emphasizing the effect that the thermal state may have on coupling of the subducting Juan de Fuca plate with the overlying North American plate. The overall objective of this numerical study is to estimate the thermal regime beneath this convergent margin, thus to contribute a better understanding of its unusual behavior, particularly the lack of large shallow thrust earthquakes in this important Pacific Northwest region. We have developed two-dimensional finite element thermal models for the Cascadia subduction zone across the central Oregon. The model includes realistic subducting slab geometry (with a varying dip angle) and a thin layer of elements to examine various properties associated with the contact between the subducting slab and the overriding plate.

## Results

Recent seismic investigations have revealed seismic velocity structure beneath an east-west profile at 45°N across the central Oregon coast [*Trehu et al.*, 1995; *Nabelek and Li*, 1995] which provide important constraints to our model geometry as shown at top of Figure 1. The mesh of the finite element model includes the trench at the origin and the Juan de Fuca plate subducting at an angle of 15° beneath the continental slope and the coast, and at a steeper angle of 40° beyond 200 km distance east of the deformation front. The right hand side of the model domain is chosen to be 520 km from the trench and the boundary condition there is a prescribed thickness of the North American plate corresponding to the depth of the 1325°C.

The predicted flow field and thermal structure from one typical numerical experiment are shown in Figures 1b and 1c, respectively. It shows a strong asthenospheric flow in the wedge of the overriding plate induced by the down going slab. This secondary flow was found to be quite important in maintaining a hotter thermal structure of the overriding plate (plate wedge). One another interesting result is that the total thickness of the subducting slab (defined by an isotherm, say 1325°C) does not change much at least down to the 400 km depth. This finding lends support to the assumption of a uniform temperature at the base of the subducting slab used in a previous 2-D thermal study of the Cascadia forearc across the Vancouver Island [*Hyndman and Wang,* 1993].

The heat flow data [*Blackwell et al.*, 1990] within 100 km distance from the east-west (EW) profile at 45°N are projected onto the profile and are shown as open circles at the top panel of Figure 2. The surface heat flow predicted by the model thermal structure (Figure 1) is shown as a solid curve and there is a good match between the mean of the heat flow data and the model although high heat flows were measured at the Cascade volcanic arc. Those high heat flow measurements are obviously related to volcanic activities beneath the arc which are not included in our current model. Numerical tests have shown that these heat flow calculations are not sensitive to the boundary conditions (thickness of the continental lithosphere) on the right side of the model domain as long as there is a significant asthenospheric flow in the plate wedge. Notice these model calculations do not include significant frictional heating along the plate contact.

The temperatures at the plate contact are shown at the bottom of Figure 2 as a function of the horizontal distance from the trench. If stick slip occurs below 350°C [*Tse and Rice*, 1986] then the seismogenic zone could extend landward about 150 km from the trench. Notice that this particular model does not include any significant frictional heating along the plate contact. Our numerical experiments have shown that the seismogenic zone is limited within a narrow zone of less than 60 km from the deformation front if significant heat is generated by the friction along the plate interface. However, the model prediction of a high heat flow near the trench is not permitted by the heat flow data. Figure 3 shows one model calculation to show the effect of the frictional heating.

We are continuing the process of digesting these preliminary modeling results and refining our finite element models to calibrate with the seismic studies across the central Oregon margin [*Trehu et al.*, 1994; *Nabelek et al.*,

1993; *Nabelek and Li*, 1995]. The preliminary modeling results will be reported in the 1994 Fall AGU Meeting in San Francisco [*Ding and Chen*, 1994] and the details of our results and interpretations will be reported later in a JGR paper.

## References

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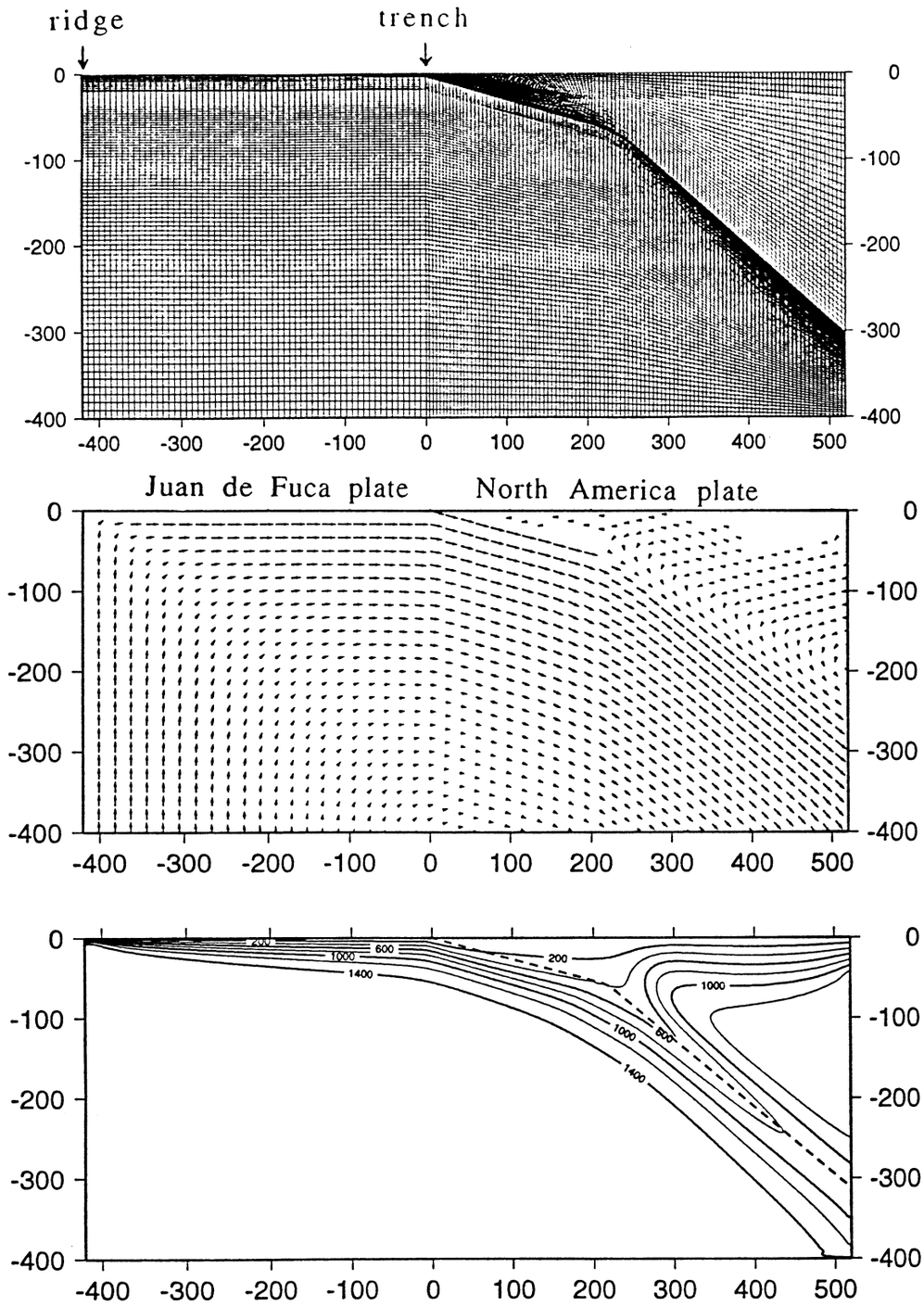


Fig. 1. Two-dimensional finite element models. (*top*) The finite element mesh of a model domain of 520 by 400 km. (*middle*) The calculated flow field shows mantle upwelling at the Juan de Fuca ridge and downwelling at the subduction zone. Note a strong asthenospheric flow in the wedge of the overriding plate. (*bottom*) Model thermal structure is shown in contours with an interval of 200°C. The plate interface is shown as a dashed line.

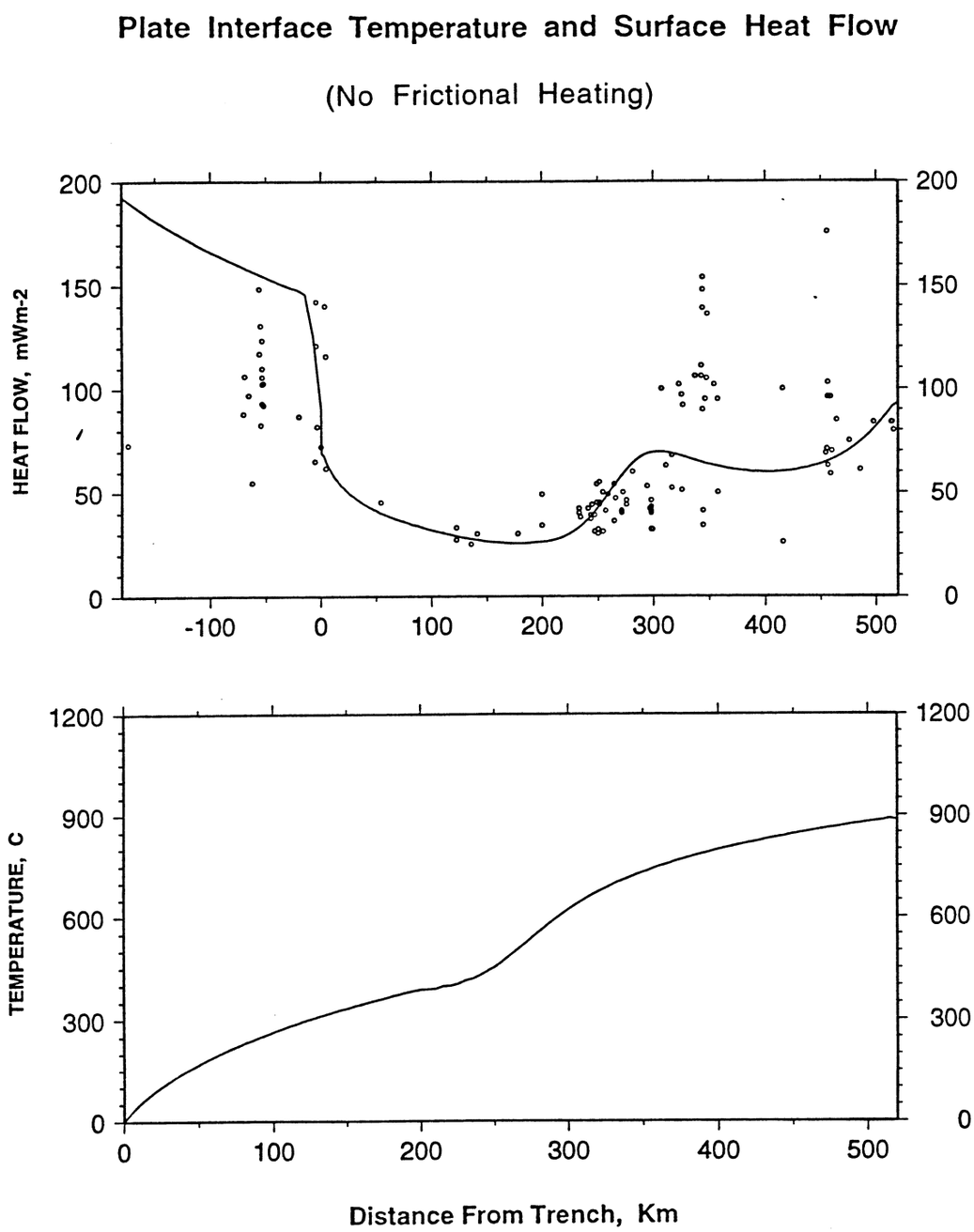


Fig. 2. Model calculations for the case without including any frictional heating along the plate interface. (*top*) Surface heat flow along an east-west (EW) profile at 45°N across the central Oregon coast. The data shown in open circles are measurements within 100 km distance from the EW profile and are projected onto the EW cross-section. Model calculations are shown as a solid curve and there is a good match between the mean of the heat flow data and the model although high heat flow exist at the Cascade volcanic arc. (*bottom*) Predicted plate interface temperatures versus distance from the trench.

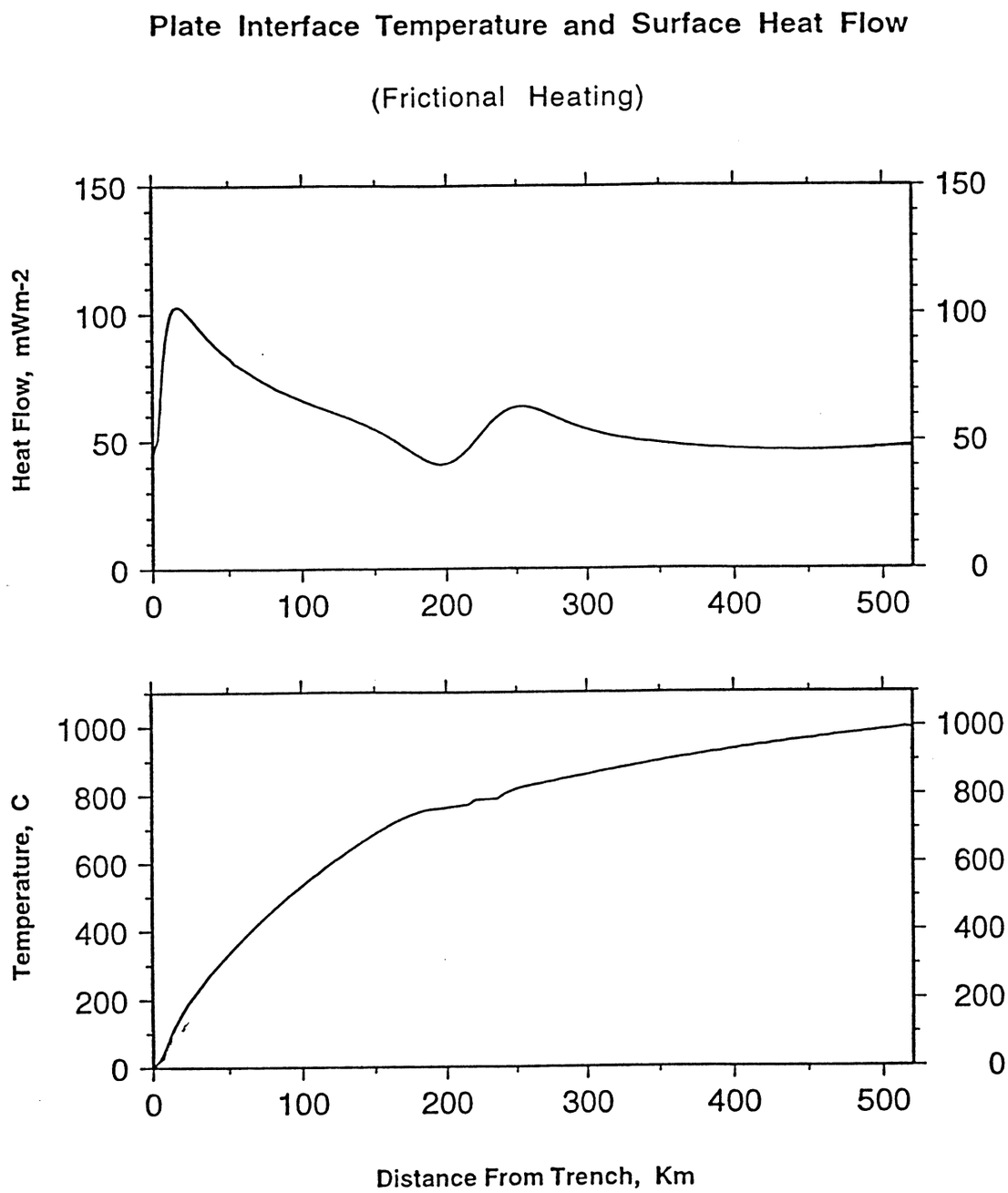


Fig. 3. Model calculations for the case including significant frictional heating along the plate interface. (*top*) Surface heat flow along the east-west profile at 45°N across the central Oregon coast. Notice a high heat flow near the trench which is not permitted by the heat flow data (top, Figure 2). (*bottom*) Predicted plate interface temperatures versus distance from the trench. The interface temperature is significantly higher than the case without frictional heating as shown at the bottom of Figure 2.

## Nontechnical Summary

This project is designed to examine the thermal structure of the Cascadia subduction zone and is aimed at emphasizing the effect the thermal state may have on coupling of the subducting Juan de Fuca plate with the overlying North American plate. The results of this investigation will help us to better understand how the Juan de Fuca plate interacts with the North American plate beneath the west coast of Oregon, therefore, improve our assessment of the earthquake hazards in this important Pacific Northwest region. The preliminary model results seem to be not consistent with the case including any significant frictional heating along the plate interface.