Pergamon

Phys. Chem. Earth, Vol. 23, No. 3, pp. 297–301, 1998

Printed in Great Britain
0079-1946/98 $19.00 + 0.00

PII: S0079-1946(98)00028-7

The Cascadia Subduction Zone: Two Contrasting Models of Lithospheric Structure

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Received 25 April 1997; accepted 28 October 1997

Abstract. The Pacific margin of North America is one of the most complicated regions in the world in terms of its structure and present day geodynamic regime. The aim of this work is to develop a better understanding of lithospheric structure of the Pacific Northwest, in particular the Cascadia subduction zone of Southwest Canada and Northwest USA (Figure 1). The goal is to compare and contrast the lithospheric density structure along two profiles across the subduction zone and to interpret the differences in terms of active processes. The subduction of the Juan de Fuca plate beneath North America changes markedly along the length of the subduction zone, notably in the angle of subduction, distribution of earthquakes and volcanism, geologic and seismic structure of the upper plate, and regional horizontal stress. To investigate these characteristics, we conducted detailed density modeling of the crust and mantle along two transects across the Cascadia subduction zone (Figure 1). One crosses Vancouver Island and the Canadian margin, the other crosses the margin of central Oregon.

1 Introduction

Our goal was to construct a density model and to compare and contrast lithospheric structure along two profiles, one in central Oregon and the other across Vancouver Island in British Columbia. Density models along these profiles were previously constructed by Couch and Riddihough (1989) for the Oregon profile and by Dehler and Clowes (1992) for the Vancouver profile. The previous density model for the Oregon profile was highly speculative, because little seismic data was available. However, detailed seismic refraction experiments were carried out in 1989-1991 (Trehu et al., 1994; Clowes et al., 1995), and a new, more exact seismic model was constructed, thereby allowing improvement in the density model.

Both previous density models were constructed independently to a depth of approximately 50 km. We tried to gather all possible geologic, geophysical, borehole and other data for the profile, and we used these data as the constraints for the density models. The densities for the Oregon (Figure 2a) and Vancouver (Figure 2b) lithosphere were obtained from the gravity inversion. The observed anomaly is shown by the gray profile, and the calculated anomaly by the black profile. The densities are indicated by numbers; dual numbers indicate a vertical gradient within a block.

2 Method

Models of crustal and mantle density were derived with a two-dimensional, linear gravity inversion technique. This technique approximates the crust and upper mantle by a set of blocks based on published seismic refraction models. Each block has a range of densities, constrained where possible by borehole measurements, seismic velocities, heat flow data, and petrologic arguments. To further constrain the models, we assume that oceanic crust has the same density-depth ratio at both transects, and that the lithosphere is close to isostatic equilibrium both in the deep ocean and east of the modern volcanic arc.

3 Results

Our results confirm that the downgoing slab dips significantly steeper beneath Oregon than beneath Vancouver Island, lending support to the idea that the Juan de Fuca plate is segmented from north to south. In addition, our model of gravity data indicates that the mantle wedge beneath western Oregon (i.e., below the western Cascades) is lighter than the mantle beneath the Canadian continental crust. This low density is in agreement with the low velocities observed in the mantle.

The anomalous block within the mantle on the Oregon profile (Figure 2a) is situated beneath the aseismic western Cascades. This anomalous block is located between the continental upper plate and the subducting Juan de Fuca plate and has a lower density than the mantle density beneath the modern volcanic arc in either segment. This density anomaly may be interpreted as a relic of the hot asthenospheric material of the Juan de Fuca ridge that moved beneath the western Oregon margin in the late Eocene - early Oligocene tectonic history.

4 Conclusions

We have found that it is possible to explain regional features of the gravity field using a common density-depth relation in the subducted slab and oceanic asthenosphere for both profiles. We recognize that there is ambiguity in these gravity inversions, and that some details in the models cannot be confirmed due to small effects (for example, the density change due to the basalt - eclogite transformation in the subducted oceanic crust). In spite of the uncertainty of densities in individual blocks, the primary conclusions regarding the main features of gravity models and average densities of the large structures are considered to be reliable.

Our gravity modeling shows that the existence of a gravity minimum at the deformation front of the Oregon margin, absent along the Vancouver margin, can be explained by the difference in bathymetry in these two regimes and the depth to the top of the subducting Juan de Fuca plate. We find that the density of the accretionary prism for the Vancouver profile must be approximately 0.1-0.2 g/cm^3 greater than that for Oregon. If the accretionary prisms along these profiles were modeled with equal densities, a density inhomogeneity in the lower part of the models would be necessary. This density difference within the accretionary prisms agrees with other data. We further note that the volume of accreted sediments is approximately twice as large at the Vancouver profile compared with the Oregon profile, and the depth of penetration of the lowered accretionary prism is greater (approximately 20 km), compared with the Oregon profile (approximately 12 km). This implies that the sediments within the accretionary prism at Vancouver Island are at a higher metamorphic grade, and therefore have higher densities.

Finally, calculations of the gravity effect of the subducted slab show that a substantial part of the coastal gravity maxima for both lines is caused by increasing density with depth in the subducting plate. If a density increase with depth is not introduced into the model, very high densities would be required for the near surface, coastal, and crustal blocks. In the proposed model, the maximum possible density of the slab was used to satisfy constraints for the average density of the near coastal crust for both profiles.

Acknowledgments. This research was supported by the USGS Earthquake Hazards Reduction Program. We thank Robert Page and Craig Weaver for their advice and support. Ellen Dawn Tobey and Katharine Favret assisted with editing and Ellen Dawn helped with figure preparation.

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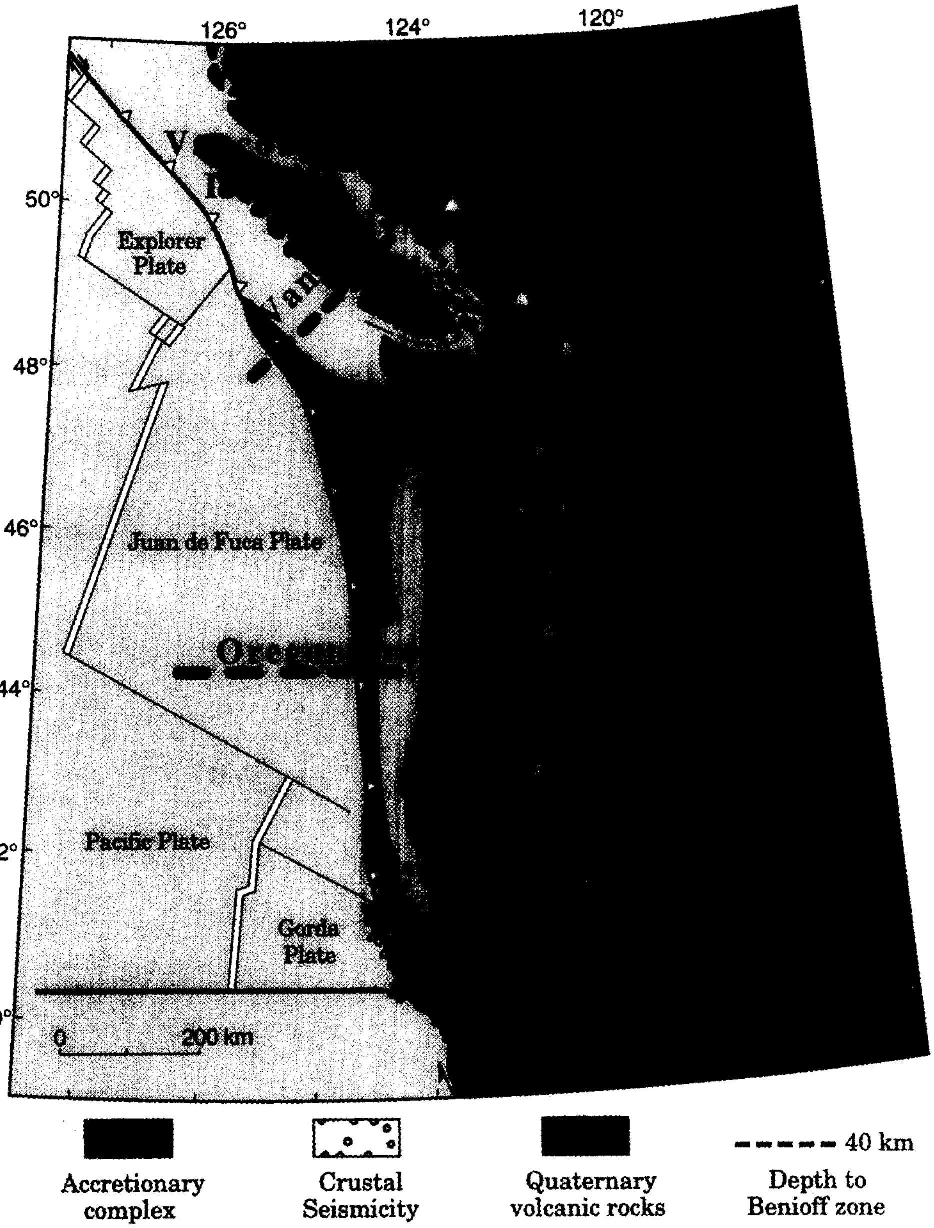

Figure 1. Generalized tectonic map of Cascadia region (modified from Ray Wells, personal communication). Black dashed lines indicate location of profiles, triangles - major volcanoes. The volcanic arc extends from Northern California to Southern British Columbia. Seismicity in the crust and subducting plate is high in Northern California and Washington State, but is absent in most of Oregon. The Juan de Fuca ridge is close to the trench, and young (~8 My old); hot oceanic crust is being subducting along this margin.

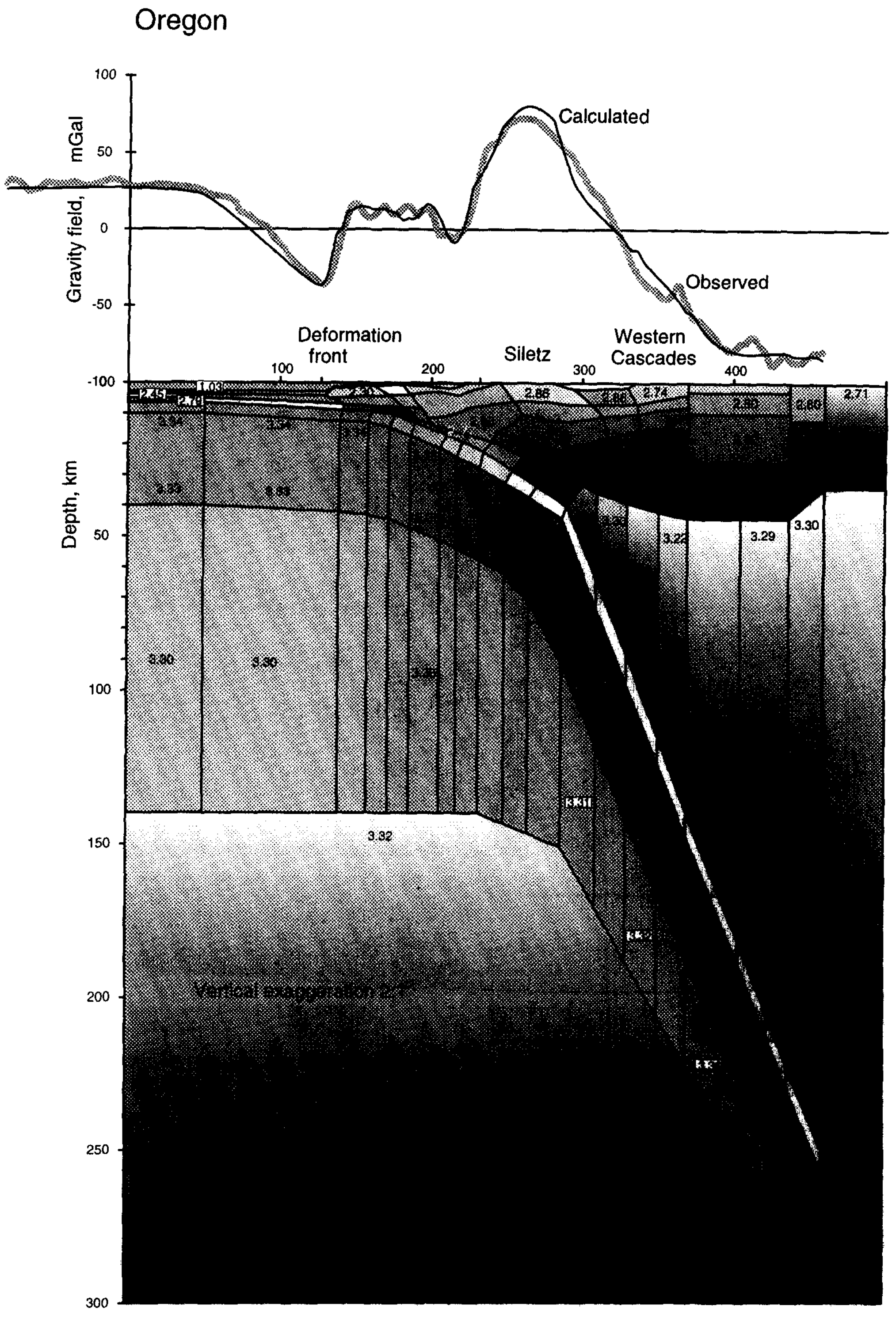

Fig. 2. (a) A density model for the Oregon lithosphere was obtained from gravity inversion. The observed anomaly is shown in gray, calculated anomaly by a profile. Densities are indicated by numbers; dual numbers indicate a vertical gradational density within block.

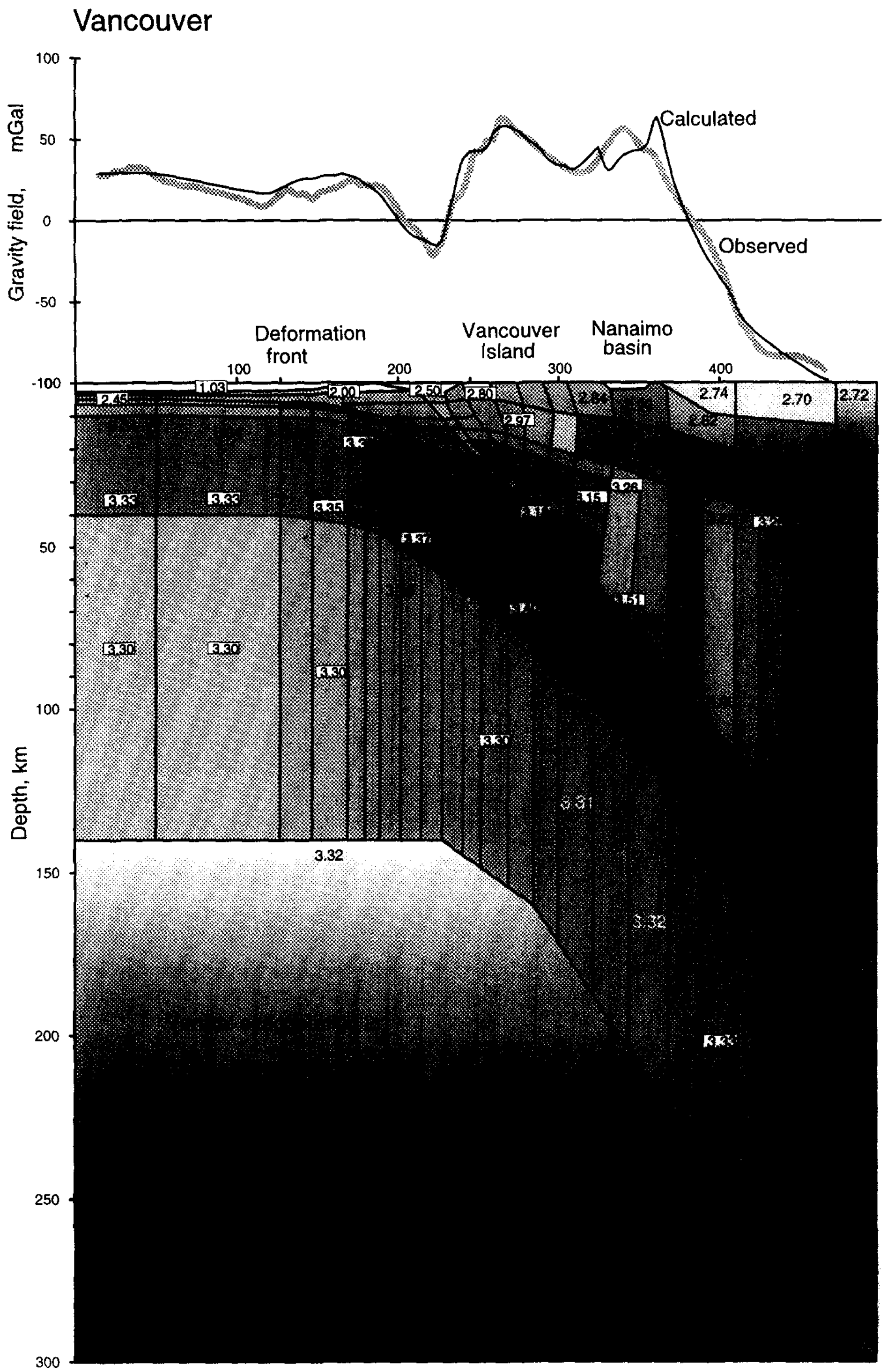

Fig. 2. (b) Vancouver lithosphere model was obtained in the same way.