Tectonophysics 638 (2015) 112–125

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Crustal magmatism and lithospheric geothermal state of western North America and their implications for a magnetic mantle

Jian Wang, Chun-Feng Li *

State Key Laboratory of Marine Geology, Tongji University, Shanghai 200092, China

ARTICLE INFO

Article history:
Received 5 April 2014
Received in revised form 18 August 2014
Accepted 1 November 2014
Available online 8 November 2014

Keywords:
Thermal gravity correction
Curie-point depth
Thermal lithospheric thickness
Mantle serpentinization
Magnetic mantle

ABSTRACT

The western North American lithosphere experienced extensive magmatism and large-scale crustal deformation due to the interactions between the Farallon and North American plates. To further understand such subduction-related dynamic processes, we characterize crustal structure, magmatism and lithospheric thermal state of western North America based on various data processing and interpretation of gravimetric, magnetic and surface heat flow data. A fractal exponent of 2.5 for the 3D magnetization model is used in the Curie-point depth inversion. Curie depths are mostly small to the north of the Yellowstone–Snake River Plain hotspot track, including the Steens Mountain and McDermitt caldera that are the incipient eruption locations of the Columbia River Basalts and Yellowstone hotspot track. To the south of the Yellowstone hotspot track, larger Curie depths are found in the Great Basin. The distinct Curie depths across the Yellowstone–Snake River Plain hotspot track can be attributed to subduction-related magmatism induced by edge flow around fractured slabs. Curie depths confirm that the Great Valley ophiolite is underlain by the Sierra Nevada batholith, which can extend further west to the California Coast Range. The Curie depths, thermal lithospheric thickness and surface heat flow together define the western edge of the North American craton near the Roberts Mountains Thrust (RMT). To the east of the RMT, large Curie depths, large thermal lithospheric thickness, and low thermal gradient are found. From the differences between Curie-point and Moho depth, we argue that the uppermost mantle in the oceanic region is serpentinized. The low temperature gradients beneath the eastern Great Basin, Montana and Wyoming permit magnetic uppermost mantle, either by serpentinization/metasomatism or in-situ magnetization, which can contribute to long-wavelength and low-amplitude magnetic anomalies and thereby large Curie-point depths.

1. Introduction

The western North American lithosphere has experienced long-term extension and magmatism since the Mesozoic, commonly attributed to the diverse interactions between the Farallon and North American plates (e.g., Dickinson, 1997, 2004, 2006; Engebretson et al., 1984; Humphreys, 1995). The long-term subduction of oceanic lithosphere established the Cordilleran orogeny and expanded the continental margin westward with accretions of subduction complexes and intra-oceanic island arcs (Dickinson, 2004). The boundary between accreted oceanic terranes and the North American craton is defined by the $^{87}Sr/^{86}Sr$ 0.704 and 0.706 lines (Fleck and Criss, 1985; King et al., 2004; Kistler and Peterman, 1978), or 0.706 and 0.708 lines (near the RMT) (Farmer and DePaolo, 1983) (Fig. 1). When the spreading ridge between the Farallon and Pacific plates approached the western edge of North America at about 30 Ma, the San Andreas Fault (SAF) started to establish along western North America, causing the Juan de Fuca and Gorda plates to subduct beneath western North America. Such complex subduction-related dynamic processes resulted in distinct tectonic provinces, such as the Cascadia subduction zone, Great Valley, Yellowstone hotspot, and Basin and Range (Fig. 1). Therefore, western North America is one of the most ideal places for understanding ocean–continent interactions.

In this work, we characterize crustal structure and lithospheric thermal state of western North America and discuss magmatism and subduction-related geodynamics processes based on processing and interpretation of potential field and heat flow data. The major geodynamic structures of western North America have been well resolved with seismic tomography using, for example, the EarthScope/USArray transportable array. However, the thermal structure and state of crust and uppermost mantle are poorly constrained, but are critical to understanding the tectonomagmatic evolution of western North America. Magnetic data are useful to constrain magmatism and geothermal state. Although a large amount of surface heat flow data has been collected, they are from uneven distributions and are limited in inferring deep geothermal structures. Lower crust and upper mantle thermal structures can be derived from seismic tomography, however, velocity

---

* Corresponding author at: School of Ocean and Earth Sciences, State Key Laboratory of Marine Geology, Tongji University, 1239 Siping Road, Shanghai 200092, China. Tel.: +86 21 6598 8582.
E-mail address: cfl@tongji.edu.cn (C.-F. Li).

http://dx.doi.org/10.1016/j.tecto.2014.11.002
0040-1951/© 2014 Elsevier B.V. All rights reserved.

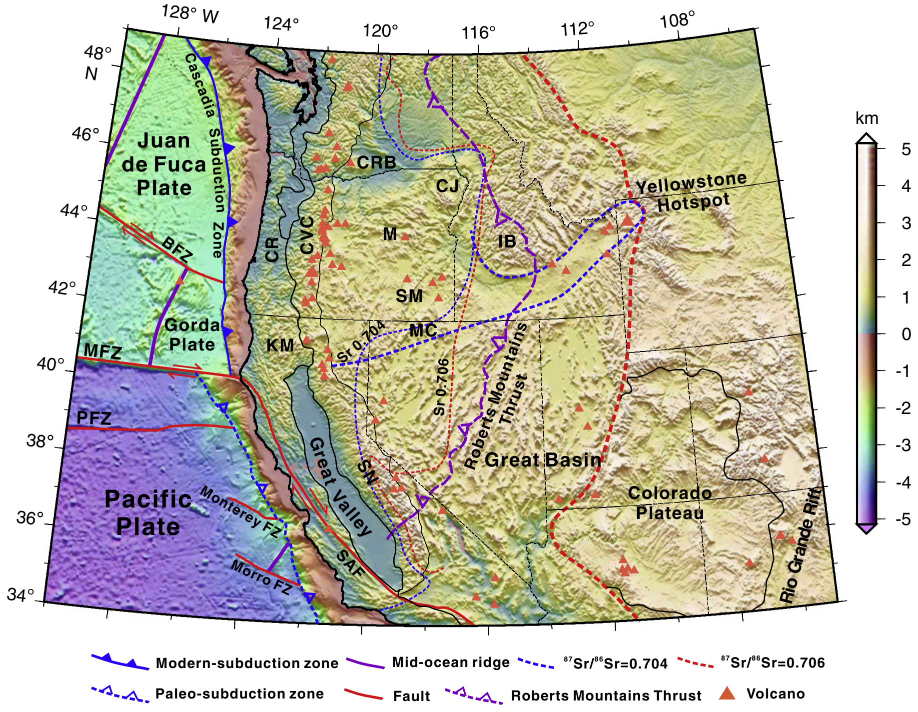

Fig. 1. Western North American topography/bathymetry and major tectonic units. Black solid lines outline the geological provinces (Dickinson, 2006; Patro and Egbert, 2008; Trehu et al., 1994; Xue and Allen, 2010). The thick red dashed line represents the eastern active margin of the Basin and Range Province. The thick blue dashed line delineates the Yellowstone–Snake River Plains track. BFZ, Blanco Fracture Zone; CJ, Chief Joseph dike swarm; CR, Coast Range; CVC, Cascades Volcanic Chain; IB, Idaho Batholith; KM, Klamath Mountains; M, Monument dike swarm; MC, McDermitt Caldera; MFZ, Mendocino Fracture Zone; Monterey FZ, Monterey Fracture Zone; Morro FZ, Morro Fracture Zone; PFZ, Pioneer Fracture Zone; SAF, San Andreas Fault; SM, Steens Mountain; SN, Sierra Nevada.

is not only related to temperature, but also to lithology, composition and presence of fluids (Goes and van der Lee, 2002).

The Curie-point depths (Z_b) estimated from magnetic anomalies are effective to reveal the regional thermal structure independently. Various studies have been carried out to investigate Z_b in the western United States, such as in the Yellowstone National Park (Bhattacharyya and Leu, 1975; Smith et al., 1977), Cascade Range (Connard et al., 1983), Nevada (Blakely, 1988), California (Ross et al., 2006), and eastern Basin and Range (Shuey et al., 1977). These studies usually focused on small continental regions using different methods, and assuming random 2D magnetization. In a recent work, Bouligand et al. (2009) studied the Curie-point depths in the western United States based on a fractal magnetization model. Here we study both western North America and northeast Pacific Ocean to understand subduction-related crustal magmatism and geodynamics (Fig. 1), by achieving stable Z_b estimates using the centroid method with a fractal correction.

2. Tectonic framework

When the spreading ridge between the Farallon and Pacific plates approached the North American plate at about 30 Ma, the Farallon plate broke along the Pioneer Fracture Zone into the Juan de Fuca (to the north) and the Monterey and Arguello microplates (southern remnant Farallon plates) (Fig. 1) (Nicholson et al., 1994; Wilson, 1988). The Monterey ridge ceased spreading at about 19 Ma (Fernandez and Hey, 1991; McCrory et al., 2009) when it was captured by the Pacific plate (Wilson et al., 2005), and remained offshore between 35 and 36°N, bounded by the Monterey Fracture Zone and the Morro Fracture Zone (Fig. 1). To the north of the Mendocino Fracture Zone (MFZ), the Juan de Fuca and Gorda plates, separated by the Blanco Fracture Zone, are subducting eastward obliquely beneath North America, resulting in a wide accretionary complex, whereas to the south of the MFZ is the dextral strike-slip San Andreas Fault formed at ca. 26 Ma (Atwater, 1970; Dilles and Gans, 1995).

The remarkable tectonism and magmatism since the late Paleogene in the western United States include the extension of the Basin and Range Province and the almost simultaneous volcanic eruptions forming the Columbia River Basalts (CRB) and the Yellowstone–Snake River Plain track (YSRP) (Fig. 1). The incipient extension of the Basin and Range started firstly in the north between 36 and 24 Ma and then in the south, followed by the extension in the central part at ca. 16 Ma (McQuarrie and Wernicke, 2005). The extension of the Great Basin, the main subdivision of the Basin and Range Province, can date back to at least 30 Ma (Eaton, 1982), and to 39 Ma in eastern Nevada and no earlier than 35 Ma in southern Nevada (Sonder and Jones, 1999). The earlier extension of the pre-Basin and Range, which initiated in an intra-arc and back-arc setting from the Late Eocene to Early Miocene, characterized by local subhorizontal detachment faults (Dickinson, 1991), can be relevant to the steepening rollback (Dickinson, 2002, 2006; Eaton, 1982) and/or removal of the Farallon subduction slab (Humphreys, 1995, 2009). The more recent extension of the Basin and Range since the Early Miocene, characterized by block faulting, was strongly influenced by the lateral traction of the San Andreas transform (Dickinson, 1991, 2006; Eaton, 1982). Extension along the western margin of the northern Nevada rift (around 118°W) has started migrating westward since 26 Ma, invoking extension and strike-slip faulting in the Walker Lane at ca. 25–22 Ma, and arrived at the Sierra Nevada–Basin and Range transition after 14–12 Ma, and the relevant volcanism has reached southern Oregon at ca. 22 Ma (Dilles and Gans, 1995; Scarberry et al., 2010; Wagner et al., 2010). Faulting in the northern Basin and Range Province has migrated both east and west since the middle Miocene, and centralized in northwestern Nevada after 10 Ma (Colgan et al., 2004).

The CRB began to erupt at ca. 16.6 Ma near the Steens Mountain (Steens Basalt) and then rapidly migrated to the northeast at ~16.1 Ma, forming the NNW-trending Chief Joseph (CJ) dike swarm and NW-trending Monument dike swarm (Picture Gorge Basalt), which cover southern Washington and eastern Oregon and comprise