Journal of Volcanology and Geothermal Research 187 (2009) 13–25

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

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

Geodynamic framework of large volcanic fields highlighted by SRTM DEMs: Method evaluation and perspectives exampled on three areas from the Cameroon Volcanic Line

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ARTICLE INFO

Article history:
Received 4 September 2008
Accepted 30 June 2009
Available online 6 July 2009

Keywords:
SRTM DEMs
Riedel system
Cameroon Volcanic Line
Tombel graben
Upper Benue valley
Ngaoundéré area
geodynamic model

ABSTRACT

This study is a part of a wider investigation to evaluate how much can be learnt by using low-cost methods such as systematic moderate-resolution remote sensing to map and quantify geological structures at the regional scale on very large volcanic provinces only partly studied in the field. Volcanic-centre and cinder-cone distribution, faults and structural lineaments are mapped combining Shuttle Radar Topography Mission (SRTM), Digital Elevation Models (DEMs) and Landsat satellite images. As an example of the method, we present the interpretation of structural data and morphological features of three contrasted areas from the Cameroon Volcanic Line (Tombel graben, Upper Benue valley, and Ngaoundéré area) for which local field studies are available for comparison. At a local scale, this remote-sensing method of mapping displays good to excellent correlations with previously published data and, by itself, it allows one to constrain the structural setting of each area. Numerical treatment of vent and cinder-cone localisation can be related to tension fractures (*T* direction), whereas numerical treatment of the lineaments constrains the associated fault system to a single transtensional (strike-slip + extension) Riedel type fracture network. The first results on the Cameroon Volcanic Line are promising and could be used at a larger scale on numerous volcanic provinces for which field data are not yet available.

1. Introduction

Recognition of the close spatial association of faults, lineaments and volcanic centres has led to the construction of models explaining the pattern of regional deformation in different geodynamic environments. Volcanoes can be associated with regional tectonic structures resulting from extensional (e.g. Smith et al., 1995), strike-slip (e.g. Aydin et al., 1990) or compressional strain (Tobisch and Cruden, 1995; Galland et al., 2007). At a local scale, vents can be related to tension fractures, e.g. in Iceland (Opheim and Gudmundsson, 1989; Chorowicz et al., 1997) or Ethiopia (Korme, 1997), or to active faults (e.g. Cello et al., 1985). Regional tectonic structures have been shown to strongly influence the growth of volcanic edifices in preferential directions (e.g. Adiyaman et al., 1998), as evidenced by the non-random localization of main eruptive centres and secondary eruptive vents (e.g. Nakamura, 1969; Connor et al., 1992). Nakamura (1977) inferred principal stress orientations in the Aleutian arc from the systematic pattern of volcanic vent alignments whereas Opheim and Gudmundsson (1989) and Chorowicz et al. (1997) showed that the distribution and shape of small vent buildings and the orientation of tension fractures were directly related to the tectonic regime. While the linear distribution of volcanoes related to tension fractures can thus be used as indicators of the tectonic stress regime, a key problem in the study of very large volcanic provinces is that numerous areas have not yet been studied in the field and that, consequently, structural and volcanologic maps are not available for such an approach. However, in modern volcanic fields, topography datasets at a kilometer scale may usually compensate the lack of such data. Volcanic centres, cinder-cones, faults and structural lineaments can be mapped combining Shuttle Radar Topography Mission (SRTM) Digital Elevation Models (DEMs) and Landsat satellite images. SRTM DEMs yield a homogeneous ~90 m spatial-resolution topographic dataset with near global coverage (from 60°N to 56°S) and display the best resolution available for numerous poorly known areas.

A suitable geodynamic environment to examine such key issues is the Cameroon Volcanic Line (CVL) now called Cameroon Hot Line (CHL; Déruelle et al., 1998; Moreau et al., 1998; Déruelle et al., 2007), which covers several thousands square kilometers. The relationship between volcanism and compressional, strike-slip and extensional deformations is not well established, especially in the central part of the CVL, due to the lack of detailed fieldwork, of volcanic-activity monitoring, or of research on the structure of the large *active volcanic fields*. Documenting the distribution of volcanic vents and volcano-tectonic structures can help identify the factors that key-control the

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doi:10.1016/j.jvolgeores.2009.06.007

spatial distribution of volcanic activity, and the influence of regional tectonics on the structure and evolution of the shields. Conversely, detailed understanding of shield structures can help unravel tectonic processes at work within the CVL. This approach is tested here through a morphostructural study and the numerical treatment of structural features of three sites from the CVL: the Tombel graben area, the Upper Benue valley (Yola branch), and the Ngaoundéré area (Adamawa plateau). These areas have been selected on the basis of the available geological maps, which allow discussion of our remote-sensing methodology. After a comparison between off-field mapping and published maps, we propose new interpretations of the structural framework related to the geodynamic environment of the studied zones.

2. Geological setting of the three selected areas from the CVL

2.1. The Cameroon Volcanic Line (CVL)

The NNW-trending Cameroon Volcanic Line (CVL) extends for more than 2000 km across the Gulf of Guinea and Africa, mainly in Cameroon (Fig. 1). It crosses both the ocean and the continental domains from Pagalu Island in the Gulf of Guinea (Atlantic Ocean) to Lake Chad. Some authors even extend the line to Tibesti and Southern Libya (Vincent, 1970; Tempier and Lasserre, 1980). The CVL comprises many Cainozoic (60 Ma to recent) volcanic centres and anorogenic plutonic ring-complexes. It is divided into two branches at its northern end, the first one westward across the Benue Valley, and the other to the east throughout the Ngaoundéré plateau. The central part of the CVL is crossed by NE–SW major faults (Moreau et al., 1987), while its oceanic part is mainly composed of volcanic islands forming a N30° linear array. Numerous hypotheses have been proposed to explain its structure and formation (see Déruelle et al., 1991 and 2007 for a review). It has been considered to result (i) from the movement of the African plate over a hotspot (Morgan, 1983). The similarities in size and shape between the CHL and the nearby Benue Trough to the NW led Fitton (1980) to postulate that the CHL resulted from an anti-clockwise rotation of the African lithosphere over a hotspot at about 80–65 Ma, thus locating the hotspot beneath Mount Cameroon instead of beneath the Benue Trough. (ii) From membrane stresses generated by movement of the African plate away from the equator (Freeth, 1978). (iii) From reactivation of ancient postpanafrican basement fractures (Moreau

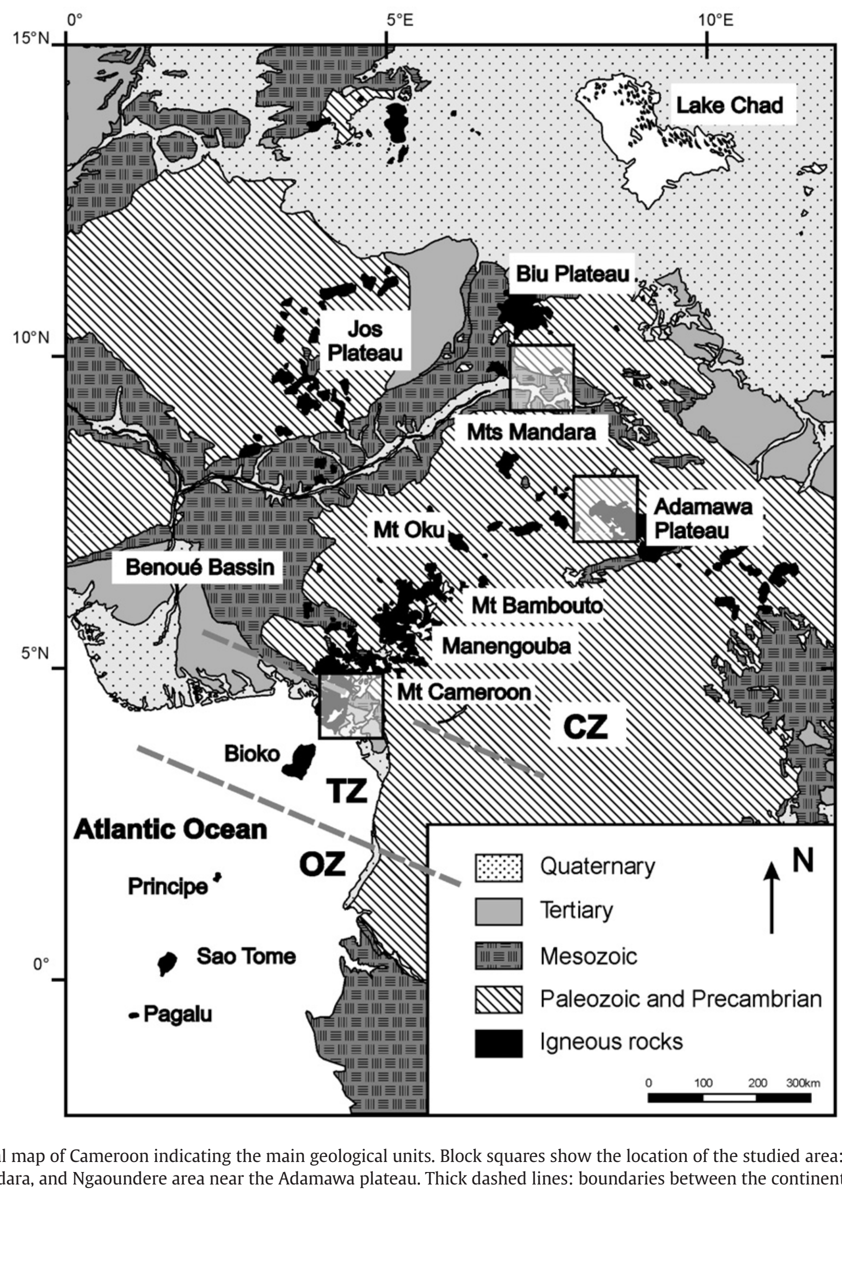

Fig. 1. Simplified general geological map of Cameroon indicating the main geological units. Block squares show the location of the studied area: Tombel graben near Mt Cameroon, Upper Benue valley near Mts Mandara, and Ngaoundere area near the Adamawa plateau. Thick dashed lines: boundaries between the continental zone (CZ), transitional zone (TZ) and the oceanic zone (OZ).