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DETERMINATION OF THE ISOSTATIC COMPENSATION MECHANISM OF THE REGION OF THE ADAMAWA DOME, WEST CENTRAL AFRICA USING THE ADMITTANCE TECHNIQUE OF GRAVITY DATA.

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ABSTRACT *: The Adamawa dome in Central Cameroon represents a post-Cretaceous uplifted region, paralled to a Precambrian Foumban Shear Zone, and characterised by Tertiary-Recent volcanic centres of the Cameroon Volcanic Line, and a long negative Bouguer anomaly similar in shape and amplitude to those of other African domes. Using the Admittance Technique of gravity data, the present study aims at computing the Isostatic Compensation Mechanism of the region of the Adamawa dome. The results show that the dome is overcompensated and fits models involving density contrasts beneath the elastic plate and the consequent upwarping of the plate above low density material at depths. A comparison of the Adamawa admittance to the East African and Ethiopian plateau shows that a dynamic compensation mechanism may not be ruled out entirely for the Adamawa dome.*

RESUME *: Le dôme de l'Adamaoua, au centre du Cameroun, est caractérisé par des volcans datant du Tertiaire au Récent et appartenant à la ligne volcanique du Cameroun. Ce dôme est parallèle à une zone cisaillée précambrienne et à une longue anomalie de Bouguer, il ressemble aux autres dômes africains par sa forme et son étendue. Dans cette étude, l'admittance ou la fonction de réponse isostatique du dôme de l'Adamaoua déterminée à partir des données gravimétriques montre que le dôme est exagérément compensé et est comparable aux modelés qui présentent des contrastes de densité entre la plaque élastique et l'escarpement subséquent de la plaque située au-dessus des couches moins denses des profondeurs. En comparant l'admittance du dôme de l'Adamaoua avec des plateaux de l'Afrique de l'Est et d'Ethiopie, on constate qu'un mécanisme de compensation dynamique est aussi une hypothèse envisageable dans ce contexte.*

INTRODUCTION

The Adamawa dome represents a post-Cretaceous uplifted and elongated zone which trends southwest-northeastwards in the West Central African region (Fig. 1). It is about 200 km wide with altitudes ranging from 800 m to about 2700 m (Fig. 2). Previous geophysical studies on this massif show that the dome is characterised by a long negative Bouguer anomaly of about – 120 mgal and 200 km wide (Collignon, 1968 ; Poudjom Djomani et al., 1997), similar in shape to the East African and Ethiopian domes (Ebinger et al., 1989). On top of the large negative anomaly is superimposed a local positive Bouguer anomaly (Poudjom Djomani et al., 1997). Browne and Fairhead (1983) attribute the large negative anomaly to low density material in the upper mantle. Poundjomm Djomani et al. (1992), see the broad negative anomaly as a consequence of lithospheric thinning (40 km) and the localised positive anomaly as due to thinning of the crust (10 km).

Seismological studies suggest a hot, low density body in the upper mantle (Dorbath et al., 1986 ; Plomerova et al., 1993 ; Tabod et al., 1992), low-Q materials at different depths in the crust and upper mantle (Bak, 1992) and the crust thins from 33 km south of the uplift to

23 km north of the dome (Stuart et al., 1985). The Adamawa dome is seismically active and the seismicity is related to movements on faults of the FSZ (Nnange et al., 1985 ; Nnange 1991 ; Tabod et al., 1992).

Coherence function analysis shows that the lithosphere is deflected and thins beneath the Adamawa dome with effective elastic thickness values ranging from 14-20 km (Nnange, 1991 ; Poudjom Djomani et al., 1992). This result on the Adamawa dome is of the same order of magnitude as those on the Kenyan dome (Ebinger et al., 1989 ; Ebinger, 1991). This study compliments previous geophysical studies of the Adamawa dome by using the admittance technique to examine its isostatic compensation and compare the results with other African domes such as the East African and Ethiopian domes

GEOLOGICAL SETTING

The Adamawa dome in Centrale Cameroon, formed during the Tertiary together with othert African volcanic uplifts such as the East African plateau, is underlain by Precambrian basement rocks, remobilised by the Pan-African episode (600 – 500 Ma) and uplifted (1 km) relative to the surrounding area. These rocks mainly schists and gneisses intruded by granites and diorites are cut by faults of the Foumban Shear Zone (FSZ), (Fig. 1). The fault zone is part of the ENE-WSW trending Pan-African Central African Shear Zone (CASZ) that extends some 2000 km from Cameroon to Sudan (Cornacchia and Dars, 1983). The FSZ, considered to be the continuation of the Pernambucco lineament in Brazil prior to continental separation (De Almeida and Black, 1967), represents a zone of weakness within the African lithosphere, reactivated since Cretaceous to Recent times and may have facilitated magma ascent to the surface (Mascle, 1976 ; Browne and Fairhead, 1983). Parallel to the FSZ and to the south of it is another dextral shear, the Sanaga Fault Zone (SFZ), stretching from Cameroon to Central African Republic (Dumont, 1986).

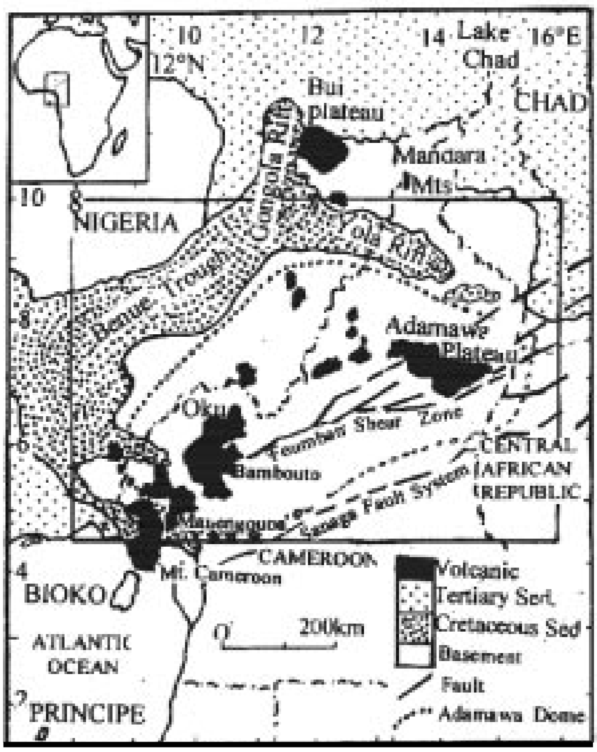

Figure 1. Simplied geology map of the region.of the Adamawa dome and adjacent areas.

The Adamawa dome as considered here includes the following volcanic centres : the Adamawa plateau, the Oku massive, mount Bambouto and the Manengouba mountain (Fig. 1). These volcanic centres together with Bui plateau in northern Nigeria, the Mandara mountains in northern Cameroon, and Mt. Cameroon at the Atlantic coast constitute the continental segment of the Cameroon Volcanic Line (CVL), trending N30°E (Fig. 1) and extends offshore to the islands of Bioko, Principe, Sao Tome and Pagalu in the Gulf of Guinea (Fitton and Dunlop, 1985). Mt. Cameroon is the best known volcano along the CVL and has been active during the past century (Deruelle, 1982) the most recent eruption being in March/ April 1999 (Ghogomu et al., 1999 ; Wandji et al., 1999).

Volcanic rocks of the oceanic sector are dominantly basalts. The continental section volcanics range from basalts to trachytes. Mt. Cameroon is composed mainly of alkaline basic lavas while Etinde is convered by nephelinite lavas. Manengouba is made up of alkali basalts, hawaiites (Jeremine, 1943), trachytes (Jeremine, 1941), rhyolitic obsidians (Tchoua, 1970) and rhyolites (Hedberg, 1968). Bamboutos lavas are mainly alkali basalts and trachytes, while Oku is composed of transitional basalts, trachytes and rhyolites (Fitton and Dunlop, 1985 ; Njilah, 1991). The Mandara mountains represent trachyte and rhyolite plugs while the Bui plateau is composed of a thick pile of basaltic lava flow. The Adamawa plateau is composed of alkaline basalts and basanited intruded by trachytes and phonolites (Temdjem, 1986). Fitton and Dunlop (1985) have observed that the basalts on both the ocean and continental segments of the CVL are geochemically and isotopically indistinguishable, thus implying a similar mantle source.

Isotope dating indicated the major part of the volcanic line was active within the last 10 Ma. The oldest dated range from 65 Ma along the continental sector to 35 Ma in the oceanic segment, thus indicating a linear zone of magmatic activity since the end of the Cretaceous period (Dunlop and Fitton, 1987). However, the volcanism shows no consistent age progression along the entire line (Dunlop and Fitton, 1987).

Another major tectonic feature spatially associated with the Adamawa dome is the Benue Trough (Fig. 1). It is a Cretaceous NE-SW trending sedimentary basin extending from the Niger delta to lake Chad. The Trough splits at its northeastern end into a northern and eastern branch – the Gongola and Yola rifts respectively (Fig. 1). The origin of the Trough is related to the opening of the South Atlantic Ocean during the early Cretaceous (Burke and Whiteman,1971) and its orientation is controlled by northeast trending dextral shear zones of late Pan-African age, reactivated later by sinistral shear (Guiraud and Maurin, 1992).

THE ADMITTANCE TECHNIQUE

On the assumption that the compensation for a delta load would be linear and isotropic, Dorman and Lewis (1970) showed that the Fourier transform of the Bouguer gravity B(k) is related to the Fourier transform of the topography counterpart H(k) via

$$B(k) = Q(K)\, H(k) \qquad 1$$

where $k=|k| = 2\pi/\lambda$ and Q(K) is the isostatic response function or the admittance that predicts gravity given topography. It should be noted that while B and H are functions of k, the horizontal wave number, Q is a scaler function of the magnitude of k. Banks and Swain (1978) and Forsyth (1985) have shown that a reasonable value of Q(K) is determined from

$$Q(K) = <B(k)\, H(k)^*>/<H(k)\, H(k)^*> \qquad 2$$

where $<H(k)\, H(k)^*>$ is the wave number-averaged power of the topography and $<B(k)H(k)^*>$ is the cross spectrum of the Bouguer gravity and topography. The angular brackets $< >$ denote averaging process over discrete wavebands and an asterisk indicates complex conjugation.

Physically, Q(K) represents the Fourier transform of the gravity field from the compensation of a point load. Thus, Q can be directly compared with theoretical Q functions from an assumed compensation mechanism. The theoretical functions differ greatly if it is assumed that a thin elastic plate is either loaded on top, loaded from below or both (Forsyth, 1985). A full discussion on the different types of loading and the respective expression are available in Forsyth (1985).

At shorter wavelengths, where gravity and topography are incoherent, surface and subsurface loads are particularly or wholly supported by the strength of the elastic plate and the admittance will not indicate reliably the form or depth of compensation if both surface and subsurface loads are present (Forsyth, 1985). On the other hand, surface and subsurface loads are both fully compensated at long wavelengths.

Both surface and subsurface loads are present in the region of the Adamawa dome (Nnange, 1991) and much of the topographic relief of the dome (Fig. 2) occurs at wavelengths longer than the flexural wavelengths of the lithosphere beneath the uplift (Nnange, 1991). As such, the uplifted region cannot be supported by the strength of the lithosphere. Rather, much of the relief of the dome must be supported by density variations within the crust or mantle (Poudjom Djomani et al., 1997), and the admittance is used to examine its compensation.

The admittance has been computed for the sub-region of about 880 x 600 km covered by rectangle located within 7 – 17°E and 4.5 – 13°N in Figure 1. The area encompases the entire Adamawa dome, the Middle and Upper Benue Trough, the Foumban Shear Zone and part of the basement region of southern Cameroon. It contains both long and short-wavelength information needed to determine the admittance and discuss the isostatic compensation associated with the Adamawa dome.

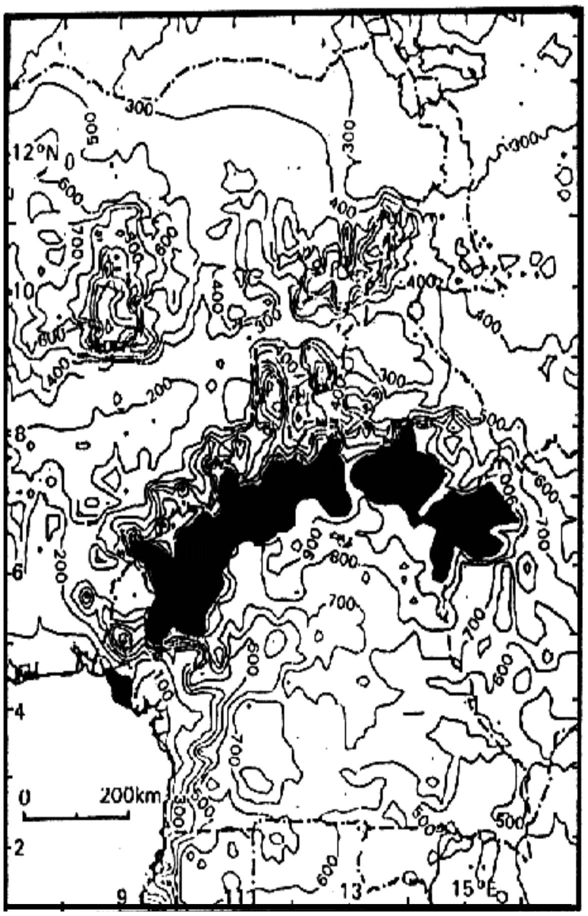

Figure 2. Topographic map of West Central Africa. Areas above 1000m in height are shaded

DATA

The data used in this study are part of a network of interconnecting lines of randomly distributed gravity stations obtained from Poudjom Djomani et al. (1995) and Nnange (1991), (Fig. 3). The topography data were obtained from heights of gravity stations. Latitudes and longitudes were converted to an x-y coordinate system using a Mercator projection and a central meridian of longitude 13°E. The irregularly spaced data (Fig. 3) were interpolated on a 10 by 10 km regular grid using the minimum curvature method of Briggs (1974) and a computer program by Swain (1976) and Browne (1984). The total grid has 88 X 82 points in the x and y directions respectively. The same transformations were applied to the gravity and topographic data.

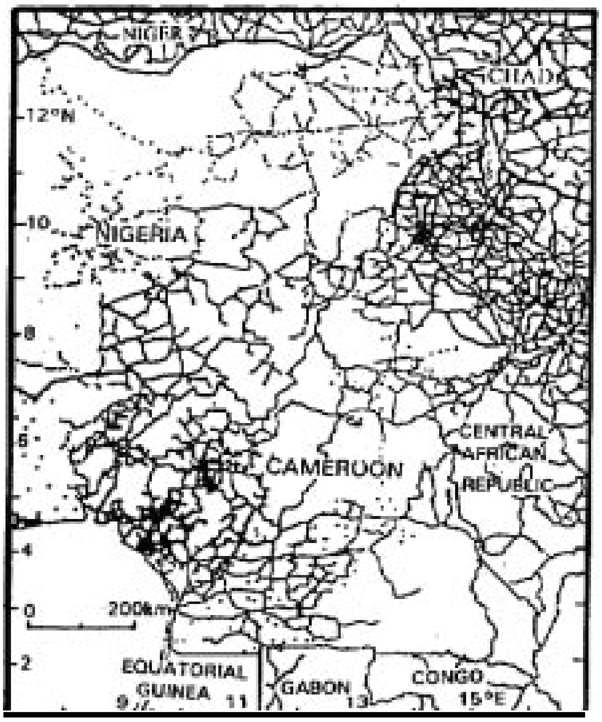

Figure 3. Gravity data coverage used in this study (After Nnange, 1991; Poudjom Djomani et al., 1992).

In order to obtain the spectral amplitudes of Bouguer gravity and topography we computed the two-dimensional Fourier transform of the data in the region using the algorithm of Singleton (1969). Prior to this transformation, the data array were reflected in the southern and eastern edges thereby ensuring continuity in the north to south and east to west in order to reduce edge effects. An output file for the admittance of the region has been obtained using equations – 2.

DISCUSSION OF RESULTS

Figure 4 shows the computed isostalic response function of the region. Wavebands over which Q was estimated are computed logarithmically in order to reduce the errors in the high frequency response as a result of the falling signal to noise ratio (Dorman and Lewis, 1970 ; Banks and Swain, 1978). The error bars represent the standard errors of the mean within each waveband.

The curve turns towards zero from wavelengths less than 150 km and the computed response is negative for all of the wavelength permitted by the data. This is an indication that major topographic features of wavelength greater than 150 km are composed of material of mean density close to reduction density (2.67g/cc).

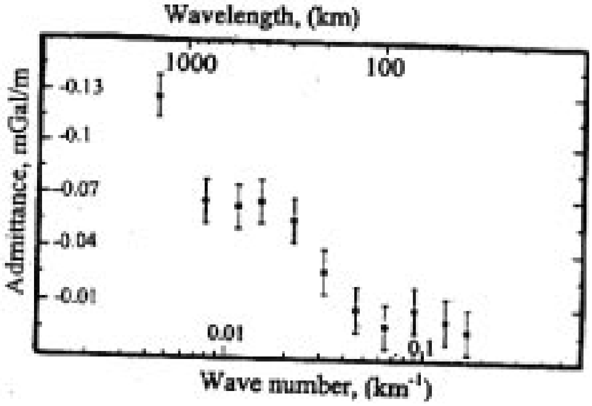

Figure 4. Admittance (Isostatic Response Function) of the area of the Adamawa dome. Errors bars are one standard deviation.

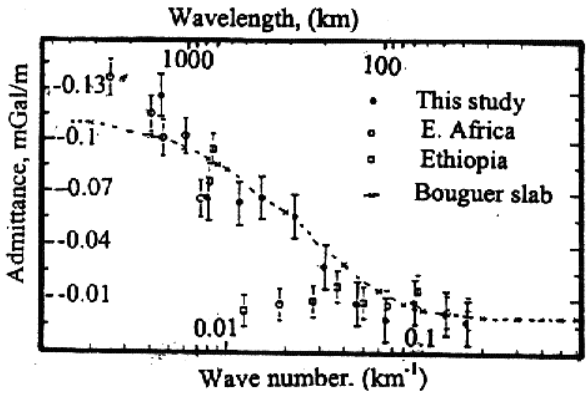

Figure 5. Comparison of admittance values of the Adamawa Dome (solid circle) and those of East Africa (open circles) and Ethiopian pplateau (open rectangles)taken from Ebinger (1991). Errors bars are one standard deviation

The admittance at the longest wavelengths (>400 km) permitted by the length of the region are less than – O.0625 mGal/m and do not show a smooth fall off. This may be a characteristic of the compensation mechanisms associated with mixed strength regions or a non-uniform plate.

Theoretical isostatic models predict that the value of the admittance will approach the Bouguer slab correction, $2\pi\delta_c G$ at long wavelength (Banks et al., 1977 ; McNutt, 1983). In this study the absolute values of the admittance at the longest wavelengths are affected by mirroring but they have the greatest power and should therefore be included (e.g. Ebinger et al., 1989). These values are greater than the Bouguer effect, the limit for isostatically compensated features (Fig. 5). That is the dome is over compensated or equivalently, there is an excess of low density material for the observed topography.

Figure 5 compares the admittance of the Adamawa region (this study), East Africa and the Ethiopia Plateau (Ebinger et al., 1989 ; Ebinger, 1991) and the Bouguer slab effect computed using a density of 2.80 g/cc. Only the longest wavelength admittance values are plotted for East Africa and the value for the longest wavelength in each of the regions represents the mirrored wavelength. From Fig. 5, it is observed that at wavelength longer that the characteristic flexural wavelength of the lithosphere, the admittance values for East Africa are more negative. Ebinger et al. (1989) have explained that the large absolute values of the admittance obtained for East Africa are indicative of a dynamic compensation suggesting active convection in the mantle. When the mirrored wavelengths is included in figure 5, the admittance values of the present study at the longest wavelengths are less negative that East Africa, Ethiopia Plateau and Bouguer slab effect. Thus, the Adamawa admittance may be a fit by local or flexural isostatic models such as crustal underplating or by simple models involving density contrasts beneath the elastic plate and the consequent upwarping of the plate above the low density material at depths. However, the admittance of the mirrored wavelength of the Adamawa region does not differ significantly from that of East Africa. As such, a dynamic compensation mechanism may not be ruled out entirely for the Adamawa region.

CONCLUSION

Our results reveal that the Adamawa plateau appears to be over compensated and this may be due to an excess low density material and probably an upwarping of the plate above the low density materials at depths. The results do not rule out a dynamic compensation observed in similar uplifts in Africa, e.g., the broad East African plateau.

The compensation mechanisms we interpret are consistent with existing geological and geophysical data which suggest a hot, low-density asthenospheric body within the upper mantly beneath the uplift.

REFERENCES

Bak, J. 1992. A seismological study of the upper-mantle Q structure beneath the Adamawa uplift in Cameroon. Ph.D. dissertation. University of Leeds Leeds, U.K.

Banks, R.J., Parker, R.L. and Huestics, S.P. 1977. Isostatic compensation on a continental scale: local versus regional mechanisms. Geophysical Journal Royal Astronomical Society 51, 431-452.

Banks, R.J. and Swain, C. J. 1978. The isostatic compensation of East Africa Proceedings Ropyal Society London. Series A, 364 : 3131 – 352.

Briggs, I.C. 1974. Machine contouring using minimum curvature. Geophysics 39, 39-48.

Browne, S.E. 1984. Gravity studies in the Sudan. A tectonic interpretation for some rifted sedimentary basins. Ph.D. dissertation. University of Leeds, Leeds, U.K.

Browne, S.E. and Fairhead, J.D. 1983. Gravity study of the Central African rift system: A model of continental disruption. Part 1: the Ngaoundere and Abu Gabra Rifts. In: P. Morgan and B.H. Baker (editors) Processess of planetary rifting. Tectonophysics 94, 187-203.

Burke, K.C. and Whiteman, A.J. 1971. Uplift, rifting and the break up of Africa. In: D.A. Tarling and S.K. Runcorn (editors) Implications of continental drift on the Earth Sciences. Academic press, London, p 732-755.

Collignon, F. 1968. Gravimetrie de Reconnaissance de la République Fédérale du Cameroun. ORSTOM, Paris, France, 35pp.

Cornacchia, M. and Dars, R. 1983. Un trait structural majeur du continent Africain: Les linéament centrafricains du Cameroun au Golfe d'Aden. Bulletin de la Société Géologique de Francs XXV(I), 101-109.

De Almeida, F.F.M. and Balck, R. 1967. Comparison structurale entre le nord-est du Brésil et l'Ouest Africain. Symposium on Continental Drift. Montevideo, Uruguay.

Deruelle, B. 1982. Risques volcanique au Mont Cameroun. Révue Geographie du Cameroun 3,33-40.

Dorbath, L., Dorbath C., Fairhead, J.D. and Stuart, G.W. 1986. A teleseismic delay time study across the Central African Shear Zone in the Adamawa region of Cameroon, West Africa. Geophysics Journal Astronomical Society 86, 751-766.

Dorman, L.M. and Lewis, B.T.R. 1970. Experimental Isostacy. 1. Theory of determination of the Earth's Isostatic Response to a concentrated load. Journal Geophysical Research 75, 3357-3365.

Dumont, J.F. 1986. Identification par télédection de l'accident de la Sanaga (Cameroun): Sa position dans le contexte des grands accidents d'Afrique Centrale et de la limite nord du craton congolais Géodynamique 2(1), 13-19.

Dunlop, H.M. and Fitton, J.G. 1987. A K-Ar and Sr-isotopic study of the volcanic rocks of the island of Principe, West Africa-evidence for mantle heterogeneity beneath the Gulf of Guinea, Contrib. Mineral. Petrol. 71, 125-131.

Ebinger, C.J. 1991. Mechnical strength of extended continental lithosphere above Afar plume. XX General Assembly IUGG Vienna, Austria.

Ebinger, C.J., Bechtel, T.D., Forsyth, D.W. and Bowin, C.O. 1989. Effective elastic plate thicknesses beneath the East African and Afar dommes. Journal Geophysical Research 94, 2883-290.

Fitton, J.G. and Dunlop, H. 1985. The Cameroon Line, West Africa, and its bearing on the origin of oceanic and continental alkaline basalt. Earth Planetary Science Letters 72, 23-38.

Forsyth, D.W. 1985. Subsurface loading and estimates of the flexural rigidity of the continental lithosphere. Journal Geophysical Research 90, 12623-12632.

Jeremine, E. 1941. Sur les laves des massifs volcanique du Cameroun occidental. Compte-Rendues de l'Academie des Sciences, Paris Tome 212, 495-498.

Jeremine, E. 1943. Contribution a l'étude pétrographique du Cameroun Occidental. Mémoire Museum, Nationale. Histoire. Nat. Nouveau. Series 17, 272-320.

Ghogomu, R.T., Njilah, I.K., Ayonghe, S.N., Njumbe, E.S. and Eno Belinga, S.M. (1999). The 1999 Eruption of Mount Cameroon. In J.P. Vicat, and P. Bilong (editors) Géologie et Environnements au Cameroun. Collection Géocam 2/1999.

Guiraud, R. and Maurin, J.C. 1992. Early Cretaceous rifts of Western and Central Africa. Tectonophysics 213, 153-168.

Hedberg, J.D. 1968. A geological analysis of the Cameroon trend. Ph.D. dissertation, Princeton University, Princeton.

Mascle, P. 1976. Le Golfe de Guinée (Atlantique Sud): un exemple d'évolution de marges atlantiques en cisaillement. Mémoire de la Société Géologique de France 128, 104.

MCNutt, M.K. 1983. Influence of plate subduction on isostatic compensation in northern California. Tectonics 2, 399-415.

Njilah, I.K. (1991). Geochemistry and Petrogenesis of the Tertiary-Quaternary Volcanic Rocks from the Oku-Ndu area. Ph.D. dissertation, University of Leeds, U.K.

Nnange, J.M. 1991. The crustal structure of the Cameroon volcanic line and the Foumban shear zone based on gravity and aeromagnetic data. Ph.D. dissertation 242p. University of Leeds, Leeds, U.K.

Nnange, J.M., Soba, D., Fairhead, J.D. and Stuart, G.W. 1985. Earthquake activity in Cameroon during 1983. Science and Technology Review Earth Science Series ½, 45-53.

Plomerova, J., Babuska, V., Dorbath, C., Dorbath L. and Lillie, R.J. 1993. Deep lithospheric structure across the Central African Shear Zone in Cameroon. Geophysics Journal International, 115, 381-390.

Poudjom Djomani, Y.H., Diament, M. and Albouy. Y. 1992. Mechanical behaviour of the lithosphere beneath the Adamawa uplift (Cameroon, West Africa) based on gravity data. Journal African Earth Sciences 15, 81-90.

Poudjom Djomani, Y.H., Nnange, J.M., Diament, M., Ebinger, C.J. and Fairhead, J.D. 1995. Effective elastic thickness and crustal thickness variations in west central Africa inferred from gravity data. Journal Geophysical Research 100, N) B11, 22047-22070.

Poudjom Djomani, Y.H., Diament, M. and Wilson, M. 1997. Lithospheric structure across the Adamawa plateau (Cameroon) from gravity studies. Tectonophysics 273, 317-327.

Singleton, R.C. 1969. An algorithm for computing the mixed radix fast Fourier transform IEEE Trans. Audio Electroacoust., Au-17, 93-103.

Stuart, G.W., Fiarhead, J.D., Dorbath, L. and Dorbath C. 1985. A seismic refraction study of the crustal structure associated with the Adamawa Plateau and Garoua Rift, Cameroon, West Africa. Geophysics Journal Royal Astronomical Society 81, 1-12.

Swain, C.J. 1976. A Fortran IV program for interpolating irregularly spaced data using the difference equations for minimum curvature. Computers and Geosecience 1, 231-240.

Tabod, C.T., Fairhead, J.D., Stuart, G.W., Ateba, B. and Ntepe, N. 1992. Seismicity of the Cameroon volcanic line, 1982-1990. Tectonophysics 212, 303-320.

Tchoua, F. 1970. Decouverte d'obsidienne dans le Mont Manengouba (Cameroon). Annale Faculte de Science Cameroun. 4, 23-30.

Temdjem, R. 1986. Le volcanisme de la région de Ngaoundéré (Adamaoua Cameroun). Etude volcanologue et pétrologique; These Doctorat, Université Clermont-Ferrand II, p18.

Wandji, P., Bardintzeff, J.M., Tchoua, F.M., Vicat, J.P., Nkouathio, D.G., Dongmo, A.K. and Fosso, J. (1999). L'éruption du Mont Cameroon de mars-avril 1999: données preliminaires. In: J.P. Vicat and P. Bilong (editors) Geologie et Environnements au Cameroun. Collection Géocam 2/1999.