Rev. Sci. et Tech. Sér Sci. Terre, 1985, 1(1 – 2)

CRUSTAL STRUCTURE OF THE ADAMAWA PLATEAU CAMEROON

G. W. STUART. J.D. FAIRHEAD
Department of Earth Sciences. Leeds University, Leeds, LS2 9JT, U. K.

L. DORBATH, C. DORBATH
O. R. S. T. O. M. , 24 Rue Bayard, 75008 Paris, France.

SUMMARY. Recordings of quarry blasts along a 300km profile across the Adamawa Plateau at the eastern end of the Cameroon Volcanic Line permitted the determination of the crustal structure of the region. To the north of the Plateau in the area of the Garoua Rift, an eastern arm of Benue Trough, the crust is about 23km thick and is underlain by upper mantle with a P–wave velocity of 7.8 km s–1. The southern part of the plateau by comparison is associated with a more normal crustal thickness of about 33km and underlain by upper mantle with a velocity of 8.0 km s–1. Between these two areas the seismological experiment was not able to delineate how the crust changes. However, if the topography and gravity field reflect crustal thickness then there is a rapid change in crustal thickness at the northern edge of the Adamawa Plateau.

1. INTRODUCTION

The Adamawa Plateau is situated in central Cameroon West Africa and represents an uplifted area at the north–eastern limit of the Cameroon Volcanic Line. The Cameroon Volcanic Line, itself, is a unique feature in that it forms a 700 km long continental segment of a much larger 1400km long volcanic chain that straddles the African continental margin (Fig 1). The continental sector of the Line extends from the Gulf of Guinea to central Cameroon and is characterised by a gently curving line of volcanic centres. The oldest of these take the form of ring complexes and give ages of 35–65 ma. It has only been in the last 10 ma that large quantities of basaltic rocks have erupted. The most recent eruption was on Mount Cameroon in October/November 1982. Dating of the oceanic and continental volcanics reveal no linear age pattern (Dunlop, 1983). Petrological studies (Fitton and Hughes, 1977; Fitton 1983) indicate the volcanic chain contains transitional to strongly alkaline volcanism, which show no obvious differences between oceanic and continental sectors and are similar in affinity to many continental rift systems.

The origin of the volcanic line has been considered to be the movement of the lithosphere over a hot spot (Morgan, 1983) or the sudden displacement of an upper mantle swell from beneath the Benue Trough, Nigeria, to beneath the present position of the volcanic chain at about 80 to 65 ma, when there was a major reorganisation of the plate boundaries surrounding the African continent (Fitton, 1980).

The basement rocks of the Adamawa Plateau consist of migmatites and granites affected by the Pan–African orogeny (500–600 ma) (Lasserre, 1967). These are cut by the Foumban shear zone, a series of faults associated with major mylonite zones, that can be traced in an ENE direction across the Adamawa Plateau and then eastwards across central Africa to the Darfur region of western Sudan (Browne and Fairhead, 1983). To the SW of the Adamawa Plateau the shear zone is obscured by volcanics. Movement of the shear zone has been shown to be dextral (Nangam, 1983) and has an estimated magnitude of 50 km (Cornacchia and Dars, 1983). De Almeida and Black (1967) consider the shear zone to have orignated in the Pan African since it can be traced, on pre–drift re–constructions, into the Natal region of Brazil as the Pernambuco fault. The shear zone

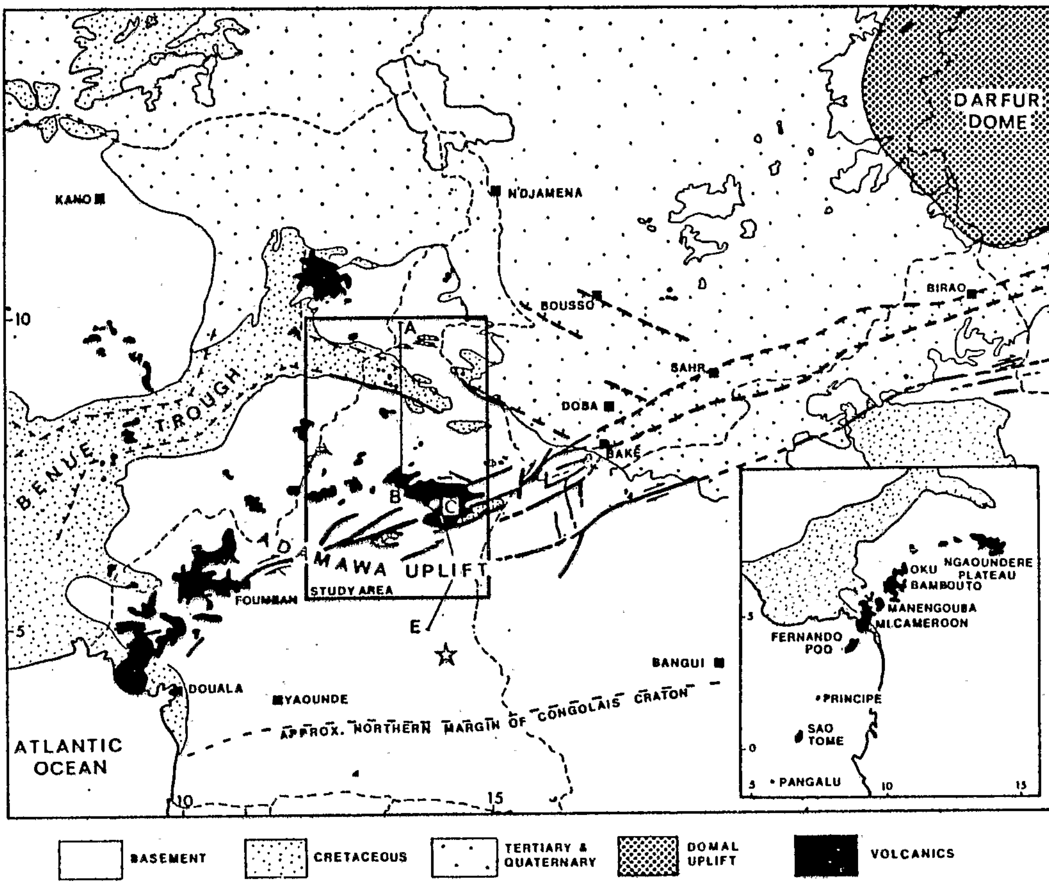

FIGURE 1

Regional tectonic setting. Study area is outlined. Dashed lines represent inferred position of faults under the cover sediments. Profile A to E is the line of the Bouguer and topographic section shown in Figure 8.

was reactivated in the Cretaceous, during the initial phases of the opening of the South Atlantic, resulting in a series of subsiding grabens along its length eg. the Doba and Bousso basins (Louis, 1970). In the Adamawa region, the Djerem–Mbere basin, north of Meiganga is an example of one such basin (Fig 2) (Le Marechal & Vincent, 1970; Nangom, 1983).

On the northern margin of the Adamawa Plateau is situated the Yola–Garoua fault controlled basin (Fig 1). This Cretaceous rift represents an eastern arm of the Benue Trough in Nigeria. In the Garoua region the rift consists of a series of en–echelon sub–basins, affected after its formation by shear tectonics in Late Cretaceous and early Tertiary times.

The Adamawa Plateau represents one of a number of similar Tertiary uplifts (Hoggar, Tibesti and Darfur), associated with volcanism, in North Africa. It is generally thought that the uplifts result from the isostatic response to a thinning of the lithosphere. The overall aim of the seismological project was to map the velocity structure of the lithosphere beneath the Adamawa uplift in a region affected by Tertiary volcanism and the Foumban shear zone. Up to 37 seismic stations were deployed as five arrays on the Adamawa Plateau and adjacent regions to provide a profile of teleseismic delay times and slowness anomalies with which to study the velocity structure of the crust and upper mantle of the uplift. This paper describes the results of a crustal refraction study to determine the lateral variation of crustal structure south, from the Garoua rift, across the uplift to just south of the Djerem–Mbere rift at Meiganga using local quarry blasts as sources. The station locations (Fig 2) were a compromise between providing sufficient coverage between the quarries for the crustal study and the requirements for a teleseismic delay time experiment.

2. THE SEISMIC EXPERIMENT

The experiment ran for 5 months, from November 1982 until March, 1983. It was a joint venture by the University of Leeds, U.K. ; Office de la Recherche Scientifique et Technique Outre–Mer (O.R.S.T.O.M., France) and Institut de Recherches Geologiques et Minières (I.R.G.M., Cameroon). Due to equipment limitations, not all the arrays ran simultaneously; the northern array (stations 18–26, Fig 2) was re–deployed in the south as stations 27–37, after two and half months recording. Each array consisted of upto 9 vertical short period seismometers, spaced at about 15km intervals. The actual geometry of the individual arrays (Fig 2) was controlled by the existing road and track distribution. The signals were telemetered to a central multichannel Geostore analogue tape recorder, whose internal time base was made absolute by recording VLF time signals from the Omega Navigation transmitter in Liberia.

There were four active quarries along the profile (Fig 2). The northern quarries, Pitoa and Garoua, are situated along the northern margin of the Garoua Rift. The PK142 quarry was on Pre-Cambrian supra–crustal rocks, while the N'gaoundere quarry, at the centre of the profile, was on Tertiary volcanics. All quarries were accurately located, only Garoua, PK142 and N'gaoundere were accurately timed. These quarries provide a 200km reversed seismic line from Garoua to N'gaoundere. Unfortuntely there were no active quarries to the south–east of N'gaoundere to reverse the southern half of the profile across the Foumban shear zone. However, a local earthquake was recorded, with an epicentre about 200km to the south of the profile and provided some Pn data from the south.

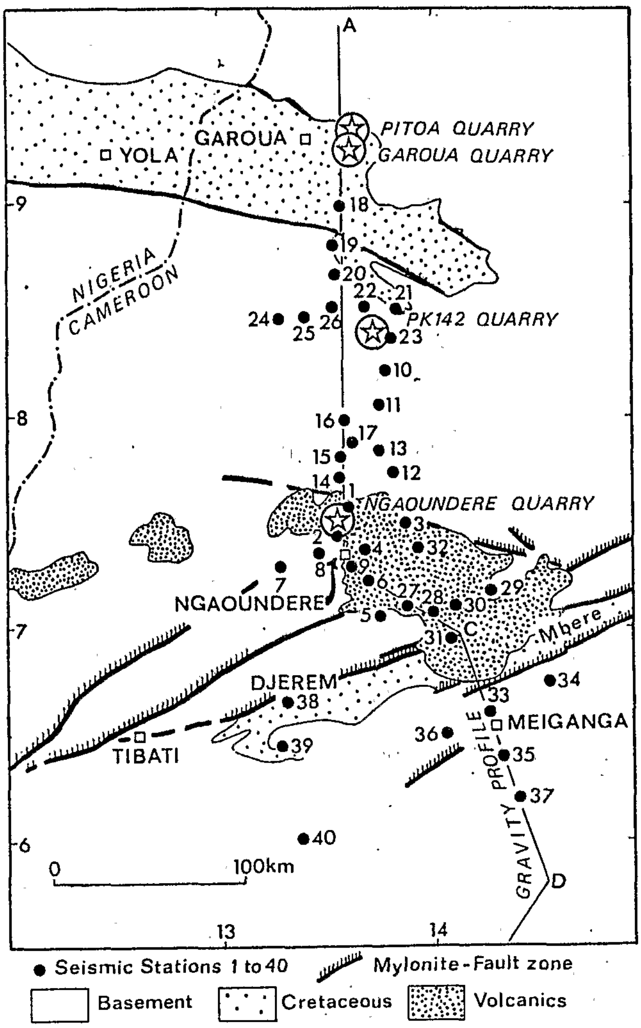

FIGURE 2

Location of the seismic stations relative to the quarries and main geological features.

3. THE DATA

During the five months of the experiment, over thirty quarry blasts were recorded. However only a sub–set of these were worth further analysis; three from the northern quarries, two from PK142 and five from N'gaoundere in the south. Examples of these events are displayed as reduced travel time seismograms an Figures 3 to 6, using a reduction velocity of 6.0 km s–1 or 8.0 km s–1.

3. 1 Garoua to N'gaoundere profile

3. 1.1 Direct waves and upper crustal phases

The first arrivals from the two northern quarries vary somewhat in character (Fig 3). Pitoa, the northern most quarry is situated on basement and as such has injected more energy into the crystalline rocks. The first arrivals at the closest stations (18 and 19), which lie on the cretaceous sediments of the Garoua Rift, have apparent velocities of 6.22 km s–1 and represent refracted waves from the Pre–Cambrian basement beneath. The observed reduced travel time of this phase of around 0.5s implies sediment thicknesses underlying the stations of around 3km (ELF

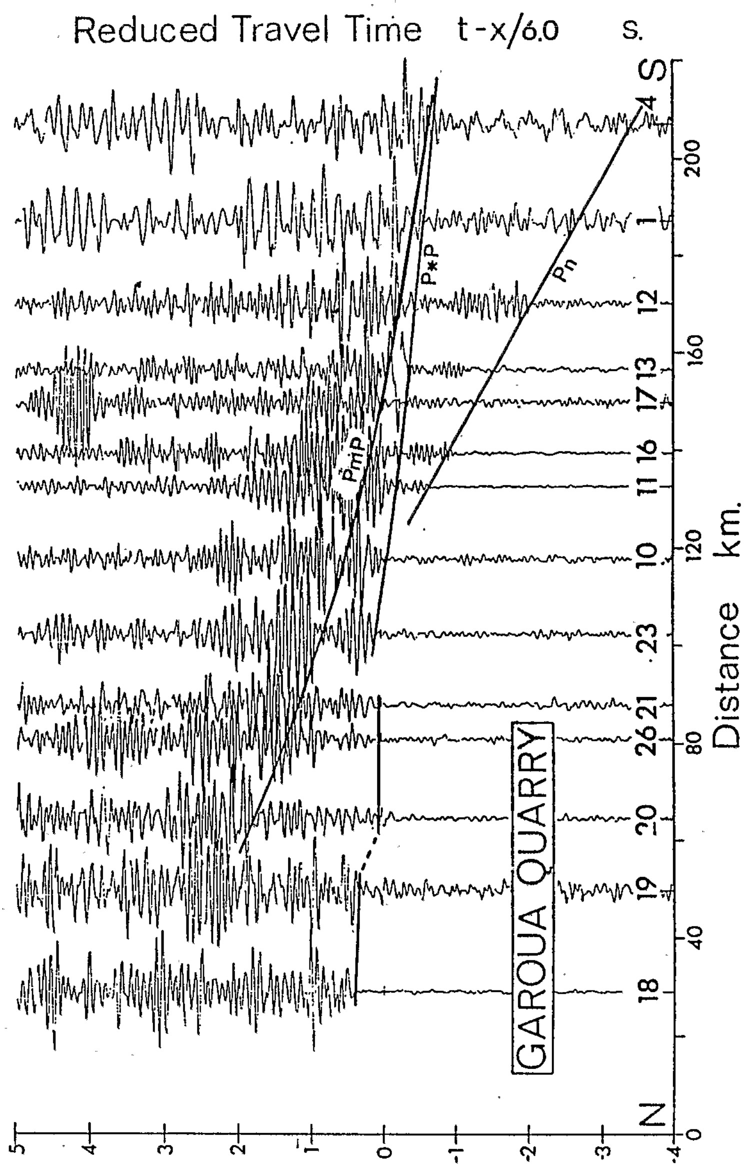

FIGURE 3a

Reduced travel time plots for seismograms recorded south from the Garoua quarry. The numbers against each trace refer to the station numbers shown in Figure 2.

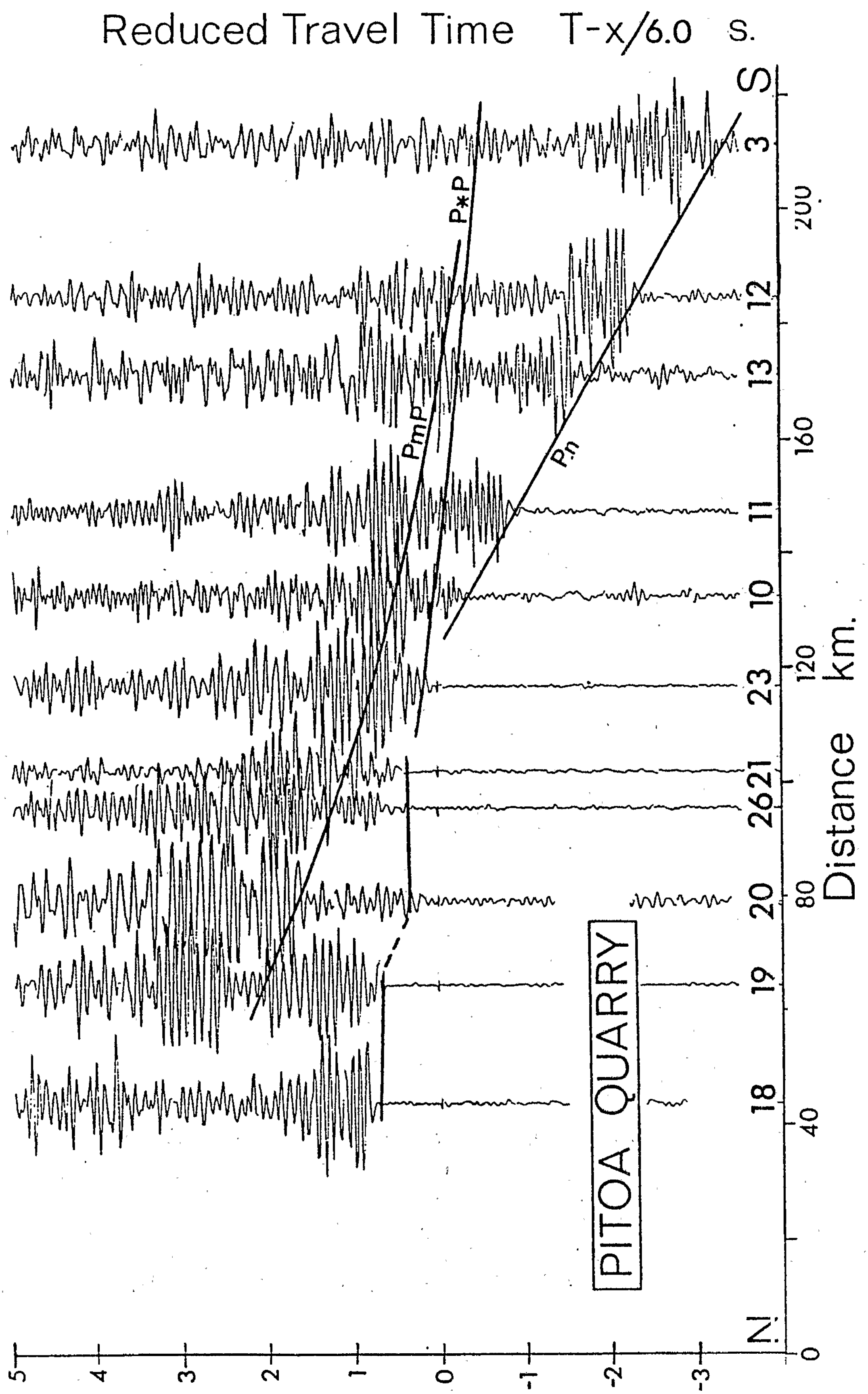

FIGURE 3b : Reduced travel time plots for seismograms recorded south from the Pitoa quarry. The numbers against each trace refer to the station numbers shown in Figure 2.

SEREPCA kindly provided average velocities from local seismic reflection work for sediments which varied from 2.5 km s—1 at the surface to 4.0 km s—1 at the base of the sediments). The same phase with a similar apparent velocity is recorded between stations 20 and 23 (Fig 3), which lie to the south of the Garoua Rift.

The northern travelling arrivals from PK142 quarry (Fig 4) show P wave velocities of 6.05 km s—1, which overlies a crust of velocity 6.2 km s—1 as shown for the northern quarries. The position and the shallow depth of this 6.22 km s—1 layer coincide with a positive Bouguer anomaly (Fig 8) which flanks the Garoua Rift and outcrops as a gabbroic body around Poli to the north of stations 24 to 26.

Station 19 is situated close to the southern boundary fault of the Garoua Rift. As such the relative reduced times between it and station 20 show an apparent velocity of 6.2 km s—1 from the south but 4.0 km s—1 from the north for which the arrivals have travelled through the Cretaceous sediments.

Moving southwards the first arrivals within 35 km from PK142 shooting southwards (Fig 4) show velocities of 5.9km s—1 while at greater distances apparent velocities of 6.2 km s—1 are picked up again. Northerly first arrivals from the N'gaoundere blasts (Fig 5) similarly show first arrivals with velocities between 5.4 and 5.9 km s—1 being overtaken at around 50km with a phase of velocity 6.2 km s—1. These data imply a layer of 3 to 4 km thick which must thin northwards towards PK142 overlying the 6.2 km s—1 layer.

From 100km up to the end of the profile the northern quarries show a phase with an apparent velocity of 6.3 km s—1 (P^*P on Fig 3). From the nature of the amplitude variation, particularly at 100 km, this phase is interpreted as a reflection from an intracrustal discontinuity at a depth of about 14.5 km with an average velocity down to the interface of 6.22 km s—1. On the reverse shot (Fig 5) the phase P^*P can be identified and gives a mean velocity of 6.2 km s—1; showing there is little dip, yet the depth to the interface is estimated to be 12.5km.

3. 1. 2 Refracted and Reflected Moho Phases.

The blasts from the northern quarries display Moho arrivals both as reflections and refractions (Fig 3). The Moho Pn refraction is clearly seen from its critical distance and becomes a first arrival from 125 km distance with an apparent velocity of 7.81 km s—1. Strong Moho reflections, PmP arrivals, can also be identified and have been utilised to estimate a crustal thickness of 23 km and an average crustal velocity of 6.29 km s—1, assuming a horizontal interface, in the region just to the south of the Garoua Rift. These data are corraborated by those from the Pitoa quarry, 15 km to the north of the Garoua quarry (Fig 3). An attempt was made to use the individual PmP reflection times and an assumed velocity model of the crust in the region to map any topography on the Moho immediately south of the Rift. However it became apparent that within the error of the assumptions and the observations there is no measureable dip on the Moho in this region.

This profile was reversed by the blast at N'gaoundere,which did not show the PmP arrivals as clearly (Fig 5). These give a crustal thickness of 22.5 km and an average velocity of between 6.2 and 6.3 km s—1. However, Pn refractions can only be seen on the furthest station from these southern shots. It is difficult to use these refracted arrivals meaningfully due to the uncertainty of the error in the estimate of the relative time corrections required to account for the lateral variation of the sediment cover across the Rift. Nevertheless the arrivals give a cross—over distance which is about 15km greater than that from the northern quarries. Since we have good control over the crustal thickness in the Garoua region from the PmP arrivals in both directions, this greater cross—over distance must imply a thicker crust below the N'gaoundere quarry itself.

To summarise these results, between the Garoua Rift and N'gaoundere the crust can be divided into an upper crust 13 to 14 km thick with a mean velocity of 6.2 km s—1 overlying a lower crust about 10km thick with a mean velocity of 6.45 km s—1. The P wave velocity below the crust is about 7.8 km s—1 and there is evidence for crustal thickening as one moves from the Garoua plain onto the Adamawa Plateau.

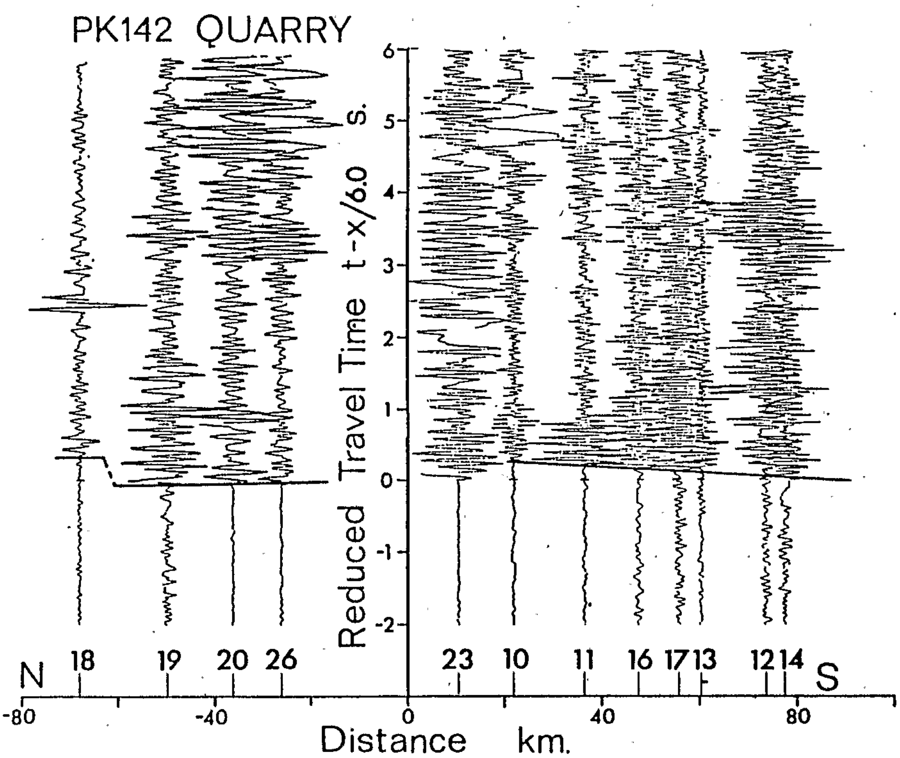

FIGURE 4
Reduced travel time plots for the seismograms recorded north and south of the PK142 quarry.

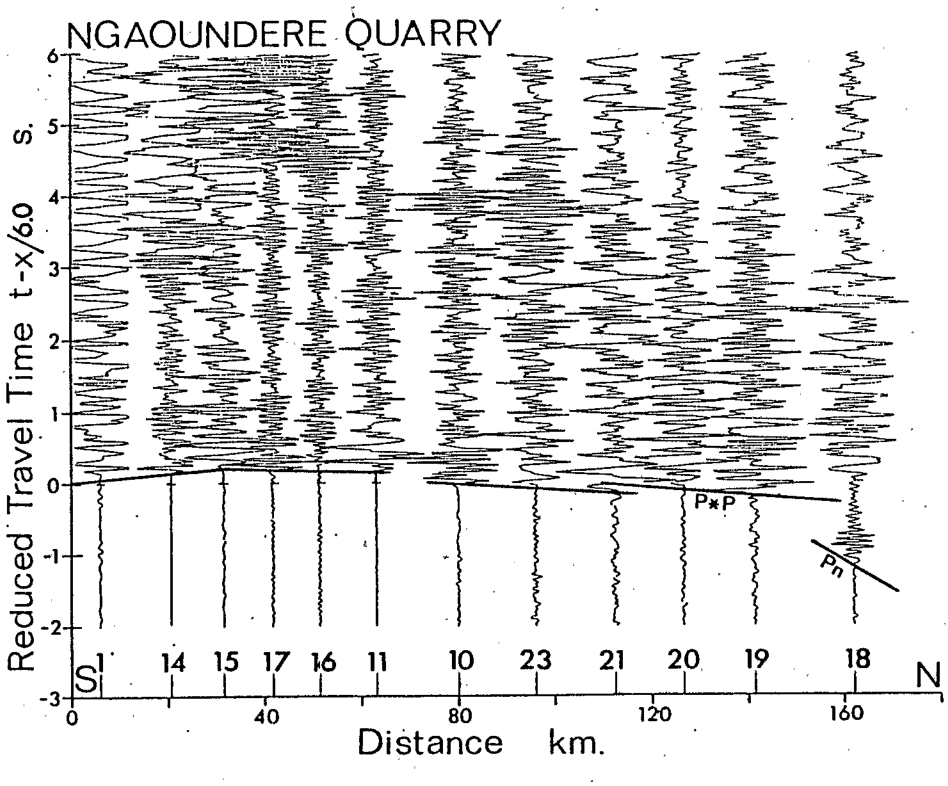

FIGURE 5
Reduced travel time plots for the seismograms recorded north of the N'gaoundere quarry.

3.2 N'gaoundere to Meiganga Profile

The data from the N'gaoundere quarry to the south–east along the length of the volcanic line and across the crest of the Adamawa Plateau, tells a different story (Fig 6). Up to distances of 60km the first arrivals are scattered, reflecting the complex surface geology. However with regionalisation one can categorise the arrivals into groups: an upper formation, probably representing the volcanics and the underlying sediments, several hundreds of metres thick, with a velocity of 5.4 km s–1 overlying a 5.97 km s–1 layer similar to that seen north of N'gaoundere. Below this layer velocities of 6.2 km s–1 are once again observed. From 70 to 90 km the intracrustal reflection P*P is seen. Since this profile is unreversed the depth to this interface is calculated by simply assuming an average velocity of 6.2 km s–1. The reflector is calculated to increase in depth southwards from 14 to 15 km.

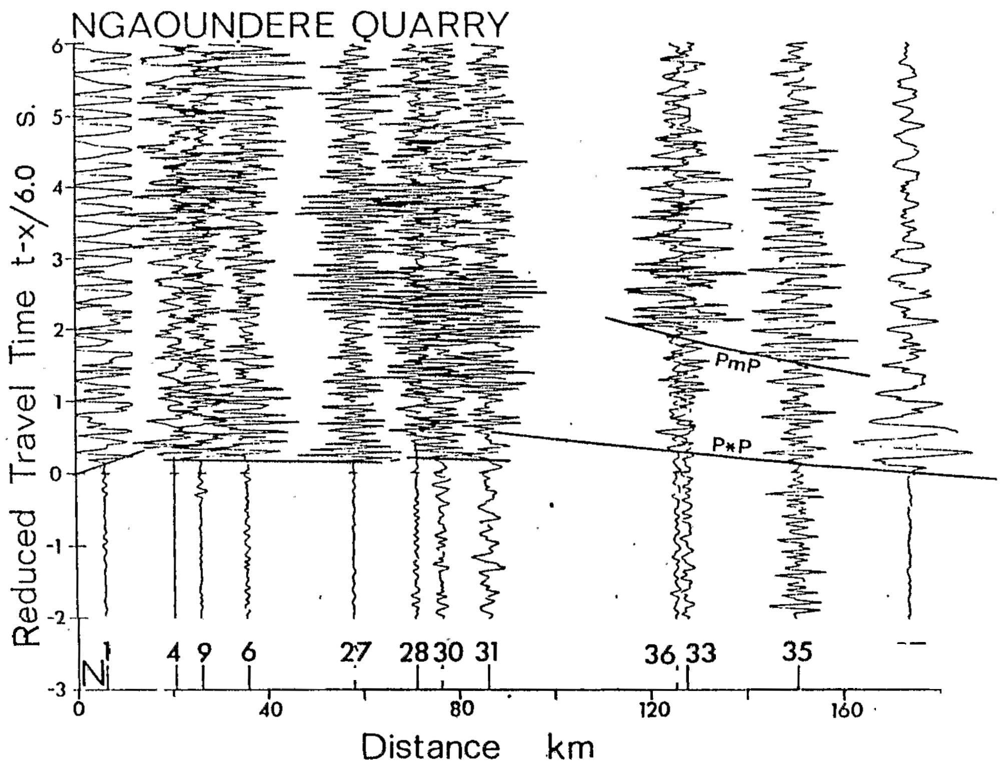

FIGURE 6
Reduced travel time plots for seismograms recorded south from the N'gaoundere quarry.

At distances greater than 120km a later reflector is observed which is interpreted as PmP. Assuming a horizontal Moho its depth is found to be 32.5 km with an average velocity of 6.20 km s–1. Pn is not observed as a first arrival even at the furthest station which lay 170km from the source. The cross–over distance for the model derived from the PmP reflections is around 170km.

The Pn data from the local earthquke (Fig 7), whose epicentre lay about 200 km south of the profile clearly shows a Pn velocity of 8.01 km s–1 on the stations to the south of the Djerem–Mbere basin. However the arrivals are far from clear to the north probably due to disruption of the signal at Moho depth across the Foumban shear zone. Tentative evidence is given in Fig 6 for a disruption in the Pn arrivals around stations 28,29 and 30, where the first arrivals from the N'gaoundere quarry become difficult to correlate.

4 Discussion

One can briefly review the results of this study of crustal structure (Fig 8) by saying that between the Garoua Rift and the northern margin of the Adamawa Plateau, one finds an abnormally thin crust underlain by upper mantle with anomously low velocity for a region of Pre–

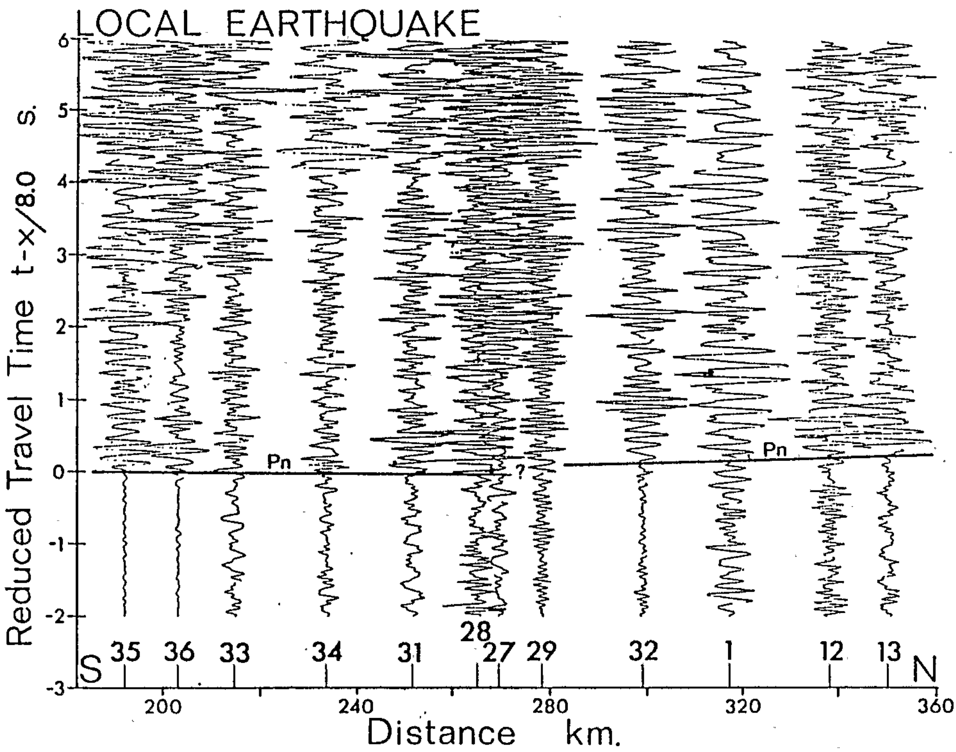

FIGURE 7 : Reduced travel time plots using a reduction velocity of 8.1 km s–1 for seismograms from the local earthquake located 200km south of Meiganga (see Figure 1)

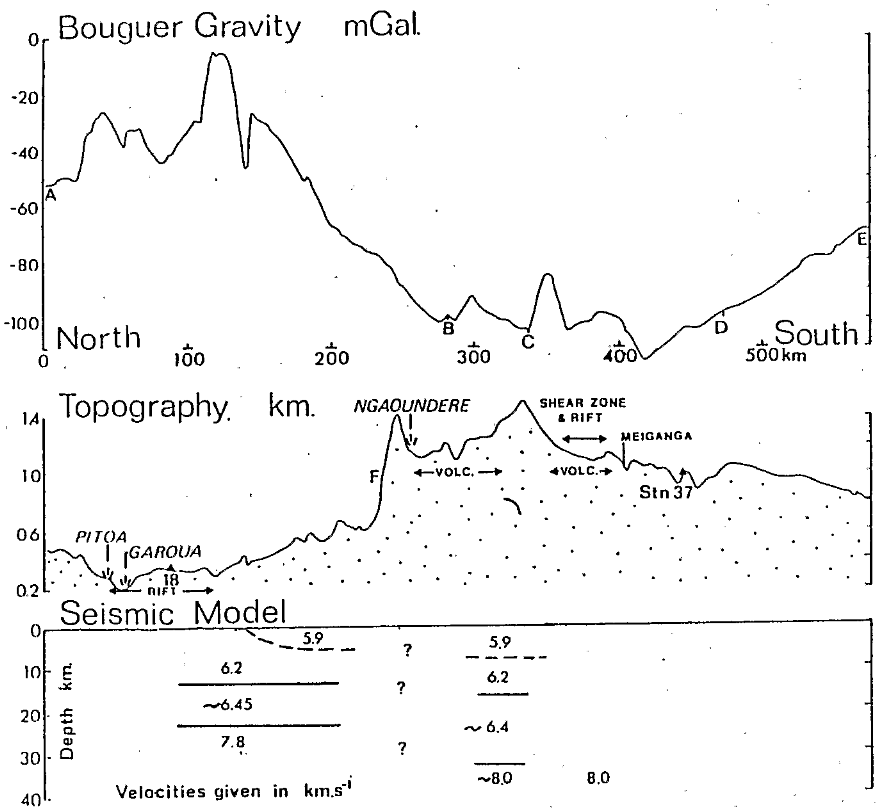

FIGURE 8 : Seismic model of the crust together with topography and Bouguer gravity along profile A to E (Figure 1).

Cambrian rocks. To the south of the Plateau the crust has a normal thickness. Between these two regions it is difficult from the data presented here to see how these contrasting crusts join. However, there is an indication from the cross—over distance of the northern Pn arrivals from the N'gaoundere quarry that the crust thickens rapidly onto the plateau at its northern margin, i.e. in the region of the fault scarp located between stations 14 and 1 (Fig 2) and marked by F in Fig 8. Such a model is consistent with the poor quality of the Pn signals recorded from the northern quarries south of station 14; the rapid change in topography (Fig 8) along the fault at F which possibly reflects isostatic compensation at the Moho and the steep gravity gradient centred over the northern margin of the Plateau. The results of a study of upper mantle nodules in the most recent volcanics south of N'gaoundere concluded that they were developed in temperature and pressure conditions corresponding to a depth of at least 25 km (M.Girod, personal communication). The volcanics erupted approximately along the extension of the numerous faults in the region and further thickening of the crust must take place towards the south. This could potentially take place at the disruption in the seismic arrivals remarked on earlier around stations 28,29 and 30.

Conclusion.

The data from four quarry blasts and local earthquake recorded by a 300km profile of seismometers installed from the Garoua Rift in the north across the Adamawa Plateau permitted the determination of crustal structure. To the north of the Plateau the crust is about 23 km thick an upper mantle Pn velocity of about 7.8 km s—1; in comparison with the southern part of the Plateau where the crust has a more normal thickness of about 33 km with an upper mantle velocity of 8.0 km s—1.

Acknowledgements

We wish to thank N.E.R.C. Great Britain; O.R.S.T.O.M. , France and I.R.G.M. , Cameroon for providing funds and logistic aid to make this project possible. Pat Bermingham helped immensely during data aquisition; Roger Clark during data processing

References

Browne, S.E. and Fairhead, J.D. 1983. Gravity study of the Central African Rift System: A model of continental disruption 1. The Ngaoundere and Abu Gabra Rifts. Tectonophysics 94, 187—203.

Cornacchia, M. and Dars, R. 1883. Un trait structural majeur du continent africain. Les lineaments centralafricaine du Cameroun au golfe d'Aden. Bull. Soc. geol. France 7, XXV, 101—109.

De Almeida, F. F. and Black, R. 1967. Comparison structurale entre le nord—est du Brésil et l'Ouest africain. Symp. Continental Drift, Montivideo.

Dunlop, H.M. and Fitton, J.G. 1979. A K—Ar and Sr— isotopic study of the volcanic rocks of the island of Principe, West Africa — evidence for mantle heterogeneity beneath the Golf of Guinea. Contrib. Mineral. Petrol. 71, 125—131.

Dunlop, H.M. 1983. Strontium isotope geochemistry and potassium—argon studies on volcanic rocks from the Cameroon Line, West Africa. Ph.D. thesis Univ. Edinburgh, UK. 347pp.

Fitton, J.G. and Hugues, D.J. 1977. Petrochemistry of the volcanic rocks of the island of Principe Gulf of Guinea. Contrib. Mineral. Petrol; 64, 257 — 272

Fitton, J. G. 1980. The Benue Trough and the Cameroon Line— a migrating rift system in West Africa. Earth Planet. Sci. Lett. 51, 132—138.

Fitton, J. G. 1983. Active versus passive continental rifting: evidence from the West Afriacan Rift System. Tectonophysics 94, 473–481.

Lasserre, 1967. Données geochronologiques nouvelles acquis au 1er janvier 1967 par la méthode au strontium appliquée aux formations crystallines et crystallophylliennes du Cameroun. Ann. Fac. Sci. Clermont Ferrand, 36, Geol. Min. Fasc 16.

Le Marechal, A. and Vincent, P. 1971. Le Fosse cretace du Sud–Adamaoua (Cameroun). Cahier ORSTOM ser Geologie 3, 60–67.

Morgan, W. J. 1983. Hotspot tracks and the early rifting of the Atlantic. Tectonophysics. 94, 123–139.

Nangom, E. 1983. Etude tectonique du fosse Cretace de la Mbere et du Djerem, Sud–Adamaoua, Cameroun. Bull. Centres. Rech. Explor.–Prod. Elf Aquitaine 7, 339–347.

Volume 1 ISSN 0258 – 4840

Numéro 1 – 2

REVUE SCIENCE ET TECHNIQUE

SCIENCE AND TECHNOLOGY REVIEW

(Série Sciences de la Terre)

Earth Science Series

MINISTERE DE L'ENSEIGNEMENT SUPERIEUR ET DE LA

RECHERCHE SCIENTIFIQUE

YAOUNDE (CAMEROUN)