GEOLOGICAL AND GEOPHYSICAL STUDIES OF THE MYSORE PLATEAU KARNATAKA

(ABSTRACT)

By
P. S. ARAVAMADHU M. Sc.

Thesis submitted for the degree of
DOCTOR OF PHILOSOPHY IN GEOLOGY
AT THE
Aligarh Muslim University, Aligarh
1977

IV

GEOLOGICAL AND GEOPHYSICAL STUDIES OF THE MYSORE PLATEAU, KARNATAKA

ABSTRACT

P.S.Arvamadhu, M.Sc.
1977

Mysore plateau forms one of the oldest terrains of the Peninsular India. It consists largely of Archaean gneissose and schistose rocks with a variety of associated intrusive rocks. Besides, the Dharwar schists, the other rock formations in this region are banded ferruginous quartzite, metabasalts and some patches of ultramafics. Prevalent types of dyke rocks, encountered in the plateau, are of epidiorite, dolerite, quartz-dolerite and olivine-dolerite. The grade of metamorphism of the Dharwar schistose rocks generally increases from north to south in the region.

The Dharwar iron ore bearing formations of Karnataka constitute one of the important tectonic sub-divisions of peninsular India. In the iron ore province several synclinal strips of gneisses and schists are conspicuous by their strike direction which varies from NNW-SSE to NNE-SSW. Deformation accompanied by uplift of the Dharwar sediments by tectonic forces, dominantly directed from east and west, not only resulted in the formation of several N-S trending folded belts, but also it has cross-folded older rocks in adjacent belts occurring to the north and south of the area. The Closepet granite forms a N-S trending linear belt between Chitaldurg schist belt in the north and the Kolar schist belt in the south.

Apart from obtaining geological data relevant to this topic, detailed gravity and magnetic investigations are carried out by the author in Karnataka in an attempt to collect some fresh data in order to interpret usefully the broad structural pattern and composition of the crust, and also to throw some new light on the configuration and inter-relationship between the individual supracrustal rock units. Data collected in the field are presented in the form of gravity maps and gravity-cum-magnetic profiles. An attempt is made to correlate the data obtained from these gravity and magnetic investigations with other relevant geophysical and geological data collected by earlier workers. Through this work, an effort is made to elucidate the sub-surface geology and composition of the plateau.

The subject matter of the work has been dealt with in such a way as to include in the beginning of this work a concise account of the geology and tectonic framework of the area, including a synthesis of different views expressed by the previous workers. The methods used in geophysical investigations of the terrain and the procedures adopted for the reduction and analysis of the data collected are presented. The free-air, Bouguer, and isostatic (Airy-Heiskanen, T=30 km) gravity anomaly maps of the study area are prepared, and the results of the qualitative analysis of these maps are presented. A critical analysis of the gravity and magnetic measurements along the three carefully selected east-west profiles taken along three different latitudes and also a northwest-southeast profile cutting across the three latitudinal profiles in this region provide useful informations in respect of the subsurface causative bodies. Correlation of some of the observed geophysical anomalies with metamorphism and tectonic set-up of the predominent rock types has also been attempted. Results obtained from the present investigations are compared and contrasted with other available geophysical and geological data. Interpretation of the integrated results so obtained from the present investigation of the plateau, has led to solve several debatable problems relating to charnockitisation of gneisses and schists at depth, and the inter-relationship between gneisses, schists and granites.

ALIGARH MUSLIM UNIVERSITY
DEPARTMENT OF GEOLOGY

S.H.RASUL
Professor and Head of the Department

Aligarh 24 December,1977

This is to certify that Mr. P.S.Arvamadhu has prepared and completed this dissertation under my supervision as a requirement for the award of Degree of Doctor of Philosophy in Geology of the Aligarh Muslim University, Aligarh. I consider this to be a piece of original work contributing some new ideas regarding the subject.

Mr. Arvamadhu is allowed to submit his thesis for the Ph.D. degree of the Aligarh Muslim University Aligarh.

S.H. Rasul
S.H. RASUL
Supervisor

GEOLOGICAL AND GEOPHYSICAL STUDIES OF THE MYSORE PLATEAU KARNATAKA

By
P. S. ARAVAMADHU M. Sc.

Thesis submitted for the degree of
DOCTOR OF PHILOSOPHY IN GEOLOGY
AT THE
Aligarh Muslim University, Aligarh
1977

CONTENTS

LIST OF FIGURES

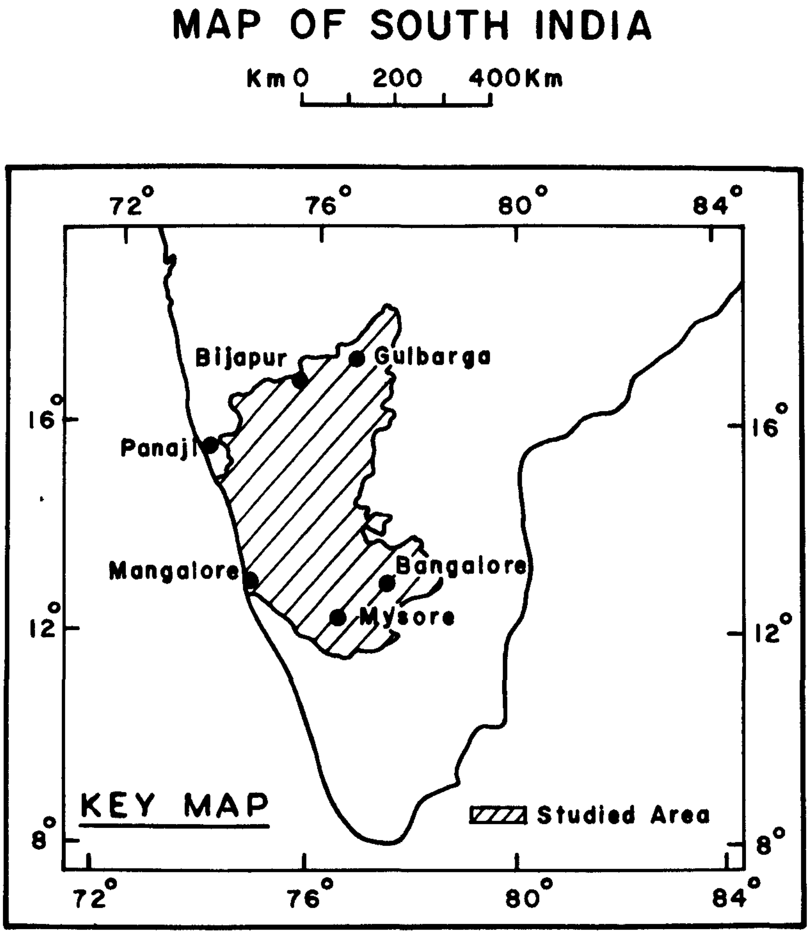

MAP OF SOUTH INDIA
Km 0 200 400Km
72° 76° 80° 84°
16°
12°
8°
Bijapur
Gulbarga
Panaji
Mangalore
Bangalore
Mysore
KEY MAP
▨ Studied Area

Fig. 1

Chapter I

INTRODUCTION

Location and Accessibility

The Mysore Plateau occupies a large portion of the Mysore province, now called Karnataka State. The area of the State is nearly 0.15 million sq. km. It occupies the south-western portion of the Indian Peninsular shield between latitudes 12° and 18°N and longitudes 74° to 78° east (Fig. 1). The plateau area under study, except for the narrow coast bordering the Arabian Sea on the west, forms an elevated tableland with an average elevation of 750 metres above the m.s.l. Generally the plateau is bordered on the west and east by steep hill ranges and scarps. Its western margin which is particularly conspicuous by its continuity of high relief, is known as the western Ghats. The plateau and its precipitous western hill ranges are some of the characteristic physiographic features of the Indian Peninsula. The hill ranges bordering the eastern margin of the plateau neither have much topographic contrast nor are they as lofty as those in the west. The featureless flat portion of the plateau (maidan) has an intersecting system of well-laid cross country roads and railways. Accessibility to the region is fairly good.

Physiography and Climate

Based on the physiographic features and climatic conditions, Mysore has been classified into three well-marked natural divisions -- the coastal plain, the Malnad and the Maidan -- each having its distinctive features.

Coastal Plain: Starting from the Arabian Sea coast on the west, the coastal plain stretches eastwards for a distance of about 250 km along the coast with a varying width of 30 to 50 km to the foot of the western ghats. The highest elevation on this plain seldom exceeds 100 to 120 metres above m.s.l. The region has been under the influence of south-west monsoon, mostly during the four months from June to September. Its average annual rainfall is 300 to 325 cms.

Malnad : Malnad or the mountainous country which forms a 30 to 40 km wide belt bordering the plateau on its western side, is a forest clad region of spectacular mountain scenery. The rain fall in the diversified Malnad is incessant as well as heavy, mostly during the monsoon season. Over the ghats and its immediate eastern slopes the annual rain fall varies from 500 to 750 centimetres but further eastwards it diminishes rapidly.

Maidan: The Maidan forms the greater portion of the state and lies to the east of Malnad. It is an undulating and featureless country with an average elevation of about 1,000 metres above the m.s.l. Here the average rainfall seldom exceeds 75 to 85 cm per year and in some of the drier districts it is even less.

The Karnataka State forms a major part of the craton which occupies the south-western portion of the peninsular shield. It is considered to be one of the three protocontinental nucleii around which the shield is developed (Naqvi et al., 1974). The craton, where a series of ancient igneous and metamorphic peninsular rocks as well as some younger sedimentary rocks are represented, had been repeatedly subjected to several episodes of orogenic movements that led to the formation of the western ghats. In spite of its great age and continuous erosion and mass-wasting throughout most of the past geological periods, the terrain has been able to retain a significant part of the representative Precambrian formations.

Previous work

Several earlier workers like Foote (1888), Smeeth (1916), Rama Rao (1940), Pichamuthu (1967), Radhakrishna (1956, 1976), Nautiyal (1966), Srinivasan and Srinivas (1974) made valuable contributions to the stratigraphy, structure, geomorphology, petrography, economic geology, etc., of the area. Some work has also been done on geochronological aspects of the Precambrian formations of Mysore by Vinogradov et al. (1964), Aswathanarayana (196), Sarkar (1968), Crawford (1969) and Venkatasubramaniam et al. (1971). Geochemical aspects of some of the Precambrian rocks of Mysore has been the subject matter of study by Naqvi et al. (1972), and Divakara Rao et al. (1975).

As a part of the Upper Mantle Project, integrated geological, geochemical and geophysical studies were carried out along the 14th parallel in Mysore by the National Geophysical Research Institute (Qureshy *et al.*, 1967). A multidisciplinary approach was made by Naqvi (1973) to study the structure and tectonics of central part of the Chitaldurga belt of the Karnataka craton. Geochemical studies of the Precambrian rock formations from this region (Naqvi *et al.*, 1972) have led to an understanding of the Precambrian crustal evolution and the composition of the primary crust of the Peninsular India. A broad based attempt to describe the protocontinental growth of the Indian shield was made by Naqvi *et al.* (1974) on the basis of a general review of the results of different disciplines on earth sciences.

Purpose of the investigation

Apart from some geological studies relevant to this topic, detailed gravity and magnetic investigations have been carried out by the author in Karnataka in an attempt to interpret the broad structural pattern and composition of the crust and also to throw some light on the configurations and inter-relationships between the individual supracrustal rock units. Data collected in the field is presented in the form of gravity maps and gravity-cum-magnetic profiles. An attempt has been made to correlate the data obtained from these gravity and magnetic investigations with the other available geophysical and geological data. Through this work, efforts have been made to elucidate the sub-surface composition and geology of the plateau.

It is obvious that several good attempts by some earlier workers have been made jointly as well as independently during the last 10 years or so to throw some valuable light on the tectonics, stratigraphy, composition of parts of the Precambrian rocks of Karnataka, largely on the basis of geological and geochemical studies. The current trend of investigation is towards an understanding of the crustal evolution of the Indian Shield and its growth from a protocontinental unit. But for building up any ingenuous concept of such topics of fundamental nature, no serious consideration was given in the past to collect geophysical data relevant to sub-surface geological studies of the Karnataka region.

Therefore, the main consideration behind the present investigation has been to advance our knowledge of the geology of the crust and subcrust of the Karnataka region through geological studies based on geophysical investigation systematically.

Presentation of work

The subject matter of the work has been dealt with in 6 chapters. Location, climate, broad physiographic features and the previous work, etc., are included in Chapter I.

In Chapter II geology and tectonic framework of the area is presented briefly.

Chapter III describes the methods by which geophysical investigations were carried out and the procedures adopted for the reduction and analysis of the data collected. (This also includes measurements of some physical parameters of rock samples collected during field work). The chapter consists of 3 sections; Section I describes briefly the manner in which gravity and magnetic data were collected and reduced. In section II, the free-air, Bouguer and isostatic (Airy-Heiskanen, T=30 km) gravity anomaly maps are described, and the results of the qualitative analysis of these maps are presented. Section III deals with the analysis of the gravity and magnetic data along three east-west profiles and a NW-SE profile across the Karnataka region. Also included in this section is the correlation of some observed geophysical anomalies with metamorphic and tectonic set-up of the Mysore rocks.

In chapter IV, results obtained during the present investigations are correlated with some other geophysical and geological data collected by earlier workers.

Probable interpretation of the results followed by a discussion is the main subject matter of Chapter V.

Chapter VI includes summary of the work and the conclusions arrived at during the present investigations.

Acknowledgements

I am extremely grateful to Professor S.H.Rasul, Head, Department of Geology, Aligarh Muslim University, Aligarh, under whose guidance and inspiration this work was carried out.

I am also thankful to Professor F. Ahmad, former Head, Department of Geology, Aligarh Muslim University, Aligarh, for his encouragement.

I am very grateful to Dr. Hari Narain, Director, N.G.R.I., Hyderabad, for permitting me to carry out this investigation and also for providing all field and laboratory facilities.

My thanks are also due to Dr. S.M. Naqvi, Scientist, N.G.R.I., for his help and encouragement for this work.I sincerely acknowledge many useful suggestions given by my colleagues, Messrs C. Subrahmanyam, S.C.Bhatia, S.Venkatachalam and Dr. D.V.Subbarao, Scientists, N.G.R.I.,Hyderabad, in the course of this work. I am very much thankful to Dr.Hasan Mohammad,Senior Scientific Officer, Atomic Minerals Division, Hyderabad, for his kind help and encouragement.

I am also thankful to Mr. Mashhood Alam Raz for typing the manuscript to the best of my satisfaction. Last, but not the least, the author wishes to thank his wife Saroja Arvamadhu, without whose patience and encouragement during the many long months this thesis was in the making, it would have been impossible to finish the work.

I also wish to acknowledge my indebtedness to the authors of the many books and articles I have freely consulted in the preparation of this work.

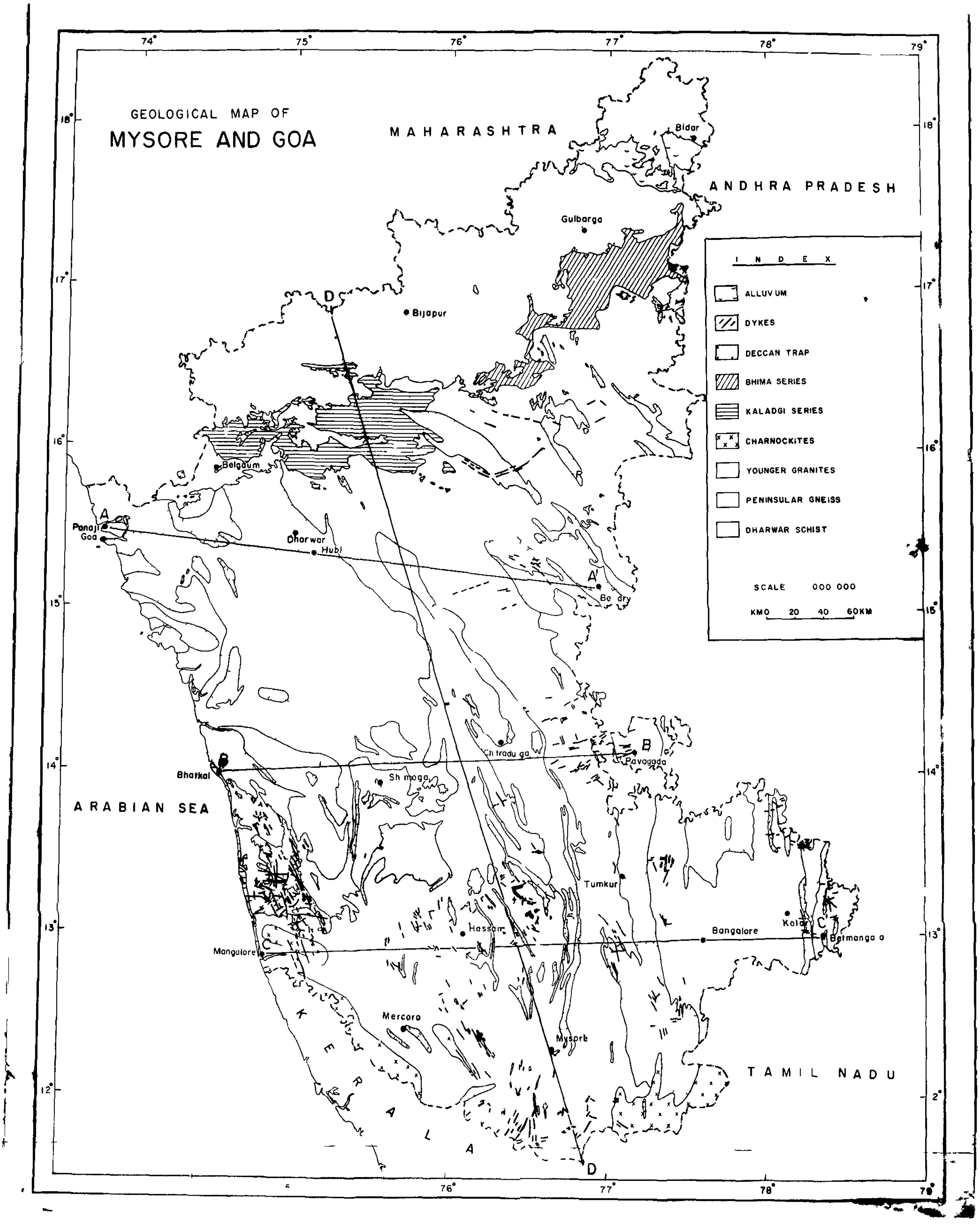

GEOLOGICAL MAP OF
MYSORE AND GOA
MAHARASHTRA
ANDHRA PRADESH
TAMIL NADU
KERALA
ARABIAN SEA
Bidar
Gulbarga
Bijapur
Belgaum
Panaji
Goa
Dharwar
Hubl
Bellary
Chitradurga
Pavagada
Bhatkal
Shimoga
Tumkur
Hassan
Mangalore
Bangalore
Kolar
Betmangala
Mercara
Mysore
A
A'
B
C
C'
D
D
INDEX
ALLUVIUM
DYKES
DECCAN TRAP
BHIMA SERIES
KALADGI SERIES
CHARNOCKITES
YOUNGER GRANITES
PENINSULAR GNEISS
DHARWAR SCHIST
SCALE 000 000
KM0 20 40 60KM
74°
75°
76°
77°
78°
79°
12°
13°
14°
15°
16°
17°
18°

Fig. 2

Widespread volcanic activity in India during the Eocene-Cretaceous times caused the spread of Deccan lavas over a vast area in parts of south and central India. The plateau remained a land mass after the Epi-proterozoic era and underwent steady denundation with occasional epirogenic uplifts. The rough superstructure of the meta-sediments and the meta-volcanics, which largely constituted the Mysore plateau at one time, was subsequently deeply eroded leaving several narrow belts of the ancient rocks.

Lithology and stratigraphy

The greater part of the Mysore plateau consists mainly of the Archaean complex -- the oldest rocks of the earth's crust (Text Fig.2). A comprehensive account of the Archaean geology has been given by Pascoe (1950), Pichamuthu (1967) and Krishnan (1968). There are similar other occurrences of the Precambrian rocks in Rajasthan, Bihar, Madhya Pradesh, but the lithology of the Mysore area is somewhat distinct and different from those of other areas. The Archean succession of Mysore was first described by Smeeth (1916). This has since been revised by Rama Rao (1962), Nautiyal (1966), Pichamuthu (1967) and Radhakrishna (1976) as given in Table (I,1a). The classification proposed by Nautiyal (1967) is based on the tectonic environments of the various units and grade of metamorphism. In Nautiyal's classification the tectonic and metamorphic cycles are correlated with the stratigraphic succession. The Precambrian formations are divided into Archean, Proterozoic and Epi-proterozoic. The Archeans consist of three units (A) primordial or basement rocks, (B) the crystalline complexes, and (C) the highly metamorphosed schists and younger migmatites.

The portion of shield falling in this area consists mostly of migmatised gneisses, granites, several older greenstone belts like Holenarsipur, Kolar, Sargur, Nuggihalli belts and younger schist belts such as Shimoga and Chitaldurg. The greenstone belts of Kolar, Holenarsipur and the younger schist belts consist mostly of metasediments and metavolcanics. They are also associated at some places with banded hematite quartzites and crystalline limestones.

Holenarsipur schist belt

The Holenarsipur schist belt of the Dharwar super group is considered to be a true greenstone belt. The belt, that covers an area of 150 sq. km south of Hassan is comp sed of chlorite-schists, tremolite-actinolite schists, hornblende-schists, etc., in addition to some metasedimentary formations (quartzites, banded magnetite-quartzite), mafic and ultramafic rocks (dunites peridotites) and younger intrusives (dolerite dykes and pegmatites). Adjoining the schist belt is the peninsular gneiss.

Kolar schist belt

The Kolar schist belt, the easternmost in the type area of the Dharwar system, consists mostly of metavolcanics. It trends north-south and extends for nearly 60 to 70 km, with a maximum width of 6 to 7 km. A wide band of highly sheared 'champion gneiss' separates the basal greywackes from the narrow band of schists, hornblende-granulites, amphibolites (mono-mineralic) and surrounded by the vast granitic and gneissic terrain. Some of the quartz reefs intruding into the schist belt contain gold and form one of the major payable gold lodes of India. There are also some narrow discontinuous bands of ferruginous quartzites on the west and a zone of conglomerates on the east of the schist belt.

Nuggihalli schist belt

The Nuggihali schist belt in Hassan district extends over a length of nearly 50 km in NNW-SSE direction with an average width of one km. This belt consists mostly of amphibolites, quartzites and micaceous schists. Ultramafic rocks (pyroxenite) occur as lenticular bodies in parts of the belt. They are altered to talc-schists at places. The ultramafic rocks in this belt, which occasionally host chromite deposits, are supposed to be situated on a mantle tapping fisure (Pichamuthu, 1974). Gneisses and gneissic granites are exposed on either side of the belt.

Chitradurga schist belt

The Chitradurga schist belt in the northern part of Karnataka consists of tightly folded gneisses, actinolite-chlorite-quartz schists, Talya conglomerates, phyllites, magnetite-quartzites, greywacke, a volcanic suite (Jogimardi traps), pyritiferous cherts, granodiorite and granites. The granites usually occupy the anticlinal fold axes.

Shimoga schist belt

The Shimoga schist belt occupies the western limit of the Dharwar anticlinorium. In this belt, talc, chlorite, biotite and hornblende schists occur within the gneisses trending NNE-SSW. These rocks are associated with quartzites, quartz schists, granites and some intrusives. The schist belts of Shimoga and Chitaldurga extend towards Goa and Bijapur for a distance of about 160 km (Iyengar, 1971).

Major Rock Groups:

The older granite-greenstone terrains, exposed over a large part of Karnataka, is a complex of banded gneisses, granitic gneisses and granites, within which the Dharwar schists occur. Among these, the general trend of peninsular gneiss is in the N-S direction and the area occupied by them is nearly 50,000sq. km. The other rock formations in this area are hornblende-schists, chlorite-schists, quartz-talc-schists, banded ferruginous qyartzites, meta-basalts and some patches of ultramafics.

The schist belts and the associated granitoids of non-charnockitic region constitute the granite-greenstone complex of the region. The schist belts consist of metavolcanics and associated metasediments of Dharwar super group. The associated granitoids are represented by Champion and Peninsular gneisses and Closepet granites. According to Naqvi, et al., (1974), the Dharwar schist belts and their equivalents, except the Kolar schist belt, are not typical greenstone belts, but representative of a transitional era of rapid transformation from simatic to sialic crust. Two distinct types of greenstone belts in the Karnataka craton, known as a Keewatin type and Dharwar type are recognised (see Ramakrishnan _et al_., 1976).

(a) _Keewatin type_ - These are mainly volcanic belts with predominent mafic to adesitic volcanics, subordinate acid volcanics, ultramafites, graphitic and sulphidic schists, iron stones, cherts and immature sediments. Rocks occurring in the Kolar and Hutti gold field areas belong to this type like wackes and polymict conglomerates. These are in many respects similar to the other occurrences of greenstone belts of the world, except the absence of a dominent ultramafic unit at the base.

(b) _Dharwar type_ - These are predominantly volcano-sedimentary belts with sediments similar to shallow water shelf facies at the base. Chitradurga, Shimoga, Holenarsipur, Babaudan belts are some examples that belong to this type.

High grade volcano-metasedimentary rocks, occurring as isolated linear bands in the gneissic complex, are termed as high grade schists. The contact between the gneissic complex and the high grade schists is diffused and concordant (Ramakrishnan, et al., 1976). They are largely migmatised schist belts. Sargur and Sakarsanahalli and the encoaves in the Closepet granites belong to this category.

Tectonic setting of the area

The regional structure and tectonic setting of the Precambrian rocks of south India has been a subject of great interest. These rocks which are widely distributed in Peninsular India, broadly include Peninsular gneisses and granites, Charnockite suite, Khondalite suite, Dharwar belts, Closepet type granites, Cuddapah and related formations, Kurnool and related formations, Trap flows and silts and numerous ultrabasic-Anorthositic-Carbonatite complexes (Narayanaswami, 1970, Fig. 1).

Some of the earlier workers (Smeeth, 1916; Rama Rao, 1940) believed the Dharwars to be the oldest among the Archaean rocks of India and the Peninsular gneisses and granites were considered as intrusives in the Dharwar. However, workers like Bruce Foote (1888) visualised that the Peninsular gneisses and granites formed a basement for the Dharwarian rocks. The Khondalites were considered as equivalent to Dharwars and the Charnockites as intrusives in them (Holland, 1900). All those rocks mentioned above, were succeeded, after the great eparchaean unconformity, by the Cuddapahs, Kurnools and their equivalents. The Peninsular gneisses and granites, Charnokites, Champion Gneisses of Mysore, Closepet granites, Ultramafic and alkaline rocks and the basic sills and dykes are considered to be emplaced as intrusive rocks in the Peninsular India. The controversy about the stratigraphic relationship between the Peninsular gneisses and schists has been summarised by Radhakrishna (1974),who considered the Peninsular gneisses as the basement over which Dharwar sediments were deposited.

Narayanaswami (1970) proposed the following three-fold division for the Precambrian systems of south India, based on litho-stratigraphic assemblages, geosynclinal associations, structural setting and tectonic patterns: (1) The charnokite-khondalite system of the Eastern Ghats of Andhra Pradesh, Orissa, Madras, Southern Mysore and Kerala, (2) the Dharwar system of Mysore, and (3) the Cuddapah-Kurnool, Kaladgi basin and Bhima valley. The salient structural and tectonic features of these systems,which fall within the study area, are presented below in brief.

1. Charnockite-khondalite system

The rocks belonging to this system are exposed in parts of southern Karnataka and include acid charnockites, intermediate gneisses and charnockites, basic and ultrabasic charnockites.

These rock groups exhibit atleast two distinct phases of folding movement. The fold system formed during the earlier of the two phases shows a general NE-SW axial trend while in the later phase crossfolds developed having their axial trends striking NNW-SSE, N-S and NNE-SSW (Narayanaswami, 1970 , Fig. 1).

2. Dharwar system

The Dharwar rocks in Karnataka are disposed along two main belts:

a) Goa-Dharwar-Shimoga belt, and
b) Gadag-Chitaldurg-Chicknayakanhalli-Mysore belt.

In between these two main schist belts, there are numerous sub-parallel detached belts occurring at Kolar, Kadiri, Ramagiri, Penner-Hagari, Copper Mountain, Sandur, Hungund, Maski-Hutti, Kurnool-Gadwal, Nalgonda and other places. The Dharwars are composed of an alternating sequence of meta-sediments consisting of quartzites, quartz muscovite-schists, muscovite-schists, conglomerates (more than one horizon), gritty graywacke phyllites and schists, chloritic phyllites and schists, sericitic phyllites and schists, shales and silts, with three or more horizons of banded ferruginous cherts and quartzites. The lowermost horizon is composed of magnetite-grunerite-quartz schist, the middle horizon of pyritic cherts and quartzites, and the upper one of hematitic cherts, jaspers and quartzites.

In addition to the above main sequence of formations, some of the detached schist belts in Southern Mysore (Holenarsipur, Nuggihalli, Nanjangud and others) are associated with meta-ultrabasic rocks like serpentinites (meta-dunites) and talc-chlorite-tremolite-actinolite schists (metapyroxenites) carrying veins and seggregations of chromite and titaniferous magnetite. The Dharwars have been folded into steeply overturned north-plugging isoclinal synclines with their axial trends directed NNW-SSE, N-S and NNE-SSW. The Dharwar folding movement had affected the rock formations to the south and east resulting in the arcuate swerves in the charnockite-khondalite belts of the Eastern Ghats and Madras-Kerala-South Mysore about a N-S axis. The synclinal belts of the Dharwars are made complicated by a series of NW-SE trending dextral cross-folds plunging to the NW, as at Gadag, Chitradurga, Shimoga, Kolar, Coorg and Wynad. They are interspersed by N-S to NNW-SSW trending sinistral cross-folds with SSW plunge in a few places as for example at Kolar, Ramagiri, Sandur, Copper mountain, Hutti and other places.

The peninsular gneisses, which form a part of the province, constitute a broad south plunging geanticlinal upwarp. The axis of the geanticline trends NW-SE and passes through the synclinal belts of Dharwars in Karnataka which constitute a major north plunging synclinorium on the western side of the anticlinorium. Towards the axial zone of the geanticline occur narrow detached schist belts of Kolar. The parallel N-S to NNW-SSE trending ranges of Closepet granites, localised along anticlinal folds, are concentrated towards the axial zone of the geanticline.

Another tectonic pattern of interest is the series NE-SW trending en echelon shear-zones within the charnockite-khondalite belts of Eastern Ghats, Madras, Kerala and Southern Mysore, which are responsible for the uplift of the Charnockite hill masses. These shear-zones as well as the NE-SW culminations and depressions are considered to be deepseated crustal features which bear some relationship to the upper mantle. The magmatic cycles associated with the geosynclinal development, orogeneses of the charnockite-khondalite system and the Dharwar system are manifestations of the upper mantle in this part of the shield. The magmatic cyclos are classified as follows: (1) Palingenetic migmatisation in charnockite-khondalite system resulting in the development of different charnockite suits, (2) amphibolites, hornblende-schists and greenstones formed by metamorphism of basic volcanic effusives in Dharwar geosyncline, (3) syntectonic (tectogenetype) ultramafic injections, dunites, periodotites and pyroxenites in Dharwar geosyncline, (4) acid (plagioclase-rich) adamellite-granites associated with the early palingenetic migmatisation of peninsular gneisses and Dharwar schists into hornblende-biotite gneiss migmatites, (5) acid alaskitic (microcline bearing) Closepet granite intrusives along N-S to NNW-SSE anticlinal folds occurring between synclinal belts of the Dharwars and (6) basic trap flows and dolerite dyke network and kimberlite pipe rocks associated with the peninsular gneiss basement complex and Dharwar schist belts.

Apart from the mafic and ultramafic suites listed above associated with the geosynclinal development and orogenesis of the precambrian systems, there are post-tectonic mafic, ultramafic, anorthosite, alkaline and carbonatite intrusives in tectonically weak zones within the South Indian Shield and noteworthy among these being ultramafic, anorthosite, alkaline and carbonatite complexes in the margins of charnockite belts along the Eastern Ghats and Madras. Ermenko et al. (1968 and 1969) and Narayanaswami (1970) have postulated deepseated faults along the charnockite terrain of Madras and the Eastern Ghats. Narayanaswami (1970) inferred that the NE-SW shear-zones in the charnockite terrain has been responsible for the uplift of the Eastern Ghats and the Charnockite hill masses in Madras, Kerala, S. Mysore. The NE-SW culminations and depressions across the Peninsula in Mysore and Andhra Pradesh, as well as the emplacement of ultramafic-anorthosite-alkaline-carbonatite complexes along the NE-SW shear-zones are deep-seated tectonic features.

Several isolated masses of granite exist within the greenstone belts of Shimoga and Chitaldurga, which were considered intrusive into the schist belts and were regarded as mantle gneiss domes (Pichamuthu, 1974). The domal masses are immediately overlain by gritty chloritic schists, reconstituted granites, and polymict conglomerates of the greenstone-granite sequence. Most of these domes are probably pre-existent basement highs, unroofed during the greenstone cycle, or uplifted due to sialic underplating to maintain isostasy (Ramakrishnan et al., 1976). From these field relationships between the Dharwar type greenstone belts and the gneissic complex it has been inferred by them that the latter formed the rigid basement to greenstone depositional cycle. They further concluded from studies made of high grade schists of Sakarsanahalli near Kolar schist belt and Kolar, that the Kolar belt was evolved after the pantectogenesis but involved in a milder thermal event.

Pichamuthu (1976) classified the granites and gneisses of Karnataka based on different tectonic conditions as (1) an early basement consisting of peninsular gneiss, (2) massive and highly foliated granites derived by local melting of the basement and (3) post-orogenic granites intruding the schists and gneisses, termed as younger granites.

Numerous basic dykes occur in and around the northern part of the Nuggihalli schist belt. The dykes extend in predominantly two trends NW and NE and these vary in thickness from 20 to 60 ft and extend for about a kilometer.

The dykes which are intrusive into the Precambrian metabasalts at Chitaldurg differ in their composition as well as in age (Naqvi et al., 1972).

Study of ultramafic rocks form one of the important methods for knowing the mantle material. Serpentinised ultramafic rocks like periodotite, dunites, occur along a length of 320 km with gneisses, granites, metasediments and metavolcanics of the Dharwar system. These ultramafics might have been metamorphosed and granitised to form the vast surrounding gneissic terrain (Divakar Rao, et al., 1974). The dunites might belong to the missing greenstone sequence (Naqvi et al., 1974) and they are considered to be older than the gneisses.

Major Rock Types and their Constituents

Brief megascopic description of the common rock types, collected in the course of taking traverses along the different profiles, are presented as follows. These rock types were also used for determining their densities in the laboratory.

1. Granites

The granites and the granitic rocks which are abundant in the area, show pink to grey colour and are broadly identified as biotite granite, granitoid gneiss and tonalite. They are medium to course grained rocks, sometimes having gneissose structures particularly developed in the granite-gneisses. They are composed of quartz, potash feldspars, plagioclase feldspars and biotite with zircon, epidote, sphene and a little of opaques as accessories.

Plagioclase is partly sericitised. Microcline, which often occurs as porphyritic crystals is partly cloudy. The microcline crystals however, lack idiomorphic outlines.

Orthoclase which is another important feldspar occasionally occurs as porphyritic grains.

Biotite is the most abandant feromagnesian mineral, and muscovite is a minor constituent. Chloritisation of biotite is a characteristic feature.

Hornblande occurs as a subordinate mafic mineral.

2. Diorite

The rock is melanocratic and medium grained and consists mostly of orthoclase and plagioclase feldspars with appreciable amounts of hornblende, and a little of opaque minerals.

3. Syenite

It is a leucocratic rock composed of plagioclase feldspars, microcline, orthoclase, and biotite. Feldspars are partly kaolinised and serictised. Biotite is sometimes chloritized. The accessories include zircon, sphene, magnetite and ilmenite.

4. Tuff

It is a 'crystal tuff' and composed of few phenocrysts of altered sodic plagioclases, embedded in a cryptocrystalline groundmass and associated with fine grained quartz. Glassy materials are common.

5. Dolerite

The rocks are dark-coloured and medium grained, consist essentially of plagioclase, clinopyroxenes and pyroxenes.

Accessories include magnetite and ilemenite.

6. Gabbro

The rock is dark-coloured coarse grained and granular, and consists mainly of plagioclase and augite. Alteration of pyroxenes to epidote is common. Accessories mainly include ilmenite and magnetite.

7. Anorthosite

It is a coarse grained light-coloured rock essentially composed of plagioclase with a little of quartz, hypersthene, chlorite, biotite, epidote and some opaques as accessories.

8. Hornfels

The rock is dark coloured, fine to medium grained, very much altered and consists mostly of quartzo-felspathic materials with few phenocrysts of altered plogioclase. Feldspars are partly sericitised and kaolinised. Accessories include magnetite, ilmenite, pyrite, sphene and rutile.

9. Slate

The rock is dark grey in colour, fine grained, and partly weathered. Slaty cleavage is well developed in most of the slates.

10. Schist

The rock is fine to medium grained. Biotite-hornblende-schists and tremolite-schists are common. Quartzo-feldspathic materials form the bulk of the rock. The prismatic grains of hornblende are roughly oriented with the result that they impart a crude schistosity to the rock. Kaolinisation and sericitisation of felspars and biotitisation of hornblende are common. Accessory minerals include epidote, ilmenite, magnatite, garnot and chlorite.

11. Amphibolite

The rock is medium grained and dark coloured and consists essentially of hornblende and biotite. Hornblende is often replaced by biotite. Plagioclase forms a minor constituent of the rock.

12. Peridotite

The rock is medium grained and dark brown coloured with olivine as the dominant mineral. Accessories include magnetite, ilmenite, pyrite and garnet.

13. Granulite and Charnockite

The rocks are medium to coarse grained and include hornblende granulite and charnockite. They consist of highly clouded coarse crystals of greenish-brown hornblende, biotite and hyperstheme. Hyperstheme is characteristic of charnockites. Accessories include ilmenite, magnetite, pyrite, rutile and zircon.

14. Feldspathic quartzite

It is a fine grained feldspathic quartzite. Quartz and feldspar are embedded in a fine-grained quartzose matrix. Biotite and sericite are slightly oriented. The rock shows in general a porphyroblastic texture.

TABLE I(A)

RECENT CONTRIBUTION TO THE PRECAMBRIAN SEQUENCE IN MYSORE

	Rama Rao (1962)	Pichamuthu (1967)		Nautiyal (1966) abbreviated
	Upper Precambrian (unconformity)	Upper Precambrian (unconformity)		Kaladgi Series (Sheared Contact)
	Felsic and porphyry dykes Closepet granites	Mafic dykes Felsic and porphyry dykes Closepet granite Charnockites Series		Upper Dharwar Metasediments (unconformity)
Gneissic System	Recrystallization of older rocks into Charnockite Series			Middle Dharwar metasediments and Jogimardi pillow lavas of Chitradurga (decollement)
	Norite dykes Hornblende dykes Peninsular dykes	Peninsular Gneiss Complex		Lower Dharwar
	Upper Dharwars	Upper Dharwar Metasediments	(Cherty ferruginous and calcareous shales, siltstones, (schists, quartsites and basal conglomerates with pebbles of (granite, granite porphyry and (B.H.Q	Metasediments and metavolcanics, syntectonic Champion Gneiss, post-tectonic diapier granites of Chitradurga, pegmatites, auriferous quarts veins, basic and ultrabasic intrusions, porphyry sills (Thrust)
Dharwar System	Middle Dharwars	Middle Dharwars	(Granitic rocks, granite (porphyry, mafic and ultramafic intrusives, metasediments	Upper Archaean schists, migmatites, para - gneisses ultrabasics, with anatectic granites intruded by porphyritic migmatites and syntectonic Closepet Granite
	Lower Dharwars	Lower Dharwars	(Champion Gneiss, rhyolites, (felsites, quarts porphyry, (Mafic flows and intrusions	(Thrust) Lower peninsular gneissic complex (Thrust) Granulitic gneisses (charnockites et al.)

TABLE I(B)

(After Radhakrishna,1976)

Age in M.Yrs.	Era	Super group	Group	Rock type (host rock)
900	PROTEROZOIC	Kurnool	Bhima	Carbonatite complexes (700 m.y.) limestones, shales, sandstones
1600		Cuddapah	Kaladgi	Shales, limestones, Cuddapah lavas, sandstone, quartzites, Kimberlite pipes (1700 m.y.)
2100		Dharwar Super Group	Ranibennur Dandeli	Banded iron formation Ankeritic limestones Graywackes (Ranibennur)
2400			Chitaldurg	Mafic dykes Younger granites (Closepet) Banded hematite quartzites (2300 m.y.) Jaspilites, limestones, phyllites, shales, conglomerates, quartzites.
2700	ARCHAEAN		Bababudan	Quartz-magnetite schists, phyllites, graphitic schists, Mafic lavas, associated cherts, conglomerates, ortho-quartzites.
2900			Gneissic complex	Migmatitic gneisses, tonalites, granodiorites and granites (age ranging from 2950 to 2500 m.y.)
3000			Sargur	Magnetite schists, amphibolites, basalts (Kolar, Hutti), Inter-related sediments, Anarthositic gabbros, peridotites, pyroxenites, gabbros (Nuggihalli)
3200				Oldest crustal material, sialic or mafic (?)

Chapter III

GEOPHYSICAL INVESTIGATIONS IN THE KARNATAKA PLATEAU

The geophysical studies that are being carried out in this area, are mainly based on the results obtained from gravity and magnetic methods of investigation and also that from other interdisciplinary subjects, viz., aeromagnetic, paleomagnetic, seismic, heat flow and radioactive data, on which some work has been done by contemporary workers.

SECTION I

One of the major organisations doing gravity studies in India is National Geophysical Research Institute (NGRI) in Hyderabad. Under the project 'Regional gravity studies in India' systematic studies in gravity have been going on in the NGRI since early 1964. The gravity studies include the collection of data in the field and compilation of data from other organisations in India where similar data is being collected. Standardisation of the data so obtained from other sources and finally the analysis and interpretation of all the relevant data are some of the important objectives of the NGRI.

The general purpose of carrying out gravity surveys by the NGRI is to cover the large gaps in the gravity network of India. The present field work was, however, carried out with a station spacing of about 6 kilometers, viz., somewhat in semi-detail. The gravity stations are usually located along the roads. In order to spread the gravity network numerous bases are established throughout India, which were tied to the national base at Dehradun whose value is 979.064 gals. Some bases, established in South India, have been reported by Qureshy and Brahmam (1969).The bases so established are accurate to 0.3 mgal. The gravity observations made by the NGRI combined with those of Survey of India and other organisations were used in the preparation of different gravity maps. A total of about 2,000 gravity stations were made use of in the preparation of the gravity maps of the Mysore plateau. The Survey of India gravity values were adjusted to the NGRI values by making some direct ties with some Survey of India stations.

The elevation control for the NGRI stations was essentially the spot heights given on the one inch equal to one mile topographic sheets of the Survey of India. In areas where such spot elevations were not available, the elevations were obtained by using two altimeters simultaneously. Survey of India and P.W.D. bench marks, and spot elevations were used as control points for reducing the altimeter data. Thus the maximum error in elevation can be taken to be the same as that of the spot elevations, which may be of the order of 6 m.

Gravity observations were made using Worden Gravimeter. By repeated observations at a number of points, the observed gravity values are found to be accurate to within 0.3 mgal. The Bouguer anomalies have been computed by assuming a density of 2.67 g/cm^3 for the topography above m.s.l. They are referred to the international gravity formula of 1930 and are corrected for terrain and curvature out to zone '0' of Hayford.

Free-air anomalies are gravity anomalies which are obtained on the assumption that there is no material between the station level and the sea level.

Taking into account the maximum errors in the observation and elevation the overall probable error in the gravity anomalies (Bouguer or Free-air) may be about ± 1.5 mgal.

The isostatic anomalies have been computed by using Airy-Heiskanen system of compensation for an assumed sea level crustal thickness of 30 km, and densities of 2.67 gm/cm^3 and 3.27 gm/cm^3 for the crustal and subcrustal materials respectively. In computing these anomalies, correction for zone 16-1 of Hayford was interpolated from an interpolation map by Karki et al. (1961). For zones A-O an interpolation map prepared by the author was used.

The different gravity maps, prepared by making use of these data, are free-air, Bouguer and isostatic anomaly maps.

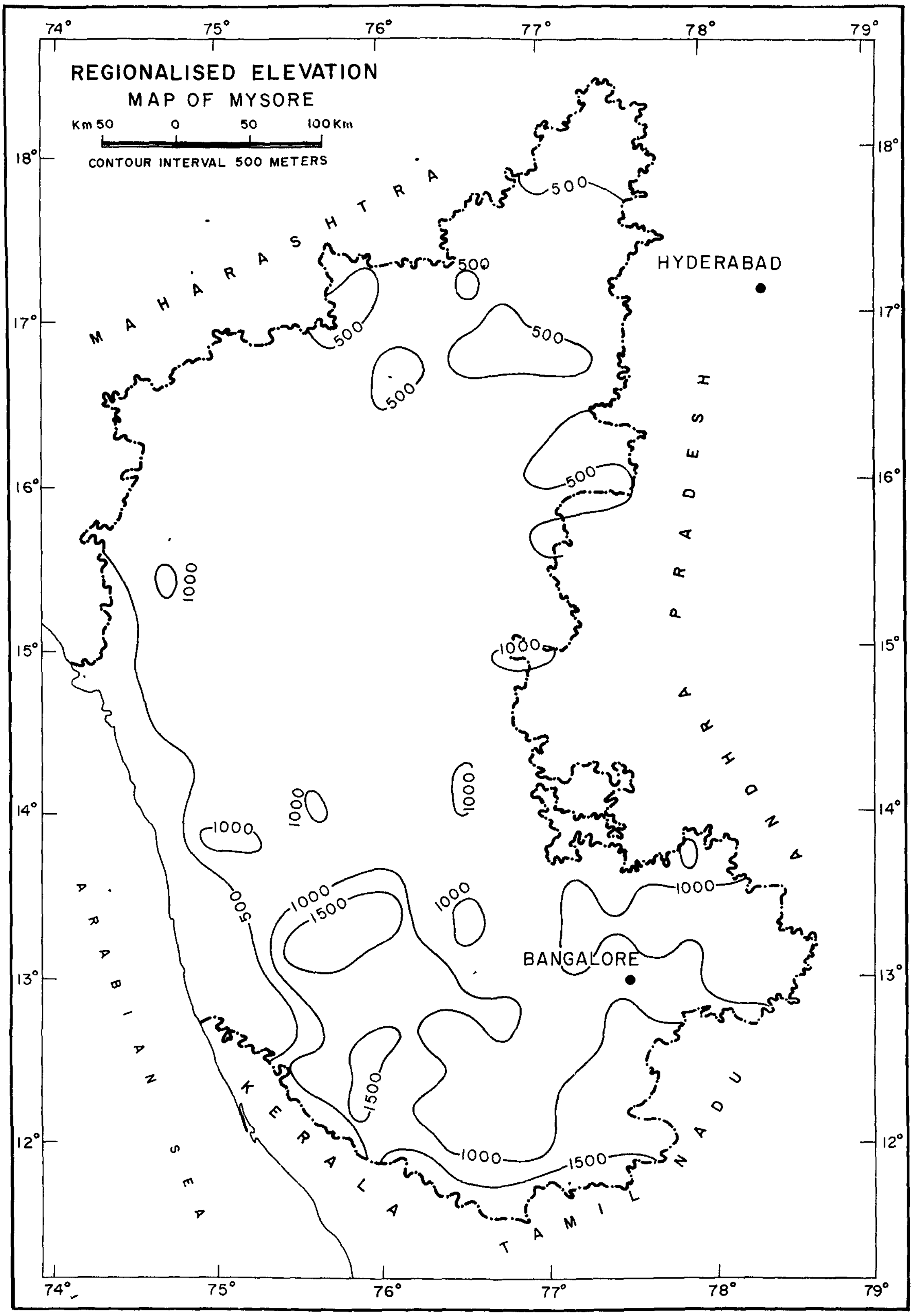

REGIONALISED ELEVATION
MAP OF MYSORE
Km 50 0 50 100 Km
CONTOUR INTERVAL 500 METERS
74°
75°
76°
77°
78°
79°
12°
13°
14°
15°
16°
17°
18°
MAHARASHTRA
ANDHRA PRADESH
TAMIL NADU
KERALA
ARABIAN SEA
HYDERABAD
BANGALORE
500
1000
1500

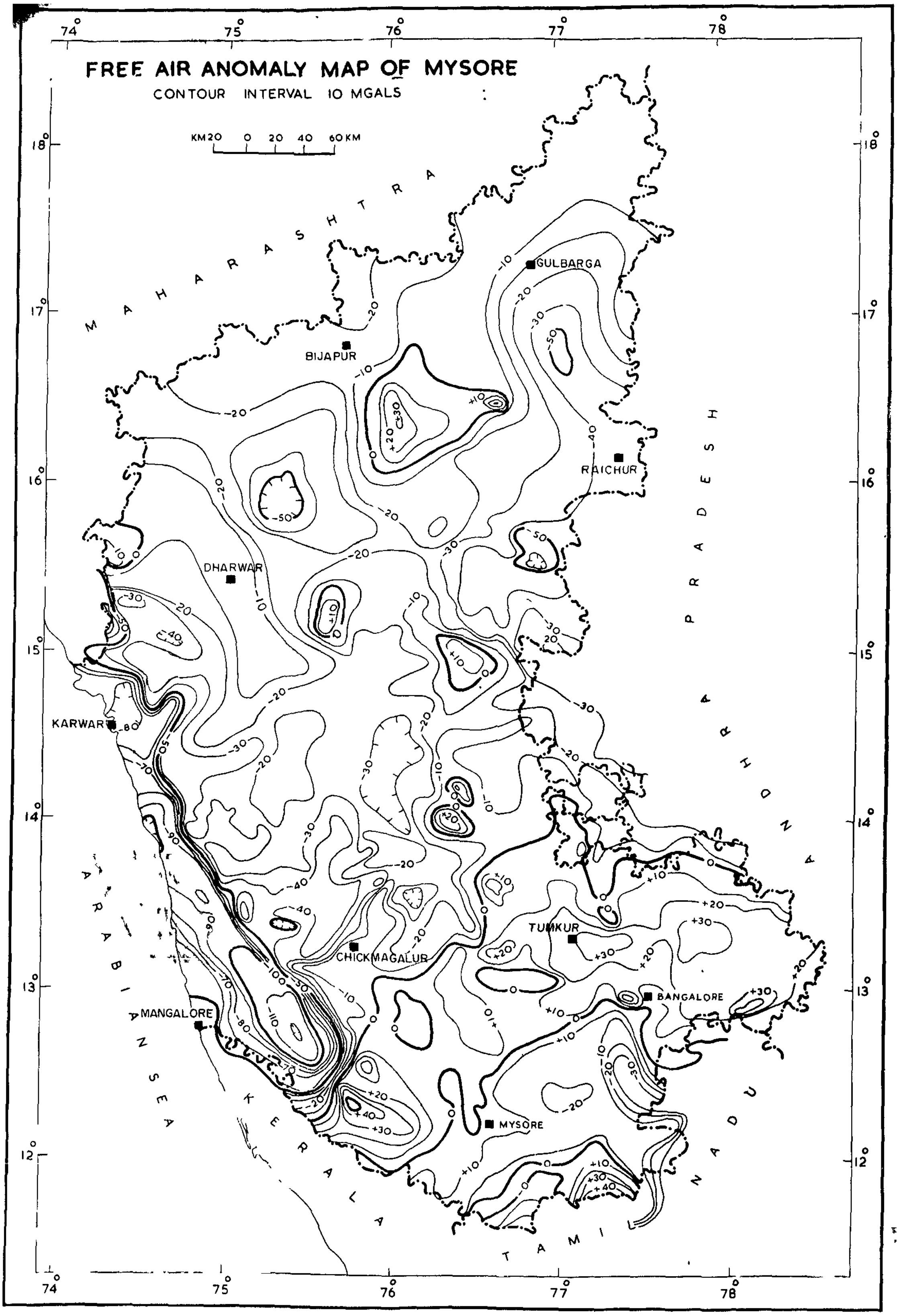
fig Fig. 3

In order to obtain a general idea of the average elevation of the plateau and to compare the gravity anomalies along with the tectonics and elevation of the area under study, a regionalised elevation map of the Karnataka plateau was prepared (Fig. 3). The regional elevation map was prepared by using the maximum topographic contour value in 15 minute grid to represent the elevation in that grid. As may be seen from the map, excepting the Northern Karnataka, where only 500 meter elevation contours are shown, rest of the region contains, in general, several 1,000 meter contours and with a few 1,500 meter contours and only one 500 meter contour passing along the western border indicating that the plateau is an elevated tableland with an average elevation of 1,000 meters. It is commonly observed that there is a relationship between gravity anomalies and surface topography; free-air anomalies are directly related to the elevation of the observation points; Bouguer anomalies are principally related to the regional elevations. On the other hand the isostatic anomalies bear more resemblance to some of the residual anomalies connected more or less with the local geology. Of the three kinds of anomalies the study of the free-air anomaly map of the plateau may give some idea of the gravity field in this elevated tableland and its isostasy.

SECTION II

Free-air Anomalies

Figure 4 shows the free-air anomaly map of Karnataka. The



FREE AIR ANOMALY MAP OF MYSORE

CONTOUR INTERVAL 10 MGALS

Fig. 4

anomaly contours have a total variation range of 170 mgal, i.e., from -120 to +50 mgal. Situated southeast and east of Mangalore, the areas showing +50 mgal and -120 mgal anomaly contours respectively, are distinctly separated from one another by a zero contour which passes across the plateau in NE-SW direction. Running almost parallel to the west coast from Karwar to Mangalore negative anomalies, ranging from -80 mgal to -50 mgal, are observed with steep gradients away from the coast. Its general trend is NW-SE. The axis of the anomaly approximately coincides with the elevation contour of 500 meters. Excepting this 'low' (-80 mgal) and the 'high' (+50 mgal) occurring west of Mysore, rest of the area is covered with the anomalies ranging from -30 mgal to +30 mgal closures. The zero anomaly contours are also observed in different parts of the area. These indicate that the average free-air anomaly approximates to zero. The -50 mgal 'low' south of Gulbarga represent topographic depression. The 30 mgal 'high' S.E. of Bijapur may reflect the topography as this is comparatively elevated area as may be seen from Geological Map of Mysore published by the G.S.I. in 1971. 50 mgal 'high' west of Mysore is observed over an elevated region of about 1,500 mts. Positive anomalies are obtained in the region between Bangalore and Tumkur over a plateau surface having an average elevation of 1,000 mts. The reasons for negative anomaly of -120 mgal in the East of Mangalore could not be known.

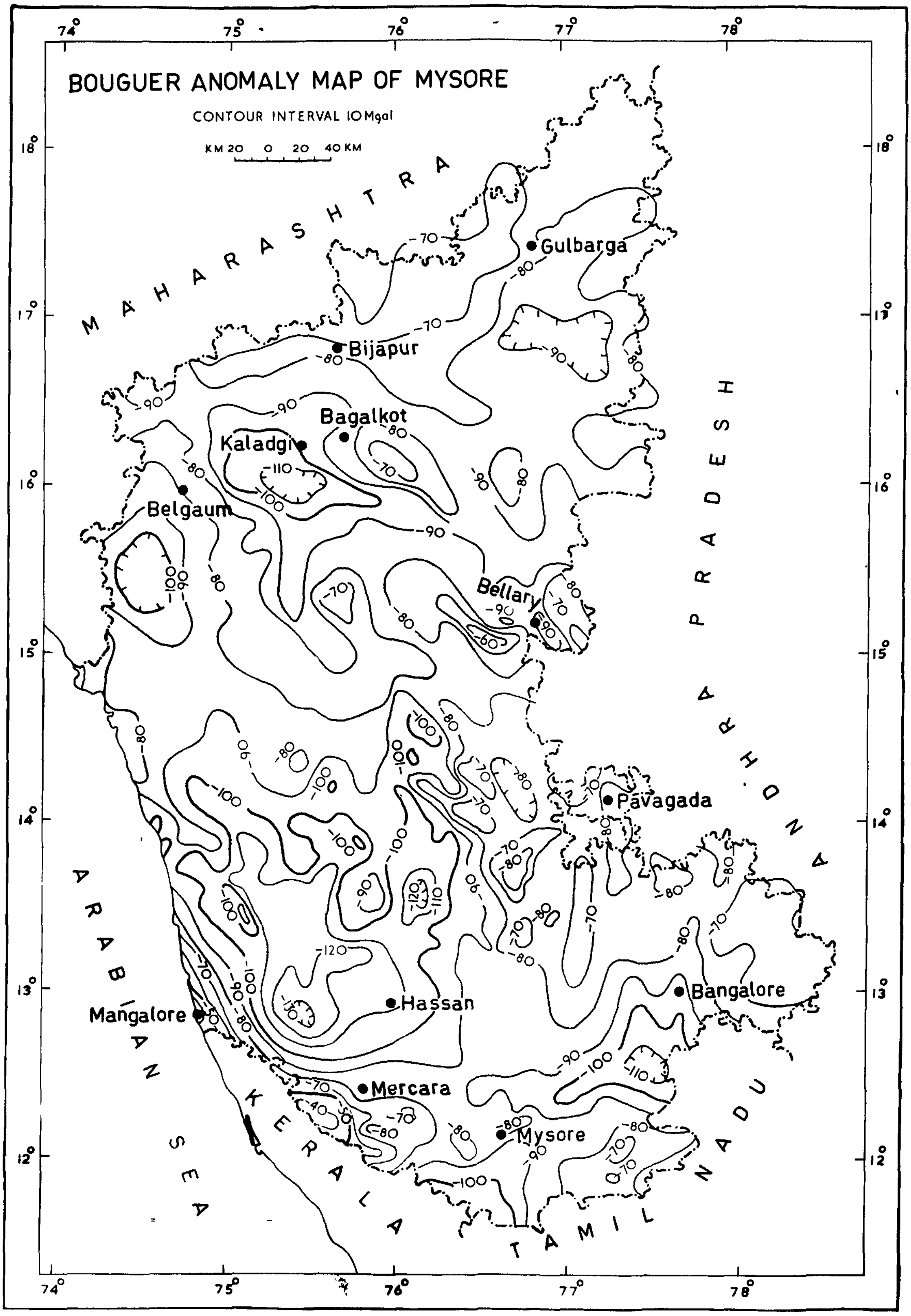

BOUGUER ANOMALY MAP OF MYSORE
CONTOUR INTERVAL 10 Mgal
KM 20 0 20 40 KM
MAHARASHTRA
ANDHRA PRADESH
TAMIL NADU
KERALA
ARABIAN SEA
Gulbarga
Bijapur
Bagalkot
Kaladgi
Belgaum
Bellary
Pāvagada
Bangalore
Hassan
Mangalore
Mercara
Mysore
74°
75°
76°
77°
78°
12°
13°
14°
15°
16°
17°
18°
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130

Fig. 5

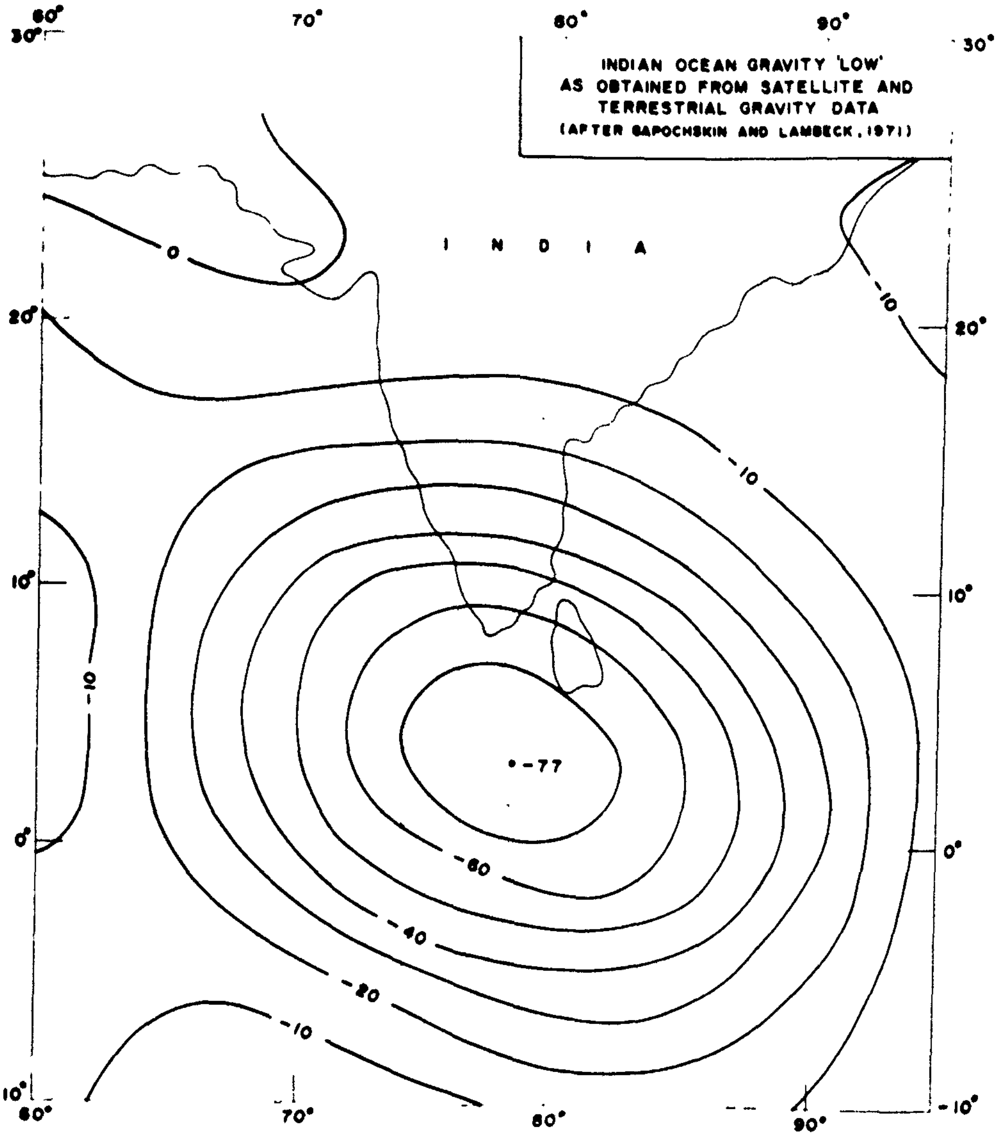

INDIAN OCEAN GRAVITY 'LOW'
AS OBTAINED FROM SATELLITE AND
TERRESTRIAL GRAVITY DATA
(AFTER GAPOCHKIN AND LAMBECK, 1971)
60°
70°
80°
90°
30°
20°
10°
0°
-10°
I N D I A
0
-10
-20
-40
-60
-77

Fig. 6

Bouguer anomalies

From the Fig. 5, it may be observed that the Bouguer anomalies, varying from -130 mgals to -40 mgals, have a range of 90 mgal. As may be seen from the B.A. map, the entire area is covered by negative anomalies. This is a normal feature over a continental crust. This negative bias in the plateau has the added significance in that it appears to be similar to that of generally prevalent negative gravity anomalies known to occur in the southern part of Indian peninsula. The probable reasons for strong negative anomalies, according to Woollard (1972), can be traced to a deeper source in the Indian Ocean as revealed from satellite data (Fig.6). From the map (Fig. 5) it may be observed that in the northern portion of the area the anomalies are broad while in the southern portion they are somewhat sharper with steeper gradients. On a comparison with the regional elevation map (Fig. 3), the broader anomalies occur over the tableland where its elevation is 500 meters whereas the southern portion of the area shows greater variation in the elevations although this variation cannot explain completely these anomalies. Geology of the plateau appears to have little relationship to this zonal anomalies. It is possible that the broad anomalies are mainly caused by deep seated bodies unrelated to surficial geology. The above statement can be further substantiated by the fact that the negative anomalies of the order -70 mgal to -80 mgal are obtained over the Deccan Traps, the average density of which is found to be 2.9 gm/cc and greater than that assumed for the crust (Krishnan, 1968). This 'low' over the Deccan traps has been explained as due to the possible presence of rift valleys beneath the Deccan Traps (Krishna Brahmam, 1975). The major part of the anomaly can be linked to deep seated causes over which are superimposed anomalies of relatively small magnitude due to the varying thickness of the high density basalts (Kailasam *et al.*, 1972). Another possibility may perhaps be linked with the idea that thick trap rocks (2 km) floating over the granitic magma over this region, caused negative anomalies as it has been suggested in the case of Boulder batholith, Montana (Warren Hamilton and Myers, 1967).

The Kaladgi limestones occurring near 16° parallel show a density of the order of 2.6 gm/cc with occasional higher values of 2.7 gm/cc. The Shahabad limestones (Bhima series) range in density range from 2.67 to 2.73 gm/cc, while the sandstones of the same series have densities varying from 2.47 to 2.64 gm/cc (Kailasam,1972). The average density of the granites and gneisses is of the order of 2.66 gm/cc and 2.68 gm/cc respectively. The average density value of Dharwar schists is 2.7 gm/cc. The Bouguer gravity map over the geologic features may be studied in the light of these density values.

The Kaladgi basin, which is partly covered on the north by the Deccan lavas, is brought out in the B.A. map as a closed feature with a peak value of -110 mgal. To the east and west of the basin, the gravity values increase rapidly suggesting faulting over the margins of the basin. Similar observations have also been made by Kailasam et al.(1972). The Bhima basin, south of Gulbarga, is characterised by a -90 mgal closure. The low gravity values of -80 mgals, observed over the Deccan traps, is also possibly due to the Bhima series underlying the traps. Thus the Kaladgi and Bhima series have possible territorial extension beneath the traps.

Gravity anomalies, ranging from -130 mgal to -110, were observed over the Dharwar schists. As the average density values of the Dharwar schists measured are higher than the density values of the crustal rocks it may be inferred that the gravity anomalies observed here are expressions of the gravity field of both the surface and subsurface geologic bodies. Superposed over these, there is another source of gravity field which also contributes to these gravity anomalies and this is the regional field, viz., deep seated effects of geologic bodies. The prevalence of strong negative anomalies over the Dharwar formations could be interpreted in the light of the negative anomalies generally observed over the plateau and in the context of the predominance of negative anomalies over the entire peninsular shield, for which Bhattacharji (1970) and Woollard (1972) gave different interpretations. From this fact it is obvious that a background (regional field) exists which tends to be negative and superposed over the local field. Thus the residual field may be positive or negative depending upon the strength of the observed anomaly source. Under these circumstances the residual anomalies obtained over the Dharwars may be either positive or negative depending upon the thickness of the Dharwar formations. As such, the negative residual values observed over the Dharwars may sometimes be due to lighter rocks underlying the schistose formations and the granites, being less dense than the average crust, might have been the cause of those anomalies. Negative anomalies of the order of -80 to -110 mgal with a peak value of -110 mgals have been obtained over the granites east of Mysore, and the measured density values of granites range from 2.64 to 2.69 in this area while the normal crustal density is assumed to be 2.67 gm/cc. Anomalies ranging from -50 mgal to -100 mgal were observed over the territory along the west coast. Anomalies varying from -70 mgal to -80 mgal have been obtained over the charnockites of this area. As the density of charnockite ranges from 2.67 to 2.73 (Krishnan 1968), gravity 'lows' of this order may not reflect the surface geology. Mention may be made here that instead of ruling out the possibility that this anomaly is caused by charnockitic bodies, it may be supposed that the possible causative body may be determined if the background noise (the regional field) is correctly evaluated and removed, and the residual anomaly obtained. It may enable one to interpret the data quantitatively. An attempt has been made by the author to interpret the gravity data quantitatively while

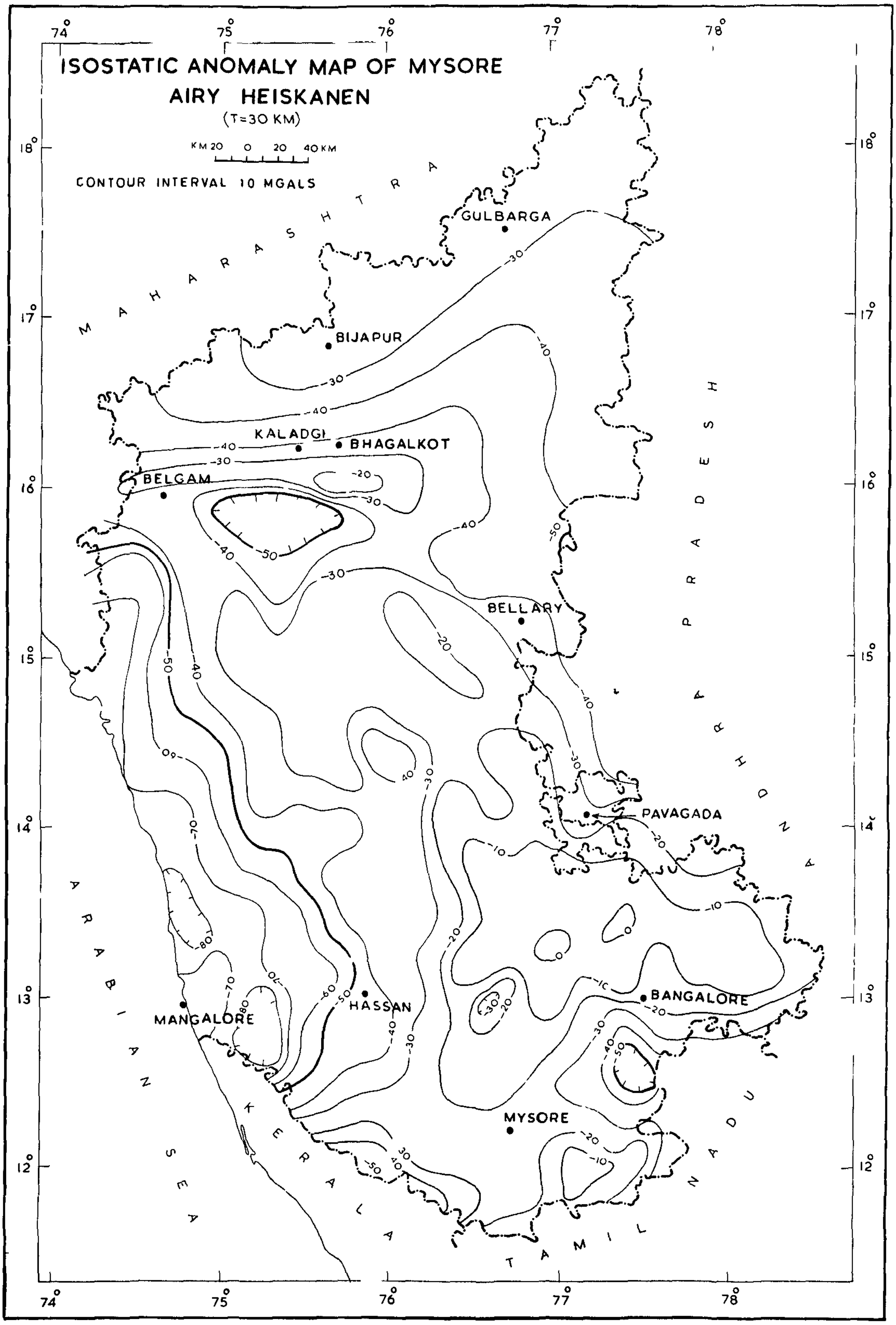

ISOSTATIC ANOMALY MAP OF MYSORE
AIRY HEISKANEN
(T=30 KM)
KM 20 0 20 40 KM
CONTOUR INTERVAL 10 MGALS
74°
75°
76°
77°
78°
12°
13°
14°
15°
16°
17°
18°
MAHARASHTRA
ANDHRA PRADESH
TAMIL NADU
KERALA
ARABIAN SEA
GULBARGA
BIJAPUR
KALADGI
BHAGALKOT
BELGAM
BELLARY
PAVAGADA
MANGALORE
HASSAN
BANGALORE
MYSORE
-10
-20
-30
-40
-50
-60
-70
-80
0

Fig-7 Fig. 7

discussing the gravity profiles in the next section. Peninsular gneisses are characterised by -80 to -100 mgals. The negative anomalies of this order on the gneisses may be partly attributed to the granites underlying the gneisses. In order to arrive at a more realistic picture of the gravity anomalies which reflect the local geology well, Airy-Heiskanen anomalies were calculated with crustal thickness 'T' = 30 km, as these gravity anomalies (computed after isostatic correction) are supposed to represent more realistic crustal model of the earth than the Bouguer anomaly. Although the mass distribution at depth appears to range from that defined by the Airy-Heiskanen concept of isostasy to that embodied in Pratt-Hayford concept (Woollard, 1966), Airy-Heiskanen anomalies are analysed here, for those types of isostatic anomalies are, in the vast number of cases, closer to earth's model derived from seismic data in various countries.

Isostatic anomalies (A-H anomalies, T=30 km)

Fig. 7 shows the isostatic anomaly map of Mysore based on Airy-Heiskanen model with T=30 km. The map is similar to Bouguer except in respect of some differences such as change in the shape of the anomalies in some areas and also in the smoothing out of the anomalies with decrease in the magnitude of the anomalies. The smoothed anomalies indicate that isostatic correction is a sort of regional correction (Hales and Gough, 1957). Isostatic anomalies were calculated for T=30 km as it is recognised that Airy-Heiskanen system of compensation for T=30 km show nearly complete isostatic equilibrium for those regions of India that lie below an arbitrary elevation of about 2,000 meters (Qureshy, 1963). Further from regression studies of gravity anomalies (Aravamadhu et al., 1970) it was established that sea level crustal thickness of 30 km as appropriate for southern peninsular India. If other assumptions such as crustal thickness and the nature of compensation, viz., local or regional, are reasonably correct, isostatic anomalies may be caused due to geologic bodies or on account of departure from isostasy as a result of tectonic processes in an area which is otherwise in equilibrium. The isostatic anomaly ranges in this region vary from -80 to zero mgals. Negative closures of the order of -50 mgals were obtained at some places near Dharwar and Mangalore. Near the Western Ghats, lying at the western boundary of the plateau, the anomalies observed vary from -80 mgals to -50 mgals. In spite of the fact that the stable crustal block of the peninsula is left undisturbed since the Precambrian times and composed mostly of denser rocks, the anomalies over the region are strongly negative. According to Bhattacharji (1970) these anomalies are due to mass-depressions associated with mass defects as a result of the age-long denudation over the peninsular plateau. The compensation effects of these mass-defects, which is of the order of 200 to 500 meters depth, are large enough to account for the negative anomalies in the region, the Bouguer effects getting automatically cancelled out. Bhattacharji (1970) is also of the opinion that this isostatic imbalance ultimately may have resulted in recent earthquake at Koyna, north of the Karnataka region.

The area is in general charactorised by predominance of broad zones of negative anomalies varying from -10 to -40 mgals with zero anomaly closures at two isolated pockets near Bangalore. The gravity 'low' of the order of -50 mgals near Dharwar may possibly be due to the low density granites underlying the schists. The gravity 'low' with a peak value -50 mgals south of Bangalore may also have been caused by the light granitic gneisses. Relatively positive values ranging from zero to -10 mgals have been observed between Pavagada, Hassan and Bangalore over an elevated region of the plateau. Summarising the analysis of the gravity maps, it may be mentioned that the gravity picture of the Karnataka is generally charactorised by low anomaly values. These regional low values are superposed over the local'highs' of the low grade greenstones (Dharwars) and peninsular gneisses, and granites (Archeans) characterised by gravity 'lows'. Almost similar features have been observed by Glikson and Lambert (1973, 1976) over the Precambrian rocks of western Australia.

The above mentioned analysis indicate the qualitative nature of the causative rock formations. A quantitative interpretation is attempted in order to determine the width and depth of the bodies due to which these anomalies may have been obtained. A set of four gravity profiles, three East-West and the fourth,

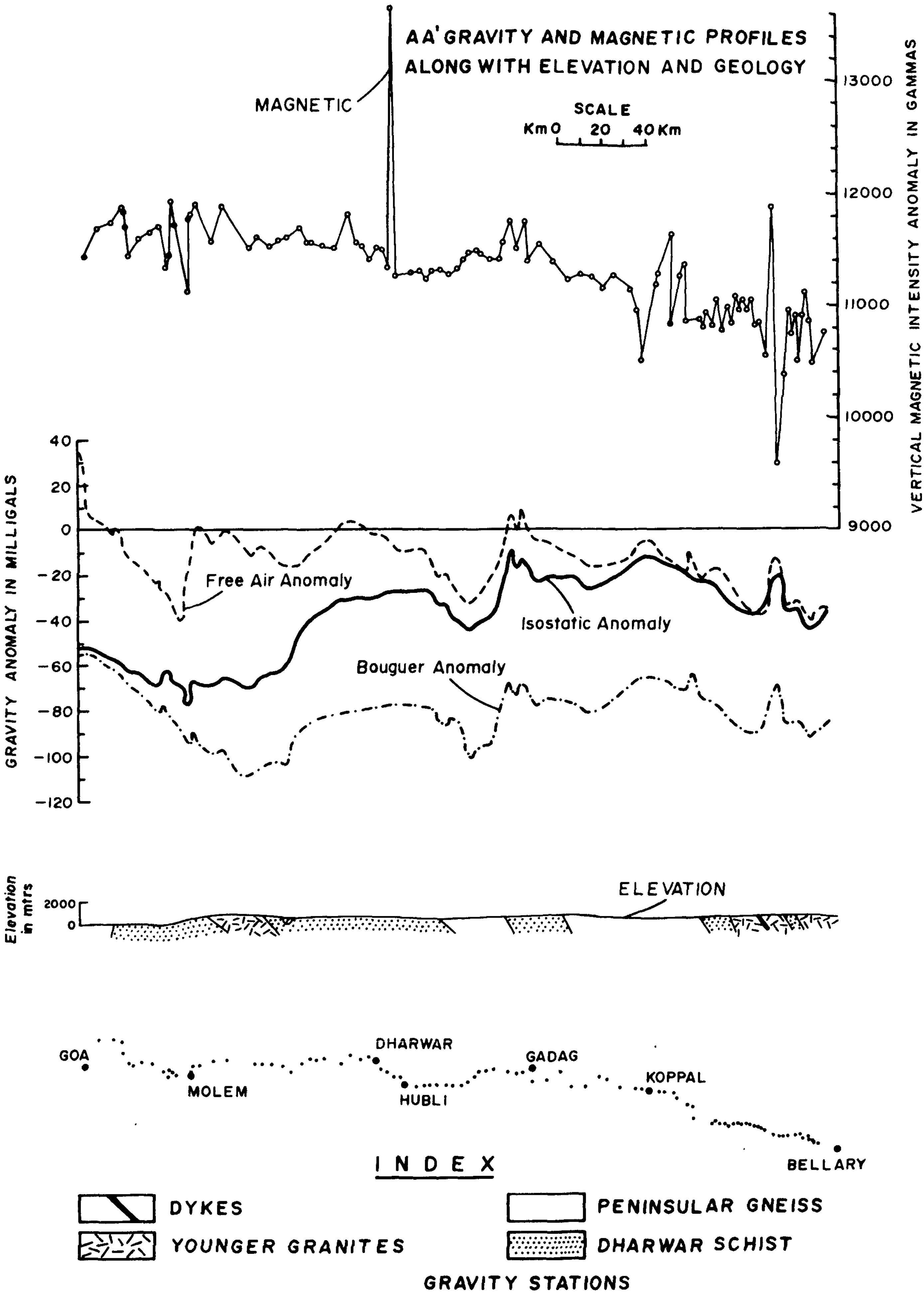

AA' GRAVITY AND MAGNETIC PROFILES ALONG WITH ELEVATION AND GEOLOGY
MAGNETIC
SCALE
Km 0 20 40 Km
VERTICAL MAGNETIC INTENSITY ANOMALY IN GAMMAS
13000
12000
11000
10000
9000
GRAVITY ANOMALY IN MILLIGALS
40
20
0
-20
-40
-60
-80
-100
-120
Free Air Anomaly
Isostatic Anomaly
Bouguer Anomaly
Elevation in mtrs
2000
0
ELEVATION
GOA
MOLEM
DHARWAR
HUBLI
GADAG
KOPPAL
BELLARY
INDEX
DYKES
YOUNGER GRANITES
PENINSULAR GNEISS
DHARWAR SCHIST
GRAVITY STATIONS

Fig. 8

approximately NW-SE was analysed quantitatively and the results are presented in the following section :

SECTION III

Analysis of gravity and magnetic profiles

The three east-west gravity profiles, along which gravity and magnetic data were collected, are (1) Goa to Bellary (AA'), (2) Bhatkal to Pavagada (BB') and (3) Mangalore to Betmangala (CC'). The fourth one DD' run approximately in NW-SE direction (Fig. 2).

As it is desirable to have a knowledge of the density values of the rock formations along the profiles for a quantitative estimate of the geologic sections, rock samples were collected at the gravity stations along the traverses and their densities were determined in the laboratory. Gneisses, schists, granites, dyke rocks and trap rocks are the rock samples whose density values were measured.

Discussion of Profiles

Profile AA' - Gravity anomalies (FA, BA and IA), elevation data and the geology along profile AA' are shown in Fig. 8. This profile, which runs from Panaji (Goa) to Bellary across the plateau was taken approximately along the East-West direction. The different geologic formations across which the profile passes through are Dharwar schists, younger granites, peninsular gneisses and dyke rocks. The different anomalies, viz., free-air, Bouguer and isostatic (Airy-Heiskanen) have similar characteristics along the profile. As may be seen in the Fig. 8, the elevation profile is practically flat (approximately at 600 meters level) starting from the coastal station, Goa, to a distance of about 65 km towards east. *The gravity anomalies show steep fall in values* from the coast to the point where there is a sharp contrast in elevation, the fall in gravity value being more conspicuous in the free-air anomaly curve which normally shows a direct dependence on topographic relief. This fall in gravity values may be due to the fault between the west coast and the continental divide which has also been revealed from geodetic and gravity studies(Bhattcharjee,1970; Kailasam, 1972) earlier. Measurement of density values of the rocks show that the average values of Dharwar schists are higher than that of the normal crust, and the density of the granites, lower than that of normal crust. The density of the peninsular gneisses is almost equal to the assumed average density of the crust. Residual anomalies are derived from Bouguer anomalies after the removal of the regional values. It may be mentioned here that although isostatic anomaly is in the theoretical sense a residual anomaly (Coron 1969), in practice there are many uncertainities about the density contrasts and the depths assumed upto the depth of lateral homogenity. It is, therefore, not desirable to make quantitative analysis with this possible speculation about the physical properties of the *deep interior (see Lafer, 1965). As such, for quantitative analysis*

Bouguer anomalies are utilised instead of the isostatic anomalies, and the regional effect removed from the Bouguer anomaly. There are many methods of removing the regional effect such as trend surface analysis; the method of least squares, moving average method, profile averaging method, etc., and each method has its own advantages and limitations. One of the simplest and best method is that of smoothing, viz., to draw a smooth line along the desired profile for which it is required to extract the regional. While drawing the regional in this case, geology is also taken into account so that the residual anomalies obtained reflect the local geology.

In magnetic survey, variations in the vertical component of the earth's magnetic field along the three East-West profiles were measured as it is a common observation that the vertical component of the geomagnetic field reflects the geologic bodies well in high magnetic latitudes (Heiland, 1946). Torsion magnetometer was used in the magnetic survey. All the values are referred to the station at Bellary and the data reduced accordingly. For applying the diurnal correction, the stations with known absolute magnetic values were occupied during a day's field work. These stations are Survey of India stations and the epoch correction for them has been made from the magnetic charts of the geomagnetic observatory at the N.G.R.I. As far as possible both gravity and magnetic stations were set up at the same site so that locating the stations and the correlation of the gravity and magnetic data is more convenient. Of course, care was taken to see that the magnetic stations were set up away from the power lines and other elements which are likely to disturb the magnetic field. Further from magnetic observatory records the magnetically disturbed days were avoided or corrected for, if the correction is small. Fig. 8 shows the magnetic profile from Goa to Bellary. The total range of the magnetic anomalies along the profile varies from 9,600 gammas to about 13,600 gammas. The maximum anomaly of 13,600 gammas is obtained near Dharwar over the schistose rocks. Again, midway between Koppal and Bellary anomaly ranging from 9,600 gammas to about 12,000 gammas was obtained. Both being short wave length anomalies they may be local anomalies reflecting surface or near surface geology. Excepting those two intense anomalies, the rest of the anomalies in this profile fluctuates above an approximate level of 11,400 gammas which may approximately be taken as the regional. One of the strong anomalous zones, mentioned above, is near Dharwar and the other one near Bellary. The relief of the anomaly near Dharwar is about 2,200 gammas and that over the other anomalous zone is about +1000 to -2000 gammas. A third anomalous zone of an amplitude smaller than the other two occurs near Koppal between Gadag and Bellary. Its relief varies from -800 to +300 gammas and it is characterised by longer wave length. This Dharwar anomaly must have been due to the existence of some magnetite-rich iron ore. The magnetic anomaly obtained near Bellary may be due to the presence of basic intrusive rocks (dolerite dykes). Both positive and negative anomalies obtained.

over the dyke rocks(assumed source of anomalies) indicate that they are most probably reversely magnetised. Magnetic anomalies ranging between -800 and +300 gammas observed near Koppal are possibly due to magnetically rich iron ores in this area or due to some highly magnetic basic rocks beneath the peninsular gneisses. Fourth anomalous zone in this traverse is near Molem about 60 km east of Goa. Magnetic anomalies varying in relief from -500 to +200 gammas have been obtained over the schistose formations near Molem. Since the schistose rocks are usually magnetically weak, these higher anomalies might have been the effect of some highly magnetised rocks underlying the schists. Excepting the above four anomalous zones, the remaining anomalies are almost uniform with minor fluctuations in values superposed on the normal field,which are possibly due to the smaller variations in the thickness of the near surface rocks. Anomalies ranging from -100 to +100 gammas have been obtained over the granites along this profile and the susceptibility values of the granites are within the range of 1 to 1.1×10^{-3}. The magnetic anomalies thus observed may be accounted for by surface and near surface rocks.

Quantitative analysis of the gravity profiles:

The gravity anomalies along the four profiles were computed taking into account the density contrast between the different outcropping geologic bodies across which gravity values were observed, using a dot chart for calculation of the gravitational

Fig. 12

GRAVITY PROFILE AA' WITH INTERPRETED GEOLOGIC SECTION

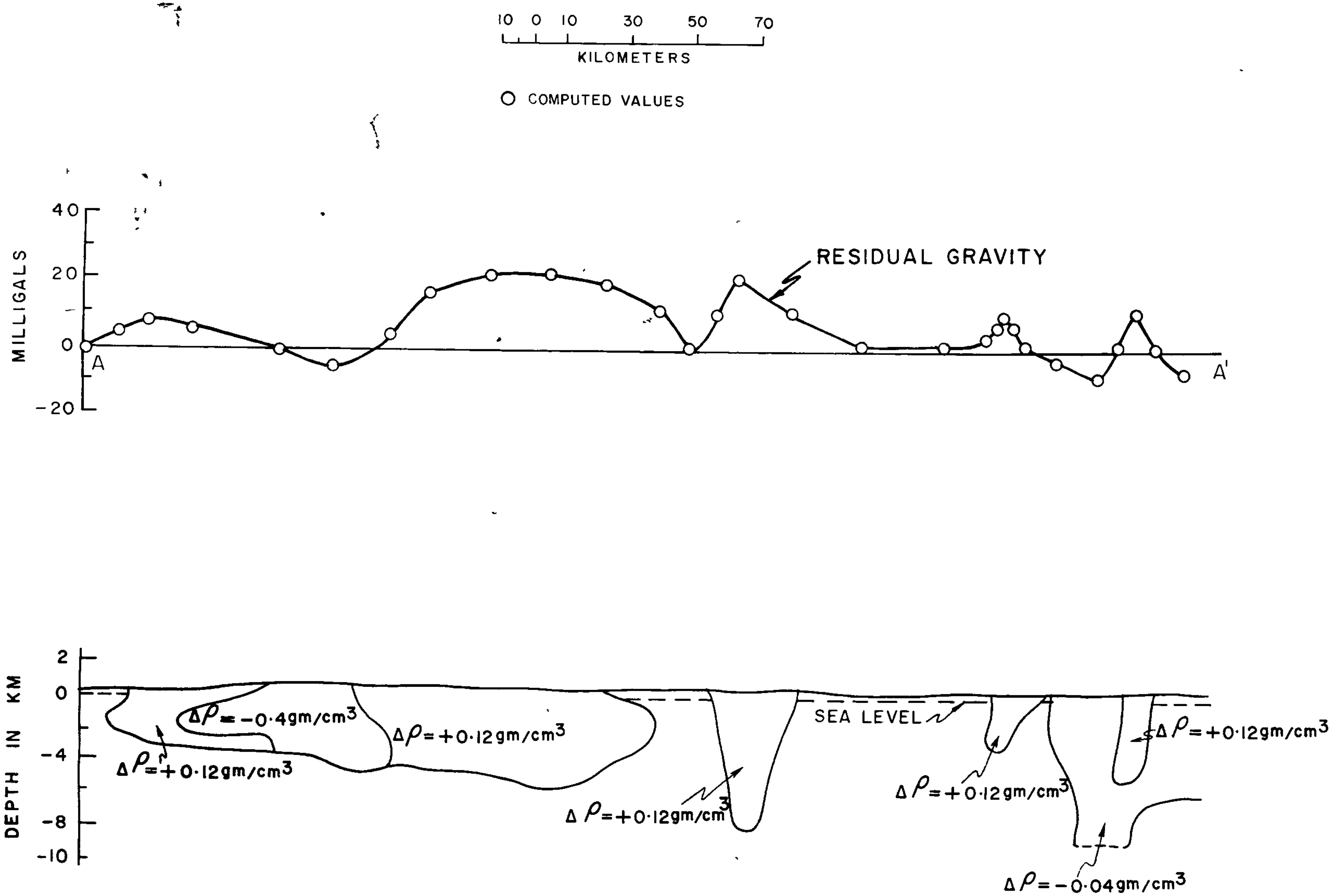


Fig - 12

attraction of two dimensional bodies (see Millet, 1967). The density values of the rock samples used in the computation of gravity anomalies along each profile are mostly those samples which were collected along the particular profile. Fig. 12 shows the gravity profile computed and observed from Panaji to Bellary. From the crustal model (Fig. 12) it may be seen that the schistose formations vary in thickness from about 4 to 8 km and the thickness of the granite varies from 4 to 9 km. The shape of the granite is also varying from a dome like to T-shaped batholith (near Bellary). Bott and Smithson (1966) concluded from gravity analyses that granitic plutons extend to depths of only about 10 km. The shape of this granite body is somewhat similar to that of the intrusive rapakivi granite of South Greenland (Bridgewater et al., 1974). Of course, the rapakivi granite massifs are characterised by lack of magnetic anomalies while this granite is somewhat magnetic with 'K' value approximately at about $1x10^{-3}$ cgs. units. This is possibly due to the development of mafic front in the Closepet granite (Divakar Rao, et al., 1969). The evidence collected from the crustal model of Dharwar schists conforms with the earlier view that the schist belongs to a single geosynclinal environment instead of representing isolated patches (Pichamuthu, 1974).

Profile BB' - This profile runs from Bhatkal to Pavagada approximately along the 14th parallel across the plateau. From

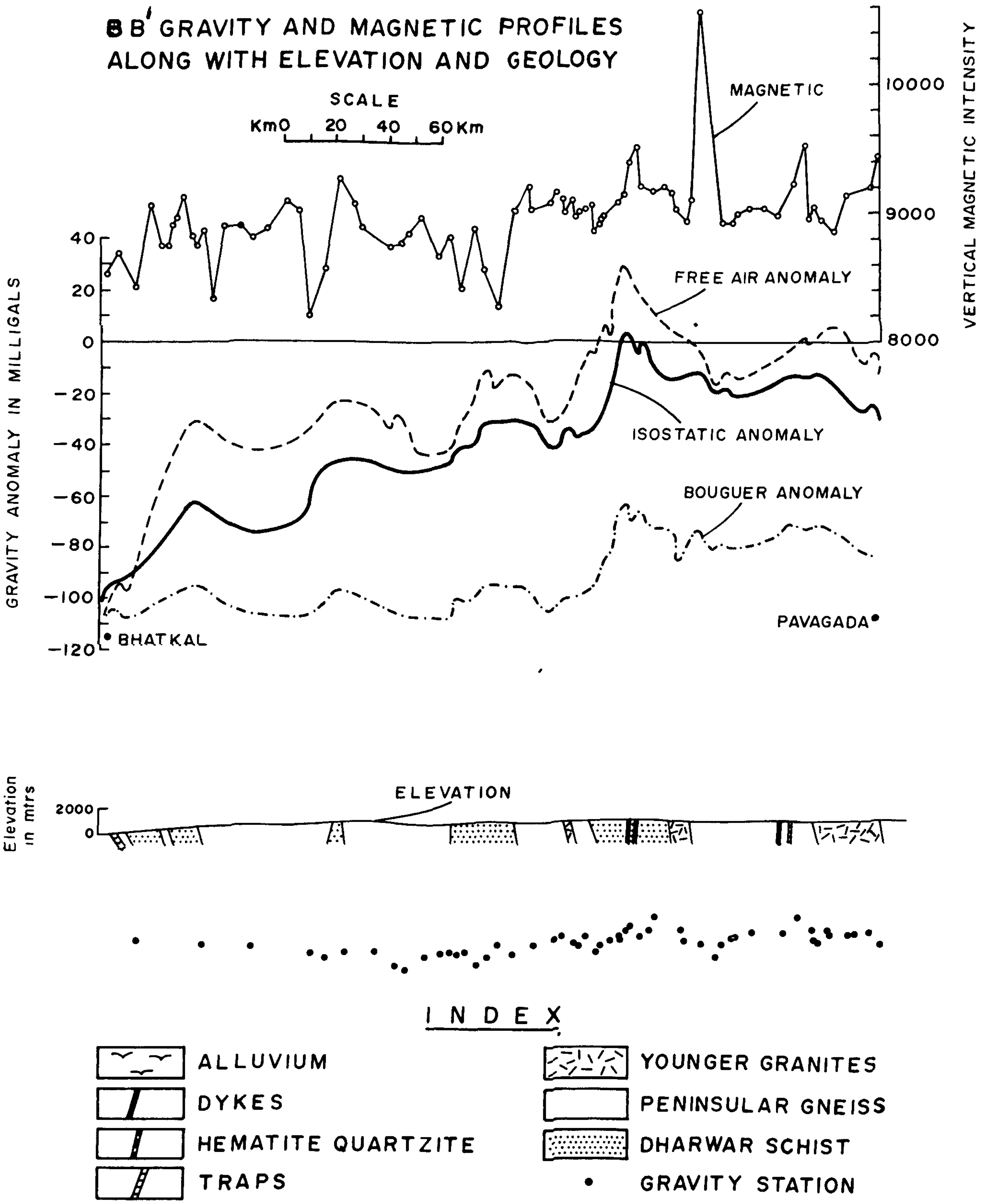

B B' GRAVITY AND MAGNETIC PROFILES
ALONG WITH ELEVATION AND GEOLOGY
SCALE
Km0 20 40 60Km
MAGNETIC
FREE AIR ANOMALY
ISOSTATIC ANOMALY
BOUGUER ANOMALY
GRAVITY ANOMALY IN MILLIGALS
40
20
0
-20
-40
-60
-80
-100
-120
VERTICAL MAGNETIC INTENSITY ANOMALY IN GAMMAS
10000
9000
8000
BHATKAL
PAVAGADA
Elevation in mtrs
2000
0
ELEVATION
INDEX
ALLUVIUM
DYKES
HEMATITE QUARTZITE
TRAPS
YOUNGER GRANITES
PENINSULAR GNEISS
DHARWAR SCHIST
GRAVITY STATION

Fig. 9

W-E it passes across the Dharwar schists, gneisses, dyke-rocks, traps, hematite quartzite, and granites including Colsepet granite. Fig. 9 shows the gravity anomalies (FA, BA and IA with T=30 km), elevation profile and the geology from Bhatkal to Pavagada. Topographic relief is almost constant at about 500 meters level from a point at a distance of roughly 20 kms away from Bhatkal. All the three curves, viz., FA, BA and IA are similar in their general characteristics except that the magnitude of their absolute values differ. In view of the short wave-length of the anomalies and as there are no major changes in topography, in all probability the anomalies are local and influenced by the surface geology. The densities of the rocks collected along this profile also suggest that the gravity anomalies are caused by variations in the lithology of the surface and near surface rocks.

Vertical magnetic intensity values vary in range from about 8,100 gammas to 10,500 gammas, the relief observed over these Precambrian formations being 2,400 gammas. Above an approximately 8,800 gammas magnetic level, the anomaly fluctuates over the geologic formations depending on the intensity of the field. Magnetic anomalies ranging from +200 gammas to -500 gammas with respect to normal field have been obtained over the Dharwars. Variations in anomalies from -600 to +1600 gammas have been obtained over the peninsular gneisses and anomalies ranging from -200 to +600 gammas have been obtained over the granites. Haematite-quartzite bands and trap rocks have yielded magnetic

BB' - GRAVITY PROFILE WITH INTERPRETED GEOLOGIC SECTION

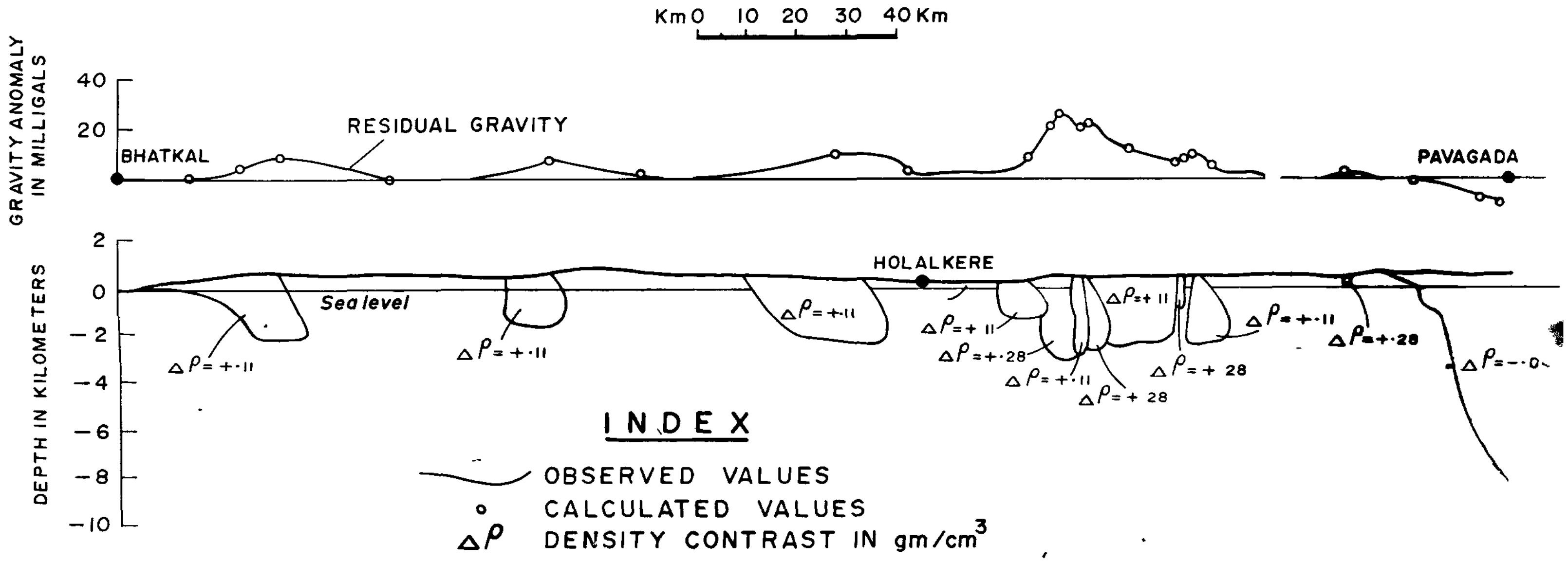


Fig. 13

values of the order of +600 gammas. Laboratory measurements show that the suceptibility values of the gneisses and schists are very low. The high magnetic anomalies observed over the gneisses and schists might have been due to the remanent magnetic field since the short wave length of the anomalies suggest that they are local and related to surface or near surface effects. A relatively great quantity of magnetic rocks in ancient shields is probably explained by regional metamorphism and ultra-metamorphism that increased the magnetite and titano-magnetite content of the rocks and hence, their high magnetic susceptibility (see Dortamn et al., 1964).

Fig. 13 shows the gravity anomaly and the interpreted crustal structure. The thickness of the schistose rocks varies from 1.5 to 4 km and the thickness of the trap rocks vary from 0.5 to 4 km, and the maximum thickness of the granite near Pavagada is found to be about 8.5 km. The outline of the section of Closepet granite near Pavagada is partially T-shaped. The variations in the magnetic anomalies over the Dharwar schists is partly due to the varying thickness of these formations. Magnetic anomalies over the Closepet granite may be due to the inclusion of some banded magnetite quartzites as the Closepet granite was reported to contain inclusions of many of the older rock formations like hornblende-granulites, hypersthene-granulites, banded magnetite-quartzites, and garnetiferous quartzites (Rama Rao, 1962). Magnetic anomaly obtained over the trap rocks are small and the measured susceptibility values of these

MANGALORE-BETMANGALA GRAVITY AND MAGNITIC PROFILES ALONG WITH ELEVATION & GEOLOGY

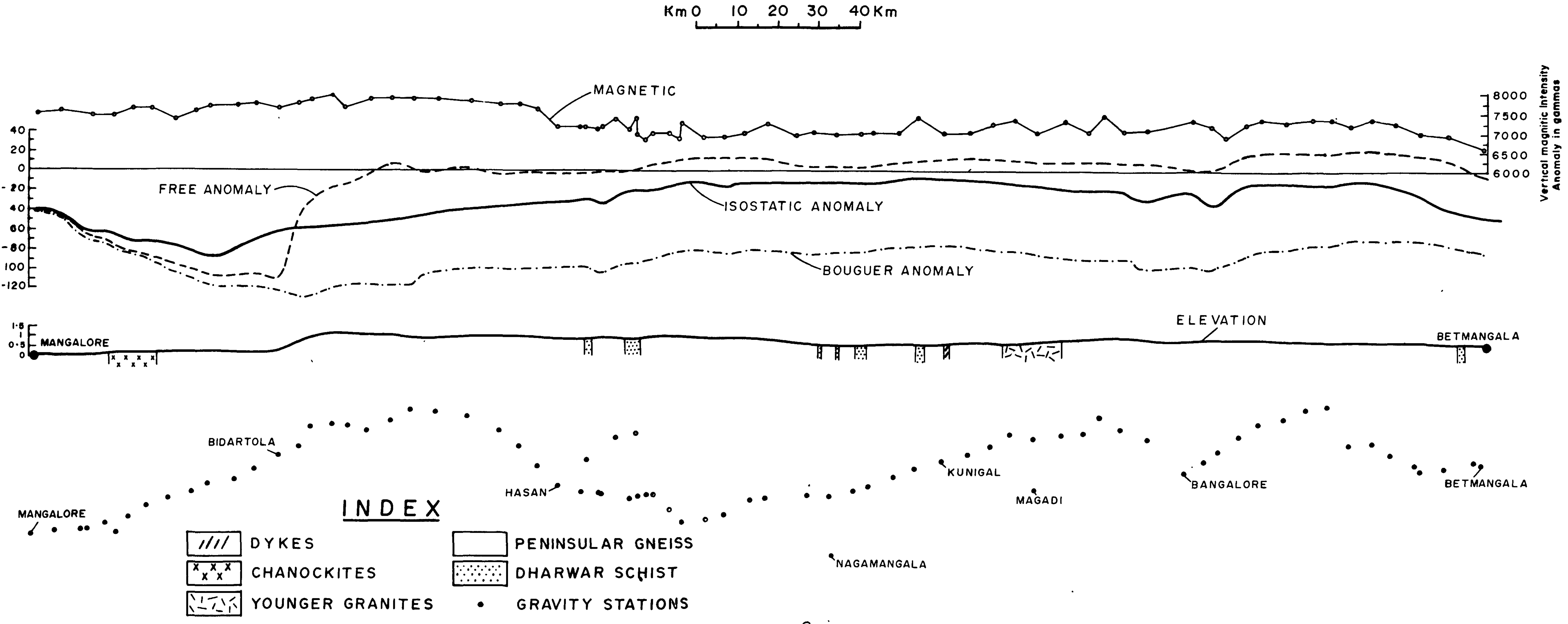


Fig -10

Fig. 10

rocks in this area are also small (Naqvi, 1973). Low magnetic values observed over the hematite quartzite is possibly due to weakly magnetic hematite quartiste.

Profile CC': Fig. 10 shows gravity (FA, BA) and IA (T=30 km) curves, elevation profile and magnetic curve along with the surface geology from Mangalore to Betmangala. The topographic profile indicates that the elevation between Mangalore and Bidartola is almost constant. There is a certain rise in elevation of about 0.6 km east of Bidartola and the rest of the profile shows little departure from this elevation. Free-air Anomaly (F.A.) follows closely the topography by the rapid increase of the anomaly with the elevation, while the Bouguer and Isostatic anomalies do not show any such marked changes in value. Excepting this difference in the anomaly pattern (FA, BA and IA), the rest of the portions of the anomaly curves have identical trends. The BA and IA curves are practically flat with minor variations in gravity anomalies. The alternate bands of schistose formations with small widths are not reflected well in the grawity curves probably due to their small widths. The charnockites in the western portion of the profile did not indicate any anomaly, possibly due to lack of any density contrast between the charnockites and the gneisses in this region. Further no gravity anomaly has been observed over the charnockites possibly due to fact that the charnockites show gradational changes with migmatites and in the contact zone retregression from the granulitic facies may lead to the charnockitisation of gneisses (Swaminath et al., 1974). All the three gravity curves (FA, BA and IA), which show a broad rise over the Peninsular gneisses in the eastern side of the section, are neither significantly related to topography nor geology. The regional value is increasing eastwards. This could possibly be due to some deep-seated effects and may also be due to the heterogeneity in composition of the Peninsular gneisses at depth (Divakar Rao et al., 1974).

Vertical intensity magnetic anomalies vary from 6,600 gammas to 7,500 gammas over the different geologic formations along this profile. Magnetic anomaly varies from 6,600 gammas to 7,500 gammas over the peninsular gneisses. If 7,000 gamma is taken as the approximate regional value, the relief in anomaly is about -400 gammas to +800 gammas. The wave length of the anomaly indicates that the source of anomaly is not shallow. There are two possibilities, viz., that the anomaly is caused by a more magnetic sub-crustal material or that the peninsular gneisses at depth are more magnetic than at the surface. The latter possibility appears to be plausible as the gneisses are reported to be heterogeneous in composition. Further, susceptibility measurements of gneisses show a wide variation in their values ranging from 50×10^{-6} to 550×10^{-6}, which shows that there is a wide variation in their magnetisation although they are weakly magnetic. Magnetic anomalies (relief) varying from -200 to 500 gammas has been obtained over the Dharwar

MANGALORE - BETMANGALA GRAVITY PROFILE WITH INTERPRETED GEOLOGIC SECTION

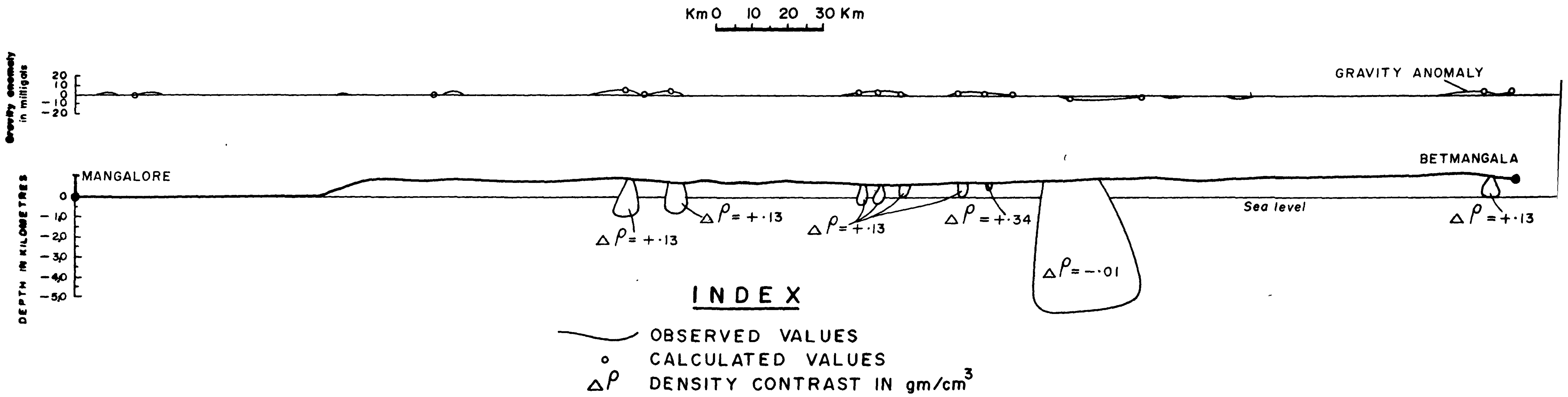


Fig-14

Fig. 14

schists. As the susceptibility values of the schistose rocks are of low order, these anamolies cannot be explained by the induced field alone. Hence the schistose rocks might be having some remanent magnetism. Magnetic anomaly of 50 gammas have been obtained over the dyke rocks. The susceptibility value of the order of $90x10^{-6}$ of the dyke rock is in conformity with the low magnetic values observed over the dyke rocks. Magnetic anomalies with a maximum relief of 400 gammas has been observed over the granites. The granites in this profile have an average susceptibility 'K' value of $2,300x10^{-6}$ (C.G.S. unit).

The gravity evidence from the analysis of this profile indicates the possibility of (1) heterogeneity of the peninsular gneisses and (2) charnockitisation of the gneisses. The magnetic data from this profile revealed that the schists, dyke rocks and peninsular gneisses are feebly magnetic. Further the gneissic rocks exhibit wide variation in their magnetism. Although it cannot be conclusively stated, it might be possible that the gneisses at depth are transformed by some physico-chemical changes into rocks with altered physical properties. Such a possibility has been also indicated by earlier geological studies (Radhakrishna, 1956; Divakar Rao, 1974).

Fig. 14 shows the gravity anomaly and the inferred geologic section from Mangalore to Betmangala. The schistose formations occur in different dome-shaped patches with a maximum thickness of 2 km. The maximum thickness of the granite has been estimated

DD'-NW-SE GRAVITY PROFILES ALONG WITH
ELEVATION AND GEOLOGY, KARNATAKA REGION

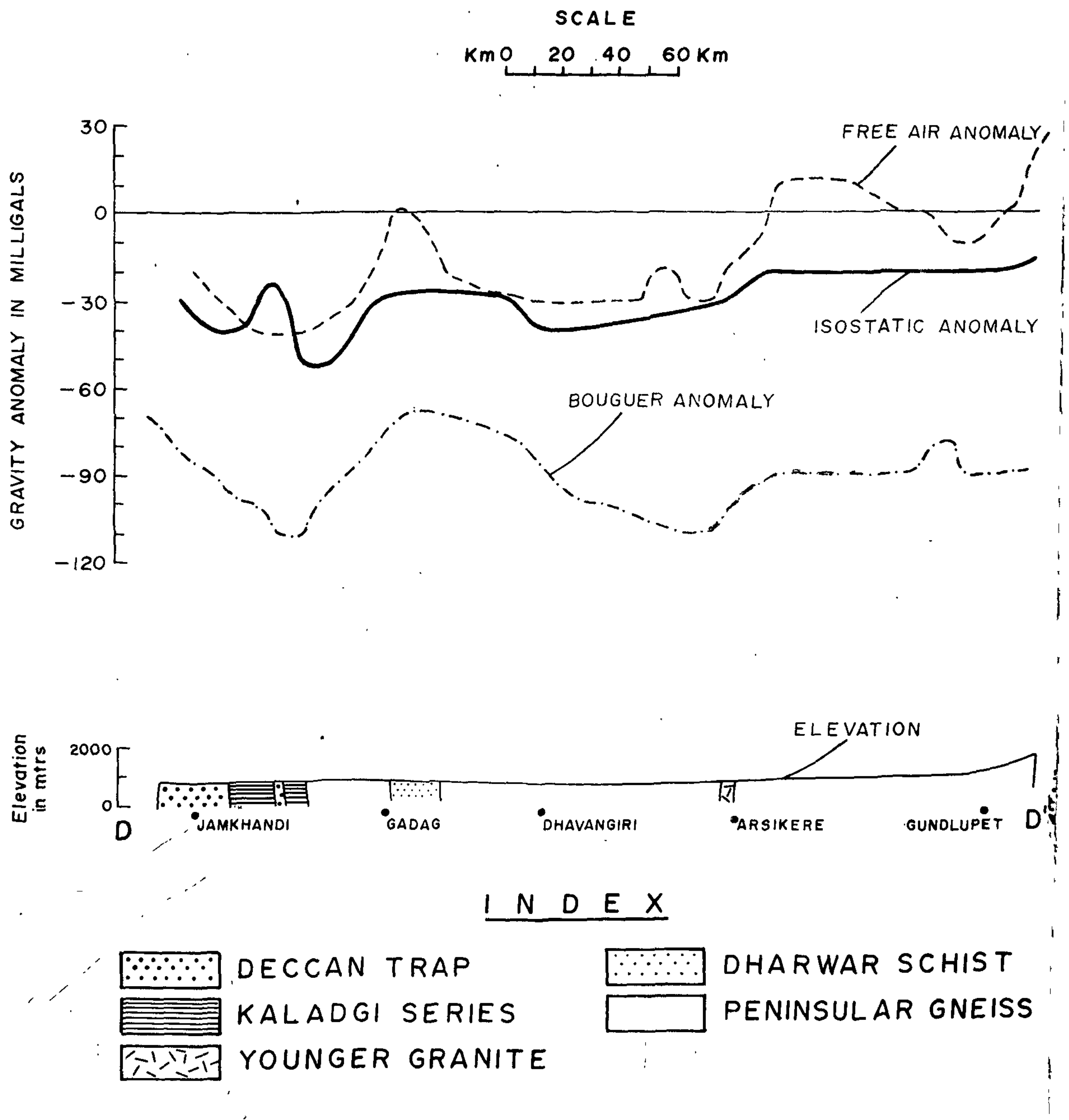


Fig - 11

Fig. 11

to about 5 km. The relative magnitude of the magnetic anomaly compared with the geologic section shows that the anomaly is not influenced comparatively by the size and shape of the structure. Magnetic anomaly of a maximum of 400 gammas, caused by the outcropping geological formation (granite) has been superposed over the regional field of the order 7,000 gammas in this profile.

Profile DD' - The profile DD' is aligned approximately in the NW-SE direction (Fig. 11). As may be seen, the elevation remains almost constant at 600 meters throughout the profile except near tho southern tip 'D', where the elevation abruptly rises upto 1,500 meters. The traverse has been taken through Mesozoic and lower tertiary rocks (Deccan trap), Kaladgi series, metavolcanics of Dharwar, Peninsular gneiss and through a small band of intrusive granite. Free-air, Bouguer and Isostatic anomaly (Airy-Heiskanen with T=30 km) profiles are mostly similar with minor variations and all of them appear to be unrelated to topography. The anomalies may have been caused by lithological changes in the rock formations of differing density values assuming that the plateau is in isostatic equilibrium. All the three gravity anomaly curves show gravity 'high' over the Dharwar schists, 'low' over the Kaladgis between Jamkhandi and Gadag. The low over the Kaladgis appearing in F.A. and B.A. curves has been resolved into one 'high' and one 'low' in the IA curve, the significance of which in terms of geology has been indicated later in this text while interpreting the profiles quantitatively.

NW-SE-GRAVITY PROFILE WITH INTERPRETED GEOLOGIC SECTION

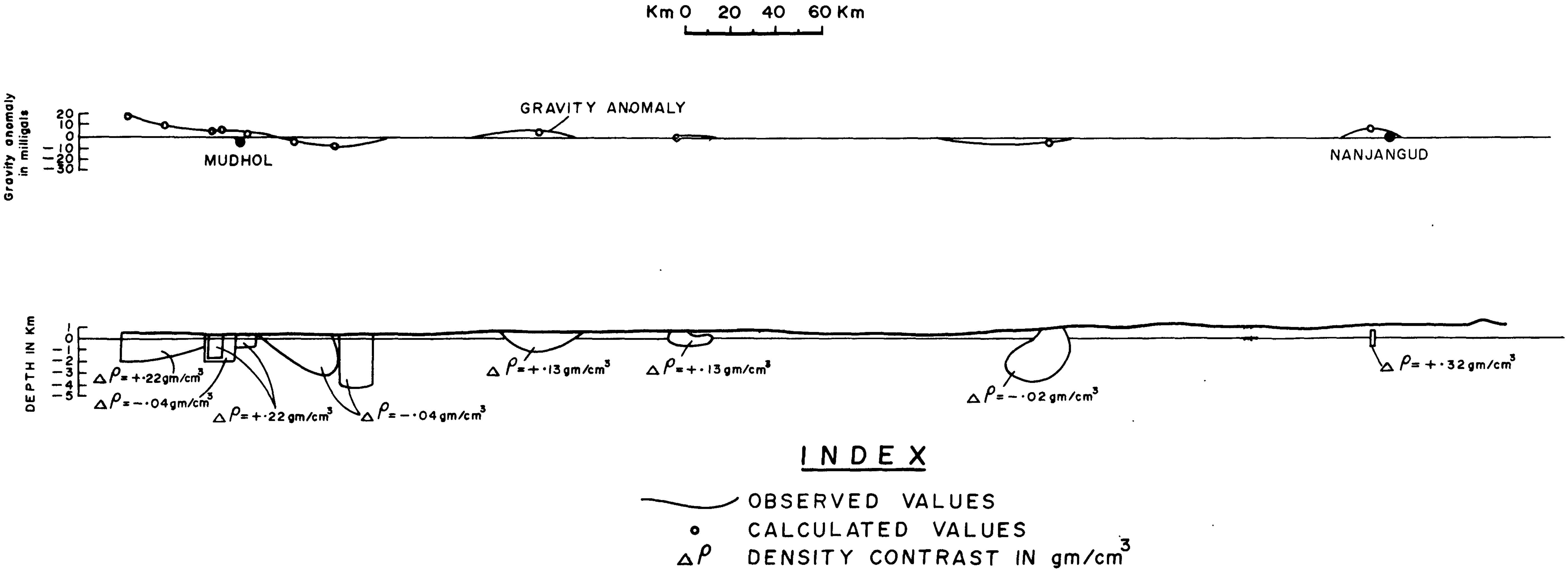


Fig-# 15.

Fig. 15

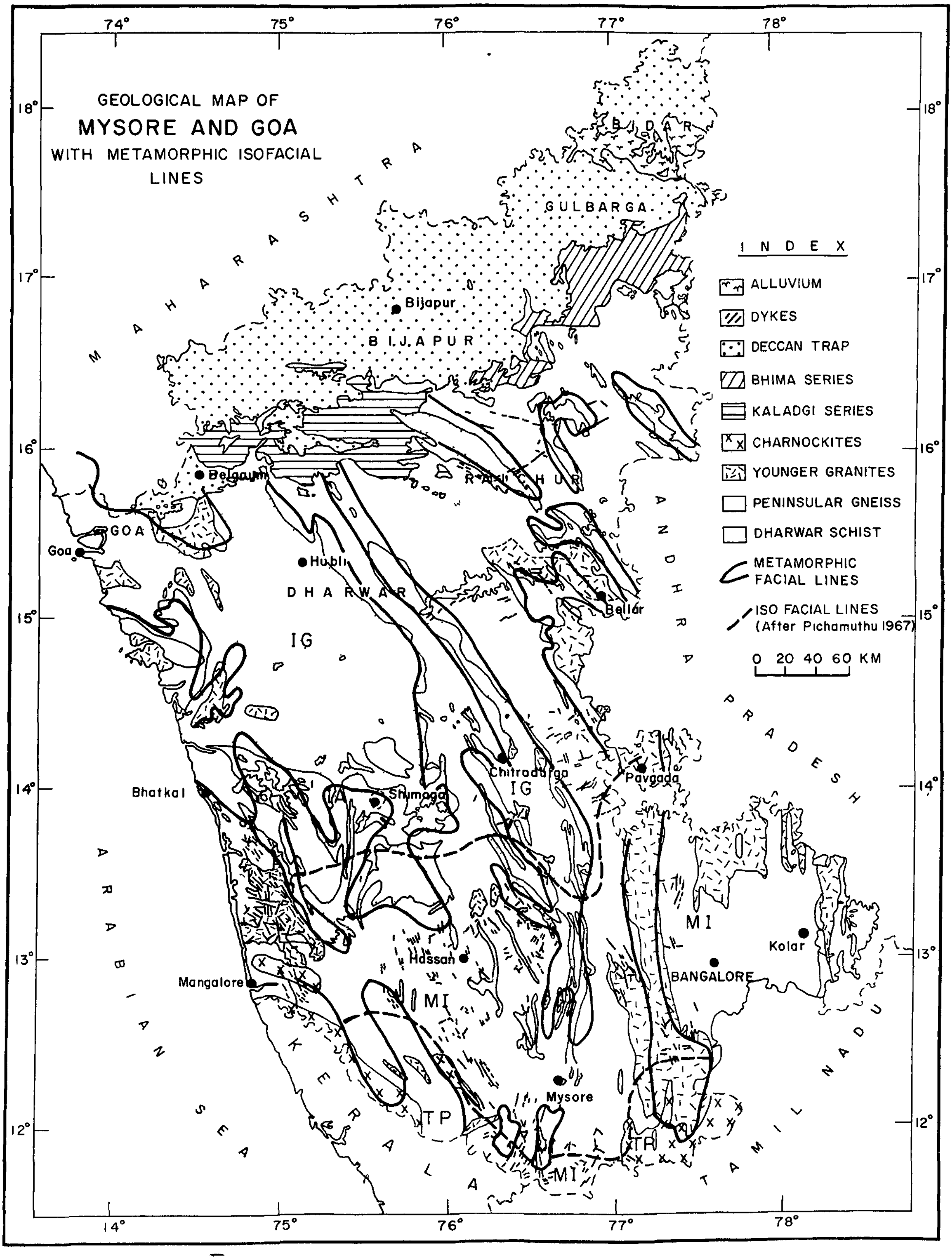


Fig · ~~15~~ 16

Fig. 16

The positive anomaly appearing in Bouguer has not been revealed in the isostatic anomaly near Gundlupet.

Fig. 15 shows the gravity (residual) profile and the interpreted geologic section along the profile DD'. The residual gravity 'high' near Mudhol has been interpreted to be due to a denser cylindrical body within the low density sediments. Further the quantitative study of this profile indicated the possible existence of a sub-surface body near Nanjangud with a width of about 2 km and a thickness of about 1.5 km having a density contrast of .32 gm/cc. It is estimated to lie at a depth of 0.5 km.

Correlation of gravity anomalies with the metamorphic rocks of Mysore

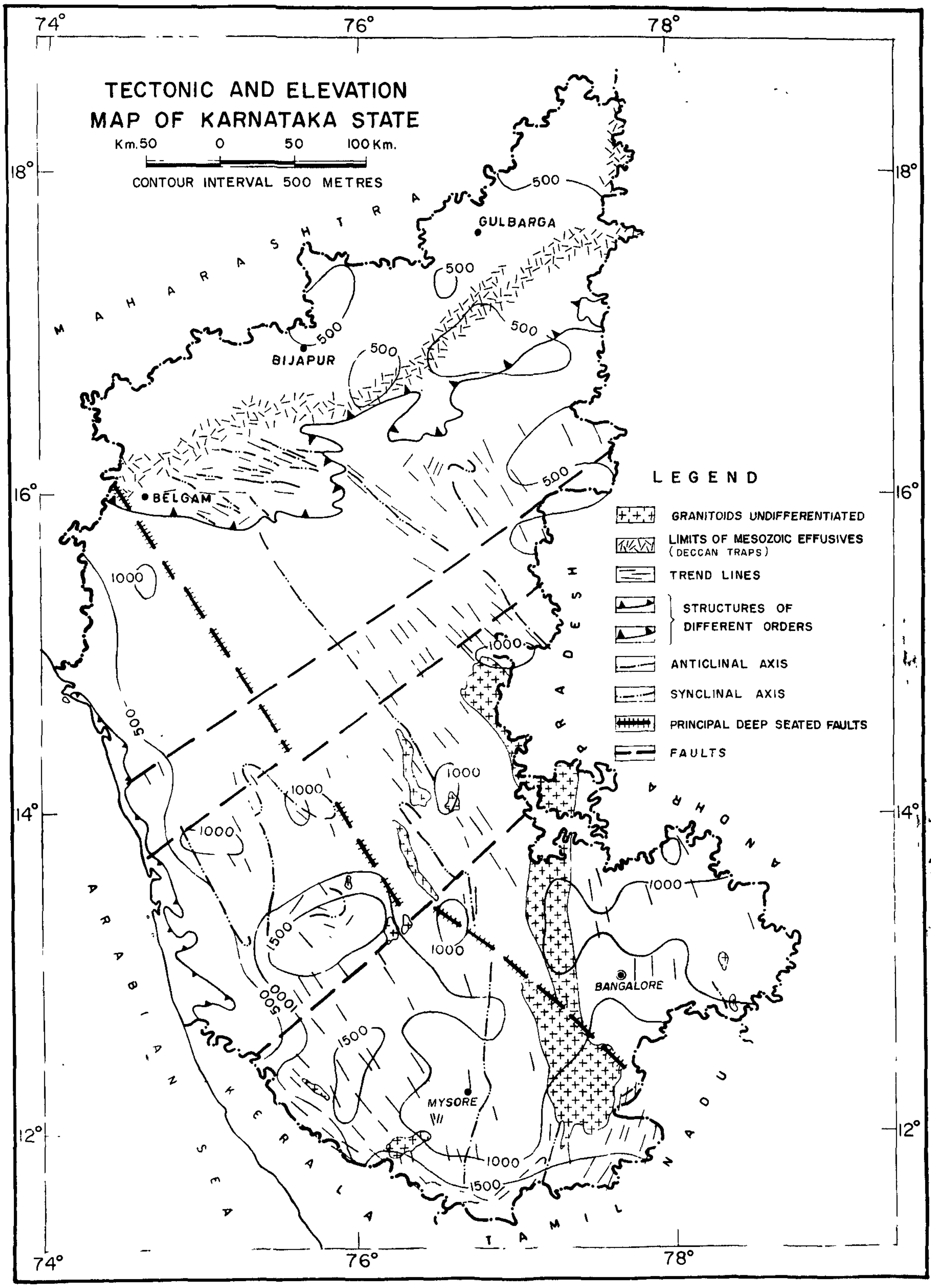
In order to have an idea of the geophysical implication in relation to metamorphism of the Archaean rocks of Mysore (Fig. 16) an attempt has been made to correlate the nature of metamorphic rocks of Mysore with Bouguer and isostatic anomaly maps of the area.

Corrleàtion with Bouguer anomaly : Bouguer anomaly of the order -70 to -100 mgals has been observed over the intermediate pressure green-schist facies zone (IG) (as defined by Murthy, 1971). Metamorphic rocks of the intermediate pressure amphibolite (IA) facies is characterised by -100 to -110 mgals. Rocks of the intermediate pressure facies - Migmatites and anatectic granites

(Mi), is characterised by -70 to -130 mgals. This zone approximately corresponds to the almandine-amphibolite facies demarcated by isogrades as defined by Pichamuthu (1967). Bouguer anomalies of the order of -70 to -100 mgals are obtained over the two pyroxene group of granulites. The various groups of metamorphic rocks in general exhibit gravity anomalies ranging from -70 mgals to -110 mgals corresponding to the intermediate pressure facies rocks. Migmatites and anatectic granites reveal at some places strong gravity anomalies (upto -130 mgals) in the region. From this it appears that metamorphism does not have a well-defined relationship with Bouguer anomaly corresponding to the progressive increase of metamorphism from north to south in the Karnataka craton. However, there appears to be a tendency for the rise of the gravity anomaly at the isograde demarcating the granulite charnockites. Qureshy (1964) also observed gravity maxima over the highly metamorphosed rocks of south India, such as charnockites and Khondalites. The reasons for the increase of the gravity anomalies from the north to the south is the general tilt of the Peninsula as postulated by Fermor (1936-40) and due to the presence of denser charnockites in the southern sector of Mysore as a result of block uplifting (Wadia, 1942).

Correlation with isostatic anomaly: To study the role of metamorphism and the physical properties of the rocks both at the surface and at depth and also because the Bouguer anomaly did not indicate any correlation, isostatic anomalies were used for this purpose. Although there is no correlation which can be stated unambiguously, Airy-Heiskanen anomalies (T=30 km) appear to show generally an increase of anomaly (rising towards less negative) from north to south corresponding to progressive increase of metamorphism in the area. As isostatic anomalies are gravity anomalies which are supposed to reflect local anomalies due to surface and near surface geologic formations, one of the possible reasons for increase of gravity values from north to south may be due to the tilt of the Peninsula towards northwest as mentioned earlier. Charnockites and granulites, which now occupy the southern sector of Mysore plateau have also partly contributed to the higher density values. Metamorphism has progressively decreased in intensity with time, which is a charecteristic feature of the cratonic areas (Swaminathan, et al., 1974). Thus the correlation of the metamorphic terrain map along with the gravity maps (Bouguer and isostatic) indicated that the gravity anomalies are perhaps more dependent on the physical properties of the constituents of metamorphic rocks than the phenomenon of metamorphism. The increase in anomaly values as one proceeds from north to south may therefore, be due to the uplift of the deeper and denser high grade charnockites during the course of tectonic evolution of the peninsula.

In order to understand the relation between geophysical observation and tectonics of the Archaean of rocks of Mysore, a



TECTONICS ARE TAKEN FROM GC PUBLISHED MAP 1968

Fig-17 in

Fig. 17

correlation was attempted, keeping in view of the limitations of the isostatic studies in relation to tectonics (see Artemyev and Artyushkov, 1967). According to their observation it is not always possible to compare and contrast isostatic and tectonic forces. Fig. 17 shows the tectonic map superposed over the regional elevation map of Karnataka State. A gravity low approximately following the synclinal and anticlinal axes, trending roughly east-west correspond to the formations in the lower Kaladgi-Bagalkot area east of Belgaum. Excepting this there is no significant relation between isostatic anomaly map and tectonic map.

Correlation between Bouguer anomaly and tectonic setting of the plateau

As may be seen from the tectonic and regional elevation map of Karnataka (Fig.17), the general elevation of the northern part of the area is of the order of 500 meters and that of the southern part averages to 1,000 meters. The structural trends of the Dharwar, which varies from NNW-SSE to NW-SE, generally coincide with lines of Bouguer minima. The average density of these schistose rocks is more than that of the crust. Out of the many possible causes for the gravity minimum over the Dharwars, apart from the possible occurrence of granites beneath the Dharwar schists in some places, viz., general negative bias of the gravity field (Woollard, 1972), tilt of the peninsula (Fermor, 1940), dissipated 'root' of Dharwar mountains (Fermor, 1919), etc., the dissipation of root appears to be the likely phenomenon that might have caused this departure of anomaly. The gravity low is observed in the Kaladgi-Bagalkot area east of Belgaum where in the lower Kaladgi sedimentaries were deposited. It is supposed by Nautiyal (1966) that a wide graben, which towards the close of the Lower Epiproterozoic times, was compressed and gave rise to asymmetric anticlinal and synclinal folds exhibited by the formations in the Kaladgi-Bagalkot-Yadwal area. The axes of the folds trend approximately east-west indicating a north-south direction of the compressional force. The gravity low observed is also East-west trending. Further negative anomalies are characteristic of grabens (Wollard, 1969). As may be seen from the B.A. map in Fig. 5, the anomaly contours are more widely distributed in the southern part than in the northern part of the plateau where the contours are also broadly spread out. According to Nautiyal (1966),the orogenic forces were not uniform during the middle Proterozoic period which has affected the southern and northern portions of the plateau by contrasting tectonic conditions. This may perhaps be one of the reasons for the different anomaly patterns in the two portions of the region. It may be, therefore, be stated that generally, the overall tectonic picture and the Bouguer anomaly map could be correlated. Mention may be made here of a statement by Nautiyal(1966) that the term 'shield' to this area can be applied only for geological periods after the upper Proterozoic when the area became stable, except for the epeirogenic movements. This gives a supporting evidence not only for geophysical (gravity) anomalies but also gives an idea of the growth and stability of the plateau. Synclinal fold axes of the Dharwar schist belt trending NNW-SSE from Dharwar through approximately Chitaldurg, Mysore and Gundlupet follow the general trend of the gravity lows. This negative anomaly, parallelling the tends of the schistose rocks, which are denser than the crustal rocks, appears to indicate subsurface anomaly, possibly of the basement. The lower proterozoic rocks granitised due to deep burial, but because their upper contacts with the underlying gneisses and granites remained sharp (Nautiyal, 1966) the gravity lows were indicated over the synclinal axial planes. Of the three major parallel faults striking SW-NE, the southernmost, and the one north of it, follow some significant pattern with gravity 'lows' but the northernmost fault did not have any such relationship with gravity. These faults being graben-like (Srinivasan and Srinivas, 1974), disjointed gravity 'lows' were noticed over these faults. Somewhat lesser negative or the gravity 'high' south-west of Bellary on the fault line may be either due to the influence of some basic intrusives or the presence of ultramafic rocks in the proximity of this gravity anomaly. The principal deep seated regional (NW-SE) fault as indicated on the tectonic map, does not appear to bear any relationship with the Bouguer anomaly. The possible explanation for this is either the gravity anomaly has not reflected the deep seated fault in this region or it is non-existant and the latter is more likely (cf. ONGC and ESCAP map, 1975).

Laboratory determinations of density and susceptibility of the rock samples

To explain the field observations, laboratory determinations of the physical parameters such as density and susceptibility of the rocks collected in the field were made. About 40 rock samples were collected during the field work along the three east-west profiles AA', BB' and CC' and the measured densities of these rocks were utilized in making the quantitative interpretation of the gravity data.

Density measurements

The rock samples collected for density measurements include granites, gneisses, schists, pegmatites, granodiorite and dyke rocks. The density measurements were made with Walker's steel yard. Table II shows the density values of the rock types measured.

Susceptibility 'K' measurements

Susceptibility 'K' values of the different rock samples collected in the field such as gneisses, schist rocks, etc., were measured with Mooney's susceptibility bridge. Table III shows the susceptibility values of the rock samples measured. The susceptibility values of gneisses generally fall within the range of 50×10^{-6} (C.G.S. units) to about 600×10^{-6}, with the exception of two samples which show abnormally high 'K' values ranging from 1160×10^{-6} and 2360×10^{-6}. As the magnetism of a rock

TABLE II: Density values of rock samples

No.	Rock type	No.of samples	Density values gm/cc	
			Range	Average
1	Peninsular gneiss	17	2.5 - 2.8	2.67
2	Schist	4	2.59 - 2.88	2.7
3	Granite	10	2.64 - 2.69	2.66
4	Dyke	4	2.98 - 3.14	2.99

TABLE III: Susceptibility 'K' values of the rock samples.

No.	Range type	No. of samples	Range of $K\times10^{-6}$
1	Peninsular gneiss	16	50 - 2360
2	Granites	7	50 - 2700
3	Schist	5	50 - 100
4	Ganodiorite	3	50 - 2700
5	Pegmatite	4	100 - 860
6	Dyke	4	90 - 3200
7	Magnetite	1	810

depends, apart from other factors such as shape and size of the magnetic grains, on the magnetite content, the variations noticed in the 'K' values of the rock samples are probably due to variations in the ferromagnetic mineral (magnetite) content in the rock. However, it may be mentioned that the 'K' values exhibited by most of the rocks are in the lower side with occasional higher values.

Chapter IV

CORRELATION OF GEOLOGICAL AND GEOPHYSICAL DATA

Introduction

The study of geology of the Karnataka region and some geophysical surveys carried out on the plateau, together with the laboratory measurements of some physical parameters such as density and susceptibility values of rock samples, collected in the field, and their petrographic characters, as presented in the previous chapters, provide useful information for interpretation. For a realistic approach to correlation of the geophysical and geological data in respect of this area each aspect of information was made use of.

Although there is a vast amount of information available on the surface geology of the Karnataka area, the available geophysical data is very meagre. The amount of geochemical data regarding some of the Precambrian rocks of Karnataka is coming up well in recent years. The inferences regarding the nature and origin of the rocks of the region from these studies individually or combined with the results of investigations, presently carried out, may explain some of the problems of the complex geology of Mysore. Integrated studies carried out in this region earlier are mainly in the form of 'band' studies, viz., geological, geophysical and geochemical studies along the 14th parallel.

From the palaeomagnetic measurements of some dyke rocks along the 14th parallel between Pavagada and Chitaldurg, it was inferred that this igneous activity could be of Precambrian age and a close similarity between Closepet and Chitaldurg granites was observed on the basis of geochemical studies (Qureshy et al., 1967). Naqvi (1973) indicated from an analysis of the integrated geophysical and geological studies in and around Chitaldurg schist belt that the gravity studies agree well with the structure of the belt and that the synclinal portions preserve thicker columns of rocks than the anticlinal ones. The total magnetic intensity picture obtained from the areal surveys carried out in 1967, over Chitaldurg schist belt indicated absence of any resolution of the lithological units (Naqvi 1973). Results of aeromagnetic surveys conducted over parts of Dharwar schist belt, (western side of Karnataka covering some schistose formations) by NGRI (Achyuta Rao 1974), indicated that, generally, major magnetic anomalies are found to coincide with schistose formations (greenstone horizons) while the peninsular gneisses present a featureless magnetic picture. Further the magnetic anomalies over the Kudremukh iron formation situated in northeast of Mangalore are ascribed to large magnetite-quartzite bodies having a great depth extent. The magnetic picture with series of magnetic 'lows' aligned in an east-west direction on the north of Gangamula (northeast of Mangalore) indicated the possibility of a fault. These results further confirmed the faulted nature of the west coast. Similar results are obtained by the author from gravity data on profile AA' (Fig. 8). Magnetic picture on the west coast also show that the anomaly is associated with the shelf edge.

The results of geophysical studies over the Deccan traps which form the northern part of the Karnataka region and beyond was studied in detail by Kailasam et al. (1972, 1976), Guha et al. (1974) and Krishna Brahmam (1975). The thickness of the trap rocks was found to be about 1.5 km from the above investigation which is almost the same as that determined by the author (Fig. 15).

Heat flow measurements in Karnataka

Terrestrial heat flow studies were being carried out by NGRI (Verma et al., 1969) since 1962 and Kolar Gold Field in Karnataka region is one of the areas where such measurements have been carried out. The results showed that the southern shield is characterised by low values of the order of 0.7 mcal/cm sec. In the region of Kolar Gold Field the low value of heat flow is associated with negative Bouguer anomaly of the order of -80 to -90mgals. Glikson (1976) interpreted the low heat flow values with the greenstone belts of western Australia in terms of a transition with depth into granites and/or granulites. The same analogy could be applied to the Precambrian rocks of Karnataka to explain the low heat flow values over the Kolar schists of Karnataka as the composition of outcropping Kolar schist and granulites do not differ much at depth (Divakar Rao et al., 1976). The above results provide also some explanation to the negative gravity anomalies over the schists.

Chapter V

INTERPRETATION OF RESULTS AND RELATED DISSUSSION

An attempt has been made to interpret here the results obtained from different sources of information collected in course of the present work.

Free air anomalies generally reflect the topography in this region.

The Bouguer gravity anomaly map shows that the Karnataka area is characterised by negative anomalies, which is normal on a continental crust. However, the strong negative gravity anomalies over the denser Precambrian rocks of the Karnataka craton shows that the anomalies can possibly be attributed partly to a deeper source. The magnitude and gradients of the Bouguer anomalies, which are different in the northern and southern portion of the region, cannot be explained by topographic variations or from the surface geology. The gravity 'lows' of the order of -70 to -80 mgal obtained over the Deccan Traps, whose thickness is about 2.0 km, cannot be attributed to trap rocks. The negative anomalies obtained may in all probability be due to deeper crustal masses or to depth variations at the crust-mantle boundary. Negative gravity anomalies need not necessarily be on account of mass deficiency of the upper crust (see Muller, 1970) and in this case their cause may be in all in probability be sought beneath traps and within the crystalline basement.

The prevalent negative Bouguer anomalies over the comparatively denser Archaean rocks, such as Dharwar schists and charnockites of this area, suggests that it is comprised of two effects, viz., deep-seated (regional) and local or surficial.

Isostatic anomalies are also, in general, negative in this region, different and lesser in their magnitude than those of Bouguer anomalies. The gravity lows observed over the schistose formations may be due to granites underlying the schists. Quantitative estimate of the possible causative bodies is attempted from gravity data. In profile AA' between Goa and Bellary, intense magnetic anomalies were obtained over the iron ores of Dharwar and Dolerite dykes between Hospet and Bellary. Since the schist rocks are weakly magnetic, the magnetic anomalies obtained over them can be attributed to the surrounding effects or underlying magnetite rich rocks. The variation in the determined thickness of the schists and the granites possibly explain the differences in the gravity and magnetic anomalies over these formations. The Bellary granite is moderately magnetic with susceptibility 'K' value of $1x10^{-3}$ C.G.S. units and its magnetism is possibly due to the mafic fronts in the Clospet granite (Bellary granite).

The gravity profile BB' which runs from Bhatkal to Pavagada, approximately along the 14th parallel, was interpreted quantitatively as composed of the schist rocks and traps with varying thickness. Small susceptibility contrast in the trap rocks yield weak magnetic anomalies in this profile. Minor magnetic anomalies obtained over the hematite quartzite may be due to dominance of nonmagnetic quartz content in the rock.

Profile CC' which runs from Mangalore to Betmangla did not give any pronounced gravity anomaly over the charnockites possibly due to lack of density differentiation between the charnockites and country rocks (gneisses) in this region. The gravity values show a rise in the anomaly over the gneisses which may possibly be due to heterogeneity in the gneissic rocks at depth. Even the magnetic anomaly exhibited higher value in this profile which further indicates that the peninsular gneisses in this area are heterogeneous and more magnetic at depth. The nature of the magnetic anomalies over the gneisses may suggest that the magnetism was acquired by the peninsular gneisses under different physico-chemical conditions.

The results of analyses of different gravity and magnetic profiles indicate the possible charnockitisation and granitisation of the country rocks, viz., peninsular gneisses, with changing physical characteristics as a result of variations of pressure and temperature conditions at depth, and the densities and susceptibilities of these three formations overlap each other.

The profile DD' indicates that the gravity anomalies, viz., Free-air, Bouguer and Airy-Heiskanen (T=30 km) are in all probability due to the ligholological changes within the rock formations. The inferred geologic section from gravity anomalies indicates that the maximum thickness of the Deccan traps is 2.5 km and that of Kaladgis is 5 km. The schist rocks vary in thickness from 1 to 1.5 km and the maximum thickness of granite is 4 km. The gravity data, near Nanjangud further indicate possible occurrence of a geologic body at a depth of about 0.5 km with a width of 2 km and a thickness of about 1.5 km.

A comparison of the Bouguer anomaly map of the region with the metamorphic terrian map of the same shows no noticeable correlation. However, a rise in gravity values (gravity maxima) approximately coincides with the isograd demarcating the high grade Charnockites as observed by the author (Aravamadhu et al., 1970) and also by Qureshy (1964). Correlation with Airy-Heiskanen (T=30 km) anomalies clarified the above observation in that there is an increase of isostatic anomalies towards positive values from north to south in the plateau. The regional background magnetic anomaly varies from 11,400 gammas to 7,000 gammas from the magnetic profiles AA' to CC'. It indicates that the depth to the basement producing the magnetic anomaly increases as one proceeds from north to south and the magnetic anomaly, produced by the high grade granulites and charnockites, predominate at the surface. Thus the gravity and magnetic anomalies give a broad and general relationship with the metamorphic rocks.

There is practically no significant correlation between the isostatic anomalies and the tectonics of the region while the Bouguer anomalies show a broad correlation with the latter. Certain geological postulates such as the tilting of the peninsula and the possible existence of the grabens in some areas in Karnataka may be correlated with the Bouguer anomaly. The possible presence or absence of the major faults in the area are indicated. Both the density and magnetic susceptibility 'K' values of the rocks collected in this region supported the field observations leading to some logical conclusions.

Last but not the least important is the petrographic study of the rocks which is necessary for the physical concept and bearing on the geophysical anomalies. The presence of amphiboles, pyroxenes as a result of high grade metamorphism in some of the rocks of southern parts of the Karnataka suggests the possible causes for relatively higher magnetic anomalies over them. The association of quartz, chlorite, phlogopite, in Dharwar limestones and in metamorphosed limestone, garnet, commingtonite, rhodonite suggests the reasons for their higher density and some times magnetism exhibited by them.

Chapter VI

SUMMARY AND CONCLUSIONS

1. According to the views of earlier workers, the Mysore plateau is considered as an integral southern part of the Indian shield made up largely of Archaean gneissose and schistose rocks with a variety of associated intrusive rocks. The grade of metamorphism of the Dharwar schistose rocks increases southwards in the Karnataka region. Adjoining and surrounding these rocks are gneisses, called Peninsular gneiss and granites, which occupy a large part of the area. The other rock formations in this region are banded ferruginous quartzites, metabasalts and patches of ultramafics, etc. Prevalent types of dyke rocks appearing in this area are of epidiorite, dolerite, quartz-dolerite and olivine-dolerite. It is believed that some of the younger granites like the Closepet granites were derived from the country rock (Peninsular gneiss) by palingenesis and metasomatism.

2. Dharwar Iron-ore bearing region of Mysore Province forms one of important tectonic subdivisions of Peninsular India. The Iron-ore Province occur as sub-parallel linear belts within the peninsular gneisses and granites. The strike of these belts varies from NNW-SSE to NNE-SSW. The dominant structural elements

in these belts are the northward plunging isoclinal synforms whose axes are steeply over-turned to the east or west. In general, the N-S, NNW-SSE and NNE-SSW axes of Dharwar folding pass into or are parallel to the northerly trending cross-fold axes within the other tectonic provinces. The Closepet granite forms a N-S trending linear belt between the Chitaldurg schist belt in the west and the detached Kolar belt in the east. Deformation and orogenic uplift of the Dharwar geosyncline about a N-S axial trend by forces dominantly from east and west not only resulted in several N-S trending Dharwar fold mountains, but it has also cross-folded the rocks occurring in other belts on the north and south of the area.

3. Gravity data collected by N.G.R.I. and other agencies such as Survey of India, O.N.G.C., Hawaii Institute, were standardised to a common datum and the standardised data has been utilised in the preparation of Free-Air, Bouguer and isostatic (Airy-Heiskanen) anomaly maps of the Karnataka area. Gravity and also magnetic data were collected from the area along three profiles taken from west to east of the area: (1) Goa (Panaji) to Bellary, (2) Bhatkal to Pavagada and (3) Mangalore to Betmangala. Density and susceptibility measurements of the rock samples such as gneisses, schists, granites, dyke and trap rocks, etc., collected at certain intervals along the three profiles, were made in the laboratory. Further one gravity profile, taken in NW-SE direction on the plateau, was constructed from the three gravity maps,

viz., free-air, Bouguer and isostatic anomaly maps.

4. Analysis of the free-air map showed that the plateau is approximately in a state of isostatic equilibrium. The Bouguer anomaly map of the region consists of negative anomalies which, of course, is to be expected in the continental zones. However, the indication of strong negative anomalies over the denser Precambrian rocks of Karnataka can perhaps be explained by some deeper source as neither the topography nor surface geology of the region could satisfactorily explain totally these anomalies. Various suggestions were put forward to explain the gravity 'low' over the Deccan traps whose thickness is small. The consistently negative Bouguer anomalies over the Archaean rocks such as Dharwar schists and charnockites of this area suggest that the anomalies are comprised of two effects, viz., deep-seated (regional) and local.

5. The Airy-Heisnanen anomaly with a crustal thickness 'T' equal to 30 km, also shows negative bias but the order of values is less. Isostatic anomalies, can be treated as residual anomalies which reflect the gravity effects of local geologic bodies. The gravity 'lows' over the schistose formations may be due to the pressure of some subsurface granite bodies underlying the schists.

6. Quantitative estimate of the causative geologic bodies was made from the gravity data obtained from the three East-West

and one North-West to South-East gravity profiles. Making use of the density values of the rocks measured in the laboratory, structure of the upper part of the crust was determined from the four different profiles.

7. In profile AA', it has been observed from the quantitative study that the schistose rocks vary in thickness from 4 to 9 km and the thickness of the granites vary from 4 to 6 km. The granite near Bellary is found to be in the form of a 'T' shaped batholith. Analysis of the magnetic data along the profile AA' revealed intense magnetic anomalies over the iron ores of Dharwar and dolerite dykes between Hospet and Bellary. The magnetic anomalies obtained over the schistose rocks are possibly due to some surrounding or underlying rocks rich in magnetite. Granites gave a comparatively high magnetic relief and the magnetism may be attributed to the magnetic minerals in the Closepet granite.

8. Quantitative estimates along profile BB' showed that the schistose rocks vary in thickness from 2 to 4 km; trap rocks from 0.5 to 4.0 km; and the maximum thickness of Pavagada granite is found to be about 8.5 km. The outline of the granite body is partly 'T' shaped. Analysis of the magnetic anomalies in this profile suggests that the gneisses and schists show high magnetic values. Small susceptibility contrast in the trap rocks yield weak magnetic anomalies. Minor magnetic anomalies obtained over the hematite-quartzite are attributed to weakly magnetic susceptibility of the rocks.

9. In profile CC', charnockites did not indicate significant gravity anomalies due to possible lack of density variation between the charnockites and the gneisses in this region. A rise in anomaly over the gneissis is possibly due to heterogeniety of the rocks at depth. The interpreted geologic section from the gravity data in this profile reveals that schistose rocks occur in indifferent dome-like patches with their thicknesses varying from 0.5 km to 2 km. The inferred granitic body is dome-shaped with a maximum thickness of about 6 km. Also the gneisses exhibited higher magnetic anomalies in this profile which further indicates that the peninsular gneisses in this area are heterogeneous and more magnetic at depth. Dyke rocks gave weak magnetic anomalies. Moderately intense magnetic anomalies have been observed over the granites.

10. The nature and magnitude of the magnetic anomalies and their variations over the peninsular gneisses suggest that they acquired magnetism under different physico-chemical conditions. Further it may be noticed that the inferred thickness of the schistose rocks decreases as one proceeds in the direction north to south of the region from 9 km to 2 km respectively. This suggests that the depth to the basement decreases from north to south. But since the magnetic anomaly does not indicate shallow basement, either the schistose rocks are gradually replaced by a material which is more magnetic and possibly composed of lighter substance as one proceeds from north to south or the basement

material is brought to a higher level after undergoing changes in its physical properties as a result of changes in pressure-temperature conditions at depth. This suggests that reworked material of the basement with altered physical properties must have been brought from depth as one approaches from north to south of the pleateau. This has been corroborated from the combined analysis of heat flow and gravity data at Kolar. Thus, the gravity and magnetic studies provide some understanding of the possible physical changes at depth and the crustal evolution.

11. Fourth gravity profile, DD', extending NW-SE and following more or less the structural trends of the Karnataka rocks, indicated maximum thickness of the trap rock (2.5 km). It further revealed the possible intrusion of a major dyke rock at Nanjangud. Correlation of gravity map (Bouguer anomaly map) with tectonics confirmed the existence of some major faults and grabens.

12. Laboratory measurements indicated that the schistose rocks are generally denser than gneisses and granites. The magnetic susceptibility values of gneisses, schists, and granites indicated that they are moderately high.

13. Although the Deccan Traps which are covered by several geophysical surveys relate to the traps existing on the northern side and beyond towards north of the Karnataka region, they provide valuable information on their tectonics. The gravity 'lows' over the Kaladgi in the northern part of the region was interpreted to be

due to the probable pressure of a graben.

14. The metavolcanics of Dharwars are characterised by low heat flow values and negative gravity anomaly values over the schist rocks at some places indicate the possible existence of granites at depth.

The results of geophysical studies carried out over the Precambrians of Karnataka compare well with the results observed over the Precambrian rocks of western Australia as mentioned in earlier chapters. This indicates the possibility that shield areas in the world possess identical characteristics.

BIBLIOGRAPHY

Achyuta Rao, D.,1974. Airborne magnetic surveys over certain regions in India and their evaluation in relation to geology and structure, unpublished Ph.D.thesis, Andhra University,Waltair.

Arvamadhu, P.S., Verma,B.K. and Qureshy,M.N.,1970. Isostatic studies in south India, *Bull., N.G.R.I.*, Vol.8, No.3 and 4, pp.41-50.

Artemyev, M.Ye and Artyushkov, Ye, V., 1967. Isostasy and tectonics, *Geotectonics*, No.5,pp. 286-293.

Aswathanarayana, U., 1964. Dating the Precambrians of India. *Proc. Int. Geol. Cong.*, 22nd Session.

Bhattacharjee, J.C.,1970. A geodynamical study of the Koyna earthquake region, *I.G.U.*, Vol.VII, Nos.1 and 2, pp. 17-27.

Bott, M.H.P. and Smithson, S.B., 1966. Gravity investigations of subsurface and mass distributions of granite batholiths. (Abs.), *Geol. Soc. Amer. Spec. Paper*, 87, p.14-15.

Bridgewater, D., et al., 1974. Crustal dam folding associated with igneous activity, *Tectonophysics*, 21, pp.57-77.

Coron, S., 1969. Gravity anomalies as a function of elevation: Some results in Western Europe,*A.G.U.*, Monograph,13, pp.304-312.

Crawford, A.R., 1969. Reconnaissance Rb-Sr dating of Precambrian rocks in S. Peninsular India. *Jour. Geol. Soc. Ind.*, 10,117-166.

Divakara Rao, V. et al., 1969. Major element geochemistry of parts of the Closepet granite pluton, Mysore State, India, *Bull. N.G.R.I.*, Vol.7, No. 4.

Divakara Rao, V. et al., 1974. Geochemistry and origin of the peninsular gneisses of Karnataka, India. *Journal Geol. Soc. of India*, Vol.15, No.3, pp. 270-277.

Divakara Rao, V., et al., 1975. Geochemistry of Dhamar ultramafics and the Archean mantle Lithos, 2, pp. 77-91.

Divakara Rao, V., et al., 1976. Geochemistry of subsurface hornblendic rocks from Kolar and the Archaean crustal composition of the Peninsular Shield. *Jour*. *Geol*. *Soc*. *Ind*., Vol.17, No.2, pp. 245-251.

Dortman, N.B.V.I., et al., 1964. Physical properties of rocks and minerals of the U.S.S.R., pp. 93-100. Nedra from the earth's crust and upper mantle, *A.C.U.* Monograph 10, p.421.

Fermor, L.L., 1919. *Proc*. *Ind*. *Sci*. *Cong*., p. 125.

Fermor, L.L., 1936-40. An attempt at the correlation of the ancient schistose formations of Peninsular India. *Mem*. *Geol*. *Surv*. *Ind*., Vol. 70.

Foote, R.B., 1888. The Dharwar System, the chief aquiferous rock series in south India. *Record* *Geol*. *Surv*. *Ind*., 21.

Gaposchkin, E.M. and Lambeck, K., 1971. Figure of Indian Ocean 'low' from J.G.R. 76, p. 4855: A shortened version of Smithsonian standard earth (II), Smithson Astrophysics Observ. Spec. Rep., 315 (1970).

Glikson, A.Y. and Lambert, I.B., 1973. Relations in space and time between major Precambrian Shield units: An interpretation of Western Australian data. Earth Planet Sci. Lett., 20, pp. 395-403.

Glikson, A.Y. and Lambert, I.B., 1976. Vertical zonation and petrogenesis of the early Precambrian crust in western Australia, *Tectonophysics*, 30, pp. 55-89.

Guha, S.K., et al., 1974. Case histories of spceial artificial crustal disturbances, Engineering Geology, 8, 59-77.

Hales, A.L. and Gough, D.I., 1959. Gravity anomalies and crustal structure in South Africa. Geophy. Jour. Roy. Astr. Soc. 2, pp. 324-336.

Heiland, C.A., 1946. Geophysical Exploration, Prentice Hall, Inc., N.Y., p. 305.

Holland, T.H., 1900. The charnockite series, a group of Archean hypersthenic rocks in Peninsular India. Mem. Geol. Surv. Ind., 28, p. 117-249.

Iyengar, S.V.P., 1971. Structure, stratigraphy and correlation of the Dharwar supergroup of rocks of Mysore and the adjoining areas, Semin. Precambrian Geology of the Peninsular Shield, Geol. Surv. India, Calcutta, 29-31, p. 52 (Abstract).

Kailasam, L.N., et al., 1972. Regional gravity studies of the Deccan Traps areas of peninsular India, Current Science, Vol. 41, No. 11, pp. 403-407.

Kailasam, L.N., et al., 1976. Deep electrical resistivity soundings in the Deccan Trap region, Current Science, Vol. 45, pp. 9-13.

Krishnan, M.S., 1968. Geology of India and Burma, Higginbathams, Madras, 536p.

Krishna Brahmam, N., 1975. Geophysical studies on Deccan Traps, Geophys. Res. Bull., Vol. 13, Nos. 1 and 2, pp. 89-105.

Lafer, T.R., 1965. Gravity, isostasy and crustal structure in the southern Cascade range, J.G.R., Vol.70, No.22, pp.5581-5597.

Millet, F.B. Jr., 1967. The dot chart for the calculation of gravitational and magnetic attraction of two dimensional bodies, Mining Geophysics, Soc. Explo. Geophysics, Vol.2, pp. 642-657.

Murthy, M.V.N., et al., 1971. The Eastern Ghats group, Records Geol. Sur. Ind., Vol.101, part 2, pp. 15-42.

Naqvi, S.M., et al., 1972. Petrochemistry of Dolerite dykes from Shimoga and Chitaldurg schist belts, Mysore, G.R.B., Vol.10, Nos.3,and 4, pp. 109-123.

Naqvi, S.M.,1973. Geological structure and Aeromagnetic and gravity anomalies in the central part of the Chitaldurg schist belt, Mysore, India, Geol. Soc.Amer. Bull., Vol. 84, pp. 1721-32.

Naqvi, S.M., et al., 1974. Geochemistry of post-Dharwar basic dykes and the crustal evolution of Peninsular India, Geol. Mag., 111(3), pp. 229-236.

Naqvi, S.M., 1974. The Protocontinental growth of the Indian Shield and the Antiquity of its rift valleys, Precambrian Research 1, pp. 345-398.

Narayana Swami, S., 1970. Tectonic setting and manifestation of the upper mantle in the Pre-Cambrian rocks of south India. In: H.Narain (Editor), Proc. U.M.P. Symposium, 2nd,Hyderabad, India, pp. 378-403.

Nautiyal S.P., 1966. Precambrians of Mysore Plateau, Presidential Address, Section of 'Geology and Geography', Proc. India. Sci. Cong., 53rd Session, pp. 1-14.

Pascoe, E.H., 1950. A manual of the Geology of India and Burma, Publ. Div., Government of India. pt. 1,p1-483.

Penti Karki et al., 1961. Topographic Isostatic reduction map for the world for Hayford zones 18-1, Airy-Heiskanen system, T-30 km. Publication of Isostatic Inst. International Assn., Geodesy, 35, 5.

Pichamuthu, C.S., 1967. The Precambrian of India in the Geological systems, the Precambrian, Vol.8, ed. K. Rankama, Lond., Interscience, pp. 1-96.

Pichamuthu, C.S., 1974. The Dharwar craton, Jour. Geol. Soc. India, Vol. 15, No. 4, pp. 339-346.

Qureshy, M.N., 1963. Gravity, elevation and isostasy in India, Bull. N.G.R.I.,Vol.I, No. 2, pp. 99-106.

Qureshy, M.N., 1964. Gravity anomalies as related to regional tectonics of peninsular India. Proc. 22nd International Geological Cong., India, Sec. 4, pp. 490-506.

Qureshy, M.N., et al., 1967. Geological, geochemical and geophysical studies along the 14th parallel in Mysore, Proc. Symp. on U.M.P., pp. 211-225.

Qureshy, M.N., et al., 1968. Role of granitic intrusions in reducing the density of the crust and other related problems as illustrated from a gravity study of the Cuddapah Basin, India, Proc. Royal Soc. Lond., Vol. 304, pp. 449-464.

Qureshy, M.N. and Krishnabrahmam, N., 1969. Gravity Bases established in N.G.R.I., Part I, Bull. N.G.R.I., Vol.1, No.1.

Radhakrishna, B.P., 1956. The Clospet granites of Mysore State, Bangalore, Mysore Geologist Association.

Radhakrishna, B.P., 1974. Peninsular Gneiss complex of Dharwar craton - A suggested model for its evolution. Jour.Geol. Soc. India, 15, 439-456.

Radhakrishna, B.P., 1976. Mineralization episodes in the Dharwar craton of Peninsular India. Jour. Geol. Soc. Ind., Vol.17, No.1, pp.79-88.

Ramakrishnan, M., Visvanatha, M.N. and Swaminath, J., 1976. Basement cover relationships of peninsular gneiss with high grade schists and greenstone belts of southern Karnataka. Jour. Geol. Soc. Ind., Vol. 17, No.1, pp. 97-111.

Rama Rao, B., 1940. The Archaean complex of Mysore. Mysore Geol. Dept. Bull., 17.

Rama Rao, B.,1962. A hand-book of the geology of Mysore State, southern India, Bangalore, Bangalore Printing and Publishing Co., pp.251.

Sarkar, S.N., 1968. Precambrian stratigraphy and geochronology of Peninsular India, Dhanbad Publishers, Dhanbad, India, pp. 34.

Smeeth, W.F., 1916. Outline of the geological history of Mysore. Department Mines, Geology, Mysore Estate Bull., 6, pp. 26.

Srinivasan, R. and Srinivas, B.L., 1974. Tectonic magmatic evolution and related metallogenesis of Karnataka State, Int. Sem. on tectonics and metallogeny of Southeast Asia and Fareast (Abs.), p.69-70.

St. Muller, 1970. Geophysical aspects of graben formations in Continental Rift Systems, Graben Problems. Int. U.M.P. Scientific Report No. 27, Struttgart, pp. 27-37.

Swaminath, J. et al., 1974. The cratonic greenstone belts of southern Karnataka and their possible relation to the charnockite mobile belt, presented at the International Seminar on Tectonics and Metallogeny, Calcutta (Abs.), pp. 38-39.

Venkatasubramaniam, V.S., Iyer, S.S. and Pal, S., 1971. Studies on Rb-Sr geochronology of the Precambrian formation of Mysore State, India. Am. Jour. Sci., 270: 43-53.

Verma, R.K. et al., 1969. Terestrial heat flow in various parts of India. Bull. Volcanologique, Tome XXXIII, 1, pp. 69-88.

Vinogradov, A.P., et al., 1964. Geology of the Indian Precambrian. Rep. 22nd Int. Geol. Cong., New Delhi.

Wadia, D.N., 1942. The making of India. Pres. Add. Proc. 29th Indian Science Congress, pt.2, pp. 3-23.

Warren, Hamilton and Bradley, Myers, 1967. The nature of batholiths, U.S.D.I., p. 554-C, G-452, Geol. Prof. Paper.

Woollord, G.P., 1966. Regional isostatic relations in U.S.A., A.G.U. Mongr., No.10, pp. 557-594.

Woollord, G.P., 1969. Regional variations in gravity, A.G.U., Monogr., 13, pp. 320-341.

Woollord, G.P., 1972. Regional variations of gravity. Nature of the solid earth, McGraw-Hill Publication, pp.463-503.