

# **Economic Mineralization**

The background image shows a vast open-pit mine with multiple terraced levels of dark rock. A red truck is driving on a dirt road in the foreground, carrying a load of dark material. To the left, there is a small pond. The sky is blue with scattered white clouds.

**K.L. SHRIVASTAVA**  
editor



# **Economic Mineralization**



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*A festschrift for  
Professor Bhawani Shanker Paliwal*

*editor*

**K.L. SHRIVASTAVA**

Professor of Economic Geology  
Jai Narain Vyas University  
Jodhpur, India



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24, I.P. Extension, Patparganj  
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Cont.

**Prof. A.S. Faroda**

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**Dr. R. Dhana Raju**

Former Add. Director AMD  
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**Dr. M. Ramkrishnan**

201, Skyline Surabhi Apt.  
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BKS III State  
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**Dr. Fareeduddin**

Former Editor  
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BANGALORE 560 019

**Prof. I.B. Singh**

Former Head  
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LUCKNOW 226 007

**Prof. A.K. Singhvi**

Senior Scientist  
Physical Research Laboratory  
Navrangpura  
AHMEDABAD 380 009

**Dr. M.N. Balasubrahmanyam**

Retd. Dy Director General GSI  
1A, 117/2 B  
Srinivasamurthy Avenue  
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Sagar University  
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Habbsiguda  
HYDERABAD 500 007

**Prof. Naresh Kochhar**

Centre of Adv. Stud. in Geol.  
Deptt. of Geology  
Panjab University  
CHANDIGARH 160 014

**Prof. O.P. Goel**

Emeritus Professor  
Department of Earth Science  
Manipur University  
IMPHAL 795 003

**Prof. B.L. Sharma**

Emeritus Professor  
Department of Geology  
MLS University  
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D74, Hauz Khas  
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MUMBAI 400 065

**Prof. V.N. Sharma**

Director  
Meerut Inst. Engg. and Tech.  
MEERUT 250 002

**Prof. P.S. Ranawat**

Dean SW  
Department of Geology  
MLS University  
UDAIPUR 313 001

**Prof. S.K. Date**

Emeritus Professor  
Department of Physics  
Pune University  
PUNE 411 001

**Prof. V.P. Singh**

Former Head, Mining, ISM  
K-227, Aashiyana Colony  
Kanpur Road  
LUCKNOW 226 012

Cont.

**Prof. M.C. Khare**

School of Studies in Earth Sci  
Jiwaji University  
GWALIOR 474 011

**Prof. V.K. Vaya**

Former Head  
Geology Deptt. JNVU  
L-7, Income Tax Colony  
Tonk Road  
JAIPUR 302 001

**Prof. S.K. Lunkad**

Founder Chairman  
Department of Geology  
Kurukshetra University  
KURUKSHETRA 136 119

**Prof. Nikhil Desai**

Head  
Department of Appl. Geol.  
M.S. University of Baroda  
VADODARA 390 002

**Prof. P.K. Verma**

Chairman  
Department of Geology  
Delhi University  
DELHI 110 007

**Prof. Ravindra Kumar**

Chairman  
Deptt. of Appl. Geol. and CAS  
Panjab University  
CHANDIGARH 160 014

**Dr. Anil Bhardwaj**

Head, Planetary Sci. Br.  
Space Physics Laboratory  
Vikram Sarabhai Space Centre  
TRIVANDRUM 695 022

**Prof. J.P. Srivastava**

Deptt. of Geology  
Delhi University  
DELHI 110 007

**Dr. Arun Kumar Shandilya**

Department of Geology  
Dungar College  
Bikaner University  
BIKANER 334 003

**Prof. Arun Kumar**

Head  
Department of Earth Science  
Manipur University  
IMPHAL 795 003

**Prof. R.K. Trivedi**

Head, Deptt. of Appl. Geol.  
Centre of Adv. Stud. in Geol.  
Dr. H.S. Gaur University  
SAGAR 470 003

**Prof. R.P. Tiwari**

Dean  
Faculty of Forestry and Geol.  
Mizoram University  
AIZAWAL 796 009

**Dr. D.K. Sinha**

Scientist 'G'  
Atomic Mineral Directorate  
1-10-153-156 Begumpet  
HYDERABAD 500 016

**Prof. V.S. Palaria**

Ex Head  
Department of Mining Engg.  
JNV University  
JODHPUR 342 011

**Prof. A.K. Sharma**

Head  
Department of Computer and  
Electrical Engineering  
MPA Technical University  
UDAIPUR 313 001

**Prof. U.C. Singh**

Chairman  
School of Studies in Geology  
Jiwaji University  
GWALIOR 474 011

**Prof. Mahshar Raza**

Chairman  
Department of Geology  
Aligarh Muslim University  
ALIGARH 202 002

**Prof. A.S. Sheoran**

Head  
Department of Mining Engg.  
JNV University  
JODHPUR 342 011

Cont.

**Prof. Madhumita Das**

Head  
Department of Geology  
Utkal University  
BHUBANESWAR 751 004

**Prof. D.C. Gupta**

Head  
Department of Appl. Geol.  
Barkatullah University  
BHOPAL 462 010

**Dr. S.S. Rathore**

Head  
Department of Mining Engg.  
MPA Technical University  
UDAIPUR 313 001

**Prof. Hari B. Srivastava**

Department of Geology  
Banaras Hindu University  
VARANASI 221 005

**Mr. Alok Tripathi**

Suptd. Geologist  
O.N.G.C. Ltd., Camp.  
JAISALMER 345 001

**Prof. T.K. Biswal**

Department of Earth Science  
I.I.T.B. Powai  
MUMBAI 400 076

**Prof. Devendra Mohan**

Department of Zoology  
JNV University  
JODHPUR 342 005

**Prof. H.C. Verma**

Department of Physics  
I.I.T. Kanpur  
KANPUR 208 010

**Prof. Rajesh K. Srivastava**

Department of Geology  
Banaras Hindu University  
VARANASI 221 005

**Dr. N. Srivastava**

Scientist  
Physical Research Laboratory  
Navrangpura  
AHMEDABAD 380 009

**Dr. S.C. Mathur**

Department of Geology  
JNV University  
JODHPUR 342 005

**Prof. L.S. Chamyal**

Department of Geology  
M.S. University of Baroda  
VADODARA 390 002

**Dr. K. Ramesh Kumar**

Scientist 'G'  
Atomic Mineral Directorate  
Sanganer  
JAIPUR 302 030

**Dr. Deepak Dhingra**

Scientist  
Physical Research Laboratory  
Navrangpura  
AHMEDABAD 380 009

**Dr. S.K. Trivedi**

Department of Geology  
JNV University  
JODHPUR 342 005

**Prof. P.K. Verma**

Department of Geology  
Vikram University  
UJJAIN 456 010

**Dr. Pankaj K. Srivastava**

Department of Geology  
University of Jammu  
JAMMU 180 006

**Dr. Rajesh Sharma**

Senior Scientist  
Wadia Inst. Himalayan Geol.  
DEHRADUN 248 001

**Dr. Krishan Kumar**

School of Studies in Env. Sci.  
Jawaharlal Nehru University  
NEW DELHI 110 001

**Mr. Hemant Kumar Jain**

Sr. Ore Dressing Officer  
Indian Bureau of Mines  
AJMER 305 002

**Dr. (Mrs.) Beena Tripathi**

Department of Geology  
JNV University  
JODHPUR 342 005

Cont.

**Dr. K.K. Sharma**

Department of Geology  
Govt. College Sirohi  
SIROHI 307 011

**Dr. D.R. Patel**

Joint Director  
Department of Geology and  
Mining  
RAIPUR 492 001

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Department of Geology  
Aligarh Muslim University  
ALIGARH 202 002

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Zoom Developers (Pvt.) Ltd.  
Safdarjang Enclave  
NEW DELHI 110 029

**Dr. Rakesh Srivastava**

Bhoj University  
BHOPAL 462 001

**Mr. Prakhar Kumar**

Scientist 'F'  
Atomic Mineral Directorate  
Sanganer  
JAIPUR 302 030

**Dr. P.K. Jain**

School of Studies in Earth Sci.  
Jiwaji University  
GWALIOR 474 011

**Dr. Hema Achyuthan**

Department of Geology  
Anna University  
CHENNAI 600 025

**Dr. Sudhir Kumar Mathur**

Lead Geologist  
Cairn Energy India  
Vipul Plaza. Suncity. Sec. 54  
GURGAON 122 002

**Prof. K.L. Shrivastava**

Department of Geology  
JNV University  
JODHPUR 342 005

# Preface

Economic Geology developed as a science, particularly in those times when it was closely linked with the pressing needs of human society. Even in prehistoric times, the development of material culture was inconceivable without the use of minerals. The neptunistic views, that water is the most important element on Earth and source of everything living or dead, and the plutonic view that the basis of everything earthly was fire, have been advocated by two Greek thinkers, Thales (640 BC) and Xenon (340 to 270 BC), respectively. They have significantly influenced our understanding of the genesis of economic mineral deposits.

Perhaps, the first truly scientific approach was expressed by Georg Bauer (1494-1555), better known as Georgius Agricola, who considered that ore veins were formed by solutions circulating in the bowels of the Earth. Since ore was usually only in veins, the necessary richness and coarseness were achieved by the term, "Ore deposit", becoming virtually synonymous with vein fillings.

James Hutton (1726-1997), a leader of the plutonists, linked the formation of ore veins with internal (magmatic and igneous molten) processes within the Earth. A.G. Werner (1749-1817), a leader of the Neptunists, favoured that veins of ore were formed from aqueous solutions flowing downward through cracks in rocks, eroding them and precipitating ores in them. Interestingly, the two schools of contradictory views gradually subsided, but as late as in the first half of the nineteenth century, when the fact was better accepted that the

ores can also be formed through the action of external geological processes, chiefly by sedimentation.

In those days, the bedded ores, accompanied by minor veins filling cracks within the adjacent sedimentary rock, attributed the vein sulphides to essentially the same source and process as those responsible for the bedded material. Breislak (1811), Boue (1822) and Scrope (1825) emphasized the likely importance of water in fluidity in magmas.

It is true that the development of ore genetic theory has been haphazard, repetitive and clearly shows an unclear pattern, yet some of these very old ideas have been revived as modern ones. Agricola (1546) was probably the first to put forth the idea of "lateral secretionist", Hutton (1788) sees to have been the first advocate of "dry ore magmas", Werner (1791) was the early proponent of "sedimentary" sulphide formation, Elie de Beaumont (1847) is probably the originator of the idea of igneous origin and aqueous transportation, well accepted by modern hydrothermalists and Sterry Hunt (1860) showed the important of surface and biological processes in collecting and localizing metals.

The first half of the twentieth century remained a period of reexamination. During this time, the contributions made by Fenner on pneumatolitic processes, Bowen on differentiation processes, Graton on hydrothermal depth zones, Emmons on lode associated with batholiths, and Buddington on selective mineralization in selective igneous rocks are worth mentioning. Schneiderhohn's genetic classification of ore deposits (1932) and Lindgren's

volume on "hypogene deposits" remained two of the most valuable documents, dominantly considering epigenetic mineralization, and perhaps, the last to restrict the term "Mineralization" as a substitute for hydrothermal processes only.

Continuing in the second half of the twentieth century, Schneiderhohn suggested that the ore materials had been extracted by hot brines from underlying pre-existing rocks. He explained "framboidal texture", low temperature "gel" and lead isotopes to indicate that sulphide ores are older than the host rocks. He suggested a regenerative process and propounded the idea popularly called "secondary mineralization". Stanton (1955) suggested that some stratiform ores are reduced sediments of old volcanic sequences with iron sulphides of sedimentary origin. It is considered as a result of interplay between sedimentary facies and volcanic emission. Further, the idea of exhalative - sedimentary type was to cover many bedded deposits of iron and manganese. It led to the fact that the sulphide "mineralization" was of volcanic affiliation (Kinkel, 1962; Goodwin, 1965).

Also, the third quarter of the twentieth century, sulphide concentration formation from modern volcanic cones in Japan, deposition of sulphide in pipes discharging geothermal drilling water in Salton Sea and the most popular among 'live' formation of ores, the deposition of sulphide ores from springs on the floor of Red Sea, which gained a milestone status in the history of the evolution of the economic mineralization. The modern discoveries remained synchronous with the final opinion of Stanton (1972) who considered "Ores" as "Ordinary rocks," and hence, ore genesis as a part of petrogenesis.

The last quarter of the twentieth century, later, witnessed an electrifying conceptual revolution and information explosion in economic geology. It happened because of the following reasons.

First, the advent and full emergence of Plate Tectonic theory which revolutionized the understanding of petrogenesis of igneous, metamorphic and sedimentary rocks during the time when ores were firmly recognized as rocks. Second, numerous discoveries of 'live' deposits, relating to collection, transport and deposition of ore/metals in a variety of 'habitats'. Third, application of scanning electron microscope to directly observe the fossilized micro life in ore deposit, greatly assisted by EPMA. Fourth, over the years, explosion in the

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invention and application in economic geology of geophysical and geochemical techniques; to include regional geophysical profiles, XRD, XRF, PIXE, LA-ICP-MS, Mossbauer spectroscopy and mass spectroscopy. Fifth, the mantle plume view which evolved parallel to the global tectonic theory, gave many logical explanations to the unanswered questions of ore genesis. Although not everyone believes in plumes, a vast amount of emerging data supported the idea, including seismic tomography of the Earth's mantle and path finder and Magellan Mission data on Mars and Venus. Sixth, high-speed computers allowed scientists to numerically model mineralization processes in a reasonable amount of time with increased accuracy. Application of computer-based data treatment and simulation practices became greatly significant as they led to more quantitative definition of some of the models.

This information explosion is greatly reflected in economic Geology. The most common textbooks suffered from either faster obsolescence or considerable revision. Many new journals exclusively devoted to economic Geology started. Accent on publication of thematic mostly multi-authored volumes appeared.

The present edited volume is also one of the result and upshots of the same race of economic mineralization against time. The purpose of this edited volume, at first, is to present new researches and to emphasize the many areas in which problems still exists with a view to contributing and encouraging further research. The second purpose is to present review articles summarizing our present knowledge authoritatively, and in so doing, demonstrate almost all aspects of the subject selected. 'Economic Mineralization'- the title has been preferred to express its modern meaning (specially post-Lindgren time) and broader perspective to cover the formation of almost all the economic minerals, epigenetic (metasomatic replacement or vein filling) and syngenetic (chemical precipitation, biogenic, volcanic exhalative), including mineral fuels.

The volume has been divided into five sections. The first section is on Crustal Evolution and Economic Mineralization. It includes eight papers. The second and third are on Economic Mineralization of Igneous Affiliation and Economic Mineralization of Sedimentary Affiliation, respectively. There are twelve papers in section two and thirteen papers in section three. Section four includes eight papers on prospecting and exploration. The fifth and the last section includes nine papers on Mining, Economics

and Environment. All the fifty papers in the volume were reviewed by the editor and invariably scrutinized and approved by at least two external referees. The editor has regretfully been forced not to include as many as 27 papers submitted for the publication in this volume because, more than one referee advised against it.

The volume sets out to present various aspects of a very broad field of economic mineralization, at a time when the competitively growing economy of

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the nations, in other words, the pressing needs of the society, are compelling economic geology to grow, and pile of data is accumulating and opinions changing very rapidly. Although care has been taken by the editor, in a work of this nature, errors of omission and commission are inevitable. I unhesitatingly own responsibility for the same. I would not find it truly rewarding unless the volume delivered the desired goods to the specialized readers, both from academia and industry. I wish, hope and

30<sup>th</sup> October, 2008  
Jodhpur

K.L. SHRIVASTAVA





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**K.L. SHRIVASTAVA**



# Professor Bhawani Shanker Paliwal — An Appreciation

Born on 19<sup>th</sup> May 1946, Professor Bhawani Shanker Paliwal hails from the city of lakes, Udaipur. He completed his school education there and also his graduation from the erstwhile University of Udaipur (now Mohanlal Sukhadia University). He continued his academic growth by doing M.Sc. Geology in the year 1970 from the University of Rajasthan. As soon as he completed his post-graduation, he was appointed as Lecturer in Geology at Government Bangur College Didwana on 18<sup>th</sup> July 1970. He was awarded UGC Teacher Fellowship in 1977 which led to the Degree of Doctor of Philosophy in Science (Geology) from the University of Rajasthan in the year 1981 under the worthy supervision of Prof. A.B. Roy.

He was the man behind starting and establishing the second prestigious Postgraduate Department of Geology in the state at a remote place like Didwana in the year 1981, next to the one quite popular at Udaipur under the umbrella of University of Rajasthan, Jaipur. After that he moved to the Government Dungar College at Bikaner as Head of the Postgraduate Department of Geology in September 1994. In the same year, he was selected as Professor of Geology at Jai Narain Vyas University Jodhpur on 22<sup>nd</sup> April 1995. Prof. Paliwal became Head of the Department on 10<sup>th</sup> February 1999 and continued for more than seven years until his superannuation on 31<sup>st</sup> May 2006. He was appointed as Dean, Faculty of Science, at Jai Narain Vyas University, Jodhpur on 1<sup>st</sup> May 2000 and served for two consecutive terms of three years each. During this period Prof. Paliwal was Member of the

Academic Council, Chairman of the Faculty of Science, Member of the Senate, Member of the Syndicate for two terms, Chairman of the University Library Board and Government Nominee in the Selection Committee. During this period he rendered his services with utmost sincerity, efficiency and wisdom. On superannuation from Jai Narain Vyas University, Jodhpur, Prof. Paliwal was appointed as U.G.C. Visiting Professor of Geology at his own *Alma Mater* Department of Geology, Mohanlal Sukhadia University, Udaipur (erstwhile Department of Geology, University of Rajasthan) on 1st June 2006.

Prof. Paliwal developed keen interest in research right in the beginning of his academic career. His first publication appeared in the Journal of the Geological Society of India in 1971, a paper which is considered as a land mark in the field of deformation of the Aravalli rocks; it was based on the findings of his M.Sc. Thesis. Subsequently, he concentrated on the region around and he has several papers to his credit on different aspects like the origin of salt in Rajasthan, sedimentary structures in the trans-Aravalli, Vindhya, Strometolites and economic mineralization. In addition to study, the deformation of the Palaeoproterozoic Aravalli rocks, Prof. Paliwal also established tectonics of the Precambrian rocks in the region. He aptly handled the issues of deposition to deformation of the Aravalli rocks in south-central Rajasthan, deformation of the Delhi rocks around Ajmer, marble deposits of Makarana and scattered outcrops of the Precambrian rocks in the sands of the great Thar Desert. He also covered several other aspects of the region like the Malani Igneous Suite,



**Professor Bhawani Shanker Paliwal**

and sediments of the Marwar Supergroup.

Prof. Paliwal's discovery of Elephant remains from the Quaternary gypsum deposits of Nagaur in the Thar Desert and Fossils of the Fish from the Palaeocene Palana Formation, received overwhelming appreciation from the geoscientific fraternity throughout the world. He investigated the problem of Fluoride in ground water of the Western Rajasthan and its impact on the human health. Prof. Paliwal is credited with the important meteorite falls like those of Didwana-Rajod and Bhawad. His discovery of life forming amino-acids like Phenylalanine, Tryptophan and Tyrosene from the 4.52 Ga. old. Didwana-Rajod meteorite raised curiosity in the scientific community. His ideas of "the extra-terrestrial origin of life and its transportation on the earth by meteorites and comets" and "the impact of extra-terrestrial bodies caused the evolution of life and its mass extinction on the earth" have impressed the geoscientists.

Prof. Paliwal had an opportunity to work with eminent geoscientists like Prof. H. Okada, Prof. M. Yoshida and Prof. N.N. Nakajima of Japan, Prof. A. Kroner and Prof. M.M. Raith of Germany, Prof. Abate of Italy, Prof. John W. Harbaugh and Prof. Nein of U.S.A. Prof. Rabban, Prof E.V. Sklyaro and Prof. Eugene Khain of Russia, Prof. R. Hutchison, Prof. S. Russell and Prof. I.A. Franchi of U.K. Prof. Alain Ploquin of France, Prof. Nan Junya of China, Prof. S.A. Wilde of Australia, Prof. Svetlana V. Bogdanova of Sweden, Prof. P.G. Cooray of Shri Lanka and Prof. K. Naha, Prof. K.S. Valdiya, Prof. A.B. Roy and Prof. N. Bhandari of India.

Prof. Paliwal was associated with UNESCO IGCP projects like IGCP-269-SEDDBA and IGCP-440 Assembly and Fragmentation of Rodinia and Growth of Asia. He was appointed as the Chairman of the South Asia in the project IGCP-269-SEDDBA for five years. Apart from this, Prof. Paliwal handled many research projects funded by the UGC, DST, and DRDO successfully.

Prof. Paliwal is a widely traveled person who visited several countries including USSR, Germany, U.K., Russia, China, France, Italy, Austria, Thailand, Australia, Hong Kong, Singapore, Sri Lanka, Bangladesh, Pakistan, Nepal, Spain, Egypt, Japan, Kenya, Somalia, U.A.E., Norway, Sweden and Switzerland in connection with research work. During these visits he has also undertaken field work in and around Siberia, Lake Baikal, Somali Plateau, Rift Valley, Tibetan Plateau, Alps, Himalaya and Atlas Mountain Ranges, Great Dividing Range, Rhine Valley, Deltas of Brahmaputra and Nile Rivers, British Channel and

coastal areas, of Spain, Eastern China and Japan.

Prof. Paliwal participated in a number of National and International Seminars held in India and abroad. He was invited to Chair Sessions in the International Geological Congress held in Moscow (USSR) in 1984 (27<sup>th</sup> IGC), Kyoto (Japan) in 1992 (29<sup>th</sup> IGC), and Florence (Italy) in 2004 (32<sup>nd</sup> IGC). "Because of his extensive work on Proterozoic sediments" Prof. Paliwal was invited to Chair the Session on Proterozoic Sediments of the 12<sup>th</sup> International Sedimentological Congress held in Canberra (Australia) in 1986. Prof. Paliwal also Chaired Sessions in the International Conferences like GEOSOM-87 held in Mogadishu (Somalia) in 1987, GEOSAS-I held in Islamabad (Pakistan) in 1992, GEOSAS-II held in Colombo (Sri Lanka) in 1995, Assembly and Fragmentation of Rodinia and Growth of Asia held in Irkutsk (Siberia, Russia) and Osaka (Japan) in 2001. Recently, Prof. Paliwal attended the 33<sup>rd</sup> International Geological Congress held in Oslo (Norway) during August 6–14, 2008 where he was the Convener of the General Symposium – Hydrogeology and Topical Symposium – Geohazards and Chaired as many as eight Sessions of this prestigious International Conference. Prof. B.S. Paliwal has been entrusted with the task of publishing the Proceedings of the Hydrogeology –HYH-2 Symposium of the 33<sup>rd</sup> International Geological Congress.

Prof. Paliwal edited two books: *The Indian Precambrian* (1998) and *Geological Evolution of Northwestern India* (1999). These books were well received and acclaimed by the geoscientists all over the world. His book, *The Indian Precambrian* was reviewed by renowned geologists like Prof. Brian Windley (Precambrian Research, Elsevier), Prof. Ravindra Kumar (Gondwana Research, Elsevier), Dr. M. Ramakrishnan (Journal, Geological Society of India), Dr. T.M. Mahadevan (DST News Letter), and Prof. Deepak C. Srivastava (IGC News Letter).

As a devoted teacher, Prof. Paliwal has produced a large number of geoscientists from Didwana, Bikaner and Jodhpur, presently working almost in all the prestigious organizations like ONGC, GSI, ISRO, SAC, GWD, DMG, CGWB, BITS, RAS, RPS and several universities and colleges. Many of his students are actively engaged in exploration and exploitation in mining, groundwater and mineral fuel activities. Some of them have received prestigious National Mineral Award of the Country. He has also supervised a dozen of students for the Doctorate Degree. Even after his superannuation at present, he is actively engaged in supervising eight students for the degree of Ph.D.

As a scholar of distinction, a dedicated researcher, and a devoted teacher, Prof. Paliwal has greatly influenced his surroundings. I was not an exception. It truly remained a matter of great honour for me to work as a colleague of Prof. B.S. Paliwal. When Prof. Paliwal joined this department as Professor in the year 1995, I was serving as Associate Professor, before becoming Professor of Geology in the year 2001. I feel proud to dedicate this book on 'Economic Mineralization', to Prof. B.S. Paliwal. By joining hands with the contributors of this volume, I wish him all the best for the future. A glimpse of his contributions over the years can be had from the following list of some of his publications.

### K.L. SHRIVASTAVA

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