LANDSLIDE SUSCEPTIBILITY MAPPING OF WAYANAD DISTRICT, KERALA, USING ANALYTICAL HIERARCHY PROCESS METHOD IN GIS ENVIRONMENT

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala, University of Calicut in partial fulfilment of the degree of

Master of Science in Applied Geology

By

ARUL THEJUS

Reg. No: CCAWMAG004

2022-2024

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA, 680125

(Affiliated to University of Calicut and re-accredited by NAAC with an A++ grade)

JULY 2024

CERTIFICATE

This is to certify that the dissertation entitled **'LANDSLIDE SUSCEPTIBILITY MAPPING OF WAYANAD DISTRICT, KERALA, USING ANALYTICAL HIERARCHY PROCESS METHOD IN GIS ENVIRONMENT'** is a bonafied record of work done by Mr. Arul Thejus (Reg. No. CCAWMAG004), M.Sc. Applied Geology, Christ College (Autonomous), Irinjalakuda in partial fulfilment of requirements for the degree of Master of Science in Applied Geology during the academic year 2022-2024.

Dr. Midhuna Vinayan

Assistant Professor and Supervisor

Dr. Anto Francis

Assistant Professor and Coordinator

Date:

Place:

External Examiner

DECLARATION

I, Arul Thejus, declare that the work included in my dissertation report named **"LANDSLIDE SUSCEPTIBILITY MAPPING OF WAYANAD DISTRICT, KERALA, USING ANALYTICAL HIERARCHY PROCESS METHOD IN GIS ENVIRONMENT"** was composed entirely by me and that it has not previously been presented, in whole or in part, in any previous application for a degree. Except where otherwise noted, the work presented here is entirely my own. This work is presented to Christ College (Autonomous), Irinjalakuda, Kerala, in a partial fulfilment of the Master of Science in Applied Geology degree requirement.

ACKNOWLEDGMENT

First and foremost, I want to express my gratitude to God Almighty, by whose mercy I am able to do this work. I wish to express my heartfelt gratitude and heartfelt thanks to, **Dr.Linto Alappat,** Dean of Research and Development of TLC (former HOD) Department of Geology and Environmental Science, Christ College(Autonomous) Irinjalakuda, **Dr. Anto Francis. K,** Co-Ordinator and **Mr. Tharun R.** Head of Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda. A successful and ultimate conclusion of this project necessitated a great deal of advice and assistance, and I consider myself very grateful to have received this during all stages of my project work. Whatever I've accomplished is entirely due to such guidance and assistance, for which I am grateful. I would like to thank my project guide, **Dr. Midhuna Vinayan** (Assistant Professor, Department of Geology & Environmental Science) Christ College (Autonomous) Irinjalakuda, for creating the project guidelines and providing support and supervision throughout the project.

I also thank other faculty members for their support and encouragement. I would prefer to take this opportunity to thank all of my classmates and friends who helped me finish my dissertation, whether directly or indirectly. I'm also thankful to the entire Christ College family for their support.

ARUL THEJUS

INDEX

CONTENT

GEOMORPHIC OBSERVATIONS IN MANIMALA RIVER BASIN

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala, University of Calicut in partial fulfilment of the degree of

Master of Science in Applied Geology

By,

ASHBY ANN MATHEW

Reg. No: CCAWMAG005

2022-2024

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA, 680125

(Affiliated to University of Calicut and re-accredited by NAAC with A++ grade)

AUGUST 2024

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA- 680125

KERALA, INDIA

CERTIFICATE

This is to certify that the dissertation entitled **"Geomorphic Observations in Manimala River Basin"** is a bonafied record of work done by **Ms. Ashby Ann Mathew**, **Reg.No. CCAWMAG005** M.Sc. Applied Geology, Christ College (Autonomous), Irinjalakuda under my guidance in partial fulfilment of requirements for the degree of Master of Science in Applied Geology during the academic year 2022-2024

Internal Guide
Mr. Tharun R
(H.O.D, Department of Geology and Environmental Science)

External Guide
Dr. Divyalakshmi K.S
(Scientist- E1, National Institute of Rock Mechanics)

Dr. Anto Francis
(Assistant Professor and Coordinator SF)

External Examiner

DECLARATION

I, Ashby Ann Mathew, declare that the work included in my dissertation report named "Geomorphic Observations in Manimala River Basin" was composed entirely by me and that it has not previously been presented, in whole or in part, in any previous application for a degree. Except where otherwise noted, the work presented here is entirely my own. This work is presented to Christ College (Autonomous), Irinjalakuda, Kerala, in a partial fulfilment of the Master of Science in Applied Geology degree requirements.

ASHBY ANN MATHEW

ACKNOWLEDGEMENT

First and foremost, I want to express my gratitude to God Almighty, by whose mercy I am able to do this work. I wish to express my heartfelt gratitude and heartfelt thanks to Mr Tharun R, H.O.D and Dr. Anto Francis. K, Co-Ordinator, Dr. Linto Alappat Dean of Research and Development of TLC Department of Geology and Environmental science, Christ College (Autonomous) Irinjalakuda, for developing the project's framework and providing regular support and supervision throughout the duration of the course study. I would like to thank my external guide Mrs. Divyalakshmi (Scientist-C, National Institute OF Rock Mechanics, Kolar Gold Fields). Also, my internal project guide, (HOD, Department of Geology & Environmental Science) Christ College (Autonomous) Irinjalakuda, for creating the project guidelines and providing support and supervision throughout the project. Also, to A successful and ultimate conclusion of this project necessitated a great deal of advice and assistance, and I consider myself very grateful to have received this during all stages of my project work. Whatever I have accomplished is entirely due to such guidance and assistance, for which I am grateful.

I also thank other faculty members for their support and encouragement. I would like to extend my thanks to Mr. Ayyappadas C.S for the continuous support provided for the completion of the dissertation. I would prefer to take this opportunity to thank all of my classmates and friends, especially Mr. Arul Thejus and Mr. R. S Ananthajith who helped me finish my dissertation. I am also thankful to the entire Christ College family for their love and support. I also express my gratitude to my parents and family members for their unwavering support and prayers throughout my life.

ASHBY ANN MATHEW

CONTENTS

LIST OF TABLES

LIST OF FIGURES

SALINE WATER INTRUSION IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJOINING THE NORTHERN BOUNDARY OF PUZHAKKAL KOLE LAND, THRISSUR DISTRICT, KERALA

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala, University of Calicut in partial fulfillment of the degree of

Master of Science in Applied Geology

By

ASWIN MENON

Reg. No: CCAWMAG006

2022 - 2024

Under the guidance of,

Mrs. ROSHINI. P. P

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA, 680125

(Affiliated to University of Calicut and re-accredited by NAAC with an A++ grade)

JULY 2024

CERTIFICATE

This is to certify that the dissertation entitled - **SALINE WATER INTRUSION IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJOINING THE NORTHERN BOUNDARY OF PUZHAKKAL KOLE LAND, THRISSUR DISTRICT, KERALA** is a bonafide record of work done by Mr. ASWIN MENON (CCAWMAG006) M.Sc. Applied Geology, Christ College (Autonomous), Irinjalakuda under my guidance in partial fulfilment of requirements for the degree of Master of Science in Applied Geology during the academic year 2022-2024.

Project Guide

Mrs Roshini P. P
Assistant Professor
Dept. of Geology and Env. Science
Christ College (Autonomous) Irinjalakuda
Kerala- 680125

Dr. Anto Francis K
Co-ordinator (Geology Self-financing)
Dept. of Geology and Env. Science
Christ College (Autonomous) Irinjalakuda
Kerala- 680125

Place: Irinjalakuda

Date: ……………

External Examiners;

1…………………………………………………

DECLARATION

I hereby declare that this dissertation work – **SALINE WATER INTRUSION IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJOINING TO THE NORTHERN BOUNDARY OF PUZHAKKAL KOLE LAND, THRISSUR DISTRICT, KERALA** is done by me. No part of the report is reproduced from other resources. All information included from other sources has been duly acknowledged. I maintain that if any part of the report is found to be plagiarized, I shall take the full responsibility for it.

Place: Irinjalakuda — ASWIN MENON

Date: …………. — Reg. No. CCAWMAG006

ACKNOWLEDGEMENT

This report is an official documentation of the dissertation work carried out in the Northern Boundary of Puzhakkal Kole Wetland, Thrissur, Kerala. This report would not have been possible without the guidance, encouragement, and support of many well-wishers and my colleagues who helped me in many ways.

I would like to express my sincere gratitude and appreciation to **Mrs. Roshini. P.P.**, Assistant Professor, Department of Geology and Environmental Science at Christ College (Autonomous) Irinjalakuda. She played a pivotal role in shaping the framework of this thesis and provided unwavering support, guidance and suggestions throughout the entire duration of the study.

I express my utmost gratitude to **Dr. Linto Alappat**, Dean of Research and Development of TLC (Former Head, Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda), **Mr Tharun R**, Head of the Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, for rendering all the help and facilities available in the department.

I am grateful to **Dr. Anto Francis K**, Coordinator (Geology Self-financing), **Dr. Anso M A**, **Ms. Ivine Joseph** and the other faculty members of the Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, for their encouragement, support and direction. I express my gratitude to **Mr. Ayyappadas C.S**, Research Scholar at Christ College (Autonomous) Irinjalakuda, for his valuable assistance in the technical aspects of my study.

I would like to take this opportunity to thank all of my teachers, classmates and friends who supported me in completing this dissertation work, whether directly or indirectly .

I am grateful to the entire Christ College family for their love, support, and guidance. I also express my gratitude to my parents and my sister for their unwavering support and prayers throughout my life. Above all, I express my gratitude to God, the Almighty, for His divine generosity and blessings showered upon me.

ASWIN MENON

ABSTRACT

Water is an essential element for the existence of life. The study focuses on saline water intrusion and the water quality of the northern boundary of Puzhakkal Kole land. The main objective of the study was to find the presence and probable source of saline water along with the determination of water quality parameters. A total of 25 borewell and 4 open well samples were collected during the month of May 2024. The salinity and electrical conductivity were measured using an EUTECH Portable EC Salinity Meter during the sample collection. The physical parameters are measured using the EUTECH Multi-Parameter and chemical concentration is measured using several titration methods. Spatial maps of the following parameters were made using Arc GIS 10.8. From the study, about 12-13 samples show significant variations from others. Spatial distribution plots indicate higher EC, Cl^-, Na total hardness, salinity and TDS in the western and southern part of the study area adjoining the sea inlet (Chettuva). The statistical analysis shows that the major water type is Mixed type accompanied by NaCl type, $MgHCO_3$ type, and CaCl type. The Gibbs diagram shows that the high concentration of some ions is mainly due to saline water intrusion and from the USSl diagram, the groundwater of the western and southern parts of the are not suitable for irrigation while the rest of the study area is suitable for irrigation.

From the study, the southern and western regions of the study area are affected by saline water while the northern and eastern parts are unaffected or free from contaminations. The southern and western part is affected by saline water intrusion from the nearby Chettuva Lake and from deep fractures connected to the sea.

THE GENESIS OF FLUORITE (± BARITE) MINERALISATION IN THE DONGARGAON MINE, CHANDRAPUR DISTRICT, MAHARASHTRA

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala, University of Calicut in partial fulfilment of the degree of

Master of Science in Applied Geology

By

DANIE MATHEW

Reg. No: CCAWMAG007

2022-2024

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA, 680125

(Affiliated to University of Calicut and re-accredited with by NAAC with A^{++} grade)

JULY 2024

भारतीय प्रौद्योगिकी संस्थान मुंबई
पवई, मुंबई- 400 076, भारत
Indian Institute of Technology Bombay
Powai, Mumbai-400 076, India
Phone : (+91-22) 2572 2545
Website : www.iitb.ac.in

Dr. Sakthi Saravanan Chinnasamy
Associate Professor of Economic Geology
Department of Earth Sciences

Phone: +91 7540878771
E-mail: chinnasamys@iitb.ac.in

CERTIFICATE

This is to certify that the report entitled **"THE GENESIS OF FLUORITE (± BARITE) MINERALIZATION IN THE DONGARGAON MINE, CHANDRAPUR DISTRICT, MAHARASHTRA"** submitted to Christ College (Autonomous), Irinjalakuda, Kerala, is a bonafide record of research work carried out by **Mr. Danie Mathew** in the Department of Earth Sciences, Indian Institute of Technology Bombay, from 10 April 2024 to 10 July 2024 under my supervision. It is also certified that the report represents his independent, original investigation without forming previously part of the material for the award of any Degree, Diploma or any other similar title in any University.

Place: Powai, Mumbai

Date: 10/07/2024

Dr. Sakthi Saravanan Chinnasamy
Associate Professor
Dept. of Earth Sciences
Indian Institute of Technology Bombay

CERTIFICATE

Certified that the dissertation work entitled "**THE GENESIS OF FLUORITE (± BARITE) MINERALISATION IN THE DONGARGAON MINE, CHANDRAPUR DISTRICT, MAHARASHTRA**" is a bonafide record of work done by Mr. Danie Mathew (Reg. No. CCAWMAG007), MSc Applied Geology at Indian Institute of Technology, Bombay during 2023-24.

Internal guide

Ms. Ivine Joseph

Assistant Professor

Dept. of Geology and Env. Science

Christ College (Autonomous), Irinjalakuda

Dr. Anto Francis K

Co-Ordinator (Geology self-financing)

Dept. of Geology and Env. Science

Christ College (Autonomous), Irinjalakuda

Place: Irinjalakuda

Date: 16/08/2024

DECLARATION

I thus certify that this dissertation - "**The Genesis of fluorite (± barite) mineralisation in the Dongargaon mine, Chandrapur district, Maharashtra**"- is my own work. The report contains no quotations from external sources. All information derived from external sources has been properly credited. I maintain that if any element of the report is discovered to be plagiarised, I will accept full responsibility. Dr. Sakthi Saravanan Chinnasamy, Associate Professor, Dept. of Earth Sciences, Indian Institute of Technology Bombay, has provided necessary supervision for the completion of the work. I followed best practises and scientific study ethics. This work is presented to Christ College (Autonomous), Irinjalakuda, University of Calicut, Kerala, in partial satisfaction of the Master of Sciences in Applied Geology degree requirements.

Place: Irinjalakuda DANIE MATHEW

Date: 10/08/2024 Reg. No.: CCAWMAG007

ACKNOWLEDGEMENT

This Masters dissertation report is official documentation of research work carried out at the Indian Institute of Technology, Bombay. It is a privilege for me to convey my gratitude and respect to those who guided and inspired the project's completion.

I would like to express my wholehearted gratitude to my mentor, **Dr. Sakthi Saravanan Chinnasamy, Associate Professor, Dept. of Earth Sciences, Indian Institute of Technology Bombay**, for including and permitting me, making timely comments and advices on completion of my research and for the valuable guidance provided.

I am very much thankful to **Dr. Mohd Qaim Raza, Post-Doctoral Fellow, Dept. of Earth Sciences, Indian Institute of Technology Bombay**, for helping and guiding me in all ways to conduct this research at the institution and for all the support provided.

I am thankful to **Ms. Ivine Joseph, Assistant Professor, Dept. of Geology and Environmental Science at Christ College (Autonomous) Irinjalakuda** for her guidance and support throughout the research work.

I express my gratitude to **Dr. Linto Alappat, Dean of Research and Development of TLC (Former Head, Dept. of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda)** and **Mr. Tharun R, Head of the Department, Dept. of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda**, for rendering all the help and facilities available in the department.

I am grateful to **Dr. Anto Francis K**, **Co-Ordinator of the M.Sc. Applied Geology** and the other faculty members of the Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, for their encouragement and direction.

I'd like to express my wholehearted gratitude to **Ms. Anjana Ajith** for her continued support and assistance in completing this research work.

I would like to take this opportunity to thank the IRCC, all the faculties of Dept. of Earth Sciences, Indian Institute of Technology Bombay and friends who helped me finish this research work, either directly or indirectly. I am grateful to the entire Christ community. Thank you to my college family for their love, support, and advice. I would also like to thank my parents and family members for their everlasting support and prayers throughout my life.

Above all, I thank God, the Almighty, for his wonderful kindness and the benefits that have been bestowed upon me.

DANIE MATHEW

ABSTRACT

Criticality of fluorite utilisation in the aerospace engineering, chemical engineering and metallurgy has attracted the attention of researchers in the recent past. Fluorite mineralisation is genetically associated with different geological environments such as magmatic-hydrothermal, hydrothermal and sedimentary. It also varies in terms of P-T-X condition and mechanism of mineralisation. The fluid characteristics of the reported hydrothermal fluorite mineralisation are typically low to moderate in temperature (<300°C), varying salinity (low to high, wt.% NaCl equivalent), aqueous carbonic in nature with varying dissolved salt types (NaCl, $CaCl_2$ etc.), source of hydrothermal fluid also varied extensively. Therefore, a detailed fluid inclusion and geochemical studies can play a vital role to constrain the genesis of hydrothermal fluorite mineralisation.

Dongargaon fluorite (±barite) deposit is situated in the Chandrapur district of Maharashtra, India. The recent field work carried out in the Dongargaon area reveals that the fluorite (±barite) mineralisation is hosted within the extensively brecciated limestone and chert. The mineralisation is botryoidal, banded, coarsely cubic crystalline and open-cavity filling. Till today, a detailed and systematic study is not carried out on the deposit and a concept-based genetic model is still lacking. Therefore, in the present study, a systematic sampling of fluorite and host rocks were performed and detailed fluid inclusion and geochemical studies are carried out.

Petrographic study revealed that along with fluorite, barites, quartz and apatite are also present as minor hydrothermal phases. Fluid inclusions were observed only in coarsely cubic crystalline fluorite and were highly varying in shape and size. The degree of fill is dominantly high and less varying. It is biphase, genetically primary and compositionally aqueous. The inclusions are very low in salinity (0.1 to 0.4 wt.% NaCl eqv.) but with higher temperature of homogenization with mean T_H above >250℃. Thus, the study and analysis indicate a meteoric source of fluid and moderate temperature source (>200℃) resulting in hydrothermal deposition of fluorite in the study area and that too in a brittle deformation zone (~ 8km), which is theoretically not possible within the depth of brittle zone of the Earth as the thermal gradient of Earth is 25℃/km.

Therefore, the current study points out to a chance of existence of a high temperature source (possibly some intrusions) resulting in hydrothermal deposition over the study area and to confirm the existence of such a source of heat, further studies and experiments are needed to be conducted.

INDEX

LIST OF TABLES

LIST OF PHOTOGRAPHS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 FLUORITE

Fluorite or Fluorspar is a critical mineral having a chemical composition of Calcium Fluoride (CaF_2), which forms in a variety of geological settings through both hydrothermal and sedimentary processes. Its occurrence is influenced by the availability of calcium and fluorine ions, as well as specific geological conditions. Fluorite crystallises in the cubic system. They are usually diagnosed by its cubic crystals and octahedral cleavage; also, by its vitreous lustre, general fine colouring, and by the fact that it can be scratched with a knife. Pure fluorite is colourless in nature, but the presence of impurities give colour to the mineral. They are seen in a wide range of vibrant colours like purple, blue, green, yellow, brown, pink, black and red with purple colour being the most popular one. Fluorite is generally seen associated with Quartz, Dolomite, Calcite, Barite, Celestine, Sulphides, Cassiterite, Topaz, Wolframite, Scheelite, Apatite (Indian Bureau of Mines, 2024; National Mineral Inventory - Fluorite, n.d.).

Each unit of fluorite consists of one Calcium (Ca) atom bonded to two Fluorine (F) atoms. They are held together by ionic bonds, with calcium ions (Ca^{2+}) being positively charged and fluoride ions (F^{-}) being negatively charged. These ions attract each other, forming a stable crystal lattice. Fluorite is chemically inert and does not readily react with most acids or common chemicals. While relatively insoluble in water, fluorite can slowly dissolve over time when exposed to acidic groundwater or soil. Fluorine in high concentration in drinking water is toxic and causes a disease known as 'Fluorosis'. Fluorite is formed or deposited in different geological settings and they are majorly:

1. Hydrothermal Formation

2. Sedimentary Formation

3. Metamorphic Processes

4. Igneous Rocks

5. Carbonatites

1. Hydrothermal Formation

Primary Hydrothermal Deposits: In these settings, hydrothermal solutions percolate through cracks and fissures in the Earth's crust. These fluids carry dissolved calcium and fluorine ions derived from the surrounding rocks. When the percolating solutions cool down under favourable conditions or react with other minerals, fluorite crystals are precipitated in that environment.

Associated Minerals: Fluorite often forms alongside other minerals such as quartz, calcite, sulphides and sometimes even with other fluorine-bearing minerals like topaz. The presence of associated minerals influences the colour and appearance of fluorite crystals.

2. Sedimentary Formation

Evaporite Deposits: Fluorite can also be found in sedimentary environments, particularly in evaporite deposits. Evaporite deposits form when saline waters in basins evaporate, leaving behind the dissolved minerals as solid deposits. If these waters contain calcium and fluorine ions in sufficient quantity, then fluorite could be precipitated and accumulated in layers.

Marine Sediments: Fluorite may also occur in marine sediments, where it forms as a result of the slow accumulation of organic matter and minerals in marine environments.

3. Metamorphic Processes

Although fluorite is not a common constituent, it could be present in certain metamorphic rocks. It is formed during the metamorphism of sedimentary rocks that contain fluorine-rich minerals or as a result of the alteration of pre-existing fluorite deposits.

4. Igneous Rocks

Fluorite is not typically associated with igneous rocks, but it can occasionally be found in small quantities in some igneous environments, particularly in granitic intrusions. This is because fluorine can be present in the magma and could crystallize into fluorite under specific conditions.

5. Carbonatites

In some rare cases, fluorite is found in carbonatite rocks. Carbonatites are igneous rocks composed primarily of carbonate minerals, and they can contain various rare minerals, including fluorite.

Physical property					Optical property		
Colour & Streak	Specific gravity	Density	Lustre	Hardness	Colour	Refractive index	Relief
colourless, blue, purple, or green and a streak of white colour.	3.0 - 3.3	3.18 - 3.25	vitreous	4	colourless	1.433 - 1.448	moderately high

Table 1.1 Physical & Optical properties of Fluorite

1.1.1 Distribution in India

India is a bulk consumer of fluorite and occurrences of commercial deposits of fluorite in India is very limited. Also grades of fluorite produced in the country does not meet the specifications of chemical industry. The country depends majorly on imports to meet its internal demand.

According to the United Nations Framework Classification (UNFC) system-based NMI (National Mineral Inventory) database, the nation's total fluorite reserves/resources as of 01.04.2020 were projected to be 20.99 million tonnes. The Reserves category includes 0.40 million tonnes of these, of which 0.23 million tonnes are classified as Proved and 0.17 million tonnes as Probable. Twenty-nine million tonnes make up the category of Remaining Resources. With 14.35 million tonnes, Gujarat holds 68% of the nation's reserves and resources. Rajasthan comes in second with 5.60 million tonnes (27%), Chhattisgarh with 0.54 million tonnes (3%) and Maharashtra with 0.49 million tonnes (2%). According to grade, the resources are divided into marketable grade, which makes up 82% of the total, poor grade (15%), and unclassified grade (2%). Apart from these, nothing is known about the Grade of around 2% resources (Indian Bureau of Mines, 2024). The End-use grade classification for fluorite as follows:

- Marketable grade (Useable/Saleable) - Fluorite of (+) 30% CaF_2 (min) by hand sorting and (+) 10% CaF_2 accepted as mill feed for production of concentrates
- Low Grade - Fluorite containing below 10% CaF_2

- Beneficiable grade - CaF_2 5% (min)
- Unclassified grade - Fluorite where the ranges of constituents vary widely

The production of fluorite (graded) at 1,237 tonnes in 2021-22 increased by 18 % as compared to that in the previous year.

There were only one reporting mine in 2021-22. The entire output was reported from a public sector mine, the Dongargaon fluorite mine, located in Chandrapur district of Maharashtra owned by Maharashtra State Mining Corporation (MSMC) Ltd. Mining is carried out by semi-mechanised opencast mining method. The mine-head closing stocks of fluorite (graded) was 98,140 tonnes in 2021-22 as against 97,818 tonnes in 2020-21 (Indian Bureau of Mines, 2024; National Mineral Inventory - Fluorite, n.d.).

1.1.2 Global distribution

China and Mexico are the world’s major producers of fluorite. The mineral is also widespread in South Africa, Mongolia and Spain. The world total reserves of fluorite/fluorspar were at 260 million tonnes. World reserves are concentrated mainly in Mexico (26%), China (19%), South Africa (16%), Mongolia (8%) and Spain (4%). Mexico had the world's largest fluorspar reserves as of 2023, at 68 million metric tons. World production of fluorite/fluorspar in 2021 decreased marginally by 6 % to 7.80 million tonnes as compared to 8.30 million tonnes in the previous year (Indian Bureau of Mines, 2024). World’s largest fluorite mine is located in San Luis Potosi, Mexico. The mine has the largest certified global fluorspar deposit with an annual volume of about 18% of global fluorspar production.

Table 1.2 picturizes the worldwide fluorspar reserve by principal countries.

Country	Reserves (in 1,000 metric tons)
World: Total (rounded)	2,60,000
Mexico	68,000
China	49,000
South Africa	41,000
Mongolia	22,000
Spain	10,000
Vietnam	5,000
USA	4,000
Iran	3,400
Other Countries	55,000

Table 1.2 Reserves of fluorspar worldwide by principal countries (in 1,000 metric tons)
(U.S. Geological Survey, 2023)

1.1.3 Applications and Uses

Fluorite does not occur naturally in high concentration of CaF_2 so as to be directly used in many of the bulk consuming industries. Fluorspar is used as a flux in the manufacture of open-hearth steel, of aluminium fluoride, of artificial cryolite, and of aluminium and without which aluminium extraction is not possible. It is also used in chemical, cement, iron and steel, ferroalloys, foundries and also in glass industries. The primary use of fluorspar is for the production of hydrofluoric acid. It is an important commercial source of fluorine. The major use of HF is the production of a wide range of fluorocarbon chemicals, including hydrofluorocarbons, hydrochlorofluorocarbons and fluoropolymers. Ceramic grade fluorite containing 85-95% CaF_2, is used in ceramic industry as a flux and as an opacifier in the production of flat glass, white or opal glass and enamels. The addition of 10–30% ceramic grade fluorspar to glass makes it opaque, white and opalescent (Indian Bureau of Mines, 2024).

1.2 Study Area

The area under study, the Dongargaon Fluorite Mine is located under the jurisdiction of Dongargaon Village, Warora Tahsil, Chandrapur district of Maharashtra, known formerly as Chanda, which is to the eastern part of the Maharashtra and falls with coordinates 20° 19' 35"N 78° 57' 45"E. The exploratory mining in Dongargaon fluorite mine started in 1989. The mining practice is carried out by manual opencast as well as partially mechanized mining methods.

Samples were collected from mineralized veins and bands of Dongargaon fluorite mine. Mineralization here generally seen as purple fluorite associated with pinkish and white barite and is dominantly unveiled as cavity fillings and in disseminated veins. Hydrothermal solution trapped by carbonate rock is credited to have produced the mineralization. Within the study area, barite is much less abundant than fluorite and therefore not exploited commercially (K. Randive, Jawadand, et al., 2021; K. Randive, Pantawane, et al., 2021).

1.2.1 Physiography

The district exposes low level plateaus in the southwestern part, plains of extrusive origin in the north-western part, structural hills and valleys the north-eastern part and the alluvial flood plains in the northern part. Maximum elevation of the area is 583m above msl in the south western part and the minimum elevation of the area is 176m in the southern part. Wardha River, Penganga River and Wainganga River are the major rivers flowing through the district. These rivers besides their tributaries drain the entire district (Geological Survey of India (Central Region), 2021).

Problem statement:

- Genesis of fluorite is unknown
- Lack of concept-based genetic model Indian fluorite deposits

1.3 Objective

1. Genesis of Fluorite in Dongargaon deposit
2. Understanding the ambient fluid P-T-X condition and mechanism of fluorite-precipitation

The major aim of the current study is to understand and get an idea about the genesis and deposition of fluorite in the Dongargaon area. The study helps in understanding the P-T-X conditions under which the deposition has taken place and also about the possible mechanism and the favourable factors that led to the fluorite mineralization.

Implication of the study:

Since fluorite is considered as a critical mineral and the fluorite deposits in India is very much incompetently studied, the current research work might be helpful for further fluorite exploration and gives clear-cut idea about fluorite deposition in areas of similar geological condition.

CHAPTER 2

REVIEW OF LITERATURE

According to Indian Bureau of Mines, 2024, Fluorite or Fluorspar is a critical mineral having a chemical composition of Calcium Fluoride (CaF_2), which forms in a variety of geological settings through both hydrothermal and sedimentary processes. According to the United Nations Framework Classification (UNFC) system-based NMI (National Mineral Inventory) database, the nation's total fluorite reserves/resources as of 01.04.2020 were projected to be 20.99 million tonnes. There were only one reporting mine in 2021-22 and that is the Dongargaon fluorite mine.

The study area is the Dongargaon fluorite mine, a public sector mine located in Chandrapur district of Maharashtra owned by Maharashtra State Mining Corporation (MSMC) Ltd. Mining is carried out by semi-mechanised opencast mining method. The mine-head closing stocks of fluorite (graded) was 98,140 tonnes in 2021-22 as mentioned in National Mineral Inventory - Fluorite, n.d..

The world total reserves of fluorspar were at 260 million tonnes as per U.S. Geological Survey, 2023 and are concentrated mainly in Mexico (26%), China (19%), South Africa (16%), Mongolia (8%) and Spain (4%).

Conferring to (Geological Survey of India (Central Region), 2021; K. Randive, Jawadand, et al., 2021; K. Randive, Pantawane, et al., 2021), the mineralization in the Dongargaon fluorite mine occurs as cavity fillings and in disseminated veins. The samples collected from mineralized veins and bands of Dongargaon fluorite mine as purple fluorite associated with pinkish and white barite. Hydrothermal solution trapped by carbonate rock is credited to have produced the mineralization. Within the study area, barite is much less abundant than fluorite and therefore not exploited commercially. The area comprises of rocks of older metamorphics such as BMQ of Sukma Group and Bengpal Group of Archaean age. Bengpal Gneiss forms the basement for all the overlying litho units with regional NW-SE trend conforming to the Mahanadi Tectonic axis and has been strongly deformed and foliated. The Godavari Supergroup overlies the Archaean basement. The Supergroup has been categorized into the Pakhal, the Penganga, the Albaka and the Sullavai

Groups. The Penganga succession comprises three formations; the Pranhita Sandstone, the Chanda Limestone and the Sat Nala Shale, in depositional order.

As mentioned in the studies of Chaudhuri, 2003 and Mukhopadhyay & Chaudhuri, 2003, significant fluorite mineralization is hosted by Chanda limestone formation and are silicified and brecciated. Barite is seen associated with the fluorite mineralization. They are generally formed as purple fluorite along with pinkish and white barite. Entrapment of hydrothermal fluids by carbonate rocks of Penganga Group is believed to be the reason for fluorite-barite mineralization in Dongargaon area.

From the study of Deb, 2003, map-scale faults, folds, joints and fractures are also exhibited locally by the Chanda limestone formation. These local structural features cut across all the contractional tectonic structures and the presence of these structural features suggests that the opening of the niches for vein materials was caused by horizontal extension across the joints.

Shepherd et al., 1985, describes fluid inclusions are cavities in which homogenous or heterogenous fluid from which the crystal had grown is trapped. It thus portrays the likely formation environment (pressure, temperature, salinity, major chemical composition) of a rock or mineral.

Conclusions by Van Den Kerkhof & Hein, 2001, regarded fluid inclusions as defects present in the crystal lattice. Fluid inclusions in rocks at the surface of the planet are produced by high-temperature geological processes and re-equilibration during uplift which is partially influenced by crystal dynamics processes such as necking down.

K. R. Randive et al., 2014, after his experimental studies on fluid inclusions defined them as small volumes of paleo-fluids trapped in minerals that gives crucial knowledge about geological processes of past as well as environment of formation, at different temperatures with varying depths. The fluid inclusions are trapped liquids, gases or crystals that could be either trapped singularly (one-phase) or as a heterogeneous mixture of more than one phase (multi-phase) and within a single cavity.

The investigation conducted by Palmer & Williams-Jones, 1996, from the Amba Dongar region, India was determined to understand the genesis of the carbonatite-hosted fluorite deposit. The region is situated 400 km northeast of Bombay. Study of fluid inclusions, analysis of stable isotopes and mineral geochemistry of the whole-rock provided indications for the investigation.

Fluid inclusion studies from fluorite indicate a low temperature-low salinity (< 160ºC and 0.6-0.3 wt.% NaCl eqv.) ore fluid. The temperature and salinity decreased as it evolved. Oxygen and hydrogen isotope analysis of fluid inclusions imply that the ore fluid was significantly meteoric in nature and that it had equilibrated with sedimentary carbonate-bearing rocks.

The study over the Niederschlag mine, Erzgebirge, South-eastern Germany was done by Haschke et al., 2021, to understand the fluorite-(barite) deposit of, using the mineralogy, petrography, fluid inclusion studies and trace element geochemistry of fluorite related to the Niederschlag deposit. There were two stages of vein deposition. Stage I fluorite is older, fine-grained, associated with quartz and forms complex breccia and replacement textures whereas the younger Stage II fluorite is accompanied by barite and often occurs as banded and coarse crystalline open-space infill. The two fluorite stages have distinctive fluid inclusion and REY systematics. Fluid inclusions in fluorite I reveal the existence of a low-medium saline (7–20% eq. wt.) fluid with homogenization temperatures of 140–180°C, whereas fluorite II inclusions have lower (80–120°C) homogenization temperatures with at least two high salinity fluids involved (18-27% eq. wt.). The younger/stage II fluorite-barite mineralization has similarities to many fluorite-barite-Pb-Zn-Cu vein deposits in Europe that are widely accepted to be related to the Mesozoic opening of the northern Atlantic Ocean.

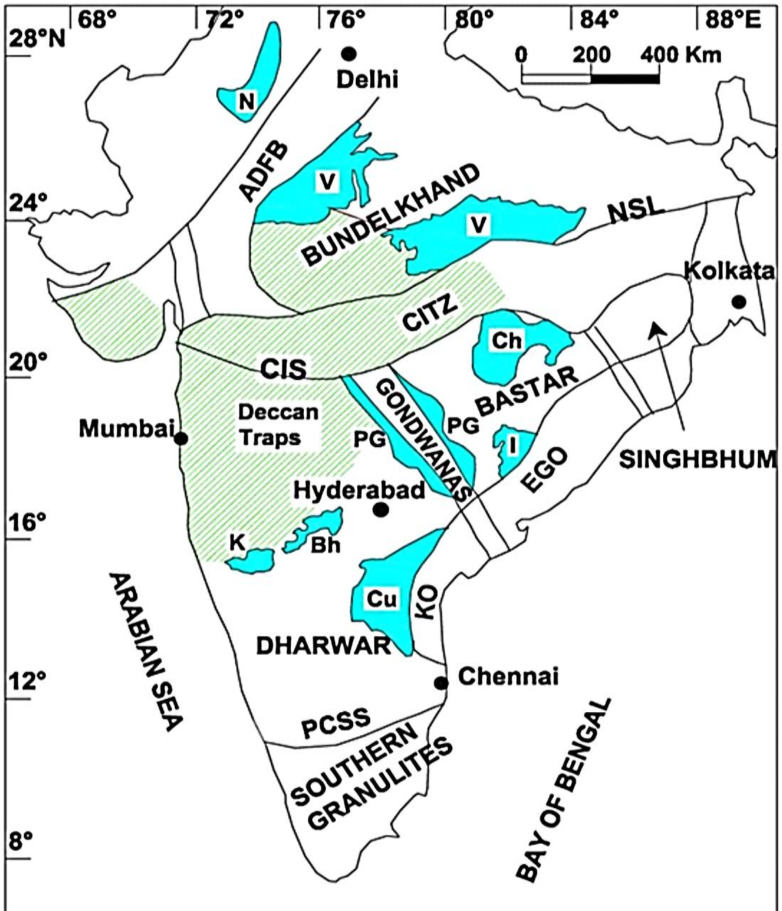
CHAPTER 3

GEOLOGICAL SETTING

3.1 Regional Geology

The Dongargaon mine is located at the western edge of the Bastar craton and between two prominent lineaments: the Godavari rift to the south and the Central Indian Tectonic Zone (CITZ) to the north. The Pranhita-Godavari valley's limestone deposition, specifically the Penganga Group of limestone, is where the fluorite-barite mineralization is found.

Photograph 3.1 Dongargaon Fluorite Mine



ADFB = Aravali-Delhi Fold Belt, CIS = Central Indian Suture CITZ = Central Indian Tectonic Zone, NSL = Narmada-Son Lineament PCSS = Palghat-Cauvery Shear System

Bh = Bhima, Ch = Chattisgarh, Cu = Cuddapah, I = Indravati, K = Kaladgi, N = Nagaur, PG = Pranhita-Godavari, V = Vindhyan

Figure 3.1 Map of Indian sub-continent showing the major cratons, basins, shear/suture zones, the Southern Granulites, lineaments and tectonic zones (Raza et al., 2021 Ore Geology Reviews)

The area comprises of rocks of older metamorphics such as BMQ of Sukma Group and Bengpal Group of Archaean age. Bengpal Gneiss forms the basement for all the overlying litho units. These basement granite gneisses and migmatites follow the regional NW-SE trend conforming to the Mahanadi Tectonic axis and has been strongly deformed and foliated with foliation trend varying from NNW-SSE to NW-SE direction with moderate to high dips (30° to 70°) towards west. A number of acidic and basic intrusive are intruded into the Bengpal Gneissic Complex (Geological Survey of India (Central Region), 2021).

The Godavari Supergroup overlies the Archaean basement. The Supergroup has been categorized into the Pakhal, the Penganga, the Albaka and the Sullavai Groups (K. Randive, Jawadand, et al., 2021; K. Randive, Pantawane, et al., 2021). The Pakhal Group marks the contact with the Achaean basement with a distinct unconformity. Penganga Group of Meso-Proterozoic age comprises of sandstone with thin intercalator bands of dark grey, fine-grained, massive, compact and reddish-brown purple, green/olive-green shale with impersistent thin limestone bands. The rocks of Penganga Group exposed over Dongargaon areas encompasses limestones with minor lime mudstones and shale sequence. These limestones are silicified and brecciated.

The Gondwana Supergroup includes continental rift-basin deposits that indicate a prolonged episode of continental sedimentation that began in the Permian and ended in the Cretaceous period, spanning for about 180 million years (Ravindra Kumar, 1991). It is made up of a 6-7 km thick sequence of fluviatile and lacustrine deposits with a glacial deposit at the base, indicating that it is of terrestrial origin with marginal marine deposits.

Lower Gondwana group mainly comprise of red argillaceous sandstone and conglomerate with interstratified shale. Sandstones representing the Gondwana Supergroup (Lower Gondwana) unconformably overlie the Penganga Group of Godavari Supergroup. Talchir Formation, which is representative of Upper Carboniferous, comprises of fine-grained, olive-green sandstone and at places it is intercalated with soft and calcareous shale. This formation is overlain by a coal bearing yellow sandstone of Barakar Formation. The Barakar formation consists of white to fawn coloured sandstones and grits with occasional conglomerates and beds of shale. This stage is containing much carbonaceous matter in the form of streak, lenticles and seams of coal. They represent the Permian Period of the Palaeozoic Era. Kamthi Formation of Upper Permian is ferruginous, buff yellow coloured arkosic sandstone as well as shale. Rocks of Penganga Group and Lower Gondwana Group are structurally deformed and folded along the NW-SE axis into a gentle anticline and is gently plunging in NW direction with a broad closure(K. Randive, Jawadand, et al., 2021; Ravindra Kumar, 1991).

Plant fossils are abundant in the Gondwana formations, and these floral varieties are primarily climate-dependent. Vertebrate and invertebrate fossils can also be noticed across the Gondwana Supergroup's strata. The common fossils of Lower Gondwana, flora like Glossopteris, Gangamopteris, Schizonuera and Phyllotheca have been recorded from Kamthi and Barakar Formations, indicating a period of Gondwanian deposition.

The Lameta Group is to the northeast of Gondwana rocks and are separated by a major boundary fault trending in NW-SE direction. They are implied by unclassified impure calcareous sediments including hard and compact limestone. The contact between the Lameta Formation and the Deccan Traps is undulating which indicates a phase of erosion of the Lameta sediments prior to the Deccan Trap eruption.

Deccan basaltic flow of Late Cretaceous overlies all the underneath strata. Pisolitic laterites of Cenozoic age overlie the deccan basalts which in turn is overwhelmed by the Quaternary alluvium consisting of gravel, sand, silt and clay (K. Randive, Jawadand, et al., 2021).

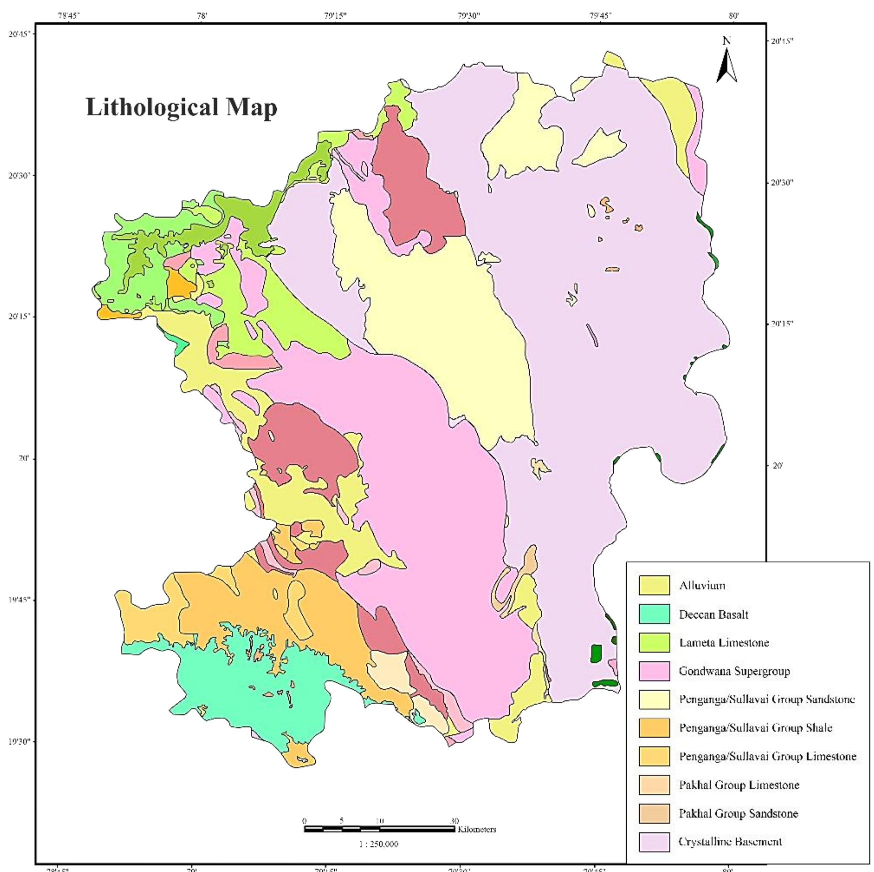


Figure 3.2 Lithological map of Chandrapur district, Maharashtra (simplified after GSI Central Region Chandrapur District Resource Map 2021) (Geological Survey of India (Central Region), 2021)

3.2 The Pranhita-Godavari Valley

It is believed that around 2500 Ma, the Indian Peninsula got stabilized. The stabilized Peninsula later got partitioned into northern and southern cratonic provinces, by an ENE-WSW trending tectonic zone, the Central Indian Tectonic Zone (CITZ). The Peninsula had formation of a number of large cratonic basins in the course of Late Palaeoproterozoic to Neoproterozoic and these large cratonic basins are known to as the Purana basins. The three major Purana basins of the South Indian cratonic province are the Pranhita-Godavari (PG) Valley, the Chattisgarh and the Cuddapah basin.

The Pranhita-Godavari Valley is a NW-SE trending valley which meets the Eastern Ghats Granulite Belt (EGGB) in the southeast and the Central Indian Tectonic Zone (CITZ) in the northwest. It is therefore a major lineament contained within the South Indian cratonic province and marking the contact between two major Archean nuclei, the Dharwar and Bastar cratons. The PG Valley is an intracratonic rift basin and a significant repository of Proterozoic sedimentary rocks in the Indian peninsula. These rocks unconformably overlies the Archaean-Palaeoproterozoic basement. The Pranhita-Godavari Basin outspreads for a stretch of ~400 km with a width of ~100 km. The sedimentation spanned for a large period of time of more than 600 Ma and the accumulated sediment thickness of the PG basin is assessed to be about 6000m. The Proterozoic sedimentary succession of the PG Valley, referred to as the Godavari Supergroup, is a collection of several unconformity-constrained sequences and is named after the Godavari River. The Godavari Supergroup exhibited multiple sedimentary, stratigraphic and structural features resultant to the intracratonic rift processes. The Valley preserves sedimentary deposit spanning for a vast period of time and these basin-filling sedimentary rocks are revealed for about 450 km stretch towards the south-eastern part of the basin. The basement of the PG valley also follows the general trend of NW-SE and is mostly linear. Limestone, dolomite and building stones are important resources of the PG basin, besides minor marble, barite and iron stone(Chaudhuri, 2003; Chaudhuri & Deb, 2004).

The stratigraphy of the PG valley continues to face much disputes that have been allied to the fault block upheaval in large-scale, by more than 1000 meters, varying degrees of subsidence and up-arching in diverse areas of the basin, and the overall erosion of thick sequences during the time range represented by the hiatuses. Two inter-regional unconformities that bound the Godavari

Supergroup separates it from the underlying Archaean crystalline cratonic basement and from the overlying Gondwana sedimentary sequence. The Godavari Supergroup is broken up into several large unconformities, some of which can be found all the way throughout the basin.

The Godavari Supergroup, the Proterozoic succession of the PG Valley, is distinguished by a wide range of lithofacies associations that testifies to several transgression and regression events as well as unequal rates of basin uplift and subsidence in both over time. There are indications of deposition in continental to deep marine environments in the lithologic assemblages. Two inter-regional unconformities that separate the Godavari Supergroup from the superimposing Gondwana Supergroup and the underlying Archaean-Palaeoproterozoic basement complex define its boundaries.

The Godavari Supergroup, have been classified into four major sequences, namely the Pakhal, the Penganga, the Albaka and the Sullavai, and these were separated by three regional unconformities towards the south-central part of the Valley. The Mallampali and Mulug Subgroups together constitute the Pakhal Group. The Pakhal and the Penganga sequences have been identified only along the southwestern margin of the Valley. The third and fourth sequences in the order of superposition, the Albaka and the Sullavai sequences respectively occur as widespread blanket deposits covering both sides of the PG Valley.

The Pakhal and Penganga Groups of the western belt is made up of mixed carbonate-siliciclastic assemblages. The Penganga Group and the Sullavai Group unconformably overlay the Pakhal Group one after the other. Both the Pakhal and the Penganga Groups were compressed in a NE-SW direction.

The thick sequences of conglomerate and coarse-grained arkose and siliciclasts over the fan-deltas and coastal fans represents the beginning of deposition of both the Mulug Subgroup and the Penganga Group and were followed by a thick succession of limestone and dolomitic limestone deposition. Diverse coastal-marine morphologies, including tidal flats, lagoons and banks define the carbonate accretion of the Mulug Subgroup along with indication of intermittent revelation. A thick deep-water ramp sequence deposited in a rapidly receding basin due to resultant intermittent faulting, subsidence and extension characterizes the carbonate depositional system of the Penganga Group. Thus, the sequences of the Mulug Subgroup and the Penganga Group that were evolved in two major transgressive events and divided by a significant pause, is now represented by the Pakhal-Penganga unconformity.

The Albaka Group is characterized of thick, blanket-type deposition of quartzarenite and shale having numerous dolomitic limestone lenses. These depositions took place majorly in shoreface and inner shelf environments together with open marine circulation and is indicative of a very stable tectonic system. The Sullavai Group is composed of thick sequence of red sandstone. The sequence revealed different depositional environment. Braided-streams represented the lower part of the depositional sequence where the upper part represented deposition in an extensive erg environment.

The thickness of the unconformity-bound sequences and numerous distinct formations increase from the central part towards the southeast region of the Valley.

The unconformity profile shows a greater rate of movement in the southeast portion of the PG valley than in the central portion, with reference to the episodic elevation and depression of the depositional boundaries. During the pre-Sullavai period, the central region exhibited positive behaviour, whereas the south-eastern region had negative behaviour. The south-eastern region was able to accommodate the building of thicker sequences due to higher subsidence in the negative area.

The stratigraphic trends specify that through the accumulation of the pre-Sullavai sequences, namely the Pakhal Group and the Albaka Group, the south-eastern part of the Valley basin was expanding and broadening at a greater rate than the north-western part and therefore the depositional width was much larger in the south-eastern area compared to north-western area of the basin.

The sequence of the mixed carbonate–siliciclastic over the central region of the northeastern belt differs significantly from the Pakhal Group mixed carbonate–siliciclastic sequence. Six formations were found in the sequence surrounding Somanpalli, which was referred to as the Somanpalli Group. The Somanpalli Group's link to the Pakhal or Penganga Groups continues to be a significant stratigraphic issue. Along the northern region of the PG Valley, the Albaka Group seems to be entirely absent but the area is dominated by the Somanpalli and Penganga Group. The southern portion of the Valley is where the Albaka Group mostly is formed and preserved. In the southwestern belt, the Mulug Subgroup underlies the Albaka Group and it is overlain by Sullavai

Group. In the north-eastern belt, it is overlain by the Sullavai Group and but a prominent fault has destroyed its lower contact.

Over the northern portion of the Valley, the Penganga and Somanpalli Groups hold the equivalent stratigraphic position between the Sullavai Group and the Pakhal Group, or the basement complex, and it is not known to contain Albaka rocks. Thus, the Albaka Group might be a lateral facies equivalent of the other two groups based on the distribution of these three groups in space.

It seems that the Valley's southern and northern regions had undergone markedly differing evolutionary processes.

3.2.1 Deformation structures

Map-scale faults and folds along NW-SE trending outcrops emblematize the Proterozoic succession of the Pranhita-Godavari basin. A set of steeply dipping-subvertical NW-SE trending faults which could be tracked for some hundred metres to more than 100 kilometres, marks the PG Valley. The faults run either parallel or subparallel to the rocks' depositional strike. Much of the faults show displacement ranging from a few hundred meters to over a few kilometres(Chaudhuri & Deb, 2004)

Photograph 3.2 Faulting in Penganga chert

The Pranhita-Godavari basin consists of a series of NNW-SSE grabens and half-grabens. The Godavari basin has been partitioned as two parallel sub-basins into the western and the eastern basins, by an ~40 km wide Godavari graben constituted by Gondwana sediments in the middle of the PG basin. The eastern sub-basin is termed as the Albaka belt and the western sub-basin is entitled as the Pakhal belt or Mallampali belt. The sub-basins also trend in NW-SE direction.

The Pakhal and the Albaka belts could have been once continuous and now separated by the Gondwana basin, or formed as two independent basins over two cratonic provenances, the Pakhal belt lying unconformably over the Archaean Dharwar craton and the Albaka belt resting with a tectonic contact on the Bastar craton. The Pakhal belt ranges from Khammam in the south to Adilabad in the north whereas the Albaka belt spreads from Bhadrachalam in the south to Chandarpur in the north.

The Pakhal and Penganga Groups are co-folded into a sequence of NW-SE trending anticlines and synclines in the middle region of the western belt of the basin, where the Pakhal, Penganga, and Sullavai Groups occur successively. The Somanpalli sequence in the eastern belt of the Valley documents consecutively built E-W strike-slip faults, imbricate thrust faults and associated shear zones, and NW-SE trending map-scale folds.

The age of the rock sequence is not well confined for the Godavari Supergroup by radiometric dating method. Lack of geochronologic data is the foremost constriction in establishing a time period for the PG basin filling events.

The unconformity profile of the Valley indicates that the key unconformity surfaces underwent upliftment and subsidence for a kilometre or more. It also suggests that various regions of the basin responded differently to the imposed tectonic stress. The south-eastern part of the basin moved up and down more dynamically than the central part. The amplitude of translation of the unconformity surfaces indicates a tectonically restrained movement of the depositional interface. The rocks of the Pakhal and Penganga Groups and their equivalents were affected by the major contractional deformation in the Valley.

The PG basin's tectonic behaviour was ‘oscillatory’ and the basin-filling processes were characterized by sudden shifts in the depositional mode brought on as a result of the quick upheaval of the basin floors along high-angle faults that extended from the basement to the sedimentary strata above.

A rift basin could be manifested by the oscillatory behaviour of the depositional interface along a slender linear zone, accompanied by large number of subparallel high angle faults and is the case of Pranhita-Godavari basin.

(Chaudhuri, 2003; Chaudhuri & Deb, 2004) (Directorate General of Hydrocarbon).

3.3 Local Geology

The Penganga Group is the unmetamorphosed Proterozoic sequence over the western fringe of the Pranhita–Godavari Valley which is dominated by deep-water lithographic limestone and shale. The sequence symbolizes a shallow shoreline to deep marine depositional environment. An early Mesoproterozoic is likely the depositional time frame of Penganga rocks. The Group overlies the basement gneiss unconformably along the south-western margin of the Valley. The Penganga succession comprises three formations; the Pranhita Sandstone, the Chanda Limestone and the Sat Nala Shale, in depositional order. The undeformed sandstones of the Sullavai Group unconformably overly the Penganga Group which in turn is overlain by Gondwana rocks.

The Pranhita Sandstone is a subarkosic sandstone with a thin shaly upper interval and with a thickness of 25–400 m marks the lower contact of the Penganga Group and is deposited in a shoreface environment. The Chanda Limestone is deposited in a deep-water environment encompassing a micritic limestone-shale sequence with numerous slope-associated autoclastic limestone mass-flow deposits, a lentil of glauconitic sandstone emplaced as submarine fan deposit and two regionally persistent horizons of deep-water bedded chert interstratified with manganese ore. The formation has a thickness of 300 m. The upper contact of the Penganga Group, the Sat Nala Shale is also a deep-water with 2000 m thickness marks but is a sand-free red to purple shale (Mukhopadhyay & Chaudhuri, 2003).

Sedimentary slope deposits and normal faults of outcrop-scale are present locally and presence of these structures indicate the deposition of rocks in extensional fault-controlled basins.

The Chanda Limestone formation is classified into three formal members the Bhimsari, the Bilari and the Ramai Members and an informal Brown heterolithic member. The categorization is based on composition, bedding features and stratigraphically regulated variants in colouration. The Formation members were deposited at different time periods of evolution under various oxidation and reduction conditions and at different regions of the platform (Mukhopadhyay & Chaudhuri, 2003).

Significant fluorite mineralization is hosted by Chanda limestone formation. These limestone deposits are silicified and brecciated. Barite is seen associated with fluorite mineralization in the formation. These Fluorite-barite mineralization occur as cavity fillings and in disseminated veins. They are generally formed as purple fluorite along with pinkish and white barite. Entrapment of hydrothermal fluids by carbonate rocks of Penganga Group is believed to be the reason for fluorite-barite mineralization in Dongargaon area.

(Chaudhuri, 2003; Mukhopadhyay & Chaudhuri, 2003; Randive et al., 2021)

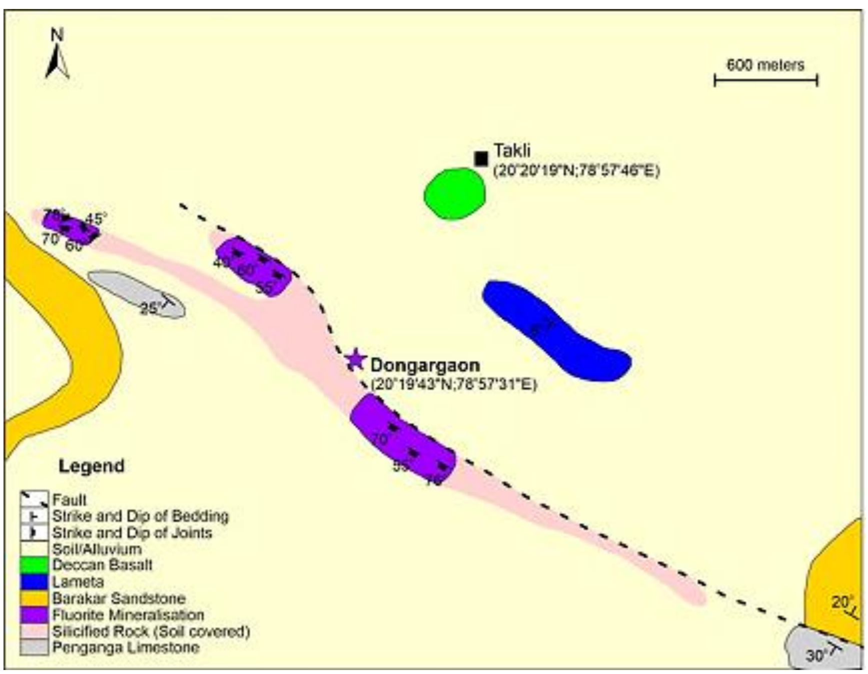
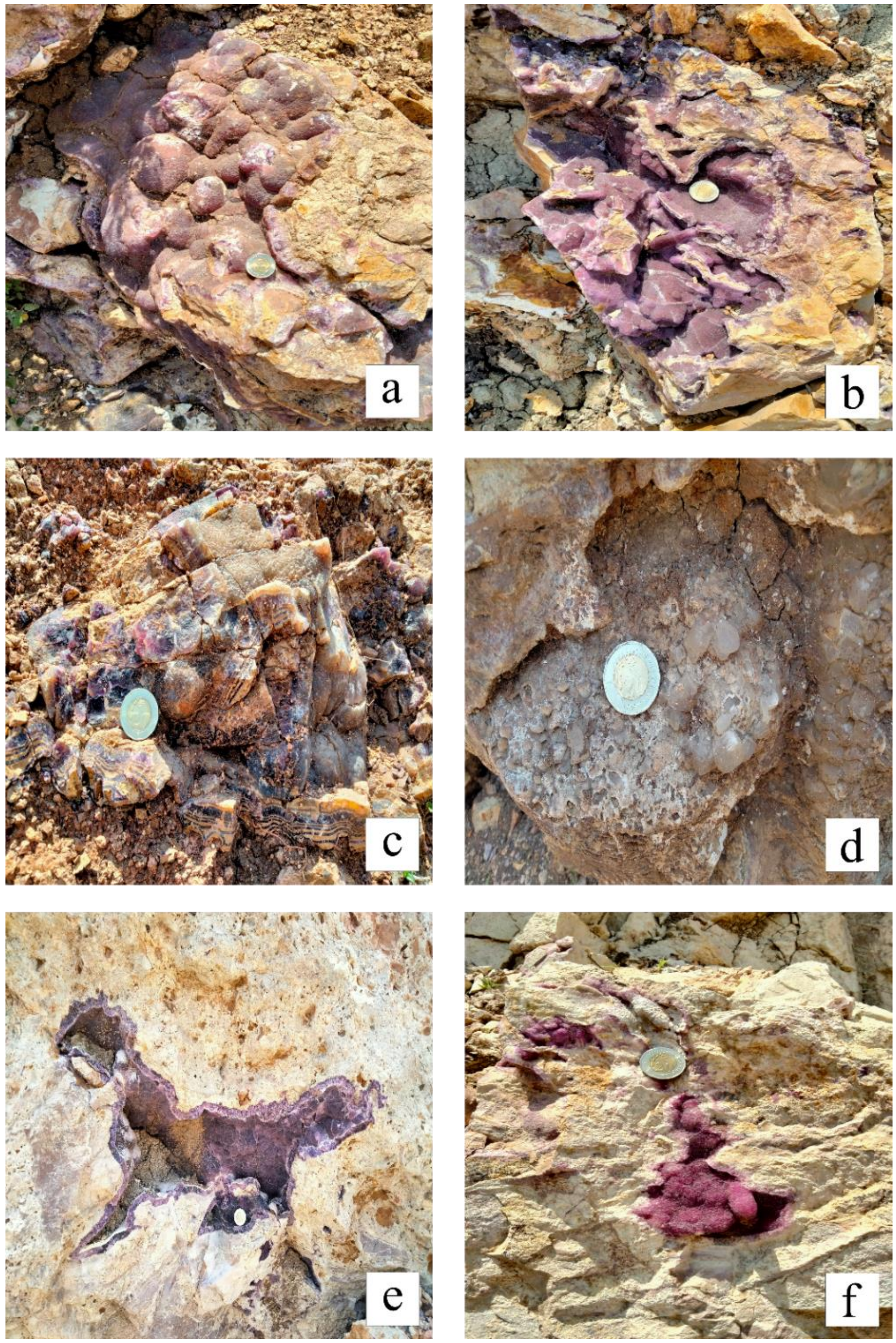


Figure 3.3 Local Geology Map of Dongargaon Mine

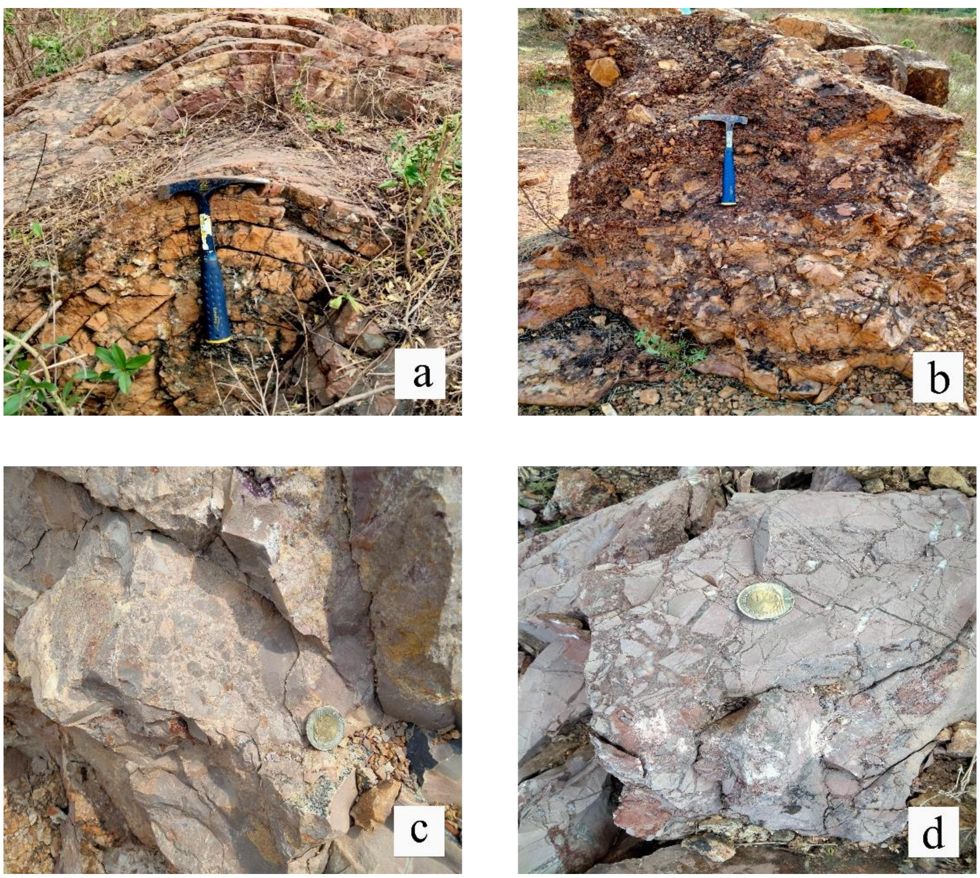


Photograph 3.3 Fluorite ores from Dongargaon Fluorite Mine; (a) & (b) Botryoidal-type fluorite, (c) Chert and fluorite bands, (d) Vein-type cubic fluorite, (e) & (f) Vug-type fluorite

Chanda limestone formation exhibits local structural features such as shear fractures, thrust faults, folds, joints and fractures of mesoscopic scale. The formation usually has slender (1–2 cm) calcite veins that are discontinuous and parallel to beds, in both flat lying strata and also along folded limestone beds.

The shear fractures in the formation are planar in the flat-lying strata and cut across single or multiple beds and makes sharp bends and become parallel to bedding. Segregated thin lenticular calcite masses are seen in bedding-parallel segments. Portions of the limestone beds are squeezed into pop-up structures at some parts. They generally reveal a curviplanar geometry in folded layers. Cataclasites, that are indicative of shear fractures are observed in this formation.

The thrust faults are having a smoothly curved geometry. These thrusts resulted in displacements that extends for a few millimeters to a few tens of centimeters. Zones of cataclasite and thin calcite veins locally depicted the thrusts.



Photograph 3.4 Structural features from Dongargaon Fluorite Mine and nearby locations; (a) Folding in Penganga chert, (b) Fault breccia in Penganga chert, (c) Fault breccia in Penganga chert, (d) Fault breccia in Penganga limestone

Folds of mesoscale nature are not seen related with faults. They arise as asymmetric pairs of anticlines and synclines, suggesting that tip-line folds were likely their ancestors. Mesoscale thrusts cut folds locally. The local folds Chanda limestone formation are generally asymmetric, doubly plunging, close to open with round, sinuous hinges. They are of class 1B as per Ramsay classification of folds.

Joints and fractures are also exhibited locally by the Chanda limestone formation. These local structural features cut across all the contractional tectonic structures. The presence of wall-perpendicular crystal development in calcite and quartz veins locally along the joint surfaces, suggests that the opening of the niches for vein materials was caused by horizontal extension across the joints.
(Deb, 2003)

CHAPTER 4

ANALYTICAL METHODS

4.1 Petrographic study

Petrography defines the systematic description and classification of rocks, primarily by microscopic analysis of thin sections of a rock/ore sample. It describes the origin, minerals composition, textural relationship and structural features of the rock, macroscopic and microscopic characteristics and thus helps in systematically grouping rocks/ores.

A significant objective of the microscopic study is that it helps to picturize the paragenesis of minerals which could also include ores and associated gangue minerals. Paragenesis defines the order of formation of associated minerals in time sequence. It gives an idea about the prevailed conditions during the formation or re-equilibration of a mineral. Paragenesis is vital in interpreting the geological history of the ore mineralization and helps in correlating different regions of the ore bodies and episodic mineralization, and therefore is of value in mineral exploration.

Merits and demerits of thin sections and polished wafers are given in table 4.1.

	MERITS	DEMERITS
THIN SECTION	• Readily available, easily prepared and conveniently stored. • Identification of minerals based on their optical properties may be performed. • Helps in establishing host rock petrography	• Cannot be used in heating stage studies as the mounting resin decomposes and darkens on heating and then fractures on cooling. • Results in the destruction of larger inclusions. • Tiny minerals fragments or lapping grit might get embedded in resin and may be mistaken as inclusions. • At higher temperatures (>100°C) while mounting samples, low temperature inclusions might get leaked.
POLISHED WAFERS	• Directly used on a heating/freezing stage. • Large inclusions are preserved and are permanently stored	• Due to greater thickness compared to thin sections, mineral identification by optical properties is difficult. • Very thin (< 100μm) wafers are required for highly coloured or milky samples, which are difficult to prepare and handle

Table 4.1 Merits and demerits of thin sections and polished wafers

4.1.1 Preparation of petrographic thin section

A side cutting station is used to cut the rock sample into pieces that are about 3 cm in size. To fix the rock sample, the glass slide's surface is ground to a rough texture using a mesh size of 800. To smooth the sample's flat surface, silicon carbide along with water are rubbed over it on a lapping plate. After that, epoxy resins (+ blue dye) are used to adhere the sample to the glass slide. After that, the sample is given at least eight (8) hours to dry. Using a thin saw, cut the sample to around 5 mm from the other side. After that, the sample is polished on a lapping plate with silicon carbide of various mesh sizes such as 400, 800, 1000, 1200, till the desired final thickness of 30 microns is reached (Fig. 4.1). It is important to notice here that as number of mesh size increases the powder size decreases.

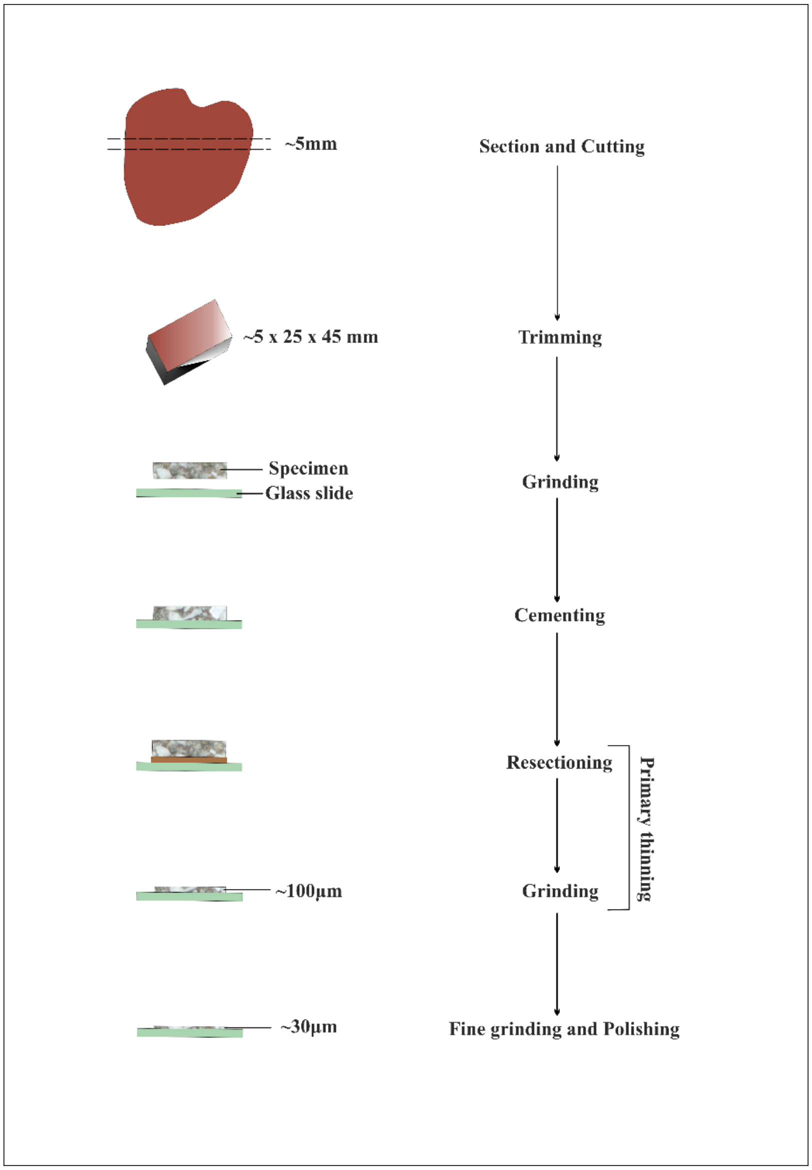


Figure 4.1 Basic steps in preparation of thin section

Twenty (20) petrographic thin sections were made from the rock samples taken from the study area, the Dongargaon Fluorite Mine, for conducting petrographic analysis. These petrographic thin sections were mentioned by the code: DFM/23/05, indicating the area under study i.e., the Dongargaon Fluorite Mine and the period of field study which was 2023 May. These twenty samples include host rock samples as well as mineralised fluorite ores.

4.2 Fluid inclusion petrographic study

Fluid inclusions depicts the possible formation environment (pressure, temperature, salinity, major chemical composition) of a rock or mineral since they are trapped portions of homogenous or heterogenous fluid from which the crystal had grown. They represent distinct samples of every fluid type that has evolved and interacted with the earth's crust and upper mantle over geological time. Understanding the nature, genesis and evolution of hydrothermal ore-forming fluids and ore genesis has been the most significant contribution of fluid inclusions. Fluid inclusions find applications as tracers in defining mineral provenances, in timing hydrothermal events, in gemmology and gem-testing and in determining overall strength of a rock (Shepherd et al., 1985). Fluid inclusions can also be defined as small volumes of paleo-fluids trapped in minerals that gives crucial knowledge about geological processes of past as well as environment of formation, at different temperatures with varying depths. The fluid inclusions are trapped liquids, gases or crystals that could be either trapped singularly (one-phase) or as a heterogeneous mixture of more than one phase (multi-phase) and within a single cavity (K. R. Randive et al., 2014).

Based on genesis fluid inclusions are classified in three categories (Table 4.2):

- Primary inclusions
- Secondary inclusions
- Pseudosecondary inclusions

PRIMARY	SECONDARY	PSEUDOSECONDARY
• Are formed during the crystallisation of the host crystal • Occur as isolated form • Trapped along the growth zones and crystal faces	• Develop in fractures after the formation of host crystal (during the healing of crystal) • Occur as trails or clusters cutting across grain boundaries	• Formation is similar to secondary inclusion but the fracturing and healing take place during the crystal growth • Occur along trails that end abruptly against growth zone or boundaries of the grain

Table 4.2 Genetic classification of inclusion

Figure 4.2 shows a schematic illustration of different types of fluid inclusions.

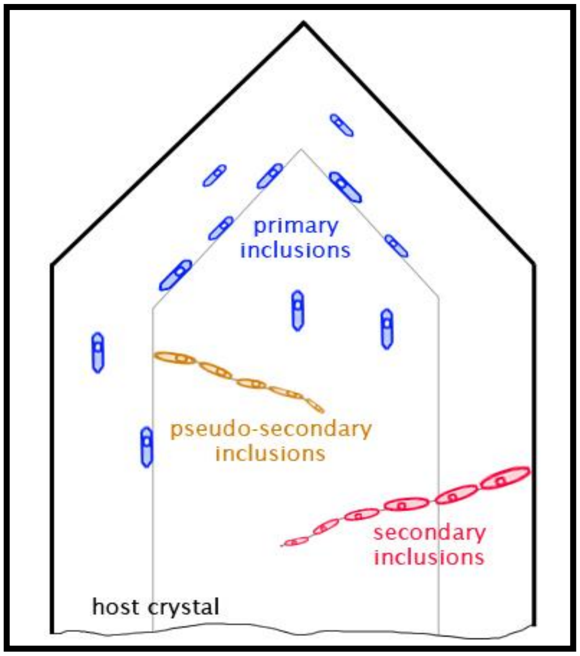


Figure 4.2 Schematic sketch showing the types of fluid inclusions: Primary, Secondary & Pseudosecondary

Fluid inclusions could be regarded as flaws present in the crystal lattice. Fluid inclusions in rocks at the surface of the planet are produced by high-temperature geological processes and re-equilibration during uplift which is partially influenced by crystal dynamics processes such as necking down (Van Den Kerkhof & Hein, 2001).

4.2.1 Roedder's Rules

For gaining dependable information about the original trapping conditions of fluid inclusions, regardless of primary or secondary inclusions, following assumptions are taken into consideration known as the "Roedder's Rules" (K. R. Randive et al., 2014).

- The inclusions should trap a single, homogenous liquid.
- Nothing is added to or removed from the inclusion after the trapping of the inclusion.
- The inclusion volume should remain constant following entrapment.

4.2.2 Degree of Fill (F)

The degree of fill (F) for a biphase aqueous inclusion is referred to as the volumetric proportion of liquid phase (V_L) to the total volume of the inclusion (V_{Tot}) and is given by the formula

$$F = \frac{V_L}{V_L + V_V}$$

$$= \frac{V_L}{V_{Tot}}$$

Degree of fill (F) helps in determining the overall density of an inclusions at the time of trapping of the inclusion. This estimation of overall density could picturize an approximate P-T isochore and thereby resulting in determination of minimum trapping temperature(Shepherd et al., 1985).

4.2.3 Preparation of wafer section

Choice of mineral is a significant step in wafer section preparation. Quartz is commonly considered as the best for wafer preparation, as it has a widespread geological occurrence, transparency and tendency to trap relatively large inclusions. Apart from that it sustains in highly weathering condition therefore preserve the fluid inclusions within it. Quartz should be ideally transparent or glassy in nature and therefore as a sample material, milky or translucent quartz varieties are mostly neglected since the inclusions present in it are expected to be very small. Other minerals that are relatively transparent and neither turbid or translucent, such as fluorite, apatite and topaz in particular, can yield good sample material. The vital criterion for any optical study of inclusions is that the wafer mineral should be transparent and lightly coloured. This doesn’t mean that opaque ore minerals are devoid of inclusions. Galena, in specifically, might have awfully well-formed cavities often evident on fresh cleavage surfaces. In soft, easily-cleaved minerals such as calcite and barite, chances of leakage and necking-down of inclusions are high. Thus, those minerals are sometimes considered less worthy. At first sight, the feldspar would appear ideal, but their fluid inclusions are usually too small and indistinct for detailed observations. In contrast, however, exceptionally well-developed melt inclusions can occur in igneous feldspar produced by rapid quenching. The variety of materials present and the geological setting in which the sample is found plays a major role in determining the choice of material for preparation of wafer section (Shepherd et al., 1985). The following is a list of the most common minerals used in fluid inclusion examinations:

1. Quartz
2. Fluorite
3. Halite
4. Calcite
5. Apatite
6. Dolomite
7. Sphalerite
8. Barite
9. Topaz
10. Cassiterite

Decide which mineral sample has to be examined for fluid inclusions. Minerals such as quartz and calcite are usually employed for examination as they are typically found in ore deposits and are good hosts for fluid inclusions. Using a rock or lapidary saw, cut a small portion of the mineral sample. The thickness of the portion should be between 100 and 300 microns so that light could be easily transmitted through it. Polish the wafer to ensure that there are no imperfections or scratches that could impede the analysis. A smooth surface can be obtained by a sequence of polishing processes using progressively finer abrasives, like diamond paste or alumina powder. Thoroughly clean the wafer to get rid of any debris, oil, or other impurities that could interfere with the analysis. The wafer can be cleaned using a solvent like acetone or ethanol. The wafer is then mounted onto a glass slide using a little amount of mounting material, such as epoxy resin or Canada balsam. Figure 4.3 below describes the entire procedure.

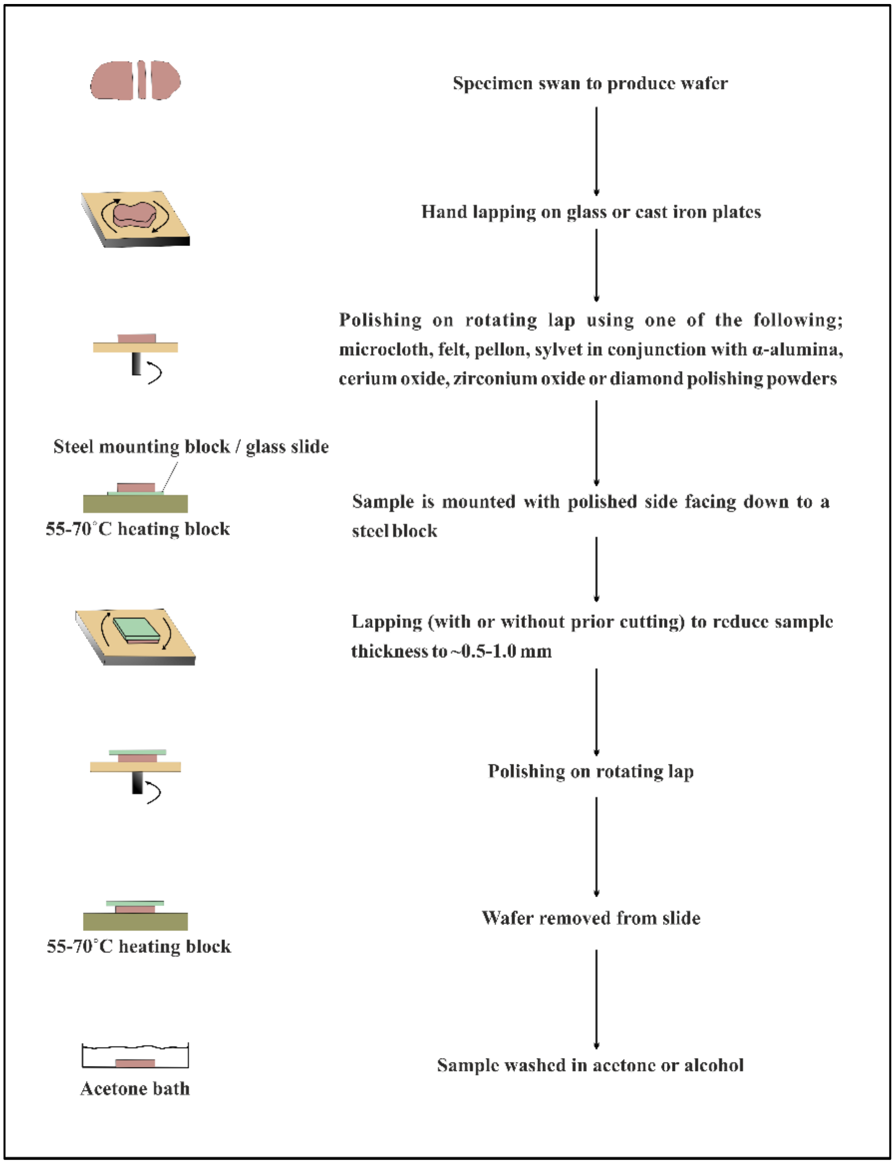


Figure 4.3 Basic steps in preparation of fluid inclusion wafers(Shepherd et al., 1985)

4.3 Microthermometry

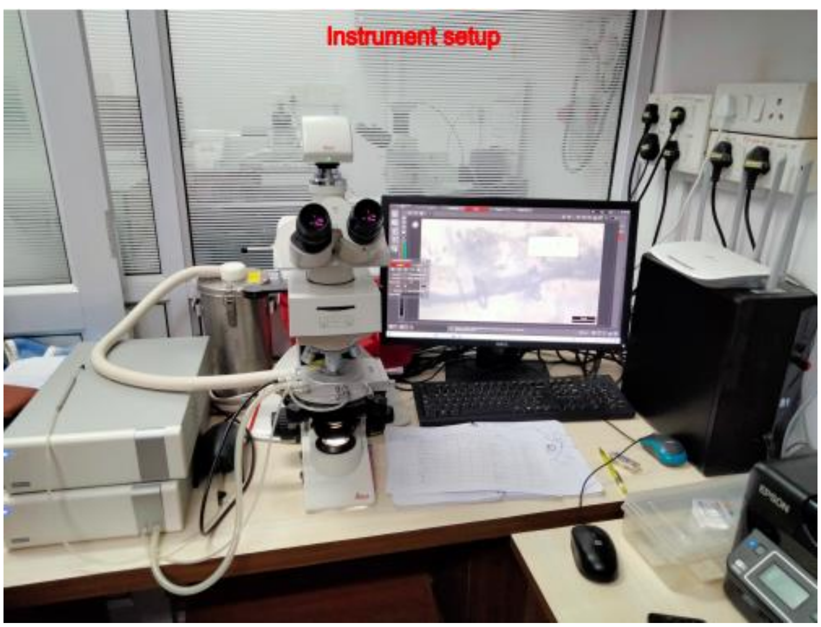
The microthermometric analysis of fluid inclusions is carried out with the help of a heating and cooling stage, a device that permits temperature changes over a broad range. The temperature at which these changes are occurring as well as the phase changes that are occurring can be seen by placing this stage under a microscope. As a standard operating procedure, the fluid inclusions are cooled to the lowest temperature the stage is capable of reaching. After that, phase changes are monitored as the temperature climbs back to room temperature. At the eutectic temperature, the first liquid in the cavity should appear, indicating the beginning of the liquid-phase phase change. Since this temperature is typical of every system, the composition of the fluid inclusion can be linked to a chemical system (K. R. Randive et al., 2014).

Based on microthermometric data, temperature of bubble bursting (T_{BB}), temperature of final ice melting (T_M Ice), temperature of homogenization (T_H) and salinity of inclusions could be calculated. Using these data, density of the inclusion can also be calculated. The overall salinity of the inclusion is given by the Bodnar equation, which is:

Salinity (wt.%) = $0.00 + 1.78\ T_M\ \text{Ice} - 0.0442\ (T_M\ \text{Ice})^2 + 0.000557\ (T_M\ \text{Ice})^3$ (Bodnar, 1993)

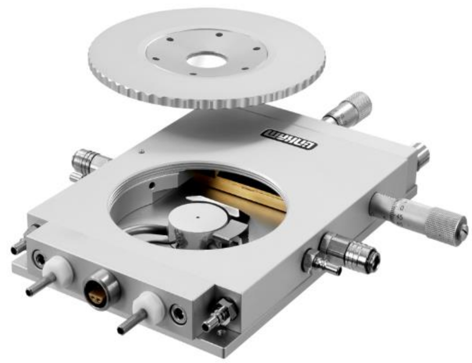
Microthermometric analysis of primary inclusions were carried at the Fluid Inclusion Laboratory of the Department of Earth Sciences, Indian Institute of Technology, Bombay.

The microthermometry experimental setup comprises of mainly three apparatus; Linkam THMSG600 heating-freezing stage, LNP96 liquid nitrogen cooling pump and T96-LinkPad temperature controller (Photograph 4.1).



Photograph 4.1 Instrumental setup

The Linkam THMSG600 heating-freezing stage (Photograph 4.2) is used to conduct the microthermometry of fluid inclusions whereas the LNP96 liquid nitrogen cooling pump, regardless of the chosen rate, regulates the pumping rate utilizing pumps and tubing to guarantee that the least amount of liquid nitrogen is used and a constant, smooth cooling curve is generated. The heating-freezing stage was fitted on a Leica (Leica DM 2700P) microscope, that allows the user to capture live images.



Photograph 4.2 Linkam THMSG600 Heating-Freezing stage

The stage has a temperature range of < -195°C to 600°C. The maximum hold time enabled during microthermometric analysis was thirty (30) minutes. Hold time represents the maximum time period for which the current temperature of the heating-freezing stage is maintained. The LNP96 liquid nitrogen cooling pump is used to enable a wide range of cooling rates from 0.01°C/min to 150°C/min. The wafer section is placed on a quartz crucible of 1.5 cm in diameter. The T96-LinkPad temperature controller is utilized to quickly create a temperature profile with the aid of the LINKSYS software installed in computer which in turn helps to control the temperature of the system and record the data. To facilitate even faster characterization, heating rates have been increased to 150°C/min.

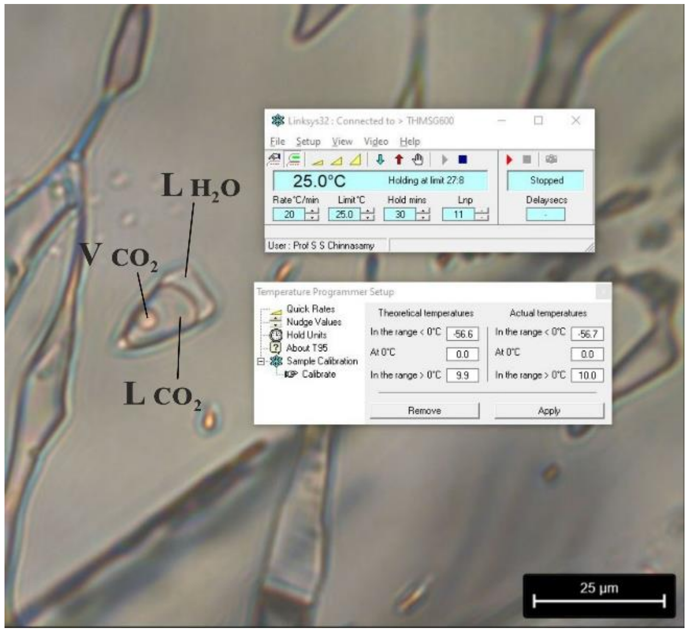
Before performing microthermometry of fluid inclusions, the Linkam THMSG600 heating-freezing stage was calibrated.

Photograph 4.3 Conducting microthermometric analysis

4.3.1 Calibration of Linkam THMSG600 heating-freezing stage

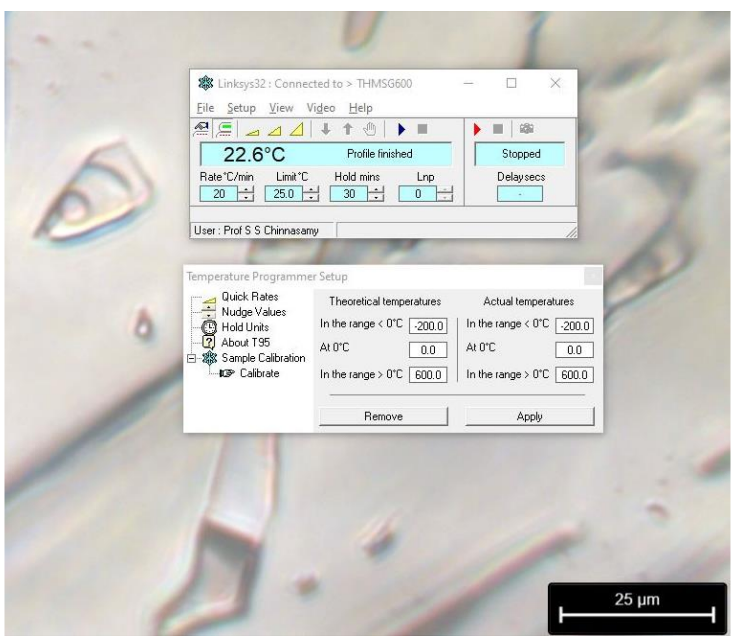
Calibration is a crucial component of thermometric analysis. Since the temperature sensor must be placed at a certain distance from the inclusion being measured, its temperature may differ from the inclusion's temperature, necessitating calibration. Additionally, this discrepancy gets larger when the stage's operating temperature moves away from ambient and therefore becoming significant cause of analytical uncertainty. To resolve this uncertainty, calibration has to be performed before analysis.

For calibration, mechanically separable synthetic H_2O - CO_2 inclusion was used. The inclusion was a polyphase inclusion comprised of three (3) mechanically separable phases; an aqueous phase, a liquid CO_2 phase and a gaseous CO_2 phase. The theoretical temperature of first melting of CO_2 (T_M CO_2) is -56.6°C, temperature of final melting of clathrate (T_M Clath) is -6°C to +12°C and temperature of homogenization of CO_2 (T_H CO_2) is +31.1°C. The apparatus might show some variations in actual temperatures of final melting and homogenization from the theoretical temperature and that is why calibration has to be performed.



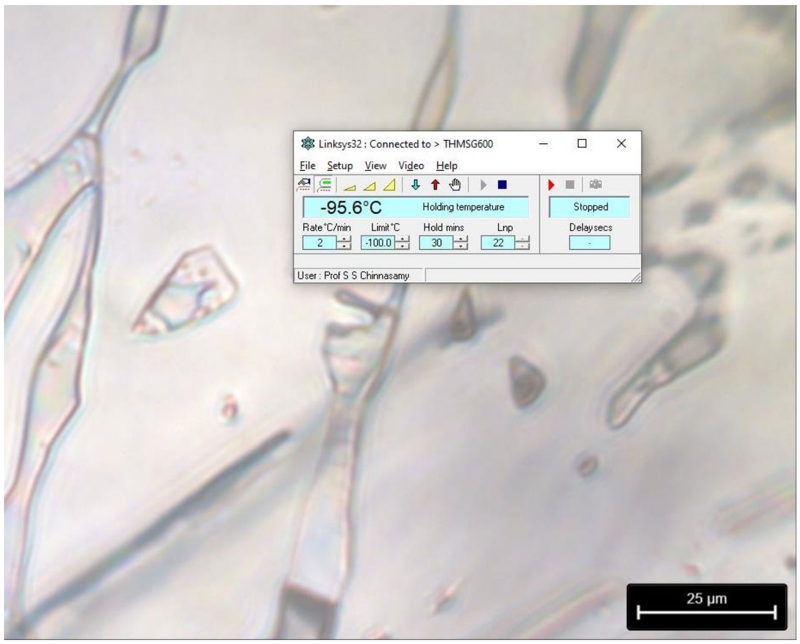
Photograph 4.4 Before stage calibration

For calibration, the stage was initially set to room temperature, i.e., 25°C and the mechanically separable synthetic H_2O - CO_2 inclusion in the wafer section was identified (Photograph 4.4). Then the actual temperature values pre-set in the LINKSYS software is noted. The existing theoretical as well as actual temperature values are removed from the LINKSYS software for starting the calibration (Photograph 4.5).



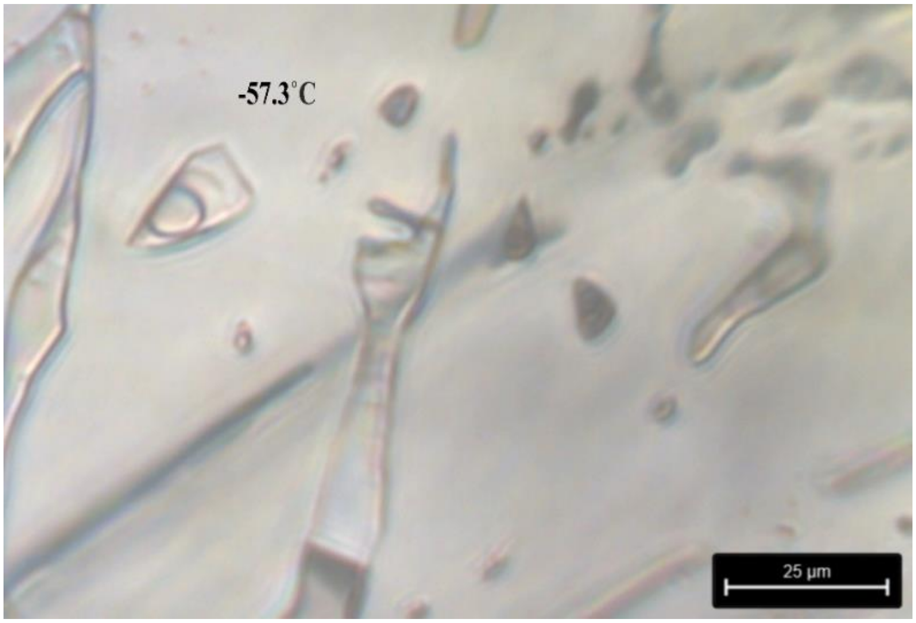
Photograph 4.5 Theoretical and pre-set actual temperature value

Liquid nitrogen is pumped to reduce the temperature of the stage. The stage is cooled till the bubble bursting happens inside the inclusion. Temperature of bubble bursting (T_{BB}) represents the temperature at which complete solidification (ice formation) of the inclusion takes place. In this synthetic H_2O - CO_2 inclusion, temperature of bubble bursting (T_{BB}) is found to be between -95°C to -97°C (Photograph 4.6).



Photograph 4.6 Temperature of bubble bursting (T_{BB})

The temperature is then increased. At -57.3°C, the CO_2 bubble completely reappears (Photograph 4.7), representing the temperature of first melting, i.e., melting of ice CO_2 (T_M CO_2). Complete melting of gaseous CO_2 occurs resulting in reappearance of bubble.

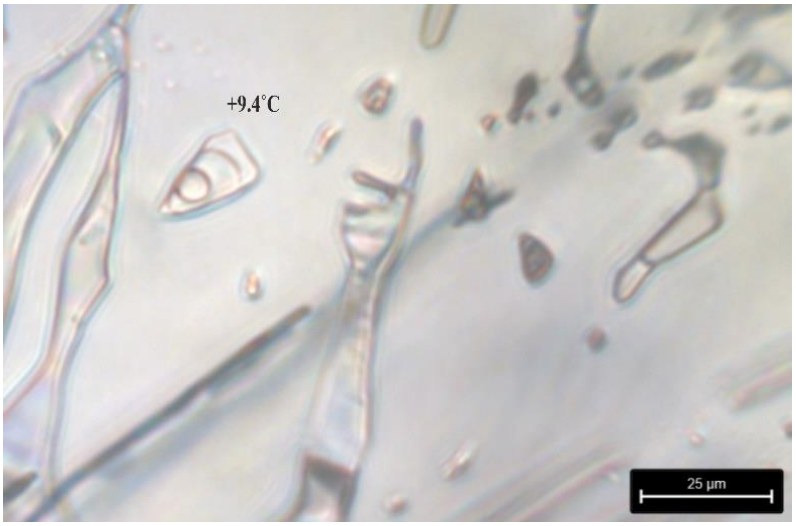


Photograph 4.7 Temperature of first melting of ice CO_2 (T_M CO_2)

The temperature is again increased. Clathrates becomes visible with rise in temperature.

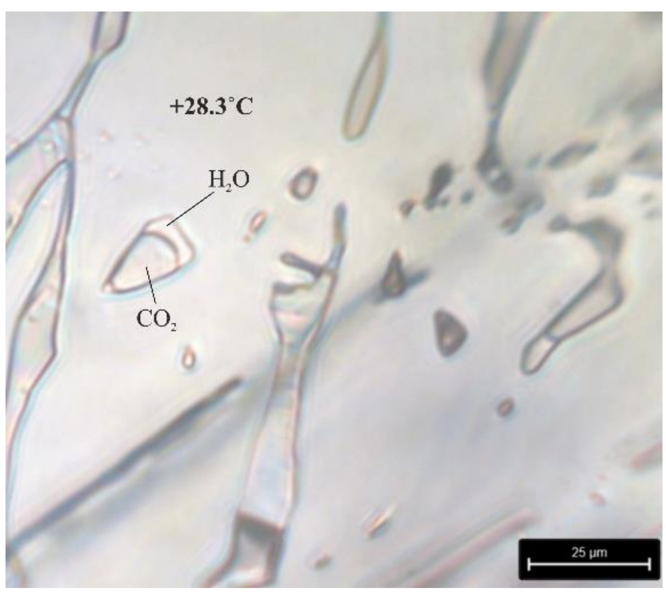
Clathrates are CO_2 hydrates (CO_2 . $5.5H_2O$). The interaction of the aqueous and non-aqueous phases during melting produces clathrates. Clathration takes place with the initial lowering of temperature (aorund -28°C). Aside from a minor angularity to the aqueous-liquid CO_2 boundary and a lessening in the volume of liquid CO_2, it is very difficult to detect clathration since the clathrates forming are generally colourless and isotropic in nature. These low-temperature compounds typically melt between -6°C and +12°C and retain a significant quantity of water in their structure. The withdrawal of water from the aqueous phase during clathration raises the concentration of salt in the leftover aqueous fluid, which causes the final ice melting temperature measured in the presence of clathrates to frequently be overestimated in relation to real salinity (Shepherd et al., 1985).

During calibration, the mean temperature of final melting of clathrate (T_M Clath) is measured to be +9.4°C (Photograph 4.8).



Photograph 4.8 Temperature of final melting of clathrate (T_M Clath)

The temperature is further increased till CO_2 homogenization temperature where liquid and vapour CO_2 homogenize into one phase either liquid or vapour. Homogenization is the process by which the mechanically separable phases of a fluid inclusion transform from a heterogenous (multi-phase) into a homogenous (single phase) state. For mechanically separable synthetic H_2O - CO_2 inclusion, the mean homogenization temperature of CO_2 phase (T_H CO_2) was attained at +28.3°C (Photograph 4.9). Total homogenisation of the synthetic fluid inclusion was avoided as inclusions with lower T_H values may be leaked in this process.



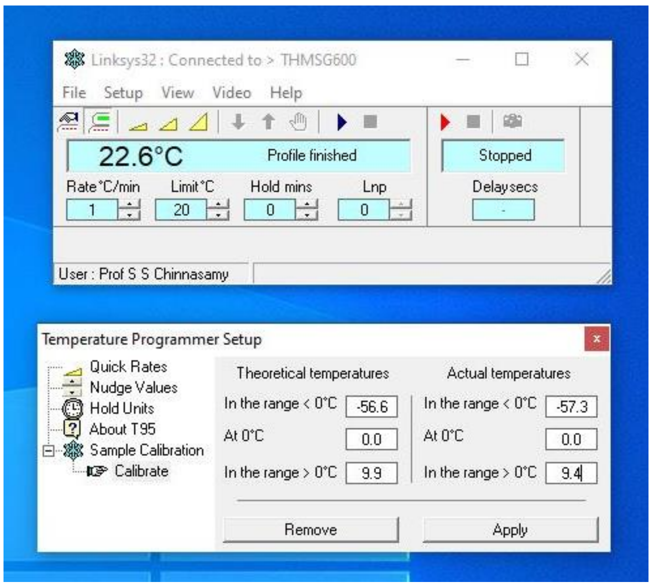
Photograph 4.9 Temperature of homogenization of CO_2 (T_H CO_2)

The calibration experiment was repeated for three times (Table 4.3) and the mean temperature values are taken.

T_{BB} (°C)	$T_{FM}CO_2$ (°C)	T_MClath (°C)	T_HCO_2 (°C)
-97.1	-57.3	9.4	28.3
-95.6	-57.3	9.4	28.3
-96.2	-57.3	9.5	28.2

Table 4.3 Calibration experiment measurements

The newly measured mean temperature values are entered in the LINKSYS software along with theoretical temperatures (Photograph 4.10).



Photograph 4.10 Addition of newly calibrated data

The calibration of Linkam THMSG600 heating-freezing stage is thus completed.

CHAPTER 5

RESULTS AND DISCUSSION

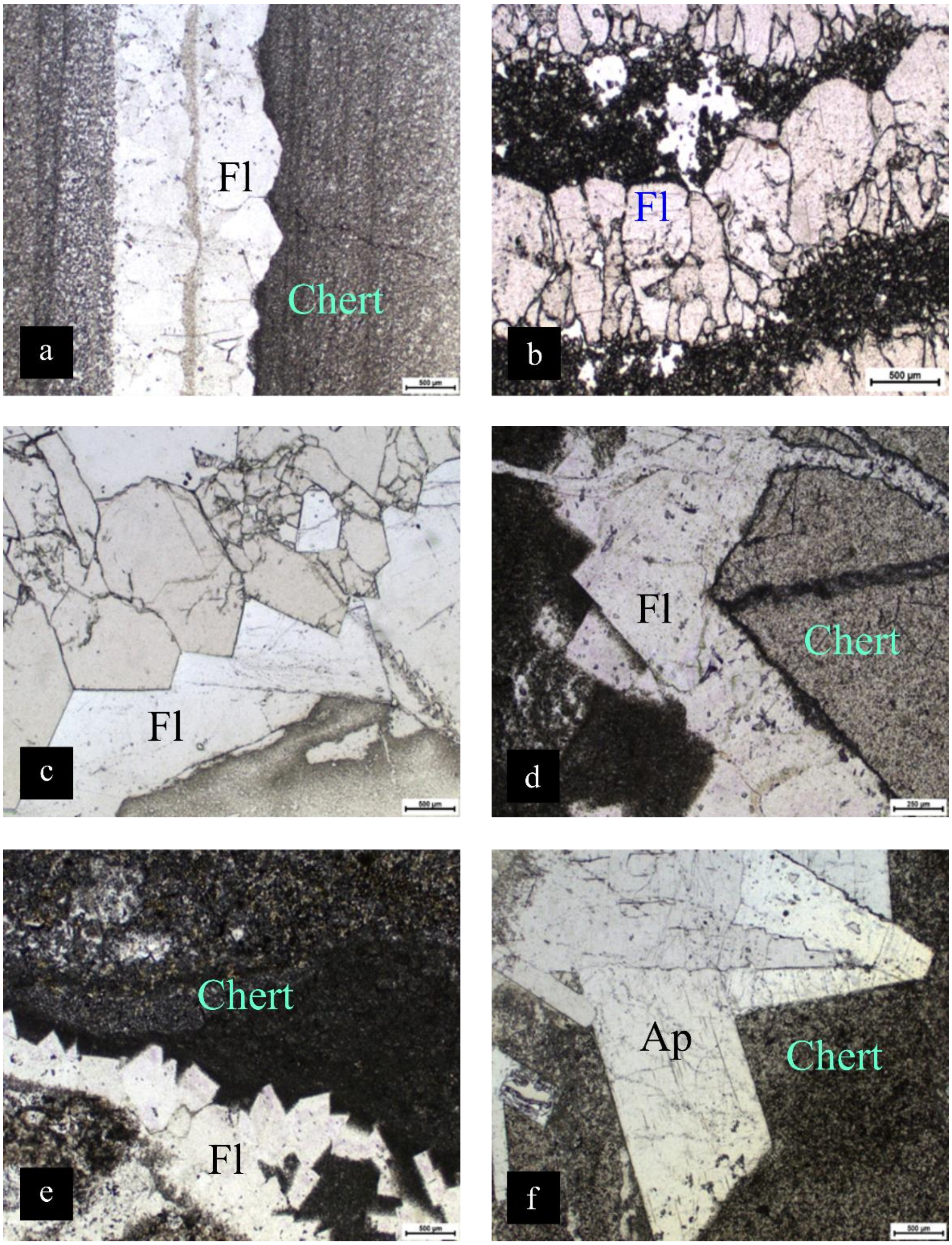
5.1 Petrography of whole-rock and hydrothermal mineral assemblage

In the detailed microscopic study of the petrographic thin sections, microcrystalline as well as cryptocrystalline grains with first order interference colours of yellow and grey, and having wavy extinction were observed. The microcrystalline grains lacked any cleavage. From the observed properties, the mineral is identified as microcrystalline and cryptocrystalline grains of quartz. The rock is thus identified as Chert. It is a sedimentary rock which generally forms due to accretion of dissolved silica into microcrystalline and cryptocrystalline varieties of silicon dioxide (SiO_2). The chert is possibly brecciated, since breccia fragments were observed in multiple petrographic thin sections. Eighteen (18) out of the examined twenty (20) thin sections, comprises chert. The remaining two petrographic thin sections; DFM/23/05 - 6A and DFM/23/05 - 6B, exhibited a twinkling effect along with crystals having perfect rhombohedral cleavage. Thus, the sections were identified as Calcite and Micritic limestone (microcrystalline). The micrite appearance is due to the recrystallization of lime mud.

Thus, from the microscopic study of petrographic thin sections, the host rock of the study area is established as Chert and Limestone. The recrystallization, brecciation and alteration of host rocks are due to hydrothermal action.

It is evident that the mineralization in the area is hosted by chert and limestone. The hydrothermal mineral assemblages are hosted in the fractures, cracks and openings present within them, as a result of hydrothermal activity.

The major mineral that could be identified in the petrographic thin sections of the study area, mainly by its isotropic nature (i.e., complete extinction) under crossed-polars (XPL) is the Fluorite. The fluorite deposits commonly exhibited a sharp contact with the host rock, which is indicative of a hydrothermal depositional phase. The fluorite grains also exhibited partial square formations, which is due to space constraint. The fluorite grains are subhedral to anhedral in shape showing medium to coarse grained texture. The fluorite mineralization is possibly identified in sixteen (16) petrographic thin sections out of twenty (20). Thus, Fluorite is the most abundant mineral in the hydrothermal mineral assemblage of the area.



Microphotograph 5.1 Petrography images under PPL; (a, c, d & e) Cubic fluorite mineralization in chert; (b) Botryoidal fluorite mineralization in chert; (f) Apatite mineralization in chert.

The second most abundant hydrothermal mineral is seen associated with fluorite, exhibiting second order interference colours and two set of cleavage with cleavage angle close to 90˚ and was identified as Barite. In the thin sections, the interference colours shown by barite is controversial as generally their interference colour is first order grey.

Coarser quartz grains were also observed, associated with the microcrystalline varieties and the coarser texture could be due to recrystallization of grains. Another microcrystalline variety of quartz, chalcedony was also identified in few samples. Hydrothermal quartz is the third most abundant mineral in the hydrothermal mineral assemblage.

In some of the samples a mineral is seen associated with quartz and barite, with parallel extinction, first order grey interference colour and polysynthetic twinning and the mineral is identified as Apatite. It is the least abundant mineral contributing to the hydrothermal mineral assemblage.

The hydrothermal mineral assemblage in the study area is thus identified as, Fluorite - Barite - Quartz - Apatite. The mineral assemblage of each sample examined is shown in the Table 5.1.

The mineralization in the host rocks occurred as veins (banded veins, disseminated veins and veins of variable thickness), cavity fillings and also as replacement deposits. Alternating parallel banded structure of host rock and mineralization was observed in the petrographic thin sections. Chert exhibited microcrystalline as well as cryptocrystalline texture. Limestone varieties were of microcrystalline (micritic limestone) and medium to coarse grained texture. The hydrothermal minerals exhibited partial crystal formations, especially hydrothermal fluorite grains showed partial square formation, which is due to space constraint. The fluorite grains are subhedral to anhedral in shape showing medium to coarse grained texture. Other minerals of the hydrothermal mineral assemblage are also subhedral to anhedral in shape with medium to coarse grained texture.

From the mineralization, structural features such as veins, sharp contacts, breccia formation and alterations of the host rocks, and the mineral assemblage, the causative factor is evidently hydrothermal in nature and thus proving the existence of a hydrothermal depositional environment in the study are, the Dongargaon Fluorite Mine.

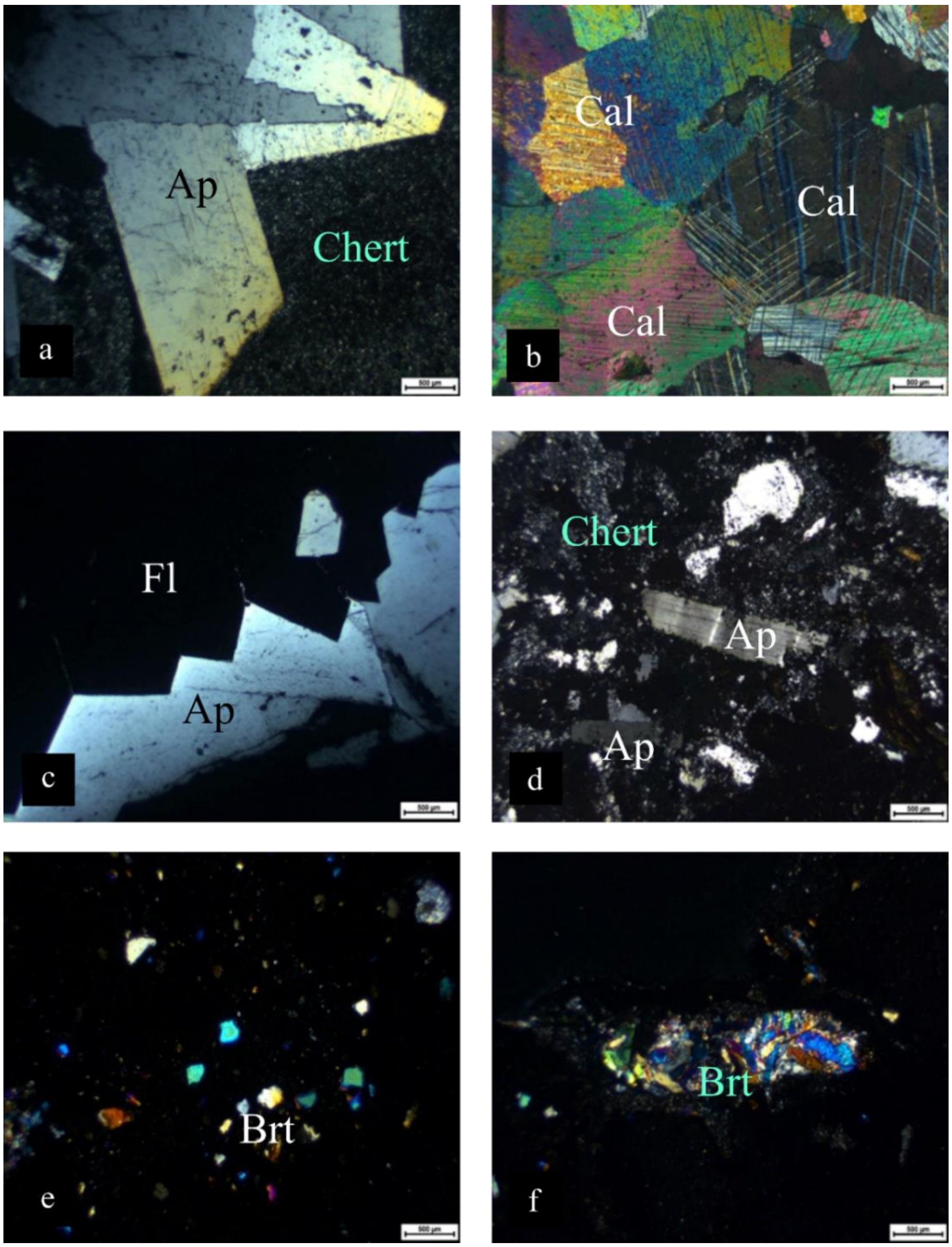
Barite mineralization in the study area might be of different generation. Two barite varieties are seen mineralized here:

- Barite having higher order interference colour, but with finer grain size

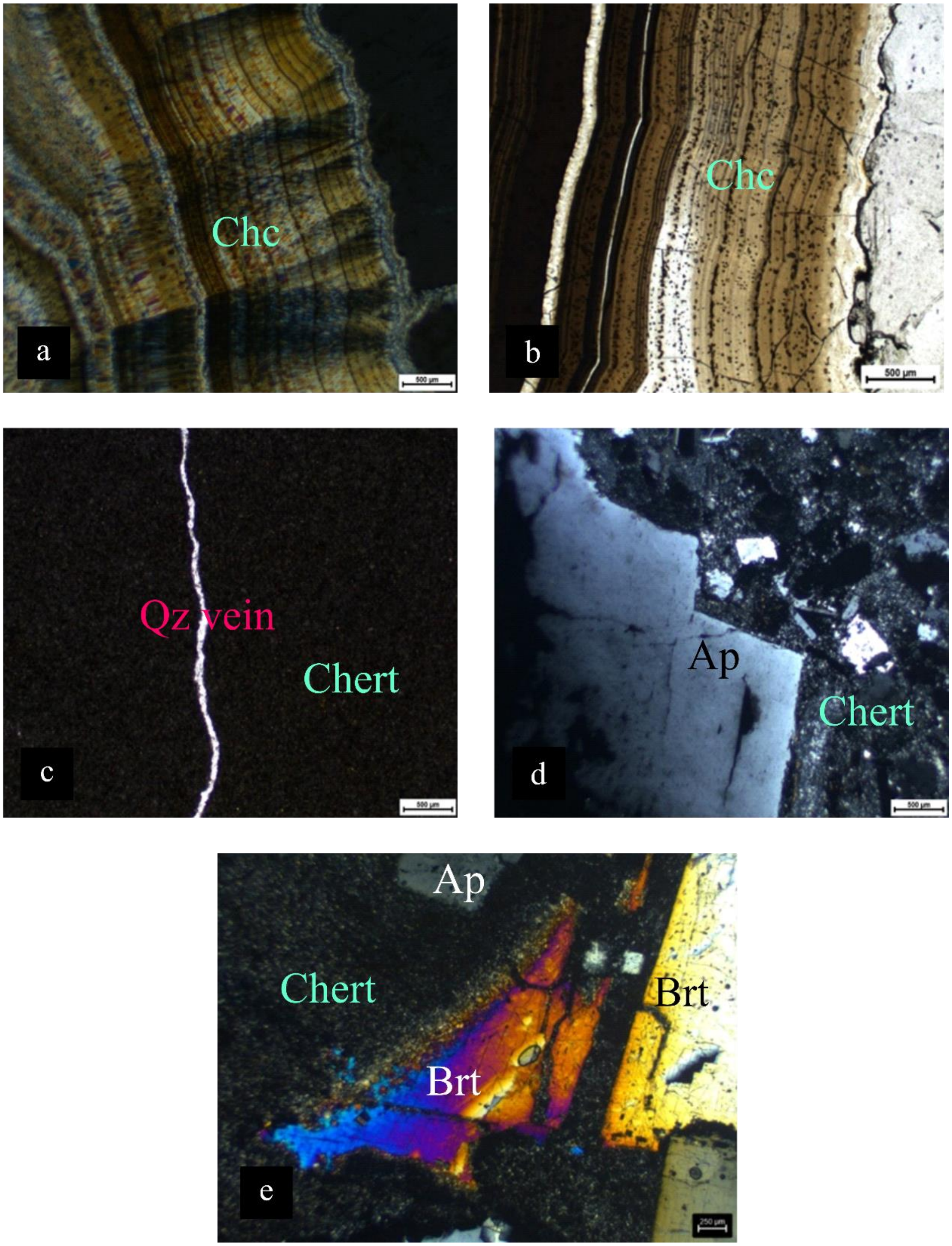
- Barite having first order interference colour, but with much coarser grain size and crystalline nature

Barite with higher order interference colour commonly seen associated with Fluorite.

Photograph 5.2 and Photograph 5.3 picturizes the hydrothermal mineral assemblage of Dongargaon fluorite mine.



Microphotograph 5.2 Petrography images under XPL; (a, c & d) Apatite mineralization in chert; (b) Calcite crystals; (e & f) Barite mineralization in chert.



Microphotograph 5.3 Petrography images under XPL (cont.); (a & b) Chalcedony seen associated with fluorite; (c) Quartz vein in chert; (d) Apatite mineralization in chert (f) Barite mineralization along with Apatite in chert.

Sample Code DFM/23/05	MINERAL ASSEMBLAGES					
	Fluorite	Barite	Quartz	Apatite	Calcite	Microcrystalline Calcite
2A	● (High)					
2B	● (High)	● (Moderate)	● (Low)	● (Very low)		
2C	● (High)	● (Moderate)				
4			● (High)			
6A					● (High)	
6B						● (High)
8A	● (High)					
10B	● (High)					
10C	● (High)	● (Low)	● (Moderate)			
11	● (High)		● (Moderate)			
12B	● (High)					
14A		● (High)				
14B		● (High)		● (Moderate)		
15	● (High)	● (Moderate)				
17A	● (High)	● (Low)	● (Moderate)			
17B	● (High)	● (Low)		● (Moderate)		
18	● (High)	● (Low)	● (Moderate)			
19	● (High)	● (Very low)	● (Moderate)	● (Low)		
20A	● (High)	● (Moderate)	● (Very low)	● (Low)		
20B		● (High)	● (Low)	● (Moderate)		

Abundance in the increasing order

● High ● Moderate ● Low ● Very low

Table 5.1 Hydrothermal Mineral Assemblage

5.2 Fluid inclusion studies and microthermometric analysis

Nine (9) wafer sections were prepared that represents the mineralization of Dongargaon fluorite mine. Out of these nine wafers, two (2) of the wafer sections have inclusion as clusters (DFM/23/05 - 1; Chip - 3 and DFM/23/05 - 14C; Chip - 1). Inclusions identified from the doubly polished wafers were all primary inclusions. They were randomly positioned, distant and isolated from other inclusions and were all within the same grain and therefore identified as primary inclusions. All the primary fluid inclusions exhibited biphase nature (i.e., mechanically separable two distinct phases). A liquid phase and a vapour phase constituted the biphase nature.

The microthermometric analysis data and fluid inclusion details are depicted in Table 5.2.

Sample Code	Chip no.	Sl. No.	P/S/Ps	Shape	DF	Size (μm)	T_M Ice (˚C)	T_H (˚C)	T_{BB} (˚C)
DFM/23/ 05 - 1	1	1	P	Irregular	0.95	~13	-	-	-37.3
		2	P	Elongated triangle	0.8	~11	0.2	-	-38.8
		3	P	Triangular	0.75	~05	3.5	-	-37.1
	2	1	P	Irregular	0.95	~13	0	237.7	-36.9
		2	P	Irregular	0.85	~25	0	> 290	-29
		3	P	Elongated	0.9	~08	0.1	250	-37.3
		4	P	Oval	0.85	~10	0.1	> 290	-36.9
	3	1	P	Irregular	0.95	~26	-	> 290	-27.8
		2	P	Elongated	0.95	~09	-	228	-37.4
		3	P	Elongated	0.9	~10	0	>290	-37.9
		4	P	Sub-rounded	0.7	~03	-0.1	248	-37.9
		5	P	Triangular	0.6	~04	-0.1	>290	-38.3
	Cluster	1	P	Elongated	0.7	~12	0	-	-35.8

		2	P	Oval	0.95	~07	-0.1	240.8	-37.7
		3	P	Elongated	0.95	~09	-0.1	>290	-37.4
		4	P	Triangular	0.95	~07	4.8	213	-37.7
		5	P	Rectangular	0.9	~06	3.6	194	-37.6
		6	P	Triangular	0.9	~07	0	>290	-37.5
		7	P	Elongated	0.8	~15	0	-	-37.1
		8	P	Elongated	0.9	~10	0	-	-38
		9	P	Elongated	0.75	~06	5.9	110	-37.4
		10	P	Triangular	0.8	~09	4.2	245	-37.6
		11	P	Triangular	0.85	~08	0	>290	-38.1
		12	P	Elongated	0.9	~18	9.2	>290	-37.7
		13	P	Elongated	0.7	~12	-	-	-
		14	P	Elongated	0.95	~20	-0.1	222	-37.3

DFM/23/05 - 2C	1	1	P	Irregular	0.9	~12	0	206	-37.7
		2	P	Irregular	0.95	~10	0	185	-37.4
		3	P	Elongated	0.95	~08	0	>290	-37.7
		4	P	Crescent	0.75	~04	2.6	150	-37.9
		5	P	Irregular	0.85	~25	0	>290	-37.2

DFN/23/05 - 11	1	1	P	Triangular	0.7	~06	-0.1	>290	-38.2
		2	P	Triangular	0.85	~06	-0.2	210	-37.6
		3	P	Triangular	0.9	~07	-0.2	180	-37.3
		4	P	Elongated	0.9	~23	-0.1	167.7	-37.7
		5	P	Rectangular	0.65	~10	-0.1	>290	-38.1
		6	P		0.95	~06	0.1	274.8	-37.6
		7	P	Triangular	0.75	~05	0.1	232	-37.4
		8	P	L-shaped	0.95	~18	0.1	>290	-37.4

		9	P	Elongated	0.85	~50	-0.1	231.2	-37
		10	P	Triangular	0.6	~11	-0.1	>290	-37.7
		11	P	Elongated	0..95	~13	0.1	240.7	-37.2
		12	P	Elongated	0.9	~14	-0.1	253.7	-37.8
		13	P	Elongated	0.9	~30	-0.1	254	-33.6

DFM/23/05 - 14C	1	1	P	Irregular	0.95	~17	-0.2	238	-37.2
	Cluster	1	P	Elongated	0.8	~30	-0.2	-	-
		2	P	Elongated	0.95	~20	0.1	-	-
		3	P	Rectangular	0.9	~06	-	226	-
		4	P	Rectangular	0.9	~05	0.2	188	-31.2

DFM/23/05 - 20	1	1	P	Bell shaped		~14	0.1	>290	-38.1
		2	P	Elongated		~07	0	>290	-37.5
		3	P	Elongated		~22	0.1	>290	.37.3
		4	P	Elongated		~05	0	>290	-37.5
	2	1	P	Triangular		~08	-	-	-38.3
		2	P	Elongated		~12	0	>290	-38.3
		3	P	Triangular		~07	17.7	197.5	-38.3
	3	1	P	Elongated		~28	0.1	223.3	-29.3
		2	P	Elongated		~14	0.1	274.6	-37.3
		3	P	Elongated		~25	0	-	-36.9
		4	P	Elongated		~30	0	-	-37.3
		5	P			~10	0.1	239.3	-37.3
		6	P	Oval		~07	0.1	237	-36.9
		7	P	Triangular		~06	0	>290	-37.8

		8	P	Oval		~30	0.3	184	-37.2
		9	P	Oval		~25	-0.2	-	-37.7
		10	P	Elongated		~40	0	-	-37
		11	P	Elongated		~12	0.1	-	-34.5
		12	P	Elongated		~09	0.4	269	-37.5
		13	P	Triangular		~05	0.2	266.8	-37.3
		14	P	Triangular		~07	0.2	259	-37.5

Table 5.2 Microthermometry data

The fluid inclusions have a size range of ~5 μm to ~50 μm (Figure 5.1) and exhibited varying shapes such as triangular, elongated, oval, irregular, etc with majorly high degree of fill (F) and with less variation.

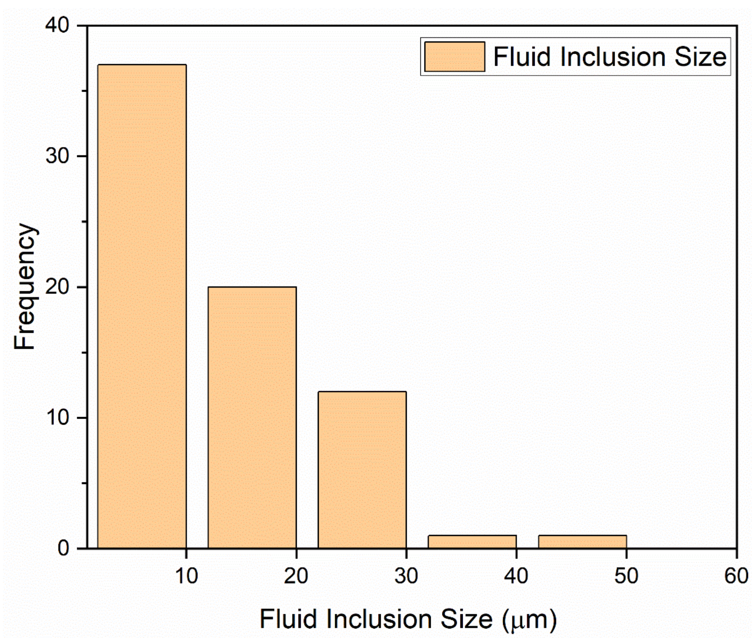


Figure 5.1 Size frequency plot of fluid inclusion

The identified primary inclusions then underwent micro thermometric analysis. Using the analysis, the temperature of final ice melting (T_M Ice) of all the inclusions within a wafer was initially estimated followed by the estimation of temperature of homogenization (T_H). During estimation of temperature of homogenization (T_H), temperature is usually raised to ≤ 290℃. The rising of temperature might result in the decrepitation of the inclusions present within a wafer. To avoid the chances of decrepitation, estimation of temperature of final ice melting (T_M Ice) of all the inclusions within a wafer is done before the estimation of temperature of homogenization (T_H) of the same inclusions.

The inclusions were initially cooled to -50°C. All the inclusions froze and the bubbles within the inclusions burst over a temperature (T_{BB}) range of -27°C to -39°C. For all the primary inclusions, temperature of first melting (T_{FM}) is not observable. If an inclusion possesses high salinity concentration, then it would exhibit higher refractive index than normal refractive index of pure water (> 1.333) and therefore changes occurring within the inclusion is easily observable. Temperature of final ice melting (T_M Ice) ranges from -0.2°C to 0.4°C for majority of the inclusions, indicating a very low salinity concentration in the inclusion (i.e., more of an aqueous nature). Fewer inclusions exhibited temperature of final ice melting (T_M Ice) > 0.4°C (2.6°C, 3.5°C, 3.6°C, 4.2°C, 4.8°C, 5.9°C and 9.2°C) . This higher temperature of final ice melting (T_M Ice) could be due to presence of some dissolved gases. Figure 5.2 shows frequency plot of temperature of final ice melting (TM Ice)

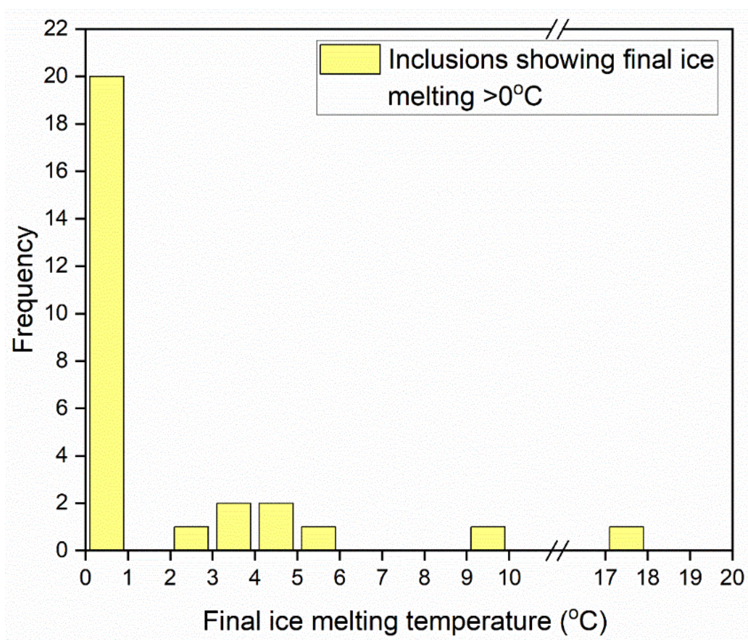


Figure 5.2 Frequency plot of temperature of final ice melting (T_M Ice)

The salinity of the inclusions is calculated from the estimated temperature of final ice melting (T_M Ice) values, using the Bodnar equation:

Salinity (wt.%) = $0.00 + 1.78\ T_M\ \text{Ice} - 0.0442\ (T_M\ \text{Ice})^2 + 0.000557\ (T_M\ \text{Ice})^3$ (Bodnar, 1993).

The salinity values are therefore estimated between 0.1 to 0.4 wt.% NaCl eqv. (Figure 5.3).

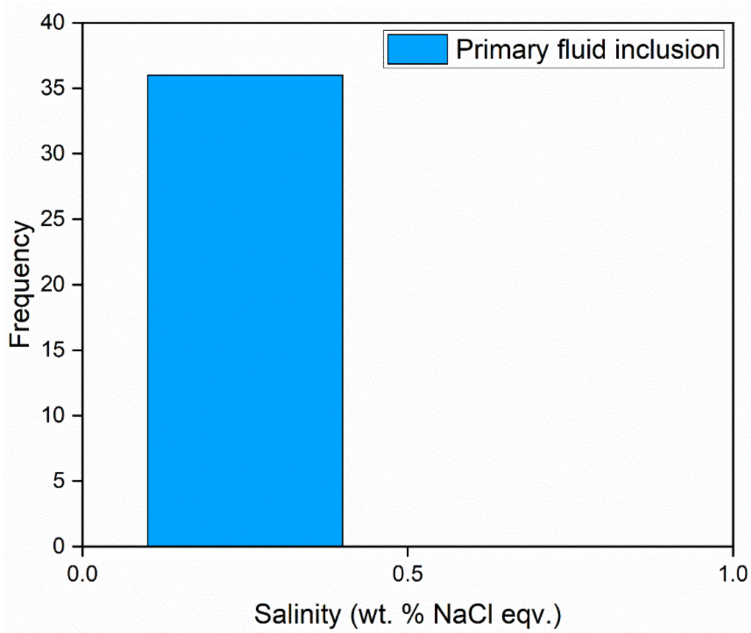


Figure 5.3 Frequency plot of salinity (wt.% NaCl eqv.) of primary inclusions

Further, temperature of homogenization (T_H) of all the inclusions were estimated. The temperatures were raised maximum till 290°C. Within in this temperature limit, most of the inclusions are homogenized into a liquid phase by the disappearance of vapour bubble and was in the temperature range 110°C - 275°C.

Figure 5.4 picturizes a frequency plot of inclusions with temperature of homogenization (T_H) < 290°C.

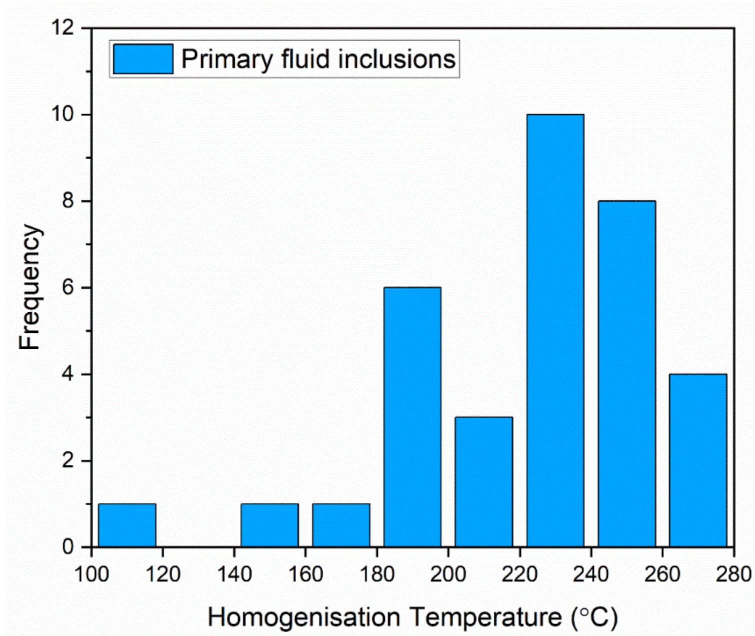


Figure 5.4 Frequency plot of inclusions with temperature of homogenization (T_H) < 290°C

The mean temperature of homogenization (T_H) comes around ~250°C.

Out of the non-homogenized inclusions, some of them only had a change in bubble size whereas the others haven't even exhibited any change. 22 inclusions were either leaked or with T_H < 290°C (Figure 5.5).

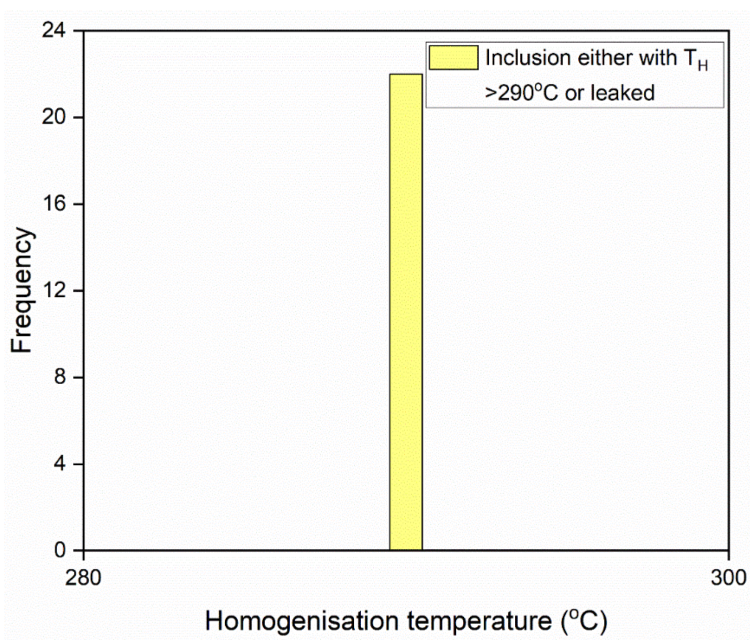


Figure 5.5 Frequency plot of inclusions with temperature of homogenization (T_H) > 290°C

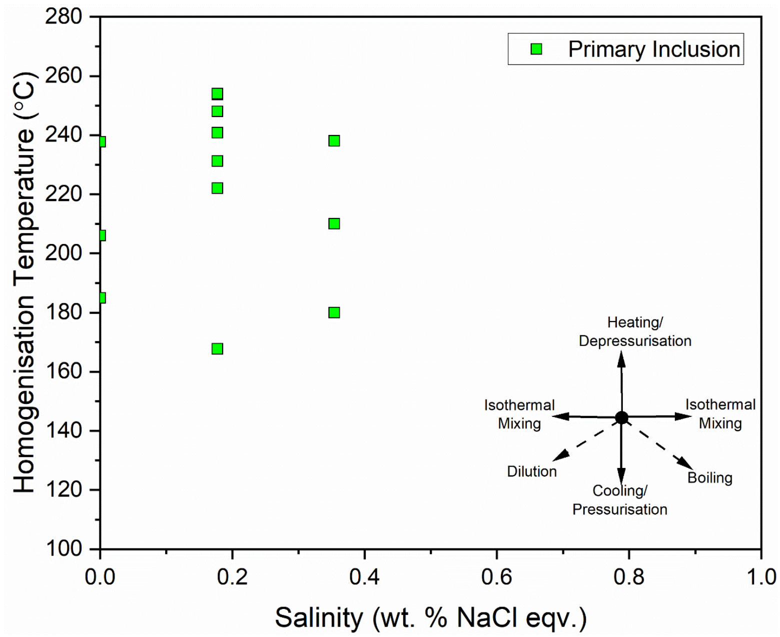
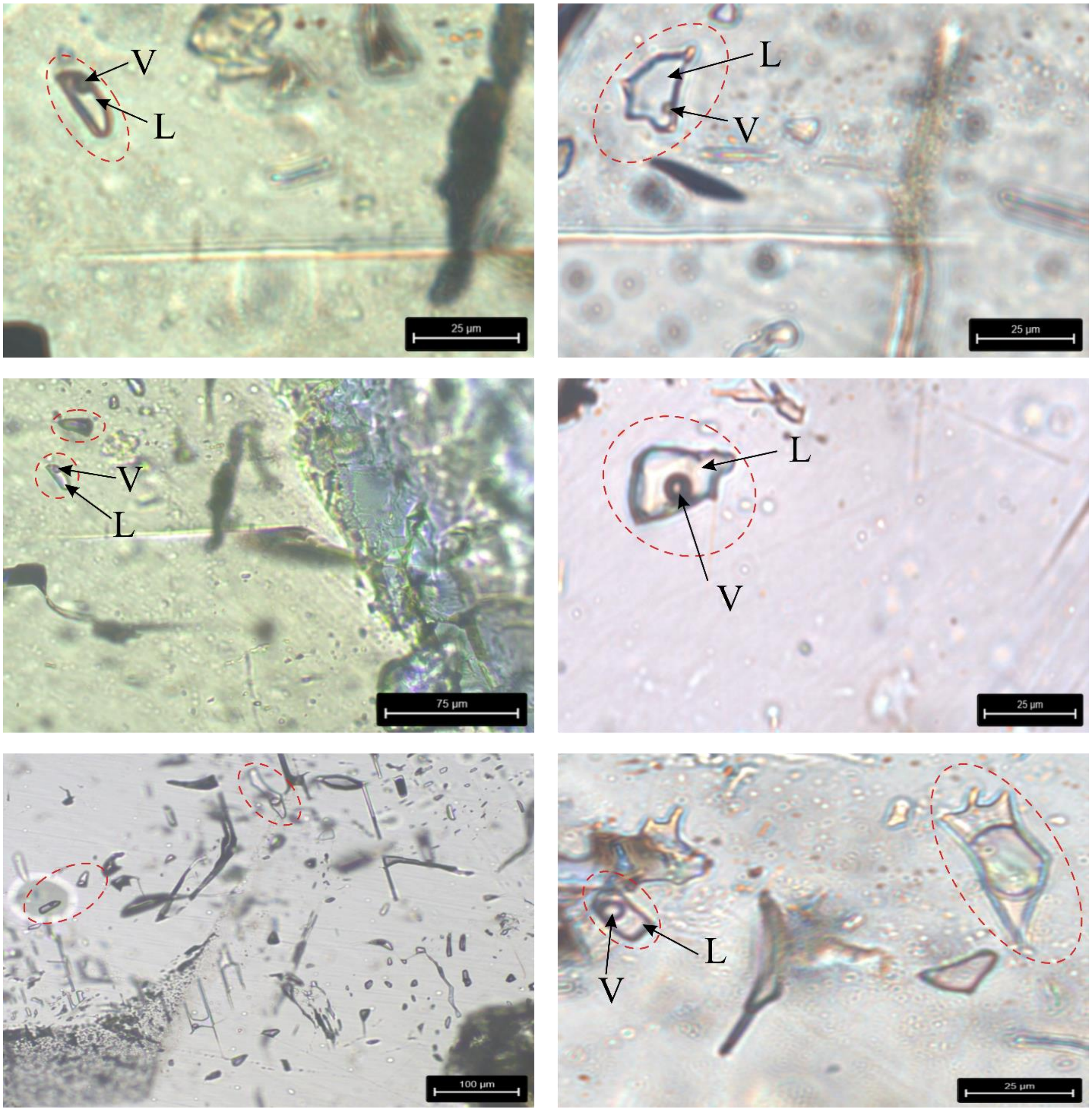
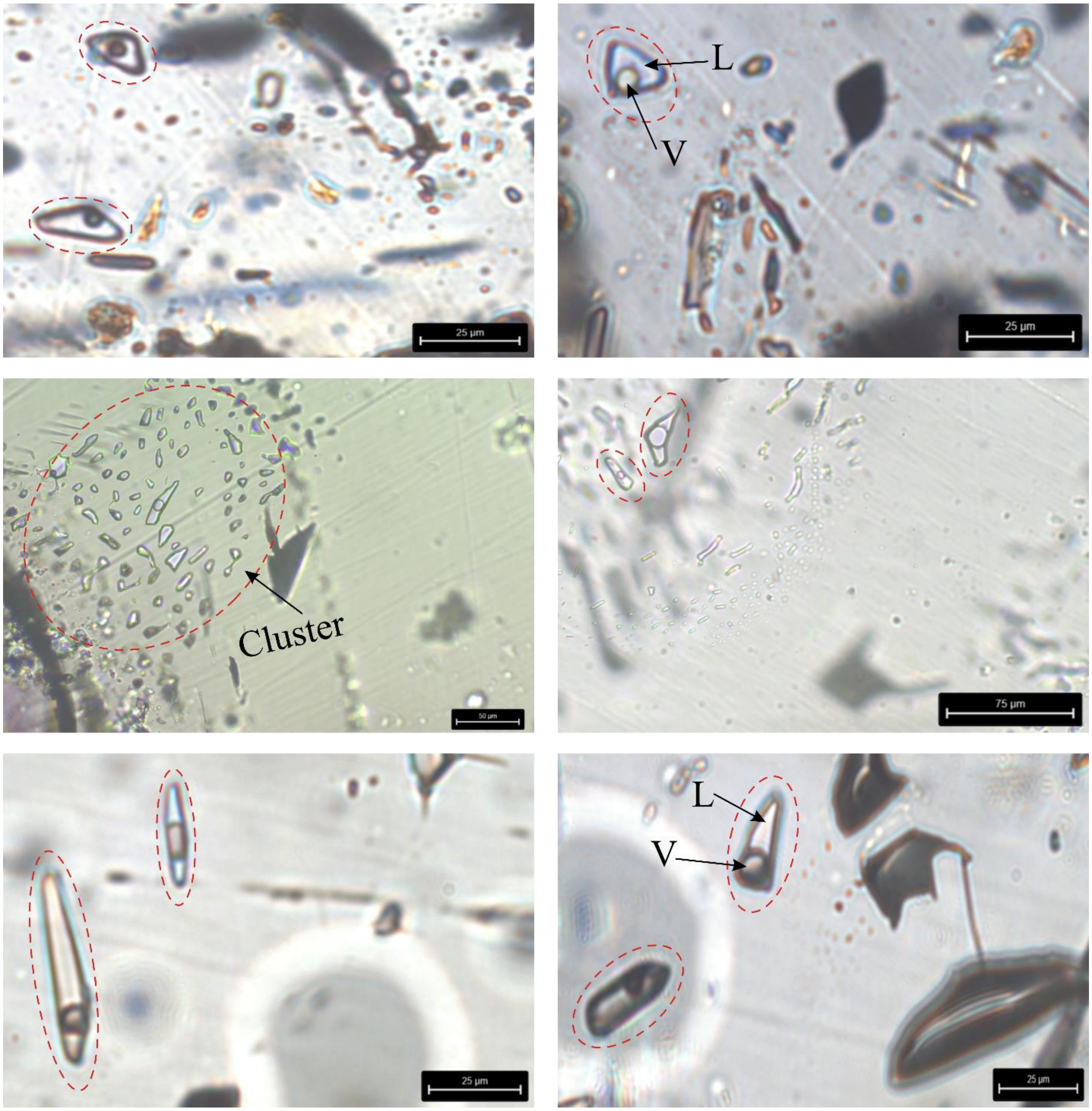


Figure 5.6 Variation in salinity with temperature of homogenization (T_H)

Photograph 5.4 (a) and photograph 5.4 (b) displays images of biphase fluid inclusions from the study area.



Microphotograph 5.4 (a) Biphase fluid inclusions



Microphotograph 5.4 (b) Biphase fluid inclusions (cont.)

CHAPTER 6

CONCLUSION

The Dongargaon fluorite mine is located at the western edge of the Bastar craton and between two prominent lineaments: the Godavari rift to the south and the Central Indian Tectonic Zone (CITZ) to the north, under the jurisdiction of Chandrapur district of Maharashtra, India. The area comprises of rocks of older metamorphics of Archaean age and forms the basement for all the overlying litho units. The Godavari Supergroup overlies the Archaean basement. The Supergroup has been categorized into the Pakhal, the Penganga, the Albaka and the Sullavai Groups. The rocks of Penganga Group exposed over Dongargaon areas encompasses limestones with minor lime mudstones and shale sequence. These limestones are silicified and brecciated. The Gondwana supergroup and the successive Lameta group overlies the Godavari Supergroup. Deccan basaltic flow of Late Cretaceous overlies all the underneath strata.

The mineralization in the area is hosted by chert and limestone. The hydrothermal mineral assemblages are hosted in the fractures, cracks and openings (veins, cavity fillings and replacement deposits) present within them, resultant of hydrothermal activity. The major mineral that could be identified in the petrographic thin sections of the study area is the Fluorite and thus it is the most abundant mineral in the hydrothermal mineral assemblage of the area, followed by Barite, hydrothermal Quartz and Apatite. The hydrothermal mineral assemblage in the study area is thus identified as, Fluorite - Barite - Quartz - Apatite. From the mineralization, structural features such as veins, sharp contacts, breccia formation and alterations of the host rocks, and the mineral assemblage, the causative factor is evidently hydrothermal in nature and thus proving the existence of a hydrothermal depositional environment in the study area, the Dongargaon Fluorite Mine.

Barite mineralization in the study area might be of different generation. Two barite varieties are seen mineralized here; barite having higher order interference colour (commonly seen associated with Fluorite), but with finer grain size and barite having first order interference colour, but with much coarser grain size and crystalline nature.

Inclusions identified from the doubly polished wafers were randomly positioned, distant and isolated primary biphase inclusions with greater variance in size and shape. They were all compositionally more of an aqueous nature which is evident from the temperature of final ice melting (T_M Ice) ranging from -0.2℃ to 0.4℃. Temperature of homogenization (T_H) of all the inclusions were estimated and are homogenized into a liquid phase by the disappearance of vapour bubble within the temperature range of 110℃ to 275℃. The mean temperature of homogenization (T_H) is around ~250℃.

Thus, the study and analysis indicated a meteoric source of fluid and a moderate source for temperature (>200°C), resulting in hydrothermal deposition of fluorite in the study area. From the petrography of whole-rock, it is evident that the area is highly brecciated and therefore the area comes in a zone of brittle deformation. The brittle deformation zone of the Earth occurs till ~ 8–10km and also the geothermal gradient of the Earth is 25°C/km. Since the mean temperature of homogenization (T_H) is around ~ 250°C, it is theoretically not possible for the fluorite mineralization to have a hydrothermal source from within the depth of brittle zone of the Earth. Therefore, the current study points out to a chance of existence of a high temperature source (possibly some intrusions) resulting in hydrothermal activity over the study area and the resulting deposition of fluorite. To confirm the existence of such a source of heat, further studies and experiments are needed to be conducted.

Further possible analysis in the study area:

- Concentration of major, trace and rare earth elements are needed to be measured to constrain the sources of dissolved solutes and for further understanding the genesis of fluorite deposit.
- The concentration can be measured using ICPMS

Since fluorite is considered as a critical mineral and the fluorite deposits in India is very much incompetently studied, the current research work might be helpful for further fluorite exploration and gives a clear-cut idea about fluorite deposition in areas of similar geological condition.

REFERENCES

Bodnar, R. J. (1993). Revised equation and table for determining the freezing point depression of H2O-Nacl solutions. In Geochimica et Cosmochimica Acta (Vol. 57, Issue 3, pp. 683–684). https://doi.org/10.1016/0016-7037(93)90378-A

Chaudhuri, A. K. (2003). Stratigraphy and palaeogeography of the Godavari Supergroup in the south-central Pranhita-Godavari Valley, south India. Journal of Asian Earth Sciences, 21(6), 595–611. https://doi.org/10.1016/S1367-9120(02)00047-0

Chaudhuri, A. K., & Deb, G. K. (2004). Proterozoic Rifting in the Pranhita-Godavari Valley: Implication on India-Antarctica Linkage. In International Association for Gondwana Research (Issue 7).

Deb, G. K. (2003). Deformation pattern and evolution of the structures in the Penganga Group, the Pranhita–Godavari Valley, India: probable effects of Grenvillian movement on a Mesoproterozoic basin. Journal of Asian Earth Sciences, 21(6), 567–577. https://doi.org/10.1016/S1367-9120(02)00048-2

Geological Survey of India (Central Region). (2021). District Resource Map, Chandrapur District, Maharashtra, Second edition, 2021.

Haschke, S., Gutzmer, J., Wohlgemuth-Ueberwasser, C. C., Kraemer, D., & Burisch, M. (2021). The Niederschlag fluorite-(barite) deposit, Erzgebirge/Germany—a fluid inclusion and trace element study. Mineralium Deposita, 56(6), 1071–1086. https://doi.org/10.1007/s00126-020-01035-y

Indian Bureau of Mines. (2024). Indian Minerals Yearbook 2022 (Part- III : Mineral Reviews) 61st Edition FLUORITE.

Mukhopadhyay, J., & Chaudhuri, A. K. (2003). Shallow to deep-water deposition in a Cratonic basin: an example from the Proterozoic Penganga Group, Pranhita–Godavari Valley, India. Journal of Asian Earth Sciences, 21(6), 613–622. https://doi.org/10.1016/S1367-9120(02)00051-2

National Mineral Inventory - Fluorite. (n.d.).

Palmer, D. A. S., & Williams-Jones, A. E. (1996). Genesis of the Carbonatite-Hosted Fluorite Deposit at Amba Dongar, India: Evidence from Fluid Inclusions, Stable Isotopes, and Whole Rock-Mineral Geochemistry. In Economic Geology (Vol. 91). http://pubs.geoscienceworld.org/segweb/economicgeology/article-pdf/91/5/934/3492163/934.pdf

Randive, K., Jawadand, S., Dora, M. L., Kadam, A. R., & Dhoble, S. J. (2021). Tailoring of thermoluminescent properties and assessment of trapping parameters of natural fluorite samples from Dogargaon fluorite mines, India. Luminescence, 36(7), 1648–1657. https://doi.org/10.1002/bio.4107

Randive, K., Pantawane, H., Dora, M. L., Kadam, A. R., Jog, M., & Dhoble, S. J. (2021). Investigation of thermoluminescence response and trapping parameters of natural barite samples from Dongargaon mine, India. Luminescence, 36(2), 460–471. https://doi.org/10.1002/bio.3964

Randive, K. R., Hari, K. R., Dora, M. L., Malpe, D. B., & Bhondwe, A. A. (2014). Study of Fluid Inclusions: Methods, Techniques and Applications. In Geol. Mag., V (Vol. 29). https://www.researchgate.net/publication/275337661_Study_of_Fluid_Inclusions_Methods_Techniques_and_Applications/citation/download

Ravindra Kumar. (1991). Fundamentals of Historical Geology and Stratigraphy of India (Third). New Age International Publishers.

Raza et al., 2021 Ore Geology Reviews

Shepherd, T. J., Rankin, A. H., & Alderton, D. H. M. (1985). A practical guide to fluid inclusion studies . Blackie.

U.S. Geological Survey. (2023). Mineral commodity summaries 2023. https://doi.org/10.3133/mcs2023

Van Den Kerkhof, A. M., & Hein, U. F. (2001). Fluid inclusion petrography. Lithos, 55(1–4), 27–47. https://doi.org/10.1016/S0024-4937(00)00037-2

PETROLOGY AND GEOCHEMISTRY OF OPHIOLITES AND ASSOCIATED AMPHIBOLITES FROM KANDRA OPHIOLITE COMPLEX, NELLORE SCHIST BELT (SOUTHEASTERN INDIA)

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala,

University of Calicut in partial fulfilment for the degree of

Master of Science in Applied Geology

By,

Delphy Manuel

(CCAWMAG008)

Under the guidance of,

Prof. Prabhakar Naraga

DEPARTMENT OF EARTH SCIENCES,

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA,680125

(Affiliated to University of Calicut & Reaccredited by NAAC with A++ grade)

JULY 2024

DISSERTATION APPROVAL CERTIFICATE

This dissertation report entitled **'Petrology and geochemistry of ophiolites and associated amphibolites from Kandra Ophiolite Complex, Nellore Schist Belt (Southeastern India)'** by Delphy Manuel (Reg. No: CCAWMAG008) is hereby approved for the degree of Master of Science in Applied Geology.

EXAMINERS

SUPERVISOR

Date: 29-07-2024

Place: Irinjalakuda

Indian Institute of Technology, Bombay (IITB),Powai,Mumbai,400076,Maharashtra

Dr.Prabhakar Naraga
Assoc.Prof.,Department of Earth Sciences,IITB

Phone No:+91 2225767295
E-mail:prabhakarnaraga@iitb.ac.in

CERTIFICATE

This is to certify that the report entitled **"Petrology and geochemistry of ophiolites and associated amphibolites from Kandra Ophiolite Complex, Nellore Schist Belt (Southeastern India)"** submitted to Christ College (Autonomous), Irinjalakuda, Kerala as part of the internship is a bonafide record of research work carried out by **Delphy Manuel** in the Department of Earth Sciences, Indian Institute of Technology, Bombay(IITB) from January-June under my supervision. It is also certified that the report represents her independent, original investigation without forming previously part of the material for the award of any Degree, Diploma or any other similar title in any University.

Date:29-07-2024

Dr.Prabhakar Naraga

DECLARATION

I, **Delphy Manuel**, Reg. No: CCAWMAG008, hereby declare that the information documented in this dissertation work entitled **'Petrology and geochemistry of ophiolites and associated amphibolites from Kandra Ophiolite Complex, Nellore Schist Belt (Southeastern India)'** is a relevant and original scientific work done under the supervision of **Prof. Prabhakar Naraga** at the Department of Earth Sciences, Indian Institute of Technology, Bombay. It has been submitted in partial fulfilment of the requirements for the award of Master of Science Degree in Applied Geology at Christ College (Autonomous), Irinjalakuda.

Place:Irinjalakuda DELPHY MANUEL

Date:29-7-2024 Reg. No: CCAWMAG008

ACKNOWLEDGEMENT

I wish to record my deep sense of gratitude and profound thanks to my supervisor, **Dr.Prabhakar Naraga**, Associate Professor, Department of Earth Sciences, Indian Institute of Technology,Bombay, for his valuable guidance and suggestions extended throughout the project. This thesis could not have materialized without his support. I would like to express my heartiest thanks to **Ms.Saumya Singh**,Ph.D.research scholar, Department of Earth Sciences,Indian Institute of Technology,Bombay,for rendering all the help and for her constant support and advices throughout the course of my study. I wish to acknowledge **Dr. Hrushikesh H**, who had taken the field photographs during his PhD course work. I place my earnest thanks to **IRCC (Industrial Research & Consultancy Centre)** for giving me the opportunity to undergo a research internship in Indian Institute of Technology, Bombay(IITB). I extend my sincere thanks to the research scholars and staff of Department of Earth Sciences, Indian Institute of Technology, Bombay who have patiently extended all sorts of help and technical support.

I am extremely grateful to **Dr.Sibin Sebastian**, Assistant Professor, Department of Geology, Christ College (Autonomous), Irinjalakuda, for his advice and guidance.I would like to take this opportunity to express my deepest gratitude to **Dr. Linto Alappat**, Dean of Research and Development of TLC, Department of Geology, Christ College (Autonomous), Irinjalakuda, **Dr**. **Anto Francis K.,** Co-ordinator (SF), Department of Geology, Christ College (Autonomous), Irinjalakuda and **Mr. Tharun R**., Head of Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda. My sincere thanks to all my teachers for their kind help and support.

I would like to pay my deep sense of gratitude to all those who have encouraged me and contributed their valuable time during my dissertation work.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

BENTHIC FORAMINIFERA AS ENVIRONMENTAL INDICATORS IN THE MANGROVE ENVIRONMENT OF KADALUNDI

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala,

University of Calicut in partial fulfilment of the degree of

Master of Science in Applied Geology

By,

ANZIA FAZIL

Reg No: CCAWMAG003

Under the guidance of

Dr. SUNITHA D

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA, 680125

(Affiliated to University of Calicut and re-accredited by NAAC with A++ grade)

JULY 2024

BENTHIC FORAMINIFERA AS ENVIRONMENTAL INDICATORS IN THE MANGROVE ENVIRONMENT OF KADALUNDI

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala,

University of Calicut in partial fulfilment of the degree of

Master of Science in Applied Geology

By,

ANZIA FAZIL

Reg No: CCAWMAG003

2022-2024

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

EXAMINERS

1…………………………

2…………………………

Dr. ANTO FRANCIS. K

Co-Ordinator

CERTIFICATE

This is to certify that the dissertation entitled "Benthic foraminifera as environmental indicators in the mangrove environments of Kadalundi" is a bonafied record of work done by Ms. Anzia Fazil (Reg.No. CCAWMAG003) M.Sc. Applied Geology, Christ College (Autonomous), Irinjalakuda under my guidance in partial fulfilment of requirements for the degree of Master of Science in Applied Geology during the academic year 2022-2024

Dr. Sunitha D
Internal Supervisor
Geology(s)

Dr Anto Francis
Coordinator

Christ College (Autonomous), Irinjalakuda
Kerala, 680125

DECLARATION

I, Anzia Fazil declare that the work included in my dissertation report named "BENTHIC FORAMINIFERA AS ENVIRONMENT INDICATORS IN THE MANGROVE ENVIRONMENTS OF KADALUNDI" was composed entirely by me and that it has not previously been presented, in whole or in part, in any previous application for a degree. Except where otherwise noted, the work presented here is entirely my own. This work is presented to Christ College (Autonomous), Irinjalakuda, Kerala, in a partial fulfilment of the Master of Science in Applied Geology degree requirements.

ANZIA FAZIL

Reg. No. CCAWMAG003

ACKNOWLEDGMENT

First and foremost, I want to express my gratitude to God Almighty, by whose mercy I am able to do this work. I wish to express my heartfelt gratitude and heartfelt thanks to **Dr Sunitha, D**, Assistant Professor, Department of Geology and Environmental Science, for creating the project guidelines and providing support and supervision throughout the project**.** I would like to extend my thanks to **Dr Anto Francis. K**, Co-Ordinator, Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, **Mr. Tharun R**. Head of Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, **Dr Linto Alappat,** Dean of Research and Development of TLC, **Dr Sibin Sebastian**, Assistant Professor, Department of Geology and Environmental Science for developing the project's framework and providing regular support and supervision throughout the duration of the course study. A successful and ultimate conclusion of this project necessitated a great deal of advice and assistance, and I consider myself very grateful to have received this during all stages of my project work. Whatever I've accomplished is entirely due to such guidance and assistance, for which I am grateful.

I would like to thank **Dr Mohammed Noohu Nazeer** Assistant Professor Department of Marine Geology and Geophysics, School of Marine Sciences, Cochin University of Science and Technology (CUSAT) for the kind support during field work.

I also thank other faculty members for their support and encouragement. I would like to extend my thanks to Mr. Ayyappadas C.S for the continuous support provided for the completion of the dissertation.

I would prefer to take this opportunity to thank all of my classmates and friends who helped me finish my dissertation, whether directly or indirectly. I'm also thankful to the entire Christ College family for their love and support.

I also express my gratitude to my parents and family members for their unwavering support and prayers throughout my life.

ANZIA FAZIL

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The benthic foraminifera are a single cell protist that are highly abundant in marine and marginal environments. They have been successfully used in many monitoring works to elucidate the status of environmental health conditions. The present study examines the foraminiferal distribution in the surface sediments of the Kadalundi Mangrove, Kozhikode. Information provided by benthic foraminifera were associated with sediment characteristics, and water parameters to characterise the environment. Three genera of benthic foraminifera were identified from the surface samples. Ammonia sp. (relative abundance of 176) were the most abundant species in the mangrove environments along the Kadalundi. Salinity, water depth, and temperature were the important parameters that determined the foraminiferal distribution. Test abnormalities were observed in Ammonia sp. at several stations; a higher quantity of abnormal tests were observed at stations with high current speeds, especially in mangrove areas. The sediment in the study areas did not show severe heavy metal contamination; therefore, the low diversity and test abnormalities were associated with natural stress from environmental conditions. Hence, for monitoring purposes, it is the first attempt of the sediments around Kadalundi Mangrove; however, no study had been conducted there using benthic foraminifera as environmental indicators. Thus, this study investigated the distribution, abundance, and diversity of benthic foraminifera and their potential use as environmental indicators in Kadalundi Mangrove. Therefore, this work serves as a baseline study for future environmental monitoring and can be compared to and used in other studies.

IMPACT OF RAINFALL ON THE SALINITY OF GROUNDWATER IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJACENT TO KOLE LAND IN THRISSUR DISTRICT, KERALA

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala, University of Calicut in partial fulfillment of the degree of

Master of Science in Applied Geology

By

ADITHYAKRISHNAN S

Reg. No: CCAWMAG001

2022 - 2024

Under the guidance of,

Dr ANTO FRANCIS K

COORDINATOR (GEOLOGY SELF- FINANCING)

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA, 680125

(Affiliated to University of Calicut and re-accredited by NAAC with an A++ grade)

JULY 2024

CERTIFICATE

This is to certify that the dissertation entitled **IMPACT OF RAINFALL ON THE SALINITY OF GROUNDWATER IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJACENT TO KOLE LAND IN THRISSUR DISTRICT, KERALA** is a bonafide record of work done by Mr. ADITHYAKRISHNAN S (CCAWMAG001) M.Sc. Applied Geology, Christ College (Autonomous), Irinjalakuda under my guidance in partial fulfilment of requirements for the degree of Master of Science in Applied Geology during the academic year 2022-2024.

Project Guide

Dr Anto Francis K

Co-ordinator (geology self-financing)

Dept. of Geology and Env.Science

Christ College (Autonomous) Irinjalakuda

Kerala-680125

Place: Irinjalakuda

Date: ……………External Examiners;

1…………………………………………………

2…………………………………………………

DECLARATION

I hereby declare that this dissertation work – **IMPACT OF RAINFALL ON THE SALINITY OF GROUNDWATER IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJACENT TO KOLE LAND IN THRISSUR DISTRICT, KERALA**, is done by me. No part of the report is reproduced from other resources. All information included from other sources has been duly acknowledged. I maintain that if any part of the report is found to be plagiarized, I shall take the full responsibility for it.

Place: Irinjalakuda ADITHYAKRISHNAN S

Date: …………. Reg. No. CCAWMAG001

ACKNOWLEDGEMENT

This report is an official documentation of the dissertation work carried out in the Northern Boundary of Puzhakkal Kole Wetland, Thrissur, Kerala. This report would not have been possible without the guidance, encouragement, and support of many well-wishers and my colleagues who helped me in many ways.

I would like to express my sincere gratitude and appreciation to **Dr Anto Francis K**, Coordinator (Geology Self-financing), Department of Geology and Environmental Science at Christ College (Autonomous) Irinjalakuda. He played a pivotal role in shaping the framework of this thesis and provided unwavering support, guidance and suggestions throughout the entire duration of the study.

I express my utmost gratitude to **Dr. Linto Alappat**, Dean of Research and Development of TLC (Former Head, Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda), **Mr Tharun R**, Head of the Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, for rendering all the help and facilities available in the department.

I am grateful to**Dr. Anso M A (**Assistant professor), **Ms.Roshini P P**, **Ms. Ivine Joseph** and the other faculty members of the Department of Geology and Environmental Science, Christ College(Autonomous), Irinjalakuda, for their encouragement, support and direction. I express my gratitude to **Mr. Ayyappadas C.S**, Research Scholar at Christ College (Autonomous) Irinjalakuda, for his valuable assistance in the technical aspects of my study.

I would like to take this opportunity to thank all of my teachers, classmates and friends who supported me in completing this dissertation work, whether directly or indirectly.

I am grateful to the entire Christ College family for their love, support, and guidance. I also express my gratitude to my parents and my sister for their unwavering support and prayers throughout my life. Above all, I express my gratitude to God, the Almighty, for His divine generosity and blessings showered upon me.

ABSTRACT

Water is crucial for all life on Earth, possessing unique properties that make it vital to the planet's biosphere. Understanding how rainfall affects groundwater salinity is essential for assessing ecosystem balance. This study focuses on the northern to southern parts of Thrissur, with particular attention to the Kole fields where some wells experience salinity during the pre-monsoon period. The main objective of this study is to examine the changes in saline groundwater due to monsoon rainfall. The study involves analyzing both physical and chemical parameters of the water. Spatial data is used to illustrate the affected areas, while bar graphs provide a visual representation of the impact, helping to better understand the field conditions. During the pre-monsoon period, certain wells in the Kole fields of Thrissur show increased salinity levels. As the monsoon arrives, rainfall introduces freshwater into the groundwater system. This influx of rainwater can potentially dilute the saline groundwater, leading to changes in its composition and quality. The study employs various methods to assess these changes. Physical parameters such as electrical conductivity and total dissolved solids are measured, along with chemical parameters like concentrations of major ions (e.g., sodium, chloride, calcium, and magnesium). These measurements are taken before and during the monsoon to track changes in groundwater salinity. Spatial mapping of the data helps identify patterns in salinity distribution across the study area. This visual representation allows researchers to pinpoint hotspots of salinity and observe how these areas respond to monsoon rainfall. The bar graphs complement this by quantifying the changes in salinity levels at different locations over time. Rainfall typically reduces groundwater salinity through dilution. As rainwater infiltrates the ground, it mixes with the existing groundwater, lowering the concentration of dissolved salts. This process can lead to significant changes in electrical conductivity, total dissolved solids, and the concentrations of major ions such as sodium, chloride, calcium, magnesium and potassium. Investigation shows that out of the 18 wells studied 9 wells showed marked reduction in physical parameter like TDS, salinity and conductivity. Similarly, chemical parameters studied viz., Ca, Mg, Na, and Cl variation in 10 locations. Significantly, nearly half of the wells studied does not show any marked variation in the physical and chemical parameters. The rainfall in the area is rather uniform and the variation in dilution may be related to the local hydrogeological conditions. The study shows that recharging with rainwater taking into account the local hydrogeological conditions can lead to improvement in the quality of saline groundwater. Also the Gibbs and USSL diagram shows

the salinity variation on different samples. Piper diagram and Correlation Matrix shows the water type based on the data analysis.

SALINE WATER INTRUSION IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJOINING TO VALAPAD - MURIYAD STRETCH

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala,
University of Calicut in partial fulfilment of the degree of

Master of Science in Applied Geology

By

HAMD BIN ABDUREHMAN

Reg. No: CCAWMAG009

2022 - 2024

Under the guidance of,

Dr. ANSO M A

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA, 680125

(Affiliated to University of Calicut and re-accredited by NAAC with an A++ grade)

JULY 2024

CERTIFICATE

This is to certify that the dissertation entitled- **SALINE WATER INTRUSION IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJOINING TO VALAPAD – MURIYAD STRETCH** is a bonafide record of work done by Mr. HAMD BIN ABDUREHMAN (CCAWMAG006) M.Sc. Applied Geology, Christ College (Autonomous), Irinjalakuda under my guidance in partial fulfilment of requirements for the degree of Master of Science in Applied Geology during the academic year 2022-2024.

Project Guide

Dr. Anso M A

Assistant Professor

Dept.of Geology and Env.

Christ College (Autonomous) Irinjalakuda

Kerala- 680125

Dr. Anto Francis K

Co-ordinator of (Geology self-financing)

Dept.of Geology and Env.

Christ college (Autonomous) Irinjalakuda

Kerala- 680125

Place: Irinjalakuda

Date: ……………

External Examiners;

1…………………………………………………

2…………………………………………………

DECLARATION

I hereby declare that this dissertation work – **SALINE WATER INTRUSION IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJOINING TO VALAPAD – MURIYAD STRETCH**, is done by me. No part of the report is reproduced from other resources. All information included from other sources has been duly acknowledged. I maintain that if any part of the report is found to be plagiarized, I shall take the full responsibility for it.

Place: Irinjalakuda HAMD BIN ABDUREHMAN

Date: …………. Reg. No. CCAWMAG009

ACKNOWLEDGEMENT

This report is an official documentation of the dissertation work carried out in the Stretch of valapad to muriyad, Thrissur, Kerala. This report would not have been possible without the guidance, encouragement, and support of many well-wishers and my colleagues who helped me in many ways.

I would like to express my sincere gratitude and appreciation to **Dr. ANSO M A**, Assistant Professor, Department of Geology and Environmental Science at Christ College (Autonomous) Irinjalakuda. She played a pivotal role in shaping the framework of this thesis and provided unwavering support, guidance and suggestions throughout the entire duration of the study.

I express my utmost gratitude to **Dr. Linto Alappat**, Dean of Research and Development of TLC (Former Head, Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda), **Mr Tharun R**, Head of the Department of Geology and Environmental Science, Christ College(Autonomous) Irinjalakuda, for rendering all the help and facilities available in the department.

I am grateful to **Dr. Anto Francis K**, Coordinator (Geology Self-financing), **Ms. Ivine Joseph** and the other faculty members of the Department of Geology and Environmental Science, Christ College(Autonomous), Irinjalakuda, for their encouragement, support and direction. I express my gratitude to **Mr. Ayyappadas C.S**, Research Scholar at Christ College (Autonomous) Irinjalakuda, for his valuable assistance in the technical aspects of my study.

I would like to take this opportunity to thank all of my teachers, classmates and friends whosupported me in completing this dissertation work, whether directly or indirectly.

I am grateful to the entire Christ College family for their love, support, and guidance. I also express my gratitude to my parents and my sister for their unwavering support and prayers throughout my life. Above all, I express my gratitude to God, the Almighty, for His divine generosity and blessings showered upon me.

HAMD BIN ABDUREHMAN

ABSTRACT

Water is a vital component for the sustenance of life. This study investigates saline water intrusion and water quality in the Valapad-Muriyad stretch of Thrissur District. The primary aim was to identify the presence and potential sources of saline water, as well as to assess water quality parameters. A total of 16 bore well samples and one open well sample were collected in May 2024. Salinity and electrical conductivity were measured on-site using an EUTECH Portable EC Salinity Meter. Physical parameters were assessed with an EUTECH Multi- Parameter Meter, while chemical concentrations were determined through various titration methods. Spatial maps for the parameters were created using ArcGIS 10.8. The findings revealed that two samples exhibited significant differences compared to the others. The spatial distribution maps showed elevated levels of electrical conductivity, chloride ions, total hardness, salinity, and total dissolved solids (TDS) in the Valapad-Muriyad stretch of the Kole wetland. The results also indicated that the Muriyad region is experiencing some saline water intrusion from surrounding areas.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SALINE WATER INTRUSION IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJOINING THE SOUTHERN BOUNDARY OF PUZHAKKAL KOLE LAND, THRISSUR DISTRICT, KERALA

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala,

University of Calicut in partial fulfillment of the degree of

Master of Science in Applied Geology

By

MEGHA C M

Reg. No: CCAWMAG010

2022 - 2024

Under the guidance of,

Ms. IVINE JOSEPH

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA, 680125

(Affiliated to University of Calicut and re-accredited by NAAC with an A++ grade)

JULY 2024

CERTIFICATE

This is to certify that the dissertation entitled - **SALINE WATER INTRUSION IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJOINING THE SOUTHERN BOUNDARY OF PUZHAKKAL KOLE LAND, THRISSUR DISTRICT, KERALA** is a bonafide record of work done by Ms. MEGHA C M (CCAWMAG010) M.Sc. Applied Geology, Christ College (Autonomous), Irinjalakuda under my guidance in partial fulfilment of requirements for the degree of Master of Science in Applied Geology during the academic year 2022-2024.

Project Guide

Ms. Ivine Joseph	Dr. Anto Francis K
Assistant Professor	Co-ordinator (Geology Self-financing)
Dept. of Geology and Env. Science	Dept. of Geology and Env. Science
Christ College (Autonomous) Irinjalakuda	Christ College (Autonomous) Irinjalakuda
Kerala- 680125	Kerala- 680125

Place: Irinjalakuda

Date: ……………

External Examiners;

1…………………………………………………

DECLARATION

I hereby declare that this dissertation work – **SALINE WATER INTRUSION IN THE FRACTURED CRYSTALLINE ROCK AQUIFER ADJOINING THE SOUTHERN BOUNDARY OF PUZHAKKAL KOLE LAND**, **THRISSUR DISTRICT, KERALA** is done by me. No part of the report is reproduced from other resources. All information included from other sources has been duly acknowledged. I maintain that if any part of the report is found to be plagiarized, I shall take the full responsibility for it.

Place: Irinjalakuda MEGHA C M

Date: …………. Reg. No. CCAWMAG010

ACKNOWLEDGEMENT

This report is an official documentation of the dissertation work carried out in the Southern Boundary of Puzhakkal Kole Wetland, Thrissur, Kerala. This report would not have been possible without the guidance, encouragement, and support of many well-wishers and my colleagues who helped me in many ways.

I would like to express my sincere gratitude and appreciation to **Ms. Ivine Joseph**, Assistant Professor, Department of Geology and Environmental Science at Christ College (Autonomous) Irinjalakuda. She played a pivotal role in shaping the framework of this thesis and provided unwavering support, guidance and suggestions throughout the entire duration of the study.

I express my utmost gratitude to **Dr. Linto Alappat**, Dean of Research and Development of TLC (Former Head, Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda), **Mr Tharun R**, Head of the Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, for rendering all the help and facilities available in the department.

I am grateful to **Dr. Anto Francis K**, Coordinator (Geology Self-financing), **Dr. Anso M A**, **Mrs. Roshini. P.P.** and the other faculty members of the Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, for their encouragement, support and direction. I express my gratitude to **Mr. Ayyappadas C.S**, Research Scholar at Christ College (Autonomous) Irinjalakuda, for his valuable assistance in the technical aspects of my study.

I would like to take this opportunity to thank all of my teachers, classmates and friends who supported me in completing this dissertation work, whether directly or indirectly.

I am grateful to the entire Christ College family for their love, support, and guidance. I also express my gratitude to my parents and my sister for their unwavering support and prayers throughout my life. Above all, I express my gratitude to God, the Almighty, for His divine generosity and blessings showered upon me.

MEGHA C M

ABSTRACT

Groundwater quality in the midlands of Thrissur is generally good. However, salinity problems are reported in borewells near the Kole Wetlands. The present study focuses on the presence and probable source of saline water intrusion in the southern boundary of Puzhakkal Kole land, Thrissur, Kerala. Water samples from 31 bore wells and 2 open wells from the periphery of the study area were collected and analyzed for the physicochemical parameters during the premonsoon period of May 2024. Before choosing the study area, a preliminary investigation study was conducted and samples were collected accordingly. From the spatial map created using pH values, it indicates that SW samples are at risk compared to the rest of the samples. From the statistical analysis, the Hill Piper trilinear plot indicates that, Most of the saline water samples like sample no 29, 10, 27, 24, and 22 comes under the CaCl water type. The Gibbs Diagram shows that only 4 samples indicates seawater dominance while the rest of samples indicates rock water dominance. The USSL Diagram shows that borewell samples in the central and southern parts of the study area are not suitable for irrigation. According to the EC, TDS, salinity, and chloride content, the central part of the study area has the highest values. A comparison study was conducted, indicating the presence of saline water in bore wells compared to open wells in the study area. From the study, few probable sources have been identified for the saline water intrusions in the study area.

PETROGRAPHY AND MINERAL REACTIONS IN GARNETIFEROUS CHARNOCKITE AND ASSOCIATED LITHOLOGIES IN AND AROUND KOTTAYAM, WESTERN MADURAI BLOCK, SOUTHERN GRANULITE TERRAIN

Project report submitted to the Christ College (Autonomous), Irinjalakuda, affiliated to the University of Calicut, in partial fulfillment of the degree of

Master of Science in Applied Geology

By

NANDAPRIYA T

REG NO. CCAWMAG011

Under the guidance of

Dr. Anto Francis K

Coordinator of Geology (Self)

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA, 680125

(Affiliated to the University of Calicut and re-accredited by NAAC with an A++ grade)

JULY 2024

<u>CERTIFICATE</u>

This is to certify that the dissertation entitled **"PETROGRAPHY AND MINERAL REACTIONS IN GARNETIFEROUS CHARNOCKITE AND ASSOCIATED LITHOLOGIES IN AND AROUND KOTTAYAM, WESTERN MADURAI BLOCK, SOUTHERN GRANULITE TERRAIN"** was the work done by Miss. Nandapriya T (Reg No. CCAWMAG011), MSc. Applied Geology, Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda. The work was carried out in partial fulfillment of the requirement for the award of the degree of Master of Science in Applied Geology during the academic year 2022-2024 of Christ college (Autonomous) Irinjalakuda, Kerala.

Place: Irinjalakuda

Date: 16/08/2024

Dr. Anto Francis K

Coordinator of Geology (Self) and project guide

Christ college (Autonomous), Irinjalakuda

External Examiner:

DECLARATION

I thus certify that this dissertation - "**PETROGRAPHY AND MINERAL REACTIONS IN GARNETIFEROUS CHARNOCKITE AND ASSOCIATED LITHOLOGIES IN AND AROUND KOTTAYAM, WESTERN MADURAI BLOCK, SOUTHERN GRANULITE TERRAIN**"- is my work. The report contains no quotations from external sources. All information derived from external sources has been properly credited. I maintain that if any element of the report is discovered to be plagiarised, I will accept full responsibility. Dr. Anto Francis K, Associate Professor, Dept. of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, has provided necessary supervision for the completion of the work. I followed best practices and scientific study ethics. This work is presented to Christ College (Autonomous), Irinjalakuda, University of Calicut, Kerala, in partial satisfaction of the Master of Sciences in Applied Geology degree requirements.

Place: Irinjalakuda NANDAPRIYA T

Date: 16/08/2024 CCAWMAG011

ACKNOWLEDGEMENT

I would like to express my heartfelt gratitude to everyone who helped me in making this project successful. I want to extend my appreciation to **Dr. Anto Francis K**, Co-ordinator (Geology self) at Christ College (Autonomous) Irinjalakuda, Kerala, for his invaluable support and guidance as my thesis guide. I am sincerely thankful to **Dr Linto Alappat**, Dean of Research and Development of TLC (Former Head, Dept. of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, for assisting me in making the necessary arrangements for the project. I am grateful to **Mr. Tharun R**, Head of the Geology Department at Christ College (Autonomous) Irinjalakuda, Kerala, for his valuable support.

I would like to convey my thanks to the Head of the Department of Marine Geology and Geophysics at Cochin University of Science and Technology, Kochi-16, for providing the necessary facilities for the research work. My deepest and greatest thanks to **Dr. Amaldev T**, Assistant Professor at the Department of Marine Geology and Geophysics, Cochin University of Science and Technology, Kochi-16, for his encouragement and for providing the facilities that helped me complete my project. My warm gratitude goes to **Mr. Rajkumar P. B**., Research Scholar at the Department of Marine Geology and Geophysics, School of Marine Science, CUSAT, Kochi-16, for his technical support and guidance in the laboratory procedures.

I extend my sincere gratitude to all my teachers and staff members of the Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, for their encouragement and assistance throughout the project. Additionally, I am sincerely thankful to my family and all my friends for their immense encouragement and support during the project work. Last but not least, I express my thanks to the Almighty for all the blessings.

NANDAPRIYA T

ABSTRACT

The Southern Indian shield is divided into the northern low-grade granite-greenstone (Dharwar) and the southern high-grade granulite terrain (Southern Granulite Terrain-SGT). The high-grade granulite terrain has been extensively studied, and several crustal blocks have been identified. The Madurai block is one of the largest Precambrian crustal blocks, divided into Western and Eastern Madurai blocks. This study focuses on the Western part of the Western Madurai block, particularly the Kottayam region, where various rock types such as garnetiferous charnockite, garnet-bearing cordierite charnockite, and garnet biotite gneiss have been observed. The study relies on field investigation and petrographic studies, which have revealed four types of mineral assemblages with reaction textures. Mineral assemblages like Grt-Opx-Crd-Spl-Bt-Kfs-Plag-Qtz and Grt-Opx-Spl-Bt Kfs-Plag-Qtz indicate granulite facies metamorphism. Disequilibrium textures like inclusions of mineral phases and corona/overprinting relation between mineral phases helped to understand mineral reactions in the different assemblages. Both prograde and retrograde reactions are deuced from reaction textures. The mineral assemblages and reaction textures are comparable to those reported from the eastern parts of Madurai block. Further studies are needed to bring out the P-T conditions of metamorphism and the geochronologic and tectonic significance of these assemblages.

TEXTURE AND MICROFOSSIL ASSEMBLAGES IN SUBSURFACE SEDIMENTS OF CENTRAL KERALA: INSIGHTS INTO QUATERNARY LAND SEA INTERACTIONS

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala,

University of Calicut in partial fulfillment of the degree of

Master of Science in Applied Geology

By,

SANIKA K S

Reg. No: CCAWMAG014

Under the guidance of,

Ms. SHAIMA M.M

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA,680125

(Affiliated to University of Calicut and re-accredited with by NAAC with A^{++} grade)

JULY 2024

CERTIFICATE

Certified that the dissertation work entitled "**TEXTURE AND MICROFOSSIL ASSEMBLAGES IN SUBSURFACE SEDIMENTS OF CENTRAL KERALA: INSIGHTS INTO QUATERNARY LAND SEA INTERACTIONS"** is a bonafide record of work done by Ms. Sanika K.S. (Reg. No. CCAWMAG014) Applied Geology in the college during 2023-2024.

Ms. Shaima M.M
Assistant professor and project guide

Dr. Anto Francis K
Co-Ordinator (Geology Self-financing)
Christ Christ College (Autonomous) Irinjalakuda

Place: Irinjalakuda

Date:

External examiners

1.

DECLARATION

I thus certify that this dissertation **"TEXTURE AND MICROFOSSIL ASSEMBLAGES IN SUBSURFACE SEDIMENTS OF CENTRAL KERALA: INSIGHTS INTO QUATERNARY LAND SEA INTERACTIONS"** is my own work. The report contains no quotations from external sources. All information derived from external sources has been properly credited. I maintain that if any element of the report is discovered to be plagiarized, I will accept full responsibility. Ms. Shaima M.M., Assistant professor, Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, Kerala, has provided necessary supervision for the completion of the work. I followed best practices and scientific study ethics. This work is presented to Christ College (Autonomous), Irinjalakuda, University of Calicut, Kerala, in partial satisfaction of the Master of Sciences in Applied Geology degree requirements.

Place: Irinjalakuda **SANIKA K S**

Date: **Reg.NO: CCAWMAG014**

ACKNOWLEDGEMENT

This report is official documentation of dissertation work carried out in the Padiyur, Kodamkulam, Kerala. It is a privilege for me to convey my gratitude and respect to those who guided and inspired the project's completion.

I would like to express my heartfelt thanks to my mentor, Ms. Shaima M.M, Assistant Professor, Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, for including me, making timely comments, and guiding me through the completion of my research.

Tharun R, Head, Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, for rendering all the help and facilities available in the department.

I would also like to thank Dr. Sijin Kumar A. V., Associate Professor, Central University of Kerala, for allowing me to conduct this research at this institution and preparing thin section as well as identifying the microfossils.

I am grateful to Dr. Anto Francis K., (Co-Ordinator of the M.Sc. Applied Geology), Dr. Linto Alappat (Dean of Research and Development of TLC, Assistant professor) and the other faculty members of the Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda, for their encouragement, direction, and affection.

I would like to express my gratitude Mr. Ayyappadas C.S for his continued support and assistance in completing the dissertation. I would like to take this opportunity to thank all of faculty, my classmates and friends who helped me finish this dissertation, either directly or indirectly. I am grateful to the entire Christ community. Thank you to my college family for their love, support, and advice. I would also like to thank my parents and family members for their everlasting support and prayers throughout my life. Above all, I thank God, the Almighty, for his wonderful kindness and the benefits that have been bestowed upon me.

SANIKA KS

ABSTRACT

Situated in the Thrissur District of Central Kerala, the Kodamkulam area offers a distinct opportunity to explore paleo-geography and land-sea interactions owing to its coastal plain location. The Kerala coast has experienced fluctuating sea levels throughout the Quaternary, resulting in present-day coastal features formed by Late Quaternary transgressions and regressions. A 15 meter deep sediment core was extracted using a standard penetration test to examine subsurface sediments. The core sediment from Padiyur, Kodamkulam, underwent textural and micropaleontological analysis. Wet sieving was utilized for the textural analysis, and fossil slides were prepared for paleontological analysis. The presence of fossil foraminifera suggests that the sediments were deposited in environments ranging from marginal marine to marine conditions due to Quaternary marine transgressions and regressions. Most of the fossil foraminifera identified were benthic, with some planktic forms also present, and Ammonia beccarii was the predominant species found, indicating a likely shallow marine shelf habitat. Additionally, the Quaternary sediments revealed peat layers, leaf impressions, heteropods, gastropods, and coral fragments, highlighting a geomorphic history marked by an initial transgression followed by regression. This evidence indicates that the shoreline initially advanced eastward approximately 41,570 and 54,510 years ago.

CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

FORAMINIFERAL DISTRIBUTION AND ASSOCIATED PATTERNS IN THE MANGROVE SEDIMENTS OF KADALUNDI

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala,

University of Calicut in partial fulfilment of the degree of

Master of Science in Applied Geology

By,

SHANA JASMIN T.K

Reg No: CCAWMAG015

Under the Guidance of

Dr. SUNITHA D

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA, 680125

(Affiliated to University of Calicut and re-accredited by NAAC with A++ grade)

JULY 2024

FORAMINIFERAL DISTRIBUTION AND ASSOCIATED PATTERNS IN THE MANGROVE SEDIMENTS OF KADALUNDI

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala,

University of Calicut in partial fulfilment of the degree of

Master of Science in Applied Geology

By,

SHANA JASMIN T.K

Reg No: CCAWMAG015

2022-2024

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

EXAMINERS

1…………………………

2…………………………

Dr. ANTO FRANCIS. K

Co-Ordinator

CERTIFICATE

This is to certify that the dissertation entitled "Foraminiferal distribution and associated patterns in the mangrove sediments of Kadalundi" is a bonafied record of work done by Ms. Shana Jasmin T. K (Reg.No. CCAWMAG015) M.Sc. Applied Geology, Christ College (Autonomous), Irinjalakuda under my guidance in partial fulfilment of requirements for the degree of Master of Science in Applied Geology during the academic year 2022-2024

Dr. Sunitha D	Dr Anto Francis
Internal Supervisor	Coordinator
Geology(s)	

Christ College (Autonomous)
Irinjalakuda, Kerala -680125

DECLARATION

I, Shana Jasmin T.K, declare that the work included in my dissertation report named "FORAMINIFERAL DISTRIBUTION AND ASSOCIATED PATTERNS IN THE MANGROVE SEDIMENTS OF KADALUNDI" was composed entirely by me and that it has not previously been presented, in whole or in part, in any previous application for a degree. Except where otherwise noted, the work presented here is entirely my own. This work is presented to Christ College (Autonomous), Irinjalakuda, Kerala, in a partial fulfilment of the Master of Science in Applied Geology degree requirements.

SHANA JASMIN T.K

Reg No. CCAWMAG015

ACKNOWLEDGMENT

First and foremost, I want to express my gratitude to God Almighty, by whose mercy I am able to do this work. I wish to express my heartfelt gratitude and heartfelt thanks to **Dr Sunitha, D**, Assistant Professor, Department of Geology and Environmental Science, for creating the project guidelines and providing support and supervision throughout the project**.** I would like to extend my thanks to **Dr Anto Francis. K**, Co-Ordinator, Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, **Mr. Tharun R**, Head of Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, **Dr Linto Alappat,** Dean of Research and Development of TLC, **Dr Sibin Sebastian**, Assistant Professor, Department of Geology and Environmental Science for developing the project's framework and providing regular support and supervision throughout the duration of the course study. A successful and ultimate conclusion of this project necessitated a great deal of advice and assistance, and I consider myself very grateful to have received this during all stages of my project work. Whatever I've accomplished is entirely due to such guidance and assistance, for which I am grateful.

I would like to thank **Dr Mohammed Noohu Nazeer** Assistant Professor Department of Marine Geology and Geophysics, School of Marine Sciences, Cochin University of Science and Technology (CUSAT) for the kind support during field work.

I also thank other faculty members for their support and encouragement. I would like to extend my thanks to Mr. Ayyappadas C.S for the continuous support provided for the completion of the dissertation

I would prefer to take this opportunity to thank all of my classmates and friends who helped me finish my dissertation, whether directly or indirectly. I'm also thankful to the entire Christ College family for their love and support. I also express my gratitude to my parents and family members for their unwavering support and prayers throughout my life.

SHANA JASMIN T.K

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

In order to study the distribution of Foraminifera and Ostracoda, the calcareous microfauna, occurring in the Kadalundi Mangrove samples, a total of one core were collected. The taxonomy and systematic study were done using ostracod treatises by Moore and Pitrat (Eds) (1961), Van Morkhoven (1963), Hartmann and Puri (1974) and other recent literature. The widely utilized classification proposed by Loeblich and Tappan (1987) has been followed in the present study for Foraminiferal identification and taxonomy. Distribution pattern of individual taxon was examined and their sediment relationship was determined for ecologic/environmental interpretation. Organic matter was determined by titration method of Gaudette et al. (1974). Estimation of $CaCO_3$ was made by adopting the procedure proposed by Piper (1947) has been incorporated in this dissertation. Previous research work on Foraminifera and Ostracoda from the Gulf of Mexico has been reviewed and presented. A total of 3 foraminiferal and 2 ostracoda species have been illustrated from the study area. Sedimentological parameters such as $CaCO_3$ and Organic matter ratios were estimated and their distribution is discussed. From the 3 foraminiferal species Ammonia shows its dominance followed by Elphidium and quinqueloculina. The 2 ostracod species also identified as *Bairdopillata sp* and *Hemicytheridea sp.* It also shows different ornamentation. It comprises carapaces as well as open valve. From the overall distribution of foraminifera and ostracod throughout the core shows abundance in their distribution. The sediment parameters also show insignificant relation with distribution of ostracod and foraminifera.

CHRONOLOGY OF ZINC SMELTING IN ZAWAR, RAJASTHAN: INSIGHTS TO THE ARCHAEOMETALLURGY IN INDIA

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala
University of Calicut in partial fulfilment for the degree of
Master of Science in Applied Geology

By,

SHILPA SHAJU M
(CCAWMAG016)

Under the guidance of,

Dr. LINTO ALAPPAT
DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE
CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA,680125
(Affiliated to University of Calicut & Reaccredited by NAAC with A++ grade)

Under the Co guidance of
Dr. NAVEEN CHAUHAN

ATOMIC MOLECULAR OPTICAL PHYSICS DIVISION
PHYSICAL RESEARCH LABORATORY(PRL), AHMEDABAD

JULY 2024

CHRONOLOGY OF ZINC SMELTING IN ZAWAR, RAJASTHAN: INSIGHTS TO THE ARCHAEOMETALLURGY IN INDIA

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala, University of Calicut in partial fulfilment of the degree of

Master of Science in Applied Geology

By,

SHILPA SHAJU M

Reg. No: CCAWMAG016

2022-2024

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

EXAMINERS

Dr. ANTO FRANCIS. K

Co-Ordinator

1…………………

2…………………

<u>**CERTIFICATE**</u>

This is to certify that the report entitled "**Chronology of Zinc Smelting in Zawar, Rajasthan: Insights into the Archaeometallurgy of India**" submitted to Christ College (Autonomous), Irinjalakuda, Kerala, as part of the dissertation, is a bona fide record of research work carried out by Shilpa Shaju M.

It is further certified that the report represents her original investigation and has not been submitted as part of the material for the award of any degree, diploma, or any other similar title at any university.

Date: **Dr. Linto Alappat**

Christ College (Autonomous)
Irinjalakuda, Kerala

DECLARATION

I, Shilpa Shaju M, hereby declare that this dissertation work titled "**Chronology of Zinc Smelting in Zawar, Rajasthan: Insights into the Archaeometallurgy of India**" is my original work. The report has not been copied or duplicated from any external sources in any manner. All information obtained from external references has been properly acknowledged.

I further affirm that if any part of this report is found to be plagiarized, I will take full responsibility for it.

Place: SHILPA SHAJU M

Date: Reg.No. CCAWMAG016

ACKNOWLEDGEMENT

I am grateful to everyone who inspired and guided the project's completion. At first, I thank PRL (Physical Research Laboratory) for offering me an opportunity to undergo a research internship which is India's utmost lab in the field of physical science. The project forms a part of the collaborative research between Department of Geology and Environmental Science, Christ College Autonomous, Thrissur, Geological Society of India, Western Region, Rajasthan and Physical Research Laboratory, Ahmedabad. The research was conceived, samples were collected under this initiative and was provided to me for laboratory studies.

I wish to express my profound sense of gratitude and genuine thanks to **Dr. Naveen Chauhan** for his timely suggestions and guidance for completion of my project. I express my sense of gratitude to **Dr. Amzad Hussain Laskar** for his guidance. Also, I extend my sincere thanks to AMOPH division and Geoscience division for allocating the lab related facilities. I would also like to thank **Ms. Malika Singhal.**, Senior Research Fellow for all the help and also for her constant support and advice throughout the completion of my work. I would also like to thank **Mr. Santunu Kumar Panda.**, Senior Research Fellow for his help and support. I would also like to thank **Mr, Ranjan Kumar Mohanty.,** Project Assistant for his help and support.

I am extremely grateful to **Dr. Linto Alappat**, Dean of Research and Development of TLC, Department of Geology, Christ College (Autonomous) Irinjalakuda for giving me this opportunity and also for his timely advice and guidance. I would like to take this opportunity to express my deepest gratitude to **Dr. Anto Francis K.**, Co-ordinator (SF), and **Mr. Tharun R.**, Head of the Department of Geology and Environmental Science, Christ College (Autonomous), Irinjalakuda. My sincere thanks to all my teachers for their kind help and support. Also, I extend my sincere thanks to all my teachers for their help and support

I take this opportunity to thank my family and friends and all those who have extended their support and for always being there throughout the completion of my project

TABLE OF CONTANTS

LIST OF TABLES

LIST OF FIGURES

"Origin of Anorthosites: Constraints from Compiled Geochemical Data from India"

Dissertation submitted to Christ College (Autonomous), Irinjalakuda, Kerala,
University of Calicut in partial fulfilment of the degree of

Master of Science in Applied Geology

By

Nandhakumar A K

Reg. No: CCAWMAG012

Under the guidance of,

Dr. SIBIN SEBASTIAN

DEPARTMENT OF GEOLOGY AND ENVIRONMENTAL SCIENCE

CHRIST COLLEGE (AUTONOMOUS), IRINJALAKUDA, KERALA, 680125

(Affiliated to University of Calicut and re-accredited by NAAC with an A++ grade)

JULY 2024

CERTIFICATE

This is to certify that the dissertation entitled **"Origin of Anorthosites: Constraints from Compiled Geochemical Data from India"** is a bonafied record of work done by Mr. Nandhakumar A K (Reg. No. CCAWMAG012), M.Sc. Applied Geology, Christ College (Autonomous), Irinjalakuda in partial fulfilment of requirements for the degree of Master of Science in Applied Geology during the academic year 2022-2024.

Date:

Place:

Supervisor **Head of the Department** **External Examiner**

DECLARATION

I Nandhakumar A K, declare that the work included in my dissertation report named **"Origin of Anorthosites: Constraints from Compiled Geochemical Data from India"**was composed entirely by me and that it has not previously been presented, in whole or in part, in any previous application for a degree. Except where otherwise noted, the work presented here is entirely my own. This work is presented to Christ College (Autonomous), Irinjalakuda, Kerala, in a partial fulfilment of the Master of Science in Applied Geology degree requirement.

ACKNOWLEDGMENT

First and foremost, I want to express my gratitude to God Almighty, by whose mercy I am able to do this work. I wish to express my heartfelt gratitude and heartfelt thanks to, **Dr. Linto Alappat,** Dean of Research and Development of TLC (former HOD) Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda, **Dr. Anto Francis. K,** Co-Ordinator and **Mr. Tharun R.** Head of Department of Geology and Environmental Science, Christ College (Autonomous) Irinjalakuda. A successful and ultimate conclusion of this project necessitated a great deal of advice and assistance, and I consider myself very grateful to have received this during all stages of my project work. Whatever I've accomplished is entirely due to such guidance and assistance, for which I am grateful. I would like to thank my project guide, **Dr. Sibin Sebastian** (Assistant Professor, Department of Geology & Environmental Science) Christ College (Autonomous) Irinjalakuda, for creating the project guidelines and providing support and supervision throughout the project.

I also thank other faculty members for their support and encouragement. I would prefer to take this opportunity to thank all of my classmates and friends who helped me finish my dissertation, whether directly or indirectly. I'm also thankful to the entire Christ College family for their support.

Nandhakumar A K

INDEX

ABSTRACT

Anorthosites are intrusive igneous rocks that are predominantly composed of plagioclase.They are formed during different times from Archean to Tertiary times. However, the origin of these rock is always a controversial problem. The outstanding questions are nature of the source of these rocks, tectonic settings of their formation, and differences in the petrogenetic processes during different times. To address these questions, anorthosites from Indian terrain are studied for their origin by compiling the available geochemical and isotopic data from literature. Anorthosites in India occur as massif,

layered, xenolith or dyke. Most of them areArchaean layered-typeor Proterozoic massifs-type. Archean anorthosites are mostly associated with mafic rocks, like gabbro, amphibolite, etc. which indicate their emplacement into oceanic crust. Proterozoic anorthosites, on the other handare associated with felsic igneous rocks, indicating intrusion into continental crust. Geochemical and Nd isotopic data reveal the origin of these rocks from mantle-derived melts. However, Proterozoic anorthosites must have undergone significant crustal assimilation before their emplacement into continental crust, as indicated by the negative epsilon Nd values. Tectonic discrimination diagrams suggest that both types of anorthosites are formed in an arc tectonic setting; Archean anorthosites in an island arc and Proterozoic anorthosites in a continental arc settings.

DECLARATION

I, Anin Mary John, declare that the work included in my dissertation report named "Seismotectonic analysis of Meenachil River Basin" was composed entirely by me and that it has not previously been presented, in whole or in part, in any previous application for a degree. Except where otherwise noted, the work presented here is entirely my own. This work is presented to Christ College (Autonomous), Irinjalakuda, Kerala, in a partial fulfilment of the Master of Science in Applied Geology degree requirements.

ANIN MARY JOHN

ACKNOWLEDGEMENT

First and foremost, I want to express my gratitude to God Almighty, by whose mercy I am able to do this work. I wish to express my heartfelt gratitude and heartfelt thanks to Dr. Linto Alappat Dean of Research and Development of TLC and Dr. Anto Francis. K, Co-Ordinator, Department of Geology and Environmental science, Christ College (Autonomous) Irinjalakuda, for developing the project's framework and providing regular support and supervision throughout the duration of the course study. I would like to thank my external guide Mrs. Divyalakshmi (Scientist-C, National Institute OF Rock Mechanics, Kolar Gold Fields). Also, my internal project guide, Mr Tharun R (HOD, Department of Geology & Environmental Science) Christ College (Autonomous) Irinjalakuda, for creating the project guidelines and providing support and supervision throughout the project. Also, to A successful and ultimate conclusion of this project necessitated a great deal of advice and assistance, and I consider myself very grateful to have received this during all stages of my project work. Whatever I have accomplished is entirely due to such guidance and assistance, for which I am grateful.

I also thank other faculty members for their support and encouragement. I would like to extend my thanks to Mr. Ayyappadas C.S for the continuous support provided for the completion of the dissertation. I would prefer to take this opportunity to thank all of my classmates and friends, especially Mr. R S Ananthajith and Mr. Arul Thejas who helped me finish my dissertation. I am also thankful to the entire Christ College family for their love and support. I also express my gratitude to my parents and family members for their unwavering support and prayers throughout my life.

ANIN MARY JOHN

Contents

LIST OF FIGURES