Institutional Report

Geological Survey of India

S RAJU*

15A&B Kyd Street, Kolkata 700 016, India

Fig. 1: GSI office at 29, JL Nehru Road, Kolkata [for use in cover/initiation of Chapter on GSI only]

Introduction

Founded in 1851, the Geological Survey of India (GSI) has made significant progress in the exploration and assessment of mineral resources (including coal) of the country through regional exploration and has provided a wide-ranging contribution to all aspects of geosciences. The principal function of GSI has been, i) to create and update national geoscientific database for mineral resource assessment through air-borne and marine surveys, ii) to conduct geotechnical, geoenvironmental and natural hazards studies, iii)

glaciology, to assess the health status of Indian glaciers, iv) seismotectonic to provide geoscience based services to the society. GSI conducts its programs through Mission-Region hybrid matrix mode with its five Mission offices and three support systems with the continued calibration of its vision by adopting the best geoscientific practices, anywhere. For operational ease, GSI has six Regions based on their geographic distribution. The Missions are responsible for envisioning activities, giving guidelines and targets to the Regions and State Units, monitoring performance, and guiding sectoral, scientific and

**Author for Correspondence: E-mail: hodm4@gsi.gov.in*

technical reports. The support systems are responsible for internal management, infrastructure, resource and policy planning. Specialized Thematic Mapping launched in the early nineties has solved many of the significant geological problems and has identified new areas for mineral exploration. National Geochemical Mapping and ground Geophysical Mapping Programmes were initiated in the year 2001 in the Obvious Geological Potential (OGP) areas for integrating geological, geochemical and geophysical data. Offshore geoscientific studies in the Exclusive Economic Zone (EEZ) and Territorial Waters (TW) along the east and west coasts of India were also taken up. Cruises onboard RV Samudra Manthan within EEZ, and RV Samundra Kaustubh and RV Samundra Shaudhikama within TW. GSI procured RV Samudra Ratnakar to replace RV Samudra Manthan. A national program titled “National High-Resolution Seabed Mapping and Natural Mineral Resource Evaluation of EEZ of India and beyond” (NHRSM & NREE) was taken up. GSI procured its own “Advanced Light Helicopter – Garuda Vasudha” equipped with sensitive state of the art aero geophysical sensors.

Mission-I: Baseline Geoscience Data Generation

Specialized Thematic Mapping

One of the significant activities of the GSI is the generation of geoscientific maps on different scales using state-of-the-art mapping cum survey techniques. GSI is also engaged in the preparation of geochemical and geophysical maps of the mineral potential areas along with the thematic geologic maps on progressively higher resolution (1:25000 or better). Aerial Survey using Remote Sensing techniques and Marine Survey is taken up to produce maps of the landmass, coastal areas, and extended economic zone (EEZ) of the country.

The preparation of geoscientific maps on different scales through the ground, marine, and airborne surveys have been a core activity of the Geological Survey of India. Mapping has been carried out to solve problems related to stratigraphy, tectonic set-up, crustal evolutionary trend, metallogeny /ore localization. Out of the total mappable area of 31.458 lakh sq km of the country, 31.190 lakh sq km has been completed by systematic geological mapping by

March 2019, i.e., a coverage to 99.14%.

Further GSI has covered 3.002 lakh sq km by specialized thematic mapping till March 2019. Mapping has brought out the surface indication of mineralization at several places, viz. Sangrām–Dangba area in Kurung–Kumney District, Arunachal Pradesh; Proterozoic/ Archaean sequences in and around Jharli-Aligarh area, Jaipur and Sikar districts, Phut Ka Bas, Amloda, Mahar Kalan. Rundal-Chitwari areas of Jaipur district, Dhal-Mohammadgarh in parts of Ajmer district of Rajasthan; Nellore schist belt in Andhra Pradesh, Chhotanagpur Gneissic Complex in Dimra-Silli sector in parts of Ranchi and Ramgarh districts, Jharkhand; Zaskar Basin in Padam Phe area, Kargil and Doda districts, J & K, Darjeeling Gneiss and Jaishidanand formations in Darjeeling Himalayas, West Bengal.

National Geochemical Mapping

National Geochemical Mapping (NGCM) is another activity of GSI, and the data from the surveys are being used in mineral exploration to target concealed mineralized bodies in soil cover areas, soil fertility assessment, human/animal health, and in establishing an environmental baseline of geochemical parameters. NGCM aims to create a seamless geochemical base map on a 1:50,000 scale, of different elements for the entire country where the primary medium of sampling is fluvial/stream sediment or slope wash material. The sampling grid size is 1km x 1km or 2km x 2km cells depending on the various terrain conditions of the country. Composite samples from these grid cells are analyzed for 64 elements to identify anomalous zone(s) of elemental concentration after due geological interpretation.

The country has a mappable area of 31.458 lakh sq km, spreading over 5112 toposheets (1:50,000 scale) depicted by hard rock, soft rock, and alluvial sediments. Till March 2019, 33.69% of landmass equivalent to 11.05 lakh sq km, spreading over 1466 full and 160 part toposheets, have been mapped. Out of 11.05 lakh, sq km covered so far, 7.44 lakh sq km area is obvious geological potential (OGP) toposheet area has been covered. A GIS-based Geochemical Database Management and Information System (GDMIS) has been developed, to create maps enhanced for mineral exploration. During FS 2015-20, a total of 85 nos. of exploration projects has been

taken up by Mission-II as a spin-off item of NGCM.

In toposheet no 65N/3 of Koraput district of Odisha and Srikakulam district of Andhra Pradesh, three mappable manganese ore bodies have been delineated with over 20% Mn in and around Kondagudivalasa-Ippakonda in the northeast to Kondamosuru in the southwest. A Cr-diopside grain was reported during heavy mineral study of samples collected from Raichur district in Topo Sheet No. 57A/15, which indicates a possibility of the presence of kimberlite/ ultramafic body in the study area.

In Koppal of Raichur district of Karnataka (TS No 57G/7 and 57G/8), the maximum value of Cr (9357 ppm) and Ni (4693 ppm) have been obtained in stream sediment samples over ultrabasic schistose rocks of Sargur Group of rocks. The soil sample from the C1 quadrant of TS No.57G/8 has shown an even higher concentration of Cr and Ni with values of 15179 ppm and 7334 ppm, respectively. The chemical results of bedrock samples have shown Uranium values up to 45ppm in Sikar district of Rajasthan.

National Geophysical Mapping

The National Geophysical Mapping Programme (NGPM) of GSI aims to generate Geophysical baseline data to help locate and delineate subsurface geological structures and develop conceptual models of mineralized belts. This is done by a combination of geological and geochemical maps to determine potential/probable target areas for mineral exploration. Thus, the gravity-magnetic anomaly maps help in planning and formulating strategies for structural and tectonic studies, geotechnical studies, mitigation of natural hazards and management of the environment, and urban planning. So far, a total area of 707, 872 sq km, has been covered by NGPM, out of which 5.25 lakh sq km was in the OGP area.

Marine Coastal Survey Division

A detailed offshore program “National High-Resolution Seabed Mapping and Natural Resources Evaluation in the EEZ (NHRSM & NRE) of India is underway. During the period Marine & Coastal Survey Division (M&CSD) of GSI has completed seabed mapping of 16454 sq km and hence a total of 132,585 sq.km out of in 5 x 2 km grid within Territorial waters (TW), and 1,867,199 sq.km in the Exclusive

Economic Zone (EEZ) beyond territorial waters has been covered so far. The total EEZ coverage including TW, is 1,999,784 sq.km out of a total EEZ area of 2,014,900 sq.km.

Vast resources of economic placer minerals, limemud, relict sands have been delineated, besides identifying an encouraging occurrence of Phosphate bearing sediments and Fe-Mn encrustations within EEZ of India.

During the period 2015-2019, M&CSD has estimated total resources of 31.27 million tonnes of placer deposits over an area of 1,277 sq.km along the east and west coast and complete resources of 101,668 million tonnes of limemud deposits over an area of 11,866 sq.km along the west coast of India.

Remote Sensing and Aerial Surveys

Aerogeophysical Surveys

The survey was conducted 120 m above the ground over an area of 37,690 sq.km having a line, spacing 2500 m. The objective was preparation, integration, and compilation of the Total intensity magnetic anomaly map to decipher the seaward extension of the features identified on land. With this, magnetic and spectrometric surveys have been completed over the entire western offshore of India.

Magnetic data has enabled us to locate the extensions of Deccan traps and the Archaean terrain, ridge-like features comprising Deccan traps, basin boundaries of Tertiary sedimentary basins, and the ridges/platforms separating them in the offshore area. The magnetic data has delineated the structural features in the form of discontinuities representing the fault and fracture systems, particularly in the transitional region.

Five zones of moderate-high spectrometric anomalous zones have been identified in this area and reported to the marine wing for follow up.

Heliborne Surveys

Heliborne surveys with gravity and magnetic surveys were carried out in Bidasar block in parts of Sikar, Nagaur, Churu districts of Rajasthan with a coverage of 4381 km. The survey was conducted over an area of 6040 sq. km traverse line, spacing 1500 m.

The high gravity and magnetic zones are associated with known ultramafic formation. Bipolar magnetic anomaly trending NE-SW observed over the south of Fatehpur associated with medium gravity probably indicates a potential zone for base metal mineralization.

Remote Sensing studies for mineral exploration, carried out during the period from 2015 to 2020 is enumerated below:

- Interpretation and integration of geological, remote sensing and aerogeophysical data over the trap covered Gondwana Basin in Nagpur was carried out during Annual Programme 2014-16. The study resulted in the delineation of five blocks for fluorite, coal, base metal, REE, and PGE in the area.
- In Annual Programme 2016-17, interpretation and integration of geological, remote sensing, and aerogeophysical data was done over Chandrapur - Brahmapuri area in Maharashtra. This resulted in the delineation of four blocks for hematite, barite, REE, and PGE studies in the area.
- Interpretation and integration of geological, remote sensing, and aerogeophysical data over the Baihar - Kutru (Extension of Malanjkhand) area in Madhya Pradesh has been finished. It has helped in the delineation of five blocks for Lateritic, bauxite, fluorite, base metal, REE, and PGE in the area.
- Interpretation and integration of geological, remote sensing, and aero-geophysical data over the Kanker-Dhamtari area in Chhattisgarh were carried out using Fuzzy statistical modelling, and favorable zones for kimberlite emplacement have been demarcated. Ground checks have resulted in the detection of indicator minerals for kimberlites. Based on integration and indicator minerals, a block (Udkuda village in Kanker district of Chhattisgarh) has been identified for further details studies for kimberlites.

In Annual Programme 2018-19, integration of Geological, Geochemical and Geophysical data carried out in parts of Kesarpur-Kusumbhari-Dudhiasol area of Odisha. The study resulted in the detection of

sulphide mineralization in Krupaduma, titaniferous-vanadiferous magnetite in the Mundhabani area, and possible mineralization of gold in the Gonali area. These areas have been demarcated for likely gold and base-metal mineralization.

Also, in Annual Programme 2018-19, interpretation and integration of geological, remote sensing, and aerogeophysical data over Shimoga schist Belt, Shimoga District, Karnataka and follow up ground check resulted in three blocks sulphide mineralization zones in the Savalanga, Erekatte, Anveri and Surrahonne areas.

In Annual Programme 2019-20 three items were taken up for Remote sensing data interpretation, ground evaluation, and geological appraisal of aerogeophysical anomaly zones.

Hyperspectral Mapping and Building of the Spectral Library

The studies carried out during the period from 2015 to 2020 and highlights are as below :

In FS 2015-17 mapping of alteration/mineralized zone and building up of Spectral Library was carried out in Chitradurga Schist Belt, including G.R. Halli & Ajjanahalli Gold Prospects. The study revealed that the metabasalt exposed near Adivala Megalhatti are extending further Northward and hosts sulphide mineralization.

In 2017-18 Spectral Geological Mapping across the Krishna river fault in Gurgunta-Deodurg area Yadgiri-Raichur districts of Karnataka was carried, and three possible blocks, namely; Jalihalli, Golapalli, and SW of Parampur were demarcated for further exploration for base metal and gold.

In 2018-19 multisensor remote sensing-based alteration zone mapping carried out in part of Kadiri, Veligallu, and Kolar schist belt for targeting mineralized zones and building up of spectral library. Consequently, three blocks viz: 1. Kadiripulikunta to Chinnaramanagaripalle 2. North of Pedapalli and 3. Pedaballe were proposed for future mineral exploration.

Data Integration Study for Targetting the Potential Blocks for Mineral Exploration

The studies carried out during the period from 2015

to 2020, and the highlights are as below:

Multi-thematic data integration and target modelling in Aladahalli-Nuggihalli area, Hassan district, Karnataka,” was carried out during FS 2015-16. High aeromagnetic anomaly, moderate to a higher order of E.M. channels (3-6), and a lower degree of spectrometric signatures available in J.C. Pura block made it a potential block for further detailed investigation for mineral potential.

Integration of Geological, geochemical, and geophysical (Heliborne & TOASS) data in parts of the Bidasar-Dariba area, Rajasthan was carried out in FS 2016-17. Anomalous copper values average 1840 ppm have been reported from felsic volcanics near Biramsar-Ki-Dungru is reported.

The area shows a high aeromagnetic anomaly and falls in the high to moderate gravity gradient zone with 15 to 20 m of sand cover. Hence the area is identified for further G-4 stage mineral exploration.

Integration of geological, aero-geophysical, geophysical, geochemical & remote-sensing data to the search of potential mineral block Near Eastern Margin of Cuddapah Basin was taken up during Annual Programme 2017-18. Approx. 1 km NE of Lambadi Tanda, Prakasam dist., A.P. and at Gajjelakonda, Prakasam district, A.P., potential blocks have been delineated for the base metal.

Mission-II: Natural Resources Assessment

History of Mineral Exploration and mining in India is closely related to the establishment of the Geological Survey of India, which is responsible for mineral resource assessment of the country in addition to the updating of national geoscientific information. GSI's activities in mineral exploration, as well as baseline surveys, have increased manifold to sustain the momentum of national economic development and to meet the increasing demands of various stakeholders.

The exploration activity of GSI have been prioritized and focused considering NMP 2008, MMDR Act 1957 and its amended version of 2015, HPC document, guidelines received from CGPB meetings, different CGPB subcommittee meetings and recommendations of SGPB committee meetings of different states and time to time guidelines received from the Ministry of Mines, keeping in view the

requirement and demand of the Nation and priority of the mineral sector.

Emphasis has been laid on the intensification of exploration for low grade-high tonnage minerals for gold, base-metals, and assessment of iron ore deposits; stress was also given to search of tungsten, rare metals, and REE, fertilizer minerals like phosphorite, potash and glauconite. The GSI has been entrusted with G2 level of investigations for Mission-IIA items and to live up to the trust 13 number of G2 stage items of mineral exploration were undertaken during Annual Plan 2018-19.

During the recent past, the GSI has carried out exploration activities for iron in Mahasamund District Chhattisgarh, West Singhbhum district Jharkhand, Sambalpur, Kendujhar, and Sundargarh districts of Odisha; Obulapuram and Ananthapur districts, Andhra Pradesh, Karimnagar, Peddapalli and Jagtial districts of Telangana. Exploration for Manganese resource assessment was carried out in Bolangir and Ganjam districts of Odisha; Vizianagaram, Srikakulam and Visakhapatnam districts of Andhra Pradesh and Shimoga district Karnataka.

Chromite resources were explored in Sindhudurg district Maharashtra, Gaya District Bihar, Urkhrul district Manipur, Hanle, Rhongo area of Leh and Photaksar, Machu, Shilshi La area south of Lamayuru, Leh, and Kargil in the Union Territory of Ladakh. Exploration to locate mineralization for PGE was carried out in Lalitpur district Uttar Pradesh (Fig. 2), Palakkad District Kerala and Kanyakumari district of Tamil Nadu.

Exploratory activities for search of gold deposits were carried out in Budhadol-Sulkhan area, Singrauli and Sidhi districts, M.P., Jashpur district Chhattisgarh; Ranchi, Saraikela-Kharsawan districts, Jharkhand (Fig. 3), Papum Pare District Arunachal Pradesh, Nornis, Kesar and Kidmong areas in UT of Ladakh, Sonbhadra district Uttar Pradesh, Haveri, Tumkur, Raichur, Gulbarga, Koppal and Bagalkot districts, Karnataka and Tiruvannamalai district Tamil Nadu.

Search for basemetals were undertaken in Betul, Singrauli and Sidhi districts, Madhya Pradesh, Bhandara and Chandrapur districts, Maharashtra, Deogarh and Mayurbhanj districts, Odisha, East Kameng district Arunachal Pradesh, Kullu district

Fig. 2: Box work in quartz vein

Fig. 3: Photomicrograph showing pseudomorphs of olivine in the ultramafic rock (PPL view)

Himachal Pradesh, Baramulla and Ganderbal districts, Union Territory of Jammu and Kashmir, Rudraprayag District Uttarakhand, Sonbhadra and Mahoba districts, Uttar Pradesh, Nellore district Andhra Pradesh, Raichur, Chitradurga, Davangere and Bellary districts, Karnataka, and Banswara, Jhunjhunu, Sikar, Alwar, Chittaurgarh, Bhilwara, Udaipur, Pali districts of Rajasthan

Diamond exploration was carried out in Panna and Chattarpur districts, Madhya Pradesh and Banda district of Uttar Pradesh, Kabirdham district Chhattisgarh, Bagalkot, Bellary and Davanagere districts, Karnataka, Mahabubnagar and Vikarabad districts, Telangana.

Exploration for tin mineralization was carried out in the West Khasi Hills district of Meghalaya. Exploratory activities to search for REE resources were undertaken in Ri-Bhoi district of Meghalaya, Bhandara district Maharashtra, district Chhota Udaipur District Gujarat, Alirajpur, Betul, Chhatarpur and Shivpuri districts, Madhya Pradesh, Banka district Bihar, Godda district Jharkhand, Angul district Odisha, Purulia district West Bengal, West Siang district Arunachal Pradesh, Kamrup (Metro) district Assam, Doda district Jammu & Kashmir, Sonbhadra district U.P., Chittoor, Cuddapah and East Godavari, districts, Andhra Pradesh, Idukki and Kasargod districts, Kerala, Thiruvallur, Vellore, Salem and Dharmapuri districts, Tamil Nadu, Nagarkurnool and Nalgonda districts, Telangana, Rajsamand, Barmer and Bhilwara districts of Rajasthan.

Exploration for coal reserves was carried out in Raigarh district of Chhattisgarh, Chhindwara and Singrauli districts, Madhya Pradesh, Angul and Sundargarh districts, Odisha, Ramanathapuram district, Tamil Nadu, Bhadrachari-Kothagudem district, Telangana and Mokochung, Nagaland to augment national energy resources. Also, to exploit and harness non-conventional energy, resources of geothermal energy were searched in the Manuguru geothermal field Khammam district, Telangana, West Coast Geothermal Province, Palghar district, Maharashtra and Kedarnath, Gangotri, Yamunotri, Tapovan, Badrinath and Dar-Dobat areas in Uttarakhand, India.

Mission-III: Geoinformatics

The primary function of Mission III – Geoinformatics is to build, maintain, and effectively manage IT resources to ensure archival and dissemination of information to stakeholders. It aims to deliver accurate, up-to-date and comprehensive products and services, and provide crucial support to all missions of the organization. Mission-III actively involved in national and international collaborative initiatives concerning the dissemination of geo-information.

Under its charter, one of the mandate of the Geological Survey of India is to “Develop and continually enhance GSI’s core competence in survey and mapping through continued accretion, management, coordination and utilization of spatial databases and function as a ‘Repository’ or ‘clearing house’ for the purpose, and use new and emerging

computer-based technologies for dissemination of geographic information and other spatial data, through cooperation and collaboration with other stakeholders in the Geoinformatics sector.” Accordingly, Mission III activities aimed at the dissemination of geoscientific information. Mission-III has formulated a new “Data Sharing and Accessibility Policy 2019” incorporating guidelines from MOM, MOD, MMDR Amendment Act 2015, and National Mineral Exploration Policy (Non-Fuel Minerals) 2016. The Data Sharing and Accessibility Policy 2019 of GSI are valid from 1st March 2019.

IT Service

The Online Core Business Integrated System (OCBIS) project is furtherance to the organizational IT enablement by a developed integrated IT systems to help the Geological Survey of India efficiently and securely manage and share its vast data/information repository. The users of OCBIS get an integrated system with URL <https://www.gsi.gov.in>, i.e., a web-based platform, which connects - core processes and related data and support systems. OCBIS aims at comprehensive data management through integrated database schema and repositories to house all geoscientific as well as administrative information. This is an open standards-based IT platform that has its enhanced IT capabilities to exchange information with external stakeholders effectively (it includes Ministry of Mines), national and state-level earth science organizations/departments, industry, and citizens.

The 29 modules, including e-governance application, have been developed and rolled out since April 2017. Most significant components of OCBIS are as follows:

BhuKosh, the integrated spatial data management portal, facilitates the users to visualize, query data, create maps, and download. This is a gateway to access GIS, geophysical and report data of GSI. Users can access a host of geoscientific data about geological mapping, geochemical mapping, geophysical mapping, aerogeophysics, seismotectonic, landslide, geochronology, and meteorites in the form of OGC compliant map services.

The FSPMIS module takes care of the complete project activity from formulation, approval, execution, monitoring, preparation, and submission of a report

and any resulting publication from the project. FSPMIS is integrated with other information systems like Laboratory Management System (LMS), Drilling Management Information System (DMIS), and Vehicle Management Information System (VMIS) and specifically with Content Management and Field Application, which is used for field data collection.

Museum artifacts have been digitally captured from GSI Museums at Nagpur, Jaipur, Lucknow and Saketi, Central Headquarters, and organized in Virtual Museum. This museum allows the users to visualize high-quality photographs of the specimens including 3D view.

Infrastructure for digital data collection from field aided by GPS integrated mobile field devices has been introduced in GSI from FS 2017-18. The theme-based field applications have been created to collect sample/observation points and data from the field in both online and offline mode. The field records are directly be uploaded to the central raw data repository at OCBIS data center for ready consultation and archival. The field device is a very rugged one and can withstand dropping impact up to 5 feet, water and dust. It has long-life, user-replaceable battery and sunlight-readable, high-sensitivity 7-inch multi-touch screen. These devices are fed with all relevant data, including maps from headquarters for consultation during fieldwork. During fieldwork, the tools facilitate the collection of sample information/observation data from the field in both online and offline mode and thus minimizing loss of information from the observation point in the area. The field observation can directly be synchronized with the Central repository in servers at the data center for ready consultation by the Project team.

Support services like CGPBIS, Grievance, RTI, Legal, Rajbhasha, Parliamentary questionnaire, are some of the other applications. Application “WRITE2DG” is designed for general people and employees for writing to the DG, GSI to quench their inquisitiveness. Elaborate training and hands-on sessions are continuing in batches for each module released for a hassle-free migration experience to the grand New OCBIS Portal.

The unpublished progress reports and maps are being uploaded through FSPMIS to make the OCBIS Project a comprehensive repository of GSI data

holding. GSI is looking forward to making the invaluable data gathered over 160 years, available to all authorized stakeholders with increased usability and flexibility.

Publication

The major categories of GSI publications are Memoirs, Bulletin Series A, B & C, Records, Special Publications, Miscellaneous Publications, Catalogues, Palaeontologia Indica, and Indian Journal of Geosciences- the in-house quarterly journal of GSI published regularly and uploaded in the OCBIS portal. A Memoir contains detailed reports on complete surveys and investigations detailing with either with a particular region or with a specific mineral in one or more regions. Records mainly cover a brief outline of activities of GSI for different Regions and CHQ. The economic geology releases under Bulletin Series The significant categories of GSI publications are Memoirs, Bulletin Series A, B & C, Records, Special Publications, Miscellaneous Publications, Catalogues, Palaeontologia Indica and Indian Journal of Geosciences-the in-house quarterly journal of GSI published regularly and uploaded in the OCBIS portal. A Memoir contains detailed reports on complete surveys and investigations detailing with either with a particular region or with a specific mineral in one or more regions. Records mainly cover a brief outline of activities of GSI for different Regions and CHQ. The economic geology releases under Bulletin Series-A, engineering geology, and groundwater under Bulletin Series-B and Bulletin Series-C document the primary data generated by various laboratories/specialized divisions. Special Publications include the proceedings in multiple symposia and seminars organized by GSI as well as a set of papers dedicated to a particular field of study in earth science or some special projects. Miscellaneous Publication is a consolidated document on Geology and Mineral Resources of different States of India. Following Publications released from April 2015 to July 2019.

Map, Geoinformatics and Data Integration

GSI has been mandated to prepare both analog and digital geological maps and their databases for the entire country, and publication of the same. Following this, maps like Geological Quadrangle Maps (GQM), District Resources Maps (DRM), Geological and

Mineral Maps of States, Mineral Belt Maps (MBM), Coal Field Maps, Marine Maps etc. and several other thematic maps are being compiled and printed under this Mission. The compilation and publication of the Sea Bed Sediment Maps of Territorial Water (TW) and Exclusive Economic Zone (EEZ) are also carried out regularly.

The Mission is publishing “*Second Edition of GQM*” that has been compiled from 1:50K digital map database for the whole India. It has in OCBIS portal completed the synthesis and updation of all India Unified Legend for 1:50K GMS, upto without level, and creation of Geometric id and implementation in 50K Geodatabase in OCBIS. It has completed the “*One-Geology (IGCP 624)*” projects. It has also published “*Quaternary Geological Atlas of India*” (Volume 1) encompassing selected quaternary terrains of India. The Mission has also completed all India Projects like “Revision of Seismotectonic Atlas of India and its Environs [SEISAT] updating it to digital (GIS) version,” “Stratigraphic Database in India in 1:50K scale upto lithounit level with stratigraphic hierarchy, colour coding, and stratigraphic notation” and “Theme based compiled geological map on Granite/Granite Complex of India.”

Besides, the Mission is also engaged in *Data Integration Modelling* for mineral commodity-wise by combining geological, geochemical, geophysical (both aero and ground), geomorphology, and alteration map data in 1:50000 scale to find out areas of probable mineralization. The area demarcated by the integration exercise is used for planning future exploration campaigns under the G-4 stage by Mission II.

Data integration modelling, a thrust area in Mission-III, has been done on Ramagiri Schist Belt and part of Jonnagiri Schist Belt of SR for base-metal and gold mineralization and for Copper mineralization in Singhbhum Shear Zone, Eastern Region; Sakoli fold belt in Maharashtra (for gold, base-metal, and tungsten) and Laterite Belt, Maharashtra (for bauxite, gold, chromite) in Central Region; South Purulia shear zone for basemetal in ER; Mahakoshal belt in NR for gold; Eastern Ghat mobile belt and Peninsular Gneissic Complex for PGE and REE; and lead, zinc and copper in Western region. Creation of Data integration model of the central and eastern part of Betul Belt in Chhindwara and Betul districts of

Madhya Pradesh through the integration of various thematic maps to find out new target areas for base metal, graphite & associated minerals has been accomplished. Integration of theoretical exploration model to discover new/concealed areas in Singhbhum shear zone and Dhanjori basin for Base metal, Gold, Nickel and associated minerals has been done. Integration of available geological, geochemical, geophysical, aero-geophysical, remote sensing and drilling data of sheet 78 O to identify the mineralization pattern. Integration of geological, geochemical, geophysical, aero-geophysical and remote sensing data of 45J degree sheet to identify new target areas for lead, zinc, copper and associated minerals.

Moreover, This Mission-III is presently pursuing the following all India projects

- Compilation and Updation of 1:2M Geological Map of India in Digital format.
- Synthesis and collation of All India National Geochemical Map data (NGCM) and National Geophysical Map data (NGPM) on 1:50000 scale and uploading in BhuKosh (OCBIS GeoPortal).
- Creation of National Geoscience Data Repository (NGDR) in GSI.
- Creation of Theme based compiled geological map on ultramafic rocks/suites of India.
- Creation of Geodatabase on a 1: 25000 scale using STM Data of selected belts of India, where such mapping has been carried out by GSI.

Mission-IV: Fundamental and Multidisciplinary Geosciences

Petrology

The petrological laboratories of GSI have offered different instrumental services to all the regions of GSI and provided petrological guidance to various officers of GSI as and when required. Besides, during the last five years, several research projects have been accomplished. Research approaches to deduce the tectonothermal evolution of the terrain and orogenesis are the main thrust area. Significant research work has been continued in the Southern

Granulite Terrain (SGT) of Tamil Nadu. It has resulted in finding the controlling factors of PGE mineralization (PGM)? In Sitampundi Layered Complex (SLC) and Mettupalayam Mafic-Ultramafic Complex (MMUC). In case of SLC, the PGM? are explained as a derivative from immiscible sulphide droplets with a possible reaction between chromite and monosulphide solid solution whereas the PGE enrichment in MMUC occurred after the chromite enrichment and it was remobilised in a chlorine-bearing aqueous solution which again re-precipitated the PGM within the shear zone at low temperature. Significant research work has been carried out to infer the tectono-thermal evolution of Eastern Madurai Block, Western Madurai Block, and Palghat-Cauvery Shear Zone of SGT.

Also, several research projects were carried out in eastern India. Petrogenesis of gold mineralization in Singhbhum Shear Zone in parts of Jharkhand was carried out in collaboration with Mission-II mineral exploration projects, and it was established that the gold mineralization is syngenetic and primary in origin which has been remobilized by the hydrothermal fluid activity at a later stage and re-deposited as epigenetic veins along with sulphide phases. Eastern Ghats Mobile Belt was studied in Odisha and it was emphasized that there are further smaller terrains within Eastern Ghats province than explained earlier. Research work in Meghalaya plateau has revealed the presence of an Archaean carbonate meta-sediment which was unknown to the world so far.

A study on the older supracrustals of Western Dharwar Craton led to the concept that plate tectonics can be dated back even up to Archean time. Subduction related tectonic setting has been suggested for the alkaline complex of Sidhi Area, MP in parts of Mahakoshal Supracrustal Belt. Studies on Betul Belt has revealed the formation of a much-discussed but lesser-known zincian spinel. It has been explained that amphibolite grade metamorphism of rhyolite has facilitated the formation of these zincian spinels.

Ore genetic study was taken up in the Bokri area within Khetri Copper Belt, where alteration zones along with the structures, metamorphic history, and the interrelationship between the minerals and ore minerals were studied to establish the ore genesis of the area.

The Experimental Petrology Laboratory carried

out projects on i) diffusion studies during hydrothermal alteration of pyroxene and amphibole ii) to trace the crystallization history of ferro-basalts of Iron Ore group of rocks in Singbhum area. A project on 'zinc in feldspar' was carried out to study the phase relations between anorthite and albite with Zn-feldspar and its significance in the natural system. Also, the research project on identifying the dependence of viscosity on temperature and composition of Deccan Trap basalts is being carried out.

Study on the genesis of ion-adsorption type REE Mineralisation in parts of Nongpoh Granitoid, Ri-Bhoi District, Meghalaya was taken under petrological research. This study has found a pegmatite intruding pelitic-migmatite with a high Σ REE value of 5665.08 ppm.

Charnockites of both igneous and metamorphic origin were reported during the petrological study on fluid controlled charnockitization of granite-gneiss in parts of West Khasi Hills District, Meghalaya. Petrographic and fluid thermometric analyses indicate at least two generations of fluid activity. Both secondary carbonic monophase and aqua-carbonic biphasic inclusions are identified from the charnockite gneiss, porphyritic charnockite, and granitoids of the area.

A study of petrology and geochemistry of the felsic volcanic rocks of Shillong Group revealed the presence of felsic meta-volcanics and volcanoclastics (coherent lava flow, scoria, pyroclastic deposits viz. tuff and ignimbrite, and epiclastic deposits). There is evidence of subaerial eruption. Strong enrichment of incompatible elements Rb, Ba, and Th are suggestive of upper crustal source in a rift setup that might have taken place within the Shillong sedimentary basin.

Geochronology and Isotope Geology

Geochronology and Isotope Geology (GIG) Division, NCEGR, Kolkata carry out *in-situ* zircon U-Pb dating and determines lead (Pb) and strontium (Sr) isotopic ratios using Laser Ablation Inductively Coupled Mass Spectrometer (LA-MC-ICPMS) instrument. Radiocarbon laboratory of the GIG Division carries out ^{14}C dating of Late Pleistocene to Holocene organic-rich geological samples using Super Low-Level Liquid Scintillation Counter (LSC).

In the last five years, GIG Division generated a database on U-Pb zircon ages of different granite bodies from Trans-Himalayan Karakoram Batholith and Lohit Plutonic Complex from western and eastern Himalayas. New U-Pb zircon ages from these granites throw light on their tectonostratigraphic evolution. Similarly, U-Pb zircon ages of undated granites, gneisses, and meta-sedimentary rocks from Aravalli-Delhi Fold Belt, Rajasthan and Dharwar Craton of South India shed new ideas on stratigraphy.

The study of Pb isotopic ratios from street dust and street food of Kolkata and also from the Korba coalfield indicated diesel as one of the primary sources of pollution. Repository work on Pb-isotopic characteristics of different coalfields of India was created. Pb-isotopic characterization of Cu-Au deposits of Khetri Copper Belt of Rajasthan was studied.

The Radiocarbon Laboratory has contributed significant knowledge in constraining the ages of neotectonic events taking place at Eastern Himalayan foothills, age of sea-level changes along the coastal areas of West Bengal.

Paleontology

In GSI, the palaeontological work is focussed on carrying out biostratigraphic, palaeobiogeographic, modern approach to determine or revisit taxonomic nomenclature, palaeoclimatic studies, refinement of age of stratigraphic unit, paleoenvironmental reconstruction, studying the taxonomic diversity, extinction events, diversification, and turnover apart from to develop innovative background concerning evolution and ecology as well as extinction mechanisms. The palaeontological researches in the Geological Survey of India for the year (2015-2020) have been carried out from a deep time to recent. The most notable findings are listed below:

Study of the faunal turnovers and extinction selective of brachiopods and bivalves throughout the Permian from Siang valley, Arunachal Pradesh revealed a diverse Lower and Upper Permian brachiopod and bivalve assemblage, the bivalves showing an expected increase in the later part. The pronounced ecological shift from the lower to upper Permian was concurrent with the onset of deep marine anoxic or euxinic conditions and low

productivity environment and climatic cooling around the Guadaloupian-Lopingian boundary. The presence of marine Upper Permian units in the east of Siang River, which has been a matter of controversy since long has been resolved, as the fossiliferous shale unit with prolific bivalves and brachiopods which contain Upper Permian taxa like *Neochonetes*, *Fusichonetes*, *Cathaysia*, *Tethychonetes*, *Spiriferella*, *Rectimarginifera* and *Costiferina* has been recorded in the southern slopes of the Dalbuing hill.

Study of foraminifera from Badura Formation, Rajasthan revealed six Early Permian foraminifera for the first time and comprised *Ammobaculites woolnoughi*, *Trochammina qulivilla*, *Rectocornuspira* cf. *lituiformis*, *Calcitorenella* aff. *elongata*, *Lagenammina* sp. These assemblages show only generic level affinity with the form described earlier from the Talchir Formation of Mahendragarh and Umria of central India. It is worthwhile to note that this foraminiferal assemblages are dominated by agglutinated foraminifera except *C.* aff. *elongata*, there is no common form registered from Badura Formation and Garu Formation of Arunachal Pradesh. Faunal assemblage in Arunachal Pradesh displays more diversity. The recorded low diversity microfossil assemblage and its association with monospecific bivalve assemblage (*Oriocrassatella* sp.) indicate low salinity, shallow water environment of deposition. The low diversity Badura microfossils developed in a shorter marine time interval compared to that of Arunachal Pradesh. This foraminiferal assemblage can be compared to that of the Australian fauna, which shows Sterlitmakian affinities.

A detailed paleontological investigation was carried out, in parts of Boulder Slate Formation, Garhwal Himalaya and in the Garu Formation, Arunachal Himalaya for fresh collection of Early Permian fossils from existing known marine sequences and the search of such new localities the basis of faunal occurrence in the examined sections, it is proposed that the Boulder Slate Formation can be sub-divided into Lower Bryozoa Zone and Upper Brachiopod Zone. The overall assemblage of Bryozoa Zone is comparable with the Fenestella Shale of Kashmir and, Brachiopod Zone consists of mixed elements of Agglomeratic Slate Series of Kashmir and Garu Formation Arunachal Himalaya

Palaeobiogeographic study of the Jurassic brachiopods from Kachchh and Jaisalmer basins of western India and also other parts of north and east Africa, Madagascar revealed two distinct faunal provinces, the Ethiopian biogeographic province, and the Indo-Madagascan biogeographic province. It was seen that endemism was much prevalent in the Kachchh Mainland part, whereas the Island brachiopods are confined to particular horizons and show more extensive diversity. The oldest occurrence of brachiopod in western India came from the Upper Bajocian Kaladongar Formation of Pachcham Island, but interestingly, the same brachiopod stock was present in the oldest marine units in the Khadir Island as well as the nearby Jaisalmer basin. The record of *Somalithyris jhalarensis* from the Late Callovian-Oxfordian units in Kachchh have evolutionary implications in the *Somalithyris-Kutchithyris* clade. Records of *Mycerosia indica*, *Bihendulirhynchia brevicostata* and *Kallirhynchia versabilis* from the Oxfordian horizons of Kachchh has palaeobiogeographic implications as all are prominent taxa in the Ethiopian Province.

An investigation on the pelagic sediments associated with ophiolites in the Andaman group of islands has brought out the presence of a rich assemblage of calcareous nanofossils, for the first time, along with radiolaria and planktonic foraminifera. The presence of radiolaria and planktonic foraminifera of Campanian -Maastrichtian affinity has been reported from this pelagic sediment for long. The pelagic sediments of Middle Andaman have yielded both the coccoliths and nannoliths along with the algal spores and cysts.

The study of microfauna from Shella Formation, Meghalaya revealed a diverse Paleocene-Eocene (P-E) microfossils, which include larger benthic foraminifera (LBF), ostracods, and planktonic foraminifera. The recovered larger benthic foraminiferal assemblage (*Setia tibetica*, *Glomalveolina primaeva*, *G. levis*, *Ranikothalia nuttalli*) points an SBZ-3 to SBZ-5 (ca~59-56 Ma) biozone for the studied section of Lakadong Limestone. Similarly, presence of *Alveolina indicatrix*, *A. schwageri*, *Assilina spira*, *Nummulites atacicus*, *N. globulus*, *N. Pinfolid* and *Assilina laxispira* suggests an age of SBZ 8 to SBZ-11 (ca ~54-49 Ma) biozone of Umlatdoh Limestone.

The microfaunal study from the Miocene sequences of Bhuban Formation leads to recover seven genera and eleven species of shark fish teeth. The shark teeth *Carcharhinusleucas*, *Carcharhinushemiodon*, *Carcharhinusbrevipinna*, *Carcharomodus escheri*, and benthic foraminifera *Miogypsina* cf. *globulina*, *Reophax* cf. *Subfusiformis* have been recorded for the first time from Bhuban Formation.

Societal Programmes

Geotechnical Investigations

The geotechnical investigations of site/project play a vital role in the safe and economic development of engineering structures. Engineering Geology Division, GSI WR is playing an essential role in national development by providing geotechnical expertise in planning, investigation, and construction of water resources development projects, atomic power plants, communication and transportation projects, etc.

The Geotechnical laboratories of GSI are equipped with various geotechnical instruments for the determination of geotechnical parameters on soil/rock/aggregates samples. Since their inception, the Geotechnical laboratories have been catering to the needs of various ongoing Engineering Geology projects and also carrying out the analysis for outside agencies on payment basis as per norms of SOC, MOM. The laboratories are actively involved in analyzing the geotechnical parameters of samples submitted by Earthquake Division, Landslide Projects, and Engineering Geology Division of GSI.

Seismic/Earthquake Studies

GSI carries out earthquake-related studies through the macro-seismic survey (post-earthquake damage survey for assigning intensity), seismic hazard microzonation, micro-seismic (aftershock) survey, geodynamic studies through campaign mode GPS, and active fault mapping. The organization has simultaneously been building Seismo-Geodetic infrastructure comprising of pan-India permanent GPS stations and broad-band seismometer.

As on July 2019, there are 22 GPS permanent stations (Fig. 4) established at Kolkata, Trivandrum, Jaipur, Pune, Dehradun, Chennai, Jabalpur, Gandhinagar, Raipur, Bhopal, Chandigarh, Patna,

Bhubaneswar, Vishakapatnam, Jammu, Agartala, Mangan (Sikkim), Nagpur, Shillong, Lucknow, Huttbay (Andaman) and Itanagar. Ten broad-band seismometers have been installed at Agartala, Itanagar, Mangan, Lucknow, Jammu, Jaipur, Pune, Trivandrum, Nagpur, and Huttbay. This infrastructure is being used for Pan-India stress/strain monitoring (Fig. 5). For the last five years, GSI has also carried out microearthquake (MEQ) studies in different regions like Tripura fold belt, west Brahmaputra basin, Assam, Mizoram state and its adjoining areas, etc., and campaign mode GPS studies across the active transverse tectonic elements in Bihar, North Bengal and North-eastern region.

For the last five years, GSI has carried out active fault investigation along selected domains of West Patna fault, Bihar; around the foothills of Assam-Arunachal Himalaya in parts of East Siang and West Siang Districts, Arunachal Pradesh; along the Himalayan foothills of Riasi district, Jammu & Kashmir and the Katrol Hill Fault, Kachchh district, Gujarat.

Besides, GSI has also completed projects like Morphotectonic mapping to the northern parts of Ganges Bengal Fault (GBF) and Malda Kishanganj Fault (MKF) falling in parts of Darjeeling district, West Bengal and Kishanganj-Araria districts, Bihar; Regional neotectonic studies for delineation/identification of active fault along the Himalayan Frontal Thrust (HFT) at the foothills of Assam-Arunachal Himalaya in parts of Papum Pare and Lower Subansiri districts, Arunachal Pradesh and Neotectonic Studies along Satlitta (Soan) Thrust in Himalayan Frontal Belt, Punjab, and Himachal Pradesh.

During the same period, GSI has carried out level B seismic microzonation at 1:25000 scale for the townships of Bhubaneswar (Odisha), Itanagar (Arunachal Pradesh), Amritsar (Punjab), Meerut (Uttar Pradesh), Srinagar (J&K), Kochi and Ernakulam (Kerala), Mangalore (Karnataka), Alwar (Rajasthan), Port Blair (Andaman) (Fig. 6) and Indore (Madhya Pradesh).

Geological Survey of India felt the necessity for continuous acquisition, recording, and analysis of seismo-geodetic parameters, which have a substantial bearing on earthquake generating process, to minimize earthquake risks. Hence Seismo-Geodetic Data

Fig. 4: Seismic-Geodetic Infrastructure of GSI

Receiving and Processing Centre (SGDRPC) was setup in 2015 for real-time acquisition through a Very Small Aperture Technique (VSAT) and processing of seismo-geodetic parameters. It is in operation with ten remote Seismo-geodetic observatories. Seismic studies at SGDRPC, CHQ include Micro-earthquake

(MEQ) survey, seismic hazard microzonation, micro-seismic (aftershock) survey, GPS monitoring for crustal movement and real-time earthquake monitoring and reporting of significant earthquakes in public domain through GSI portal, generation of monthly/quarterly seismological bulletin and archival

Fig. 5: Time-series depiction of data acquired by GPS permanent station installed at Itanagar since December 2015. Data processed using GAMIT/GLOBK

of earthquake data for organization to contribute the seismological inputs to the nation for research purposes and to provide information on the nature and extent of faulting and its relationship with past and present seismogenic potential zone.

To understand the seismicity pattern, nature and distribution of seismogenic source and subsurface heterogeneity of the West Brahmaputra Basin, comprehensive seismic monitoring was carried out by establishing temporary seismic networks consisting of nine seismographs installed at different locations in the West Brahmaputra Basin in (Fig. 7). A total number of 400 earthquakes ($M < 5.0$) were located, and the data set are plotted as an epicentral map. It was found that most of the earthquake magnitudes

(M_L) are in the range of 3.0 to 4.0 and few earthquakes are of magnitude more than 4.0. Hypocentral depth of located earthquake showed variation from 3.0 to 60 km and very few earthquakes occurred at depth more than 100 km. The epicentral map shows higher seismicity along either side of the Dhansiri-Kopili fault in the eastern part of the area as well as along Dudhnoi/Kulsi faults in adjoining Shillong Plateau in the southern part of the area. Scattered seismicity has been observed in the entire West Brahmaputra Valley.

Studies on Landslide

Geological Survey of India (GSI) carries out three types of landslide investigations namely, (i) landslide

Fig. 6: Seismic & Tsunami hazard assessment of Port Blair and its surrounding areas

Fig. 7: Tectonic map (after GSI, 2000) showing the epicenter location of earthquakes in West Brahmaputra Basin with seismic network of stations (GWH: Guwahati; KMP: Kamrup; BNH: Byernihat; TZP: Tezpur; MLD: Mangaldai; UDL: Udalguri; MSP: Mushalpur; CHG: Chhaigaon; BRP: Barpeta; GLP: Goalpara; KKR: Kokrajhar; MRG: Morigaon; AMG: Amguri). The solid line (red) and dotted lines indicate fault/thrust and lineaments, respectively. (BDF: Bomdila Fault, MCT: Main Central Thrust, MBT: Main Boundary Thrust, MFT: Main Frontal Thrust, AF: Atherket Fault, DKF: Dhansiri-Kopili Fault, DNF: Dudhnoi F., KF: Kulsi F., OF: Oldham F., BT: Barapani Thrust; NT: Naga Thrust, DT: Dapsi Thrust)

inventory mapping, (ii) landslide susceptibility mapping on a macro-scale (1:25,000/50,000) and mesoscale (1:10,000/5000); and (iii) site-specific study of landslide including monitoring. All the above landslide studies are carried out as per the laid-down Standard Operational Procedure (SOP) of the Landslide Disaster Management Plan of Geological Survey of India (GSI).

During 2015-2020, GSI rolled out the National Landslide Susceptibility Mapping (NLSM) Programme to prepare seamless landslide susceptibility maps on a 1:50,000 scale for 0.42 million sq.km. lying in hilly regions. These maps are the most fundamental inputs for the estimation of landslide hazard and risk, which helps the planners/administrators/insurers in relevantly allocating the resources while tackling such hazards. The objective

of this national programme is to create a seamless GIS-based dynamic National Landslide Susceptibility Geodatabase for the country on a 1:50,000 scale and to prepare a nation-wide repository on GIS-based Landslide Inventory to be completed by Annual Programme 2019-20. The program was initiated in Uttarakhand state after the tragedy of 2013, wherein 15,810 sq.km. area was completed during Annual Programme 2014-15. Subsequently, the program was implemented in other regions of GSI, in total the Landslide susceptibility maps for the 223,680 sq.km area (Fig. 8) in priority-1 and 29,151 sq.km area in priority-2 area has been completed till March 2019. The compiled final maps have been uploaded in GSI's webportal for viewing and downloading by all stakeholders.

In recent years, the prominence of landslides as

Fig. 8: Distribution of the areas to be covered under NLSM in India

one of the major disasters and the growing demand for digital data ineffective decision-making processes has necessitated the collation of all the analog data to a common platform of Geographical Information System (GIS) which makes data storage, retrieval, updation, processing and broader dissemination of the scientific data/information easy. In this endeavor, GSI has, so far, published four compendiums of landslide studies encompassing on Darjeeling-Sikkim Himalayas (Ghosh *et al.*, 2015) on NW Himalayas (Jaiswal *et al.*, 2016a), on Southern parts of Western Ghats (Jaiswal *et al.*, 2016b) on Maharashtra (Ghosh *et al.*, 2018) during the work of GSI till 2014. The last volume of the compendium series for Northeastern states is under progress.

During the period, GSI also took up research projects to further cause of reducing the landslide disaster risk. It involved developing a methodology for hazard and risk, instrument-based landslide monitoring; Interferometric synthetic-aperture radar (InSAR) based landslide monitoring, development of an experimental people Centric Early Warning system, Experimental

Regional Landslide Early Warning system, and use of 3D Terrestrial Laser scanner for slope stability assessment etc. A few of the projects undertaken so far include, Development of GIS-based, qualitative/ quantitative landslide hazard and risk analysis methods on macro-scale (1:50,000/ 25,000) by incorporating the consequences of an extreme event – an application in the Mandakini valley, Rudrapur District, Uttarakhand.

- Geotechnical assessment and instrument aided monitoring of Barkot Landslide, Tehri Garhwal district Uttarakhand, for developing Instrument based Early Warning System (EWS).
- Empirically derived rainfall threshold-based Early Warning System (EWS) for landslide hazards in Darjeeling district, West Bengal. [Under this project the first time an experimental People-Centric Landslide Early Warning system was deployed in Giddapahar, West Bengal].
- Monitoring of Chibo and Gayabari (14th mile) landslides, Darjeeling District, West Bengal using InSAR. [This collaborative project between Geological Survey of India and Natural Resources, Canada (NRCAN) was for monitoring ground displacement of Gayabari (14th Mile) and Chibo landslides using InSAR analysis of multi-temporal RADARSAT-2 imageries].
- Study of landscape dynamics in Darjeeling Himalayas, West Bengal, and Nilgiris, Tamil Nadu. [This Collaborative project with British Geological Survey under LANDSLIP will help in developing an experimental a Regional Landslide Early Warning System].

- Site-specific mapping of unstable slopes on the right bank of Bhagirathi River in Devprayag using 3D terrestrial laser scanner, Tehri Garhwal district, Uttarakhand. [Under this program, GSI has developed the core capacity and use of 3D Laser Scanner for topographical mapping and slope stability assessment].
- Application of SAR Interferometry for delineation of active ground deformation zones in parts of Darjeeling district, West Bengal. [This project aims to use ground deformation maps in Landslide Susceptibility to delineate hazard].

GSI took up collaborative programs on landslides with other national agencies (National Remote Sensing Centre-NRSC, Defence Terrain Research Laboratory-DTRL) and international agencies (Natural Resources, Canada – NRCAN, British Geological Survey) on Development of experimental Landslide Early Warning system, site-specific landslide monitoring etc.

GSI carried out post-disaster landslide investigations of major landslides during the last five years and the data is available in the GSI web portal for download (<https://www.gsi.gov.in>). The initial post-disaster investigations during the period include the major landslide events of the 2018 deluge in Karnataka and Kerala. More than 1800 landslides were documented during the investigation. GSI also regularly updates the landslide database of the entire country through the Bhukosh and Landslide hazard web page of the GSI web portal.

GSI undertook Landslide studies in mesoscale (1; 10,000) in Assam, Sikkim, Tamil Nadu and West Bengal along the critical road corridors and habitat areas on the request from stakeholders and also carried out many site-specific landslide studies both for DPR preparation and geological input for stabilizing the landslides, viz. 5th Mile Landslide on Gangtok-Nathula road, Sikkim; Valley View Village, Kodapanund Ambedkar Nagar Landslides in Tamil Nadu; Landslide in Kurusumala, Kottayam; Landslide in Amboori village, Tiruvananthapuram; Vellurkunnamm landslide Kallarkutty Landslide, in Kerala; Wariya and Banderkot villages, Narendranagar landslide, Mansadevi Landslide, Haridwar Jurassic Landslide in Uttarakhand, Trangla Landslide in Jammu & Kashmir, Idukki District, Kerala, etc. Besides,

identification of vulnerable inhabited slopes in parts of Raigad, Ratnagiri in Pune and Thane districts of Maharashtra was also completed.

Engineering Geology Division

Geological Survey of India is a pioneer in the realm of geoscientific studies having a saga studded with 164 years of dedicated service to the nation since its inception in 1851. Its outstanding and immense contribution over the years has eventually enabled this great organization to assume the role of principal geo-scientific advisor to the Government of India.

The history of engineering geological investigation in India dates back to 1880 when Sir R.D. Oldham studied the problems of slope stability in Nainital, Uttarakhand. TH Holland investigated massive landslide incidences in Garhwal and Darjeeling Himalayas in 1893 and 1899, respectively. Subsequently, Dr. JB Auden promoted engineering geological investigation in 1945. Engineering Geology Division was introduced in GSI to unravel and solve the myriad challenges of Geology encountered in the development of major water resources projects and control natural hazards like landslides. Gradually the services were extended to other various Civil Engineering Projects like rail-road alignment, bridge/tunnel, runways, nuclear power projects, erection of heavy engineering structures and multi-storied building complexes, urban development etc. which require and involve the skill and knowledge of inter-disciplinary approach. In the process, E.G. Division of GSI has carved out a significant niche in this specialized field with its illustrious background visible in the construction of engineering marvels like Bhakra Dam in Punjab, Hirakund Dam in Odisha, Rihand Dam in UP, Idukki Dam in Kerala, Nagarjun Sagar Dam in AP, Tungabhadra Dam in Karnataka, Salal & Uri H.E. Projects in J & K, Nathpa Jhakri H.E. Projects in HP, Tehri Dam in Uttarakhand and DVC Projects in West Bengal & Jharkhand, to name a few.

In the neighbouring country of Bhutan, GSI rendered invaluable services in the development of hydroelectric projects in Tala and Chukha and is presently associated with Punatsangchu-I & II H.E. Projects. GSI has been accorded a vital role by the Government of India in clearing Detailed Project Reports (DPR) of different hydroelectric projects in India, Nepal and Bhutan, considering its leading

participation in various stages of investigations in this arena.

Engineering Project Evaluation (EPE) Division

Engineering Project Evaluation (EPE) Division, GSI, DGCO, New Delhi is engaged in evaluation of the “geological and geotechnical details” of the Detailed Project Reports (DPRs) of major hydroelectric and multi-purpose projects costing more than 1000 Crores for enabling the Central Electricity Authority (CEA), Ministry of Power, Government of India to issue the necessary techno-economic clearance (TEC). The EPE Division is an integral part of this entire appraisal process of CEA for the Geology volume of the DPR and thereby contributes to nation-building by augmenting the HE projects of the country.

The EPE Division of GSI involves a critical review of DPRs about the geological and geotechnical aspects of the significant water resources development projects, preparation of comments/suggestions and subsequent observations on the replies obtained from the project authorities/ developers/ DPR preparing agencies at multiple levels. This also includes assessing the adequacy of exploration/ investigations carried out at the DPR stage and accordingly suggesting the relevant technical modifications/ recommendations make the DPR realistic/ bankable to minimize geological surprises, time and cost overruns during actual construction. An optimal and quality geological appraisal is a prerequisite to the engineers for arriving at safe and cost-effective design parameters of various appurtenant structures of major civil infrastructure projects. To properly execute the above evaluation process, the EPE Division participates in the Technical appraisal/Review/TEC meetings for each project held at CEA as an expert organization with members from Central Water Commission (CWC), Central Soil and Material Research Station (CSMRS), State Government representatives, Project Authorities and other related agencies, also undertakes technical field visits to some of the project sites as and when required.

Geotechnical Laboratory

Geological Survey of India (GSI) has a legacy of pioneering works in geotechnical investigation, especially in the field of public good sciences e.g. Engineering Geology, Landslide studies and

Earthquake Geosciences. Its involvement in geotechnical studies dates back to 1859, starting from services rendered for Calcutta-Patna railway alignment to Nainital landslide in 1880 to innumerable Water Resource Development (WRD) and Communication projects in India and overseas. Even after the independence in 1947, GSI through its Engineering Geology faculty continued its supports to Nation building by rendering geological and geotechnical services to various multi-purpose WRD projects such as Bhakra Nangal in HP; Hirakud in Odisha; Damodar Valley projects in WB; Idduki in Kerala; Kadamparai Pumped storage UG- HEP in Tamil Nadu, Tehri in the UK etc. The list is exhaustive and diverse, but the commonality lies in the Lab support rendered by the Regional Geotechnical Laboratories of GSI in providing the quality geotechnical inputs required for these projects.

GSI has six Geotechnical Laboratories (GT-Lab) located in the GSI's Regional Headquarters at Kolkata (Eastern Region), Hyderabad (Southern Region), Nagpur (Central Region), Jaipur (Western Region), Lucknow (Northern Region), and Shillong (Northeastern Region). The GT-Labs cater to the demand of all WRD, Landslide, and Earthquake Geology projects located in different Regions/State units of GSI and also requests from other stakeholders.

Desert Geology

The investigation entitled ‘Quaternary evolution of Banas River along the eastern part of Rajasthan’ was made and the area under investigation includes PGRS studies followed by strip geological and geomorphological mapping. Geologically, the western part of the study area comprises of phyllite, quartzite, calc-silicate, mica-schist, gneiss, dolomitic-marble with later intrusions of pegmatite and quartz vein of Mangalwar Complex of Bhilwara Supergroup. Geomorphologically, this area has residual hill, pediment, peneplain and valley fill units. The active tectonics features such as unpaired terraces and fault scarps have been recorded in the geomorphic maps along the river transect.

Environmental Geology and Public Health Hazard Studies

Environmental Geology studies NR during the last five years have carried out a project of societal importance

in terms of ground and surface water contamination, its health impact, to identify nature and magnitude of the problem, delineation of the affected area, and source of contamination.

GSI, Northern Region, has completed the Geoenvironmental Appraisal of the major district of Uttar Pradesh. During the period between 2014-2019, geoenvironmental appraisal studies were done in Ghazipur and Chandauli district with particular emphasis on Arsenic contamination. Detailed and systematic Arsenic contamination study and analysis of surface/groundwater and sub-surface sediments to know the extent and pattern of concentration of Arsenic, approximate depth of affected aquifer and its geogenic causes have been carried out in Ghazipur, Chandauli, Gorakhpur, and Gonda districts of Uttar Pradesh (UP). In the Ganga alluvial plain of UP, fluoride contamination study during 2014-2019 was done in the Pratapgarh district.

Study of groundwater contamination was undertaken during Annual Programme 2015-16 & 2016-17 to study the nature, magnitude and causes of contamination and to locate uncontaminated groundwater aquifers in Baghpat district, UP. The analytical results of the groundwater sample show TDS content up to 1215 ppm and alkaline nature. A trace element study in groundwater reveals very high contamination of aluminium, barium, iron, uranium, lead and fluoride. A geothermal source of water was also recorded from 'Dera Sacha Sauda' (77°25'10.9"E, 26°06'11.2"N) located in Barnawan village. The synthesis of various analytical results reveals that the groundwater contamination of Zn, Al, Cr, and NO₃²⁻ is due to anthropogenic factors in the area. The U, Ba and F-contamination in groundwater appear to be of geogenic in nature.

The incidences of dental and skeletal fluorosis were identified where the fluoride content in groundwater is more than 1.5 ppm (WHO, 2011) in Kharera Salgiawas, Raghunathpura, Kakalwar, Niwaria, Srinagar, Santhali, Kushalpur, Sirohi Munia Khurd and Digana villages of the district. The scientific contribution from this study includes the identification of fluoride bearing biotite, which is responsible for releasing fluoride ions during natural weathering processes prevailing in Ca-poor aquifer of an alkaline environment. So, it can be concluded that high incidences of fluoride in the area are geogenic

in nature. Besides these, the intake of Ca-rich food is suggested to lower down the effect of both dental & skeletal fluorosis. The district administration and development authorities may utilize the prepared fluoride-free aquifer maps of the area for the drinking water supply. The area overlain by the dunal landforms should be utilized as groundwater recharge site which would minimize the fluoride content in the aquifer by the natural process of dilution. In the Eastern part of India, the GSI had done extensive work along the oscillation zone of Ganga covering districts infested with Arsenic problem during 2004-2009 and had delineated the depth which had maximum contamination. They underlined an extra peninsular source for Arsenic inflow through sediments draining into the Bihar plains by perennial rivers of the Himalayan region.

Glaciology

GSI initiated systematic studies on the secular movement of glaciers in parts of Himachal Pradesh, Karakoram, Kashmir, Sikkim Himalaya, and Uttarakhand. Post-1947, the studies again got momentum during the 'International Geophysical Year' (1957-58), and 'International Hydrological Decade' (IHD: 1965-74) and later as part of the International Hydrological Programme (IHP). Subsequently, a separate Division on 'Snow, Ice and Glacier' was established by GSI in 1974, which was later rechristened as Glaciology Division.

Assessment of annual mass balance, annual glacier flow, recording of microclimatic parameters, snout monitoring, geomorphological mapping on 1:5,000 scale were taken up for long term monitoring of Hamtah glacier, Lahaul & Spiti district, Himachal Pradesh which is located in Chandra fifth-order basin of Chenab basin. Besides these, other studies included meltwater chemistry, OSL dating, GPR profiling, etc. Kargil and Leh districts in Jammu & Kashmir and Lahaul & Spiti district, Himachal Pradesh, are two critical areas having a large concentration of glaciers.

To evaluate the interannual recessional pattern of the glaciers and understanding the glacio-geomorphic history, pre-field base maps were prepared on 1:50,000 scale based on Survey of India (SOI) Toposheet, aerial photographs, Corona & Landsat (MSS, TM and ETM+) satellite data and with the help of Google Earth images. The detailed snout

mapping of all glaciers on a 1:5000 scale was carried using Total Station. Based on the use of previous satellite data and present surveyed data, time series snout recession and area variation maps were prepared to estimate recession pattern over the last five decades besides altitudes of ablation and accumulation zone of the glaciers.

Worldwide receding of mountain glaciers is one of the most reliable evidence of the changing global climate. In high mountainous terrains melting of glaciers, increases the risk of glacial related hazards. One of these risks is Glacial Lake Outburst Floods (GLOFs). As glaciers retreat, glacial lakes form behind moraine or ice 'dams.' These 'dams' are comparatively weak and can breach suddenly, leading to a discharge of huge volume of water and debris. Such outbursts have the potential of releasing millions of cubic meters of water in a few hours causing catastrophic flooding downstream with severe damage to life and property.

The inventory is being prepared on the ArcGIS platform using the medium to high-resolution cloud-free satellite images viz. LISS III, LISS IV-FMX and freely available satellite imageries. The various parameters i.e. V-Order basin, Glacier Lake Identity No., Name, Glacier No., Longitude, Latitude, Length (m), Width (m), Area (km²), Depth (m), Volume (m³), Elevation (m asl), Orientation, Drainage, Class/type and Vulnerability have been computed and the potentially dangerous lakes have been identified. Glacial lake number system has been similar to the Inventory of the Himalayan Glacier published by GSI wherein all the lakes (excluding supra-glacial lakes) have been numbered in accordance to the V-Order basin (Inverse Strahler System), and within the basin, the number has been done clock-wise starting from the outlet of major stream from the basin.

Glaciers and snow cover constitute the most important freshwater resource and are considered as the water towers. As glaciers are the most visible indicators of global change, the studies in the Himalayan glaciers have evoked enormous interest.

The significant contributions made by GSI in the field of snow, ice, and glaciers can be broadly classified in the following five categories.

- Assessment of glacier resources

- Glacier regime studies
- Climate variability studies
- Societal glaciological studies
- Other specialized studies

Assessment of glacier resources of Indian Himalaya was undertaken as per the guidelines of Temporary Technical Secretariat (TTS) for the World Glacier Inventory. The Indian part of Himalaya alone contains 9575 glaciers locking up about 1100 cu.m of ice in water equivalent (w.eq.). State-wise, the highest concentration of glaciers and glacierised areas lies in Jammu & Kashmir, followed by Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. Shyok Valley, Jammu & Kashmir contains the highest number as well as ice volume of glaciers.

Till date snout monitoring of 58 glaciers has been done under a secular movement study program. Out of these, several glaciers were monitored for repeat observations. The majority of the glaciers have shown continuous recession during the twentieth and twenty-first centuries.

Under the societal studies, significant contributions have been made in the assessment of avalanches and GLOF. The avalanche assessment studies were both for human settlements as well as Hydroelectric Power projects. As a part of GLOF studies, assessment of Gepang Gath glacial lake and compilation of an inventory of glacial lakes was undertaken. Inventory of glacial lakes of Uttarakhand has been completed while the compilation of the inventory of glacial lakes in Himachal Pradesh and Jammu & Kashmir is in progress.

Polar Studies

GSI has been carrying out geological studies in the area surrounding Schirmacher Oasis in central Dronning Maud Land, East Antarctica since the inception of the Indian Antarctic program in 1981, and since 2006 in Larsemann Hills region. After the establishment of the "Himadri" station in the Arctic in 2009, GSI has extended its polar studies program to both the poles. These studies include yearly measurements on the changes in polar glacier front and accumulation/ablation over an ice shelf and ice sheet for obtaining information on the state of the

polar ice sheet vis-à-vis the impact of climate change. During 2014-19, officers from GSI have participated in 34th, 35th, 36th, 37th and 38th Indian Scientific Expedition to Antarctica for the study of Dronning Maud Land and Prydz Bay regions of East Antarctica. The studies taken up included (1) glaciological Studies in Central Dronning Maud Land, East Antarctica (2) geological mapping and geodynamics in Dronning Maud Land and Prydz Bay regions, East Antarctica. (3) sedimentology and clay mineralogy of lake sediments from Schirmacher Range and Larsemann Hills in East Antarctica as well as NyAlesund area in Svalbard, Arctic for deciphering palaeoclimatic history (4) glaciological Studies in the Larsemann Hills, East Antarctica for assessing the impact of climate change (5) integrated monitoring of Vestre Broggerbreen Glacier, Svalbard Arctic (on expedition basis). The work during the last five years has led to more than 25 research publications in national and international journals apart from technical reports and several oral presentations at national conferences. The research work will continue during the present year 2019-20 in Polar Regions.

Meteorite & Planetary Science Division

During the last four years, the research projects of MPSD have covered mainly two significant themes:

Study of meteorites

Several projects have been taken up on the meteorites from the National Meteorite Repository and the newly retrieved meteorite falls for detailed studies in a collaborative mode with other research organizations or independently by GSI. These projects have been discussed in brief in the following subheads.

Semi-quantitative Laser spectroscopic approach was taken up to study chondritic olivine and pyroxene with Raman spectroscopic evaluation of shock-induced changes in the meteoritic phases. The common observations from study of 12 nos. of meteorites of varying chemical and petrological types by Electron probe microscopic analysis and Raman spectroscopy demonstrated that this could be a handy tool to bring out information on mineral modes and compositional variations within different solution series.

Petrogenetic study of equilibrated chondrites (on ten samples) was carried out to decipher the thermal

history, shock metamorphic features and the relationship between textural maturity and metamorphic temperature in these meteorites.

A collaborative item between GSI and PRL was taken up to study the newly fallen Mukundpura meteorite, which is a rare carbonaceous chondrite, for its genetic classification and determination of its cosmic ray exposure age.

A collaborative item between GSI and IISc Bangalore was taken up to study 11 nos. of ordinary chondrites to understand the origin and evolution of chondritic meteorites. During this project, four meteorite samples have been registered with the Meteorite Society.

Study of impact craters of India

Two projects, as below, have been completed on the impact craters of India, namely Lonar crater of Maharashtra, Dhala crater of Madhya Pradesh, and Ramgarh crater of Rajasthan.

A comparative study on the three craters was taken up, highlighting the response of the three different underlying target rock to an extraterrestrial impact. For this shock-related deformation features in these impact, structures were carried out, and an assessment of the impact and shock calibration was also attempted.

A collaborative item between GSI and AMDER, NR has been taken up for 3-D basin modelling and characterizing impact-induced shock distribution profile of the Dhala (Mohar) Structure of Madhya Pradesh.

Mineral Physics

During the period from January 2015 to June 2019, in Mineral Physics Laboratory of NCEGR Kolkata, XRD analysis of 2447 samples from different FSP items of regions was done involving generating of 245 XRD analytical reports. Total revenue of Rs. 1, 48,184.00 was made by XRD analysis of samples of outside agencies. Thermogravimetry and Differential Thermal Analysis of 455 samples were carried out for mineral phase identification.

XRD analytical software was upgraded to High Score Plus, which is capable of quantitative XRD data analysis using the Rietveld refinement method.

Facilities for complete processing of clay for systematic separation and clay mineralogy studies was established, the clay processing lab is equipped with instruments such as High-Speed Cooling Centrifuge, hot air oven, muffle furnace, cyclo-mixer etc. Procurement of a new state of the art XRD with Micro Diffraction facility is underway.

Mission-V: Training and Capacity Building (Geological Survey of India Training Institute)

Geological Survey of India Training Institute (GSITI) was established in 1976 with the prime objective of orienting new recruits. GSITI serves in bridging the gap between academic knowledge and the professional approach particularly of newly inducted geoscientists, to create efficiency. This is achieved by exposing practicing geoscientists to new developments in fields related to their specialization. At present GSITI gives periodical in-service training at various hierarchical levels to all the employees of GSI to enable individuals to shoulder the expected higher responsibilities. The training programs are designed based on training requirements of different Government agencies, both State and Central academic institutions and of other countries as per foreign policy etc. Geological Survey of India Training Institute (GSITI), with its headquarter at Hyderabad, is presently running training programs at four RTDs (Regional Training Divisions) and four FTCs (Field Training Centers) across India (Fig. 9).

Training courses are conducted by GSITI under the following categories

Induction Training
Designed for new recruits about responsibilities that they are expected to execute on assuming charge. It is residential and of long duration. Newly recruited Geoscientists of other organizations are also accommodated based on requests. Promotion Linked Training (PLT): PLTs are linked to career progression and are conducted for employees of different streams at various levels.

Thematic Training

It is designed to build professional competency and enhance technical expertise on various branches of geosciences among the geoscientists of GSI and other stakeholders. Basic, Refresher, and Advanced type Thematic pieces of training are being imparted as per

the needs of Mission-I, Mission-II, Mission-III and Mission-IV. The duration of such courses varies from one to two weeks.

Administrative and Management Training

Such pieces of training are imparted to the employees of the department at different levels to develop the mindset and necessary skills on Administrative, Vigilance, Legal, Finance, Leadership, Project Planning and other aspects of Management. The duration of such programs is generally of three days to one week.

International Training

Under ITEC (Indian Technical and Economic Cooperation), Ministry of External Affairs, Govt. of India, GSITI conducts Courses on Geographic Information System, Remote Processing for International participants. The duration of these programs is for four weeks.

Sponsored Training

GSITI conducts ISRO sponsored training, one of the applications of remote sensing and GIS in mineral exploration, and the second on the form of Geoinformatics in Disaster Management.

Besides, custom made training is conducted on a payment basis for the officials of PSUs and other Government and non-Government organizations.

International Affairs Division

International Affairs Division (IA), under the Policy Support System of GSI at Kolkata, deals with techno-administrative matters pertaining to the International Affairs of GSI with international perspective. The principal objective of this division is to strengthen the areas of bilateral cooperation with countries where bilateral understanding/agreements already exist, and also to explore the possibility to enter into new contracts with technologically advanced countries and to countries whom India can offer assistance in developing the mineral resources.

GSI maintains continuous correspondence and communication with MOM about international collaborative activities which include technical write-ups, preparation and evaluation of MoUs, facilitating the participation of GSI officers in the Joint Working

Group (JWG) of different countries and take follow up action on the recommendations suggested in JWGs.

International organizations/Institutes interested in collaborative research projects with GSI and correspondence with MoM in this regard are handled by this division. Besides, this division guides and facilitates the participation of GSI officers in various international forums both inside and outside the country e.g. training, seminars, symposia, workshops, trade fairs, mining exhibition etc. whenever required.

This division under Policy Support System, Central Headquarters, Kolkata, will continue to identify emerging geoscience issues that have international significance and are of immediate as well as long term concerns for this country.

A brief outline of the essential activities highlighting the achievements of the IA division from 2015 to date

is given below:

- Meeting and communication had been carried out for bilateral collaboration with 32 countries.
- A total of 177 GSI officers visited abroad to render consultancy services and attend meetings, conferences, training and various exhibition.
- One officer was deputed for two years in Punatsangchu-I Hydroelectric Project, Bhutan.
- Seven MoUs were signed between GSI and different countries in the field of earth science and rendering geotechnical consultancy for hydroelectric projects.
- Three business meetings were conducted during the 35th IGC.
- 14 IGCP Projects were attended by GSI officers.