

**GEOLOGICAL REPORT ON THE RECONNAISSANCE SURVEY (G-4
STAGE EXPLORATION) FOR PHOSPHATE & ASSOCIATED
MINERALS**

IN

KAPHALDA BLOCK

DISTRICT: DEHRADUN, STATE: UTTARAKHAND

(Under NMET Programme)

(TEXT, ANNEXURES AND PLATES)



A MINI RATNA COMPANY

MINERAL EXPLORATION AND CONSULTANCY LIMITED

(Formerly Mineral Exploration Corporation Limited)

(A Government of India Enterprise)

CORPORATE OFFICE, NAGPUR

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काफलदा ब्लॉक, उत्तराखंड में फॉस्फेट के लिए आवीक्षण सर्वेक्षण (G-4चरण) पर भूवैज्ञानिक रिपोर्ट

अध्याय – 1

कार्यकारी सारांश

1.1.0 परिचय

1.1.1 रॉक फॉस्फेट (फॉस्फोराइट) एक अवसादी शैल है जिसमें कैल्शियम-फॉस्फेट खनिजों की अधिकता है और फॉस्फेटिक उर्वरक उद्योग में इसका उपयोग प्रमुख कच्चे माल के रूप में होता है, जिसके कारण कृषि के लिए फॉस्फोरस का उपयोग महत्वपूर्ण है। भारत में फॉस्फेट की कमी है: इसके कुल रॉक-फॉस्फेट संसाधन लगभग 311.25 मिलियन टन हैं (जिनमें से उत्तराखंड में लगभग 24.18 मिलियन टन है) और देश अपनी लगभग 90% फॉस्फेटिक पोषक आवश्यकता आयात के माध्यम से पूरी करता है, जिसमें वर्ष 2023-24 में लगभग 8.81 मिलियन टन रॉक फॉस्फेट आयात किया गया। इस सामरिक महत्व को ध्यान में रखते हुए, (खान मंत्रालय, 2023 में) फॉस्फोरस को भारत के 30 महत्वपूर्ण खनिजों में शामिल किया गया है। स्वदेशी भंडार को बढ़ाने के उद्देश्य से, एमईसीएल को उत्तराखंड के मसूरी सिंक्लाइन स्थित काफलदा ब्लॉक में फॉस्फेट और संबद्ध खनिजों के लिए आवीक्षण सर्वेक्षण (G-4) स्तर सौंपा गया, जिसकी अनुमानित लागत ₹318.44 लाख है।

1.2.0 ब्लॉक स्थान और पहुँचने की सुविधा

1.2.1 काफलदा ब्लॉक का क्षेत्रफल 16.68 वर्ग किलोमीटर है और यह भारतीय सर्वेक्षण विभाग (सर्वे ऑफ इंडिया) टोपोशीट संख्या 53J/03 में आता है। यह ब्लॉक उत्तराखंड के देहरादून और टिहरी-गढ़वाल जिलों के काफलदा, सिल्ला सेरा, भंसवालगाँव, क्यार कुली भट्टा, सिमियारी, फुलेटा, दुर्मला, भूस्ती और छमरोली गाँवों के भीतर एवं आसपास स्थित है। ब्लॉक मसूरी सिंक्लाइन की पूर्वी भुजा पर स्थित है और देहरादून से लगभग 33 किलोमीटर पूर्व में है, जहाँ तक पहुँचने के लिए मालदेवता-डुबरा मोटरेबल कच्ची सड़क का उपयोग किया जाता है। निकटतम रेल स्टेशन देहरादून है और निकटतम हवाई अड्डा जॉली ग्रांट है, जो लगभग 50 किलोमीटर दूर है। भू-आकृति दुर्गम है और समुद्र तल से ऊँचाई लगभग 1000 से 2400 मीटर तक है। ब्लॉक के कार्नर बिंदुओं के निर्देशांक तालिका 1.1 में दिए गए हैं।

**तालिका-1.1 : काफलदा ब्लॉक (G-4), जिला-देहरादून एवं टिहरी गढ़वाल,
उत्तराखंड की ब्लॉक सीमा के कार्नर बिंदुओं के निर्देशांक**

कार्डिनल बिंदु	डाब्ल्यूजीएस 84 (डीएमएस)		यूटीएम जोन -44 (m)		एलिवेशन (m)
	अक्षांश	देशांतर	पूर्वांक (m)	उत्तरांक (m)	
A	30.4147694°N	78.1608994°E	303249.53	3366701.88	~1,450 m
B	30.4400741°N	78.1823790°E	305598.41	3370142.96	~1,850 m

C	30.4109443°N	78.2197475°E	309065.18	3365800.12	~2,200 m
D	30.3859338°N	78.1963554°E	306578.83	3362511.49	~1,600 m

1.3.0 भूविज्ञान

1.3.1 ब्लॉक में मसूरी सिक्लाइन की संरचना उजागर होती है, जिसमें क्रोल फॉर्मेशन से लेकर लोअर टाल फॉर्मेशन तक का अनुक्रम मिलता है। यह क्षेत्रीय रूप से मुख्य सीमा भ्रंश (Main Boundary Thrust - MBT) और मुख्य केंद्रीय भ्रंश (Main Central Thrust - MCT) द्वारा सीमाबद्ध है। 1:12,500 पैमाने पर किए गए भू-मानचित्रण में टाल फॉर्मेशन की पाँच इकाइयाँ पहचानी गईं — कार्टजाइट/सैंडस्टोन कार्टज-ब्रेक (Quartz-wacke), ऑलिव शेल, बेंडेड शेल और ब्लैक शेल जिसमें चर्टी फॉस्फेटिक शेल की पट्टियाँ हैं। ये इकाइयाँ क्रोल फॉर्मेशन के डोलोमाइट और डोलोमिटिक चूना पत्थर के ऊपर स्थित हैं। फॉस्फेट युक्त ब्लैक शेल/चर्टी शेल टाल फॉर्मेशन के निचले हिस्से में, क्रोल-टाल संपर्क पर और उसके ठीक ऊपर पाया जाता है। खनिजीकृत पट्टियाँ उत्तर पश्चिम – दक्षिण पूर्व (NW-SE) दिशा में फैली हुई हैं, जो क्षेत्रीय संरचनात्मक प्रवृत्ति के समानांतर हैं। पेट्रोग्राफिक अध्ययन (08 नमूनों पर) ने कार्टज-प्रधान संघटना दर्शाया — आर्कोज़, कार्टज-वैक, कार्बोनेशियस स्लेट, स्लेट, माइक्रिटिक लाइमस्टोन और कार्बोनेशियस शेल। मिनरोग्राफिक अध्ययन (10 पॉलिश सेक्शन पर) ने पाइराइट और मैग्नेटाइट को प्रमुख अयस्क खनिज के रूप में दिखाया, साथ ही गौण रूप में ग्योथाइट-हैमेटाइट और अल्प मात्रा में चाल्कोपाइराइट भी पाया गया। एक्सआरडी विश्लेषण (20 नमूनों पर) ने फॉस्फेट खनिज को एपेटाइट (फ्लुओरएपेटाइट/हाइड्रॉक्सिलएपेटाइट) के रूप में पुष्टि की, जो समृद्ध टैंच नमूनों में प्रमुख अवस्था के रूप में उपस्थित है।

1.4.0 ब्लॉक में खनिजीकरण

1.4.1 मसूरी सिक्लाइन एक सुव्यवस्थित फॉस्फोराइट पट्टी है, जहाँ दुर्मला, मालदेवता, मस्राना, किमोई और भूस्ती-जालिखाल में कार्य किया गया है। यहाँ फॉस्फेट क्रोल-टाल संपर्क पर, प्रारंभिक कैम्ब्रियन लोअर टाल के चर्ट सदस्य के भीतर परतबद्ध रूप में पाया जाता है। सन् 1966 से 1971 के बीच भारतीय भूवैज्ञानिक सर्वेक्षण द्वारा की गई व्यवस्थित खोज में सिक्लाइन के अधिकांश ब्लॉकों में रॉक फॉस्फेट और फॉस्फोराइट (15% से अधिक P_2O_5) दर्ज किया गया। काफलदा ब्लॉक सिक्लाइन की पूर्वी भुजा पर स्थित है और यह दुर्मला तथा भूस्ती-जालिखाल के उच्च-ग्रेड क्षेत्रों के बीच स्ट्राइक के साथ निरंतर फैला हुआ है। इसकी अनुकूल स्तरानुक्रमिक और संरचनात्मक स्थिति के आधार पर इसे पुनःज्ञान सर्वेक्षण (रिकोनीसेंस सर्वे) हेतु लिया गया।

1.5.0 पूर्व गवेषण

1.5.1 मसूरी सिक्लाइन एक सुव्यवस्थित फॉस्फोराइट पट्टी है, जहाँ दुर्मला, मालदेवता, मस्राना, किमोई और भूस्ती-जालिखाल में कार्य किया गया है। यहाँ फॉस्फेट क्रोल-टाल संपर्क पर, प्रारंभिक कैम्ब्रियन लोअर टाल के चर्ट सदस्य के भीतर परतबद्ध रूप में पाया जाता है। 1966 से 1971 के बीच भारतीय भूवैज्ञानिक सर्वेक्षण द्वारा की गई व्यवस्थित खोज में सिक्लाइन के अधिकांश ब्लॉकों में रॉक फॉस्फेट और

फॉस्फोराइट (15% से अधिक P_2O_5) दर्ज किया गया। काफलदा ब्लॉक सिंक्लाइन की पूर्वी भुजा पर स्थित है और यह दुर्मला तथा भूस्ती-जालिखाल के उच्च-ग्रेड क्षेत्रों के बीच स्ट्राइक के साथ निरंतर फैला हुआ है। इसकी अनुकूल स्तरानुक्रमिक और संरचनात्मक स्थिति के आधार पर इसे पुनःज्ञान सर्वेक्षण (रिकोनीसेंस सर्वे) हेतु लिया गया।

1.6.0 एमईसीएल द्वारा किया गया गवेषण

1.6.1 G-4 पुनःज्ञान सर्वेक्षण की अनुशंसा TCC-II, एनएमडीटी की पाँचवीं बैठक (जनवरी 2025) में की गई थी और इसे ईसी, एनएमडीटी की चालीसवीं बैठक (फरवरी 2025) में स्वीकृति प्रदान की गई। वर्ष 2025 में हुई भारी बादल फटने (क्लाउडब्रस्ट) की घटनाओं के कारण पहुँच मार्ग बाधित हो गया और कार्य में विलंब हुआ। परियोजना कार्यालय दिनांक 9 जनवरी 2026 को स्थापित किया गया तथा क्षेत्रीय कार्य दिनांक 17 जनवरी 2026 से प्रारंभ हुआ। इस सर्वेक्षण के उद्देश्य थे: (a) 1:12,500 पैमाने पर भूवैज्ञानिक मानचित्र तैयार करना; (b) क्रोल-टाल संपर्क, चर्ट, फॉस्फेट शैल और अधारोपित शैल का बेडरॉक एवं चैनल/ट्रेंच नमूनाकरण द्वारा खनिजीकृत क्षेत्रों को प्रमाणित करना, ताकि फॉस्फेटिक क्षितिज की मोटाई मापी जा सके; (c) ब्लॉक को G-3 स्तर तक उन्नत करना, जिससे राज्य सरकार द्वारा इसका नीलामी किया जा सके।

1.7.0 भूवैज्ञानिक मानचित्रण और नमूनाकरण

1.7.1 कुल 16.68 वर्ग किलोमीटर क्षेत्र का मानचित्रण 1:12,500 पैमाने पर किया गया। सतही बेडरॉक के 100 नमूनों और ट्रेंच T1 से T5 तक के 37 चैनल नमूनों का एक्सआरएफ द्वारा 10 रेडिकल्स के लिए विश्लेषण किया गया; 11 नमूनों का ICP-MS द्वारा 34 तत्वों और आरईई के लिए परीक्षण किया गया; 20 नमूनों का एक्सआरडी द्वारा विश्लेषण किया गया; 08 नमूनों का पेट्रोग्राफी और 10 का मिनरोग्राफी अध्ययन किया गया; तथा 100 घन मीटर ट्रेंचिंग पूर्ण की गई। ड्रिलिंग अभी तक नहीं की गई है। प्रस्तावित कार्य की मात्रा और उसकी उपलब्धि का सारांश तालिका 1.2 में दिया गया है।

तालिका-1.2 : काफलदा ब्लॉक में एमईसीएल द्वारा प्रस्तावित कार्य की मात्रा बनाम उपलब्धि

क्रम सं.	कार्य मद	इकाई	अनुमोदित	उपलब्धि
1	भूवैज्ञानिक मानचित्रण (1:12,500 पैमाना)	वर्ग. कि.मी.	16.68	16.68 (100 %)
2	एक्सआरएफ – 10 रेडिकल्स (सरफेस + ट्रेंच)	नग	200	137 (100 सरफेस + 37 ट्रेंच)
3	आईसीपी-एमएस – 34 तत्व और आरईई	नग	20	11
4	एक्सआरडी	नग	30	20
5	प्रेट्रोलोजिकल अध्ययन	नग	20	08
6	मिनरोग्राफिक अध्ययन	नग	10	10
7	ट्रेंचिंग	घन मी.	100	100 (100 %)

8	ड्रिलिंग	मीटर	300	0
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1.8.0 भू-रासायनिक परिणाम

1.8.1 सतह पर फॉस्फेट की मात्रा कम है: 100 बेडरॉक नमूनों में से लगभग 80% में P_2O_5 की मात्रा 0.25% से कम पाई गई, और केवल नमूना BR/99 में 3.10% (एक लौहयुक्त फॉस्फोराइट) दर्ज किया गया। हालाँकि, ट्रेंच नमूनों ने फॉस्फेटिक क्षितिज को काटा और स्पष्ट रूप से उच्च ग्रेड लौटाए, जिनमें दो नमूने 5% P_2O_5 कट-ऑफ से ऊपर थे — T4/02 (6.60%) और T3/09 (6.06%)। इसके अतिरिक्त कई अन्य नमूने 1% से 3.7% के बीच रहे, जो मुख्यतः ट्रेंच T3 और T4 में केंद्रित थे। ट्रेस-तत्व विश्लेषण से मध्यम बहुधात्विक संवर्धन (Zn अधिकतम 700 ppm, Pb अधिकतम 383 ppm, As अधिकतम 172 ppm, Ba अधिकतम 941 ppm और Cr अधिकतम 228 ppm) दर्ज हुआ। दुर्लभ पृथ्वी तत्व (आरईई) हल्के-आरईई संवर्धित पाए गए (La/Yb 5 से अधिक)। सभी नमूनों में सोना पता लगाने की सीमा से नीचे रहा। ब्लॉक में कोई भूभौतिकीय सर्वेक्षण नहीं किया गया और क्षेत्र के लिए भारतीय सर्वेक्षण विभाग का कोई एनजीपीएम या एनजीसीएम डेटा उपलब्ध नहीं है।

1.9.0 भूवैज्ञानिक रिपोर्ट की तैयारी

1.9.1 भूवैज्ञानिक रिपोर्ट का संकलन एमईसीएल, नागपुर के कॉर्पोरेट कार्यालय में किया गया, जिसमें भूवैज्ञानिक और भू-रासायनिक आँकड़ों का एकीकरण किया गया। विभिन्न मानचित्रों और प्लेटों की तैयारी के लिए ArcGIS, AutoCAD और CorelDraw का उपयोग किया गया, जबकि भू-रासायनिक और सांख्यिकीय आरेखों के लिए पायथन-आधारित विश्लेषण अपनाया गया।

1.10.0 निष्कर्ष

1.10.1 एमईसीएल ने काफलदा ब्लॉक (16.68 वर्ग किलोमीटर) में फॉस्फेट हेतु G-4 पुनःज्ञान सर्वेक्षण पूरा किया। इस क्षेत्र में अनुकूल क्रोल-टाल स्तरीकरण तथा फॉस्फेट युक्त ब्लैक शेल/चर्टी शेल क्षितिज उपस्थित है, और एक्सआरडी विश्लेषण ने समृद्ध ट्रेंच नमूनों में एपेटाइट की पुष्टि की। सतही ग्रेड की कम मात्रा और ट्रेंच नमूनों में दर्ज उच्च ग्रेड (अधिकतम 6.60% P_2O_5) के बीच का अंतर इस सर्वेक्षण की प्रमुख खोज है। फॉस्फेट क्षितिज पतला है (चर्ट सदस्य लगभग 4 मीटर), सतह पर कम उजागर है और अधिकांशतः क्रोल-टाल संस्पर्क के नीचे छिपा हुआ है। यह छिपाव मुख्यतः अवसादी पिचिंग और स्वेलिंग तथा ब्लॉक की संरचनात्मक जटिलता के कारण है, विशेषकर एमबीटी क्षेत्र के निकट, जहाँ लघु हिमालयी संरचनाएँ आपस में इम्ब्रिकेटेड हैं और टाल फॉर्मेशन फॉस्फेटिक क्षितिज के ऊपर चढ़ी हुई है। अतः खनिजीकरण को अनुपस्थित न मानकर, इसे संरचनात्मक रूप से नियंत्रित और छिपा हुआ माना गया है।

1.11.0 अनुशंसाएँ

अनुशंसा की जाती है कि काफलदा ब्लॉक को छिपे हुए फॉस्फेटिक क्षितिज की पुष्टि और सीमांकन हेतु G-3 गवेषण स्तर तक उन्नत किया जाए। चूँकि वर्तमान G-4 सर्वेक्षण के दायरे और समयसीमा में विस्तृत संरचनात्मक जाँच संभव नहीं थी, इसलिए एमबीटी क्षेत्र के निकट एक अलग और समर्पित संरचनात्मक कार्यक्रम संचालित किया जाना चाहिए ताकि ब्लॉक की इम्ब्रिकेटेड ज्यामिति को स्पष्ट किया जा सके। इसके बाद एक ड्रिलिंग कार्यक्रम चलाया जाए, जिसमें स्काउट बोरहोल्स को अनुकूल T3-T4 ट्रेंच सेक्टर में स्थापित किया जाए और उन्हें इस प्रकार झुकाया जाए कि वे क्षितिज की डाउन-डिप निरंतरता को काट सकें। इससे गहराई पर क्षितिज की मोटाई, ग्रेड और निरंतरता स्थापित की जा सकेगी।

**GEOLOGICAL REPORT ON THE RECONNAISSANCE SURVEY (G-4
STAGE) FOR PHOSPHATE IN KAPHALDA BLOCK, UTTARAKHAND**

CHAPTER-I

EXECUTIVE SUMMARY

1.1.0 INTRODUCTION

1.1.1 Rock phosphate (phosphorite) is a sedimentary rock rich in calcium-phosphate minerals and the principal raw material of the phosphatic-fertiliser industry, for which phosphorus has no substitute in agriculture. India is deficient in phosphate: its total rock-phosphate resources are about 311.25 million tonnes (of which Uttarakhand holds about 24.18 million tonnes), and the country meets roughly 90 % of its phosphatic-nutrient requirement through imports, importing about 8.81 million tonnes of rock phosphate in 2023-24. In recognition of this importance, phosphorous has been included among India's 30 critical minerals (Ministry of Mines, 2023). To build up indigenous reserves, MECL was assigned a Reconnaissance Survey (G-4) for phosphate and associated minerals in the Kaphalda Block of the Mussoorie Syncline, Uttarakhand, at an estimated cost of Rs. 318.44 lakhs.

1.2.0 LOCATION AND ACCESSIBILITY OF THE BLOCK

1.2.1 The Kaphalda Block covers an area of 16.68 sq. km and falls in Survey of India Toposheet No. 53J/03, in and around the villages Kaphalda, Silla Sera, Bhanswalgaon, Kyar Kuli Bhatta, Simiyari, Fuleta, Durmala, Bhusti and Chhamroli of Districts Dehradun and Tehri-Garhwal, Uttarakhand. The Block lies on the eastern limb of the Mussoorie Syncline, about 33 km east of Dehradun, and is approached from Dehradun via the Maldevta–Dubra motorable kachha road. Dehradun is the nearest railhead and Jolly Grant is the nearest airport (about 50 km). The terrain is rugged, with altitudes of about 1000 to 2400 m above mean sea level. The co-ordinates of the corner points of the Block are given in Table 1.1.

**Table-1.1: Co-ordinates of Corner Points of the Block boundary of
Kaphalda Block (G-4), District-Dehradun & Tehri Garhwal,
Uttarakhand**

Cardinal Points	WGS 84 (DMS)		UTM Zone-44 (m)		Elevation (m)
	Latitude	Longitude	Easting (m)	Northing (m)	
A	30.4147694°N	78.1608994°E	303249.53	3366701.88	~1,450 m
B	30.4400741°N	78.1823790°E	305598.41	3370142.96	~1,850 m
C	30.4109443°N	78.2197475°E	309065.18	3365800.12	~2,200 m

D	30.3859338°N	78.1963554°E	306578.83	3362511.49	~1,600 m
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1.3.0 GEOLOGY

1.3.1 The Block exposes a succession from the Krol Formation to the Lower Tal Formation of the Mussoorie Syncline, which is bounded regionally by the Main Boundary Thrust (MBT) and the Main Central Thrust (MCT). Geological mapping on a 1:12,500 scale identified five mappable units of the Tal Formation — Quartzite/Sandstone (quartz-wacke), Olive Shale, Black Shale with Cherty Phosphatic Shale bands, and Banded Shale — overlying the dolomite and dolomitic limestone of the Krol Formation. The phosphate-bearing Black Shale/Cherty Shale occupies the lower part of the Tal formation at and just above the contact of Krol–Tal formation, and the mineralised bands trend NW–SE, parallel to the regional structural grain. Petrographic study of 08 samples showed a quartz-dominated assemblage (arkose, quartz-wacke, carbonaceous slate, slate, micritic limestone and carbonaceous shale), and mineragraphic study of 10 polished sections showed pyrite and magnetite as the dominant ore minerals with subordinate goethite–hematite and traces of chalcopyrite. XRD of 20 samples confirmed the phosphate mineral as apatite (fluorapatite/hydroxylapatite), present as a major phase in the trench samples.

1.4.0 MINERALISATION IN THE BLOCK

1.4.1 The Mussoorie Syncline is a well-established phosphorite belt, worked at Durmala, Maldeota, Masrana, Kimoi and Bhusti–Jalikhil, where the phosphate is stratabound at the Krol–Tal contact within the Chert Member of the Early Cambrian Lower Tal. Systematic exploration by the Geological Survey of India between 1966 and 1971 recorded rock phosphate and phosphorite (more than 15 % P₂O₅) in most Blocks of the syncline. The Kaphalda Block lies on the eastern limb, continuous along strike between the high-grade Durmala and Bhusti–Jalikhil tracts, and was taken up for reconnaissance on the strength of this favourable stratigraphic and structural position (Text Figure 8.1).

1.5.0 EXPLORATION CARRIED OUT BY MECL

1.5.1 The G-4 reconnaissance survey was recommended in the 5th meeting of the TCC-II, NMET (January 2025) and approved in the 40th meeting of the EC, NMET (February 2025). Heavy cloudbursts in 2025 rendered the approach road un-operational and delayed the work; the project office was set up on 9th January 2026 and field work commenced on 17th January 2026.

1.5.2 The objectives of the survey were: (a) preparation of a geological map on a 1:12,500 scale; (b) proving the mineralised zones by bedrock and channel/trench sampling of the

Krol–Tal contact, cherts, phosphate rock and the overlying shales, so as to measure the thickness of the phosphatic horizon; and (c) upgrading the Block to the G-3 stage for auction by the State Government.

1.6.0 GEOLOGICAL MAPPING AND SAMPLING

- 1.6.1 A total of 16.68 sq. km was mapped on a 1:12,500 scale. One hundred bedrock samples and 37 trench channel samples (from trenches T1 to T5) were analysed for 10 radicals by XRF; 11 samples for 34 elements and REE by ICP-MS; 20 samples by XRD; 08 samples for petrography and 10 for mineragraphy; and 100 cubic metres of trenching was completed. Drilling has not yet been undertaken. The proposed quantum of work and its achievement are summarised in Table 1.2.

Table-1.2: Proposed quantum of work versus achievement by MECL in the Kaphalda Block.

Sl. No.	Item of Work	Unit	Approved	Achieved
1	Geological Mapping (1:12,500 scale)	sq. km	16.68	16.68 (100 %)
2	XRF – 10 radicals (surface + trench)	Nos	200	137 (100 surface + 37 trench) (68.5%)
3	ICP-MS – 34 elements and REE	Nos	20	11 (55%)
4	XRD	Nos	30	20 (67%)
5	Petrological studies	Nos	20	08 (40%)
6	Mineragraphic studies	Nos	10	10 (100 %)
7	Trenching	Cu. m	100	100 (100 %)
8	Drilling	Metres	300	0

1.7.0 GEOCHEMICAL RESULTS

- 1.7.1 At the surface, phosphate is low: of the 100 bedrock samples about 80 % carry P₂O₅ below 0.25 %, and only sample BR/99 reaches 3.10 % (a ferruginous phosphorite). The trench samples, however, intersected the phosphatic horizon and returned distinctly higher grades, with two samples above the 5 % P₂O₅ cut-off, namely T4/02 (6.60 %) and T3/09 (6.06 %), and several others between 1 % and 3.7 %, concentrated in trenches T3 and T4. Trace-element analysis shows a modest polymetallic enrichment (Zn 700 ppm, Pb 383 ppm, As 172 ppm, Ba 941 ppm and Cr 228 ppm); the rare earth elements

are light-REE enriched (La/Yb greater than 5); and gold is below the detection limit in all samples. No geophysical survey was carried out in the Block, and no NGPM or NGCM data of GSI are available for the area.

1.8.0 PREPARATION OF THE GEOLOGICAL REPORT

- 1.8.1 The geological report was prepared at the Corporate Office, MECL, Nagpur, by integrating the geological and geochemical data. ArcGIS, AutoCAD and CorelDraw were used for the preparation of the various maps and plates, and Python-based analysis was used for the geochemical and statistical plots.

1.9.0 CONCLUSION

- 1.9.1 MECL completed a G-4 reconnaissance survey for phosphate over the 16.68 sq. km Kaphalda Block. The favourable Krol–Tal stratigraphy and the phosphate-bearing Black Shale/Cherty Shale horizon are present, and XRD confirms apatite in the enriched trench samples. The contrast between the low surface grades and the above-cut-off trench grades (upto 6.60 % P₂O₅) is the key finding of the survey: the phosphate horizon is thin (chert member about 4 m thick), poorly exposed and largely concealed beneath the Krol–Tal contact. The concealment is attributed to sedimentary pinching and swelling of the horizon and, chiefly, to the structural complexity of the Block close to the MBT zone, where the Lesser Himalayan formations are imbricated and the Tal Formation rides up over the phosphatic horizon. The mineralisation is therefore interpreted as structurally controlled and concealed rather than absent. The Block couldn't be upgraded to G3 Stage, as mentioned at 1.5.1.

1.10.0 RECOMMENDATIONS

- 1.10.1 It is recommended that the Kaphalda Block be upgraded to the G-3 stage of exploration to confirm and delineate the concealed phosphate horizon. As a thorough structural investigation was beyond the scope and the timeline of the present G-4 survey, a separate and dedicated structural programme should be carried out near the MBT zone to resolve the imbricate geometry of the Block, followed by a drilling programme with scout boreholes sited on the favourable T3–T4 trench sector and inclined to intersect the down-dip continuation of the horizon, so as to establish its thickness, grade and continuity at depth.

CHAPTER-2

2.1.0 DETAILS OF THE QUALIFIED PERSON(S) / EXPLORATION AGENCY

TITLE	DETAILS
(a) Name:	MINERAL EXPLORATION AND CONSULTANCY LIMITED (Formerly Mineral Exploration Corporation Limited) (A Govt. of India Enterprise; A Miniratna-I PSE) (Ministry of Mines, Govt of India)
(b) Communication Address:	Dr. Babasaheb Ambedkar Bhawan, Highland Drive Road, Seminary Hills, Nagpur-440006.
(c) Contact Mobile No:	0712-2510289, 0712-2511829
(d) E-Mail id:	gm-exploration@mecl.gov.in
(e) Qualification of Technical Personnel	M.Sc. Geology/Applied Geology/M. Tech (Geoexploration)
(f) Experience:	Professionals have more than 25+ years of experience
(g) Affiliation to any organization/company, if yes, specify the name of the organization or company.	-

2.2.0 PERSONNEL ASSOCIATED IN EXPLORATION WORK

2.2.1 The list of personnel associated with the execution of different exploration activities carried out in Kaphalda Block (G-4), District: Dehradun, Uttarakhand is given in the Table No. 2.2.

Table-2.2: List of Personnel associated with Exploration Work

S No.	Title	Name of the Personnel
1	Overall Guidance	Shri Shrikant Sharma, HoD (Exploration)
2	Overall planning, Coordination & Supervision	Shri Shrikant Sharma, HoD (Exploration)
		Shri Swarup Dhara, Senior Manager (Geology)
3	Project Management/OIC	Shri Yashu Joshi, Manager (Geology)
Physical Execution of Work		
4	Geology	Shri Dashmesh Singh, Asst. Manager (Geology)
5	Chemical Laboratory	Shri Shrikant Sharma, HoD (Exploration)
		Shri Rohit Sharma, Seniro Manager (Chemical)
		Shri Deepti Rahangdale, Senior Manager (Chemical)
		Shri Bojana, Manager (Chemical)
		Shri Piyush Kanti Mahanti, Manager (Chemical)
		Fawaz Asstt., Manager (Chemical)
6	Petrographic studies	Shri Sayantan Pal, Manager (Geology)
7	Documentation	Shri Yashu Joshi, Manager (Geology)
		Shri Dashmesh Singh, Asst. Manager (Geology)
8	Hindi Translation	Shri Srikant Rai, Sr. Hindi Officer
9	Reprography and Printing	Shri Pradeep Singh Negi, OIC, Survey & Map Section
		Shri Durgesh Devarshi, E-0, Survey & Map Section.

2.3.0 ACKNOWLEDGEMENT

2.2.1 MECL express their sincere gratitude to the following individuals and organizations for their valuable contributions and support throughout this reconnaissance survey (G-4) for Phosphate exploration in the Kaphalda Block, Dehradun. We extend our heartfelt appreciation to Shri. Brijesh Kumar Sant (IAS), 'Director General' of Geology and Mining Unit, and Shri. Anil Kumar, 'Additional Director', and Shri Dinesh Kumar, HoD (Geology), DGM, Uttarakhand for their continuous support in facilitating logistics arrangements and official liaison work, ensuring the successful execution of the fieldwork. We would also like to acknowledge the local communities in the villages of Bhusti-Jalikhal, Sila and Suwalkholi in the Block, for their co-operation which facilitated our field operations smoothly. Finally, we extend our appreciation to all those who have directly or indirectly contributed to the successful completion of this reconnaissance survey, whose names may have been inadvertently omitted.

CHAPTER-3
TITLE AND OWNERSHIP

3.1.0 TITLE OF THE REPORT

Table – 3.1: Table Showing Ownership of Kaphalda Block (G-4), District: Dehradun, Uttarakhand.

(i) Name of the explorer/Mining or prospecting rights holder.	Mineral Exploration and Consultancy limited, NMET and The Office of Directorate of Geology & Mining, Uttarakhand.
Address:	<i>Directorate of Geology and Mining, Bhopalpani Grant (Kadaikhala), Raipur-Thano Airport Motor Road, P.O. Dhanyari, District: Dehradun, PIN-248008, Uttarakhand, India.</i>
Telephone No.	9622346843
E-Mail id:	dir.ukdgm@gmail.com
(ii) Details of period of prospecting/mineral right if any:	Field Session : January 2026 to June 2026
In case of a license or lease:	NA
(a) Date of grant:	NA
(b) Date of execution:	NA
(c) Period of license or lease:	NA
(d) Date of completion	NA

CHAPTER-4

DETAILS OF THE AREA

4.1.0 LOCATION AND ACCESSIBILITY OF THE BLOCK

- 4.1.1 Kaphalda Block is located in the Raipur Tehsil of Dehradun district, Uttarakhand (with parts extending into the Tehri-Garhwal district), a hilly area nestled in the foothills of the Himalayas. The Block covers an area of 16.68 Sq. Km, and falls under the Survey of India Toposheet No. 53J/03. The region is surrounded by several villages, including Kaphalda, Silla Sera, Bhanswalgaon, Kyar Kuli Bhatta, Simiyari, Fuleta, Durmala, Bhusti and Chhamroli, each contributing to the area's rich cultural varieties and agricultural farms. Situated approximately 33 kilometres east of Dehradun city, the Kaphalda Block lies on the eastern limb of the Mussoorie Syncline and is well connected with the major urban centers while maintaining its serene, semi-rural character.
- 4.1.2 The Block's proximity to Dehradun, the state capital, offers easy availability of all the logistics and local residents daily needs. Dehradun Railway Station is about 35 kilometres away, and Rishikesh is another nearby railhead, while Jolly Grant Airport is about 50 kilometres from the Block. Additionally, the area's closeness to popular tourist destinations like Mussoorie, Sahastradhara, Maldevta, Rishikesh and Haridwar makes it an attractive location for both residents and tourists seeking to explore the natural and cultural wonders of Uttarakhand.
- 4.1.3 The area is accessible via rough and rural roads, with the Maldevta-Dubra motorable kachha road passing near the Block, serving as a crucial route for transportation and connectivity. Well-metalled roads are largely absent in the area, and along with the few motorable kachha roads, they ensure that the Block remains accessible through most of the year, facilitating the movement of people and goods. However, the monsoon season is harsh on the region. Due to the presence of shale and slate rocks at the top of the hills, heavy rains cause slope failures every year during the monsoon, necessitating significant road repairs.
- 4.1.4 Geologically, the region is landslide-prone due to Himalayan tectonic zone, which necessitate careful planning for future exploration and mining development projects to balance growth with environmental conservation of the Block.

Table-4.1**Table 4.1: Co-ordinates of Cardinal Points of the Block boundary of Kaphalda (G-4) Block. Dist.: Dehradun, Uttarakhand**

Cardinal Points	WGS 84 (DMS)		UTM Zone-44 (m)		Elevation (m)
	Latitude	Longitude	Easting (m)	Northing (m)	
A	30.4147694°N	78.1608994°E	303249.53	3366701.88	~1,450 m
B	30.4400741°N	78.1823790°E	305598.41	3370142.96	~1,850 m
C	30.4109443°N	78.2197475°E	309065.18	3365800.12	~2,200 m
D	30.3859338°N	78.1963554°E	306578.83	3362511.49	~1,600 m

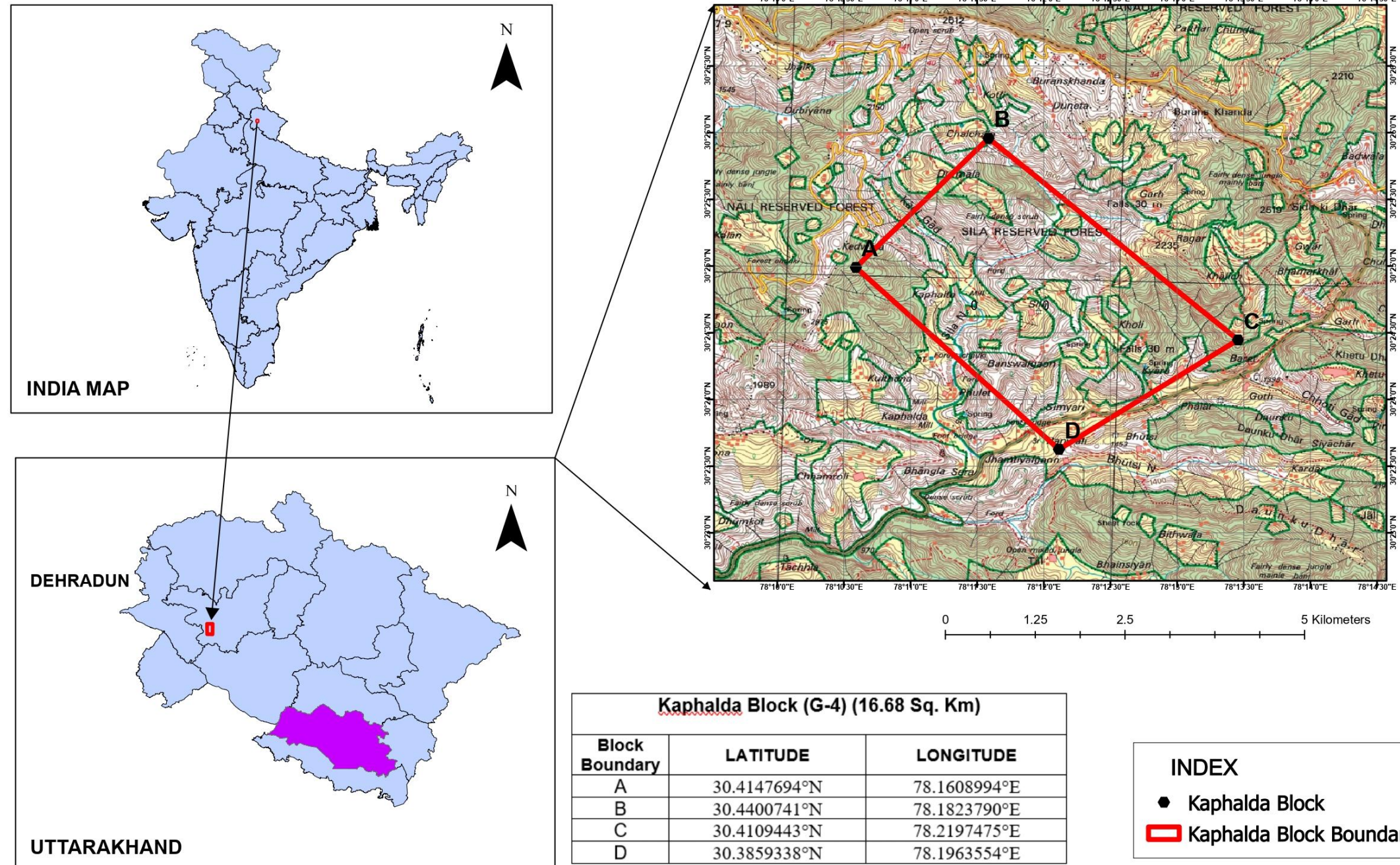
4.2.0 DETAILS OF THE AREA WITH LANDUSE

The Block falls within the Sila (Silla) Reserved Forest, and a major part of it lies in the Chandi Reserved Forest area of Dehradun district. Government land (Bilanam), Charagah and private-land data for the nearby villages are not available at present. The Block is free from any eco-sensitive zone and wildlife sanctuary area, and no Archaeological Survey of India (ASI) site or existing mining lease occurs within it. The area of the Block is shown in fig. 4.1

4.3.0 MINERAL(S) UNDER INVESTIGATION

4.3.1 The Block was explored for rock phosphate

Location Map of Kaphalda Block, Dehradun/Tehri-Garhwal, Uttarakhand



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Ministry of Mines, Govt of India Enterprise, MINIRATNA-I CPSE
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Text Figure 4.1: Location Map of Kaphalda Block for Phosphate, District- Dehradun, Uttarakhand

CHAPTER-5

PHYSIOGRAPHY AND ENVIRONMENT

5.1.0 RELIEF OF THE AREA WITH MINIMUM AND MAXIMUM ELEVATION, DRAINAGE PATTERN, NATURAL WATER COURSES, RESERVOIRS, ETC.

5.1.1 The Kaphalda Block lies on the outermost fringe of the Lesser-Himalaya of Garhwal, immediately to the north and north-east of the Siwalik foothills and the Doon Valley. The main topographic feature of the area is the imposing ridge, trending roughly NW-SE to NNW-SSE lying to the north of the broad Dehradun Valley between the rivers Yamuna on the west and Ganga on the east. The Block occupies the eastern limb of the Mussoorie Syncline. Numerous spurs branch off in diverse directions from this main ridge. Rugged topography, characteristic of the Himalaya and typical of any young fold mountain, with hill ranges rising steeply from 800 meters above m.s.l. to over 2590 meter above m.s.l. and deeply cut valleys, clothed with a verdant cover of Pine, Deodar, Rhododendron and Oaks at higher reaches and bushes and shrubs at lower altitudes, dominate the landscape. The geomorphologic character of the alignment of ridges and valleys at places suggests that the topography is somewhat mature and of second order, with anticlines forming valleys and the synclines forming the ridges, the Lal-Tibba ridge forming the core of the main Mussoorie Syncline

5.1.2 The climate is tropical monsoon type, modified to some extent by the effects of altitude and the situation of the area in the continental interior. Winter is fairly severe with occasional snow falls between December and March. Summer season starts from April and the outdoor activities can best be done up to the end of June, when the monsoon breaks out. The rains are generally heavy and continue up to early September. The mean annual rainfall is about 250 cm. The drainage of the area is of consequent type. The water of the southern slope of the Mussoorie ridge (between Mussoorie and Agarakhal-Nagani) drains into the Ganga through many streams, the prominent among them are Suswa Nadi, Song, Jakhan Rao, Chandna Rao and Huinl (Hewnal) river. Among these, the Song River drains the Block area, and its main tributaries are the Kaligad, Bandal and Chiphaldi nala. The water of the northern slope of the Mussoorie ridge flows through various streams into the Aglar, a tributary of the river Yamuna.

5.2.0 FLORA & FAUNA

- 5.2.1 The human population has scared away the wild animals from the area around the township of Mussoorie and other easily approachable places, but the interior parts and densely forested areas are still infested with a variety of wild animals, the most common ones being panther, wild bear, barking deer, wild goat and jungle fowl.

5.3.0 ROADS, RAILWAY TRACK, ELECTRIC TRANSMISSION LINE, TELEPHONE LINE, ETC.

- 5.3.1 Kaphalda Block, in the Maldevta–Song valley area of Dehradun, Uttarakhand, faces significant infrastructure challenges, particularly in its road network. The area is characterized by poor road conditions, with single-lane narrow kachha (unmetaled) roads that are prone to damage, especially during monsoon periods when slope failures are common. These road issues greatly impact local transportation and accessibility, particularly given the Block's hilly terrain.
- 5.3.2 Despite the road network limitations, the Block is connected to basic utility infrastructure. There is no direct railway track in the area, the nearest station being at Dehradun city, about 35 km away. The Block is linked to the National power grid through transmission lines that supply power to local villages. Telephone infrastructure, including both landlines and mobile networks, is also present, though mobile communication is more prevalent. However, the challenging topography of the region affects the consistency and reliability of these utility services in the area.

5.4.0 HOST POPULATION (LOCAL TRIBES), HUMAN SETTLEMENTS WITHIN AND NEARBY THE AREA

- 5.4.1 The population of the Kaphalda Block area primarily consists of local communities native to the Dehradun and Tehri-Garhwal region. While not classified as tribal areas, these settlements include a mix of rural and semi-urban populations. The area is home to traditional Garhwali communities, as the region is part of the Garhwal division of Uttarakhand. The locals mostly engage in small-scale agriculture, horticulture and allied activities.
- 5.4.2 Local settlements within and around the Block, such as Kaphalda, Silla Sera, Bhanswalgaon, Kyar Kuli Bhatta, Simiyari, Fuleta, Durmala, Bhusti and Chhamroli, are typically small to medium-sized villages scattered across the hilly terrain. The layout of these settlements follows the topography, with houses built on terraces. The nearby developed area of Maldevta, and the sulphur springs of Sahastradhara further

west, attract visitors, and this proximity to popular spots influences the livelihood patterns of some residents, leading to small guesthouses or homestays in places.

5.5.0 SOCIO DEMOGRAPHIC PROFILE OF THE AREA AND NEARBY

5.5.1 The social fabric of the area is a mix of traditional Garhwali culture and more modern influences due to its proximity to Dehradun city. The community structure retains many traditional elements, with a mix of joint and nuclear families. The area's economy is diverse, encompassing agriculture, small-scale industries and service-sector jobs. Education levels vary across the region, with a trend towards improved literacy rates, especially among younger generations.

5.5.2 The socio-demographic profile of the Kaphalda Block and its surrounding areas is characterized by a mix of rural and semi-urban populations. The region is primarily inhabited by native Garhwali communities, featuring the diverse castes and social groups typical of Uttarakhand's hill regions. The population consists of various age groups, with a trend towards younger demographics in the more urbanized areas nearer to Dehradun city.

5.5.3 Education levels show variation, with higher literacy rates observed in areas closer to Dehradun due to better access to educational facilities. The economy is diverse, including traditional agriculture, small-scale industries and service-sector jobs. The proximity to Dehradun influences employment patterns, with some residents commuting to the city for work.

5.6.0 The cultural landscape is rich in Garhwali traditions, evident in local festivals, cuisine and social practices. Owing to its closeness to Dehradun, the region is also exposed to more modern, urban influences, creating an environment where traditional practices coexist with contemporary lifestyles.

5.7.0 HISTORICAL SITES AND ARCHAEOLOGICAL MONUMENTS, PLACES OF WORSHIP, PUBLIC UTILITIES ETC.

5.7.1 While the Kaphalda Block itself is not known for significant historical sites or archaeological monuments, the surrounding area of greater Dehradun is rich in cultural heritage. The sulphur springs and caves of Sahastradhara, to the west of the Block, are a notable site attracting both tourists and pilgrims, and hold historical and cultural significance in the region.

5.7.2 Places of worship in the area include small local temples dedicated to Hindu deities, reflecting the predominantly Hindu population of Uttarakhand. These temples often serve as community gathering spaces and play a role in preserving local traditions and festivals.

5.7.3 Regarding public utilities, the Kaphalda Block, being part of Dehradun district, has basic infrastructure in place. This includes primary health centers, government schools and local administrative offices. However, the extent of these facilities varies with location within the Block, with areas closer to Dehradun city having better access to public services.

The villages nearer to Dehradun city have access to the more advanced facilities of the urban center for healthcare, education and other public services. However, the challenging terrain and road conditions in the Block affect the ease of access to these urban amenities for the far villages.



Photograph 5.1: View of the South-Western Kaphalda Block from a hill top.

5.8.0 FORESTS, SANCTUARIES, NATIONAL PARK AND WILD LIFE SANCTUARIES ETC.

5.8.1 The Kaphalda Block and surrounding areas of Dehradun are part of the forest rich Himalayan foothills. These forests are home to a variety of flora and fauna,

contributing to the area's biodiversity. The region is characterized by diverse forest types, primarily subtropical moist deciduous forests. The forests in and around Dehradun support a rich wildlife population, including species like barking deer, wild boar and various primates. The region is particularly noted for its avian diversity, attracting birdwatchers and nature enthusiasts (Photograph 5.1).

- 5.8.2 A major part of the Block falls within the Sila and Chandi Reserved Forest. While the Block itself does not contain any designated national park or wildlife sanctuary, it lies in proximity to several important protected areas. The Rajaji National Park, located partly in Dehradun district, is a significant conservation area known for its elephant population, leopards and diverse bird species. The park represents the joining of three sanctuaries: Rajaji, Motichur and Chilla.

5.9.0 FLORA AND FAUNA WITHIN AND NEARBY

- 5.9.1 The Kaphalda Block and its surrounding areas are part of the diverse ecosystem of the Himalayan foothills, characterized by rich biodiversity in both flora and fauna.
- 5.9.2 The flora of the area predominantly features subtropical moist deciduous forests. Common tree species include Sal (*Shorea robusta*), Teak (*Tectona grandis*) and various species of Oak and Pine. The understorey is often rich in shrubs, ferns and herbs. At higher elevations one finds rhododendron species, a flower of high medicinal value. The region is also known for its medicinal plants, traditionally used in Ayurvedic practices.
- 5.9.3 The fauna of the region is diverse, with larger mammals such as leopard, barking deer, wild boar, langur and wild bear, and smaller mammals like porcupine and civet. They are commonly seen at night and in the early morning, and field activities should be avoided at these times. The area is also rich in avian diversity, with species like the great barbet, Himalayan bulbul and various eagles and owls. Snakes and lizards are common, and the area supports a wide variety of butterflies, moths and other insects. In the nearby Rajaji National Park, larger mammals like elephant and tiger occur, though these are unlikely to be seen in the immediate vicinity of the Block.

5.10.0 WATER BODIES SUCH AS RIVER, NALA, STREAM, RESERVOIR, ETC

- 5.10.1 The Kaphalda Block and its surrounding areas are characterized by a network of water bodies typical of the intermontane valley of Dehradun in the Himalayan region. The Block is drained by the Song River and its tributaries, the Kaligad, Bandal and

Chiphaldi nala. The hilly terrain is drained by numerous seasonal streams and nalas that play a crucial role in the local hydrology, especially during the monsoon season when they carry rainwater down the slopes. Apart from these, the area has several smaller natural springs, common in the Himalayan foothills, which often serve as important water sources for local communities.

- 5.10.2 The flow and volume of these water bodies vary significantly between the monsoon and dry seasons. The terrain is highly susceptible to rapid changes due to factors like rainfall and landslides.

5.11.0 CLIMATIC CONDITIONS

- 5.11.1 The climatic conditions of the area are influenced by its geographical location in the Lesser Himalayan region. The area experiences a diverse range of conditions owing to its varying altitudes and terrain. It is characterized by distinct seasons, with cold winters and mild summers. Topography plays a significant role in shaping the local climate, with higher altitudes experiencing cooler temperatures and increased precipitation compared to the lower-lying areas.
- 5.11.2 The Kaphalda Block, located in the Maldevta–Song valley area of Dehradun, experiences a subtropical highland climate typical of the lower Himalayan region, with moderate temperatures throughout the year and distinct seasonal variations.
- 5.11.3 There are mainly four seasons: Winter (December to February), Summer (March to June), and Monsoon (July to September), while Autumn (October to November) serves as a transitional period. Summers are warm but not excessively hot, while winters are cool; owing to its elevation the area generally experiences milder temperatures compared to the plains. The region receives significant rainfall, primarily during the south-west monsoon season from July to September. The mean annual rainfall is about 250 cm. Humidity levels are generally moderate to high, especially during and immediately after the monsoon, while the winter months tend to be drier. The area experiences mountain and valley breezes typical of hilly regions, which influence daily temperature fluctuations and weather patterns. These local wind systems can influence daily temperature fluctuations and weather patterns.

5.12.0 OTHER PHYSIOGRAPHIC, SOCIAL AND ENVIRONMENTAL FACTOR

- 5.12.1 The Kaphalda Block is situated in the upper zones of Himalayan foothills, characterized by undulating terrain with varying elevations. The Block lies exactly above the MBT, leading to abrupt height from 600-800 msl to 2200-2500 msl. This

topography influences local microclimates, vegetation patterns and land use, with a mix of gentle slopes and steeper hillsides and a potential for soil erosion, slumping and landslides during heavy rains.

- 5.12.2 The Block's environment is influenced by its forest cover, water resources and human activities. The area faces the challenge of balancing development needs with the preservation of local ecosystems and the sustainable use of springs and streams, which is particularly important given the reliance on these water sources. During monsoons, erosion is a major issue due to the hilly terrain.
- 5.12.3 Waste management is poorly addressed problem of the region; despite the tourist footfall in nearby areas, waste handling remains inadequately managed.

CHAPTER-6

INFRASTRUCTURE

6.1.0 LOCAL INFRASTRUCTURE WITH ROADS, RAILWAYS, PORT FACILITIES, ELECTRICITY, WATER.

6.2.0 The road network in and around the Kaphalda Block is characterized by narrow, single-lane kachha (unmetaled) roads. The Maldevta–Dubra motorable kachha road passes near the Block and serves as the main link. These roads are prone to damage, especially during monsoon periods when slope failures are common. The challenging terrain and weather conditions often lead to maintenance issues, affecting local transportation and accessibility. Despite these challenges, the roads connect the Block to Dehradun city and the nearby areas of Maldevta and Sahastradhara.

6.3.0 The Kaphalda Block itself does not have a railway station. The nearest railway connectivity is available at Dehradun Railway Station, about 35 km away, which connects the region to major cities across India. Being a landlocked area in the Himalayan foothills, the Kaphalda Block does not have any port facilities. The nearest major ports are hundreds of kilometres away on India's coastline.

6.4.0 The Block is connected to the national power grid, with electricity supply managed by the Uttarakhand Power Corporation Limited (UPCL). However, due to the hilly terrain and occasional extreme weather conditions, the power supply faces interruptions, especially in the more remote parts. Some areas rely on local transformers and distribution networks.

6.5.0 Water supply in the Block is a mix of natural sources and limited municipal infrastructure. The Block is drained by the Song River and its tributaries, and the area has several natural springs. The extent of piped water supply varies and is not sufficiently available; many households rely on local springs or river water, especially where municipal water infrastructure is limited. Additionally, the Sahastradhara stream serves as a vital water source for the Dehradun city and surrounding villages, catering to both household and potable water needs (Kaur, 2023).

6.6.0 The Kaphalda Block, situated in the Garhwal Himalayan region, is geologically sensitive and tectonically prone to man-induced disaster events. The area faces a range

of natural hazards, including earthquakes, landslides, heavy rains, floods, flash floods, cloudbursts and forest fires, due to the uneven relief, mountainous terrain, slope instability and erratic heavy rainfall (Kaira et al., 2023). Heavy cloudbursts in July and September 2025 rendered the approach road un-operational for nearly five months, delaying the commencement of field work in the Block.

- 6.7.0 The adoption of solar-based systems, such as solar trees, has been explored as a clean energy solution for the mountainous region, emphasizing the importance of sustainable energy practices (Kumar et al., 2021).



Photograph 6.1: Road infrastructure of the Kaphalda Block, totally damaged throughout by the continuous monsoon. a) River-side road approaching from Dehradun to Maldevta to the Kaphalda Block, damaged all along the river banks; b) inside road of the Kaphalda Block, approaching from the western to the eastern side; c) inside road of the Kaphalda Block, from north (top) to south (bottom).

CHAPTER-7

GEOLOGY OF THE BLOCK

7.1.0 BRIEF REGIONAL GEOLOGY OF THE AREA OUTLINING THE BROAD GEOLOGICAL, STRATIGRAPHICAL AND STRUCTURAL FRAME WORK.

7.1.1 The Kaphalda Block lies within the Mussoorie Syncline, one of the four synclinal basins of the Krol Belt (together with the Nigali Dhar, Korgai and Garhwal synclines) that preserve the phosphate-bearing Lower Tal sequence of the Lesser Himalaya (Auden, 1934; Valdiya, 1980; Mazumdar et al., 1999). Here a thick Proterozoic to Lower Cambrian sedimentary pile of the Nagthat–Blaini–Infra Krol–Krol–Tal succession is folded into a broad, doubly plunging syncline. The litho-stratigraphy of the syncline used in this report follows the classification of Shanker, Ghose and Puri, summarised in Table 7.1.

Table-7.1: Litho-stratigraphic classification of the Mussoorie Syncline (after Ravi Shanker, Ghose & Puri).

Age	Group / Formation	Member / Litho-units	Thickness
Older Paleozoic (?)	Garhwal Thrust Unit	Schistose-phyllites, limestone and quartzite, volcanic tuffs	—
— Garhwal Thrust —			
Late to Mid. Eocene	Subathu Formation	Olive Shale, Shell-marl and Limestone	—
— Unconformity (?) —			
Late / Mid. Cretaceous	Upper Tal Formation	Limestone member (shaly calcareous grits); Quartzite member (quartzite with thin grey-green shales, red siltstone, often mud-cracked)	20 m / 1300 m

Mid. Jurassic to Lower Cretaceous	Lower Tal Formation	Calcareous member; Arenaceous member (massive banded siltstone / sub-greywacke); Argillaceous member (silty shale, splintery/banded calcareous shale, black micaceous pyritic carbonaceous shale); Chert member with Phosphate Unit and Chert Unit	5 m; 300–500 m; 150 m; 10 m + 200 m
— Discontinuity (submarine diastem) / overlap —			
Triassic (?)	Transition Zone / Krol (upper)	Argillaceous limestone (often phosphatic, interlayered with thin streaks of phosphate rock and chert, brecciated at places); light grey argillaceous limestone; purple and grey shale/slate	—

7.1.2 The Tal Formation is separable into a Lower Tal and an Upper Tal on the basis of lithology and mappable contacts, the boundary marking a break in sedimentation and a shift from marine to more marginal-marine conditions. The Lower Tal is the mineralised unit. Its basal Chert Member carries the phosphorite towards its top and is made up of thickly bedded black cherts with intercalations of grey shale; the chert becomes nodular upwards, just below the main phosphatic zone. The phosphate content of the nodules tends to vary inversely with their size, the smaller nodules being the more phosphatic, while the enclosing cherty matrix is largely barren. Pyrite is common in the Chert Member, indicating reducing conditions of deposition (Banerjee et al., 1997; Mazumdar et al., 1999).

- 7.1.3 Above the Chert Member lie the argillaceous, arenaceous and calcareous members of the Lower Tal, comprising black to olive pyritic and carbonaceous shale, banded calcareous shale and quartzose sandstone. The Upper Tal is dominantly a quartzitic sequence with a thin calcareous cap, and is divided into a Quartzite Member and an overlying Limestone Member.
- 7.1.4 The Krol Formation underlies the Tal and forms the oldest unit exposed in the area. Its upper part, mapped in and around the Block, consists of thickly bedded to massive dolomite and dolomitic limestone passing up into yellow-weathering argillaceous limestone and calcareous shale (the Krol 'E' or Upper Krol of Auden, 1934). The Krol–Tal contact is the critical marker horizon that localises the phosphorite throughout the belt (Banerjee et al., 1997).

7.2.0 REGIONAL STRUCTURE

- 7.2.1 The Mussoorie Syncline is a large, asymmetric and doubly plunging fold in the Outer Lesser Himalaya, bounded to the south by the Main Boundary Thrust (MBT), which separates it from the Siwaliks, and to the north by the Main Central Thrust zone (Valdiya, 1980). The southern limb dips moderately to steeply south while the northern limb is gentler, and the axis plunges gently towards the east-southeast, so that the phosphate-bearing Lower Tal progressively passes below cover towards the eastern closure of the fold. Repeated folding, together with strike-parallel shears and transverse faults that offset and locally duplicate the beds, has strongly influenced the present distribution and continuity of the phosphate horizon (Auden, 1934; Valdiya, 1980).

7.3.0 REGIONAL MINERALIZATION

- 7.3.1 The principal mineralisation of the Mussoorie Syncline is stratabound sedimentary phosphorite hosted by the basal chert–shale–carbonate part of the Lower Tal Formation of Early Cambrian (Tommotian) age. The productive tracts of Durmala, Maldeota, Masrana, Kimoi and Bhusti–Jalikhhal all sit at or just above the Krol–Tal contact (Auden, 1934; Banerjee et al., 1997; Khan et al., 2016).
- 7.3.2 The phosphate mineral is carbonate-fluorapatite (francolite) and collophane, associated with microcrystalline quartz, dolomite, calcite, pyrite, hematite and organic matter (Kumar et al., 2026). The phosphorite carries moderate rare earth element contents with light-REE enrichment over the heavy REE and a shale-normalised

pattern that shows a negative Ce anomaly and a slight positive Eu anomaly, a signature widely read as reflecting deposition from oxic sea water that mixed with upwelled, organic-rich anoxic bottom water (Mazumdar et al., 1999; Khan et al., 2016).

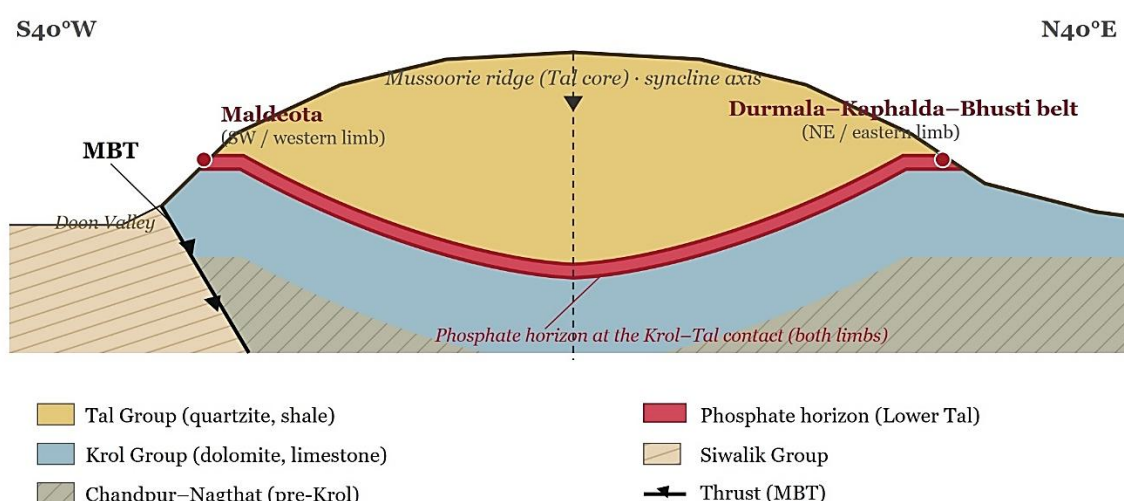
7.3.3 Carbon-isotope and geochemical work across the Krol–Tal boundary in the Durmala mine section records a marked negative carbon-isotope excursion together with phosphorus and trace-metal enrichment, marking a drowning of the Krol carbonate platform and an oceanic anoxic event that preceded and foliated phosphogenesis (Banerjee et al., 1997). Phosphate precipitation is interpreted to have taken place on a shallow, storm-influenced carbonate ramp during a transgression, through the microbial breakdown of organic matter and repeated reworking of early apatite (Mazumdar et al., 1999).

7.3.4 The Kaphalda Block lies on the eastern limb of the Mussoorie Syncline, in between the strike from the high-grade Durmala and Bhusti–Jalikhil tracts, and was taken up for reconnaissance on this favourable lithology and the continuation of the Phosphate horizon (Text Figure 7.1).

10

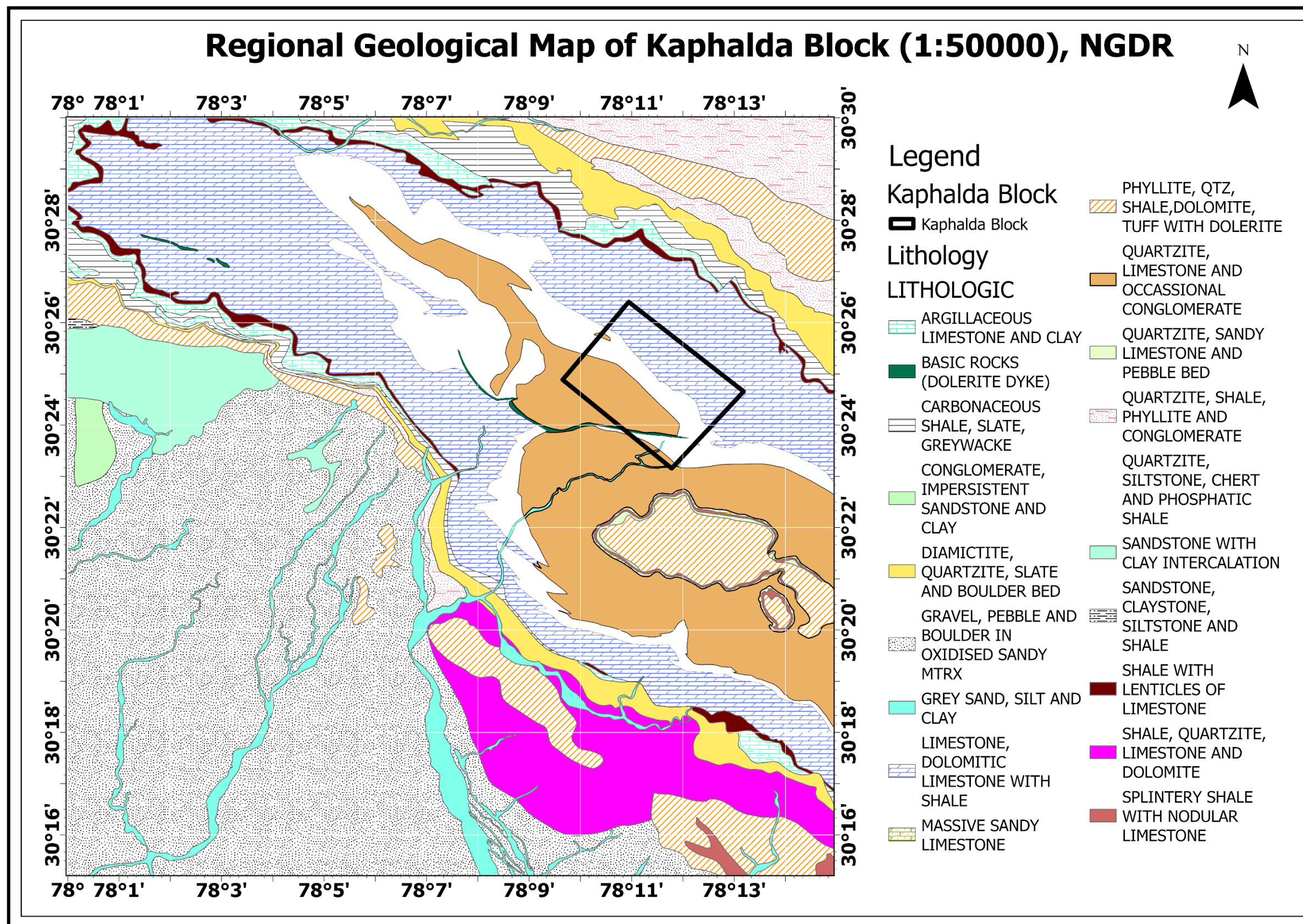
Schematic transverse geological section across the Mussoorie Syncline

Phosphate horizon = Lower Tal chert–black shale (apatite) at the Krol–Tal contact, on both limbs



Schematic, not to scale. After Auden (1934), Valdiya (1980), Banerjee et al. (1997) and Mazumdar et al. (1999).

Text Figure 7.1: Schematic Geological section across the Mussoorie Syncline and Lesser Himalaya, after Auden(1934), Valdiya(1980), Banerjee et al. (1997), Bose & Mukherjee (2019) and Biswas et al. (2022); phosphate model from Mazumdar et al. (1999).



Text Figure 7.2: Regional Geological Map at 1:50000 (NGDR).

7.4.0 LOCAL GEOLOGICAL SETTING DETAILING THE COMMON ROCK TYPES, CONTROLS OF MINERALIZATION, DETAILS OF OLD WORKINGS IF ANY, SURFACE EXPOSURES.

7.4.1 The Kaphalda Block occupies the eastern limb of the Mussoorie Syncline. Geological mapping on a 1:12,500 scale over the entire 16.68 sq. km of the Block has identified five distinct mappable units within the Tal Formation, namely Quartzite, Olive Shale, Black Shale (with Cherty Phosphatic Shale bands) and Banded Shale, while the Krol formation comprises limestone to dolomitic limestone. The area predominantly comprises rocks of the Tal Formation, which normally overlie the limestone sequence of the Krol Formation. The local stratigraphic succession is given below (after GSI).

Table- 7.2: Litho-stratigraphic classification of Kaphalda Block.

FORMATION	MEMBER	LITHO UNITS
Lower Tal Formation	Arenaceous member	Quartzite / Sandstone (quartz-wacke)
	Argillaceous Member	Olive/Green Shale, Black Shale, Cherty Phosphatic Shale bands, Banded Shale
-----DISCONTINUITY/OVERLAP----- -		
Krol formation	Calcareous Member	Light to and bluish grey Dolomite and Dolomitic limestone intercalated with Shale/Slate/Siltstone and yellow limestone layers.

7.4.2 The Kaphalda Block is part of the Mussoorie Syncline, which is bounded by two major tectonic features, the Main Boundary Thrust (MBT) and the Main Central Thrust (MCT) (Valdiya, 1980). The MBT, which is tectonically and seismically active at present, marks the boundary between the Shivaliks and the Lesser Himalaya. The Main Central Thrust (MCT) constitutes the major tectono-stratigraphic boundary between the Lesser Himalaya and the Greater (Higher) Himalayan Crystalline domain., with a distinct change in the style and orientation of structures and in the grade of metamorphism (Valdiya, 1980). Within the Block, the phosphatic Black Shale/Cherty

Shale bands and the olive shale of the Argillaceous Member extend in a NW–SE direction. The area has an altitude difference of about 1000 to 2400 m MSL.

7.5.0 DESCRIPTION OF ROCK TYPES

7.5.1 The litho-units mapped in the Block include Quartzite/Sandstone, Olive/Green Shale, Black Shale, Cherty Phosphatic Shale, Banded Shale and Dolomite/Dolomitic Limestone of the Krol Formation. Thin units of shale/slate, siltstone, impure limestone and yellow limestone are found intercalated with the dolomites and shale but are not mappable as separate units. A detailed description of the rock types is given below.



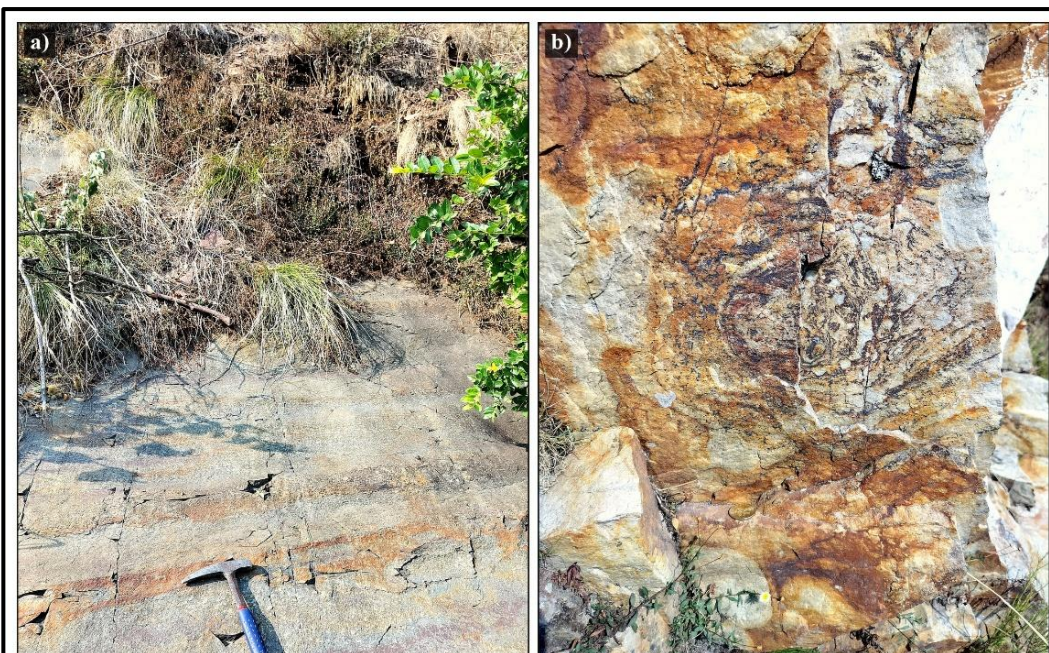
Photograph 7.1: The photo is captured vertically, to show the soil profile across the mountain sectional profile.

7.5.2 TOP SOIL

7.5.2.A The heavy rainfall conditions of the area result in flushing out of most of the top soil, exposing the rock throughout the Block. In a few grass fields, organic-rich soil is preserved and used for grazing. The rocks are asymmetrically folded, which leads to a negligible thickness of soil cover on the steep slopes and 2 to 3 m on the gentler slopes. The river valleys, nalas and piedmont areas are covered with alluvium and debris/scree, which is fresh material eroded and deposited annually during the monsoon. The grain shape ranges from sub-rounded to rounded in the river valleys and angular on the piedmont slopes, indicating minimal transportation and largely in-situ conditions (Photograph 7.1).

7.5.3 **Quartzite / Sandstone (Arkosic)**

7.5.3.A Quartzite and arkosic sandstone (quartz-wacke) form a prominent litho-unit exposed on the surface in the Block. The sandstone is fine to medium grained with a granular texture, composed dominantly of quartz and feldspar with subordinate lithic fragments. At places the quartzite is intensely folded, and thin sulphide specks are observed along fractures. Titanium content in these rocks is consistent with a near-shore, barrier-bar depositional setting. Desiccation marks and ripple marks are preserved locally, indicating shallow-water conditions. Quartzite displays distinct Liesegang banding and dendritic manganese/iron oxide infiltration, forming concentric, diffusion rings through rhythmic chemical precipitation (Photograph 7.2).



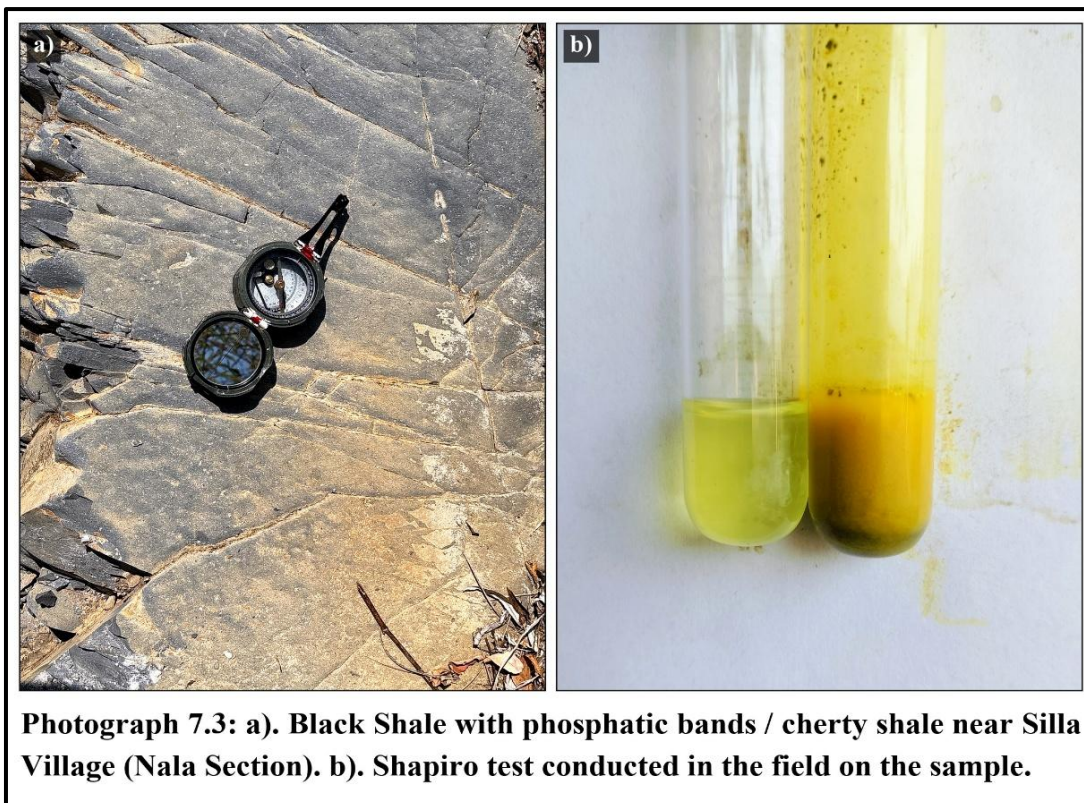
Photograph 7.2: a). Wave ripple marks in Arkosic Sandstone. b). Intricate Liesegang diffusion rings and iron-manganese staining etched into quartzite (Rs. 5, Coin resting at the lower-left ledge for Scale).

7.5.4 Olive / Green Shale

7.5.4.A Olive/Green Shale of the Argillaceous Member is well exposed and extends in a NW–SE direction across the Block. It contains primarily chlorite and dips gently in the Block. The unit is finely laminated and grades locally into banded shale.

7.5.5 Black Shale and Cherty Phosphatic Shale

7.5.5.A Black Shale, with intercalated Cherty Phosphatic Shale bands, is the litho-unit of principal interest for phosphate in the Block and is best exposed in the nala sections near Silla village. It is a dark grey to black, very fine grained, thinly laminated, carbonaceous and pyritic rock deposited under anaerobic, organic-rich conditions. The phosphatic bands occur as thin, discontinuous cherty layers within the black shale. A concentric ring of phosphate outcrops was observed near Silla village, where field Shapiro (molybdate) tests were carried out on selected samples (Photograph 7.3).



7.5.6 Banded Shale

7.5.6.A Banded Shale occurs as finely cleaved, banded and often calcareous shale that weathers buff. It is intercalated with the black and olive shale units and is not always separable at mapping scale.

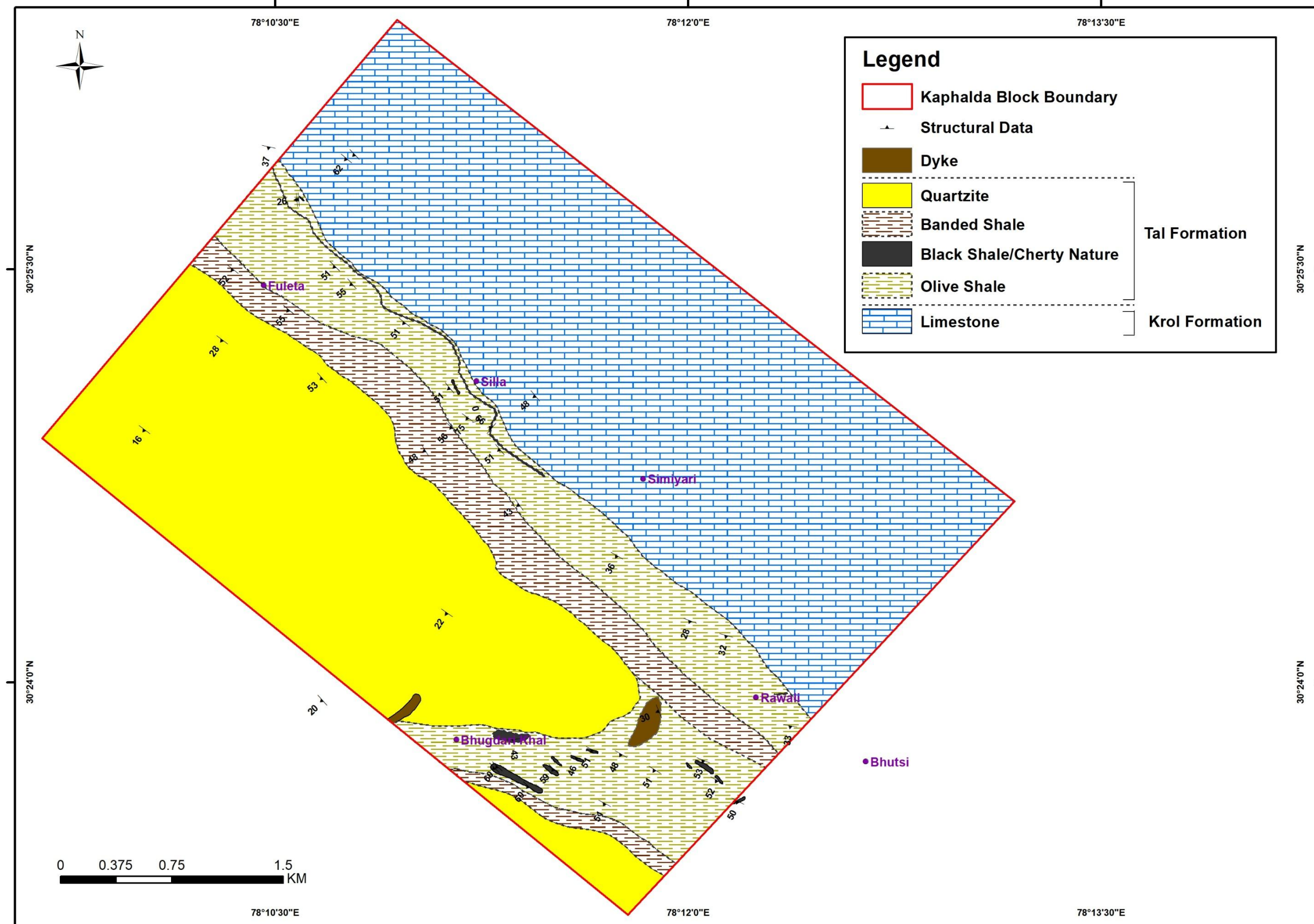
7.5.7 Dolomite / Dolomitic Limestone (Krol Formation)

7.5.7.A Dolomites are generally medium to fine grained, massive, compact and exhibit characteristic elephant-skin weathering at places. They range from dolomitic limestone to dolomite and vary in colour from bluish-grey or steel/light grey to grey-black. The light-coloured rocks, rich in carbonate and classify as dolomitic to impure limestone, whereas the dark grey units are massive, stratified dolomite intercalated with siltstone and yellow-weathering argillaceous limestone. These rocks are highly jointed, and bedding is generally obscure in the more massive varieties (Photograph 7.4).



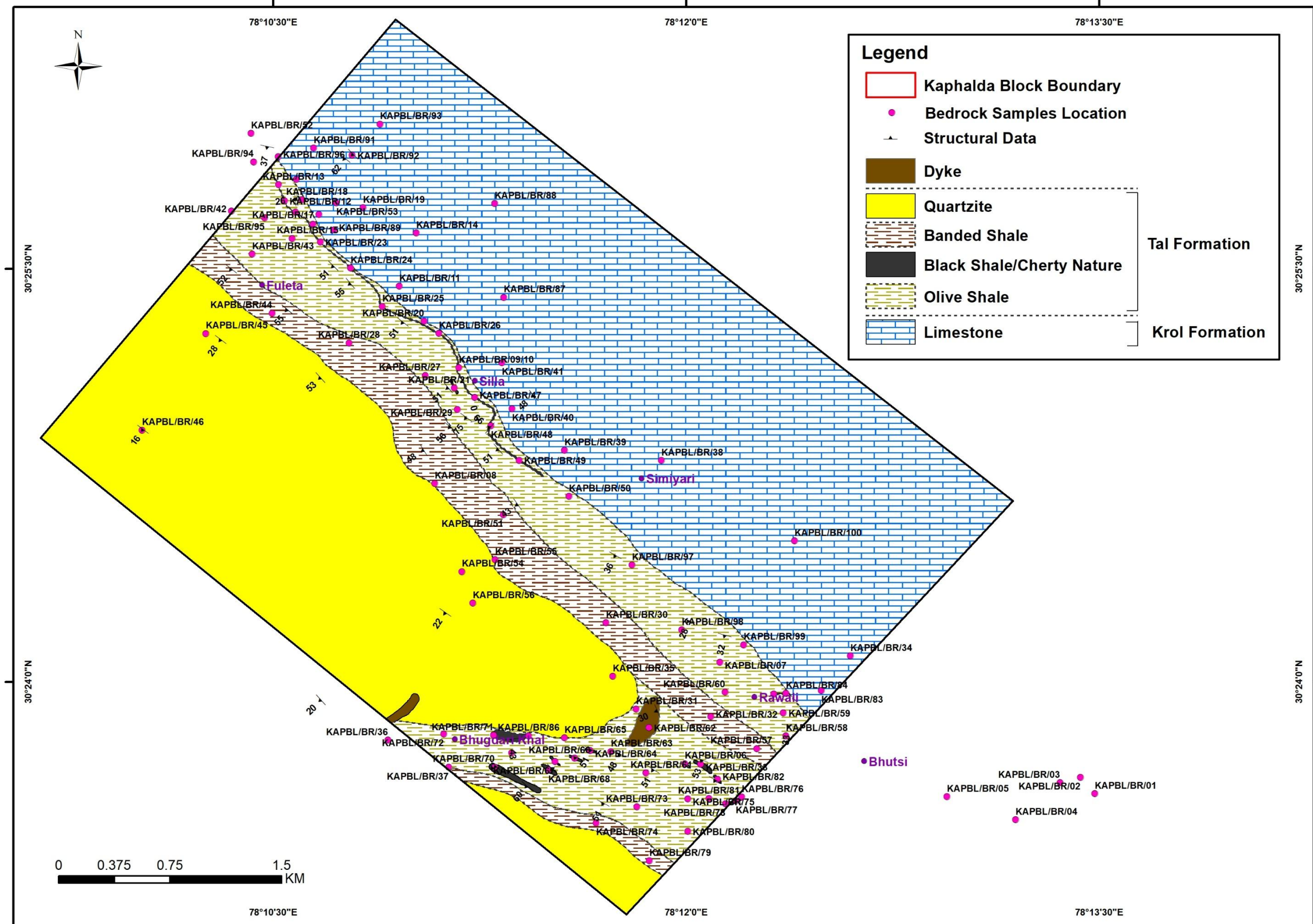
Photograph 7.4: Dark grey, fine-grained, hard and compact dolomite of the Krol Formation, exposed as a well-jointed outcrop traversed by thin white calcite veinlets (hammer for scale).

GEOLOGICAL MAP OF KAPHALDA BLOCK, DIST: DEHRADUN & TEHRI GARHWAL, UTTARAKHAND



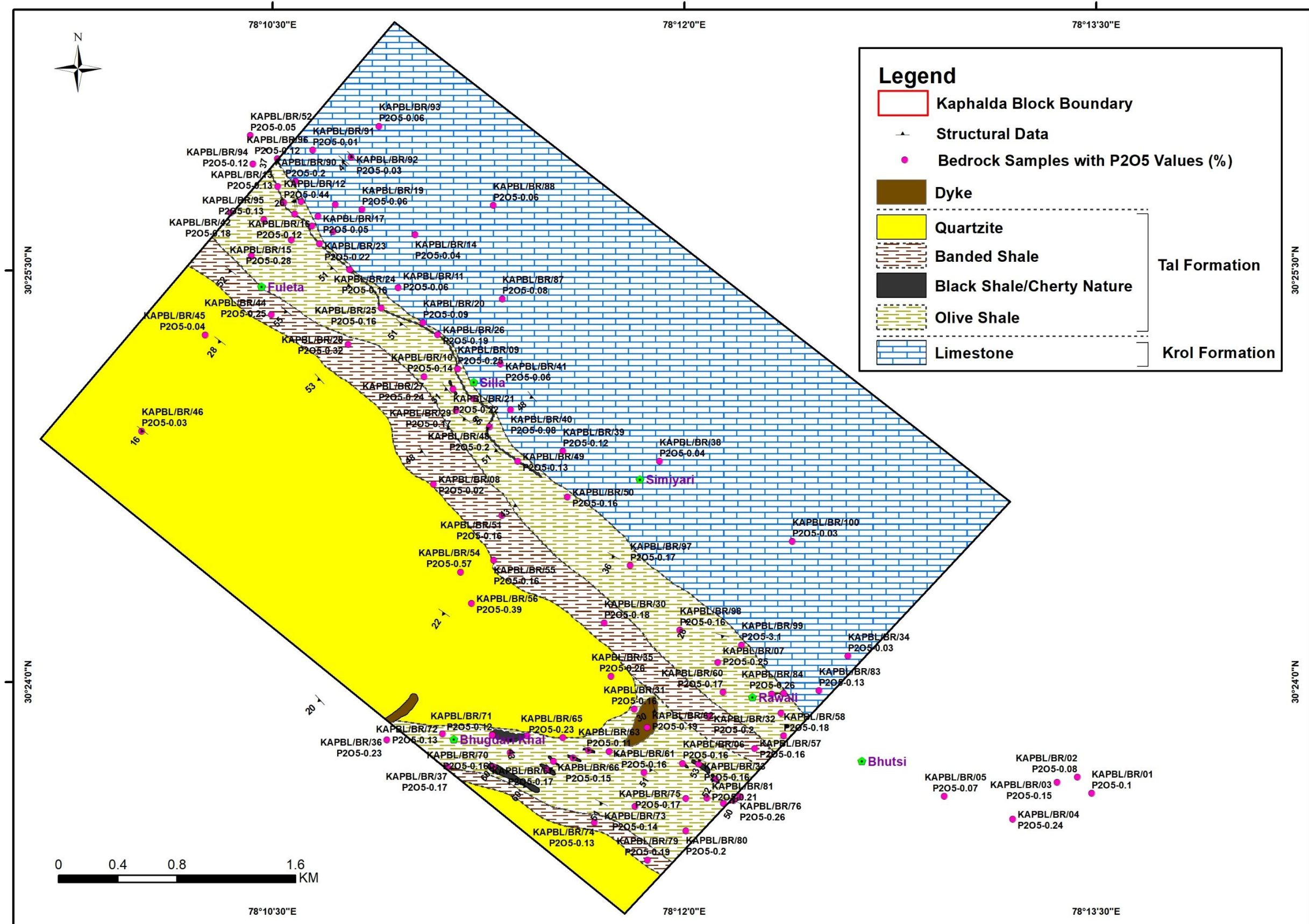
Text figure 7.3: Geological Map of Kaphalda Block, Distt. -Dehradun, Uttarakhand.

SAMPLE LOCATION ON GEOLOGICAL MAP OF KAPHALDA BLOCK, DIST: DEHRADUN & TEHRI GARHWAL, UTTARAKHAND



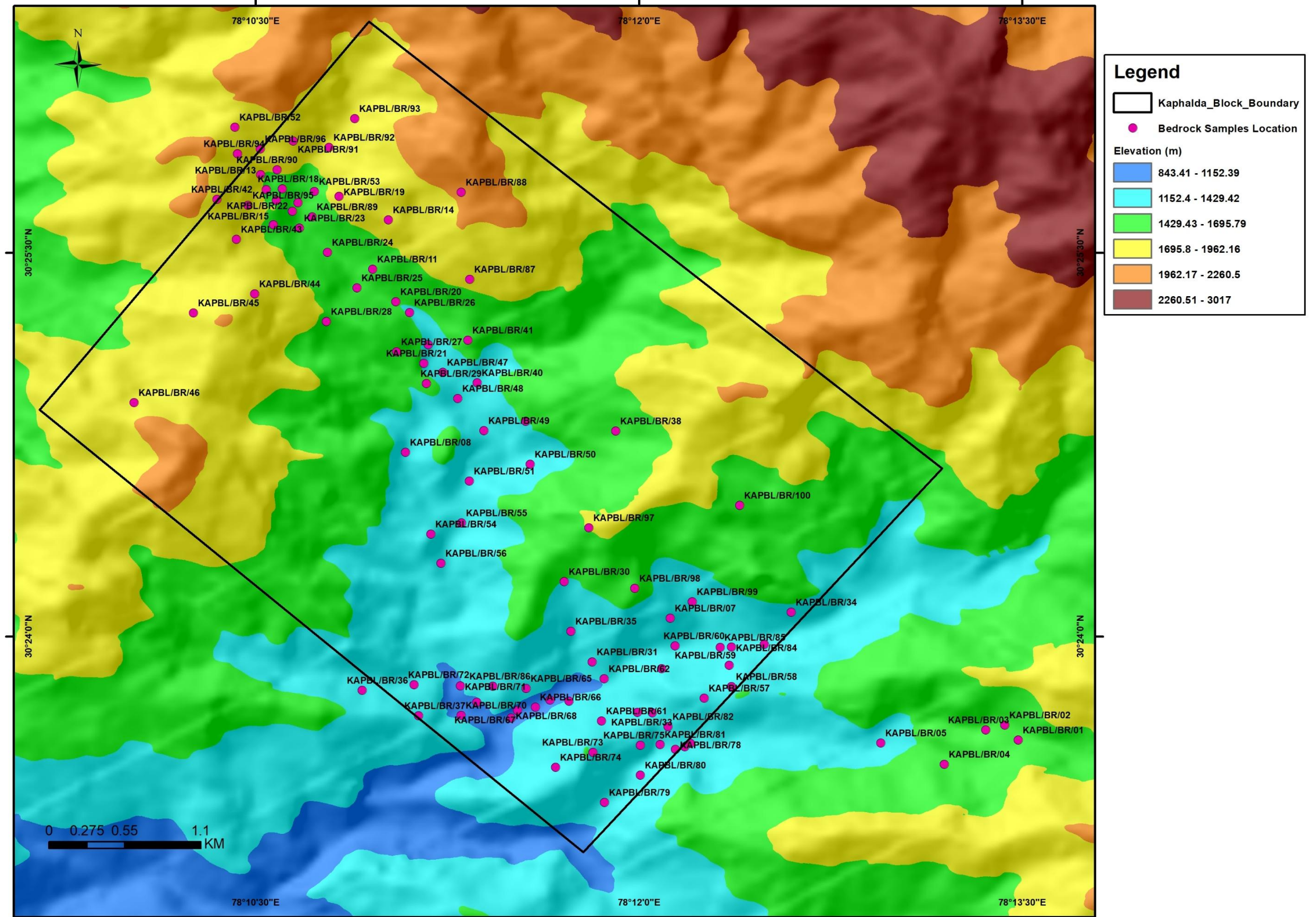
Text Figure 7.4: Sample locations Map of Kaphalda Block, Distt. -Dehradun& Tehri Garhwal, Uttarakhand

P₂O₅% VALUES ON GEOLOGICAL MAP OF KAPHALDA BLOCK, DIST: DEHRADUN & TEHRI GARHWAL, UTTARAKHAND



Text figure 7.5: P₂O₅ Values on Geological Map of Kaphalda Block, Dist: Dehradun & Tehri Garhwal, Uttarakhand

DIGITAL ELEVATION MAP (DEM) WITH SAMPLE LOCATIONS OF KAPHALDA BLOCK, DISTT. -DEHRADUN & TEHRI GARHWAL



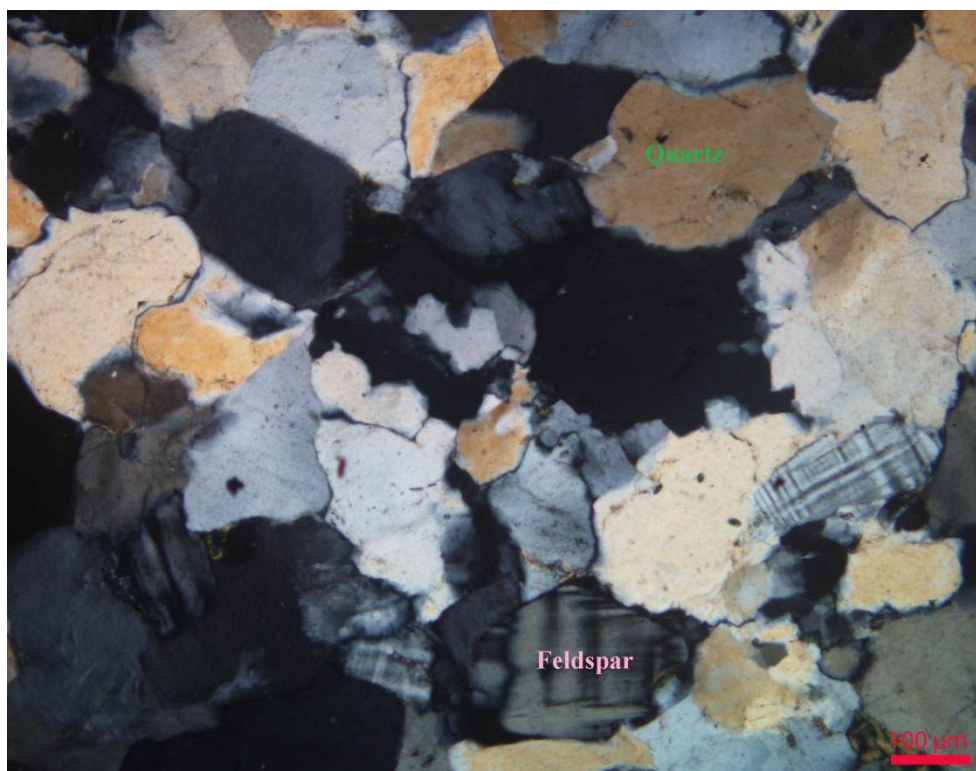
Text figure 7.6: Digital Elevation Map (DEM) with Sample locations of Kaphalda Block, Distt. -Dehradun & Tehri Garhwal, Uttarakhand

7.6.0 PETROGRAPHIC STUDIES

- 7.6.1 Petrographic studies of 08 bedrock samples (KPBL/P/1 to KPBL/P/8) were carried out. The rock types identified are arkose, quartz-wacke/impure limestone, carbonaceous slate, micritic limestone intruded by quartz veins, slate, carbonaceous-matter-rich limestone/dolostone and carbonaceous shale. The mineral-wise description is given below (Pmg-1 to Pmg-4)
- 7.6.2 **Quartz** is the dominant mineral in most samples, present as very fine silt- to sand-sized clasts, generally sub-angular to sub-rounded, showing crude alignment along the foliation and, in the arkose, well sorting and tight packing.
- 7.6.3 **Feldspar** occurs as fine to medium clasts, commonly altering to very fine clay minerals and sericite, particularly the plagioclase.
- 7.6.4 **Calcite** and **Dolomite** are important components of the calcareous samples, occurring as very fine micro-crystalline micrite, sparry patches, lensoidal aggregates, rhombic dolomite aggregates, and as thin veins and veinlets.
- 7.6.5 **Sericite/Muscovite** and **Biotite** occur as very fine disseminated flakes showing parallel alignment and crenulation, often interleaved with each other, and Chlorite is present as very fine flakes and patches in accessories.
- 7.6.6 **Carbonaceous** matter is present in the darker samples as very fine amorphous aggregates aligned along the foliation and segregated in thin sub-parallel laminations, imparting the slaty character. Ferruginous matter occurs as reddish patches and patchy fillings.
- 7.6.7 **Opaques** (dominantly iron oxides and sulphides) occur as very fine to fine subhedral to anhedral grains, segregated pockets, streaks and fillings. Tourmaline and Zircon are noted as very fine prismatic grains in the accessories, and Gypsum occurs as very fine long prismatic to flaky grains.

7.7.0 MINERAGRAPHIC STUDIES

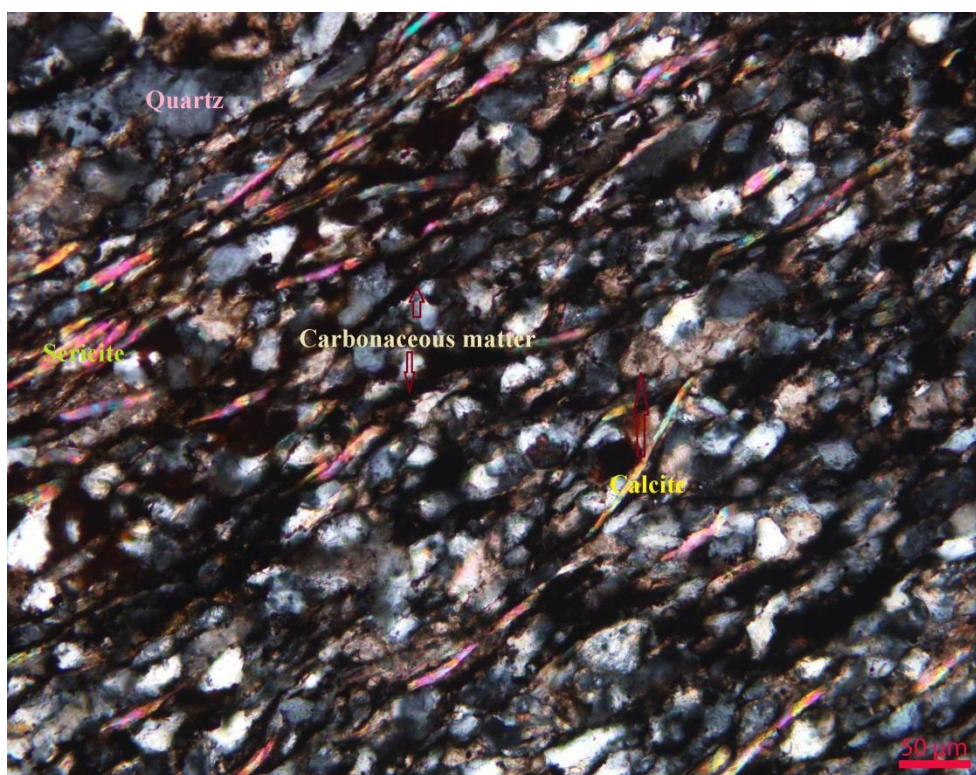
- 7.7.1 Mineragraphic studies of 10 polished sections (KPBL/M/01 to KPBL/M/10) were carried out. The ore minerals make up about 1 to 5 % of the sections and are dominated by pyrite and magnetite, with subordinate goethite-hematite, graphitoid and traces of chalcopyrite. The mineral-wise description is given below (Pmg-5 to Pmg-8).



Pmg – 1: Photomicrograph showing association of fine to medium sand sized subangular to subrounded, well sorted and tightly packed clasts of quartz and feldspar in arkose as seen under crossed nicols.

Specimen No.: KPBL/P/1

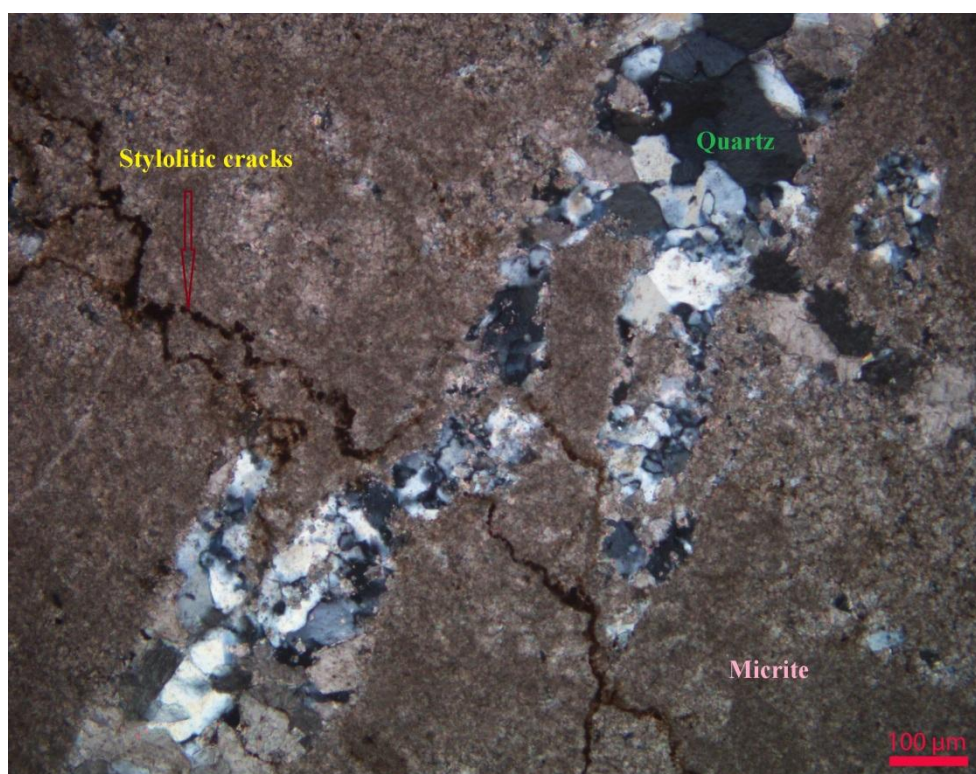
Magnification: 100X



Pmg-2: Photomicrograph depicts association of quartz, calcite, carbonaceous matter and sericite, where carbonaceous matter and sericite are showing parallel alignment in carbonaceous slate as seen under crossed nicols.

Specimen No.: KPBL/P/3

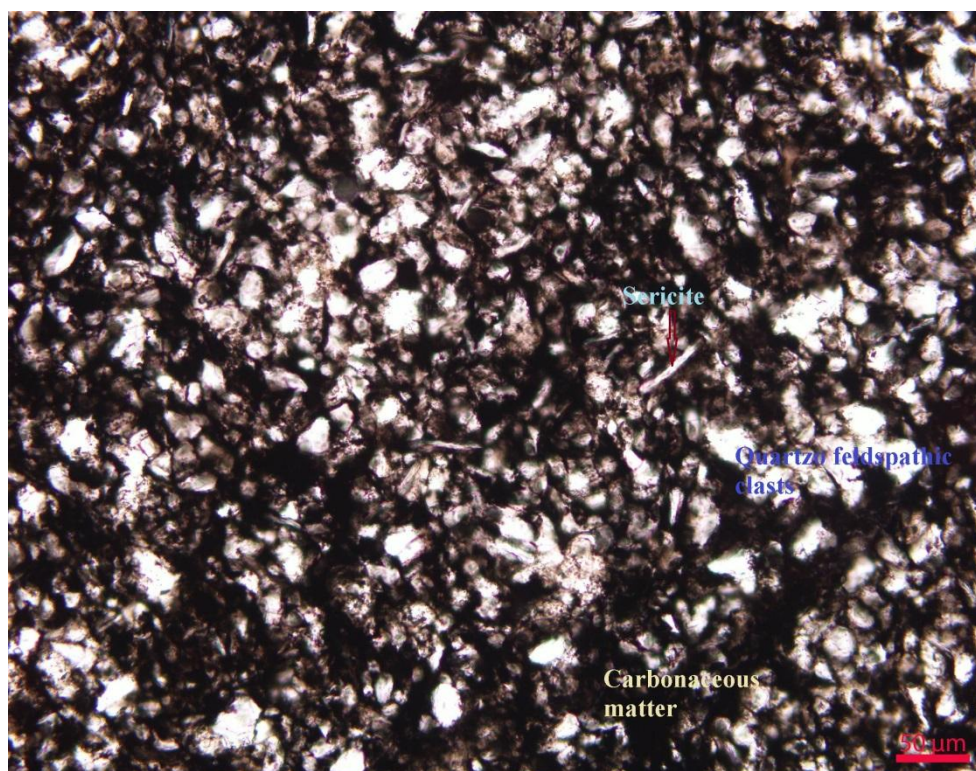
Magnification: 200X



Pmg-3: Photomicrograph showing stylolitic cracks and quartz vein intrusions within micritic limestone as seen under crossed nicols.

Specimen No.: KPBL/P/4

Magnification: 100X

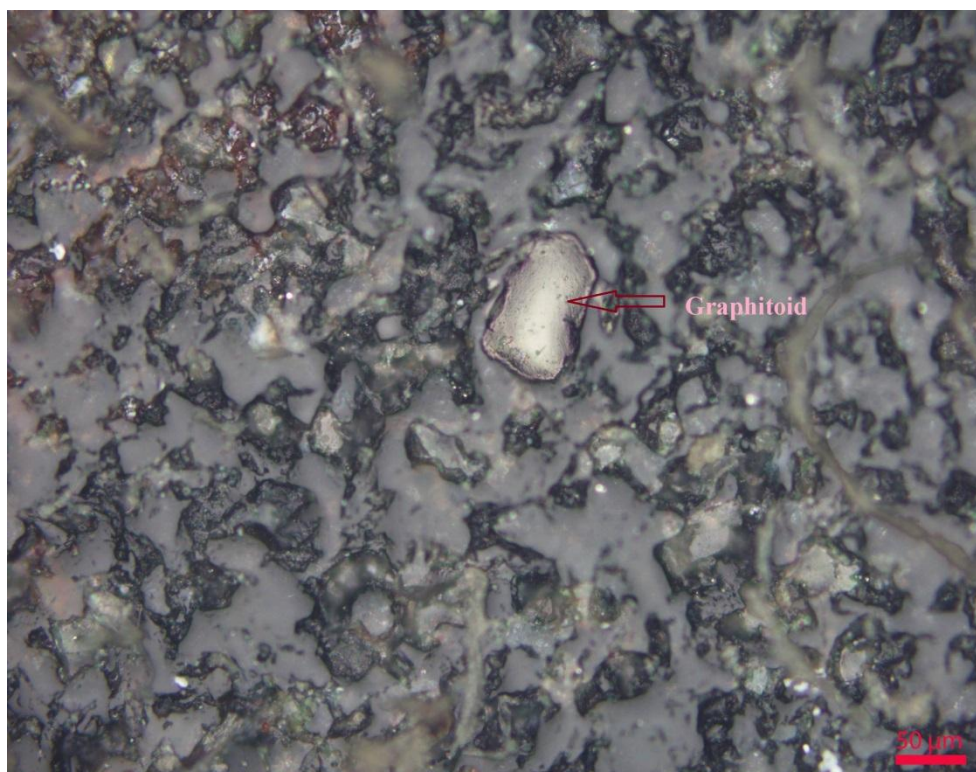


Pmg – 4: Photomicrograph depicts association of quartzo-feldspathic clasts, carbonaceous matter and sericite in carbonaceous shale as seen under plane polarized light.

Specimen No.: KPBL/P/8

Magnification: 200X

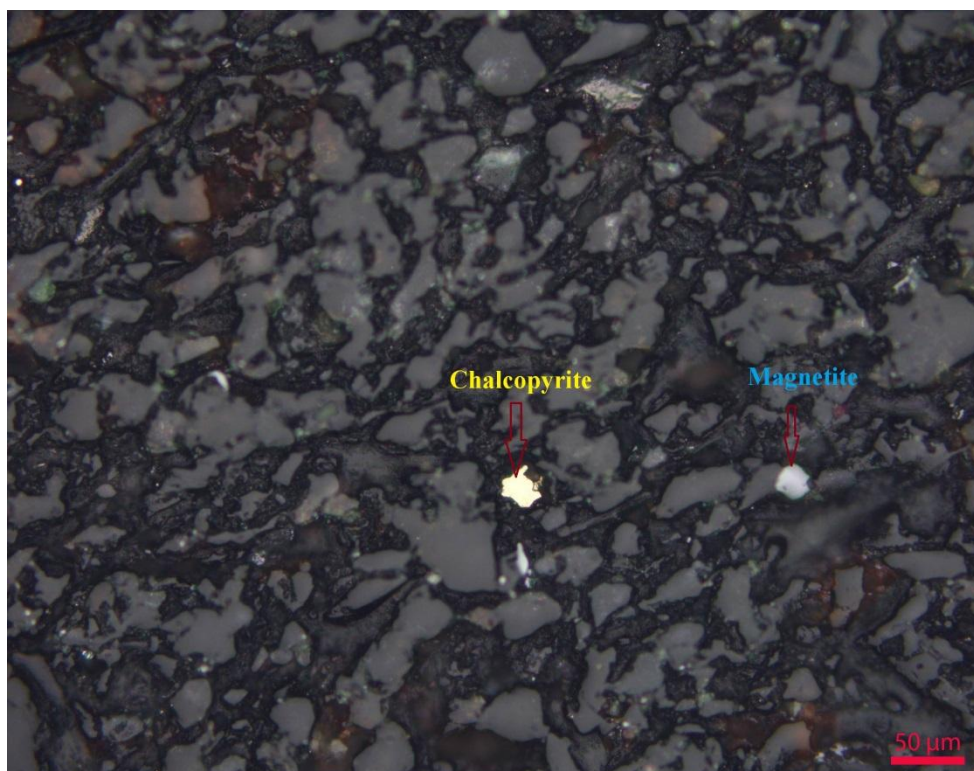
- 7.7.2 **Pyrite** occurs as very fine to fine anhedral grains, specks, segregated patches and, at places, as intrusive veins/veinlets disseminated throughout the sections. It is a major ore mineral, ranging up to about 85% of the opaque assemblage in the carbonaceous, pyritic shale samples.
- 7.7.3 **Magnetite** occurs as very fine to fine subhedral to anhedral, bladed and skeletal grains in dissemination and is the dominant ore mineral in several sections (up to 100 %), reflecting the ferruginous nature of parts of the sequence.
- 7.7.4 **Goethite** and **Hematite** together occur as intermixed patchy and hairline fillings that show compositional zoning in areas, representing the secondary oxidation products of the primary iron minerals.
- 7.7.5 **Graphitoid** is noted as fine to very fine anhedral and streaky patches in pockets, consistent with the carbonaceous character of the host shale. Chalcopyrite is present only as very fine specks in traces and is locally replaced by goethite along fractures.



Pmg – 5: Photomicrograph showing fine graphitoid patch as seen under reflected light.

Specimen No.: KPBL/M/02

Magnification: 200X



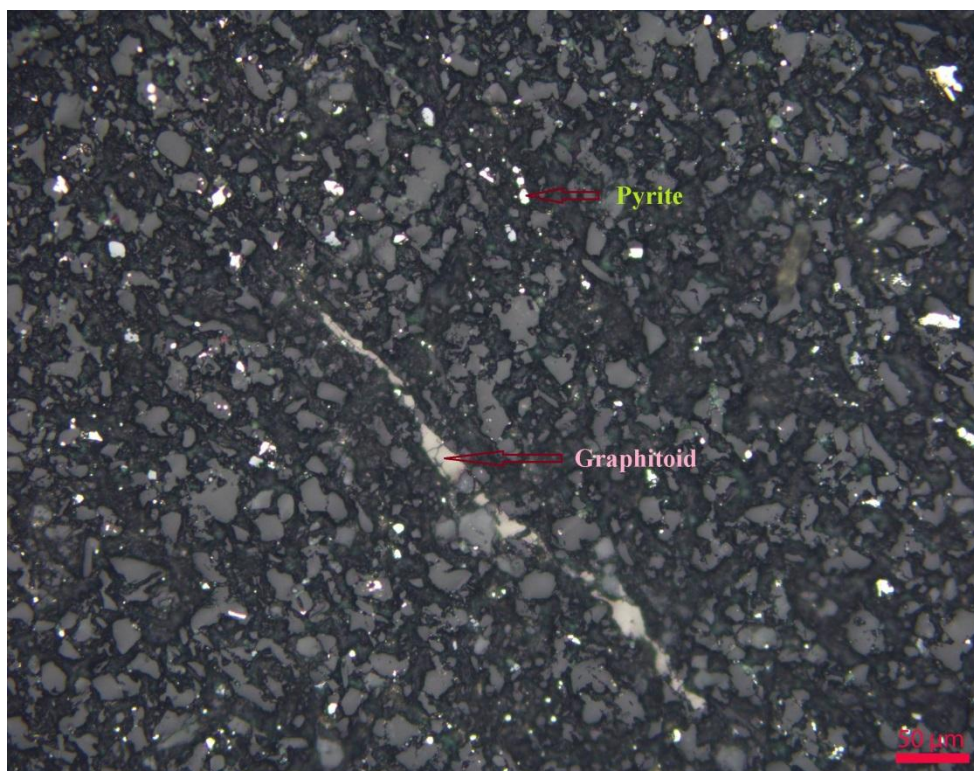
Pmg – 6: Photomicrograph depicts very fine grains of chalcopyrite and magnetite as seen under reflected light.
Specimen No.: KPBL/M/07 **Magnification:** 200X



Pmg – 7: Photomicrograph showing fine to very fine subhedral to anhedral dissemination of pyrite as seen under reflected light.

Specimen No.: KPBL/M/08

Magnification: 200X



Pmg – 8: Photomicrograph depicts very fine dissemination of pyrite and streaky fillings of graphitoid as seen under reflected light.

Specimen No.: KPBL/M/09

Magnification: 200X

7.8.0 STRUCTURES

- 7.8.1 The Kaphalda Block, located on the eastern limb of the Mussoorie Syncline, preserves the effects of both ductile and later brittle deformation associated with the Himalayan orogeny. The bedding and the phosphatic Black Shale/Cherty Shale and olive shale bands trend broadly NW–SE, parallel to the regional strike of the Lesser Himalayan sequence. Folding is prominent in the competent quartzite units, which are locally intensely folded and faulted. Fault-propagation folds and associated fracturing are developed at places, providing secondary permeability.
- 7.8.2 The Mussoorie Syncline is a large, asymmetric and doubly plunging fold in the Outer Lesser Himalaya, bounded to the south by the Main Boundary Thrust (MBT), which separates it from the Siwaliks, and to the north by the Main Central Thrust zone (Valdiya, 1980). Its phosphorite is stratabound, tied to the basal chert and black-shale member of the Lower Tal Formation at and immediately above the Krol–Tal formation contact (Banerjee et al., 1997; Mazumdar et al., 1999, Text Figure 7.1). The first-order control on the position of the phosphate horizon is therefore the fold geometry itself, that is, its place on a given limb and the plunge of the fold axis. The Kaphalda Block

occupies the eastern part of the eastern limb of the syncline, where the axis plunges east-southeast, so the phosphatic horizon is expected to descend progressively below cover towards the east and to lie at shallow depth beneath the mapped Black Shale/Cherty Shale bands.

7.8.3 Recent structural work in the Garhwal Lesser Himalaya, including the Dhanaulti and Sategal sectors immediately adjoining the Block, has documented two generations of exposure-scale brittle structures superimposed on the folds: hinterland-verging back-shears (Bose and Mukherjee, 2019) and conjugate arc-parallel shears (Biswas et al., 2022). Paleostress analysis of these fabrics records an early phase of arc-parallel extension, with stretching along about 131° – 311° (broadly NW–SE), followed by arc-parallel compression along about 133.5° – 313.5° . This NW–SE structural grain is the very trend along which the phosphatic Black Shale/Cherty Shale and olive shale bands of the Kaphalda Block have been mapped (Photograph 7.5), which confirms that the mineralised bands follow the regional fold-and-shear architecture rather than cutting across it.

7.8.4 For exploration, this structural control has three practical consequences. First, the bands should be laterally persistent along the NW–SE strike but deepen down the east-southeast plunge, so scout boreholes are to intersect the down-dip, likely continuation of the inclined horizon rather than drilled vertically. Second, the same brittle shears and transverse faults that cut the belt can offset, tectonically thin or structurally repeat the thin phosphate horizon; the rapid along-strike changes in thickness and the discontinuity long reported from the south-eastern Mussoorie Syncline are attributable

to this faulting, superimposed on the original sedimentary pinch-and-swell (Bose and Mukherjee, 2019; Biswas et al., 2022). In steeply dipping trench and borehole sections, true thickness must accordingly be distinguished from apparent thickness, and genuine stratigraphic thickening from fault repetition. Third, fracture and shear zones provide secondary permeability that can locally remobilise and leached phosphate during weathering; the better trench grades obtained in the T3 and T4 sector (P_2O_5 up to 6.60 %), (Photographs 12.1 & 12.3) may in part reflect such structurally focused enrichment.

7.8.5 It is therefore recommended that a detailed structural map of the Kaphalda Block, showing bedding attitude, the fold-axis trace and its plunge, and the principal shear and fault sets, be prepared to guide the sub-surface programme. The most favourable

drill targets are the dilational intersections of the NW–SE bedding-parallel shears with the transverse (about NE–SW) fault sets, particularly in the T3–T4 sector where the phosphatic horizon has already been intersected in trenches. Further, it can be integrated with the geochemistry for a better confidence in locating the concealed, higher-grade phosphate horizon at depth.



Photograph 7.5: Asymmetric (inclined) anticline developed in thinly-bedded, platy grey limestone/dolomite. The competent carbonate beds arch over a broad, rounded hinge zone with a gently-dipping left limb and a steeper right limb, implying an inclined axial plane; the limbs preserve numerous minor parasitic folds and flexures produced by flexural-slip folding of the thin laminae. The beds are further dissected by prominent bedding-plane partings, joints and cross-cutting fractures with small offsets (minor faults), recording brittle deformation superimposed on the earlier ductile folding (hammer for scale).

7.9.0 MINERALISATION

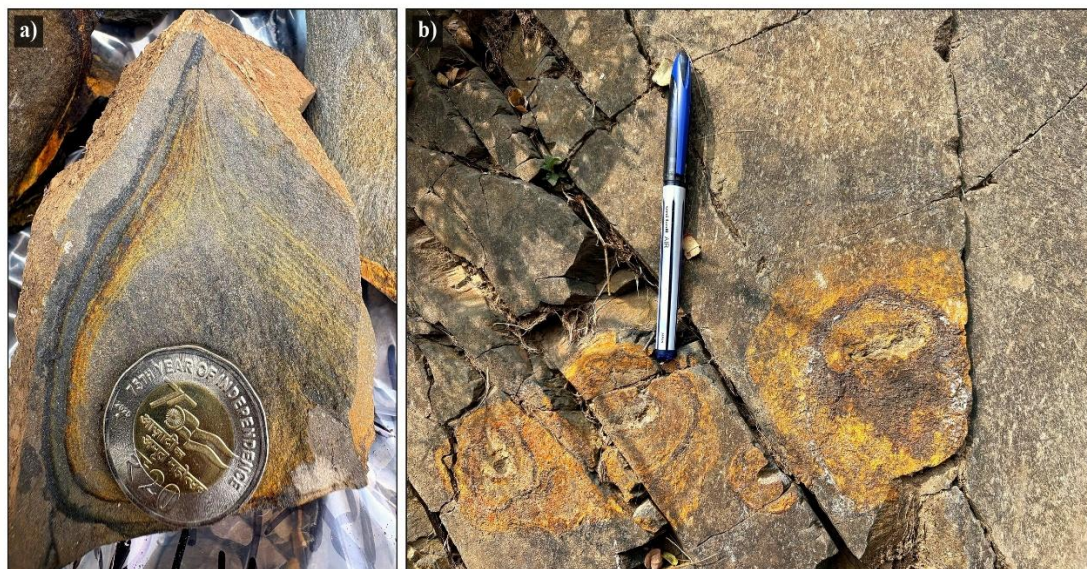
7.9.1 The Black Shale and Cherty Phosphatic Shale bands of the Lower Tal (Argillaceous/Chert Member) are the primary litho-units that host phosphate in the Block, consistent with the regional phosphorite model of the Mussoorie Syncline. Pyrite, magnetite, limonite and goethite are the associated ore minerals, and the nodules in the shale and cherty bands are enriched in these phases.

7.9.2 At the surface, P_2O_5 concentration is low: of the 100 surface bedrock samples, about 80% were below 0.25 %, and only sample BR/99 found 3.10% (a ferruginous

phosphorite). This reflects the strongly weathered and diluted nature of the surface exposure, as also indicated by the regional map prepared by PPCL, which shows few prominent surface phosphatic exposures in this part of the syncline.

- 7.9.3 Trenching across the mapped Black Shale/Cherty Shale bands, however, intersected the phosphatic horizon at shallow sub-surface levels, out of the 37 trench channel samples (trenches T1 to T5), the horizon is best developed in trenches T3 and T4, which were reported up to 6.60% P_2O_5 (T4/02) and 6.06% (T3/09), with several intervals between 1% and 3.7%. The enriched intervals are calcareous, consistent with a carbonate-fluorapatite (collophane/francolite) phosphorite. This confirms that a phosphatic horizon is present within the Block, concealed beneath the weathered surface and localised in the T3–T4 sector.
- 7.9.4 The occurrence of high-grade phosphate within the Mussoorie Syncline is a well-established by eminent scholars, and the favourable Krol–Tal stratigraphy is present in the Block (Text Figure 8.1). As the trench grades are expected to improve down-dip below the zone of weathering and carbonate leaching, a few scout boreholes are planned at the more favourable locations, particularly in the T3–T4 sector, to confirm the thickness, grade and continuity of the concealed phosphatic horizon at depth (Photograph 7.6).
- 7.9.5 The phosphatic horizon locally displays well-developed Liesegang banding. Near Silla Village, blocks of the phosphate rock show concentric, rhythmic colour bands in which iron-oxide-rich (yellow-brown) laminae alternate with grey phosphatic/host laminae, forming nested rings that follow the outline of the slab (Photograph 7.6a). These bands represent rhythmic, diffusion-controlled precipitation fronts that developed as iron- and phosphate-bearing pore fluids migrated through the porous rock and precipitated periodically during diagenesis and subsequent weathering. A comparable expression occurs in the interbedded black shale, where bedding surfaces carry orange-brown concentric ring nodules, each built of iron-oxide rings concentrated around a central nucleus and grading outward into the grey shale (Photograph 7.6b). These nodules record secondary remobilisation and rhythmic re-concentration of iron-oxide—following oxidation of pyrite and other Fe-bearing phases—together with phosphate around nucleation centres. Both features are hosted by the phosphatic horizon of Lower Tal chert–black shale and reflect supergene to epigenetic redistribution of phosphate by oxidising, phosphate-bearing fluids moving along porosity, fractures and bedding planes. Such ring structures, and the associated

pervasive iron-oxide staining, serve as useful field pathfinders that mark zones of local phosphate re-concentration within the weathered phosphorite.



Photograph 7.6: a). Liesegang concentric rings of phosphate in the outcrop near Silla Village (Rs. 20 coin for scale). b). Concentric iron-oxide and phosphate rings developed within nodules in the Black Shale (pen for scale).

CHAPTER-8

PREVIOUS WORK

8.1.0 DETAILS OF PREVIOUS EXPLORATION CARRIED OUT BY OTHER AGENCIES

- 8.1.1 Geological interest in the Tal rocks of the Mussoorie area is nearly two centuries old. Fisher (1832) first distinguished the Tal rocks of Landour from the Krol limestone of Mussoorie, and Medlicott (1864) formally named the rocks of Tal formation in the Tal Valley east of the Ganga. Subsequent mapping by Middlemiss (1887) and, more comprehensively, by Auden (1934) established the four-fold basinal distribution of the Tal formation and the structure of the Krol Belt. Phosphatic rock at Midlands, Mussoorie, was first reported by King (1885), building on the earlier discovery of phosphatic nodules in the shales by Rev. J. Parson. Auden's (1934) mapping of the Krol Belt across Himachal Pradesh and Uttarakhand remains the framework within which all later phosphate exploration has been carried out.
- 8.1.2 Systematic phosphate work began with H.N. Singh (1960–61), who mapped the Mussoorie area, subdivided the Tal formation into Lower, Middle and Upper units, and recognised phosphatic rock within the black shale and cherts of the Lower Tal. Encouraging results from the Lower Tal–Krol contact in the adjoining Sirmur district (Dass, 1961), followed by the work of R.N. Srivastava and K.N. Ali, established the Lower Tal black shale–chert association above the Krol limestone as the principal phosphorite horizon. This, together with the wider impetus given to the search for inland phosphate after 1966, led to an intensified exploration programme across the whole Mussoorie Syncline. The genesis and age of this phosphorite have since been documented in detail by Banerjee et al. (1997) and Mazumdar et al. (1999).
- 8.1.3 The Geological Survey of India explored the area between 1966 and 1971 in three stages: (i) reconnaissance and structural mapping on a 1:31,680 scale to map the potential phosphatic horizons; (ii) detailed large-scale mapping of the potential areas with pitting, trenching, sampling and analysis to assess the grade and reserves; and (iii) sub-surface exploration by drilling and exploratory mining in the Nagani, Kimoi, Masrana, Maldeota, Durmala, Paritibba–Chamasari and Bhusti–Jalikhil deposits. Drilling was intensified in Maldeota (West), Durmala and Bhusti on the basis of analytical data, and pits, short inclines and adits were driven in the Masrana,

Chamasari and Maldeota areas to ascertain the depth of weathering and the down-dip variation in grade.

8.1.4 From these investigations it was found that rock phosphate and phosphorite (phosphate rock with more than 15 % P_2O_5) occur in almost all the Blocks of the Mussoorie Syncline, though the bands vary in thickness, lateral extent and grade. The comparatively persistent and better-grade phosphate occurs in bands more than one metre thick, considered the minimum minable thickness, and the bands generally improve towards the southeast in thickness, grade and strike continuity. From about 0.45–4.58 m and ~10 % P_2O_5 at Toneta on the northwest, the grade improves in the Kimoi–Masrana–Durmala and Bhusti–Jalikhali–Mathiangaon Blocks on the northern limb and in the Paritibba, Chamasari and Maldeota Blocks on the southern limb. In the southeastern part of the syncline the bands are generally of lesser extent and show rapid changes in thickness and discontinuity along strike, owing to sedimentary overlap, tectonic elimination and pinching and swelling. The phosphate is predominantly present in the Chert Member of the Lower Tal Formation, but phosphatisation is seen in the upper horizons of the underlying Krol Formation, as in the Nagani and Chaunpa–Kumali Blocks.

8.1.5 The area-wise strike length, thickness, range and weighted-average P_2O_5 content of the phosphate bands established during this regional exploration are summarised in Table 8.1.

8.2.0 RELEVANCE TO THE KAPHALDA BLOCK

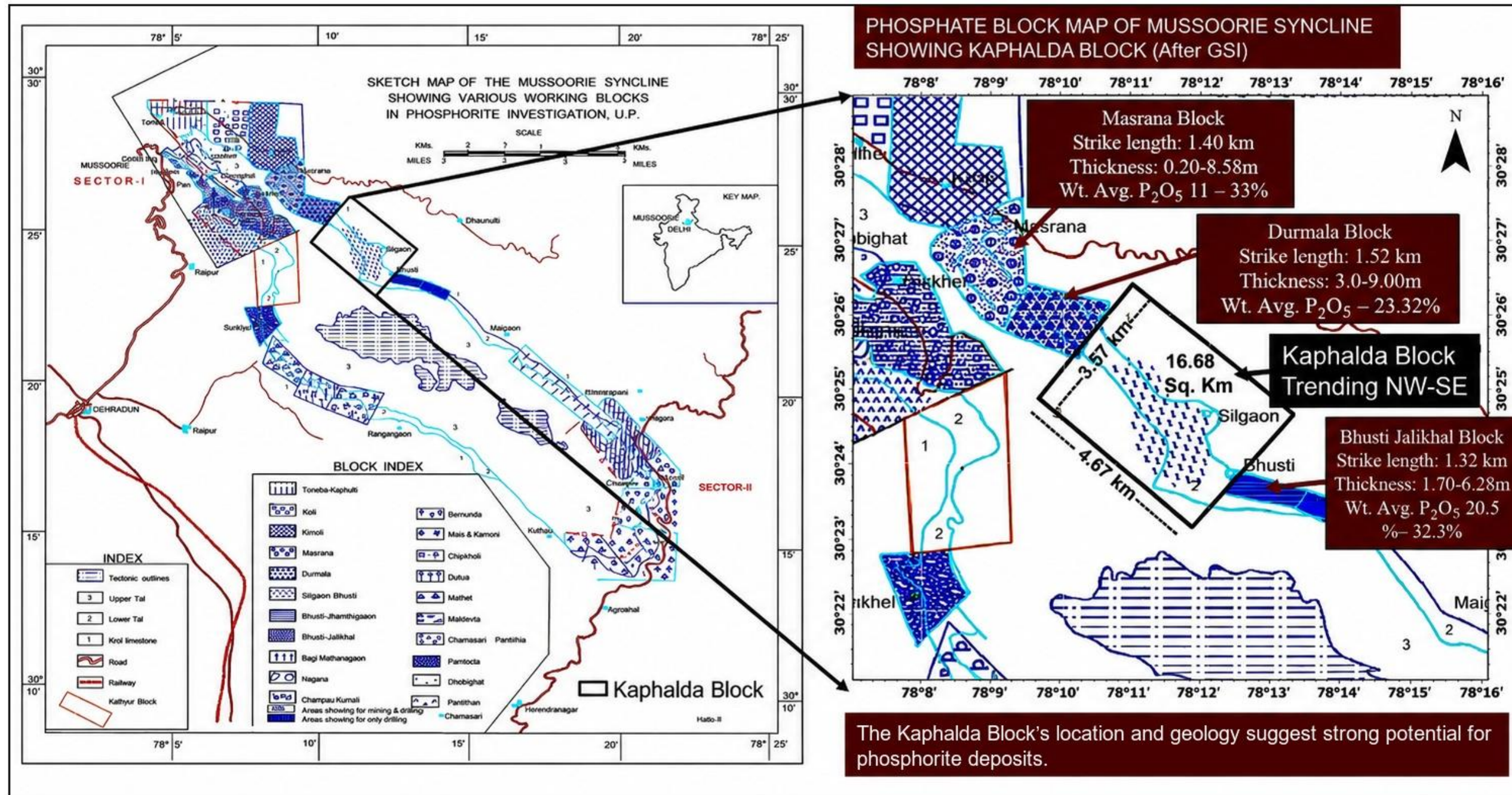
8.2.1 The Kaphalda Block lies on the eastern limb of the Mussoorie Syncline, immediately along strike from some of the best-explored and highest-grade phosphate tracts of the belt, namely the Durmala, Bhusti–Jalikhali and Chiphaldi–Dubra Blocks (Table 8.1). Regional studies place the phosphorite in the basal chert–phosphorite member of the Lower Tal Formation, conformably overlying the Krol dolostone, with the Krol–Tal contact acting as the critical marker horizon across the belt (Banerjee et al., 1997; Mazumdar et al., 1999; Kumar et al., 2026). In the Bhusti–Durmala sector the primary phosphate horizon is about 0.4 to 7.5 m thick and dips 35–65° S, thinning and becoming nodular towards the eastern periclinal closure of the syncline. The Kaphalda Block therefore occupies a favourable stratigraphic and structural position, and the present G-4 reconnaissance was taken up to test the strike continuity of this horizon into the Block (Text Figure 8.1).

Table-8.1: Phosphate bands of the Mussoorie Syncline (area-wise), after GSI/PPCL.

Sl. No.	Block	Strike length	Thickness	Range / weighted-avg P ₂ O ₅ %
1	Tonesa-Kaphulta	2 km	0.60 m	15 %
2	Kolu	3.2 km	0.37–1.04 m	10–12.7 %
3	Kimoi	1.0 km	0.50–4.48 m	11–29.3 %
4	Masrana	1.4 km	0.20–8.58 m	11–33 %
5	Durmala	1.52 km	3.0–9.00 m	23.32 %
6	Silgaon-Bhusti	2.8 km	0.12–0.65 m	33.7–36.9 %
7	Bhusti-Jhamtigaon	3.1 km	0.46–2.55 m	26.4–35.5 %
8	Bhusti-Jalikhali	1.32 km	1.70–6.28 m	20.5–32.3 %
9	Bagi-Mathinggaon	2.72 km	0.45–2.95 m	22.8–32.3 %
10	Nagani	1.25 km	few cm–2.45 m	13.9–19.2 %
11	Chauma-Kumali	1.2 km	0.10–2.4 m	15–34.0 %
12	Berunda	0.75 km	0.15–0.90 m	3–21 %
13	Malas	1.7 km	0.90–2.40 m	7–11 %
14	Chiphaldi	2.36 km	0.20–2.00 m	21.8–36 %
15	Dubra	2.5 km	0.13–2.04 m	17.2–31.1 %
16	Mathet	2.5 km	0.60–1.20 m	20.4–32.5 %
17	Maldeota	1.30 km	0.45–7.8 m	15–30.9 %

8.3.0 OBSERVATIONS AND RECOMMENDATIONS OF PREVIOUS WORK

8.3.1 The general picture that emerges from the earlier work is that better-grade, more persistent phosphate is confined to bands thicker than about one metre in the Chert Member of the Lower Tal, that surface trench grades are commonly enhanced by the leaching of carbonate during weathering and so may not represent the grade at depth, and that structural complications (faulting, tectonic elimination and sedimentary pinch-and-swell) strongly control the continuity of the bands. These observations directly informed the trenching and the planned scout drilling in the Kaphalda Block, where the target horizon is largely concealed beneath the mapped Black Shale/Cherty Shale bands.



Text Figure 8.1: Regional Geological Map of the Mussoorie Syncline Showing the Phosphorite blocks explored by PPCL (map prepared by the GSI), with the Kaphalda Block (16.68 Sq. Km, trending NW-SE) and the adjoining Masrana, Durmala and Bhusti-Jalikhali blocks; the enlarged inset gives the strike length, thickness and weighted-average P_2O_5 grade of east block.

CHAPTER-9

GEOCHEMICAL AND GEOPHYSICAL DATA

9.1.0 GEOCHEMICAL DATA

9.1.1 The primary samples of the Block were analysed for major oxides by XRF and for trace elements and rare earth elements by ICP-MS. The major oxides determined are P_2O_5 %, CaO %, MgO %, Na₂O %, K₂O %, MnO %, SiO₂ %, Al₂O₃ %, Fe₂O₃ % and LOI %. The trace and rare earth elements determined include Sc, Ti, V, Cr, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Ag, Cd, Sn, Sb, Cs, Ba, Hf, Ta, W, Au, Pb, Bi, Th, U and the REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu). A total of 137 samples (100 surface bedrock and 37 trench samples from trenches T1 to T5) were analysed for the 10 radicals by XRF, 11 samples were analysed for 34 elements by ICP-MS, and 20 samples were analysed for mineral phases by XRD. All analyses were carried out at the MECL Chemical Laboratory, Nagpur (ISO 9001:2015 certified).

9.1.2 Selected samples were crushed, homogenised by coning and quartering and powdered to -200 mesh; about 200 g of each sample was analysed. The geochemical data were plotted on the lithological map to understand the chemical signatures and phosphate distribution across the Block.

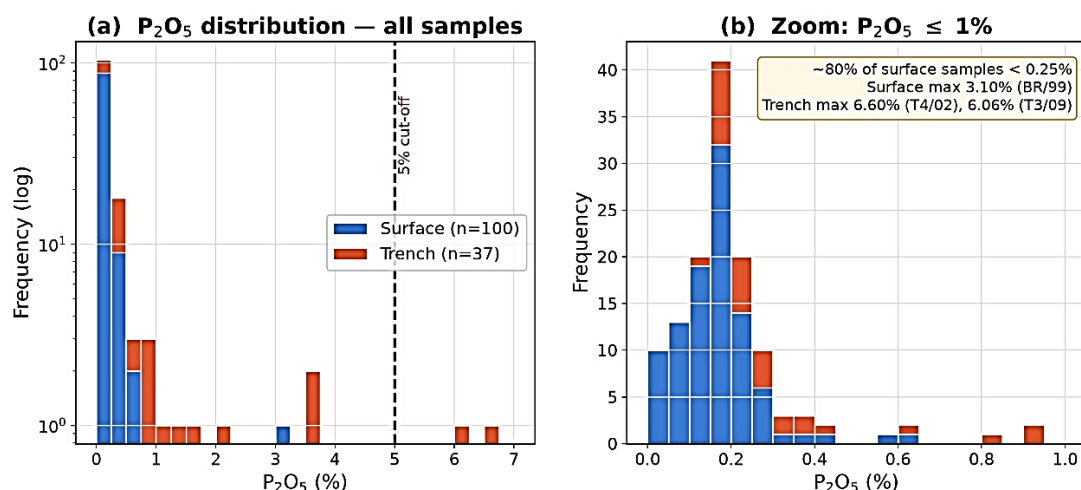
9.2.0 DISTRIBUTION OF P_2O_5 IN SURFACE BEDROCK SAMPLES

9.2.1 The P_2O_5 content of the 100 surface bedrock samples ranges from a minimum of 0.01 % to a maximum of 3.10 %. The Frequency distribution shown in Text Figure 9.1, is strongly-skewed towards left: about 80 % of the samples carry P_2O_5 below 0.25 %, roughly 16 samples fall between 0.25 % and 0.50 %, three samples lie between 0.50 % and 1.00 % (BR/54 = 0.57 %, BR/82 = 0.62 %), and only one sample, BR/99, is anomalous at 3.10 % P_2O_5 (a ferruginous siliceous phosphorite with Fe₂O₃ = 14.95 % and SiO₂ = 41.24 %). This long right tail, with the bulk of the values below 0.25 % and a single high value, indicates that the phosphatic horizon is thin, discontinuous and largely concealed at the surface, where it is further tapered by the enclosing siliceous and carbonate rocks.

9.3.0 DISTRIBUTION OF P_2O_5 IN TRENCH SAMPLES

9.3.1 Five trenches (T1 to T5) were excavated across the mapped Black Shale/Cherty Shale bands, and 37 channel samples were analysed. In contrast to the surface bedrock, the trench samples intersected the phosphatic horizon and returned distinctly higher P_2O_5 values, up to 6.60 % (T4/02) and 6.06 % (T3/09). The enrichment is concentrated in trenches T3 and T4, with P_2O_5 of 6.60 % (T4/02), 6.06 % (T3/09), 3.67 % (T3/02), 3.55 % (T3/03), 2.09 % (T3/04), 1.64 % (T4/03), 1.34 % (T3/05) and 1.15 % (T4/01), whereas trenches T1, T2 and T5 remain below about 0.4 % P_2O_5 . The higher-grade trench intervals are calcareous (CaO of 11–17 %) with moderate LOI, consistent with a carbonate-fluorapatite (collophane/francolite) phosphorite. This confirms that a phosphatic horizon is present within the Block at shallow sub-surface levels and is best developed in the T3–T4 sector, even though it is not well expressed at the weathered surface.

9.3.2 The trench samples that have $P_2O_5 \geq 1$ % are listed in Table-9.1. The values rise sharply from the surface bedrock, where about 80% of samples carry less than 0.25 % P_2O_5 , to the T3 and T4 trench channels, which reach up to 6.60 % P_2O_5 . This increase in the value is very crucial geochemical data of the area, which is suggesting the concentration of P_2O_5 % is increasing with depth.



Text Figure-9.1: Frequency Distribution of P_2O_5 in surface and trench samples.

9.4.0 MAJOR-OXIDE RELATIONSHIPS

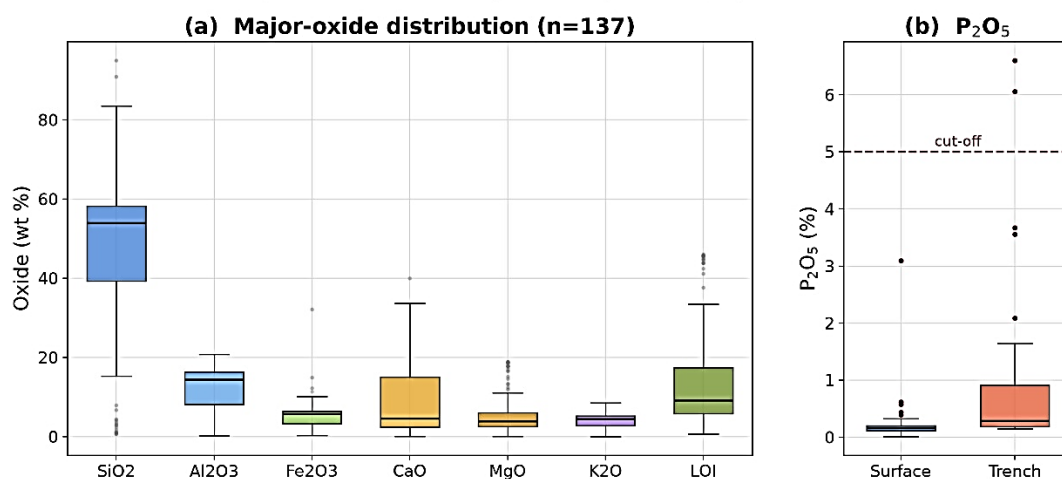
9.4.1 The data separate into two chemically distinct lithological populations. The first is a carbonate population (dolomitic limestone/dolostone), marked by high CaO (20–40 %), high MgO (10–19 %) and high LOI (>40 %), with correspondingly low SiO_2 . The

second is a siliceous population (quartzite and siliceous metasediments), marked by high SiO₂ (>50 %, rising to 95 % in the chert bands such as BR/54) and low CaO and LOI. SiO₂ therefore varies inversely with CaO, MgO and LOI, a pattern that reflects simple dilution between silica and carbonate (Text Figure 9.3). The box-and-whisker plots (Text Figure-9.2) summarise the range and spread of the ten major oxides, showing the very wide SiO₂ range, the coherent carbonate population high in CaO, MgO and LOI, and the low, tightly clustered P₂O₅ values that characterise most of the samples.

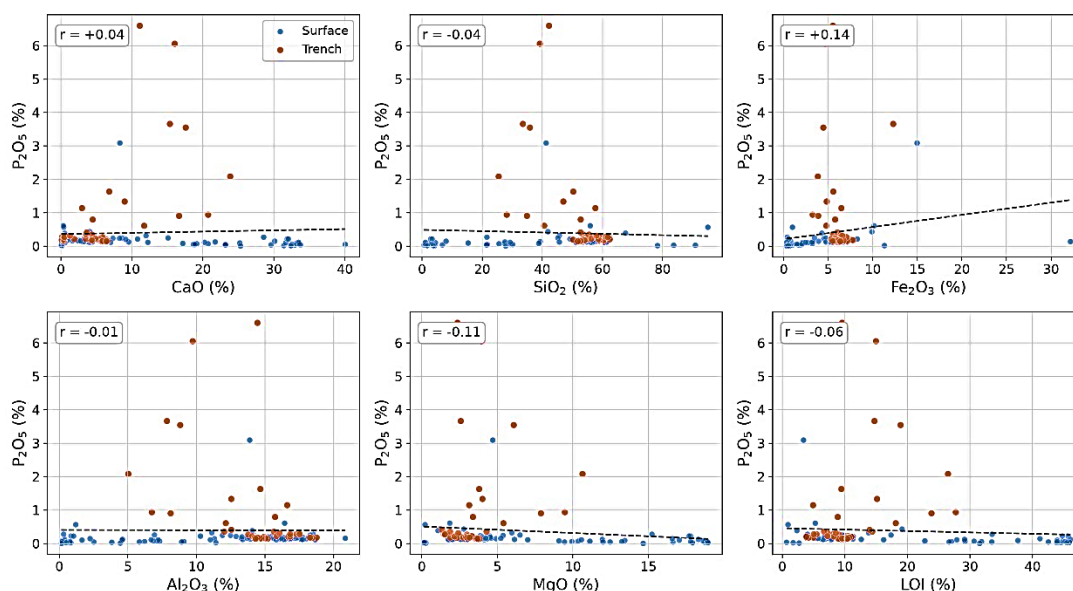
9.4.2 In the phosphatic samples, P₂O₅ correlates positively with CaO, consistent with a calcium-phosphate (apatite/collophane) host, and, in the ferruginous surface sample BR/99, with Fe₂O₃. The association of phosphate with iron in the weathered surface material suggests that hematite/goethite partly replaces collophane in the oxidised zone, whereas the fresher, calcareous trench material better preserves the primary carbonate-apatite. In the non-phosphatic samples, P₂O₅ shows only weak correlations with the other oxides (Text Figure-9.2).

Table-9.1: The trench samples (P₂O₅ ≥ 1 %).

Trench / Sample	P ₂ O ₅ %	CaO %	MgO %	SiO ₂ %	Fe ₂ O ₃ %	LOI %
T4/02 (KPL-122)	6.60	11.08	2.36	42.13	5.49	9.56
T3/09 (KPL-135)	6.06	15.99	3.94	39.11	4.62	14.92
T3/02 (KPL-117)	3.67	15.32	2.57	33.51	12.27	14.71
T3/03 (KPL-118)	3.55	17.57	6.07	35.88	4.43	18.90
T3/04 (KPL-119)	2.09	23.83	10.63	25.41	3.79	26.48
T4/03 (KPL-123)	1.64	6.80	3.80	50.20	5.55	9.45
T3/05 (KPL-133)	1.34	8.94	4.00	46.95	4.79	15.11
T4/01 (KPL-137)	1.15	2.97	3.14	57.57	6.47	4.90



Text Figure-9.2: Box-and-Whisker plots of major oxides.



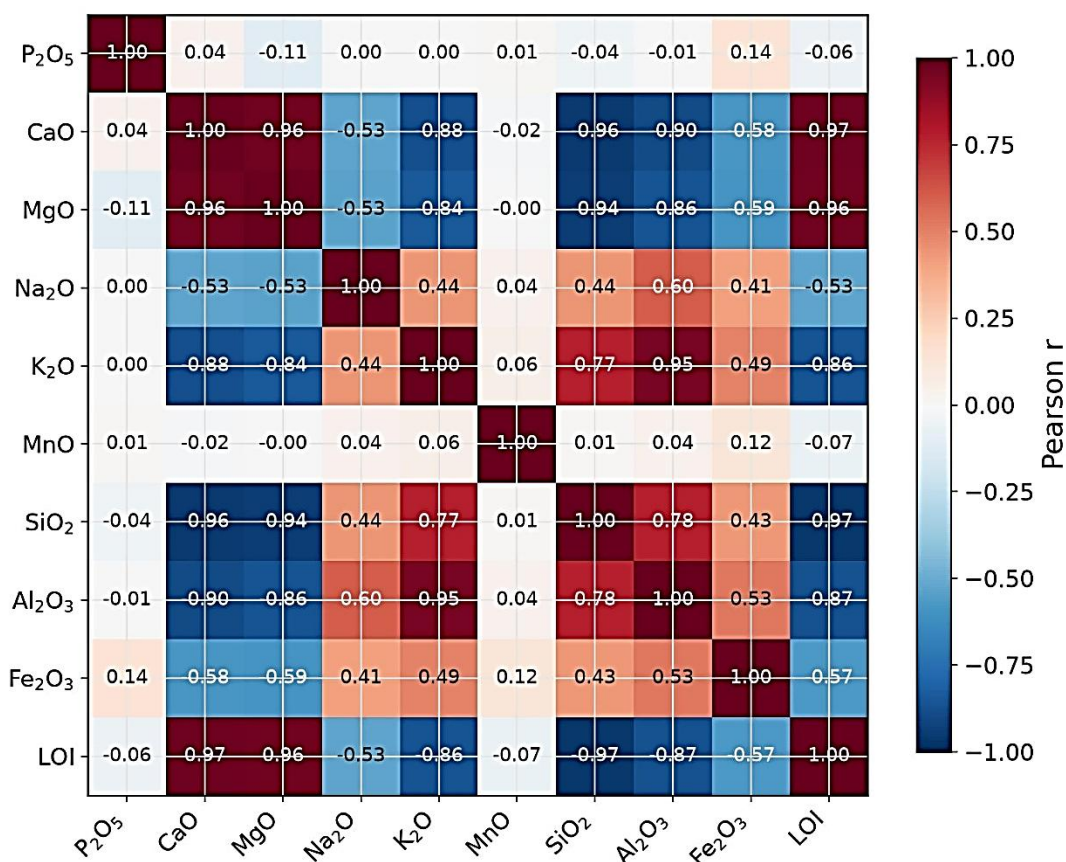
Text Figure-9.3: Bivariate plots of P_2O_5 versus major oxides.

9.4.3 The Pearson correlation analysis of major oxides ($n = 137$) shown in Text Figure-9.4, suggests a distinct geochemical dichotomy driven by mixing and dilution between carbonate and detrital siliciclastic phases.

9.4.3.1 Carbonate Phase (CaO – MgO – LOI)

- a) **Very Strong Positive Correlation** ($r = 0.96$ to 0.97): CaO, MgO, and LOI (Loss on Ignition) correlate almost perfectly with one another.

- b) Indicates the dominant presence of carbonate minerals (e.g., calcite CaCO_3 and dolomite $\text{CaMg}(\text{CO}_3)_2$). High LOI represents volatile loss (primarily CO_2) during calcination.



Text Figure-9.4: Pearson correlation of major oxides (n=137).

9.4.3.2 Siliciclastic / Detrital Phase (SiO_2 – Al_2O_3 – K_2O – Na_2O – Fe_2O_3)

- Strong Positive Correlation** ($r = 0.41$ to 0.95):
- Al_2O_3 and K_2O correlate exceptionally strongly ($r = 0.95$).
- SiO_2 correlates strongly with Al_2O_3 ($r = 0.78$) and K_2O ($r = 0.77$).
- Reflects the presence of clay minerals, feldspars, and quartz (aluminosilicate s/clastic sediment input).

9.4.3.3 Carbonate vs. Silicate Antagonism (Dilution Effect)

- Extremely Strong Negative Correlation** ($r = -0.84$ to -0.97): CaO , MgO , and LOI are intensely anti-correlated with SiO_2 , Al_2O_3 , and K_2O .
- Represents a binary mixing system where carbonate deposition dilutes detrital clastic sediments (and vice-versa). As the carbonate content increases, the siliciclastic/clay proportion decreases proportionally.

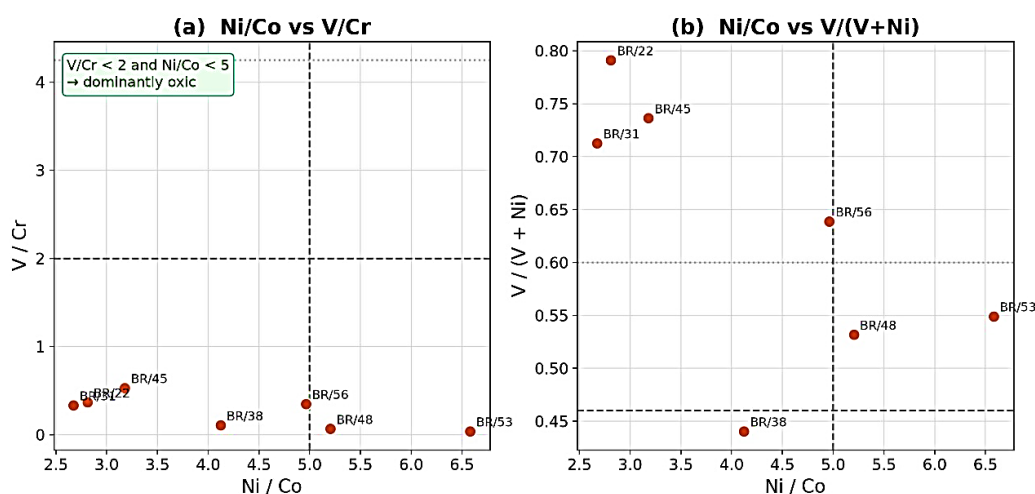
9.4.3.4 Independent / Accessory Phases (P_2O_5 and MnO)

- a) **Near-Zero Correlation** ($r \approx -0.11$ to $+0.14$): Neither oxide shows meaningful correlation with any of the major framework-forming oxides.
- b) Phosphorus and manganese are controlled by independent depositional, redox, or secondary processes (e.g., minor accessory apatite or secondary manganese coatings) rather than the primary rock-forming matrix.

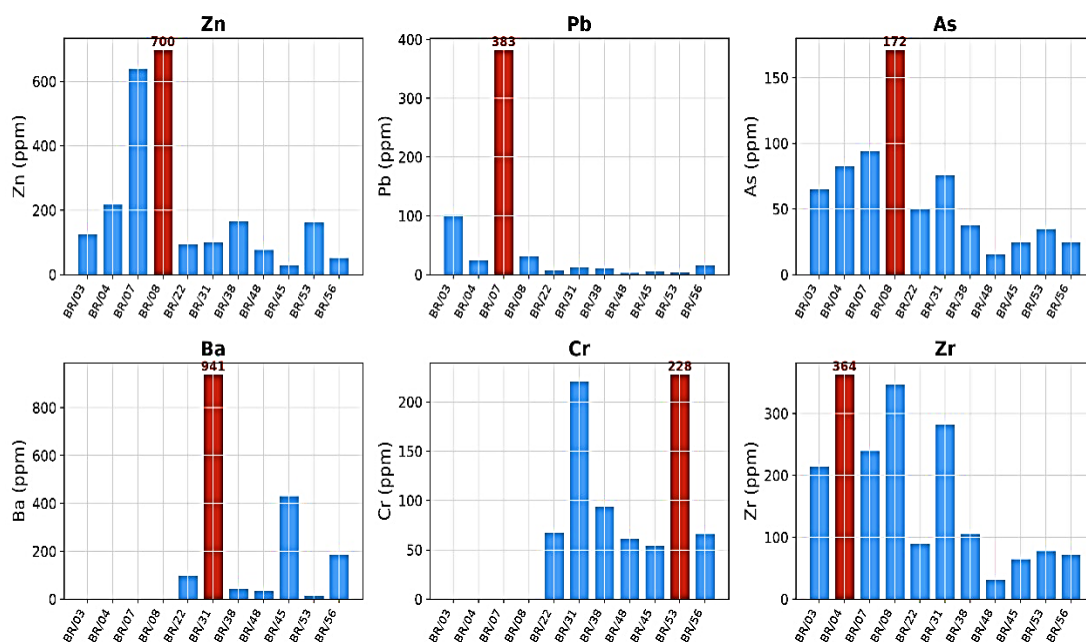
9.5.0 TRACE-ELEMENT GEOCHEMISTRY

9.5.1 Trace-element analysis of 11 samples by ICP-MS shows a modest polymetallic character in certain intervals. Few notable values are Zn 699.7 ppm (BR/08) and 641.7 ppm (BR/07), Pb 383.2 ppm (BR/07) and 103.0 ppm (BR/03), As 171.7 ppm (BR/08), Ba 940.8 ppm (BR/31) and 433.7 ppm (BR/45), Cr 228.3 ppm (BR/53) and 221.6 ppm (BR/31), and Zr 363.9 ppm (BR/04). These enrichments are hosted mainly by the carbonaceous, pyritic black shale, where sulphide and organic matter concentrate the base metals and arsenic. Gold is below the detection limit ($\text{Au} < 0.1$ ppm) in all analysed samples. The concentrations of these pathfinder elements across the eleven analysed samples are shown in (Text Figure-9.6), in which the Zn, Pb, As, Ba and Cr peaks stand out in the carbonaceous, pyritic black-shale samples.

9.5.2 Redox-sensitive trace-element ratios were used to characterise the depositional environment. In the analysed samples the Ni/Co ratio ranges from about 2.7 to 6.6 (mostly below 5) and the V/Cr ratio is consistently below 2 (0.04–0.53). Following the criteria of Jones and Manning (1994), $\text{Ni/Co} < 5$ and $\text{V/Cr} < 2$ indicate dominantly oxic bottom-water conditions with intermittent reducing episodes during deposition of the host sediments. (Text Figure-9.5).



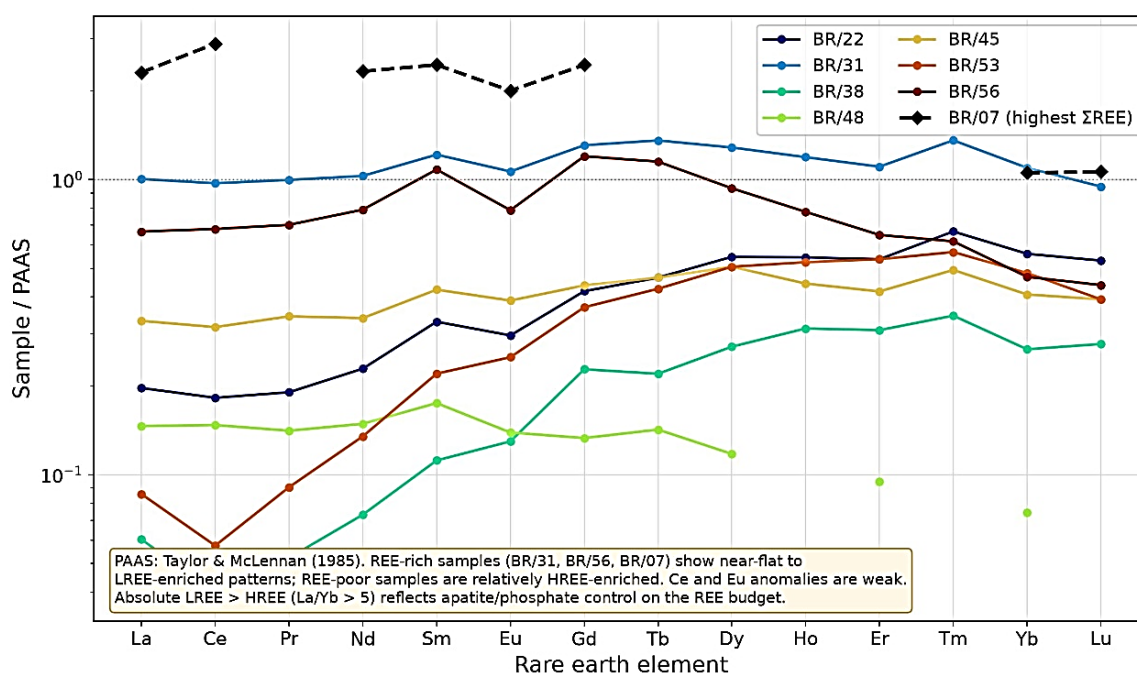
Text Figure-9.5: Palaeo-redox proxies (after Jones & Manning, 1994).



Text Figure-9.6: Pathfinder trace-element concentrations (ICP-MS, 11 samples); highest value highlighted.

9.6.0 RARE EARTH ELEMENTS

9.6.1 The total rare-earth-element (REE) content reaches about 460 ppm in BR/07 (La = 10.2.8 ppm, Ce = 254.9 ppm), while BR/31 has the highest Σ REE at about 200 ppm. Every sample is enriched in the light REE relative to the heavy REE, with La/Yb greater than 5 — a strongly fractionated pattern typical of marine phosphorites and phosphatic sediments. Because this light-REE enrichment is concentrated in the phosphatic and carbonaceous layers, the rare earths here could be worth recovering as a by-product, and this possibility should be studied in more detail. On the plot normalised to Post-Archaean Australian Shale (PAAS; Text Figure-9.7), the REE-rich samples (BR/31, BR/56 and BR/07) show near-flat to light-REE-enriched patterns, whereas the REE-poor samples are comparatively enriched in the heavy REE. The Ce and Eu anomalies are weak, which indicates that the REE content of the samples is controlled mainly by their apatite/phosphate content.



Text Figure-9.7: PAAS-Normalized REE patterns.

9.7.0 MINERAL PHASES BY X-RAY DIFFRACTION (XRD)

9.7.1 Mineral phases were determined by XRD on 20 samples (08 surface bedrock and 12 trench samples covering from T3 & T4 trenches). The rock-forming assemblage is dominated by quartz, dolomite and muscovite, with subordinate albite, orthoclase, microcline, illite, calcite, ankerite and chlorite (chamosite/clinochlore), and accessory titanite, pyrite, goethite, hematite, magnetite, kaolinite, gypsum and glauconite, consistent with the siliceous and carbonate lithologies and their carbonaceous-pyritic shale members.

9.7.2 Critically, the phosphate mineral is confirmed as apatite (fluorapatite and hydroxylapatite) and it appears as a major crystalline phase in exactly the enriched trench samples, namely T3/02, T3/03, T3/09 and T4/02, and as a minor to trace phase in T3/04, T3/05, T4/01 and T4/03. It is also present as fluorapatite in the anomalous surface sample BR/99. The presence of glauconite in the phosphatic trench samples (T3/09, T4/02) supports a marine, sediment-starved depositional setting for the phosphate horizon. The quartz-dominated bedrock samples (BR/07, BR/08, BR/31, BR/54) carry no apatite, consistent with their low P_2O_5 Table-9.2.

Table-9.2: Representative XRD mineral phases, Kaphalda Block (apatite-bearing samples highlighted).

Sample	Major ($\geq 5\%$)	Minor (1–5 %)	Trace ($\leq 1\%$)
BR/01	Dolomite, Quartz	Muscovite	Titanite, Kaolinite, Magnesite
BR/99	Fluorapatite, Quartz, feldspars (andesine, microcline, orthoclase, oligoclase)	Albite, Biotite	Hematite-Ilmenite, Anorthite
T3/02	Quartz, Muscovite, Dolomite, Hydroxylapatite	Anhydrite, Zeolite	Titanite
T3/03	Dolomite, Quartz, Muscovite, Fluorapatite	Albite	—
T3/04	Dolomite, Quartz	Fluorapatite, Muscovite, Titanite, Hydroxylapatite	Ankerite, Biotite
T3/05	Quartz, Dolomite, Muscovite	Fluorapatite	Albite
T3/09	Quartz, Dolomite, Apatite, Muscovite	Ankerite, Glauconite, Albite	Calcite, Gypsum
T4/01	Quartz, Muscovite, Chamosite	Orthoclase, Illite, Calcite	Biotite, Zeolite, Titanite, Hydroxylapatite, Ankerite
T4/02	Quartz, Muscovite, Fluorapatite	Feldspar, Glauconite	Magnesite
T4/03	Quartz, Muscovite, Dolomite	Fluorapatite, Chamosite, Calcite, Microcline, Pyrite	Biotite
BR/54 (chert)	Quartz	—	Calcite, Cuprite, Pyrite

9.8.0 SUMMARY OF ANALYTICAL RESULTS

9.8.1 The complete analytical results of the major oxides by XRF, the 34 elements and REE by ICP-MS, and the mineral phases by XRD, petrographic and mineragraphic results for all the samples collected from the Block are given in Annexure-II, to Annexure-VII.

9.9.0 GEOPHYSICAL DATA

9.9.1 Geophysical survey has not been carried out in the Block by MECL. There is no available NGPM (National Geophysical Mapping) or NGCM (National Geochemical Mapping) data of GSI for the present exploration Block.

CHAPTER-10

EXPLORATION UNDERTAKEN DURING CURRENT INVESTIGATION

10.1.0 INTRODUCTION

- 10.1.1 Rock phosphate, or phosphorite, is a sedimentary rock rich in calcium-phosphate minerals, chiefly carbonate-fluorapatite and collophane, and it is the raw material for the phosphatic-fertiliser industry. There is no substitute for phosphorus in agriculture, and about nine-tenths of rock phosphate output is used for fertilisers and animal-feed supplements, the rest going to industrial chemicals, detergents, food and pharmaceutical products, and allied uses. Rock phosphate is also a source of by-product fluorine and a secondary resource for uranium (Indian Bureau of Mines, 2024).
- 10.1.2 India is deficient in both apatite and rock phosphate. As per the National Mineral Inventory (UNFC system, as on 1.4.2020), the total resources of apatite are about 21.11 million tonnes and of rock phosphate about 311.25 million tonnes, of which only 30.87 million tonnes are in the reserves category and 280.37 million tonnes are remaining resources. About 34 % of the rock-phosphate resources lie in Jharkhand, 30 % in Rajasthan, 19 % in Madhya Pradesh and roughly 8 % each in Uttar Pradesh and Uttarakhand. Uttarakhand accounts for about 24.18 million tonnes of rock-phosphate resources, all in the remaining-resource category. Grade-wise, low-grade material dominates (about 37 %), followed by beneficiable (22 %), soil-reclamation (15 %), blendable (10 %) and chemical-fertiliser grade (9 %) (Indian Bureau of Mines, 2024).
- 10.1.3 Domestic production of phosphorite/rock phosphate was about 1.558 million tonnes in 2023–24, a fall of about 21 % from the previous year, from eight reporting mines. Rajasthan contributed nearly 85 % of the output and Madhya Pradesh the balance, the leading producers being Rajasthan State Mines & Minerals Ltd (Udaipur) and the Madhya Pradesh State Mining Corporation (Jhabua and Chhatarpur). No apatite has been produced since 2017–18 (Indian Bureau of Mines, 2024).
- 10.1.4 World production of phosphate rock has stayed broadly within the 220–255 million-tonne range over 2017–2023, reaching about 237 million tonnes in 2023. Output is dominated by China, followed by Morocco, the United States and Russia (Table 10.1). Production dipped around 2019–2020 and has since recovered, while global demand

for phosphatic fertilisers has continued to climb with population growth (Indian Bureau of Mines, 2024).

Table-10.1: World production of phosphate rock, 2017–2023 (after Indian Bureau of Mines, 2024; BGS World Mineral Production).

Country	2017	2018	2019	2020	2021	2022	2023	CAGR 20–23 (% p.a.)
World	255,000	230,000	226,000	222,000	241,000	234,000	237,000	+2.2%
China	123,132	96,326	93,324	88,000	104,107	104,745	105,309	+6.2%
Morocco	32,800	37,600	35,300	40,700	38,122	30,456	28,675	-11.0%
USA	27,900	25,700	23,300	23,500	21,600	19,800	19,600	-5.9%
Russia	13,200	13,600	13,800	13,800	14,100	14,400	14,400	+1.4%
Peru	8,450	10,308	11,092	8,594	10,776	10,955	11,920	+11.5%
Jordan	8,688	8,022	9,223	8,938	10,015	11,258	11,454	+8.6%
Saudi Arabia	5,800	6,090	6,200	8,000	8,400	8,700	9,900	+7.4%

10.1.5 The gap between India's small, declining domestic output and its large requirement is bridged almost entirely by imports, and the country is about 90% import-dependent for its phosphatic nutrients. In 2023–24 India imported about 8.81 million tonnes of rock phosphate (3.84 million tonnes ground and 4.97 million tonnes unground) valued at roughly Rs. 12,683 crores, sourced mainly from Morocco, Jordan, Togo, Algeria and Egypt (Table 10.2). On top of this, the country imports of the order of 2.5 million tonnes of phosphoric acid and about 5.67 million tonnes of di-ammonium phosphate (DAP) every year, largely from China, Oman, Saudi Arabia, Jordan, Egypt and Morocco (Indian Bureau of Mines, 2024).

Table-10.2: India's imports of rock phosphate, 2022–23 and 2023–24 (after Indian Bureau of Mines, 2024).

Item	2022–23		2023–24 (P)	
	Qty (t)	Value (₹ cr)	Qty (t)	Value (₹ cr)

Rock phosphate (ground)	3,910,889	7,162.6	3,838,444	6,025.6
Rock phosphate (unground)	5,180,702	7,974.4	4,972,510	6,657.3
Total rock phosphate	9,091,591	15,137.0	8,810,954	12,682.9

- 10.1.6 India's economy remains strongly agrarian, with agriculture supporting the livelihood of nearly half the country's workforce and underpinning national food security. Sustained growth in food-grain and horticultural production depends directly on an assured and affordable supply of phosphatic fertilisers, for which phosphorus has no substitute. The heavy and rising import bill for rock phosphate, phosphoric acid and finished phosphatic fertilisers is therefore both a food-security concern and a significant drain on the national exchequer, widening the trade deficit and exposing the farm sector to global price shocks, freight volatility and geopolitical supply risk. Reducing this import reliance by building up indigenous phosphate reserves has accordingly become a pressing national priority.
- 10.1.7 In recognition of this strategic importance, the Ministry of Mines, Government of India, included phosphorous (rock phosphate) among the 30 critical minerals identified for the country in 2023, and the subsequent National Critical Mineral Mission has prioritised their exploration and domestic development (Ministry of Mines, 2023). Against this backdrop, the conversion of India's remaining phosphate resources into reserves through fresh exploration has become the need of the hour, and central agencies such as GSI and MECL have intensified work in the country's phosphate-bearing belts. It is within this national mandate that MECL has taken up reconnaissance exploration of the phosphate-bearing Lower Tal horizon of the Mussoorie Syncline in Uttarakhand, of which the Kaphalda Block forms a part.
- 10.1.8 The Reconnaissance Survey (G-4) for Phosphate and Associated Minerals in the Kaphalda Block (area 16.68 sq. km), Districts Dehradun and Tehri-Garhwal, Uttarakhand, was recommended in the 5th meeting of the TCC-II, NMET (27th –28th January 2025) and approved in the 40th meeting of the EC, NMET (19th February 2025), and the same was intimated to MECL vide MoM letter No. F.No.23/584/2025-NMET/952 dated 5th March 2025. The estimated cost of the project is **Rs. 318.44 lakhs** and the approved duration is 12 months.
- 10.1.9 Heavy cloudbursts in July and September 2025 left the approach road un-operational for nearly five months and delayed the start of work. The project office was set up on

9th January 2026 and field work commenced on 17th January 2026. Geological mapping, surface and trench sampling along with the chemical analysis, have been achieved and completed.

10.2.0 OBJECTIVES OF INVESTIGATION

10.3.1 The exploration is proposed with the following objectives:

- Preparation of Geological map on 1:12,500 Scale.
- To prove the mineralised zones by bedrock and channel sampling from outcrops and trenches, with trenches opened at convenient intervals to expose sections of the Krol–Tal contact, cherts, phosphate rock and the overlying shales, so as to measure the thickness of the phosphatic and associated rocks and study their lateral and vertical relationships.
- To upgrade the Block to the G-3 level and facilitate the State Government in auctioning the Block.

Table – 10.2: Proposed Quantum of Work vs. Actual achievement by MECL in Kaphalda Block, District: Dehradun, Uttarakhand

Sl. No.	Item of Work	Unit	Approved	Achieved
1	Geological Mapping (1:12,500 scale)	sq. km	16.68	16.68 (100 %)
2	Sampling by XRF – 10 radicals (surface 100 + trench 40 + BH 60)	Nos	200	137 (surface 100 + trench 37) (68.5%)
3	ICP-MS – 34 elements (REE and trace)	Nos	20	11 (55%)
4	XRD	Nos	30	20 (08 bedrock + 12 trench/bedrock) (67%)
5	EPMA	Nos	15	0
6	Petrological studies	Nos	20	08 (40%)
7	Minpareraphic studies	Nos	10	10 (100 %)
8	Trenching	Cu m	100	100 (100 %)
9	Drilling	Metres	300	0

10.4.0 DETAILS OF GEOLOGICAL MAPPING

10.4.1 To achieve the objectives, the methodology adopted comprised a literature review and the preparation of a first-generation geological map from satellite and Google Earth images and topographic maps, followed by contact mapping in the field using GPS and standard geological equipment. Contact mapping was carried out in and around the Kaphalda, Silla Sera, Bhanswalgaon and adjoining villages, and a total of 16.68 sq. km was mapped on a 1:12,500 scale, identifying five mappable units of the Tal Formation and the underlying Krol carbonates (Plate III).

10.5.0 DETAILS OF SURFACE SAMPLING, TRENCHING, DRILLING, ETC.

10.5.1 A total of 100 surface bedrock samples and 37 trench channel samples (from trenches T1 to T10) were analysed for the 10 radicals by XRF, and 11 samples were analysed for 34 elements and REE by ICP-MS. In addition, samples were studied by XRD for mineral phases, 08 samples were studied for petrography and 10 for mineragraphy. A total of 100 cubic metres of trenching was completed. Drilling has not yet been undertaken; a few scout boreholes are planned at the favourable trench locations to test the phosphatic horizon at depth.

10.5.2 The trenching intersected the phosphatic horizon that is not well expressed at the surface, returning P_2O_5 up to 6.60 % (T4/02) and 6.06 % (T3/09) in trenches T3 and T4. The geological outcrop map, the sample-location map, the trench-location and trench-section maps, the DEM map and the associated analytical work are presented in the relevant Plates and Annexures, and the complete primary chemical analysis of the surface and trench samples is tabulated in (Annexure - II to VII).

CHAPTER-11

LOCATION OF DATA POINTS

11.1.0 ACCURACY AND QUALITY OF SURVEY USED TO LOCATE BLOCK BOUNDARY

11.1.1 The entire survey work has been carried out with the help of GPS (Make-BAP Precision), Model- 'S' series) and surface features i.e., roads, village boundaries, temples/mosque, ponds, river/nalas and Block boundary co-ordinates has been determined by toposheets. The photograph of GPS is given in Photo-11.1.

**Table 11.1: Co-ordinates of the cardinal points of Block Boundary of Kaphalda Block
Dist.: Dehradun, Uttarakhand**

Cardinal Points	WGS 84 (DMS)		UTM Zone-44 (m)		Elevation (m)
	Latitude	Longitude	Easting (m)	Northing (m)	
A	30.4147694°N	78.1608994°E	303249.53	3366701.88	~1,450 m
B	30.4400741°N	78.1823790°E	305598.41	3370142.96	~1,850 m
C	30.4109443°N	78.2197475°E	309065.18	3365800.12	~2,200 m
D	30.3859338°N	78.1963554°E	306578.83	3362511.49	~1,600 m

11.2.0 QUALITY AND ADEQUACY OF TOPOGRAPHIC CONTROL

11.2.1 Block boundary co-ordinates, elevation points and sample points were surveyed by GPS. The topographic surface features, and contours survey by area Toposheet. Positional (horizontal) accuracy of the GPS is ± 5 m while the elevation (vertical) accuracy is ± 10 m. The detailed geological map of Kaphalda Block was prepared on 1:12,500 scale.



Photograph 11.1: a). GPS (Make - BAP Precision), Model - 'S' series. b). Toposheet No. 53J/03 used with the advanced Navigation applications for appropriate sampling. c). Google Earth Imagery of the Kaphalda Block.

CHAPTER-12

SAMPLING TECHNIQUE

12.1.0 NATURE AND QUALITY OF SAMPLING AND MEASURES TAKEN TO ENSURE SAMPLE REPRESENTATIVE

12.1.1 The sampling strategy for the G-4 Exploration Project targeting Phosphate in the Kaphalda Block was designed to ensure the collection of representative samples across the investigated area.

12.2.0 SAMPLING METHODS

12.2.1 Detailed geological mapping was conducted to understand the geological setup to target mineralization, focusing on rock types, known mineral occurrences, and structural features. The sampling density was prepared based on 1:12,500 scale. According to the Mussoorie model shown in text figure 8.1, denser sampling grids were employed in areas with probable zones. However, sampling was not feasible in the extrapolated strike due to the dense and inaccessible forest, and in the northern sector of the Block, the ore body zone was concealed by alluvium in the Sahastradhara river valley. Further, Surface samples was collected for bedrock, and trench samples Photograph 12.1 (a, b), a total of 10 trenches were excavated and subsequent channels were cut on the sections at the phosphate potential areas, two of them are shown in Photograph 12.2 (a, b), Photograph 12.3 (a, b), and trench location Map and a schematic diagram of trench sections of T1, to T5 are shown in Text figure 12.1 to Text figure 12.3 and in Plate-VII to Plate-IX. The samples were analysed for Chemical, X-ray diffraction (XRD) and petrography studies. Bedrock (Block/grab) samples were taken with the help of sledge hammer and chisel, the trench and channel samples were collected with the help of sledge hammer, chisel, shovel, crow-bar.

12.2.2 During the sampling, surface was properly cleaned and each sample was collected in separate plastic bags with proper labelling. After collecting each sample, all the instruments were properly cleaned before proceeding for next sample collection to maintain quality and to avoid contamination.



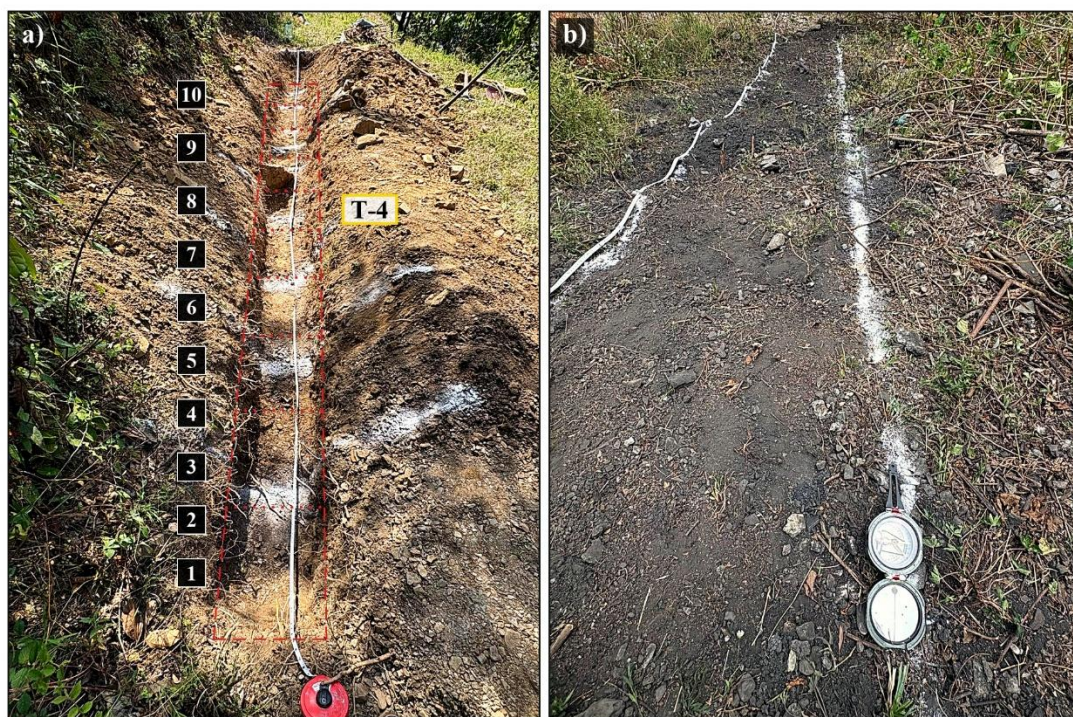
Photograph 12.1: a). Trench (T-3) excavated on the phosphate potential zone and sampled at 1 m intervals over a total length of 10 m (samples 1-10); b). Trench face showing the depth of the excavated cut, with a person for scale.



Photograph 12.2: a). Trench (T-7) excavated on the phosphate potential zone and sampled at 1 m intervals over a total length of 10 m (samples 1-10); b). Trench face with a geological compass placed for scale.

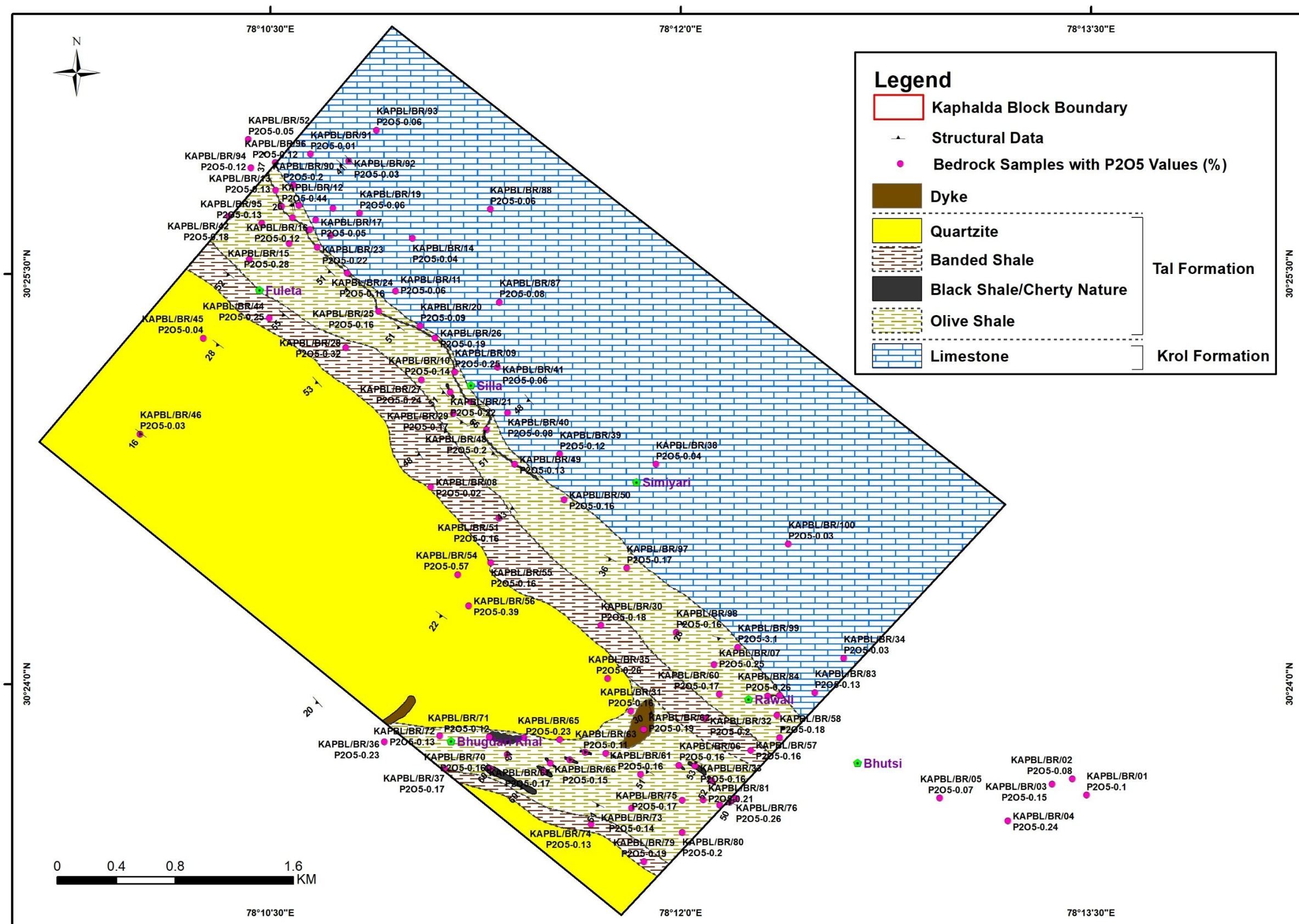
12.2.3 To ensure that the collected samples accurately represented the lithounits in the Kaphalda Block, precise documentation of sample locations, standardized sampling procedures, and regular cleaning of sampling instruments were implemented. Precise recording of sample locations using GPS coordinates or detailed mapping ensures proper spatial representation. Standardized sampling protocols were followed for sample size, collection depth, and sample handling to maintain consistency throughout the Block.

12.2.4 A total sample of 100 bedrock, 37 trenches samples were analysed for XRF and out of which 11 samples undergone for ICP-MS for trace and REEs analysis, 08 no. collected for Petrography and 10 no. for Mineragraphy and 20 samples collected for XRD. The Analysis for both has been done in MECL laboratory, Nagpur. The value of the analysis has been given in (Annexure - II to IX).



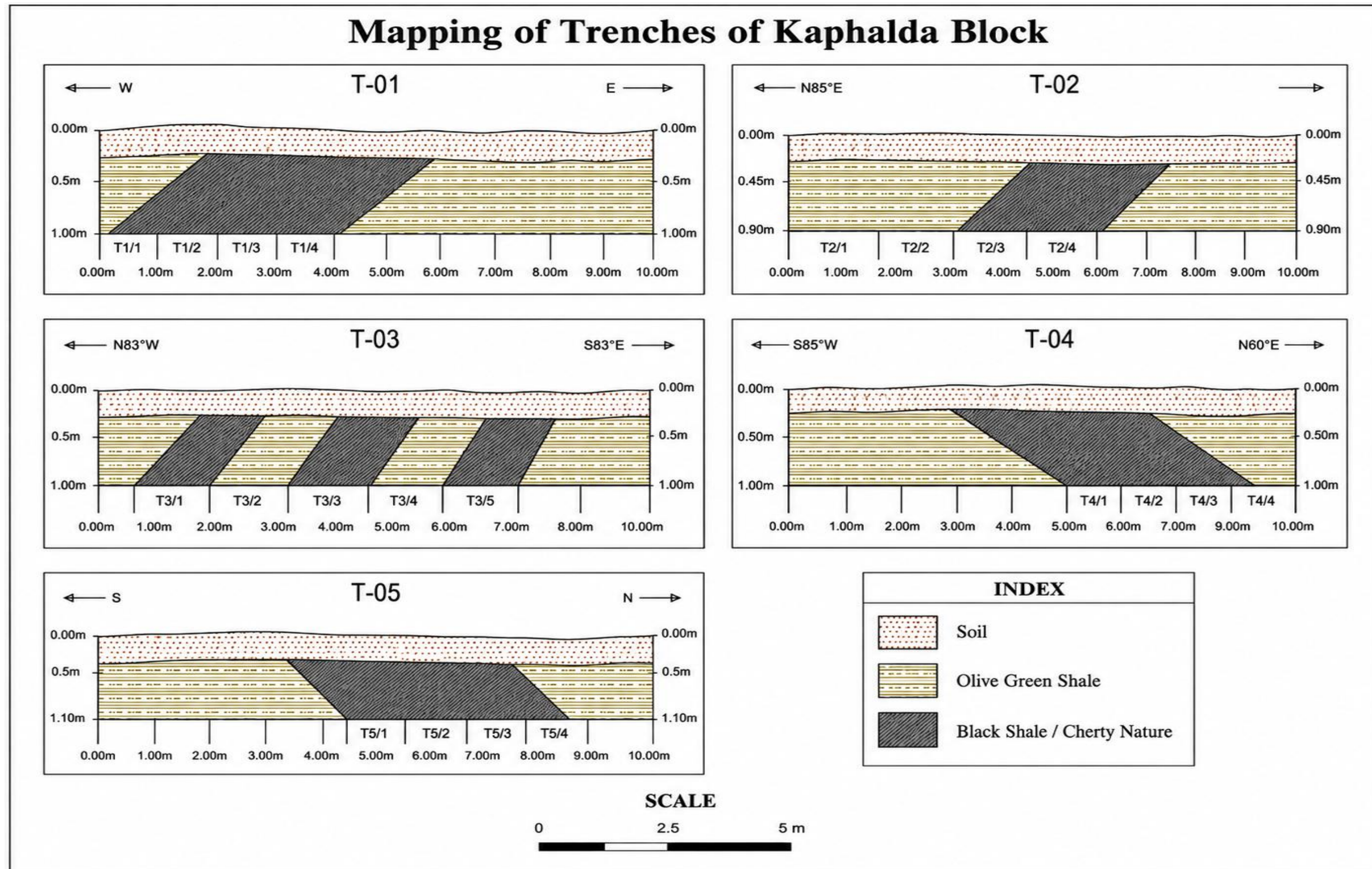
Photograph 12.3: a). Trench (T-4) excavated on the phosphate potential zone and sampled at 1 m intervals over a total length of 10 m (samples 1-10), with a measuring tape laid along its length; b). Chalk-marked boundaries along the trench sampling section.

TRENCH LOCATIONS ON GEOLOGICAL MAP OF KAPHALDA BLOCK, DIST: DEHRADUN & TEHRI GARHWAL, UTTARAKHAND

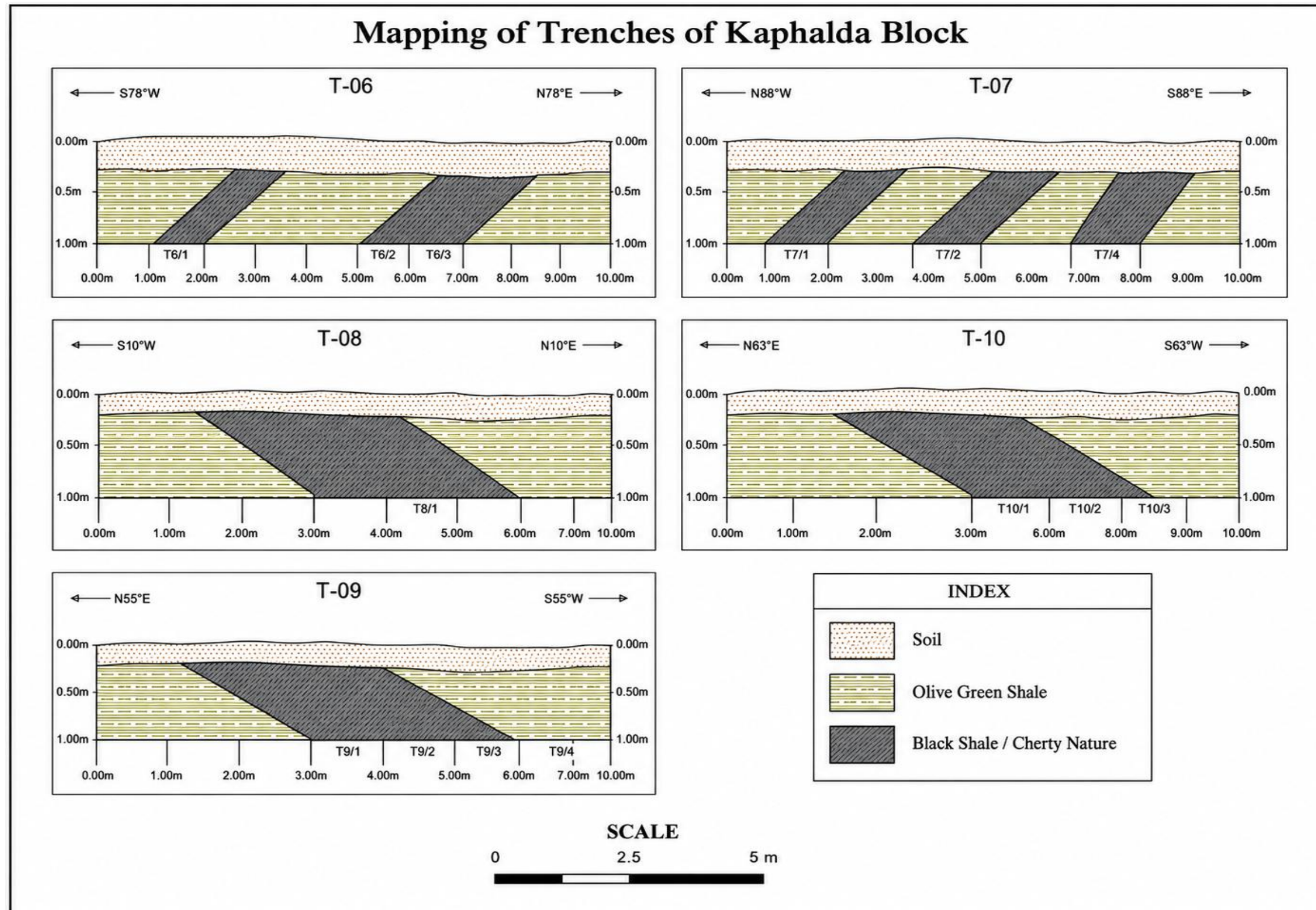


Text Figure 12.1: Trench Locations (T1 to T10) on Geological Map of Kaphalda Block.

SECTION MAP OF TRENCHS FROM T1 TO T5 KAPHALDA BLOCK, DIST: DEHRADUN & TEHRI GARHWAL, UTTARAKHAND



Text Figure 12.2: Schematic Diagram of trench Sections of T1 to T5 of Kaphalda Block.



Text Figure 12.3: Schematic Diagram of trench Sections of T6 to T10 of Kaphalda Block.

CHAPTER-13

DRILLING TECHNIQUES AND DRILL SAMPLING EMPLOYED

13.1.0 DRILLING TYPES AND DETAILS

13.1.1 The present exploration was carried out for Phosphate in G-4 Kaphalda Block with only geological mapping and sampling. Thus, drilling was not carried out in this Block.

CHAPTER-14

SUB SAMPLING TECHNIQUES AND SAMPLE PREPARATION

14.1.0 WHETHER RIFFLED, TUBE SAMPLED, ROTARY SPLIT, ETC., AND WHETHER SAMPLED WET OR DRY.

14.1.1 During the present exploration, a total of 137 nos. of primary bedrock samples were collected, 14 nos. of external check samples were prepared. The primary and external check samples have been analysed for 10 radicals i.e., P_2O_5 %, CaO%, MgO%, Na₂O%, K₂O%, MnO%, SiO₂%, Al₂O₃%, Fe₂O₃% & LOI% by WD-XRF and trace elemental analysis have been done for 11 samples by ICP-MS, i.e., Ga, Cr, Co, Ba, Sr, Rb, Z, Y, Nb, Ce, Nd, Ta, Cd, Sb, Sc, As, Th, Cu, Ag, Au, As, Mn, Ti, V, Cr, Ni, Pb, Zn, Sb, Sn, Mo, W, Cd, Co and REEs at Chemical Laboratory of MECL, Nagpur. The, external check samples have been analysed for 10 radicals at Jawaharlal Nehru Aluminium Research Development and Design Centre, (JNARDDC) Nagpur (A Government Laboratory).

14.2.0 NATURE, QUALITY AND APPROPRIATENESS OF THE SAMPLE PREPARATION TECHNIQUE

14.2.1 The details of sampling procedure for primary samples are described in Para Quality of the sample preparation is maintained by proper cleaning, maintenance of the equipment and proper crushing, sieving and coning and quartering of samples. For sample preparation proper technique and expertise has been used.

14.3.0 QUALITY CONTROL PROCEDURES ADOPTED

14.3.1 The primary samples have been collected from entire probable mineralized zones and the samples have been prepared at centralized mechanized sampling unit, Nagpur. The standard sampling procedure in supervision of qualified sampling technician has been adopted to control the quality of samples. Similarly, external check samples have also been prepared under the supervision of qualified sampling technician following the standard sampling procedure.

14.4.0 MEASURES TAKEN TO ENSURE THE SAMPLING IS REPRESENTATIVE OF THE IN-SITU MATERIAL COLLECTED

14.4.1 All the primary bedrock samples have been marked and prepared for P_2O_5 %, CaO %, MgO %, Na_2O %, K_2O %, MnO %, SiO_2 %, Al_2O_3 %, Fe_2O_3 % and trace elemental analysis. Precise recording of sample locations using GPS coordinates or detailed mapping ensures that the samples collected represent specific areas within the Block. This allows for spatial correlation and analysis of variations across the area. Proper cleaning of the sampling surface before collecting each sample minimizes contamination from previous samples or external sources. Using separate plastic bags with proper labeling for each sample ensures traceability and reduces the risk of mix-ups. These practices promote consistency throughout the sampling process.

14.4.2 The measures outlined here are some challenges associated with obtaining representative samples and in-situ samples, heavy rainfall creates more valleys and more debris on surface of the designated Block. Rainfall movement can scour and mix materials from various lithounits units, potentially leading to samples that don't accurately reflect the underlying bedrock composition. Bedrock chip samples collected from vertical sections/exposer to avoid the mixture of materials from different sources and Trench samples are taken by digging on the surface atleast 1 m across 2 x 10 meters dimension and channel samples were taken nearly 6-8 inches deep on vertical sections across 1 to 3 meters length. In Kaphalda Block, the sampling for phosphate done for Bedrock for surface and chip sampling for Trench. Soil/Stream samples are not taken into consideration due to the in-situ problems of rainfall debris, in hilly region and more appropriately targeting the source rock, through trenches and sections exposed on hill ridges.

14.5.0 WHETHER SAMPLE SIZES ARE APPROPRIATE TO THE GRAIN SIZE OF THE MATERIAL BEING SAMPLED

14.5.1 Standardized exploration practices typically establish guidelines for sample size based on the target material and exploration stage. Considering the potential presence of hilly terrain of the region, the grain size of the collected materials was variable in grain size of the bedrock samples. However, lake sediments/clay are of finer grain sizes relatively. The primary samples have been prepared (–) 200 mesh size and all the other samples have been prepared from primary samples.

CHAPTER-15

QUALITY OF ASSAY DATA AND LABORATORY TESTS

15.1.0 THE NATURE, QUALITY AND APPROPRIATENESS OF THE ASSAYING AND LABORATORY PROCEDURES

15.1.1 The primary samples for phosphorite mineralization have been analysed for 10 radicals i.e., P_2O_5 %, CaO%, MgO%, Na₂O%, K₂O%, MnO%, SiO₂%, Al₂O₃%, Fe₂O₃% & LOI% and Trace elements. The analysis has been carried for 10 radicals and LOI by WD-XRF, REEs by ICP-MS and mineral phases identifications by XRD in Chemical Laboratory of MECL (a NABL accredited laboratory) and Jawaharlal Nehru Aluminium Research Development and Design Centre, (JNARDDC) Nagpur (A Government Laboratory).

15.2.0 ICP-MS ANALYTICAL METHODS AND PROCEDURES

15.2.1 Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) was employed for the quantitative analysis of a suite of 10 radicals and trace elements in geochemical samples collected for the G-4 exploration project. This analytical technique utilizes an Agilent make ICP-MS instrument and offers exceptional detection capabilities, ranging from low-concentration analyses in the parts per billion (ppb) and parts per trillion (ppt) range to measurements of elements present in parts per million (ppm) concentrations. The accuracy and precision (standard deviation) achieved for these 10 radicals and trace elements were either excellent (<5%) or good (5-10%).

15.3.0 SAMPLE PREPARATION

15.3.1 A standardized dissolution procedure involving hydrochloric acid (HCl), hydrofluoric acid (HF), and nitric acid (HNO₃) was employed for sample preparation. This process was carried out within screw-top Teflon bombs using a microwave digester to ensure complete dissolution of the geochemical materials.

15.4.0 LABORATORY SAFETY MEASURES

15.4.1 Throughout the chemical analysis process, stringent laboratory safety protocols were strictly followed. These protocols included:

- a) Mandatory use of department-approved safety goggles and apron attire within the laboratory environment.

- b) Consistent utilization of fume hoods when handling hazardous or potentially irritating chemicals.
- c) Clear and accurate labeling of all containers to ensure proper identification of their contents.
- d) Adherence to the "once-a-container" principle, where chemicals are never returned to their original containers after exposure.
- e) Minimization of chemical usage, employing clean and dry spatulas for chemical retrieval, and proper disposal of excess materials.
- f) Implementation of appropriate precautions to avoid burns, including the use of beaker tongs for handling hot containers.
- g) Immediate rinsing of any chemical spills on the skin with copious amounts of water.
- h) Prompt cleanup and disposal of broken glassware in designated areas.
- i) Observance of designated waste disposal procedures, with specific protocols for liquid and solid waste materials.

15.5.0 QUALITY CONTROL PROCEDURES

15.5.1 To ensure the accuracy and reliability of the analytical data, a comprehensive suite of quality control (QC) procedures was systematically implemented during the analysis of the radicals. These procedures encompassed:

- a) Analysis of certified reference materials and measurement standards to verify instrument calibration and analytical accuracy.
- b) Inclusion of blind samples within the analytical batch to assess potential biases introduced during sample preparation or analysis.
- c) Utilization of QC samples and control charts for continuous monitoring of analytical performance.
- d) Analysis of blanks to detect and quantify any potential background contamination arising from reagents or instrument processes.
- e) Analysis of spiked samples to evaluate matrix effects and overall analytical recovery.
- f) Performance of duplicate analyses and the use of internal check standards to assess data precision and consistency.

15.6.0 XRF ANALYTICAL METHODS AND PROCEDURES

15.6.1 X-ray fluorescence (XRF) spectroscopy was employed for the geochemical analysis of bulk rock samples collected for the Kaphalda Block G-4 Exploration project. This technique utilizes an Axios mAx XRF instrument (Panalytical make) to determine the elemental composition of the samples. In Kaphalda Block samples XRF studies has been done for Major Oxides SiO₂%, Al₂O₃%, Fe₂O₃%, Na₂O%, K₂O%, P₂O₅ %, MgO%, MnO%, CaO%, TiO₂%, LOI.

- a) Model - Axios mAx.
- b) Make – Panalytical
- c) Pellet preparation-Hydraulic Press
- d) Standards (CRM) - NCSDC-16006

15.7.0 PELLET PREPARATION

15.7.1 Standardized pellet preparation method was used to ensure sample homogeneity and consistency for XRF analysis. This process involved the following steps:

- a) **Sample Grinding:** Each sample was pulverized to a fine powder using a grinding mill to achieve a particle size of less than 200 mesh.
- a) **Hydraulic Press Pellet Formation:** A precisely weighed portion of the pulverized sample (5 grams) was mixed with 10 grams of boric acid, acting as a binding agent.
- b) The mixture was then pressed into a 40 mm diameter pellet using a hydraulic press at a pressure of approximately 20-22 tons.

15.8.0 INSTRUMENT CALIBRATION AND ANALYSIS

15.8.1 Prior to sample analysis, the XRF instrument was meticulously calibrated using certified reference materials (CRM) such as NCSDC-16006. This calibration ensured the accuracy and reliability of the measured elemental concentrations. Following calibration:

- a) The prepared pellet was placed in the designated sample holder of the XRF instrument.
- b) The instrument settings were verified to ensure adherence to established protocols.
- c) XRF analysis was initiated using the instrument software, automatically controlling the measurement process.

- d) The XRF instrument bombarded the sample with X-rays, causing the atoms within the sample to emit characteristic fluorescent X-rays.
- e) The emitted X-rays were detected and analyzed by the instrument, generating quantitative data on the elemental composition of the sample.

15.9.0 DATA RECORDING AND QUALITY CONTROL

15.9.1 The results obtained from the XRF analysis were documented on quantitative contents of oxides in each sample. This report detailed the elemental concentrations for each sample, along with relevant information regarding the analysis conditions. Additionally, the software embedded within the XRF instrument performed intermediate checks using a dedicated bead standard, further ensuring the quality and consistency of the analytical data.

15.10.0 LOSS ON IGNITION (LOI)

15.10.1 The weight loss on ignition (LOI) technique was employed to determine the number of volatile components present within the rock samples. This analysis followed the Wet-Classical Laboratory (WCL) procedure, which involved:

15.10.2 Precisely weighing a dried sample (previously oven-dried at 110°C) and placing it in a pre-weighed platinum crucible.

- a) Heating the sample in a furnace at 1000°C for approximately one hour.
- b) Once cooled, the sample was re-weighed.
- c) The difference in weight between the pre- and post-ignition measurements was expressed as a percentage, representing the LOI value.

15.11.0 NATURE OF QUALITY CONTROL PROCEDURES ADOPTED

15.11.1 The standard procedure for chemical analysis as per provision made in the proposal for QA/QC has been followed. All the primary samples have been analysed in the Chemical Laboratory of MECL. In order to assess the bias and inaccuracies in analytical determination, one standard, one blank and one repeat sample has been analysed for each number of primary samples.

15.12.0 In order to ensure the accuracy of the analysed samples, few CRMS are used in the analysis. The Certified Reference Material (CRM) was processed under similar conditions as samples and run after every 20 samples, the values of which have been tabulated in the table below. For ICP-MS: NCS DC-73022 (Approved by China

National Analysis Centre for Iron and Steel, Beijing, China) has been used as certified reference material. For XRF: GBW07103 and GBW07105

CRM NCS DC-73022 (Approved by China National Analysis Centre for Iron and Steel, Beijing, China).			
Element	Value	Element	Value
Al₂O₃	13.61%	Cr	72 ± 3
CaO	4.32%	Cu	28.2
Fe₂O₃	5.89%	Pb	42.5
K₂O	2.48%	Zn	134
MgO	1.72%	Ni	31.2
Na₂O	1.62%	Co	15.8
P₂O₅	0.16%	Mn	812
SiO₂	61.5%	As	12.4
TiO₂	0.65%	Hg	0.072
LOI	6.35%	Mo	0.7
Ba	412	Nd	40.0
Sr	98	V	89
Zr	156	Sc	13.5

15.13.0 CHECK ANALYSIS FROM THIRD PARTY NABL ACCREDITED LABORETORY

15.13.1 The third-party samples analyses have been carried out at Jawaharlal Nehru Aluminum Research Development and Design Centre, (JNARDDC) Nagpur (A Government Laboratory). A total of 13 numbers of external check samples is analysed for 08 radicals for phosphate analysis. The comparative studies of primary vs external check analysis for samples will be attached as Annexure-VIII.

15.13.2 Comparison of Primary Vs External Check Assay Value of Phosphate

15.13.3 In accordance to the standard practice of quality assurance and quality control, external check samples analysis has been carried out at Jawaharlal Nehru Aluminium Research Development and Design Centre, (JNARDDC) Nagpur (A Government Laboratory). 10% of primary samples, i.e. 13 no. of samples for 08 radicals including P₂O₅ % have been analysed as external check sample. The comparison charts of all the 08 radicals are shown in Text Figure 15.1.

15.14.0 SECURITY AND CHAIN OF CONTROL OF SAMPLES SHOULD BE CLEARLY MENTIONED

15.14.1 Strict adherence to chain of custody protocols ensured the integrity of the geochemical samples throughout the process, from collection to analysis. A

dedicated, centralized mechanized sampling unit handled sample preparation. Qualified sampling technicians oversaw the entire process, ensuring proper labelling and tagging of each sample. Standard procedures were meticulously followed during sample preparation to minimize the risk of contamination. The sampling unit's physical separation from the chemical laboratory further eliminated any potential for cross-contamination. Documentation and Traceability:

15.14.2 A comprehensive chain of custody record was maintained throughout the process. This record documented the movement of each sample from the field to the laboratory, including details such as:

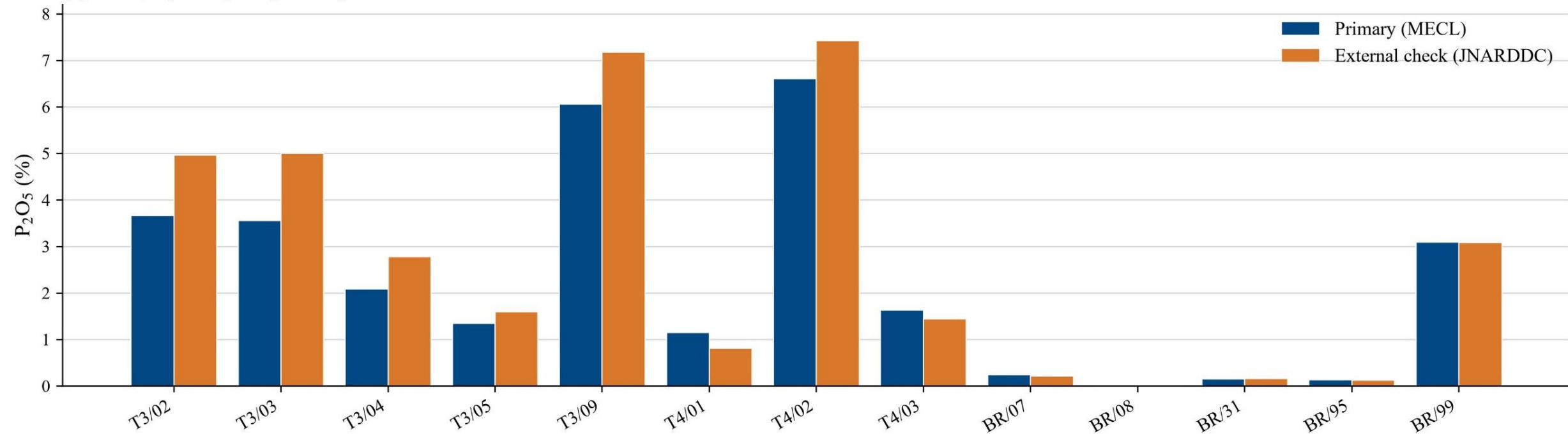
- a) Sample identification number
- b) Location of Sample
- c) Name of sampling personnel
- d) Any Specific instruction for crushing
- e) Date of Dispatch of Sample

15.14.3 This chain of custody record served as a verifiable audit trail, ensuring the traceability of each sample and upholding the integrity of the collected data. Depending on the specific project requirements, additional security measures could be implemented. These might include tamper-evident seals placed on sample containers, secure storage facilities, and controlled access procedures within the sampling unit and laboratory.

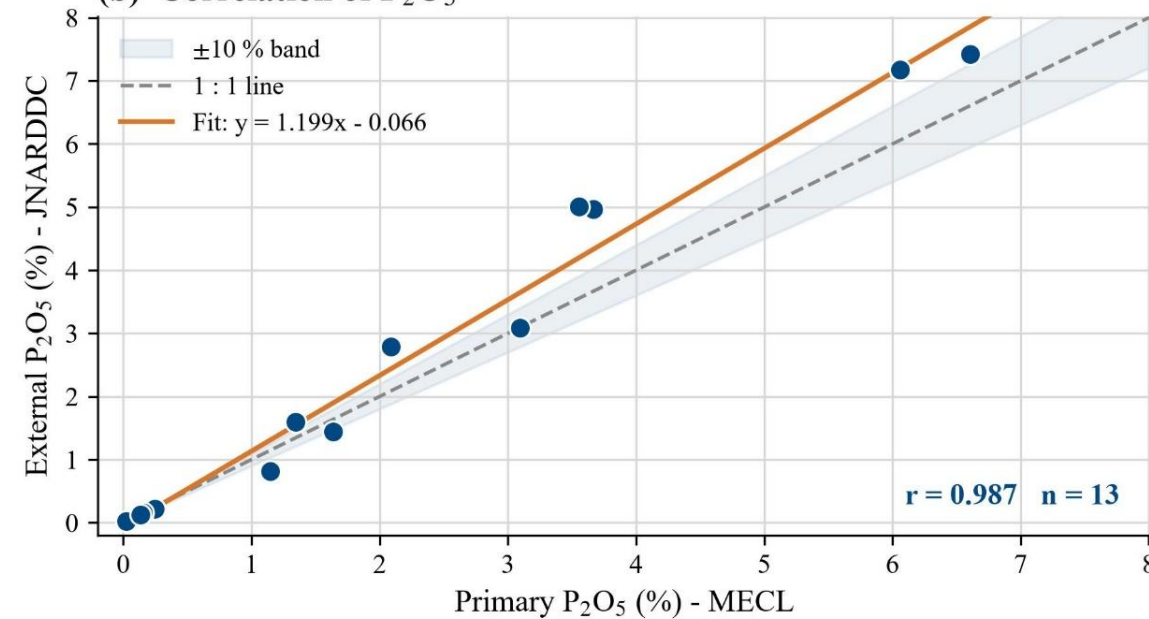
Primary (MECL) versus External Check (JNARDDC) Analysis - Kaphalda Block

Inter-laboratory comparison of 13 external check samples (P_2O_5 and other radicals by WD-XRF)

(a) P_2O_5 by sample - primary vs external check



(b) Correlation of P_2O_5



(c) Inter-laboratory QA statistics (all radicals)

Radical	Prim. mean %	Ext. mean %	Mean bias	MARD %	r
P2O5	2.29	2.68	+0.390	17.1	0.987
CaO	8.94	7.44	-1.503	27.8	0.993
MgO	3.96	4.24	+0.277	18.9	0.968
MnO	0.07	0.05	-0.007	13.9	0.987
SiO2	47.97	54.86	+6.890	14.0	0.991
Al2O3	12.03	11.00	-1.036	13.0	0.957
Fe2O3	6.96	4.82	-2.147	38.1	0.991
LOI	10.80	9.71	-1.097	17.5	0.991

MARD = mean absolute relative difference; bias = external - primary.

Text Figure-15.1: Primary (MECL) versus external check (JNARDDC) P_2O_5 % and multi-radical comparison for 13 check samples, (a) sample-wise P_2O_5 , (b) correlation with 1:1 line and $\pm 10\%$ band ($r = 0.987$), (c) QA statistics; which shows close agreement with a minor positive external bias at high grade.

CHAPTER-16

MOISTURE

16.1.0 All the analyses for phosphate in rock samples were carried out with natural moisture.

CHAPTER-17

BULK DENSITY

- 17.1.0 The present exploration was conducted for phosphate mineralization in the Kaphalda G-4 Block, Dehradun, for which bulk density measurements have not been carried out.

CHAPTER-18

BENEFICIATION STUDIES

- 18.1.0 Given the limited scope of that exploration and, the phosphate ore body was not established at the required cutoff grade of 5% P_2O_5 content. Thus, no beneficiation studies were conducted in that Block.

CHAPTER-19

RESOURCE ESTIMATION TECHNIQUE

19.1.0 GENERAL

19.1.1 The Reconnaissance Survey (G-4) for phosphate in Kaphalda Block was carried out to assess the mineral potential of the area. The exploration was completed by geological mapping of nearly 16.68 sq. km and surface sampling. A comprehensive analysis was conducted on 137 primary samples, encompassing bedrock for phosphate. Based on the analysis of the samples, a few were reported with values slightly above the cut-off (5% P_2O_5) and two trench samples had an anomalous value of ~6%. However, the extension of the ore body was not delineated at the cut-off grade. Thus, with limited values, a resource zone had not been estimated for the Block.

CHAPTER-20

REPORTING OF RESOURCES

20.1.0 As discussed in chapter-18, no Phosphate ore body has been established at required cut off (5% P_2O_5), hence resource has not been estimated in this Block.

CHAPTER-21

SUMMARY AND RECOMMENDATIONS

21.1.0 SUMMARY

- 21.1.1 The Kaphalda Block exposes a succession of Krol Formation and Lower Tal Formation and is dominated at the surface by Quartzite and arkosic Sandstone (quartz-wacke) of the Arenaceous Member. The litho-contact between the Krol and Tal formations is exposed within the Block, and the phosphate-bearing Black Shale and Cherty (chert) Member occupies the lower succession of the Tal formation at and immediately above this Krol–Tal contact. The chert member mapped in the Block is thin, reaching only about 04 m in thickness, and the Black Shale/Cherty Shale unit is not well exposed at the surface.
- 21.1.2 Petrographic and mineragraphic study of the bedrock and trench samples shows a quartz-dominated assemblage with feldspar, calcite, dolomite, sericite and carbonaceous matter, and an opaque assemblage of pyrite and magnetite with subordinate goethite–hematite and traces of chalcopyrite. X-ray diffraction confirmed the phosphate mineral as apatite (fluorapatite/hydroxylapatite), which occurs as a major crystalline phase in the enriched trench samples, indicating the presence of a phosphatic horizon within the Block.
- 21.1.3 Geochemically, the surface bedrock samples analysed at low phosphate values, about 80 % of the 100 samples carrying P_2O_5 below 0.25 % and only one sample (BR/99) reaching 3.10 %. In contrast, the trench channel samples intersected distinctly higher grades, with two samples, T4/02 (6.60 % P_2O_5) and T3/09 (6.06 % P_2O_5), exceeding the 5 % P_2O_5 cut-off grade and several others in the range of 1 to 3.7 %. The rare earth elements show light-REE enrichment with La/Yb greater than 5, while gold is below the detection limit in all analysed samples. This marked contrast between the low surface grades and the above-cut-off trench grades is illustrated by the frequency distribution of P_2O_5 in the surface and trench samples (Text Figure-9.1); the trench intervals also carry a modest polymetallic content (Zn, Pb, As, Ba and Cr) (Text Figure-9.6), and the phosphatic and carbonaceous intervals are light-REE enriched, as shown by the PAAS-normalised REE patterns (Text Figure-9.7).
- 21.1.4 The contrast between the low surface values and the above-cut-off trench values is the key finding of this survey. It indicates that the phosphate horizon is not properly

exposed at the surface and that the economic grades are concealed beneath the Krol–Tal contact horizon. The poor surface expression is attributed to the thinness of the chert member (about 04 m), to sedimentary pinching and swelling of the phosphate horizon, and, most importantly, to the structural complexity of the Block. The Kaphalda Block lies close to the Main Boundary Thrust (MBT) zone, where the Lesser Himalayan formations are uplifted and split into imbricate thrust slices with repetition and inversion of the litho-stratigraphic units (Valdiya, 1980; Luirei et al., 2023). Superimposed on the folds are two generations of brittle structures, hinterland-verging back-shears and arc-parallel shears, documented from the adjoining Dhanaulti–Sategal sector (Bose and Mukherjee, 2019; Biswas et al., 2022). In such a setting the Tal Formation can ride up along these structures and conceal the under lying phosphatic horizon, which is consistent with the horizon being intersected in trenches but poorly seen at the surface.

21.1.5 Overall, the G-4 reconnaissance survey confirms the Krol–Tal stratigraphy and the phosphate-bearing chert–black shale horizon is present in the Kaphalda Block, which lies directly along strike from the known high-grade Durmala and Bhusti–Jalikhil tracts of the Mussoorie Syncline. The proximity of the Block to the MBT zone and to regional folds, together with the above-cut-off grades recorded in the trenches, marks it as a prospective but structurally complex target area, whose phosphate potential is concealed rather than absent (Banerjee et al., 1997; Mazumdar et al., 1999). The above-cut-off grades confined to the T3–T4 trenches, set against the largely barren surface bedrock (Text Figure-9.1), reinforce the interpretation that the high-grade phosphate horizon is concealed at shallow depth beneath the Krol–Tal contact rather than being absent.

21.1.6 **RECOMMENDATIONS**

21.1.7 In view of the above, it is recommended that the Kaphalda Block be taken up for further exploration and upgraded to the G-3 stage, using drilling so as to confirm and delineate the concealed phosphate horizon within the Block.

21.1.8 The surface exposure of the phosphate horizon is limited and the P_2O_5 values are correspondingly low, whereas the trenches have shown promising values above the 5% cut-off grade. This might indicate that the phosphate is concealed beneath the Krol–Tal contact. The concealment is interpreted to result from the structural complexity of the area near the MBT zone; however, within the limited scope of a

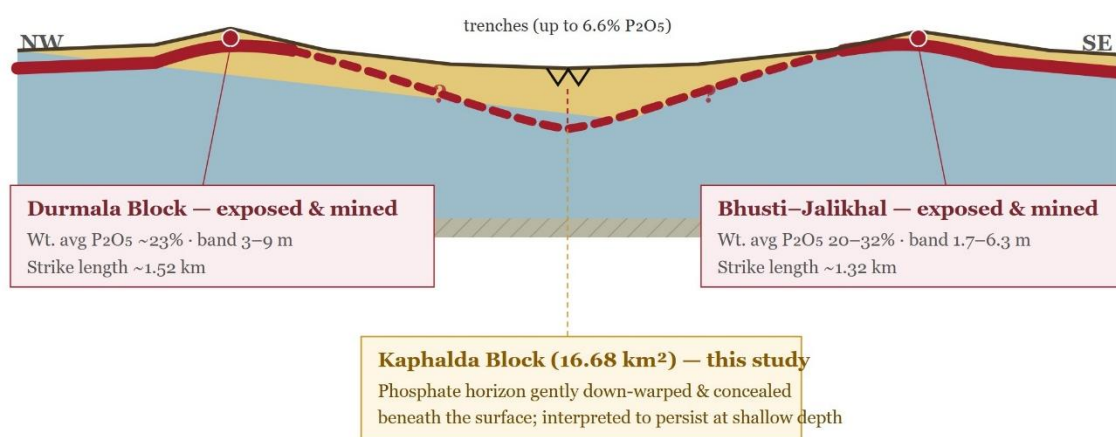
G-4 reconnaissance survey and the timelines set by the NMEDT, a thorough structural investigation to resolve this complexity has not been possible.

21.1.9 It is therefore further recommended that a separate, focused structural study programme be carried out in and around the Block, close to the MBT zone, to understand the imbrication and the concealed geometry of the phosphate horizon. This should be followed by a drilling programme, with scout boreholes sited on the favourable trench sector (particularly T3–T4) and inclined borehole to intersect the down-dip continuation of the horizon, to reveal the sub-surface rocks and to establish the thickness, grade and continuity of the concealed phosphatic horizon at depth (Text Figure 21.1).

Hypothetical (interpolated) subsurface geological section

Along the Durmala–Kaphalda–Bhusti belt (NW–SE): phosphate horizon concealed beneath the Kaphalda Block

Interpretive / hypothetical — geometry inferred, not to scale



Hypothetical interpretation, not to scale. After Valdiya (1980), Bose & Mukherjee (2019), Biswas et al. (2022); block data after GSI/PPCL.

Text Figure 21.1: Schematic Geological section across the Mussoorie Syncline and Lesser Himalaya, after Auden(1934), Valdiya(1980), Banerjee et al. (1997), Bose & Mukherjee (2019) and Biswas et al. (2022); phosphate model from Mazumdar et al. (1999), and Block data from NGDR/PPCL.

CHAPTER-22

PLATES AND MAPS

- 22.1.0 Location Map of the Block showing various topographic and physiographic features nearby the Kaphalda Block is given as Plate-I.
- 22.1.1 Regional Geology Map on 1:50,000 scale is given as Plate-II.
- 22.1.2 Geological Map on 1:12,500 scale is given as Plate- III.
- 22.1.3 Sample Location Map on Geological Map at 1:12,500 scale is given as Plate-IV.
- 22.1.4 Sample Location with Phosphate Values on Geological Map given as Plate-V.
- 22.1.5 Sample Location with DEM of the area given as Plate-VI
- 22.1.6 Trench Location Map on Geological Map given as Plate-VII
- 22.1.7 Schematic Diagram of Trench Section is given as Plate-VIII & Plate-IX

CHAPTER-23

ANNEXURE / ENCLOSURES TO THE REPORT

23.1.0 The report includes all the relevant annexure and maps, plans, sections, photographs & photomicrograph etc. List of annexures, tables, maps/plans/sections, photographs, Text figures & photomicrograph etc. are provided before the start of the Text part of the Geological Report.

CHAPTER-24

ANY OTHER INFORMATION

24.1.0 There is no additional information available in the Block.

CHAPTER-25

CERTIFICATE FROM THE QUALIFIED PERSON WITH NAME, DATE AND SIGNATURE

This is to certify that geological report has been prepared in respect of Reconnaissance Survey (G-4) for Phosphate in Kaphalda Block, District Dehradun, State: Uttarakhand. The report was produced by Mineral Exploration and Consultancy Limited (MECL) on behalf of the National Mineral Exploration Trust (NMET). The report adheres to the Minerals (Evidence of Mineral Contents) Rules, 2015, as specified under the Mineral Auction Rules, 2015, and amended up to 2021.

NAME: **SHRIKANT SHARMA**

DESIGNATION: **HoD (EXPLORATION)**

DATE: 30-09-2026

LOCALITY INDEX

Locality	Latitude	Longitude	Elevation (m)
Rangargaon	30°17'06.00" N	78°12'29.00" E	1023
Silkoti	30°28'59.50" N	78°01'22.00" E	1658
Kaphalda	30°23'10.10" N	78°08'46.93" E	1500
Sarona	30°24'21.49" N	78°09'02.67" E	1600
Timilimansingh	30°23'05.23" N	78°08'11.36" E	1197

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ABBREVIATIONS USED

SL. No.	Abbreviation	Full form
1	UNFC	United Nation Framework Classification
2	NMI	National Mineral Inventory
3	IBM	Indian Bureau of Mines
4	DGCO	Directorate General Camp Office
5	GSI	Geological Survey of India
6	MECL	Mineral Exploration and Consultancy Limited
7	CPSE	Central Public Sector Enterprises
8	NMET	National Mineral Exploration Trust
9	TCC	Technical cum Cost Committee
10	EC	Executive Committee
11	DMG, UP	Directorate of Geology & Mining, Uttar Pradesh
12	NABL	National Accreditation Board for Testing and Calibration Laboratories
13	JNARDDC	Jawaharlal Nehru Aluminium Research Development and Design Centre
15	MEMC	Minerals (Evidence of Mineral Contents)
16	MMDR	Mines & Minerals (Development and Regulation)
17	NH	National Highway
18	WGS-84	World Geodetic System-84
19	UTM	Universal Transverse Mercator
20	RL	Reduced Level
21	cu m	Cubic Meter
22	ICP-MS	Inductively Coupled Plasma Mass Spectrometry
23	DGPS	Differential Global Positioning System
24	DMS	Degree Minute Second
25	M / m	Meter
26	mt	Million Tonne
27	Sq. km	Square Kilometer
28	M. Sc.	Master of Science
29	M. Sc. Tech	Master of Science Technology
30	NDDP	Net District Domestic Product
31	mRL	Reduced Level in metre
32	R.F.	Reserve Forest
33	P.F.	Protected Forest
34	QA/QC	Quality Assessment/ Quality Checks
35	WD-XRF	Wavelength Dispersive X-ray Fluorescence
36	CRM	Certified Reference Material
37	SARM	South African Reference Material
38	ICP-OES	Inductively Coupled Plasma Optical Emission spectroscopy
39	XRD	X-Ray Diffraction
40	ML	Mining Lease
41	NGCM	National Geochemical Mapping
42	NGPM	National Geophysical Mapping
43	AMSE	Airborne Mineral Surveys and Exploration