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Generation, Thar Block II, Pakistan

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Abstract: *Acid Rock Drainage (ARD), also known as Acid Mine Drainage (AMD), occurs when sulfide-bearing mine wastes like pyrite are exposed to oxidizing conditions in the presence of water. In the Thar region, the Thar coal deposit, a lignite-grade coal found in the oldest sedimentary formation (Bara – Eocene/Pliocene), poses significant environmental risks. Pyrite, the primary source of sulfur in coal, contributes to acid generation and spontaneous combustion. ARD in Thar Coal Mine (Block II) could result in acidic water contaminating the dune sand aquifer, which is the main source of domestic water in the region. This study evaluates the ARD potential of the Thar coal deposit and explores mitigation methods. Acid generation testing on samples from Bara, sub-recent, and dune sand formations revealed that coal and carbonaceous claystone from the Bara formation are potential acid-forming (PAF) and prone to ARD. Meanwhile, waste layers from dune sand and sub-recent formations are classified as non-acid-forming (NAF) rocks. Acid Neutralizing Capacity (ANC) tests showed that the dune sand and sand lenses from the sub-recent formation have moderate to strong acid-neutralizing capacity, which could be utilized to counteract acid generation by being strategically placed with PAF materials.*

Keywords: Acid generation potential, Potential acid forming rock, Acid neutralization capacity, Bara formation

INTRODUCTION

Acid rock drainage (ARD), also known as acid mine drainage (AMD), refers to the outflow of acidic water from coal and metal mines. While ARD is a naturally occurring process due to rock weathering, it is significantly exacerbated by human activities such as mining operations and construction projects like transportation routes and dam building. This process occurs when sulfide minerals, particularly pyrite, are exposed to air and water, resulting in the formation of sulfuric acid. ARD poses risks to ecosystems, and human health by increasing water acidity and dissolving harmful metals. Addressing and mitigating ARD is crucial not only during the operational phase of a mine but also after its closure [1]. Geochemistry of rocks can help to quantify the mine drainage chemistry [2], [3]. Pyrite (FeS_2) is commonly associated with coal deposits. Its oxidation occurs spontaneously in nature, causing environmental problems like Acid Rock or Mine Drainage. Pyrite oxidation takes place when the mineral is exposed to air and water. ARD involves the oxidation of pyrite and other sulfides, and yields Fe^{3+} and sulfuric acid. The overall chemical reaction governing pyrite oxidation is:

$$FeS_2 + 15/4O_2 + 7/2H_2O \text{ ---- } Fe(OH)_3 + 2SO4_2^- + 4H^+$$

Thar region is mainly comprised of 03 sedimentary formations (see Table I). Due to the presence of pyrite in Bara Formation which is also the source of sulfur in Thar coal (lignite), ARD potential is present during mining of lignite in Thar Block-II. According to Environmental Social Impact Assessment Report (ESIA), it was identified that Thar coal mine (Block-II) is prone to produce acid rock leaching due to presence of Pyrite (FeS_2) in Bara formation. To predict mine drainage quantitatively some tests that can be completed rapidly and evaluate the total reactive component of the rock are called acid base accounting (ABA) tests. These tests usually include the analysis of the Acid Production Potential and Acid Neutralization Capacity, ABA has been used to identify and plan mitigation for ARD potential from Thar coal mine (Block-II) [4].

LOCATION OF STUDY AREA

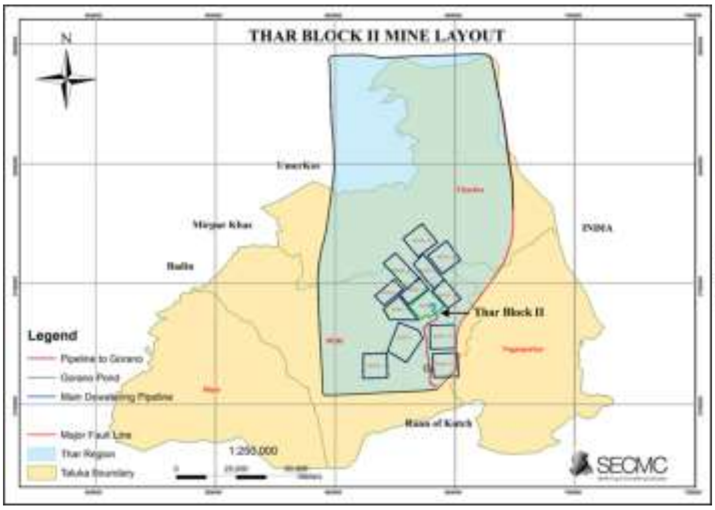
Pakistan hold the 7th largest lignite resources in the world with about 200 billion tons of coal, mainly discovered in Thar region with about 176 billion tons of lignite resource. The Thar desert of Pakistan is portion of a much larger desert extending to north and east to India [5]. Thar coal field is located in the south-eastern part of Sindh. The extension of entire lignite bearing area in Thar is about 9100 Km² [6]. Thar Block-II covers an area of about 95.5 sq. km. As of today, 12 blocks have been demarcated in Thar from which Thar Block-II covers an area of about 95.5 sq. km. (Fig. 1) with coal resource of 2.4 billion tons.

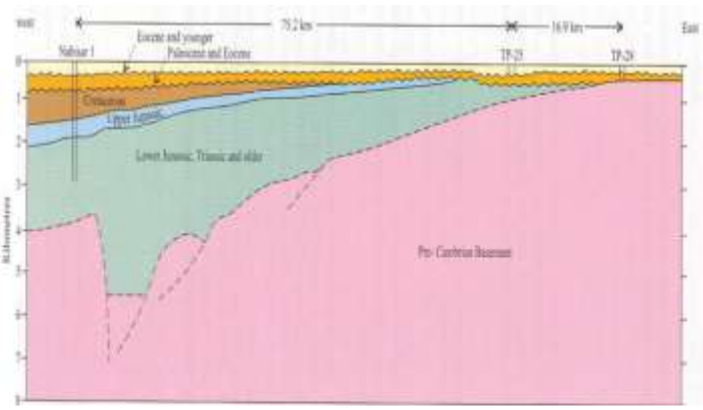
A. Climate

The climate in Thar is dry monsoon-type subtropical, with long-term annual precipitation of app. 200 mm/a, which practically all falls in July-September. The annual precipitation can vary significantly (See Table I). Thus acid forming rocks (and/or pyrite) will be exposed to water for a very limited period only. This will limit the amount of acid generated in the dump.

GENERAL GEOLOGY OF THE STUDY AREA

The Thar coal field lies within the Lower Indus Platform





(b)

(a)

Fig. 1 (a) Location map of study area, Thar Block-II, Sindh. (b) Generalized cross-section of Thar [5]

Basin. The basement consists of predominantly granitic rocks of Precambrian age that were exposed and eroded in Mesozoic times [5]. The erosion cycle was followed by the deposition of the fluvial-deltaic Bara Formation during Palaeocene and Early Eocene, in a period with environmental conditions suitable for the formation of coal. Subsequently the region remained stable, resulting neither in the deposition of younger rocks nor in the erosion of the relatively thin Palaeocene-Early Eocene unit. The Thar coals occur in Bara Formation of middle Palaeocene to early Eocene age, which is in turn unconformably overlain by sub Recent alluvial deposits. During the Neogene, the area subsided and was traversed by the Indus river system, which deposited the Pliocene alluvial sediments with an average thickness of 60-75 m. The Recent succession is composed of dune sand with athickness of 50-90 m [5]. The lignite-bearing Bara Formation varies between 80 m and 120 m of thickness and is mainly composed of fluvial sandstones at the base grading upward into carbonaceous claystones with intercalated coal seams in the middle and upper parts. Thar coals are brownish black, greyish black and black in colour and poorly cleated to well cleated and compact. The Bara coals contain scattered resin globules of coal seams up to 30 cm thick and patches of fine-grained pyrite [8]. Reference [9] suggest that the Bara Formation was deposited in near-shore mires that formed in a subsiding basin during a relative low stand. The stratigraphic contacts of the Bara Formation are marked by unconformities with the Precambrian basement at the base and Pliocene alluvial deposits at the top (see Table II). The Bara Formation is structurally simple with minor faulting and strata dipping gently at around 2° to the west-northwest. The Thar deposit limit to the south is the Rann of Kutch Fault with E-W orientation. To the north the coal thins abruptly at approx. 26°10' of latitude. To the east the boundary is either the paleo-coastline or an erosional limit due to uplifting in post-Eocene times [5] (Fig. 1). Stratigraphy of study area is nearly horizontal and no large scale faulting has been identified.

METHODOLOGY

Sample Collection & Preservation

31 samples have been collected to cover the complete section or stratigraphy of Thar coal mine (Block-II). Generally, lithology of Thar coal is divided into sub-units (see Table III) for lithological identification and geological modelling. Sample details with location and unit lithology tabulated in Table IV and illustrated in Fig.2. Collected samples were preserved in double polythene bags and tightly packed using tie clips to avoid contamination and moisture loss. Collected samples transported to ALS Global Lab Australia via DHL for detailed testing.

Sample preparation was performed by ALS lab using their inhouse method i.e. EN020PR [10], EN35 [11], EN84 (dry and crush) [12], EN24 (HCl digest; 1g of soil is digested in 30 ml of 30% HCl and the resultant digest bulked and filtered for analysis by ICP) [13] and GEO30 (dry and pulverize up to 100gm) [14].

Sample Testing

ALS Global Lab tested 31 samples upon authors request and analyze Acid Production Potential (APP) also known as Maximum Potential Acidity (MPA) reported as Kg H2SO4 per ton. Net Acid Production Potential (NAPP), Net Acid Generation (NAG) on pH 4.5 and 7.0, Acid Neutralizing Capacity (ANC) in terms of Kg H2SO4 and %CaCO3 with Fizz rating and other parameters which required for assessment and mitigation plan for ARD study (see Table IV).

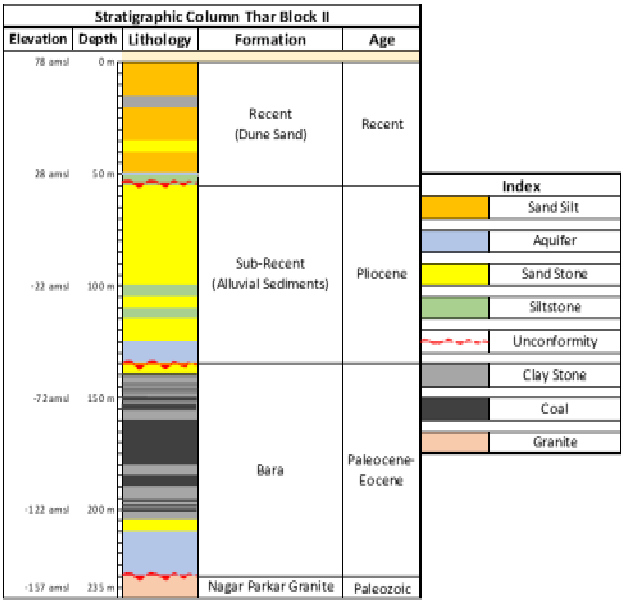
APP is a measure of the total sulfuric acid producing potential of a material, irrespective of whether that material may also have the potential to produce alkali. APP is determined from the analysis of total sulfur in the sample and is calculated assuming a total conversion of sulfur to sulfuric acid, which essentially states the mass of sulfuric acid that could potentially be produced per ton of material sampled. During pyrite oxidation, two moles of S in FeS_2 produce two moles of H2SO4 and therefore the S content (%) can be used to calculate APP (Kg H_2SO_4/ton) [4].

$$APP\ (Kg\ H_2SO_4/ton) = \frac{S\,(\%) * 10 * 2(moles\ H_2SO_4) * 98.07\ (\frac{g}{mol})}{2\ (moles\ S) * 32.06\ (\frac{g}{mol})}$$

Table I Rainfall data of Thar Block-II, Sindh, Pakistan (Monsoon season)

Year (July – Sep)	Rainfall (mm)
2019	238
2020	443
2021	310
2022	608
2023	645
2024	528

Table II Stratigraphy of Thar Block-II, Sindh, Pakistan [15]



NAPP is useful for screening samples into potential acid producers (positive result) and non-acid producers (negative result). NAPP suffers from the tendency to over predict the acid production potential because it does not differentiate between acid producing and non-acid producing forms of sulfur. A positive result indicates excess acid production (potentially acid forming) and a negative result indicates excess acid consumption (non-acid forming). NAPP was determined using EA009 [16]. NAPP = Acid Production Potential (APP or MAP - Maximum Acid Potential) minus Acid Neutralizing Capacity (ANC). NAPP may be +ve, zero or -ve. NAPP report in terms of Kg H2SO4/ton [17].

NAG (also referred to as Net Acid Production – NAP) uses hydrogen peroxide to oxidize any sulfides present in the sample. The acid produced from the oxidation reaction may subsequently be partially or totally consumed by acid neutralizing components of the sample – hence the reference to Net generation. Any remaining acidity is determined by back titration to both pH 4.5 and 7.0 to provide further information on the source of the acidity [16]. NAG was tested using EA011 [18], inhouse method of ALS, Titrimetric procedure determines net acidity in a soil following peroxide oxidation. Titrations to both pH 4.5 and pH 7 are reported. Unit of NAG is Kg H2SO4/ton.

ANC measures the capacity of a sample to neutralize any acid that is produced. In the ANC analysis a finely ground sample is reacted with a known amount of hydrochloric acid. The resultant solution is back titrated to pH 7.0 with sodium hydroxide to determine the amount of acid neutralized by the

Table III Showing the lithological units of Thar Block-II, Sindh, Pakistan

Formation	**Age**	**Lithological Units**	**Description**
Recent (Dune Sand)	Recent	DS1	Recent dune sand above compacted layer
		DSC	Compacted Sandstone
		DS2	Recent Dune sand below compacted layer

		SL	Sand Lense
Sub-Recent (Alluvial Sediments)	Pliocene	ST	Siltstone
		SC1	Silty Claystone 1
		CS1	Clayey Siltstone 1
		SC2	Silty Claystone 2
		CS2	Clayey Siltstone 2
		SC3	Silty Claystone 3
		A2	2nd Aquifer
Bara	Paleocene - Eocene	IB11	IB 1-1 Interburden
		CL11	CL 1-1 Coal Seam
		IB12	IB 1-2 Interburden
		CL12	CL 1-2 Coal Seam
		IB21	IB 2-1 Interburden
		CL21	CL 2-1 Coal Seam
		IB22	IB 2-2 Interburden
		CL22	CL 2-2 Coal Seam
		IB23U	IB 2-3 Interburden Upper Split
		CL23U	CL 2-3 Coal Seam Upper Split
		IB23L	IB 2-3 Interburden Lower Split
		CL23L	CL 2-3 Coal Seam Lower Split
		IB24U	IB 2-4 Interburden Upper Split
		CL24U	CL 2-4 Coal Seam Upper Split
		IB24L	IB 2-4 Interburden Lower Split
		CL24L	CL 2-4 Coal Seam Lower Split
		IB27U	IB 2-7

			Interburden Upper Split
		SL	Sand Lense
		CL27U	CL 2-7 Coal Seam Upper Split
		IB27L	IB 2-7 Interburden Lower Split
		CL27L	CL 2-7 Coal Seam Lower Split
		IB28U	IB 2-8 Interburden Upper Split
		CL28U	CL 2-8 Coal Seam Upper Split
		IB28L	IB 2-8 Interburden Lower Split
		CL28L	CL 2-8 Coal Seam Lower Split
		IB31	IB 3-1 Interburden
		A3	3rd Aquifer Sub-burden

carbonates and other acid consuming minerals present in the original sample. ANC may be reported as either kg CaCO3or Kg H2SO4 equivl/ton. ANC was tested through EA013 [19]. A fizz test is done to semi quantitatively estimate the likely reactivity. The soil then reacted with known excess quantity of an appropriate acid. Titration determines the acid remaining, and the ANC can be calculated from comparison with a blank titration.

The pH value indicates whether the material is acid or alkaline. A pH below 5.5 suggests that prior acid generation may have occurred pH was tested by PC titrator using ALS method EA005-P [20]. This procedure determines pH of water samples by automated ISE. This method is compliant with NEPM (2013) Schedule B (3).Total sulfur analyzed using method ED042T [21] in which dried and pulverized sample is combusted in a high temperature furnace in the presence of strong oxidants / catalysts. The evolved S (as SO2) is measured by infra-red detector. Sulphate was determined by ALS using inhouse method named ED040T [22], Total sulfate is determined off a HCl digestion by ICPAES as S and reported as SO4.

Data Analysis

Data analysis is performed using Acid-Base accounting (ABA) methodology. ABA accounting tests have the advantage of simplicity and low cost analysis [4]. Dataset includes complete vertical section of Thar coal block (see Table IV). Objective is to distinguish potentially acid.

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Table III Sample details with easting, northing, elevation and lithological unit

S. No.	Sample ID	Easting	Northing	Elevation - Top	Lithological Unit	
1	IPS-01	640518	2740283.13	49.15	DS-01	Dune Sand
2	IPS-02	640518	2740283.13	44.94	DSC	Compacted Sand
3	IPS-03	640375.01	2740511.64	35.27	DS-02	Dune Sand
4	IPS-11	641030.29	2740833.27	18.2	SL	Sand Lens (SubRecent)
5	IPS-04	641030.29	2740833.27	19.29	SC-01	Silty Claystone
6	IPS-05	640655.065	2740531.811	9.062	SC-01	Silty Claystone
7	IPS-06	640479.26	2740596.85	3.38	CS-01	Clayey Siltstone
8	IPS-07	640902.928	2740405.499	-8.727	SC-02	Silty Claystone
9	IPS-08	640768.821	2740742.314	-38.853	CS-02	Clayey Siltstone
10	IPS-09	640781.416	2740737.413	-45.207	SC-03	Silty Claystone
11	IPS-10	640549.76	2740946.06	-48.52	A2	Aquifer Sand
12	1-IB11	640831.281	2740679.071	-61.076	IB11	Carby Claystone
13	IPC-10-1	640578.535	2740739.985	-62.14	IB12	Carby Claystone
14	2-CL12	640833.09	2740679.71	-61.325	CL12	Coal
15	3-IB21	640878.891	2740703.245	-65.361	IB21	Carby Claystone
16	4-IB22	640901.016	2740677.007	-67.821	IB22	Carby Claystone
17	IPC-10-7	640578.535	2740739.985	-68.12	IB22	Carby Claystone
18	5-CL22	640923.948	2740656.528	-70.161	CL22	Coal
19	IPC-10-2	640578.535	2740739.985	-72.46	CL22	Coal
20	6-IB23U	640927.687	2740652.247	-70.634	IB23U	Carby Claystone
21	IPC-10-3	640578.535	2740739.985	-72.98	IB23U	Carby Claystone
22	7-CL23U	640966.585	2740610.997	-73.438	CL23U	Coal
23	IPC-10-4	640578.535	2740739.985	-74.98	CL23U	Coal
24	IPC-10-5	640578.535	2740739.985	-77.14	CL23L	Coal
25	IPC-10-6	640578.535	2740739.985	-78.64	IB24U	Carby Claystone
26	IPC-10-8	640578.535	2740739.985	-80.13	CL24	Coal
27	IPC-10-9	640578.535	2740739.985	-83.11	CL24	Coal
28	IPC-10-10	640578.535	2740739.985	-83.91	IB27U	Carby Claystone
29	IPC-10-15	640578.535	2740739.985	-99.79	IB27L	Carby Claystone
30	IPC-10-19	640578.535	2740739.985	-108.79	IB28U	Carby Claystone
31	IPC-10-22	640578.535	2740739.985	-114.9	IB31	Carby Claystone

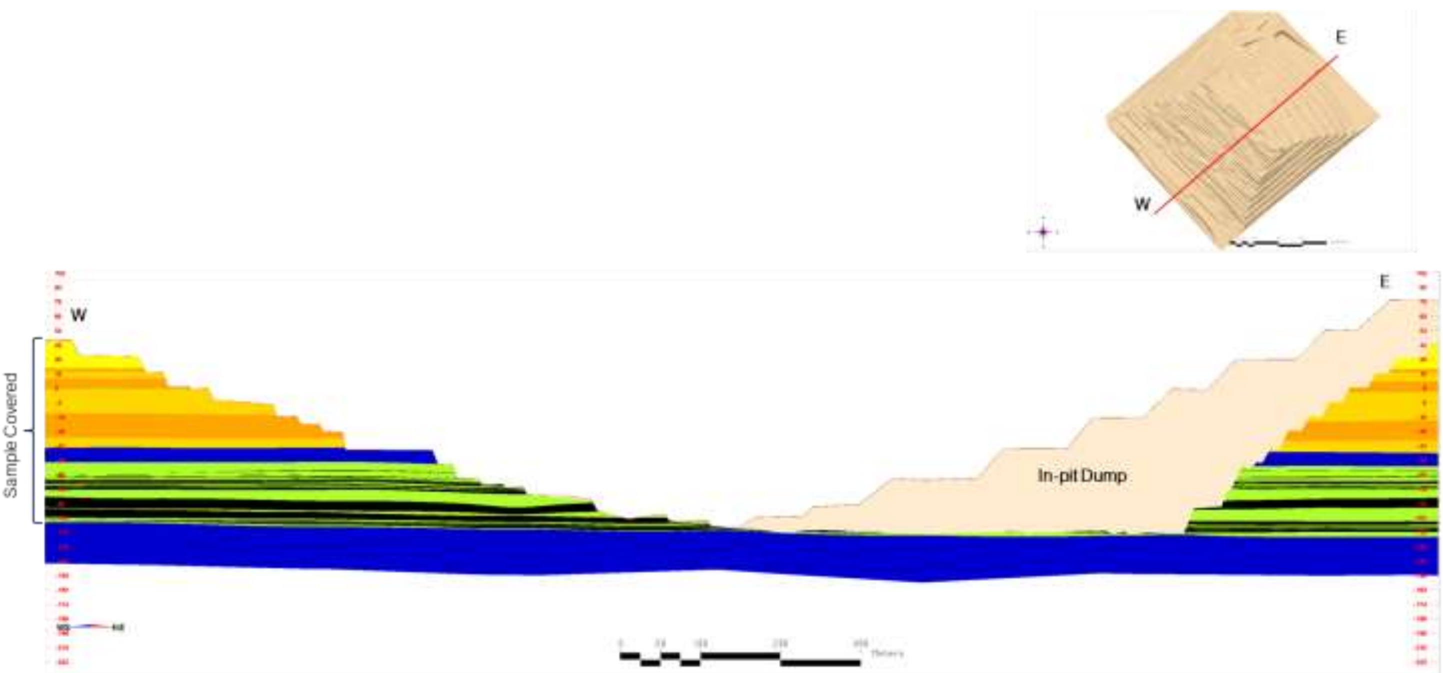

Table IV Summary data for acid base accounting parameters of Thar coal mine (Block-II), where reported (<) means the results lower than the detectable limit

S.No.	Sample ID	Lithological Unit	Acid Prodcution Potential (APP) Kg H2SO4/ton	Acid Neutralizing Capacity (ANC) Kg H2SO4 equiv/ton	Acid Neutralizing Capacity (ANC) % CaCO3	Net Acid Prodcution Potential (NAPP) Kg H2SO4/ton	Fizz Rating		Net Acid Generation, pH-4.5 (NAG) Kg H2SO4/ton	Net Acid Generation, pH-7.0 (NAG) Kg H2SO4/ton	Sulfur as SO4 mg/kg	Total Sulfur %	Net Neutralization Potential NNP	Neutralization Potnetial Ratio NPR	Potential Acid Forming Rock (PAF)	Non Acid Forming Rock (NAF)	Amount of Dune Sand to be Mixed with Acid Prone Material
1	IPS-01	DS-01 (Dune Sand)	0	181	18.5	-181	3	Strong	<0.1	<0.1	<100	<0.01	180.7	591.5		Yes	
2	IPS-02	DSC (Compacted Sand)	0	114	11.6	-114	2	Moderate	<0.1	<0.1	<100	<0.01	113.7	372.5		Yes	
3	IPS-03	DS-02 (Dune Sand)	0	200	20.4	-200	3	Strong	<0.1	<0.1	<100	<0.01	199.7	653.6		Yes	
4	IPS-11	SL (Sand Lense)	0	50.7	5.2	-51	2	Moderate	<0.1	<0.1	<100	<0.01	50.4	165.7		Yes	
5	IPS-04	SC-01 (Silty Claystone)	1	7.1	0.7	-6	1	Slight	<0.1	<0.1	200	0.03	6.2	7.7		Yes	
6	IPS-05	SC-01 (Silty Claystone)	1	4.6	0.5	-4	0	None	<0.1	<0.1	110	0.03	3.7	5.0		Yes	
7	IPS-06	CS-01 (Clayey Siltstone)	0	5.4	0.5	-5	1	Slight	<0.1	<0.1	230	<0.01	5.1	17.6		Yes	
8	IPS-07	SC-02 (Silty Claystone)	1	8.2	0.8	-7	1	Slight	<0.1	<0.1	170	0.04	7.0	6.7		Yes	
9	IPS-08	CS-02 (Clayey Siltstone)	1	2.2	0.2	-1	0	None	<0.1	<0.1	180	0.04	1.0	1.8	Uncertainity		
10	IPS-09	SC-03 (Silty Claystone)	0	10.3	1	-10	1	Slight	<0.1	<0.1	120	<0.01	10.0	33.7		Yes	
11	IPS-10	A2 (Aquifer Sand)	2	1.7	0.2	1	0	None	<0.1	0.8	<100	0.08	-0.7	0.7		Yes	
12	1-IB11	IB11 (Carby Claystone)	218	<0.5	<0.1	218	0	None	202	256	83500	7.13	-217.7	0.0	Yes		132%
13	IPC-10-1	IB12 (Carby Claystone)	79	4.6	0.5	74	0	None	54.5	74.8	2670	2.57	-74.0	0.1	Yes		45%
14	2-CL12	CL12 (Coal)	93	14.2	1.4	79	1	Slight	66.6	119	18200	3.05	-79.1	0.2	Yes		48%
15	3-IB21	IB21 (Carby Claystone)	47	2.9	0.3	44	0	None	34.3	43.7	1680	1.55	-44.5	0.1	Yes		27%
16	4-IB22	IB22 (Carby Claystone)	72	<0.5	<0.1	72	0	None	60.2	76.6	6820	2.34	-71.1	0.0	Yes		44%
17	IPC-10-7	IB22 (Carby Claystone)	178	6.6	0.7	172	0	None	96.3	158	7140	5.83	-171.8	0.0	Yes		104%
18	5-CL22	CL22 (Coal)	35	29.4	3	6	1	Slight	171	263	2110	1.16	-6.1	0.8	Yes		4%
19	IPC-10-2	CL22 (Coal)	215	22.7	2.3	192	1	Slight	182	274	990	7.02	-192.1	0.1	Yes		116%
20	6-IB23U	IB23U (Carby Claystone)	87	0.6	<0.1	86	0	None	80.6	90.9	5240	2.84	-86.3	0.0	Yes		52%
21	IPC-10-3	IB23U (Carby Claystone)	162	2.6	0.3	159	0	None	125	156	3510	5.29	-159.3	0.0	Yes		96%
22	7-CL23U	CL23U (Coal)	35	30	3.1	6	1	Slight	145	242	1630	1.16	-5.5	0.8	Yes		3%
23	IPC-10-4	CL23U (Coal)	104	28.9	2.9	75	1	Slight	82	131	670	3.39	-74.8	0.3	Yes		45%
24	IPC-10-5	CL23L (Coal)	67	37.6	3.8	30	2	Moderate	124	217	910	2.2	-29.7	0.6	Yes		18%
25	IPC-10-6	IB24U (Carby Claystone)	8	7	0.7	1	0	None	<0.1	<0.1	230	0.25	-0.7	0.9	Uncertainity		
26	IPC-10-8	CL24U (Coal)	67	27.2	2.8	41	1	Slight	58.5	109	420	2.2	-40.1	0.4	Yes		25%
27	IPC-10-9	CL24L (Coal)	29	29.8	3	-1	1	Slight	73.9	136	440	0.94	1.0	1.0	Uncertainity		
28	IPC-10-10	IB27U (Carby Claystone)	32	8.8	0.9	23	0	None	<0.1	6	550	1.05	-23.3	0.3	Yes		14%
29	IPC-10-15	IB27L (Carby Claystone)	5	5.2	0.5	<0.5	0	None	<0.1	5.8	160	0.17	0.0	1.0	Uncertainity		
30	IPC-10-19	IB28U (Carby Claystone)	41	8.3	0.8	33	0	None	26.7	50.3	1780	1.34	-32.7	0.2	Yes		20%
31	IPC-10-22	IB31 (Carby Claystone)	15	6.1	0.6	9	0	None	2.8	12.9	220	0.48	-8.6	0.4	Yes		5%

Table V NPR and NNP evaluation criteria

Potential Acid Forming (PAF) Rock	NNP < -20 NPR < 1
Non Acid (NAF) Forming Rock	NNP > 20 NPR > 1
Area of Uncertainty	NNP -20 to +20 NPR 1 to 3

forming rock (PAF) samples from non-acid forming rock (NAF) samples and examine trends or relationships between rocks. Neutralization potential ratio (NPR) is the ratio of the ANC and APP and Net neutralization potential (NNP) is the difference between ANC and APP. NPR and NNP is used for estimating a potential risk for acid mine drainage. The NPR and NNP can be calculated and evaluated by using below criteria (see Table V) [23].

The Fizz rating is also evaluated by using below criteria which stated that; 0 – No reaction, 1 – Slight reaction, 2 – moderate reaction, 3 – strong reaction, 4 – very strong reaction and 5 – lime or carbonate reaction.

PAF, NAP and area of uncertainty of all samples have been classified using Table V. Amount of dune sand (NAP) also calculated to mix with PAF to make it neutralize. Amount of dune sand is calculated in percentage (%) but dividing the NAPP (Kg H2SO4/ton) with average of ANC (Kg H2SO4/ton) (see Table IV).

RESULTS AND DISCUSSION

Acid base accounting of complete stratigraphic section of Thar coal mine indicates potential acid forming rock (PAF), non-acid forming rock (NAF) and area of uncertainty (see Table IV). Non-acid forming characters of Dune Sand (recent) and Alluvial Deposit (sub-recent) matches well with geological information from these lithologies. Moreover, dune sand (recent) deposit shows strong to moderate Fizz ratings and high acid neutralizing capacity (ANC) values ranging from 114 to 200 Kg H_2SO_4/ton, making it a first choice to use as acid neutralizing agent to be mixed with PAF material during sequencing and dumping of mine material. Amount of Dune Sand which needs to be mixed with PAF is calculated and vary in line with net acid production potential (NAPP) of particular rock (see Table IV).

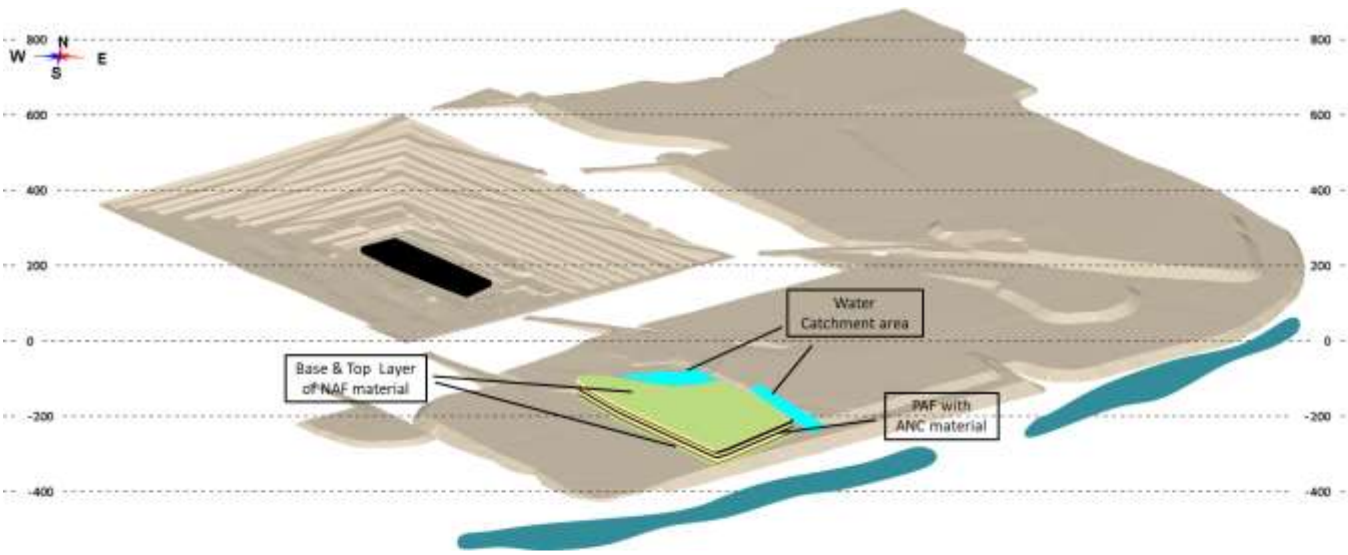

Fig. 3 Schematic illustration of dumping sequence with ANC material to avoid acid rock drainage and leaching

Alluvial (sub-recent) deposit also showing moderate to none NAPP values. Coal bearing Bara Formation which includes coal and carby claystone are major culprit for acid generation or classified as PAF and highest NAPP value of 218 Kg H_2SO_4/ton recorded in IB11 (carby claystone). Considering the divers nature of rocks or material availability in mine, a comprehensive plan is developed to avoid acid rock drainage by utilizing the available ANC material with PAF material during sequencing and storage, so that acid rock drainage can be avoided and mitigate using in-situ material. Dumping area has the highest potential risk of acid rock drainage where acid prone material is being dumped and exposed to sunlight for oxidation. On all dumping areas and where these PAF material is stored a comprehensive dumping plan needs to be followed which is outlined below:

1. Floor of non-acid forming material (NAF) should be developed first where potential acid forming (PAF) material is planned to store or dump, it should be act as a bottom layer or bottom seal to avoid acid leaching in sub-surface.

2. Store or dump PAF or acid prone material with ANC material (dune sand) in accordance with the percentage mentioned in Table IV on relevant dumping site.

3. After the completion of PAF material with ANC material, develop a cap layer or top and side seal layer with NAF material i.e. Dune Sand and Sub-recent alluvial deposit and seal them completely from bottom to top.

4. Develop a catchment area or trenches near storage or dumping site so that water samples can be collected and examine for any potential acid formation and leaching (Fig. 3).

4. Piezometers needs to be drilled/installed at the back side of dumping area where potential acid forming rock is being dumped for monitoring the pH content of seepage water.

Moreover naturally, Thar coal site is blesses with a thick layer of Dune Sand (see Table II) so it is also act as an natural ANC layer and it helps to mitigate the leaching of acid rock drainage to subsurface.

SUMMARY AND CONCLUSION

The results indicate that all the coal and carby claystone layers from bara formation are potential acid forming and are prone to acid rock drainage. However, waste layers from dune sand and sub-recent formation are classified as non-acid forming rocks. Acid neutralizing capacity results indicate that dune sand formation and sand lens from sub-recent formation has moderate to strong acid neutralization capacity and can be used with potential acid forming rock in accordance with the provided percentage in Table IV to mitigate the acid rock drainage and leaching.

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