

# Contents

<i>Acknowledgements</i>	XXIX
<i>Preface</i>	XXXI
<i>Conversion table</i>	XXXV
<b>I Introduction</b>	<b>I</b>
1.1 Excavations and their classification	1
1.2 Surface excavations	2
1.3 Underground excavations	2
1.4 Importance of minerals and brief history of their recovery	3
1.5 Current status of mineral industry	6
1.6 Excavation technologies/systems – development & growth	6
1.7 Unique features of mineral industry	14
1.7.1 Different phases of mine life	16
1.8 Brief history of civil work excavations including tunneling	16
1.9 The current scenario	18
1.9.1 Population growth	18
1.9.2 Lifestyle	19
1.9.3 Globalization	19
1.9.4 Buyer's market	19
1.9.5 Technological developments and renovations	20
1.9.6 Information technology (IT) and its impacts	20
1.10 Tomorrow's mine & civil excavations	20
1.11 The way forward	22
Questions	22
References	23
<b>2 Rocks, minerals and mineral inventory evaluation</b>	<b>25</b>
2.1 Formation process and classification	25
2.1.1 Igneous rocks	27
2.1.2 Sedimentary rocks	27
2.1.3 Metamorphic rocks	28
2.2 Rock cycle & type of deposits	29
2.3 Texture, grain size and shape	29
2.3.1 Grain sizes and shapes	31
2.3.2 Durability, plasticity and swelling potential of rocks	31

## Contents

2.4	The concepts of mineral resources and reserves; mineral inventory, cutoff grade and ores	32
2.4.1	Some important ores – chemical & mineralogical composition	32
2.5	Geological structures	32
2.5.1	Geometry of a deposit	32
2.5.2	Forms of deposits	34
2.5.3	Structural features of rock mass	34
2.6	Physical and mechanical characteristics of ores and rocks	37
2.6.1	Rocks as rock mechanics	37
2.6.2	Rock composition	38
2.6.3	Rock strength	40
2.7	Some other properties/characteristics	41
2.7.1	Hardness of minerals	41
2.7.2	Rock breakability	42
2.8	Related terms – rock and mineral deposits	43
2.9	Mineral inventory evaluation	45
2.9.1	Introduction	45
2.9.2	Grade computation from borehole data	46
2.9.3	Mineral inventory modelling/estimation techniques	46
2.9.3.1	Method of polygons	47
2.9.3.2	Triangle or triangular prism method	48
2.9.3.3	Cross-sectional method	49
2.9.3.4	Inverse Square Distance Weighting (IDW) method	50
2.9.3.5	Classical statistics	50
2.9.3.6	Geostatistics	50
2.9.3.7	Non-linear estimation techniques in geostatistics	51
2.9.4	Important considerations for evaluation of the mineral inventory	53
2.9.4.1	Homogeneity and mode of origin	53
2.9.4.2	Geological and mineralogical boundaries	53
2.9.5	Computation of the mineral inventory	55
2.9.5.1	Logical steps followed	55
2.9.5.2	Graphical presentation of data	55
2.9.5.3	Statistical analysis and cumulative probability distribution	56
2.9.5.4	Structural analysis – the semi-variogram	56
2.9.5.5	Trend surface analysis	57
2.9.5.6	Checking the variogram model	57
2.9.5.7	Block kriging	57
2.9.5.8	Block dimensions	57
2.9.5.9	Kriging procedure	58
2.9.6	Graphical presentation of the kriged results	58
2.9.7	Grade-tonnage calculation and plotting the curves	60
2.9.8	Selection of a suitable mining/stoping method	61
2.10	Resources classification by UNECE	62
2.11	The way forward	66
	Questions	66
	References	69

<b>3 Prospecting, exploration &amp; site investigations</b>	<b>71</b>
3.1 Introduction	71
3.2 Prospecting and exploration	71
3.2.1 Finding signs of the mineral in the locality or general indications	71
3.2.1.1 Geological studies	72
3.2.1.2 Geo-chemical studies	72
3.2.2 Finding the deposit or preliminary proving	73
3.2.2.1 Geophysical methods/studies/surveys	73
3.2.2.2 Putting exploratory headings	77
3.2.3 Exploring the deposits or detailed proving – prospecting drilling	78
3.3 Phases of prospecting and exploration program	81
3.4 Site investigations for civil constructions, or any excavation project including tunnels and caverns	82
3.5 Rocks and ground characterization	84
3.5.1 Rock strength classification	84
3.5.2 Rock mass classifications	85
3.6 Rock quality designation (RQD)	85
3.6.1 Q (Rock mass quality) system	87
3.6.2 Geomechanics classification (RMR system)	87
3.6.3 Rock structure rating (RSR)	91
3.7 Geological and geotechnical factors	93
3.8 The way forward	93
Questions	95
References	96
<b>4 Drilling</b>	<b>97</b>
4.1 Introduction – unit operations	97
4.2 Primary rock breaking	97
4.3 Drilling	98
4.4 Operating components of the drilling system	98
4.5 Mechanics of rock penetration	99
4.5.1 Top-hammer drilling	100
4.5.2 Down-the-hole (DTH) drilling	100
4.5.3 Rotary drilling	101
4.5.4 Auger drill	101
4.5.5 Rotary abrasive drilling	102
4.6 Rock drill classification	102
4.6.1 Tunneling/development drill jumbos	105
4.6.2 Shaft jumbos	105
4.6.3 Ring drilling jumbos	105
4.6.4 Fan drilling jumbos	106
4.6.5 Wagon drill jumbos	106
4.6.6 DTH drill jumbos	106
4.6.7 Roof bolting jumbos	107

## Contents

4.7	Motive power of rock drills	107
4.7.1	Electric drills	107
4.7.2	Pneumatic drills	107
4.7.3	Hydraulic drills	107
4.8	Drilling accessories	108
4.8.1	Extension drill steels	109
4.8.2	Bits	109
4.8.3	Impact of rock-type on drilling performance	111
4.9	Selection of drill	111
4.10	Summary – rocks drill applications	112
4.11	Drilling postures	114
4.12	The way forward	114
	Questions	114
	References	116

## 5 Explosives and blasting

5.1	Introduction – explosives	117
5.2	Detonation and deflagration	117
5.3	Common ingredients of explosives	118
5.4	Classification of explosives	118
5.4.1	Primary or initiating explosives	118
5.4.2	Secondary explosives	119
5.4.3	Pyrotechnic explosives	119
5.4.4	Low explosives	119
5.4.5	Commercial explosives – high explosives	120
5.4.5.1	Gelatin explosives	120
5.4.5.1.1	Dynamites (straight dynamite, ammonia dynamite)	120
5.4.5.1.2	Blasting gelatin	121
5.4.5.1.3	Semi gelatin	121
5.4.5.2	Wet blasting agents	121
5.4.5.2.1	Slurry explosives	122
5.4.5.2.2	Emulsions	122
5.4.5.2.3	Heavy ANFO	122
5.4.5.3	Dry blasting agents	122
5.4.5.3.1	Explosive ANFO	122
5.4.5.3.2	ANFO mixing	123
5.4.5.3.3	ANFO loading	123
5.4.5.4	Pneumatic loaders and principles of loading	124
5.4.5.4.1	Pressure type loaders	124
5.4.5.4.2	Ejector type loader	125
5.4.5.4.3	Combine type (combining pressure and ejecting features)	125
5.4.5.5	Safety aspects	125
5.4.5.6	Static hazards associated with ANFO loading	126
5.4.5.7	Special types of explosives	127
5.4.5.7.1	Permitted explosives	127

5.4.5.7.2	Seismic explosives	127
5.4.5.7.3	Overbreak control explosives	127
5.4.6	Military explosives	127
5.5	Blasting properties of explosives	128
5.5.1	Strength	128
5.5.2	Detonation velocity	129
5.5.3	Density	131
5.5.4	Water resistance	131
5.5.5	Fume characteristics, or class, or medical aspects	131
5.5.6	Oxygen balance	131
5.5.7	Completion of reaction	133
5.5.8	Detonation pressure	133
5.5.9	Borehole pressure and critical diameter	133
5.5.10	Sensitivity	133
5.5.11	Safety in handling & storage qualities	134
5.5.12	Explosive cost	134
5.6	Explosive initiating devices/systems	134
5.6.1	Detonator system	135
5.6.1.1	Detonators	135
5.6.1.2	Instantaneous detonators	137
5.6.1.2.1	Plain detonator	137
5.6.1.2.2	Instantaneous electric detonators	137
5.6.1.3	Delay detonators	137
5.6.1.3.1	Electric delay detonators	137
5.6.1.3.2	Electronic delay detonators	138
5.6.1.3.3	Non-electric delay detonators: detonating relays (ms connectors)	138
5.6.1.3.4	Primaget and anodet non-electric delay blasting systems	139
5.6.1.3.5	The nonel system	139
5.6.1.3.6	Combine primadet-nonel system	140
5.6.1.3.7	The hercudet blasting cap system	140
5.6.1.3.8	Advantages of short delay blasting	140
5.6.2	Fuse/cord system	141
5.6.2.1	Safety fuse	141
5.6.2.2	Detonating fuse/cord (DC)	141
5.6.2.3	Igniter cords (IC)	141
5.7	Explosive charging techniques	142
5.7.1	Water gel (slurry loader)	143
5.8	Blasting accessories	143
5.8.1	Exploders	143
5.8.2	Circuit testers	144
5.8.3	Other blasting tools	146
5.9	Firing systems – classification	146
5.9.1	While firing with a safety fuse	146
5.9.2	Firing with electric detonators	146
5.9.3	Non-electric systems	146

## Contents

5.10	Ground blasting techniques	147
5.10.1	Control/contour blasting	147
5.10.1.1	Pre-splitting	147
5.10.1.2	Cushion blasting	148
5.10.1.3	Smooth blasting & buffer blasting	148
5.10.1.4	Line drilling	149
5.11	Secondary breaking	149
5.11.1	Secondary rock breaking methods	150
5.11.1.1	With the aid of explosives	150
5.11.1.1.1	Plaster shooting	150
5.11.1.1.2	Pop shooting	150
5.11.1.1.3	Releasing jammed muck from the draw points	151
5.11.2	Without aid of explosives	151
5.11.2.1	Mechanical rock breaking	151
5.11.2.1.1	Manual breaking	151
5.11.2.1.2	Mechanical rock breakers	151
5.11.2.1.3	Hydraulic rock breakers	151
5.11.2.1.4	Teledyne rock breaker	152
5.11.2.2	Electrical rock breaking	153
5.11.2.2.1	Rock breaking by the use of high frequency current	153
5.11.2.3	Hydraulic boulder splitter	155
5.12	Use, handling, transportation and storage of explosives	155
5.12.1	Magazine	156
5.13	Explosive selection	157
5.14	Blasting theory	158
5.14.1	Adverse impacts of explosives	158
5.14.1.1	Ground/land vibrations	160
5.14.1.2	Air blast and noise	162
5.14.1.3	Rock throw	162
5.15	Drilling and blasting performance	163
5.15.1	Percentages pull	163
5.15.2	Over-break factor	163
5.15.3	Degree of fragmentation	163
5.15.4	Overall cost	163
5.16	Recent trends in explosives and blasting technology	165
5.17	Concluding remarks	168
	Questions	168
	References	172
<b>6</b>	<b>Mucking, casting and excavation</b>	<b>175</b>
6.1	Introduction	175
6.2	Muck characteristics	176
6.3	Classification	177
6.4	Underground mucking units	177
6.4.1	Overshot loaders	177

6.4.2	Autoloaders – hopper loaders and LHDs	178
6.4.2.1	Autoloaders – mucking and delivering	178
6.4.2.2	Mucking and transporting – load haul and dump units (LHDs)	181
6.4.2.2.1	Constructional details	181
6.4.2.2.2	Special provisions	181
6.4.2.2.3	Buckets of LHD and other dimensions	181
6.4.2.2.4	LHD tyres	182
6.4.2.2.5	Distance, gradient and speed	182
6.4.2.2.6	Ventilation	182
6.4.2.2.7	Latest developments	183
6.4.2.3	Desirable features	183
6.4.2.3.1	Perfect layout	183
6.4.2.3.2	Suitable drainage and road maintenance	183
6.4.2.3.3	Well-fragmented muck	184
6.4.2.3.4	Maintenance	184
6.4.2.3.5	Trained personnel	184
6.4.2.4	Advantages	184
6.4.2.5	Limitations	185
6.4.2.6	Manufacturers	185
6.5	Arm loaders	186
6.5.1	Gathering-arm-loader (GAL)	186
6.5.2	Arm loaders for sinking operations	186
6.5.3	Riddle mucker	186
6.5.4	Cryderman mucker	186
6.5.5	Cactus-grab muckers	186
6.5.6	Backhoe mucker	187
6.6	Scrapers	187
6.7	Mucking in tunnels	187
6.7.1	Dipper and hydraulic shovels	188
6.7.2	Mucking in TBM driven tunnels	188
6.8	Surface – excavation, loading and casting units	188
6.9	Wheel loaders – front end loaders	189
6.10	Backhoe	190
6.11	Hydraulic excavators	190
6.12	Shovel	191
6.13	Dragline	192
6.13.1	Multi bucket excavators	195
6.14	Bucket chain excavator (BCE)	195
6.15	Bucket wheel excavator (BWE)	195
6.16	Calculations for selection of shovel/excavator	198
6.17	Total cost calculations	200
6.18	Governing factors for the selection of mucking equipment	200
6.19	The way forward	201
	Questions	202
	References	204

## Contents

<b>7 Transportation – haulage and hoisting</b>	<b>205</b>
7.1 Introduction	205
7.2 Haulage system	205
7.2.1 Rail or track mounted – rope haulage	206
7.2.1.1 Rope haulage calculations	208
7.2.1.1.1 Direct rope haulage system	208
7.2.1.1.2 Endless rope haulage system	209
7.2.1.2 Scope and applications of rope haulage	209
7.2.2 Locomotive haulage	209
7.2.2.1 Electric locomotives	210
7.2.2.2 Battery locomotives	211
7.2.2.3 Combination locomotives	211
7.2.2.4 Diesel locomotives	211
7.2.2.5 Compressed air locomotives	212
7.2.2.6 Other fittings	213
7.2.2.7 Locomotive calculations	213
7.3 Trackless or tyred haulage system	214
7.3.1 Automobiles	214
7.3.2 LHD	214
7.3.3 Shuttle car	215
7.3.4 Underground trucks	215
7.3.4.1 Trackless or tyred haulage system	217
7.4 Conveyor system	221
7.4.1 Belt conveyors	221
7.4.1.1 Conveyor calculations	223
7.4.2 Cable belt conveyors	224
7.4.3 Scraper chain conveyors	224
7.5 Hoisting or winding system	225
7.5.1 Head-frame or head-gear	226
7.5.2 Shaft conveyances	226
7.5.3 Rope equipment	226
7.5.4 Classification of hoisting system	228
7.5.4.1 Multi-rope friction winding system	229
7.5.5 Hoisting cycle	231
7.5.6 Calculations of suspended load during hoisting	231
7.5.7 Use of safety devices with a hoisting system	234
7.6 Aerial ropeway	234
7.6.1 Aerial ropeway calculations	235
7.7 Ropes	236
7.7.1 Rope calculations	239
7.8 Track and mine car	240
7.8.1 Track	240
7.8.2 Mine cars	240
7.9 The way forward	241
Questions	242
References	247

<b>8 Supports</b>	<b>249</b>
8.1 Introduction – necessity of supports	249
8.2 Classification of supports	250
8.3 Self support by in-place (in-situ) rock	250
8.3.1 Support by the use of natural pillars	250
8.3.2 Use of artificial supports	252
8.3.2.1 Brick and stone masonry	252
8.3.2.2 Wooden (timber) supports	252
8.3.2.2.1 Calculations with regard to wooden supports	253
8.3.2.3 Steel supports	256
8.3.2.3.1 Steel props, powered and shield supports	257
8.3.2.3.2 Rock bolting	259
8.3.2.4 Concrete supports	265
8.3.2.5 Support by filling	268
8.4 Selection of support	270
8.4.1 Measures to preserve the stability of the stope or workings or to minimize problems of ground stability	270
8.5 Effect of ore extraction upon displacement of country rock and surface	271
8.6 The way forward	272
Questions	272
References	274
<b>9 Drives and tunnels (conventional methods)</b>	<b>277</b>
9.1 Introduction – function of drives and tunnels	277
9.2 Drivage techniques (for drives and tunnels)	277
9.3 Drivage techniques with the aid of explosives	278
9.3.1 Pattern of holes	278
9.3.1.1 Mechanized-cut kerf	279
9.3.1.2 Blasting off the solid	279
9.3.1.2.1 Parallel hole cuts	279
9.3.1.2.2 Verification of pattern of holes	291
9.3.2 Charging and blasting the rounds	292
9.3.2.1 Placement of primer	292
9.3.2.2 Stemming	292
9.3.2.3 Depth of round/hole	292
9.3.2.4 Charge density in cut-holes and rest of the face area	292
9.3.3 Smooth blasting	293
9.3.3.1 Charging and blasting procedure	294
9.3.3.2 Use of ANFO in drives and tunnels	295
9.4 Muck disposal and handling (mucking and transportation)	295
9.5 Ventilation	298
9.5.1 Mine opening ventilation	299
9.5.1.1 Using general air flow	299
9.5.1.2 Using auxiliary fans: forcing, exhaust or contra rotating	299
9.5.2 Ventilation during civil tunneling	301

## Contents

9.6	Working cycle (including auxiliary operations)	302
9.7	Driving large sized drives/tunnels in tough rocks	303
9.7.1	Full-face driving/tunneling	303
9.7.2	Pilot heading technique	304
9.7.3	Heading and bench method	305
9.8	Conventional tunneling methods: tunneling through the soft ground and soft rocks	305
9.9	Supports for tunnels and mine openings	307
9.9.1	Classification	308
9.9.2	Selection of supports	311
9.10	Driving without aid of explosives	314
9.11	Pre-cursor or prior to driving civil tunnels	315
9.11.1	Site investigations	315
9.11.2	Location of tunnels	315
9.11.3	Rocks and ground characterization	315
9.11.4	Size, shape, length and orientation (route) of tunnels	317
9.11.5	Preparatory work required	317
9.12	Past, present and future of tunneling technology	317
9.13	Over-break and scaling – some innovations	319
9.14	Longer rounds – some trials	319
9.15	The way forward	322
	Questions	323
	References	325
<b>10</b>	<b>Tunneling by roadheaders and impact hammers</b>	<b>327</b>
10.1	Tunneling by boom-mounted roadheaders	327
10.2	Classification boom-mounted roadheaders	330
10.2.1	Ripper (transverse) type roadheaders – (Cutter heads with rotation perpendicular to the boom axis)	330
10.2.1.1	Bar type	331
10.2.1.2	Disc type	331
10.3	Milling or longitudinal (auger) roadheaders	331
10.3.1	Borer type roadheaders	332
10.4	Classification based on weight	333
10.5	Advantages of roadheaders	333
10.6	Important developments	333
10.7	Procedure of driving by the heading machines	335
10.8	Auxiliary operations	336
10.8.1	Ground support	336
10.9	Hydraulic impact hammer tunneling	336
10.10	Excavation procedure and cycle of operations	336
10.10.1	Hammer's working cycle	337
10.11	Merit and limitations	338
10.12	Partial face rotary rock tunneling machines	338
10.13	Excavators	339
10.13.1	Excavators mounted within shield	339
10.13.1.1	Excavator buckets	339

10.14	Excavator with multiple tool miner (MTM) attachments	340
10.14.1	Excavator mounted within a shield	340
10.14.2	Excavator-mounted cutter booms (Partial face machines for NATM)	341
10.15	The way forward	342
	Questions	342
	References	343
<b>11</b>	<b>Full-face tunnel borers (TBMs) &amp; special methods</b>	<b>345</b>
11.1	Introduction	345
11.1.1	Improved understanding	345
11.2	Tunneling methods and procedures	346
11.3	Full-face tunneling machines	347
11.3.1	Full-face tunnel borers (mechanical) TBM – open and shielded	348
11.3.2	Mechanical excavation of the full cross-section with open type machines	351
11.3.2.1	Open main beam machines	351
11.3.2.2	Single shield	353
11.3.2.3	Double shield	353
11.3.2.4	Enlarging TBM	354
11.4	Mini tunnel borers	358
11.5	Boring system	358
11.6	Rock cutting tools and their types	359
11.6.1	Cutting head configuration	359
11.7	TBM performance	361
11.7.1	Economical aspects	361
11.8	Size of unit and its overall length including its trailing gear	362
11.8.1	Advantages	362
11.8.2	Disadvantages	362
11.9	Backup system/activities	363
11.9.1	Muck disposal	363
11.9.2	Single track	363
11.9.3	Double track	363
11.9.4	Continuous conveyor system	363
11.9.5	Other back-ups include	364
11.10	TBMs for soft ground/formations	365
11.10.1	Full-face shield with picks	365
11.10.2	Compressed air shields	367
11.10.3	Slurry shield	369
11.10.4	Earth pressure balance	369
11.10.4.1	Segments	370
11.10.4.2	Back filling	370
11.10.4.3	Auxiliary construction measures	371
11.10.5	Developments	372
11.11	Phases of tunneling project	375
11.11.1	Tunnel portal	375
11.11.2	Phases of a TBM project	375

## Contents

11.12 Future technology	375
11.12.1 Hard rock TBMs	376
11.12.2 Soft ground machines	376
11.13 New Austrian tunneling method (NATM)	378
11.13.1 NATM design philosophy and typical features	378
11.13.2 Ground categories and tunneling procedures	379
11.13.2.1 Excavation sequence	379
11.13.3 Semi-mechanized methods	379
11.14 Tunneling through abnormal or difficult ground using special methods	382
11.14.1 Ground treatment	382
11.14.1.1 Reinforcement	382
11.14.1.2 Treatment that tackles the problems arising due to the presence of water	383
11.14.1.3 Lowering water table/ground water	383
11.14.1.4 Use of compressed air to hold back water	383
11.14.1.5 Grouting	385
11.14.1.6 Freezing	386
11.15 Cut and cover method of tunneling	386
11.16 Submerged tubes/tunnels	386
11.17 The way forward	387
Questions	387
References	389

## 12 Planning 393

12.1 Economic studies	393
12.1.1 Phases or stages in economic studies	393
12.1.1.1 Preliminary studies or valuation	394
12.1.1.2 Intermediate economic study or pre-feasibility study	394
12.1.1.3 Feasibility study	394
12.1.1.3.1 Information on deposit	394
12.1.1.3.2 Information on general project economics	395
12.1.1.3.3 Mining method selection	395
12.1.1.3.4 Processing methods	395
12.1.1.3.5 Ecology	395
12.1.1.3.6 Capital and operating costs estimates	396
12.1.1.3.7 Project cost & rates of return	396
12.1.1.3.8 Comments	396
12.1.2 Conceptual mine planning and detailed project reports	396
12.1.2.1 Conceptual studies/models	396
12.1.2.2 Engineering studies	398
12.1.2.3 Models and detailed design	398
12.2 Mine design elements	398
12.2.1 Mineral resources and reserves	400
12.2.2 Cutoff grade	402

12.2.2.1	Mining & process plant input-output calculations (for a copper mining complex)	405
12.2.2.2	Cutoff grade calculations	406
12.2.3	Interrelationship amongst the mine design elements	406
12.2.4	Mine life	407
12.2.4.1	Phases or stages during mine life	408
12.3	Dividing property for the purpose of underground mining	409
12.3.1	Panel system	411
12.3.2	Level system	411
12.3.3	Level interval	412
12.4	Mine planning duration	413
12.5	Mine development – introduction	414
12.6	Access to deposit or means of mine access	415
12.7	System – opening up a deposit	417
12.7.1	Opening deposit in parts	417
12.7.2	Opening up the whole deposit	417
12.8	Positioning and developing the main haulage levels	420
12.8.1	Selecting development in ore or rock (country rock)	420
12.8.2	Vertical development in the form of raises	423
12.8.3	Connecting main levels by ramps/declines/slopes	424
12.8.4	Determination of optimal load concentration point	424
12.8.4.1	Analytical method	424
12.8.4.2	Graphical method: funicular diagram	425
12.9	Size and shape of mine openings and tunnels	426
12.10	Pit top layouts	428
12.11	Pit bottom layouts	428
12.11.1	Types of pit bottom layouts	429
12.12	Structures concerning pit bottom layouts	431
12.13	The way forward	431
	Questions	432
	References	437
<b>13</b>	<b>Excavations in upward direction – raising</b>	<b>439</b>
13.1	Introduction	439
13.2	Raise applications in civil and construction industries	439
13.3	Classification – types of raises for mines	440
13.4	Raise driving techniques	441
13.5	Conventional raising method: open raising	441
13.6	Conventional raising method: raising by compartment	442
13.7	Raising by the use of mechanical climbers: Jora hoist	443
13.8	Raising by mechanical climbers: Alimak raise climber	443
13.8.1	Preparatory work and fittings	447
13.8.2	Ignition and telephone systems	447
13.8.3	Cycle of operations	447
13.8.4	Performance	448
13.8.5	Design variants	448
13.8.6	Air-driven unit	448

## Contents

13.8.7	Electrically driven unit	448
13.8.8	Diesel-hydraulic unit	449
13.9	Blasthole raising method: long-hole raising	449
13.9.1	Marking the raise	449
13.9.2	Equipment installation	449
13.9.3	Drilling	450
13.9.4	Raise correlation	450
13.9.5	Blowing and plugging the holes	450
13.9.6	Charging and blasting	451
13.9.7	Limitations	452
13.9.8	Advantages	452
13.10	Blasthole raising method: drop raising	453
13.11	Raising by the application of raise borers	456
13.12	Raise boring in a package – BorPak	459
13.13	Ore pass/waste rock pass	459
13.13.1	Size and shape	460
13.13.2	Ore pass lining	461
13.13.3	Design consideration of rock pass/ore pass	461
13.14	The way forward	464
	Questions	465
	References	466

## **14 Shaft sinking** **469**

14.1	Introduction	469
14.2	Location	469
14.3	Preparatory work required	470
14.4	Sinking appliances, equipment and services	470
14.5	Sinking methods and procedure	472
14.6	Reaching up to the rock head	472
14.6.1	Pre-sink	473
14.7	Sinking through the rock	474
14.7.1	Drilling	475
14.7.2	Blasting	477
14.7.3	Lashing and mucking	478
14.7.4	Hoisting	478
14.7.5	Support or shaft lining	480
14.7.6	Auxiliary operations	480
14.7.6.1	Dewatering	480
14.7.6.2	Ventilation	480
14.7.6.3	Illumination	482
14.7.6.4	Shaft centering	482
14.7.6.5	Station construction and initial development	482
14.8	Special methods of shaft sinking	483
14.9	Piling system	484
14.10	Caisson method	484
14.10.1	Sinking drum process	484
14.10.2	Forced drop-shaft method	486

14.10.3 Pneumatic caisson method	486
14.11 Special methods by temporary or permanent isolation of water	487
14.11.1 Cementation	487
14.11.1.1 Boring/Drilling	487
14.11.1.2 Cementation	487
14.11.1.3 Sinking and walling	488
14.12 The freezing process	488
14.12.1 Drilling and lining of boreholes	489
14.12.2 Formation and maintenance of the ice column	490
14.12.3 Actual sinking operations	491
14.12.4 Thawing of ice wall	491
14.12.5 Freezing – shafts	492
14.12.6 Ground freezing practices in Germany	492
14.13 Shaft drilling and boring	495
14.13.1 Shaft drilling	495
14.13.2 Shaft boring	495
14.14 Safety in sinking shafts	497
14.14.1 Field tests and measurements	497
14.15 The way forward	499
Questions	500
References	501
<b>15 Large sub-surface excavations</b>	<b>503</b>
15.1 Introduction	503
15.2 Caverns	503
15.2.1 Constructional details – important aspects	505
15.2.1.1 Construction procedure	506
15.3 Powerhouse caverns	508
15.4 Oil storage caverns	508
15.5 Repository	509
15.6 Salt cavern storage	512
15.7 Aquifer storage	513
15.8 Exhibition hall caverns	514
15.9 Underground chambers in mines	516
15.10 Equipment and services selection	517
15.11 The way forward	522
Questions	523
References	524
<b>16 Underground mining/stoping methods &amp; mine closure</b>	<b>527</b>
16.1 Introduction	527
16.1.1 Factors governing choice of a mining method	527
16.1.1.1 Shape and size of the deposit	527
16.1.1.2 Thickness of deposit	528
16.1.1.3 Dip of the deposit	529
16.1.1.4 Physical and mechanical characteristics of the ore and the enclosing rocks	529

## Contents

16.1.1.5	Presence of geological disturbances and influence of the direction of cleats or partings	532
16.1.1.6	Degree of mechanization and output required	532
16.1.1.7	Ore grade and its distribution, and value of the product	534
16.1.1.8	Depth of the deposit	534
16.1.1.9	Presence of water	535
16.1.1.10	Presence of gases	535
16.1.1.11	Ore & country rock susceptibility to caking and oxidation	535
16.1.2	Desirable features of selecting a stoping method	536
16.1.3	Classification – stoping methods	538
16.2	Open stoping methods	540
16.2.1	Open stoping method – room & pillar stoping	540
16.2.1.1	Introduction	540
16.2.1.2	Stope preparation	540
16.2.1.3	Unit operations	541
16.2.1.4	Stoping operations	544
16.2.1.5	Bord and pillar	545
16.2.1.6	Block system	546
16.2.1.7	Stope and pillar	548
16.2.1.7.1	Advantages	549
16.2.1.7.2	Limitations	549
16.2.2	Open stoping method – shrinkage stoping	549
16.2.2.1	Introduction	549
16.2.2.2	Stope preparation	551
16.2.2.3	Unit operations	551
16.2.2.4	Stoping operations	552
16.2.2.5	Layouts	552
16.2.2.5.1	Winning the pillars	552
16.2.2.5.2	Advantages	552
16.2.2.5.3	Limitations	553
16.2.3	Open stoping method – sublevel stoping	553
16.2.3.1	Introduction	553
16.2.3.2	Sublevel stoping with benching	554
16.2.3.3	Blasthole stoping	554
16.2.3.4	Longitudinal sublevel stoping	554
16.2.3.5	Transverse sublevel stoping	556
16.2.3.6	Blasthole drilling	556
16.2.4	Large blasthole stoping	558
16.2.4.1	Stope preparation (general procedure)	558
16.2.4.2	VCR method	562
16.2.4.3	Unit operations	562
16.2.4.4	Layouts	563
16.2.4.4.1	Advantages	564
16.2.4.4.2	Limitations	564
16.2.4.4.3	Winning the pillars	564

16.3	Supported stoping methods	564
16.3.1	Supported stoping method – stull stoping	564
16.3.1.1	Introduction	564
16.3.1.2	Unit operations	566
16.3.1.3	Auxiliary operations	566
16.3.1.4	Stope preparation	566
16.3.1.5	Stoping	566
16.3.1.6	Layouts	566
16.3.1.6.1	Variants	567
16.3.1.6.2	Advantages	567
16.3.1.6.3	Limitations	567
16.3.2	Supported stoping method: cut & fill stoping	567
16.3.2.1	Introduction	567
16.3.2.2	Stope preparation	568
16.3.2.3	Stoping	569
16.3.2.4	Unit operations	569
16.3.2.5	Auxiliary operations	570
16.3.2.5.1	Advantages	570
16.3.2.5.2	Limitations	570
16.3.2.5.3	Variants	570
16.3.2.6	Cut and fill with flat back	571
16.3.2.7	Cut and fill with inclined slicing	572
16.3.2.8	Post and pillar cut and fill stoping	572
16.3.2.9	Stope drive or undercut and fill stoping	574
16.3.2.9.1	Filling methods during deep mining	574
16.3.2.9.2	Top slicing (An undercut-and-fill method)	576
16.3.2.9.3	Filling materials	577
16.3.3	Supported stoping method – square set stoping	582
16.3.3.1	Introduction	582
16.3.3.2	Stope preparation	582
16.3.3.3	Stoping	583
16.3.3.4	Unit operations	583
16.3.3.5	Auxiliary operations	583
16.3.3.6	Layouts	583
16.3.3.6.1	Advantages	584
16.3.3.6.2	Limitations	584
16.4	Caving methods	584
16.4.1	Caving method – longwall mining	584
16.4.1.1	Introduction	584
16.4.1.2	Unit operations	585
16.4.1.3	While mining coal	585
16.4.1.4	Stope preparation	585
16.4.1.5	Stoping operations	586
16.4.1.6	Layouts	586
16.4.1.6.1	Advantages	589
16.4.1.6.2	Limitations	589
16.4.1.7	Mining at ultra depths	590

## Contents

16.4.2	Caving method – sublevel caving	594
16.4.2.1	Introduction	594
16.4.2.2	Unit operations	596
16.4.2.2.1	Variants	596
16.4.2.3	Stope preparation (transverse sublevel caving)	596
16.4.2.4	Stope preparation (sublevel caving – longitudinal)	598
16.4.2.5	Layouts	598
16.4.2.5.1	Advantages	598
16.4.2.5.2	Limitations	599
16.4.3	Caving method – block caving	600
16.4.3.1	Introduction	600
16.4.3.2	Unit operations	601
16.4.3.2.1	Variants	602
16.4.3.3	Methods of draw	604
16.4.3.4	Stope preparation	605
16.4.3.5	Layouts	606
16.4.3.5.1	Advantages	612
16.4.3.5.2	Limitations	612
16.5	Common aspects	613
16.5.1	Stope design	616
16.5.1.1	Model parameters	616
16.5.1.2	Design parameters	617
16.5.2	Application of computers in stope design and economic analysis	620
16.5.3	Proposed methodology for selection of a stoping method for the base metal deposits with a case study	620
16.6	Mine liquidation	633
16.6.1	Liquidation of the stopes of different types	633
16.6.2	Planning liquidation	634
16.6.3	Liquidation techniques	634
16.6.4	Pillar types & methods of their extraction	635
16.6.4.1	Pillar extraction methods	636
16.6.4.2	Planning a heavy-blast for liquidation purpose	637
16.6.5	Case studies	637
16.6.5.1	Heavy blasting at a copper mine	637
16.6.5.2	Remnant pillars' blast at lead-zinc mine	642
16.6.5.2.1	Blast planning	642
16.6.5.2.2	Results of the blast	643
16.7	Planning for mine closure	646
16.7.1	Introduction	646
16.7.2	Phases – mine closure	646
16.7.3	The integrated mine closure planning guidelines (toolkit)	646
16.7.3.1	Salient features (parameters to be considered) for closure planning	648
16.7.3.2	Guidelines/toolkit details	652
16.7.3.3	Glossary	668
16.8	The way forward	671
	Questions	671
	References	681

<b>17 Surface excavations</b>	<b>685</b>
17.1 Introduction – surface mining methods	685
17.2 Open pit mining	685
17.2.1 Open pit elements	686
17.2.1.1 Bench angle or slope	688
17.2.2 Overall pit slope angle	688
17.2.2.1 Computation of overall pit slope angle	688
17.2.3 Stripping ratio	691
17.2.4 Overall pit profile	693
17.2.4.1 Coning concept for open pit design	693
17.2.5 Stripping sequence	694
17.3 Haul roads	695
17.4 Ramp and its gradient	695
17.5 Open cast mining/strip mining	697
17.5.1 Introduction	697
17.5.2 Design aspects	697
17.5.3 Operational details – surface mines	698
17.5.3.1 Planning	699
17.5.3.2 Site preparation	699
17.5.3.3 Opening up the deposit	699
17.5.4 Development	701
17.5.4.1 Waste rock dumps	701
17.5.5 Bench blasting design patterns	701
17.5.5.1 Linear formulas	702
17.5.5.2 Power formulas derived by statistical analysis	704
17.5.5.3 Formulas related to energy transfer in rock blasting, burden and blasthole diameter	704
17.5.5.4 Tatiya and Adel's formula to determine burden with respect to blasthole diameter	705
17.5.5.5 Powder factor method	705
17.5.6 Drilling and blasting operations	706
17.5.7 Cast blasting	709
17.5.8 Muck handling	710
17.5.9 Selection of excavator and transportation units	710
17.5.10 Calculations for selection of shovel/excavator	710
17.5.10.1 Time factor	710
17.5.10.2 Operational factor ( $O_f$ )	710
17.5.10.3 Bucket fill factor ( $B_f$ )	711
17.5.11 Theoretical output from an excavator/hr	714
17.5.12 Output from a continuous flow unit	715
17.5.13 Transportation schemes	715
17.5.14 In-pit crushing and conveying	715
17.5.15 Dumping site	716
17.5.16 Integrated or matching equipment complex	719
17.5.16.1 Global Positioning System (GPS)	720
17.5.17 Quarrying of dimension stones	720
17.6 Quarrying of dimension stones	721

## Contents

17.6.1	Drilling	721
17.6.2	Line drilling	726
17.6.3	Discontinuous or spaced drilling	727
17.6.4	Drilling and blasting	727
17.6.4.1	Blast results at Vanga granite quarry in southern Sweden	730
17.6.5	Wire cutter – helicoid and diamond	731
17.6.6	Cutter saw and rock channellers (impact cutting machines)	734
17.6.6.1	Merits	735
17.6.6.2	Disadvantages	735
17.7	The diamond belt saw	735
17.7.1	Water jet technology	736
17.7.2	Thermal cutting	737
17.7.3	Underground quarrying	738
17.8	Earth movers	738
17.9	The way forward	745
	Questions	745
	References	751
<b>18</b>	<b>Hazards, occupational health and safety (OHS), environment and loss prevention</b>	<b>753</b>
18.1	Introduction	753
18.2	Potential excavation hazards	754
18.2.1	Hazards (risks) analysis and management	757
18.3	Safety and accidents	758
18.3.1	Terminology	758
18.3.2	Safety strategies	759
18.3.3	Safety elements	760
18.3.3.1	People/mine workers	760
18.3.3.2	The systems	768
18.3.3.3	The working environment (conditions)	770
18.3.4	Accidents	771
18.3.4.1	Accidents/incident analysis & calculations	771
18.3.4.2	Common accident areas/heads	773
18.3.4.3	Accident costs	774
18.3.4.4	Remedial measures	774
18.3.4.5	Measures/preparedness	774
18.3.4.6	Hazards analysis methods	774
18.4	Occupational health and surveillance	778
18.4.1	Industrial hygiene	778
18.4.1.1	Aqueous effluents – permissible quality & efficient discharge	778
18.4.1.2	House keeping	779
18.4.1.3	The 5S concept	779
18.4.2	Working conditions	780

18.4.3	Ergonomics	781
18.4.3.1	Introduction	781
18.4.3.2	Impacts of poor ergonomics	781
18.4.4	Occupational health surveillance	782
18.4.4.1	Organizational culture and workplace stresses	783
18.4.4.2	'Presenteeism' – lost performance at work	784
18.4.4.3	Periodic health surveillance: based on exposure-risk	784
18.4.4.4	Notified diseases and preventive measures	785
18.5	Environment degradation and mitigation measures	786
18.5.1	Balance system/equation	787
18.5.2	Environmental degradation	787
18.5.3	Environmental management	788
18.5.4	Environmental system	788
18.6	Loss prevention	788
18.6.1	Classification – losses	788
18.6.2	Abnormalities	791
18.6.3	5W-2H analysis	793
18.6.4	Wastage	798
18.6.5	Case-study illustrating computation of financial losses	799
18.6.6	Use of Information Technology (IT) in integrating processes and information	800
18.7	The way forward	801
	Questions	802
	References	805

## **19 Sustainable Development** **807**

19.1	Sustainable Development (SD) in mining	807
19.1.1	Sustainable development	807
19.1.2	Global issues & backlog on sustainable development	807
19.1.3	Sustainable development in mining	807
19.2	Stakeholders and sustainable development	809
19.2.1	Principles/guidelines for SD by ICMM	809
19.2.2	Status of SD in mining, based on stakeholders' views though a survey by globalscan	811
19.3	Scenarios influencing mining industry	813
19.3.1	Population growth and resulting impacts/implications	813
19.3.2	Use of minerals by world's citizens	813
19.3.3	Mineral consumption trends	815
19.3.4	Status of quality, quantity, type of mineral and <i>resources</i> depletion	815
19.3.5	Mineral consumption prediction	817
19.3.6	Mining industry's inherent problems and challenges	818
19.3.7	Global risk ranking and competitiveness in the mining sector	819
19.4	Is mining industry equipped to meet the challenges?	819
19.4.1	Technological developments in mining	819
19.4.2	Initiatives already taken globally to meet demand of minerals mass consumption	821

## Contents

19.5	Proposed strategy to run mines is an economically viable (beneficial) way	821
19.5.1	Exploration: huge, intensive & speedy together with bringing precision in ore evaluation techniques	822
19.5.2	Establishing mineral inventory, cutoff grade and ore reserves	822
19.5.3	Division of mineral property (i.e. orebody or coal deposits into level and panels)	823
19.5.4	Locale-specific challenges and proposed solutions/way-outs	824
19.5.4.1	Underground metalliferous mining challenges	824
19.5.4.2	Underground coal mining challenges	824
19.5.4.3	Open cast/open pit mines (coal & non coal) challenges	825
19.5.5	Mining difficult deposits using non-conventional technologies	826
19.5.6	Improved fragmentation – a better way to extract minerals (ore, waste rocks, overburden) to save energy	826
19.5.7	Precision in operations – maximizing recovery	827
19.5.8	The critical path to full automation	828
19.5.9	Effective utilization of resources through standardization & benchmarking	833
19.5.10	Needs-based changes, research and development	833
19.6	Measures for SD through improvements environmentally, socially and ethically	834
19.6.1	HSE – a critical business activity for sustainable development	834
19.6.2	Economic development regional as well as local – A case-study	835
19.7	Legal compliances and mining policy	836
19.7.1	Mining laws – legislation	836
19.7.2	Minerals & mining policy	837
19.8	Quality of human resources	838
19.8.1	Academic (educational) status and standard of mining schools	838
19.9	The ultimate aim	839
19.9.1	Contented employees & stakeholders	839
19.9.2	Efficient systems including best practices	840
19.9.3	Legal compliance including Environment Management Systems (EMS)	840
19.9.4	World Class Management (WCM)	840
19.10	The way forward: proposed milestones/strategy	840
	Questions	842
	References	845
	Subject index	847