IDENTIFICATION OF HYDROTHERMAL ALTERATION ZONES FOR PORPHYRY COPPER AND GOLD EXPLORATION USING SATELLITE REMOTE SENSING DATA

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Remote Sensing)

Faculty of Geoinformation and Real Estate
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JUNE 2012

This thesis is dedicated to my beloved Mother, Father, Sister and my brother

Thank you very much for your kind help and encouragement.

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my deepest gratitude and appreciation to my research supervisor Prof. Sr. Dr. Mazlan Hashim for his constructive advice, guidance, commitment and supportive encouragement throughout this research.
I am really thankful of Geoinformation and Real Estate faculty for complete assistance during all stages of the research.

My appreciation is also given to my family for financial support during my education. I would like to thank all my friends especially Amir Khosravi, Rasol Sadeghi, Mahmmod Asadi, Amir Bagheri, Dr. Mohsen Khalily and Dr. Mehdi Mazar Atabaki.

ABSTRACT

This study developed a new approach to extract geologic information for porphyry copper and epithermal gold exploration in the arid and semi-arid regions using combined satellite remotely sensed data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Advanced Land Imager (ALI) and Hyperion sensors. Two copper mining districts have been selected in southeastern segment of the NW-SE trending Urumieh-Dokhtar Volcanic Belt that is located in the Tethyan Copper Belt of Iran. The performance of the principal component analysis, band ratio and minimum noise fraction methods was evaluated for ASTER and ALI data to enhance vegetation, iron oxide/hydroxide, clay minerals and lithological units. Spectral angle mapper (SAM), linear spectral unmixing (LSU), matched-filtering (MF) and mixture-tuned matched-filtering (MTMF) methods were tested on shortwave infrared (SWIR) bands of ASTER and ALI to distinguish the phyllic, argillic and propylitic alteration zones associated with porphyry copper mineralization. Analytical Imaging and Geophysics (AIG)-Developed hyperspectral analysis processing methods were used for spectral bands covering the SWIR spectral range (2.0 to 2.4 μm) of the Hyperion data for mapping predominant mineral assemblages in hydrothermal alteration zones. A field reconnaissance, X-ray diffraction (XRD) analysis and spectral reflectance measurements were performed to verify the results of the study. It is concluded that the integration of spectral information derived from ASTER, ALI and Hyperion data can produce comprehensive and accurate information for copper and gold resource investigations. This approach has a strictly regional interest to Middle Eastern economic geologists for the reconnaissance stages of exploring high economic-potential copper and gold mineralization zones in the arid and semi-arid regions.

ABSTRAK

Kajian ini membangunkan kaedah baru menyari maklumat geologi bagi gali cari porfir tembaga dan epiterma emas di kawasan-kawasan kontang dan separa-kontang dengan mengunakan kombinasi data satellite remote sensing daripada penderia Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Advanced Land Imager (ALI) dan Hyperion. Dua daerah perlombongan tembaga yang dipilih bagi kajian ini berada dalam kawasan segmen tenggara jaluran gunung berapi Urumieh-Dokhtar yang berada dalam arah aliran Barat Laut-Tenggara dan terletak di jaluran tembaga Tethyan Iran. Penilaian kaedah analisis komponen utama, nisbah jalur dan fungsi hinggar minimum keatas data ASTER dan ALI telah dijalankan bagi menonjolkan tumbuh-tumbuhan, oksida besi/ hidrolsida, mineral liat dan unit-unit litologi. Teknik *spectral angle mapper* (SAM), *spectral linear unmixing* (LSU), *matched-filtering* (MF) dan *mixture-tuned matched-filtering* (MTMF) telah diuji pada jalur-jalur infra merah pendek (SWIR) ASTER dan ALI bagi membezakan zon-zon perubahan *phyllic*, *argillic* dan *propylitic* yang berkaitan dengan pemendapan porfir tembaga. Kaedah pemprosesan data hiperspektral *Analytical Imaging and Geophysics* (AIG) telah digunakan pada jalur-jalur *spectral* dalam julat SWIR (2.0 to 2.4 μm) data Hyperion bagi pemetaan himpunan mendapan utama dalam zon-zon perubahan hidroterma. Tinjau lapangan, analisis pembelauan X-ray (XRD) dan pengukuran pembalikan *spectral* sampel telah jalankan bagi mengesahkan dapatan kajian. Kesimpulannya, integrasi maklumat *spectral* yang di terbitkan daripada data ASTER, ALI dan Hyperion boleh menghasilkan sumber maklumat gali cari yang komprehensif dan tepat bagi tembaga dan emas. Kaedah ini mempunyai kepentingan serantau terutamanya kepada para ahli geologi ekonomi di Timur Tenggah bagi peninjauan zon-zon pemendapan tembaga dan emas yang mempunyai potensi ekonomi tinggi di kawasan kontang dan separa-kontang.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
1	**INTRODUCTION**	**1**
	1.1 Background of the study	1
	1.2 Problem Statement	6
	1.3 Objectives	8
	1.4 Scope of the study	9
	1.5 Publications derived from this research	10
2	**LITERATURE REVIEW**	**11**

	2.1	Porphyry Copper Deposit	11
	2.2	Visible near-infrared and shortwave infrared radiation spectra of hydrothermal alteration minerals	22
	2.3	Hyperspectral and multispectral sensors for mapping porphyry copper deposits	26
	2.4	Mapping lithology and hydrothermal alteration minerals using ASTER data	29
	2.5	Mapping lithology and hydrothermal alteration minerals using EO1 data	45
	2.6	Previous remote sensing studies in the Urumieh-Dokhtar Volcanic belt	49
	2.7	Summary	51
3	**METHODOLOGY**		**52**
	3.1	Introduction	52
	3.2	Geological setting	53
		3.2.1 Urumieh-Dokhtar Volcanic Belt	53
		3.2.1.1 Meiduk porphyry copper deposit	58
		3.2.1.2 Sar Cheshmeh porphyry copper deposit	59
	3.3	Research Instruments	61
		3.3.1 ASTER Data	61
		3.3.2 Earth Observing One (EO1) Data	67
		3.3.3 Field reconnaissance and laboratory data	72
		3.3.4 ASTER spectral library	73
	3.4	Methodology	74
		3.4.1 Preprocessing of ASTER Data	74

3.4.2 Preprocessing of EO1 Data 75
3.4.3 Image processing methods 76
3.4.3.1 Principal Component Analysis (PCA) 78
3.4.3.2 Band ratioing 79
3.4.3.3 Minimum Noise Fraction (MNF) 80
3.4.3.4 Spectral mapping methods 81
3.4.3.4.1 Spectral Angle Mapper (SAM) 82
3.4.3.4.2 Linear Spectral Umixing (LSU) 83
3.4.3.4.3 Matched Filtering (MF) 84
3.4.3.4.4 Mixture Tuned Matched Filtering 84
3.4.3.5 AIG-Developed Hyperspectral Analysis methods 85
3.5 Summary 87

4 RESULTS, ANALYSIS AND DISCUSSION 88

4.1 Introduction 88
4.2 The results of conventional image processing methods 89
4.2.1 Principal Component Analysis (PCA) 89
4.2.2 Band Ratio 111
4.2.3 Minimum Noise Fraction (MNF) 123
4.3 The result of spectral mapping methods 130
4.3.1 Spectral Angle Mapper (SAM) 132
4.3.2 Linear Spectral Umixing (LSU) 134
4.3.3 Matched Filtering (MF) technique 138
4.3.4 Mixture Tuned Matched Filtering (MTMF) 138

4.4 AIG-Developed Hyperspectral Analysis methods 144
4.5 Comparison of the image processing methods 152
4.6 Field verification 153
4.7 Summary 165

5 CONCLUSION 166

5.1 Conclusion 166
5.1.1 Enhancement of hydrothermally altered rocks 168
5.1.2 Discrimination of hydrothermal alteration 169
5.1.3 Detection of predominant hydrothermal minerals 170
5.1.4 Capability of image processing methods used 171
5.1.5 Verification of the image processing results 172
5.2 Recommendations for future research 173

REFERENCES 174

Appendix A 213

LIST OF TABLES

TABLE NO.	TITLE	PAGE
3.1	The technical characteristics of ASTER data	64
3.2	The performance characteristics of the ALI and ETM+	68
3.3	The performance characteristics of the Hyperion sensor	71
4.1	Eigenvector matrix of principal components analysis on VNIR+SWIR bands of ASTER data for the Meiduk	91
4.2	Eigenvector matrix of principal components analysis on VNIR+SWIR bands of ASTER data for the Sar Cheshmeh	91
4.3	Eigenvector matrix of principal components analysis on TIR subsystem of ASTER data, the Meiduk scene	100
4.4	Eigenvector matrix of principal components analysis on TIR subsystem of ASTER data, the Sar Cheshmeh scene	100
4.5	Eigenvector matrix of principal components analysis on VNIR bands of ALI data, the Meiduk scene	106
4.6	Eigenvector matrix of principal components analysis on VNIR bands of ALI data, the Sar Cheshmeh scene	106
4.7	Eigenvector matrix of principal components analysis on SWIR bands of ALI data, the Meiduk scene	107
4.8	Eigenvector matrix of principal components analysis on SWIR bands of ALI data, the Sar Cheshmeh scene	107
4.9	The percentage of eigenvalues for all of MNF bands extracted from ASTER VNIR bands, the Meiduk and Sar	123

	Cheshmeh scenes	
4.10	The percentage of eigenvalues for all of MNF bands extracted from ASTER SWIR data, the Meiduk and Sar Cheshmeh scenes	123
4.11	The percentage of eigenvalues for all of MNF bands extracted from ASTER TIR data, the Meiduk and Sar Cheshmeh scenes	123
4.12	The percentage of eigenvalues for all of MNF bands extracted from ALI SWIR data, the Meiduk and Sar Cheshmeh scenes	123
4.13	Statistic results of unmixing end-member minerals, Meiduk/Sara subset scene	134
4.14	Statistic results of unmixing end-member minerals, Sar Cheshmeh/Seridune subset scene	134

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Copper world production trends since 1900	12
2.2	Copper prices from 2003 to 2011 in USD per ton	13
2.3	Copper output in 2005 shown as percentage of the top producer	13
2.4	Panoramic view of the porphyry copper deposits	15
2.5	Worldwide locations of porphyry copper deposits	16
2.6	Hydrothermal alteration zones associated with porphyry copper deposit	18
2.7	ASTER spectral bands in the wavelength of the electromagnetic spectrum. (B) The comparison of ASTER spectral bands with Landsat-7 TM/ETM^+	20
2.8	Laboratory spectra of muscovite, kaolinite, alunite, epidote, calcite, and chlorite resampled to ASTER bandpasses	22
2.9	Laboratory spectra of epidote, calcite, muscovite, kaolinite, chlorite and alunite. (B) Laboratory spectra of limonite, jarosite, hematite and goethite	26
2.10	Comparison of ASTER, AVIRIS and Landsat Thematic Mapper (TM) VNIR and SWIR image spatial and spectral characteristics: (A) Swath width and spatial resolution. (B) Spectral bands	29
3.1	NASA's 2000 GeoCover global orthorectified Landsat 7	54

	mosaics merged image of Iran. The study area is located in black cube in southeastern part of the image	
3.2	Simplified Geology map of the southeastern part of the Urumieh-Dokhtar Volcanic Belt. Study areas are located in the ellipsoidal polygons	57
3.3	Geological map of Meiduk region	59
3.4	Geological map of Sarcheshmeh region	60
3.5	Stereoscopic capability and characteristics of three separate subsystems of ASTER sensor	64
3.6	Applications of ASTER data in wide range of science research	65
3.7	view of the “morning constellation” consists of landsat-7, EO1, SAC-C and Terra platforms	67
3.8	The comparison of Signal-to-Noise Ratios of the ALI bands and ETM^+	69
3.9	The comparison of ALI, ETM+, and ASTER spectral bandpasses on the subject of hydrothermal alteration mineral mapping	70
3.10	Hyperion ground track in relation to ALI and Landsat-7 ETM^+	70
3.11	Hyperion and ASTER spectral bands compared to Landsat-7 ETM^+	72
3.12	Simplified flow chart of the methodology used in this study	77
3.13	Diagram showing the performance of Mixture Tuned Matched Filtering (MTMF) method	85
3.14	AGI processing methods for hyperspectral data analysis	86
4.1	(A) PC4 image for the Meiduk ASTER scene; (B) PC4 image for the Sar Cheshmeh ASTER scene	93

4.2	(A) PC5 image for the Meiduk ASTER scene; (B) PC5 image for the Sar Cheshmeh ASTER scene	94
4.3	(A) PC6 image and (B) PC7 image for the Meiduk ASTER scene	96
4.4	(A) PC6 image and (B) PC7 image for the Sar Cheshmeh ASTER scene	98
4.5	RGB color composite of PC5, PC6, and PC7 image for the Meiduk (A) and Sar Cheshmeh (B) ASTER scenes	99
4.6	(A) PC2 image and (B) PC4 image for the Meiduk ASTER scene	102
4.7	(A) PC2 image and (B) PC3 image for the Sar Cheshmeh ASTER scene	103
4.8	(A) RGB color composite of PC2, band 10, and PC4 image for the Meiduk ASTER scene. (B) RGB color composite of PC2, band 10, and PC3 image for the Sar Cheshmeh ASTER scene	105
4.9	(A) RGB color composite of PC3 (SWIR), PC3 (VNIR), and band 1 image for the Meiduk ALI scene	109
4.9	(B) RGB color composite of PC3 (SWIR), PC3 (VNIR), and band 1 image for the Sar Cheshmeh ALI scene	110
4.10	ASTER StVI= (Band3/Band2)*(Band1/Band2) image for the Meiduk scene (A), and the Sar Cheshmeh scene (B)	112
4.11	ASTER band ratio image of 4/2 for the Meiduk and Sara mines (A), and for the Sar Cheshmeh and Seridune mines (B)	113
4.12	(A) ASTER RBD-ratio image of RBD5, RBD6, and RBD8 in RGB for the Meiduk region. (B) The Sar Cheshmeh region	116

4.13	ASTER band ratio image of 5/6, 7/6, and 9/8 in RGB (A) for the Meiduk; and (B) for the Sar Cheshmeh scene	117
4.14	ASTER band ratio image of 13/14, 14/12, and 7 in RGB for the Meiduk (A) and the Sar Cheshmeh scene (B)	119
4.15	(A) ALI band ratio image of 4/2, 8/9, and 5/4 in RGB for the Meiduk ALI scene	121
4.15	(B) ALI band ratio image of 4/2, 8/9, and 5/4 in RGB for the Sar Cheshmeh ALI scene	122
4.16	(A) RGB color composite of MNF eigenimages 1, 2, and 3 extracted from ASTER SWIR bands for the Meiduk scene. (B) For the Sar Cheshmeh scene	126
4.17	(A) RGB color composite of MNF eigenimages 1, 2, and 3 extracted from TIR bands for the Meiduk scene and (B) for the Sar Cheshmeh scene	127
4.18	(A) RGB color composite of MNF eigenimages 1, 2, and 3 extracted from ALI SWIR bands for the Meiduk scene	128
4.18	(B) RGB color composite of MNF eigenimages 1, 2, and 3 extracted from ALI SWIR bands for the Sar Cheshmeh scene	129
4.19	Laboratory spectra of end-member minerals from ASTER spectral library plotted in the SWIR subsystem	131
4.20	SAM classification image of muscovite, kaolinite, and epidote images as RGB color composite that overlaid on the gray-scale image background for the Meiduk ASTER scene (A), and for the Sar Cheshmeh ASTER scene (B)	133
4.21	Two-dimensional scatter plots, showing unmixing	136

	pixel's value with very low (zero) RMS error for end-member minerals. (A) Moscovite; (B) Kaolinite; (C) Epidote	
4.22	LSU classification image of muscovite, kaolinite, and epidote fractional abundance images as RGB color composite that overlaid on the gray-scale image background. (A) For the Meiduk/Sara ASTER subset scene. (B) For the Sar Cheshmeh/Seridune ASTER subset scene	137
4.23	MF classification image of muscovite, kaolinite, and epidote MF score images as RGB color composite that overlaid on the gray-scale image background of the ASTER subset scenes. (A) For the Meiduk/Sara ASTER subset scene. (B) For the Sar Cheshmeh/Seridune ASTER subset scene	140
4.24	Two-dimensional scatter plots indicate mapped pixels with low infeasibilities and high MF scores for end-member minerals. (A) Muscovite; (B) Kaolinite; (C) Epidote	141
4.25	MTMF classification image of muscovite, kaolinite, and epidote MF score images as RGB color composite that overlaid on the gray-scale image background of the ASTER subset scenes. (A) For the Meiduk/Sara ASTER subset scene; (B) For the Sar Cheshmeh/Seridune ASTER subset scene	142
4.26	MTMF visual results derived from SWIR bands of ALI subscene. (A) For the Meiduk ALI subscene. (B) For the Sar Cheshmeh ALI subscene	143
4.27	MNF eigenvalue plot for selected bands of Hyperion data	144

4.28	(A) RGB color composite of MNF bands 1, 2, and 3 extracted from Hyperion selected bands for the Meiduk/ Sara mines	145
4.28	(B) RGB color composite of MNF bands 1, 2, and 3 extracted from Hyperion selected bands for the Sar Cheshmeh/Seridun mines	146
4.29	Extracted mineral signatures from Hyperion analysis for iron oxide/hydroxide minerals	148
4.30	Extracted mineral signatures from Hyperion analysis for clay alteration minerals	148
4.31	(A) SAM classification image of the distribution of spectrally predominant iron oxide/hydroxide minerals in the hydrothermally altered rocks that showed as colored pixels in the Mieduk/Sara subset scene. (B) Sar Cheshmeh/Seridune subset scene	150
4.32	(A) SAM classification image of the distribution of spectrally predominant clay alteration mineral assemblages in the hydrothermally altered rocks that showed as colored pixels in the Mieduk/Sara subset scene. (B) Sar Cheshmeh/Seridune subset scene.	151
4.33	Field photographs of the study area. (A) Panoramic view of the volcanic rocks. (B) Panoramic view of the sedimentary rocks	155
4.33	Field photographs of the study area. (C) Regional View of Gossan (iron oxide minerals). (D) Volcanic rocks and Gossan	156
4.33	Field photographs of the study area. (E) Regional view of the open-pit quarry of Meiduk porphyry copper mine. (F) Regional view of the open-pit quarry of Sarcheshmeh porphyry copper mine.	157
4.33	Field photographs of the study area. (G) View of the	158

	phyllic zone. (H) View of the phyllic zone	
4.33	Field photographs of the study area. (I) Close-up of the phyllic zone. (J) Close-up of the phyllic zone	159
4.33	Field photographs of the study area. (K) View of the Argillic alteration zone. (L) View of the Propylitic alteration zone	160
4.34	Results of XRD for specific alteration zones (A) Phyllic rock samples; (B) Argillic rock samples; (C) Prophylitc rock samples	161
4.35	Laboratory reflectance spectra of altered rock samples, arrows pointed the maximum absorption	162
4.36	Simplified alteration map illustrates the distribution of hydrothermally altered rocks in the Meiduk mine. This map was produced using Hyperion data. The sampling sites are marked by stars	163
4.37	Simplified alteration map illustrates the distribution of hydrothermally altered rocks in the Sar Cheshmeh mine. This map was produced using published alteration map and Hyperion data. The sampling sites are marked by stars	164

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Remote sensing technology has been used in diverse aspects of Earth sciences, geography, archeology and environmental sciences. Earth scientists have focused on global experiences in environmental geology, mineral and hydrocarbon exploration using remote sensing data. Economic geologists can achieve reconnaissance information via remote sensing data for exploring porphyry copper and epithermal gold mineralization, and additional new prospects around the world, including those yet to be discovered.

The economic development of a country largely depends on its mineral resourses. Increasing demands of minerals by the society due to the exponential increase in population and industrialization emphasize on replenishing of depleting reserves by locating new prospects of ore deposits. Therefore, an organized mineral exploration program is required for a steady growth of a country. Remote sensing technology can provide a boost for mineral exploration investigations. It is capable of collecting data from vast areas through the use of sophisticated sensor systems mounted on satellite or aircraft.

Remote sensing data play a vital role in the initial stages of copper/gold exploration especially in the arid and semi-arid realms, where earth's surface is well-exposed due to very sparse to non-existent vegetation cover. Hydrothermal alteration minerals with diagnostic spectral absorption properties in the visible and near infrared through the shortwave length infrared regions can be identified by multispectral and hyperspectral remote sensing data as a tool for the initial stages of porphyry copper and epithermal gold exploration (Di Tommaso and Rubinstein, 2007; Zhang et al., 2007; Gersman et al., 2008; El Desouky et al., 2008; Van Ruitenbeek et al., 2008; Bedini et al., 2009; Gabr et al., 2010; Ramadan and Abdel Fattah, 2010; Bishop et al., 2011; Pour et al., 2011; Pour and Hashim, 2011a, 2011b, 2011c, 2011d, 2012a, 2012b; Bedini, 2011; Amer et al., 2012; Zoheir and Emam, 2012).

In the initial stage of remote sensing technology development (1970s), geological mapping and mineral exploration were among the most prominent applications (Rowan et al., 1974; Goetz et al., 1975; Abrams et al., 1977; Rowan et al., 1977). Multispectral and hyperspectral remote sensing sensors were used for geological applications, ranging from a few spectral bands to more than 100 contiguous bands, covering the visible to the shortwave infrared regions of the electromagnetic spectrum (Abrams et al., 1983; Rowan et al., 1984; Crowley et al., 1989; Spatz and Wilson, 1995; Clark et al., 1991; Cocks et al., 1998, Kruse et al., 1999; Goetz, 2009; Van der Meer et al., 2012).

Landsat Multi-Spectral Scanner (MSS), Landsat Thematic Mapper (TM) and Syste`m Pour l'Observation de la Terre (SPOT) with four to seven spectral bands have been used for regional scales of geological mapping (Goetz and Rowan, 1981; Goetz et al., 1982; Goetz et al., 1983; Sultan et al., 1987; Tangestani and Moore, 2000; Kavak and Inan, 2002, Kaya et al., 2004; Kavak, 2005). HyMap and the Airborne Visible/IR Image Spectrometer (AVIRIS) hyperspectral sensors with 126 to 224 contiguous bands were used to provide information about hydrothermal alteration minerals on the Earth's surface (Clark et al., 1991; Cocks et al., 1998; Kruse, 1999; Abdelsalam and Stern, 2000; Perry, 2004; Hallman and Ramsey, 2004). Several investigations have discovered that remote sensing hyperspectral sensors are capable to map spectrally distinct hydrothermal alteration minerals, which are important in porphyry copper and epithermal gold deposits exploration (Crowley et al., 1989; Crowley and Clark, 1992; Kruse, 1993; Boardman et al., 1995; Crosta et al., 1998; Cocks et al., 1998; Kruse, 1999; Kruse, 2003; Kruse et al., 2003; Gersman et al., 2008; Bedini et al., 2009).

Recognizing hydrothermally altered rocks through remote sensing instruments have been widely and successfully used for the exploration of epithermal gold, porphyry copper, massive sulfide and uranium deposits (Velosky et al., 2003; Rajesh, 2008; Di Tommaso and Rubinstein, 2007; Van Ruitenbeek et al., 2008; Zhang et al., 2007; Goetz, 2009; Azizi et al., 2010; Pour et al., 2011; Pour and Hashim, 2011a, 2011b, 2011c, 2011d; Bedini, 2011; Amer et al., 2011). Landsat Thematic Mapper /Enhanced Thematic Mapper^{+} (TM/ETM^{+}) image has been used for detecting alteration mineral assemblages associated with epithermal gold and porphyry copper mineralization. Shortwave infrared bands (bands 5 and 7) of TM/ETM^{+} have been used as a tool to identify hydroxyl-bearing minerals in the reconnaissance stages of copper/gold exploration (Rowan et al., 1977; Podwysocki et al., 1984; Crosta and Moore, 1989; Okada et al., 1993; Sabins, 1996; Sabins, 1997; Abdelsalam and Stern, 2000). Band ratio of 5/7 is sensitive to hydroxyl (OH) minerals, which are found in the alteration zones (Kusky and Ramadan, 2002; Inzana et al 2003; Aydal et al., 2007; Rajesh, 2008; Ramadan and Abdel Fattah, 2010). The broad extent of these bands does not allow discriminating specific alteration zones and minerals by TM/ETM^{+} data, which are important for exploring high economic-potential zone for copper/gold mineralization.

Hyperspectral sensors such as HyMap and the Airborne Visible/IR Image Spectrometer (AVIRIS) with more than 100 continuous bands in shortwave infrared region have been also used to obtain accurate information about hydrothermal alteration mineral assemblages (Cocks et al., 1998; Kruse et al., 1999; Kruse and Boardman, 2000; Gersman et al., 2008; Bedini et al., 2009; Bedini, 2009; Goetz, 2009; Bedini, 2011; Van der Meer et al., 2011). Expensive mobilization and small coverage and not readily available data are problems associated with hyperspectral data for geological mapping applications (Smailbegovic and Taranik, 1999).

Recently, the launch of sophisticated remote sensors developed by National Aeronautics and Space Administration (NASA) on the earth orbiter spacecraft such as EOS/Terra and EO1 platforms, has created opportunities for improving the quality and reducing the cost of remote sensing data. The Earth Observing System (EOS)/Terra platform was launched into a near-polar orbit at an altitude of 702 km on 18 December 1999. EOS/Terra is an advanced spaceborne platform carrying three sophisticated sensor consisting of (i) the Moderate Resolution Imaging Spectrometer (MODIS); (ii) the Multiangle Imaging SpectroRadiometer (MISR); and (iii) the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (Pieri and Abrams, 2004).

The Earth Observing-1 (EO-1) satellite was launched on 21 November of 2000 as part of NASA's New Millennuim Program (NMP) technology path-finding activities to enable more effective (and less costly) hardware and strategies for meeting earth science mission needs in the 21st century. The EO-1 platform includes three of the most advanced remote sensing instruments (i) The Advanced Land Imager (ALI); (ii) Hyperion; and (iii) The Linear Etalon Imaging Spectral Array (LEISA) Atmospheric Corrector (LAC). These sensors can be used in a variety of scientific disciplines (Beck, 2003; Ungar et al., 2003). The EO-1 platform orbits in a ground track coverage that is one minute later than Landsat-7 Thematic Mapper. Following EO-1, in nearly the same orbit, are Satelite de Aplicanciones Cientificas (SAC-C; an Argentinean satellite) and EOS/Terra (Folkman et al., 2001; Ungar et al., 2003).

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) remote sensor has sufficient spectral resolution in the shortwave length infrared radiation bands for mapping hydrothermal alteration mineral zones associated with porphyry copper and epithermal gold mineralization (Pour and Hashim, 2011b). Since 2000, ASTER data have been widely and successfully used in lithological mapping and mineral exploration (Hewson et al., 2001; Rowan and Mars, 2003; Rowan et al., 2003; Junek, 2004; Hellman and Ramsey, 2004; Galvao et al., 2005; Watts and Harris, 2005; Vaughan et al., 2005; Hubbard and Crowly, 2005; Rowan et al., 2005; Kavak, 2005; Mars and Rowan, 2006; Rowan et al., 2006; Ducart et al., 2006; Ren and Abdelsalam, 2006; Di Tommaso and Rubinstein, 2007;

Khan et al., 2007; Moghtaderi et al., 2007; Kruse, 2007; Sanjeevi, 2008; Moore et al., 2008; Tangestani et al., 2008; Carranza et al., 2008; Khan et al., 2008; El Desouky et al., 2008; Mezend et al., 2009; Azizi et al., 2010; Amer et al., 2010; Aboelkhair et al., 2010; Gabr et al., 2010; Mars and Rowan, 2010; Kratt et al., 2010; Pour et al., 2011; Pour and Hashim, 2011a, 2011b, 2011c, 2011d, 2012a, 2012b; Gubert et al., 2011; Oztan and Suzen, 2011; Haselwimmer et al., 2011; Mars and Rowan, 2011; Bedini, 2011; Vicente and Fiho, 2011; Salati et al., 2011; Tangestani et al., 2011; Rejendran et al., 2011, 2012; Amer et al., 2012; Zoheir and Emam, 2012).

ALI has six unique wavelength channels spanning the visible and near infrared (0.4-1.0 micrometer (μm)). Because of their respective band center positions, ALI is especially useful for discriminating among ferric-iron bearing minerals in the standpoint of geologic mapping applications (Hubbard et al., 2003; Hubbard and Crowley, 2005).

Hyperion shortwave infrared bands (2.0 to 2.5 μm) can uniquely identify and map hydroxyl-bearing minerals, sulfates and carbonates in the hydrothermal alteration assemblages (Kruse et al., 2003; Gersman et al., 2008; Bishop et al., 2011). First subset of visible and near infrared bands between 0.4 and 1.3 μm can also be used to highlight iron oxide minerals (Bishop et al., 2011).

The near coincidence of EO1 and EOS/Terra platforms allows obtaining images of the same ground areas, resulting comprehensive remote sensing information for the reconnaissance stages of mineral exploration. A comparison approach can also to be used between ASTER, ALI and Hyperion imagery in the field of mineral exploration. Spectral information extraction from ASTER, ALI and Hyperion data has a great ability to assist economic geologists for exploring high economic-potential copper and gold mineralization zones in the arid and semi-arid realms of the Earth. With this in mind, this investigation is concerned with an application of sophisticated image processing methods to ASTER, ALI and Hyperion data for spectral information extraction to highlight hydrothermal alteration zones associated with porphyry copper and epithermal gold mineralization in an arid and semi-arid regions of the Earth.

1.2 Problem Statement

Rapid advances in remote sensing technology and digital image processing techniques have created the best opportunities for detailed mapping and understanding of the earth's surface with perspective of mineral exploration.

Iran is a semi-arid country that is located in the Alpine-Himalian orogenic and metalogenic belt (Tethyan Copper Belt) with great potentials for exploring porphyry copper and epithermal gold deposits. Yearly precipitation averages very low in the most parts of Iran especially in the southeastern segment, thus the deposit's exposure is well due to sparse and nonexistent vegetation cover, which makes it quite suitable for remote sensing analysis. In Iran, due to the unsystematic copper and gold exploration techniques and lack of modern exploration technology, there are numerous unexplored and additional prospects of porphyry copper and epithermal gold deposits. High spectral, spatial and radiometric resolution remote sensing sensors can be the most important tool to detect subtle anomalies associated with unidentified porphyry copper and epithermal gold deposits.

This research develops a successful case application of ASTER, ALI and Hyperion remote sensing data and image processing methods to detect hydrothermal alteration zones associated with porphyry copper and epithermal gold mineralization in the southeastern part of the Urumieh-Dokhtar Volcanic Belt, Iran. The results have important implications in identifying of probable porphyry copper mineralization, and can be extrapolated to virgin or remote areas for exploring high economic-potential porphyry copper and epithermal gold mineralization zones in the arid and semi-arid regions of the Earth.

In this investigation, we selected the NW-SE trending Urumieh-Dokhtar Volcanic Belt as a case study that is located in the Tethyan Copper Belt of Iran. In this belt, the abundance of known and mined porphyry copper and gold deposits reflects its economic potential, which warrants the exploration for new and additional prospects. Our image analyses focuses on the Meiduk and Sar Cheshmeh porphyry copper deposits, which are located in the southeastern part of the Urumieh-Dokhtar

Volcanic Belt, SE Iran, where copper and molybdenum are actively being mined. As the literature admits, few remote sensing studies were carried out in the Urumieh-Dokhtar Volcanic Belt of Iran (Tangestani and Moore, 2002; Ranjbar et al., 2004; Mars and Rowan 2006; Tangestani et al., 2008). However, the previous investigations have been not studied many parts of the Urumieh-Dokhtar Volcanic Belt in detail by the integration of the ASTER, ALI and Hyperion remote sensing data and sophisticated image processing methods at both regional and district scales.

This study is concerned with an application of sophisticated image processing methods to ASTER, ALI and Hyperion data for spectral information extraction to highlight hydrothermal alteration zones associated with porphyry copper and epithermal gold mineralization such as phyllic, argillic and propylitic mineral assemblages in the southeastern part of the Urumieh-Dokhtar Volcanic Belt, SE Iran. The most important purpose of this investigation is to use effective image processing methods to ASTER, ALI and Hyperion data aimed at spectral information extraction for the recognition of high economic-potential areas (the phyllic alteration zone) associated with porphyry copper and epithermal gold mineralization.

1.3 Objectives

The objectives of this research are:

(1) To enhance the hydrothermally altered rocks associated with porphyry copper mineralization, the boundary of lithological units and vegetation by applying conventional image processing methods such as principal component analysis, band ratio and minimum noise fraction using VNIR, SWIR and TIR bands of ASTER, and VNIR and SWIR bands of ALI at regional scale.

(2) To discriminate the phyllic, argillic and propylitic alteration zones, as well as to highlight high economic-potential areas (the phyllic alteration zone) for porphyry copper mineralization by performing spectral mapping methods such as spectral angle mapper, linear spectral unmixing, matched-filtering and mixture-tuned matched- filtering using SWIR bands of ASTER and ALI at both regional and district scales.

(3) To detect predominant hydrothermal alteration mineral assemblages in specific alteration zones using spectral bands covering the visible and near infrared (0.4 to 1.3 μm) and shortwave infrared (2.0 to 2.4 μm) spectral ranges of Hyperion data by running Analytical Imaging and Geophysics (AIG)-Developed hyperspectral analysis processing methods.

(4) To compare the capability of image processing methods used and the results derived from ASTER, ALI and Hyperion data to identify high economic-potential areas for porphyry copper mineralization and lithological units.

(5) To verify the remote sensing results through comparison with comprehensive field reconnaissance, X-Ray diffraction (XRD) analysis and laboratory spectral measurements.

1.4 Scope of the Study

This contribution uses 14 bands of ASTER, 10 bands of ALI and 196 bands of Hyperion data, including two cloud-free level 1B ASTER, ALI and Hyperion scenes, which cover two large mining districts (Meiduk and Sar Cheshmeh porphyry copper deposits) in the southeastern part of Urumieh-Dokhtar Volcanic Belt.

To accomplish specific image processing objectives, ASTER, ALI and Hyperion images of both target sites were processed using the ENVI (Environment for Visualizing Images) version 4.5, ERMapper version 6.4 and ERDAS IMAGINE version 9.2 software packages.

A comprehensive field reconnaissance was carried out to verify the image processing results during 10 to 15 December 2010. Geological locations were measured by a Magellan GPS with an average accuracy 7 m. Samples for laboratory studies were collected through a systematic sampling of fresh and surface-weathered sides of representative hydrothermally altered rocks. The samples were taken from two sites within the open-pit quarry of the Meiduk and Sar Cheshmeh mines and surrounding areas.

Ground photos were taken of the geomorphology, rock units and hydrothermally altered rocks. The mineralogy of fine grained samples was studied using X-ray diffraction (XRD) technique for bulk mineralogy of the hydrothermally altered rocks. The XRD analyses were implemented on bulk powder using an X-ray diffractometer D8ADVANCE model at the Material laboratory in *Universiti Teknologi Malaysia (UTM)*.

Spectral reflectance measurements were made using an Analytical Spectral Devices (ASD) spectroradiometer Fieldspac® model, which records a reflectance spectrum across an overall spectral range of 325–2500 nm (nanometer) with a 10 nm individual band width. The measurements were performed at the remote sensing laboratory in *Universiti Teknologi Malaysia (UTM)* using a contact probe and a built-in illumination source.

1.5 Publications derived from this research

This thesis is written based on our publications derived from the results of comprehensive study using ASTER, ALI and Hyperion remote sensing data in identifying of probable porphyry copper mineralization in the southeastern part of the Urumieh-Dokhtar Volcanic Belt, SE Iran. This contribution achieved impact factor 7.586 by published journal papers. Some under review journal articles are still waiting to be evaluated.

We attempted to write the thesis based on university format to conserve the continuity and organization of the thesis. Litureture review has up dated to published papers in recent months, and research methodology has been explained in detail to give better information for broad readership. All of the published journal papers and under review articles have been used in the results, analysis and discussion section. However, conclusions can be found in the final chapter of the thesis. The published journal papers, conference papers and under review articles are listed in Appendix A.

REFERENCES

Abdelsalam, M. and Stern, R. (2000). Mapping gossans in arid regions with Landsat TM and SIR-C images, the Beddaho Alteration Zone in northern Eritrea. *Journal of African Earth Sciences*, 30(4), 903-916.

Aboelkhair, H., Yoshiki, N., Yasushi, W. and Isao S. (2010). Processing and interpretation of ASTER TIR data for mapping of rare-metal-enriched albite granitoids in the Central Eastern Desert of Egypt. *Journal of African Earth Sciences*, 58(1), 141-151.

Abrams, M.J., Brown, D., Lepley, L. and Sadowski, R. (1983). Remote sensing of porphyry copper deposits in Southern Arizona. *Economic Geology*, 78, 591-604.

Abrams, M.J. and Brown, D. (1984). Silver Bell, Arizona, porphyry copper test site report: Tulsa, Oklahoma, The American Association of Petroleum Geologists, The Joint NASA–Geosat Test Case Project, Final Report, chapter 4, p. 4-73.

Abrams, M. and Hook, S.J. (1995). Simulated ASTER data for geologic studies. *IEEE Transactions on Geoscience and Remote Sensing*, 33(3).

Abrams, M. (2000). The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER): data products for the high spatial resolution imager on NASA's Terra platform. *International Journal of Remote Sensing*, 21, 847-859.

Abrams, M., Hook, S. and Ramachandran, B. (2004). *ASTER User Handbook, Version 2.* Jet Propulsion Laboratory, California Institute of Technology. Online: http://asterweb.jpl. nasa.gov/content/03_data/04_Documents/aster_ guide_ v2.pdf

Ackerman, R. (2009). *"A Bottom In Sight For Copper"*. Forbes. http://www.forbes.com/2009/02/04/copper-frontera-southern-markets-equity-0205_china_51.html.

ACORN TM 5.0. (2004). Tutorial, ImSpec LLC, Advanced Imaging and Spectroscopy, ImSpec LLC.

Adams, J.B., Smith, M.O. and Gillespie, A.R. (1993). *Imaging spectroscopy: Interpretation based on spectral mixture analysis*. In: Pieters, C.M., Englert, P.A.J. (Eds.), Remote geochemical analysis: Elemental and mineralogical composition. Cambridge University Press, New York, p. 145-166.

Adams, J.B., Sabot, D.E., Kapos, V., Almeida, F., Roberts, D.A., Smith, M.O. and Gillespie, A.R. (1995). Classification of multispectral images based on fractions of endmembers: application to land cover change in the Brazilian Amazon. *Remote Sensing of Environment,* 52, 137-154.

Aftabi, A. and Atapour, H. (1997). Geochemical and petrological characteristics of shoshonitic and potassic calcalkaline magmatism at Sarcheshmeh and Dehsiahan porphyry copper deposits, Kerman, Iran. Res. Bull. Isfahan University 9, p.127-156 (in Persian).

Alavi, M. (1980). Tectonostratigraphic evolution of the Zagros-sides of Iran. *Geology,* 8, 144-149.

Alavi, M. (1994). Tectonic of the Zagros orogenic belt of Iran: new data and interpretations. *Tectonophysics* , 229, 211-238.

Amer, R., Kusky, T. and Ghulam, A. (2010). Lithological mapping in the Central Eastern Desert of Egypt using ASTER data. *Journal of African Earth Sciences,* 56 , 75-82.

Amer, R., Kusky, T. and El Mezayen, A. (2012). Remote sensing detection of gold related alteration zones of Um Rus Area, Central Eastern Desert of Egypt. Advances in Space Research 49, 121-134.

Amidi, S.M. (1984). Geological map of the Saveh quadrangle: Tehran, Geological Survey of Iran, scale 1:250,000.

Amiraie, A. (1991). The study of mineralization and hydrothermal alteration at Meiduk porphyry copper deposit, M.Sc. thesis. Shiraz University, p. 125. (in Persian).

Atapour, H. and Aftabi, A. (2007). The geochemistry of gossans associated with Sarcheshmeh porphyry copper deposit, Rafsanjan, Kerman, Iran: Implications for exploration and the environment. *Journal of Geochemical Exploration*, 93, 47-65.

Aydal, D., Ardal, E. and Dumanlilar, O. (2007). Application of the Crosta technique for alteration mapping of granitoidic rocks using ETM+ data: case study from eastern Tauride belt (SE Turkey). *International Journal of Remote Sensing*, 28(17), 3895-3913.

Azizi, H., Tarverdi, M.A. and Akbarpour, A. (2010). Extraction of hydrothermal alterations from ASTER SWIR data from east Zanjan, northern Iran. *Advances in Space Research*, 46, 99-109.

Baldridge A.M., Hook, S.J., Grove, C.I. and Rivera, G. (2009). The ASTER spectral library version 2.0. *Remote Sensing of Environment*, 113, 711-715.

Barry, P.S. and Pearlman, J. (2001). The EO-1 Misson: Hyperion data. *National Aeronautics and Space Administration (NASA)*, p: 35-40.

Barry, P., Pearlman, J.S., Jarecke, P. and Folkman, M. (2002). Hyperion data collection: performance assessment and science application. *IEEE Transactions of Geosciences and Remote Sensing*, 3, 1439-1499.

Beck, R. (2003). *EO-1 User Guide, Version 2.3*. University of Cincinnati.

Bedell, R.L. (2001). Geological mapping with ASTER satellite: new global satellite data that is a significant leap in remote sensing geologic and alteration mapping. *Special Publication Geology Society of Nevada*, 33, 329–334.

Bedini, E., Van Der Meer, F. and Van Ruitenbeek, F. (2009). Use of HyMap imaging spectrometer data to map mineralogy in the Rodalquilar caldera, southeast Spain. *International Journal of Remote Sensing*, 30 (2), 327-348.

Bedini, E. (2009). Mapping lithology of the Sarfartoq carbonatite complex, southern West Greenland, using HyMap imaging spectrometer data. *Remote Sensing of Environment*, 113, 1208-1219.

Bedini, E. (2011). Mineral mapping in the Kap Simpson complex, central East Greenland, using HyMap and ASTER remote sensing data. *Advances in Space Research*, 47, 60-73.

Ben-Dor, E., Kruse, F.A., Lefkoff, A.B. and Banin, A. (1994). Comparison of three calibration techniques for utilization of GER 63-channel aircraft scanner data of Makhtesh Ramon, Nega, Israel. *Photogrammetric Engineering and Remote Sensing*, 60(11), 1339-1354.

Berberian, M. and King, G.C. (1981). Towards a paleogeography and tectonic evolution of Iran. *Canadian Journal of Earth Sciences*, 18, 210-265.

Berberian, F. and Berberian, M. (1981). Tectono-plutonic episodes in Iran. In: Gupta, H.K., Delany, F.M. (Eds.), Zagros Hindukosh, Himalaya Geodynamic Evolution, American Geophysical Union, Washington, DC, p. 5-32.

Berberian, F., Muir, I.D., Pankhurst, R.J. and Berberian, M. (1982). Late Cretaceous and early Miocene Andean type plutonic activity in northern Makran and central Iran. *Journal of Geological Society of London*, 139, 605-614.

Berger, B.R., King, T.V.V., Morath, L.C. and Phillips, J.D. (2003). Utility of high-altitude infrared spectral data in mineral exploration: Application to northern Patagonia Mountains, Arizona. *Economic Geology*, 98, 1003–1018.

Bertoldi, L., Massironi, M., Visona, D., Carosi, R., Montomoli, C., Gulbert, F., Naletto, G. and Pelizzo, M.G. (2011). Mapping the Buraburi in the Himalaya of Western Nepal: Remote Sensing analysis in a collisional belt with vegetation cover and extreme variation of topography. *Remote Sensing of Environment*, 115, 1129-1144.

Biggar, S. F., Thome, K. J., McCorkel, J. T. and D'Amico, J. M. (2005). Vicarious calibration of the ASTER SWIR sensor including crosstalk correction. *Proceedings International Society Optical Engineering*, 5882, 588217.

Bishop, C.A., Liu, J.G. and Mason, P.J. (2011). Hyperspectral remote sensing for mineral exploration in Pulang, Yunnan Province, China. *International Journal of Remote Sensing*, 32(9), 2409-2426.

Boardman, J.W. (1989). Inversion of imaging spectrometry data using singular value decomposition. In: *IGARSS'89, 12th Canadian Symposium on Remote Sensing*, p. 2069-2072.

Boardman, J.W. (1992). Sedimentary facies analysis using imaging spectrometry: a geophysical inverse problem. Unpublished Ph.D. thesis, University of Colorado.

Boardman, J.W. (1993). Automated spectral unmixing of AVIRIS data using convex geometry concepts: in summaries, Fourth JPL Airborne Geoscience Workshop.

Boardman J. W. and Kruse, F. A. (1994). Automated spectral analysis: A geologic example using AVIRIS data, north Grapevine Mountains, Nevada: *in Proceedings, Tenth Thematic Conference on Geologic Remote Sensing, Environmental Research Institute of Michigan, Ann Arbor, MI,* p. I-407 - I-418.

Boardman, J.W., F.A. Kruse. and Green, R.O. (1995). Mapping target signatures via partial unmixing of AVIRIS data. *Summaries, Proceedings of the Fifth JPL Airborne Earth Science Workshop*, 23–26 January, Pasadena, California, JPL Publication 95–1, v. 1, p. 23–26.

Boardman, J. W. (1998). Leveraging the high dimensionality of AVIRIS data for improved sub-pixel target unmixing and rejection of false positives: mixture tuned matched filtering, in: *Summaries of the Seventh Annual JPL Airborne Geoscience Workshop*, Pasadena, CA, p. 55.

Boomeri, M., Kazuo, N. and David, R. L. (2009). The Meiduk porphyry Cu deposit, Kerman, Iran: A geochemical analysis of the potassic zone including halogen element systematics related to Cu mineralization processes. *Journal of Geochemical Exploration*, 103, 17-29.

Bouley, B.A., St. George, P. and Wetherbee, P.K. (1995). Geology and discovery at Pebble Copper, a copper-gold porphyry system in northwest Alaska. *Canadian Institute of Mining, Metallurgy and Petroleum Special,* 46, 422-435.

Boustani, F. (2008). Sustainable Water Utilization in Arid Region of Iran by Qanats. *World Academy of Science, Engineering and Technology,* 43, 213-216.

Brown, A. and Lester, M.T. (2006). Plan B 2.0: *Rescuing a Planet Under Stress and a Civilization in Trouble*. New York: W.W. Norton. p. 109.

Bryant, R., Moran, M.S., McElory, S.A., Holifield, C., Thome, K.J., Miura, T. and Biggar, S.F. (2003). Data Continuity of Earth Observing 1(EO-1) Advanced

Land Imager (ALI) and Landsat TM and ETM+. *IEEE Transactions of Geosciences and Remote Sensing,* 41(6).

Carranza, E.J. and Hall, M. (2002). Where are porphyry copper deposits spatially localized? A case study in Benguet province, Philippines. *Natural Resource Research*, 11(1), 45-59.

Carranza, E.J. and Hall, M. (2002). Mineral mapping with Landsat Thematic Mapper data for hydrothermal alteration mapping in heavily vegetated terrain. *International Journal of Remote Sensing,* 23 (22), 4827-4852.

Carranza, E.J.M., Van Ruitenbeek, F.J.A., Hecker, C., Van der Meijde, M. and Van Der Meer, F.D. (2008). Knowledge-guided data-driven evidential belief modeling of mineral prospectivity in Cabo de Gata, SE Spain. *International Journal of Applied Earth Observation and Geoinformation*, 10, 374-387.

Castro, L, A.I. (2004). An assessment on the potential of mapping hydrothermal alteration from ASTER short wavelength infrared image data based on image simulation experiment. Unpublished M. Sc. Thesis. International Institute for Geo-information Science and Earth Observation Enschede, the Netherlands.

Chabrillat, S., Pinet, P.C., Ceuleneer, G., Johnson, P.E. and Mustard, J.F. (2000). Ronda peridotite massif: methodology for its geological mapping and lithological discrimination from airborne hyperspectral data. *International Journal of Remote Sensing*, 21, 2363-2388.

Chang, Q., Jing, L. and Panahi, A. (2006). Principal component analysis with optimum order sample correlation coefficient for image enhancement. *International Journal of Remote Sensing,* 27 (16), 3387–3401.

Chen, X., Warner, T.A. and Campagna, D.J. (2007). Integrating visible, near-infrared and short-wave infrared hyperspectral and multispectral thermal imagery for geological mapping at Cuprite, Nevada. *Remote Sensing of Environment*, 110, 344–356.

Clark, R.N. and Roush, T.L. (1984). Reflectance spectroscopy: quantitative analysis techniques for remote sensing applications. *Journal of Geophysical Research*, 89, 6329–6340.

Clark, R.N., King, T.V.V., Klejwa, M. and Swayze, G.A. (1990). High spectral resolution reflectance spectroscopy of minerals. *Journal of Geophysical Research,* 95, 12653-12680.

Clark, R.N., Swayze, G.A., Gallagher, A., Gorelick, N. and Kruse, F.A. (1991). Mapping with imaging spectrometer data using the complete band shape least-squares algorithm simultaneously fit to multiple spectral features from multiple materials. In: *Proceedings, 3rd Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Workshop*, p. 2–3.

Clark, R.N., Swayze, G.A. and Gallagher, A. (1992). Mapping the mineralogy and lithology of Canyonlands, Utah with imaging spectrometer data and the multiple spectral feature mapping algorithm. In: *Summaries of the Third Annual JPL Airborne Geoscience Workshop,* p. 11-13.

Clark, R.N., Swayze, G.A., Gallagher, A., King, T.V.V. and Calvin, W.M. (1993). The U.S. Geological Survey, Digital Spectral Library: Version 1: 0.2 to 3.0 microns: U.S. Geological Survey Open File Report 93-592, 1340 p., http://speclab.cr.usgs.gov (August 1999).

Clark, R.N. and Swayze, G.A. (1995). Mapping minerals, amorphous materials, environmental materials, vegetation, water, ice, and snow, and other materials. In: *The USGS Tricorder Algorithm, Summaries of the Fifth Annual JPL Airborne Earth Science Workshop*, p. 39-40.

Cloutis, E.A. (1996). Hyperspectral geological remote sensing: evaluation of analytical techniques. *International Journal of Remote Sensing*, 17 (12), 2215-2242.

Cocks, T., R. Jenssen, A. Stewart, I. Wilson. and T. Shields. (1998). The HyMap Airborne Hyperspectral Sensor: The System, Calibration and Performance. *Proc. 1st EARSeL Workshop on Imaging Spectroscopy (M. Schaepman, D. Schläpfer, and K.I. Itten, Eds.)*, 6-8 October 1998, Zurich, EARSeL, Paris, p. 37-43.

Cox, D.P. (1986). Descriptive model of porphyry Cu: U.S. Geological Survey Bulletin 1693.

Crosta, A. and Moore, J. (1989). Enhancement of Landsat Thematic Mapper imagery for residual soil mapping in SW Minais Gerais State, Brazil: a prospecting case history in Greenstone belt terrain. In: *Proceedings of the 7th ERIM Thematic Conference: Remote sensing for exploration geology*, p. 1173-1187.

Crosta, A.P., Sabine, C. and Taranik, J.V. (1998). Hydrothermal Alteration Mapping at Bodie, California, using AVIRIS Hyperspectral Data. *Remote Sensing of Environment*, 65, 309-319.

Crosta, A.P., Souza Filho, C.R., Azevedo, F. and Brodie, C. (2003). Targeting key alteration minerals in epithermal deposits in Patagonia, Argentina, Using ASTER imagery and principal component analysis. *International Journal of Remote sensing*, 24, 4233-4240.

Crosta, A.P. and Filho, C.R. (2003). Searching for gold with ASTER. *Earth Observation Magazine*, 12 (5), 38–41.

Crowley, J.K. and Vergo, N. (1988). Near-infrared reflectance spectra of mixtures of kaolin group minerals: use in clay mineral studies. *Clays and Clay Mineral*, 36(4), 310-316.

Crowley, J.K., Brickey, D.W. and Rowan, L.C. (1989). Airborne imaging spectrometer data of the Ruby Mountains, Montana: mineral discrimination using relative absorption band-depth images. *Remote Sensing of Environment*, 29(2), 121-134.

Crowley, J.K. and Clark, R.N. (1992). AVIRIS study of Death Valley evaporite deposits using least- squares band-fitting methods. In: *Summaries of the Third Annual JPL Airborne Geoscience Workshop*, p.29-31.

Cudahy, T.J., Hewson, R., Huntington, J.F., Quigley, M.A. and Barry, P.S. (2001). The performance of the satellite-borne Hyperion hyperspectral VNIR-SWIR imaging system for mineral mapping at Mount Fitton, South Australia. *IEEE IGARSS Proceedings*, p. 9-13.

Cudahy, T.J. and Barry, P.S. (2002). Earth magmatic-seawater hydrothermal alteration revealed through satellite-borne Hyperion imagery at Panorama, Western Australia. *IEEE IGARSS Proceedings*, vol, I. p. 590-592.

Cunningham, C.G., Rye, R.O., Rockwell, B.W., Kunk, M.J. and Councell, T.B., (2005). Supergene destruction of a hydrothermal replacement alunite deposit at Big Rock Candy Mountain, Utah—Mineralogy, spectroscopic remote sensing, stable-isotope, and argon-age evidences. *Chemical Geology*, v. 215, 317–337.

Dalton, J.B., Bove, D.J., Mladinich, C.S. and Rockwell, B.W. (2004). Identification of spectrally similar materials using the USGS Tetracorder algorithm: the calcite-epidot-chlorite problem. *Remote Sensing of Environment*, 89, 455- 466.

Datt, B., McVicar, T.R., Van Niel, T.G., Jupp, D.L.B. and Pearlman, J.S. (2003). Preprocessing EO-1 Hyperion hyperspectral data to support the application of agricultural indices. *IEEE Transactions on Geoscience and Remote Sensing*, 41(6), 1246-1259.

De Carvalho, O.A. and Meneses, P.R. (2000). Spectral Correlation Mapper (SCM); An Improvement on the Spectral Angle Mapper (SAM). *Summaries of the 9th JPL Airborne Earth Science Workshop, JPL Publication*, 00-18, p.9.

Dilles, J.H. and Einaudi, M.T. (1992). Wall-rock alteration and hydrothermal flow paths about the Ann-Mason porphyry copper deposit, Nevada-a 6-km vertical reconstruction. *Economic Geology*, 87, 1963-2001.

Dimitrijevic, M.D. (1973). Geology of Kerman region. *Geological Survey of Iran Report*, 52, p. 334.

Diner, D.J., Beckert, J.C., Bothwell, G.W. and Rodriguez, J.I. (2002). Performance of the MISR instrument during its first 20 months in earth orbit. *IEEE Transactions on Geoscience and Remote Sensing*, 40 (7), 1449–1466.

Di Tommaso, I. and Rubinstein, N. (2007). Hydrothermal alteration mapping using ASTER data in the Infiernillo porphyry deposit, Argentina. *Ore Geology Reviews*, 32, 275-290.

Ducart, D.F., Crosta, A.P. and Filio, C.R.S. (2006). Alteration mineralogy at the Cerro La Mina epithermal prospect, Patagonia, Argentina: field mapping, short-wave infrared spectroscopy, and ASTER images. *Economic Geology*, 101, 981-996.

El Desouky, H.A., Muchez, P., Dewaele, S., Boutwood, A. and Tyler, R., 2008. Postorogenic origin of the stratiform Cu mineralization at Lufukwe, Lufilian Foreland, Democratic Repulic of Congo. *Economic Geology*, 103, 555-582.

Farrand, W.H. and Harsanyi, J.C. (1994). Mapping distributed geological and botanical targets through constrained energy minimization. *Proc. 10th Thematic Conference on Geological Remote Sensing, San Antonio, TX*, 9–12 May 1994, pp. I-419–I-429.

Farrand, W.H. and Harsanyi, J.C. (1997). Mapping the distribution of mine tailings in the Coeur d'Alene River Valley, Idaho, through the use of a constrained energy minimization technique. *Remote Sensing of Environment*, 59 (1), 64–76.

Farhoudi, G. (1978). A comparison of Zagros geology to island arcs. *Journal of Geology,* 86, 323-334.

Feld, G.W., Anderson, G.P., Cooley, T.W., Matthew, M.W., Adler-Golden, S.M., Berk, A. and Lee, J. (2003). Analysis of Hyperion Data with the FLAASH Atmospheric Correction Algorithm. *IEEE Transactions of Geosciences and Remote Sensing*, p. 90-92.

Ferrier, G. and Wadge, G. (1996). Application of imaging spectrometry data to mapping alteration zones associated with gold mineralization in southern Spain. *International Journal of Remote Sensing*,17, 331-350.

Ferrier, G., White, K., Griffiths, G., Bryant, R. and Stefouli, M. (2002). The mapping of hydrothermal alteration zones on the island of Lesvos, Greece, using an integrated remote sensing data set. *International Journal of Remote Sensing*, 23, 341–356.

Filho, C.R.S., Tapia, C.H., Crosta, A.P. and Xavier R.P. (2003). Infrared spectroscopy and ASTER imagery analysis of hydrothermal alteration zones at the Quellaveco porphyry copper deposit, southern Peru. *ASPRS 2003 Annual conference proceedings*. May 2003, Anchorage, Alaska. p. 48-61.

Folkman, M., Pearlman, J., Liao, L. and Jarecke, P. (2001). EO-1/Hyperion hyperspectral imager design, development, characterization, and calibration. Hyperspectral Remote Sensing of the Land and Atmosphere. *Proceedings of SPIE,* 4151, p. 40-51.

Forster, H., Fesefeldt, K. and Ku¨rsten, M. (1972). Magmatic and orogenic evolution of the central Iranian volcanic belt. *24th International Geology Congress*, Section 2, 198-210.

Fujisada, H. (1995). Design and performance of ASTER instrument. *Proceedings of SPEI, International Society of Optical Engineering*, 2583, 16-25.

Gabr, S., Ghulam, A. and Kusky, T. (2010). Detecting areas of high-potential gold mineralization using ASTER data. *Ore Geology Reviews*, 38, 59-69.

Gad, S. and Kusky, T. (2007). ASTER spectral ratioing for lithological mapping in the Arabian–Nubian shield, the Neoproterozoic Wadi Kid area, Sinai, Egypt. *Gondwana Research*, 11, 326-335.

Galva˜o L.S., Almeida-Filho, R. and Vitorello, I. (2005). Spectral discrimination of hydrothermally altered materials using ASTER short-wave infrared bands: Evaluation in a tropical savannah environment. *International Journal of Applied Earth Observation and Geoinformation*, 7, 107-114.

Geological Survey of Iran. (1973). Exploration for ore deposits in Kerman region, report no,Yu/53.

Gersman, R., Ben-Dor, E., Beyth, M., Avigad, D., Abraha, M. and Kibreba, A. (2008). Mapping of hydrothermally altered rocks by the EO-1 Hyperion sensor, northern Danakil, Eritrea. *International Journal of Remote Sensing*, 29 (13), 3911-3936.

Gillespie, A., Abrams, M. and Yamaguchi, Y. (2005). Scientific results from ASTER. *Remote Sensing of Environment*, 99, 1.

Girouard, G., Bannari, A., El Harti, A. and Desrochers, A. (2004). Validated Spectral Angle Mapper Algorithm for Geological Mapping: Comparative Study between Quickbird and Landsat-TM. XXth, *ISPRS Congress*.

Gillespie, A.R., Matsunaga, T., Rokugawa, S. and Hook, S.J. (1998). Temperature and emissivity separation from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images. *IEEE Transactions on Geoscience and Remote Sensing 36*, 1113-1126.

Gomez C., Delacourt, C., Allemand, P., Ledru, P. and Wackerle, R. (2005). Using ASTER remote sensing data set for geological mapping, in Namibia. *Physics and Chemistry of the Earth*, 30, 97-108.

Goetz, A.F.H., Rock, B.N. and Rowan, L.C. (1983). Remote sensing for exploration: An overview. *Economic Geology*, 78, 573–590.

Goetz, A.F.H. (2009). Three decades of hyperspectral remote sensing of the Earth: A personal view. *Remote Sensing of Environment*, 113, S6-S16.

Goodenough, D.G., Dyk, A., Niemann, K.O., Pearlman, J.S., Chen, H., Han, T., Murdoch, M. and West, C. (2003). Processing Hyperion and ALI for Forest Classification. *IEEE Transactions of Geosciences and Remote Sensing*, 41(6).

Gordon, R. B., Bertram, M. and Graedel, T. E. (2006). "Metal stocks and sustainability". *PNAS* 103 (5), 1209–1214.

Green, A. A., Berman, M., Switzer, P. and Craig, M. D. (1988). A transformation for ordering multispectral data in terms of image quality with implications for noise removal. *IEEE Transactions of Geosciences and Remote Sensing*, 26(1), 65-74.

Green, R.O., Pavri, B.E. and Chrien, T.G. (2003). On-Orbit Radiometric and Spectral Calibration Characteristics of EO-1 Hyperion Derived With an Underflight of AVIRIS and *In Situ* Measurements at Salar de Arizaro, Argentina. *IEEE Transactions of Geosciences and Remote Sensing*, 41(6).

Gustafson, L.B. and Hunt, J.P. (1975). The porphyry copper deposit at El Salvador, Chile. *Economic Geology*, 70, 857–912.

Hammond, C. R. (2004). *The Elements, in Handbook of Chemistry and Physics* 81st edition. CRC press.

Harsanyi, J.C., Farrand, W.H. and Chang, C.I. (1994). Detection of subpixel signatures in hyperspectral image sequences. *Proceedings of 1994 ASPRS Annual Conference,* Reno, Nevada, p. 236-247.

Hajian, H. (1977). Geological map of the Tafresh area: Tehran, Geological Survey of Iran, scale 1:100,000.

Haselwimmer, C. E., Riley, T. R. and Liu J. G. (2011). Lithologic mapping in the Oscar II Coast area, Graham Land, Antarctic Peninsula using ASTER data. *International Journal of Remote Sensing,* 32(7), 2013-2035.

Hassanzadeh, J. (1993). Metallogenic and tectonomagmatic events in the SE sector of the Cenozoic active continental margin of central Iran (Shahr e Babak area, Keman Province) Ph.D. thesis, University of California, Los Angeles, p.204.

Hearn, D.R., Digenis, C.J., Lencioni, D.E., Mendenhall, J.A., Evans, J.B. and Walesh, R.D. (2001). EO-1 Advanced Land Imager overview and spatial performance. IEEE Transactions of Geosciences and Remote Sensing, P. 897-899.

Hecker, C., Van der Meijid, M. and Van der Meer, F. (2010). Thermal infrared spectroscopy on feldspar-successes, limitation and their implications for remote sensing. *Earth-Science Reviews*, 103, 60-70.

Hellman M.J and Ramsey M.S. (2004). Analysis of hot springs and associated deposits in Yellowstone National Park using ASTER and AVIRIS remote sensing. *Journal of Volcanology and Geothermal Research*, 135, 195- 219.

Hezarkhani, A. (2006). Hydrothermal evolution of the Sar-Cheshmeh porphyry Cu–Mo deposit, Iran: Evidence from fluid inclusions. *Journal of Asian Earth Sciences*, 28, 409-422.

Hezarkhani, A. (2009). Hydrothermal fluid geochemistry at the Chah-Firuzeh porphyry copper deposit, Iran: Evidence from fluid inclusions. *Journal of Geochemical Exploration*, 101, 254-264.

Hewson, R.D., Cudahy, T.J. and Huntington, J.F. (2001). Geological and alteration mapping at Mt Fitton, South Australia, using ASTER satellite-borne data. *IEEE Transactions of Geosciences and Remote Sensing*, p.724-726.

Hewson, R.D., Cudahy T.J., Mizuhiko, S., Ueda, K. and Mauger, A.J. (2005). Seamless geological map generation using ASTER in the Broken Hill–Curnamona province of Australia. *Remote Sensing of Environment*, 99, 159-172.

Holliday, J.R. and Cooke, D.R. (2007). Advances in geological models and exploration methods for copper and gold porphyry deposits, *in* Milkereit, B., ed., Proceedings of Exploration 07: *Fifth Decennial International Conference on Mineral Exploration:* Toronto, Prospectors and Developers Association of Canada, p. 791−809.

Hooper, R.J., Baron, I., Hatcher, R.D. and Agah, S. (1994). The development of the southern Tethyan margin in Iran after the breakup of Gondwana: implications of the Zagros hydrocarbon province. *Geosciences,* 4, 72-85.

Hosseinjani, M. and Tengestani, M.H. (2011). Mapping alteration minerals using sub-pixel unmixing of ASTER data in the Sarduiyeh area, SE Kerman, Iran. *International Journal of Digital Earth*, 4 (6), 487-504.

Hubbard, B.E., Crowley, J.K. and Zimbelman, D.R. (2003). Comparative alteration mineral mapping using visible to shortwave infrared (0.4-2.4 μm) Hyperion, ALI, and ASTER imagery. *IEEE Transactions on Geoscience and Remote Sensing*, 41(6), 1401-1410.

Hubbard, B.E. and Crowley, J.K. (2005). Mineral mapping on the Chilean–Bolivian Altiplano using co-orbital ALI, ASTER and Hyperion imagery: Data dimensionality issues and solutions. *Remote Sensing of Environment*, 99, 173-186.

Hubner, H. (1969a). Geological map of Iran sheet no. 5, southcentral Iran: Tehran, National Iranian Oil Company, scale 1:1,000,000.

Hubner, H. (1969b). Geological map of Iran sheet no. 6, southeast Iran: Tehran, National Iranian Oil Company, scale 1:1,000,000.

Hunt, G.R., Salisbury, J.W. and Lenhoff, C.J., (1971a). Visible and near-infrared spectra of minerals and rocks: III. Oxides and hydroxides: *Modern Geology*, v. 2, p. 195–205.

Hunt, G.R., Salisbury, J.W. and Lenhoff, C.J., (1971b). Visible and near-infrared spectra of minerals and rocks: IV. Sulphides and sulphates: *Modern Geology*, v. 3, p. 1–14.

Hunt, G. R. and Salisbury, J. W. (1974). Mid-infrared spectral behavior of igneous rocks. Technical Report AFRCL-TR-75-0356, US Air Force Cambridge Research Laboratory, Cambridge, MA.

Hunt, G. R. and Salisbury, J. W. (1975). Mid-infrared spectral behavior of sedimentary rocks. Technical Report AFRCL-TR-75-0356, US Air Force Cambridge Research Laboratory, Cambridge, MA.

Hunt, G. R. and Salisbury, J. W. (1976). Mid-infrared spectral behavior of metamorphic rocks, Technical Report AFRCL-TR-76-0003, US Air Force Cambridge Research Laboratory, Cambridge, MA.

Hunt, G. (1977). Spectral signatures of particulate minerals in the visible and near infrared. *Geophysics,* 42, 501-513.

Hunt, G,R. and Ashley, P. (1979). Spectra of altered rocks in the visible and near infrared. *Economic Geology,* 74, 1613-1629.

Hunter, E.L. and Power, C.H. (2002). An Assessment of Two Classification Methods for Mapping Thames Estuary Intertidal Habitats Using CASI Data. *International Journal of Remote Sensing,* 23(15), 2989-3008.

Huntington, J.F. (1996). The role of remote sensing in finding hydrothermal mineral deposits on Earth. Evolution of Hydrothermal Ecosystems on Earth (and Mars?). Wiley, England, p. 214-234.

Inzana, J., Kusky, T., Higgs, G. and Tucker, R. (2003). Supervised classifications of Landsat TM band ratio images and Landsat TM band ratio image with radar for geological interpretations of central Madagascar. *Journal of African Earth Sciences*, 37, 59-72.

Iwasaki, A. and Tonooka, H. (2005). Validation of a crosstalk correction algorithm for ASTER/SWIR. *IEEE Transactions Geoscience and Remote Sensing*, 43(12), 2747-2751.

Jacobsen, J.B.J. (1975). Copper deposits in time and space. *Mineral Sciences Engineering*, 7 (4), 337–371.

James, K., Vergo, C. and Vergo, N. (1988). Near-infrared reflectance spectra of mixtures of kaolin-group minerals: use in clay mineral studies. *Clay and Clay Minerals*, 36(4), 310-316.

Jankovic, S. (1984). Metallogeny of the Alpine granitoids in the Tethyan-Eurasian metallogenic belt. *Proceedings of the 27th International Geological Congress,* Moscow, 4-14 August, 1984, p.247-274.

Jensen, J.R. (2005). *Introductory Digital Image Processing*. Pearson Prentice Hall, Upper Saddle River.

Junek, P. (2004). Geological mapping in the Cheleken Peninsula, Turkministan area using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data, *ISPRS Conference*. May 2004, California, USA.

Justice, C., Townshend, J. (2002). Special issue on the Moderate Resolution Imaging Spectroradiometer (MODIS): a new generation of land surface monitoring. *Remote Sensing of Environment*, 83 (1–2), 1– 2.

Kanlinowski, A. and Oliver, S. (2004). ASTER Mineral Index Processing. Remote Sensing Application Geoscience Australia. Australian Government Geoscience Website: http://www.ga.gov.au/image_cache/GA7833.pdf , access date 20 June 2010.

Kang, Q., Rong, Y., Xiangjun, L. and Xiaolian, D. (2005). Application of spectral angle mapping model to rapid assessment of soil salinization in arid area. *IEEE Transactions of Geosciences and Remote Sensing*, p. 2355-2357.

Kavak, K.S. (2005). Recognition of gypsum geohorizons in the Sivas Basin (Turkey) using ASTER and Landsat ETM+ images. *International Journal of Remote Sensing,* 26, (20), 4583-4596.

Kesler, S.E. and Wilkinson, B.H. (2008). Earth’s copper resources estimated from tectonic diffusion of porphyry copper deposits. *Geology,* 36, 255–258.

Khan S.D., Mahmood, K. and Casey, J.F. (2007). Mapping of Muslim Bagh ophiolite complex (Pakistan) using new remote sensing, and field data. *Journal of Asian Earth Sciences,* 30, 333-343.

Khan, S. D. and Mahmood, K. (2008). The application of remote sensing techniques to the study of ophiolites. *Earth-Science Reviews,* 89, 135-143.

Kirwin, D.J., Foster, C.N. and Garamjav, D. (2003). The discovery history of the Oyu Tolgoi porphyry copper-gold deposits, South Gobi, Mongolia: *NewGenGold 2003 Conference, Perth, 2003, Proceedings*: Adelaide, Australian Mineral Foundation, p. 130−146.

Kratt, C., Calvin, W. M. and Coolbaugh, M. F. (2010). Mineral mapping in the Pyramid Lake basin: Hydrothermal alteration, chemical precipitates and geothermal energy potential. *Remote Sensing of Environment*, 114 (10), 2297-2304.

Krohn, M.D., Abrams, M.J. and Rowan, L.C. (1978). Discrimination of hydrothermal altered rocks along the Battle Mountain–Eureka, Nevada, mineral belt using Landsat images: *U.S. Geological Survey Open-File Report*, 78–585, p 84.

Kruse, F.A., Boardman, J.W., Lefkoff, A.B., Heidebrecht, K.B., Shapiro, A.T., Barloon, P.J. and Goetz, A.F.H. (1993). The Spectral Image Processing System (SIPS) – Interactive Visualization and Analysis of Imaging Spectrometer Data. *Remote Sensing of Environment*, 44, 145-163.

Kruse, F. A. and Lefkoff, A. B. (1993). Knowledge-based geologic mapping with imaging spectrometers: *Remote Sensing Reviews, Special Issue on NASA Innovative Research Program (IRP) results*, v. 8, p. 3 -28.

Kruse, F. A., Boardman, J. W. and Huntington, J. F. (1999). Fifteen Years of Hyperspectral Data: Northern Grapevine Mountains, Nevada: in *Proceedings of the 8th JPL Airborne Earth Science Workshop*: Jet Propulsion Laboratory Publication, JPL Publication, 99-17, p. 247- 258.

Kruse, F.A and Boardman, J. W. (2000). Characterization and Mapping of Kimberlites and Related Diatremes Using Hyperspectral Remote Sensing. *Proceedings*, *2000 IEEE Aerospace Conference.*, *Big Sky*, *MO*, March 18-24.

Kruse, F.A., Bordman, J.W. and Huntington, J.F. (2003). Comparison of airborne hyperspectral data and EO-1 Hyperion for mineral mapping. *IEEE Transactions of Geosciences and Remote Sensing*, 41(6), 1388-1400.

Kruse, F.A. (2003). Mineral Mapping with AVIRIS and EO-1 Hyperion. *Presented at the 12th JPL Airborne Geoscience Workshop,* 24 – 28 February, 2003, Pasadena, California.

Kruse, F. A., Perry, S.L. and Caballero, A. (2006). District-level mineral survey using airborne hyperspectral data, Los Menucos, Argentina. *Annals of Geophysics*, 49 (1), 83-92.

Kruse, F. A. and Perry, S.L. (2007). Regional mineral mapping by extending hyperspectral signatures using multispectral data. *IEEE Transactions of Geosciences and Remote Sensing*, v 4, p.1-14.

Kusky T, M. and Ramadan, T.M. (2002). Structural controls on Neoproterozoic mineralization in the South Eastern Desert, Egypt: an integrated field, Landsat TM, and SIR-C/X SAR approach. *Journal of African Earth Sciences,* 35, 107-121.

Lencioni, D.E., Digenis, C.J., Bicknell, W.E., Hearn, D.R. and Mendenhall, J.A. (1999). Design and performance of the EO1 Advanced Land Imager. *SPIE conference on sensors, systems, and next generation satellites III*, Florence, Italy, 20 Spetember 1999.

Liao, L., Jarecke, P., Gleichauf, D. and Hedman, T. (2000). Performance characterization of the Hyperion imaging spectrometer instrument. *Proceedings of SPIE*, 4135, 264-275.

Lobell, D.B. and Asner, G.P. (2003). Comparison of Earth Observing-1 ALI and Landsat ETM+ for Crop Identification and Yield Prediction in Mexico. *IEEE Transactions of Geosciences and Remote Sensing*, 41(6).

Lowell, J.D. and Guilbert, J.M. (1970). Lateral and vertical alteration-mineralization zoning in porphyry ore deposits. *Economic Geology and the Bulletin of the Society of Economic Geologists*, 65(4), 373-408.

Malekizadeh, A. (1999). Geochemistry and petrogenesis of granite batholiths of Siah Kuh plutonic complex. Unpublished MSc thesis, Shahid Bahonar University, Kerman, I.R. Iran, p. 208.

Manske, S.L. and Paul, A.H. (2002). Geology of a major new porphyry copper center in the Superior (Pioneer) district, Arizona. *Economic Geology*, 97, 197-220.

Mars, J. C. and Rowan, L.C. (2006). Regional mapping of phyllic- and argillic-altered rocks in the Zagros magmatic arc, Iran, using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data and logical operator algorithms. *Geosphere*, 2(3), 161-186.

Mars, J.C. and Rowan, L.C. (2007). Mapping sericitic and argillic-altered rocks in southeastern Afghanistan using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data, U.S. Geological Survey Open-File Report 2007–1006, 1 plate, http://pubs.usgs.gov/of/2007/1006/.

Mars, J. C. and Rowan, L.C. (2010). Spectral assessment of new ASTER SWIR surface reflectance data products for spectroscopic mapping of rocks and minerals. *Remote Sensing of Environment*, 114, 2011-2025.

Mars, J. C. and Rowan, L.C. (2011). ASTER spectral analysis and lithologic mapping of the Khanneshin carbonate volcano, Afghanistan. *Geosphere,* 7, 276-289.

Massironi, M. L., Bertoldi, P., Calafa, D., Visona, A., Bistacchi, C., Giardino, A. and Schiavo, B. (2008). Interpretation and processing of ASTER data for geological mapping and granitoids detection in the Saghro massif (eastern Anti-Atlas, Morocco). *Geosphere*, 4(4), 736 -759.

Mendenhall, J.A., Ryanhoward, D.P. and Willard, B.C. (2000). Earth Observing-1 Advanced Land Imager: instrument and flight operations overview. MIT Lincoln Laboratory Project Report EO1-1, 23 June 2000.

Mezned, N., Abdeljaoued, S. and Boussema, M.R. (2007). ASTER multispectral imagery for spectral unmixing based mine talling cartography in the north of Tunisia. *ISPRS Conference*, April 2007, Nevada, USA.

Mezned, N., Abdeljaoued, S. and Boussema, M.R. (2009). A comparative study for unmixing based Landsat ETM+ and ASTER image fusion. *International Journal of Applied Earth Observation and Geoinformation*, 12(1), 131-137.

Modarres, R. and Da Silva V. P. R. (2007). Rainfall trends in arid and semi-arid regions of Iran. *Journal of Arid Environments*, 70, 344-355.

Moghtaderi, A., Moore F. and Mohammadzadeh, A. (2007). The application of Advanced Space-borne Thermal Emission and Reflection (ASTER) radiometer data in the detection of alteration in the Chadormalu paleocrater, Bafq region, Central Iran. *Journal of Asian Earth Sciences*, 30, 238–252.

Moore, F., Rastmanesh, F., Asady, H. and Modabberi, S. (2008). Mapping mineralogical alteration using principal component analysis and matched filter processing in Takab area, north-west Iran, from ASTER data. *International Journal of Remote Sensing,* 29, (10), 2851-2867.

National Aeronautics and Space Administration. (2002). Earth Observing-1 Advanced Land Imager. Online: http://eo1.gsfc.nasa.gov/Technology/ALIhome1.htm

National Aeronautics and Space Administration. (2004). Earth Observing-1 EO1General Mission. Online: http://eo1.gsfc.nasa.gov/new/general/

Ninomiya, Y., Fu, B. (2002). Mapping quartz, carbonate minerals and mafic–ultramafic rocks using remotely sensed multispectral thermal infrared ASTER data. *Proceedings of SPIE,* 4710, 191-202.

Ninomiya, Y. (2003a). A stabilized vegetation index and several mineralogic indices defined for ASTER VNIR and SWIR data. *Proc. IEEE 2003 International Geoscience and Remote Sensing Symposium (IGARSS'03)* v. 3, Toulouse, France, 21–25 July 2003, p.1552-1554.

Ninomiya, Y. (2003b). Advanced remote lithologic mapping in ophiolite zone with ASTER multispectral thermal infrared data. *Proc. IEEE 2003 International Geoscience and Remote Sensing Symposium (IGARSS'03)* v. 3, Toulouse, France, 21–25 July 2003, p.1561-1563.

Ninomiya, Y. (2003c). Rock type mapping with indices defined for multispectral thermal infrared ASTER data: case studies. *Proceedings of SPIE*, 4886, 123-132.

Ninomiya, Y. (2004). Lithological mapping with ASTER TIR and SWIR data. *Proceedings of SPIE*, 5234, 180-190.

Ninomiya, Y., Fu, B. and Cudahy, T.J. (2005). Detecting lithology with Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) multispectral thermal infrared ‘‘radiance-at-sensor” data. *Remote Sensing of Environment*, 99 (1-2), 127-139.

Okada, K., Segawa, K. and Hayashi, I. (1993). Removal of the vegetation effect from LANDSAT TM and GER imaging spectroradiometer data. *ISPRS Journal of Photogrammetry and Remote Sensing*, 48 (6), 16-27.

Ott, N., Kollersberger, T. and Andrés, T. (2006). GIS analyses and favorability mapping of optimized satellite data in northern Chile to improve exploration for copper mineral deposits. *Geosphere*, 2(4), 236–252.

Oztan, N.S. and Suzen, M.L. (2011). Mapping evaporate minerals by ASTER. *International Journal of Remote Sensing*, 32 (6), 1651-1673.

Perelló, J., Cox, D., Garamjav, D., Sanjdorj, S., Diakov, S., Schissel, D., Munkhbat, T.O. and Gonchig, O. (2001). Oyu Tolgoi, Mongolia: Siluro- Devonian porphyry Cu-Au-(Mo) and high-sulfidation Cu mineralization with a Cretaceous chalcocite blanket. *Economic Geology*, 96, 1407-1438.

Pearlman, J.S., Barry, P.S., Segal, C.C., Shepanski, J., Beiso, D. and Carman, S.L. (2003). Hyperion, a Space-Based Imaging Spectrometer. *IEEE Transactions on Geoscience and Remote Sensing*, 41(6), 1160-1173.

Perko, K.L., Huggins, R.W., Heisen, P.T., Miller, G.E., McMeen, D.J., Dod, T., Staren, J., Sank, V. and Nguyen, X. (2001). EO-1 technology validation report X-band phase array antenna.

Perry, S.L. (2004). Spaceborne and airborne remote sensing systems for mineral exploration-case histories using infrared spectroscopy. In: King, P.L., Ramsey, M.S., Swayze, G.A. (Eds.), Infrared Spectroscopy in Geochemistry, Exploration Geochemistry, and Remote Sensing. Mineralogic Association of Canada, London, Canada, p. 227-240.

Pieri, D. and Abrams, M. (2004). ASTER watches the world's volcanoes: a new paradigm for volcanological observations from orbit. *Journal of Volcanology and Geothermal Research*, 135, 13-28.

Pirajno, F. (1992). *Hydrothermal mineral deposits: principal and fundamental concepts for the exploration geologist*. Springer-Verlag, Berlin, p. 709.

Podwysocki, M.H., Mimms D.L., Salisbury J.W., Bender L.V., and Jones O.D. (1984). Analysis of Landsat-4 TM data for lithologic and image mapping purpose, *Proceedings of Landsat-4 Science Investigations Summary*, Greenbelt, Maryland, v. 2, p. 35-39.

Pour, B. A., Hashim, M. and Marghany, M. (2011). Using spectral mapping techniques on short wave infrared bands of ASTER remote sensing data for alteration mineral mapping in SE Iran. *International Journal of the Physical Sciences,* 6(4), 917-929.

Pour, B.A. and Hashim, M. (2011a). Identification of hydrothermal alteration minerals for exploring of porphyry copper deposit using ASTER data, SE Iran. *Journal of Asian Earth Sciences*, 42, 1309-1323.

Pour, B.A. and Hashim, M. (2012a). The application of ASTER remote sensing data to porphyry copper and epithermal gold deposits. *Ore Geology Reviews*. 44, 1-9.

Pour, B. A. and Hashim, M. (2012b). Identifying areas of high economic-potential copper mineralization using ASTER data in Urumieh-Dokhtar Volcanic Belt, Iran. Advances in Space Research 49, 753-769.

Pour, B. A. and Hashim, M. (2011b). Spectral transformation of ASTER and the discrimination of hydrothermal alteration minerals in a semi-arid region, SE Iran. *International Journal of the Physical Sciences*, 6(8), 2037-2059.

Pour, B. A. and Hashim, M. (2011c). Application of Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data in geological mapping. *International Journal of the Physical Sciences*, 6(33), 7657-7668.

Pour, B. A. and Hashim, M. (2011d). The Earth Observing-1 (EO-1) satellite data for geological mapping, southeastern segment of the Central Iranian Volcanic Belt, Iran. *International Journal of the Physical Sciences*, 6(33), 7638-7650.

Qiu, F., Abdelsalam, M. and Thakkar, P. (2006). Spectral analysis of ASTER data covering part of the Neoproterozoic Allaqi-Heiani suture, Southern Egypt. *Journal of African Earth Sciences*, 44, 169–180.

Raines, G.L. (1978). Porphyry copper exploration model for northern Sonora, Mexico. *U.S. Geological Survey Journal of Research*, 6, 51–58.

Rajendran, S., Thirunavukkarasu, A., Balamurugan, G. and Shankar, K. (2011a). Discrimination of iron ore deposits of granulite terrain of Southern Peninsular India using ASTER data. *Journal of Asian Earth Sciences*, 41, 99–106.

Rajendran, S., Al-Khirbasha S., Pracejusa, B., Nasira, S., Al-Abria, A. H., Kusky, T.M. and Ghulam, A. (2012). ASTER detection of chromite bearing mineralized zones in Semail Ophiolite Massifs of the northern Oman Mountains: Exploration strategy. *Ore Geology Reviews*, 44, 121-135.

Rajesh, H.M. (2008). Mapping Proterozoic unconformity-related uranium deposits in the Rockole area, Northern Territory, Australia using Landsat ETM+. *Ore Geology Reviews*, 33, 382-396.

Ramadan, T.M. and Abdel Fattah, M.F. (2010). Characterization of gold mineralization in Garin Hawal area, Kebbi State, NW Nigeria, using remote sensing. *The Egyptian Journal of Remote Sensing and Space Science*, 13, 153-163.

Ranjbar, H., Honarmand, M. and Moezifar, Z. (2004). Application of the Crosta technique for porphyry copper alteration mapping, using ETM+ data in the southern part of the Iranian volcanic sedimentary belt. *Journal of Asian Earth Sciences,* 24, 237–243.

Ranjbar, H., Masoumi, F. and Carranza, E.J.M. (2011). Evaluation of geophysics and spaceborne multispectral data for alteration mapping in the Sar Cheshmeh mining area, Iran. *International Journal of Remote Sensing*, 32 (12), 3309-3327.

Raziei, T., Daneshkar, P., Arasteh, R. and Saghfian, B. (2005). Annual Rainfall Trend in Arid and Semi-arid Regions of Iran. *ICID 21st European Regional Conference* 2005- 15-19 May 2005, Frankfurt (Oder) and Slubice - Germany and Poland.

Ren, D. and Abdelsalam, M.G. (2006). Tracing along-strike structural continuity in the Neoproterozoic Allaqi-Heiani Suture, southern Egypt using principal component analysis (PCA), fast Fourier transform (FFT), and redundant wavelet transform (RWT) of ASTER data. *Journal of African Earth Sciences*, 44, 181–195.

Regard, V., Bellier, O., Thomas, J.-C., Abbassi, M.R., Mercier, J., Shabanian, E., Feghhi, K. and Soleymani, S. (2004). Accommodation of Arabia-Eurasia convergence in the Zagros-Makran transfer zone, SE Iran: A transition between collision and subduction through a young deforming system. *Tectonics* 23 (4), p.24.

Research Systems, Inc. (2008). *ENVI Tutorials*. Research Systems, Inc., Boulder, CO.

Resmini, R.G., Kappus, M.E., Aldrich, W.S., Harsanyi, J.C., Anderson, M. (1997). Mineral mapping with hyperspectral digital imagery collection experiment

(HYDICE) sensor data at Cuprite, Nevada, USA. *International Journal of Remote Sensing*, 18 (7), 1553-1570.

Rio, T. L. (2000). Interpretation of LANDSAT TM imagery, Kerman region, Iran. Unpublished Report of National Iranian Copper Industries Company, p.42.

Rio, T.L. (2001). Structural interpretation of the Kerman belt, Iran. Unpublished Report of National Iranian Copper Industries Company, p.15.

Rockwell, B. W. and Hofstra, A.H. (2008). Identification of quartz and carbonate minerals across northern Nevada using ASTER thermal infrared emissivity data, implications for geologic mapping and mineral resource investigations in well-studied and frontier areas. *Geosphere,* 4(1), 218–246.

Rowan, L.C., Wetlaufer, P.H., Goetz, A.F.H., Billingsley, F.C. and Stewart, J.H. (1974). Discrimination of rock types and detection of hydrothermally altered areas in south-central Nevada. *U.S. Geological Survey Professional Paper*, 883, 35 p.

Rowan, L.C., Goetz, A.F.H. and Ashley, R.P. (1977). Discrimination of hydrothermally altered and unaltered rocks in visible and near infrared multispectral images. *Geophysics,* 42 (3), 522-535.

Rowan, L.C. and Wetlaufer, P.H. (1981). Relation between regional lineament systems and structural zones in Nevada. American Association of Petroleum Geologists Bulletin, v. 65, p. 1414–1432.

Rowan, L.C. and Mars, J.C. (2003). Lithologic mapping in the Mountain Pass, California area using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data. *Remote Sensing of Environment*,84, 350-366.

Rowan, L.C., Hook, S.J., Abrams, M.J. and Mars, J.C. (2003). Mapping hydrothermally altered rocks at Cuprite, Nevada, using the Advanced

Spaceborne Thermal Emission and Reflection Radiometer (ASTER), a new satellite-imaging system. *Economic Geology*, 98(5), 1019-1027.

Rowan, L.C., Mars, J.C. and Simpson, C.J. (2005). Lithologic mapping of the Mordor N.T, Australia ultramafic complex by using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). *Remote Sensing of Environment*, 99, 105-126.

Rowan, L.C, Robert G. S. and John C. (2006). Distribution of hydrothermally altered rocks in the Reko Diq, Pakistan mineralized area based on spectral analysis of ASTER data. *Remote Sensing of Environment*, 104, 74-87.

Rowins, S.M. (1999). Reduced porphyry copper-gold deposits: a newly recognized style of gold mineralization. *Geological Society of American Abstract with program*, 31(7), A92.

Ruiz-Armenta, J. R. and Prol-Ledesma, R. M. (1998). Techniques for enhancing the spectral response of hydrothermal alteration minerals in Thematic Mapper images of Central Mexico. *International Journal of Remote Sensing*, 19, 1981-2000.

Sabins, F.F. (1987). *Remote Sensing Principles and Interpretation*. 2ned. Freeman, New York.

Sabins, F.F. (1996). *Remote Sensing Principles and Interpretation*, third ed. Freeman & Co, New York, USA.

Sabins, F.F. (1997). *Remote sensing strategies for mineral exploration*. In: Rencz, A.E. (Ed.), Remote Sensing for the Earth Sciences. John Wiley & Sons, Inc., New York, p. 375-447.

Sabins, F.F. (1999). Remote sensing for mineral exploration. *Ore Geology Reviews*, 14, 157-183.

Sabzehei, M. (1994). Geological Quadrangle Map of Iran, No. 12, Hajiabad, 1:250,000, First compilation by Berberian, M. and Final compilation and revision by Sabzehei, M., Geological Survey of Iran.

Sabziparvar, A. A. and Shetaee, H. (2007). Estimation of global solar radiation in arid and semi-arid climates of East and West Iran. *Energy*, 32, 649-655.

Sadeghi, A. R., Kamgar-Haghighi, A. A., Sepaskhah, A. R., Khalili, D. and Zand-Parsa, S. (2002). Regional classification for dryland agriculture in southern Iran. *Journal of Arid Environments*, 50, 333-341.

Sanjeevi, S. (2008). Targeting limestone and bauxite deposits in Southern India by spectral unmixing of hyperspectral image data. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*. Vol. XXXVII. Part B8. Beijing 2008.

San, B.T. and Suzen, M.L. (2010). Evaluation of different atmospheric correction algorithms for EO-1 Hyperion imagery. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*. Vol. XXXVII. Part 8. Kyoto Japan 2010. 392-397.

Saric, V. and Mijalkovic, N. (1973). Metallogenic map of Kerman region, 1:500000 scale. In: Khadem, N., Nedimovic, R. (Eds.), Exploration for Ore Deposits in Kerman Region: Geological Survey of Iran Report, 53, p.247.

Salati, S., Van Ruitenbeek, F.J.A., Van der Meer, F.D., Tangestani, M.H. and Van der Werff, H. (2011). Lithological mapping and fuzzy set theory: Automated extraction of lithological boundary from ASTER imagery by template matching and spatial accuracy assessment. *International Journal of Applied Earth Observation and Geoinformation*, 13, 753-765.

Scheidt, S., Ramsey, M. and Lancaster, N. (2008). Radiometric normalization and image mosaic generation of ASTER thermal infrared data: An application to extensive sand and dune fields. *Remote Sensing of Environment*, 112(3), 920−933.

Schwarz, J. and Staenz, K. (2001). Adaptive threshold for spectral matching of hyperspectral data. *Canadian Journal of Remote Sensing*, 27(3), 216-224.

Schmidt, R.G. (1976). Exploration for porphyry copper deposits in Pakistan using digital processing of Landsat-1 image data. *U.S. Geological Survey Journal of Research*, 4(1), 27–34.

Schmitz, S. and Christopher, F. (1986). "The Rise of Big Business in the World, Copper Industry 1870–1930". *Economic History Review*, 239 (3), 392–410.

Schott, J.R. (2007). *Remote sensing. The image chain approach*. Second edition. Oxford University Press, New York, p.451.

Sengor, A.M.C. (1991). Late Paleozoic and Mesozoic evolution of the Middle Eastern Tethysides: Implications for the Paleozoic Geodynamics of the Tethyan Realm. IGCP Project 276, Newsletter No. 2, p. III-149.

Settle, J.J. and Drake, N.A. (1993). Linear mixing and the estimation of ground cover proportions. *International Journal of Remote Sensing*, 14, 1159-1177.

Stelter, M. and Bombach, H. (2004). "Process Optimization in Copper Electrorefining". *Advanced Engineering Materials*, 6 (7), 558.

Shahabpour J. (2005). Tectonic evolution of the orogenic belt in the region located between Kerman and Neyriz. *Journal of Asian Earth Sciences*, 24, 405 -417.

Shahabpour J. (2007). Island-arc affinity of the Central Iranian Volcanic Belt. *Journal of Asian Earth Sciences*, 30, 652-665.

Shafiei, B., Haschke, M. and Shahabpour, J. (2009). Recycling of orogenic arc crust triggers porphyry Cu mineralization in Kerman Cenozoic arc rocks, southeastern Iran. *Mineralium Deposita*, 44, 265-283.

Shafiei, B. (2010). Lead isotope signatures of the igneous rocks and porphyry copper deposits from the Kerman Cenozoic magmatic arc (SE Iran), and their magmatic-metallogenetic implications. *Ore Geology Reviews*, 37 (1-2), 27-36.

Shimabukuro, Y.E., and Smith, J.A. (1991). The least-squares mixing models to generate fraction images derived from remote sensing multispectral data. *IEEE Transactions of Geosciences and Remote Sensing*, 29, 16-20.

Sillitoe, R.H. (1972). A plate tectonic model for the origin of porphyry copper deposits. *Economic Geology*, 67, 184-197.

Sillitoe, R. H. (2008). Major gold deposits and belts of the North and South American Cordillera: Distribution, tectonomagmatic settings, and metallogenic considerations. *Economic Geology*, 103, 663-687.

Sillitoe, R. H. (2010). Porphyry Copper Systems. *Economic Geology*, 105, 3-41.

Singer, D.A., Berger, V.I., Menzie, W.D. and Berger, B.R. (2005). Porphyry Copper Deposit Density. *Economic Geology*, 100, 491–514.

Singer, D.A., Berger, V.I. and Moring, B.C. (2008). Porphyry copper deposits of the world: Database and grade and tonnage models: U.S. Geological Survey Open-File Report 2008−1155 (http://pubs.usgs.gov/of/ 2008/1155).

Singh, A. and Harrison, A. (1985). Standardized principal components. *International Journal of Remote Sensing*, 6, 883–896.

Smailbegovic, A. and Taranik, J.V. (1999). Dollars and sensing – The Economics of Remote Sensing in Economic Geology Application. In: Rogres, R.H. (Ed.), *Proceedings of the Thirteenth International Conference on Applied Geologic*

Remote Sensing. Vancouver, British Columbia, Canada, 1–3 March I, p. 195–203.

Spatz, D.M. and Wilson, R.T. (1995). Remote sensing characteristics of porphyry copper systems, western America Cordillera, *in* Pierce, F.W., and Bolm, J.G., eds.: Arizona Geological Society Digest, v. 20, p. 94-108.

Stocklin, J. and Nabavi, M.H. (1973). Tectonic Map of Iran, 1:2,500,000, Geological Survey of Iran.

Stocklin, J. (1974). Possible ancient continental margins in Iran. In: Burk,C.A., Drake, C.L. (Eds.), The Geology of Continental Margins, Springer, Berlin, p. 873-887.

Stocklin, J. (1977). Structural correlation of the Alpine range between Iran and Central Asia. Me´moire Hors-Se´rve No. 8 dela Socie´te´ Geologique de France 8, 333-353.

Sultan, M., Arvidson, R.E. and Sturchio N.C. (1986). Mapping of serpentinites in the Eastern Desert of Egypt using Landsat Thematic Mapper data. *Geology*, 14, 995-999.

Sultan, M., Arvidson, R.E., Sturchio. N.C. and Guinness, E.A. (1987). Lithologic mapping in arid regions with Landsat thematic mapper data: Meatiq Dome, Egypt. *Geological Society of America Bulletin,* 99(6), 748-762.

Swayze, G.A. and Clark, R.N. (1995). Spectral identification of minerals using imaging spectrometry data: evaluating the effects of signal to noise and spectral resolution using the Tricorder Algorithm. In: *Summaries of the Fifth Annual JPL Airborne Earth Science Workshop*, p. 157-158.

Tangestani, M. H. and Moore, F. (2000). Iron oxide and hydroxyl enhancement using the Crosta Method: a case study from the Zagros Belt, Fars province, Iran, *International Journal of Applied Earth Observation and Geoinformation*, 2, 140-146

Tangestani, M.H., Moore, F. (2002). "Porphyry copper alteration mapping at the Meiduk area, Iran". *International Journal of Remote Sensing*, 23 (22), 4815-4825.

Tangestani, M. H., Mazhari, N., Ager, B. and Moore, F. (2008). Evaluating advance spaceborne thermal emission and reflection radiometer (ASTER) data for alteration zone enhancement in a semi-arid area, northern shahr-e-Babak, SE Iran. *International Journal of Remote Sensing*, 29(10), 2833-2850.

Tangestani, M.H., Jaffari, L., Vincent, R.K. and Sridhar, B.B.M. (2011). Spectral characterization and ASTER-based lithological mapping of an ophiolite complex: A case study from Neyriz ophiolite, SW Iran. *Remote Sensing of Environment*, 115, 2243-2254.

Titley, S.R. (1972). Intrusion and wallrock porphyry copper deposits. *Economic Geology and the Bulletin of the Society of Economic Geologists*, 67, 122.

Titley, S.R. and Beane, R.E. (1981). Porphyry copper deposits- Part I: Geological settings, petrology and tectogenesis. *Economic geology 75th Anniv. special volume*, 214-235.

Thome, K., Palluconi, F., Takashima, T. and Masuda, K. (1998). Atmospheric Correction of ASTER. *IEEE Transactions of Geosciences and Remote Sensing*, 36(4), 1119-1211.

Thome, K.J., Biggar, S.F. and Wisniewski, W. (2003). Cross Comparison of EO-1 Sensors and Other Earth Resources Sensors to Landsat-7 ETM+ Using Railroad Valley Playa. *IEEE Transactions of Geosciences and Remote Sensing*, 41(6).

Tosdal, R.M. and Jeremy, R. (2001). Magmatic and structural controls on the development of porphyry Cu or Mo or Au deposits. *Economic Geology,* 14, 157-181.

Ungar, S.G. (2002). Overview of the Earth Observing One (EO-1) Mission. *IEEE Transactions of Geosciences and Remote Sensing*, p.568-571.

Ungar, S.G., Pearlman, J.S., Mendenhall, J.A. and Reuter, D. (2003). Overview of the Earth Observing One (EO-1) Mission. *IEEE Transactions on Geoscience and Remote Sensing*, 41(6), pp. 1149-1159.

U.S. Geological Survey. (2010). *Porphyry Copper Deposit Model*. Scientific Investigations Report, 2010–5070–B.

Van der Meer, F., Vasquez-Torres, M. and Van Dijk, P.M. (1997). Spectral Characterization of Ophiolite Lithologies in the Troodos Ophiolite Complex of Cyprus and its Potential in prospecting for Massive Sulphide Deposits. *International Journal of Remote Sensing*, 18(6), 1245-1257.

Van der Meer, F. and De Jong, S.M. (2000). Improving the results of spectral unmixing of Landsat thematic mapper imagery by enhancing the orthogonality of end-member. *International Journal of Remote Sensing*, 21(15), 2781-2797.

Van der Meer, F.D., Van der Werff, H.M.A., Van Ruitenbeek, F.J.A., Hecker, C.A., Bakker, W.H., Noomen, M.F., Van der Meijde, M., Carranza, E. J.M., Boudewijn de Smeth, J. and Woldai, T. (2012). Multi- and hyperspectral geologic remote sensing: A review. *International Journal of Applied Earth Observation and Geoinformation*, 2012, 112-128.

Van Ruitenbeek, F. J.A., Pravesh, D., van der Meer F.D., Cudahy, T., Van der Meijde, M., Hale, M. (2006). Mapping white micas and their absorption wavelengths using hyperspectral band ratios. *Remote Sensing of Environment*, 102, 211–222.

Van Ruitenbeek, F.J.A., Van der Werff, H.M.A., Hein, K.A.A. and Van der Meer, F.D. (2008). Detection of pre-defined boundaries between hydrothermal alteration zones using rotation-variant template matching. *Computers and Geosciences*, 34, 1815-1826.

Vaughan, R. G., Hook S.J., Calvin W.M. and Taranik J.V. (2005). Surface mineral mapping at Steamboat Springs, Nevada, USA, with multi-wavelength thermal infrared images. *Remote Sensing of Environment*, 99, 140-158.

Velosky, J.C., Stern, R.J. and Johnson, P.R. (2003). Geological control of massive sulfide mineralization in the Neoproterozoic Wadi Bidah shear zone, southwestern Saudi Arabia, inferences from orbital remote sensing and field studies. *Precambrian Research*, 123 (2-4), 235-247.

Vicente, L.E. and Filho C.R.S. (2011). Identification of mineral components in tropical soils using reflectance spectroscopy and advanced spaceborne thermal emission and reflection radiometer (ASTER) data. *Remote Sensing of Environment*, 115, 1824–1836.

Waldhoff, G., Bubenzer, O., Bolten, A., Koppe, W. and Bareth, G. (2008). Spectral analysis of ASTER, Hyperion, and Quickbird data for geomorphological and geological research in Egypt (Dakhla Oasis, Western desert). *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences.* Vol. XXXVII. Part B8. Beijing 2008. 1201-1206.

Walker, R.T. (2006). A remote sensing study of active folding and faulting in southern Kerman province, S.E. Iran. *Journal of Structural Geology*, 25, 654-668.

Waterman, G.C. and Hamilton, R.L. (1975). The Sarcheshmeh porphyry copper deposit. *Economic Geology*, 70, 568-576.

Watts, D.R. and Harris, N.B. W. (2005). Mapping granite and gneiss in domes along the North Himalayan antiform with ASTER SWIR band ratios. *Geological Society of America Bulletin*, 117(7/8), 879-886.

Wickert, L.M. and Budkewtisch, P. (2004). ASTER a geological mapping tool for Canada's north. Case study: the Becher Island, Hudson Bay, Nunavut, Canada. *IEEE Transactions of Geosciences and Remote Sensing*, p.1300-1303.

Wolfe, J.A. (1998). Arc magmatism and mineralization in North Luzon and its relationship to subduction at the East Luzon and North Manila Trenches. *Southeast Asian Earth Sciences*, 2(2), 79-93.

Wulder, M.A., White, J.C., Goward, S.N., Jeffrey G.M., Irons, J.R., Herold, M., Cohen, W.B., Loveland, T.R. and Woodcock, C.E. (2008). Landsat continuity: Issues and opportunities for land cover monitoring. *Remote Sensing of Environment*, 112, 955-969.

Xu, Y., Qizhong, L., Shao, Y. and Wang, L. (2004). Extraction Mechanism of Alteration Zones using ASTER Imagery. *Geosciences and Remote Sensing Symposium, IGARSS 04, Proceedings 2004 IEEE International,* 6, p. 4174-4175.

Yamaguchi Y.I., Fujisada, H., Kudoh, M., Kawakami, T., Tsu, H., Kahle, A.B. and Pniel, M. (1999). ASTER instrument characterization and operation scenario. *Advanced Space Research*, 23(8), 1415-1424.

Yamaguchi Y.I., Fujisada, H., Kahle, A.B., Tsu, H., Kato, M., Watanabe, H., Sato, I. and Kudoh, M. (2001). ASTER instrument performance, operation status, and application to Earth sciences. *IEEE Transactions of Geosciences and Remote Sensing*, p. 1215-1216.

Yamaguchi, Y. and Naito, C. (2003). Spectral indices for lithologic discrimination and mapping by using the ASTER SWIR bands. *International Journal of Remote Sensing*, 24(22), 4311-4323.

Yuhas, R.H., Goetz, A.F.H. and Boardman, J.W. (1992). Discrimination among semi-Arid landscape endmembers using the Spectral Angle Mapper (SAM) Algorithm. *Summaries of the 4th JPL Airborne Earth Science Workshop, JPL Publication* , 92-41 p.147-149.

Yujun, Z., Jianmin, Y. and Fojun, Y. (2007). The potentials of multi-spectral remote sensing techniques for mineral prognostication – Taking Mongolian Oyu Tolgoi Cu-Au deposit as an example. *Earth Science Frontiers*, 14(5), 63-70.

Zhang, X., Pazner, M. and Duke, N. (2007). Lithologic and mineral information extraction for gold exploration using ASTER data in the south Chocolate Mountains (California). *Journal of Photogrammetry and Remote Sensing*, 62, 271-282.

Zhang, X. and Pazner, M. (2007). Comparison of Lithologic Mapping with ASTER, Hyperion and ETM Data in the Southeastern Chocolate Mountains, USA. *Photogrammetric Engineering and Remote Sensing*, 73(5), 555-561.

Zoheir, B. and Emam, A. (2012). Integrating geologic and satellite imagery data for high-resolution mapping and gold exploration targets in the South Eastern Desert, Egypt. *Journal of African Earth Sciences*, 66-67, 22-34.

APPENDIX A

1) **Pour, B.A., Hashim, M (2011 a).** Identification of hydrothermal alteration minerals for exploring of porphyry copper deposit using ASTER data, SE Iran. Journal of Asian Earth Sciences 42, 1309-1323. **Impact factor: 2.215.**

2) **Pour, B.A., Hashim, M (2012 a).** The application of ASTER remote sensing data to porphyry copper and epithermal gold deposits. Ore Geology Reviews 44, 1-9. **Impact factor: 2.079.**

3) **Pour, B. A., Hashim, M (2012 b)**. Identifying areas of high economic-potential copper mineralization using ASTER data in Urumieh-Dokhtar Volcanic Belt, Iran. Advances in Space Research 49, 753-769. **Impact factor: 1.076.**

4) **Pour, B. A., Hashim, M (2011 b)**. Spectral transformation of ASTER and the discrimination of hydrothermal alteration minerals in a semi-arid region, SE Iran. International Journal of the Physical Sciences 6(8), 2037-2059. **Impact factor: 0.554.**

5) **Pour, B. A., Hashim, M., Marghany, M (2011)**. Using spectral mapping techniques on short wave infrared bands of ASTER remote sensing data for alteration mineral mapping in SE Iran. International Journal of the Physical Sciences 6(4), 917-929. **Impact factor: 0.554.**

6) **Pour, B. A., Hashim, M (2011 c)**. Application of Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data in geological mapping. International Journal of the Physical Sciences 6(33), 7657-7668. **Impact factor: 0.554.**

7) **Pour, B. A., Hashim, M** (**2011 d)**. The Earth Observing-1 (EO-1) satellite data for geological mapping, southeastern segment of the Central Iranian Volcanic Belt, Iran. International Journal of the Physical Sciences 6(33), 7638-7650. **Impact factor: 0.554.**

8) **Pour, B. A., Hashim, M., Marghany, M (2010)**. Characterization of ASTER Data for Mineral Exploration. Proceedings of MRSS 6th International Remote Sensing & GIS conference and Exhibition, April 2010. Page 48.

9) **Pour, B. A., Hashim, M** (**2010)**. ASTER Spectral Ratioing for Lithological and Mineral Mapping. Proceedings of Map Asia 2010 Conference, Kuala Lumpur, Malaysia, July 2010. Page 40.

10) **Pour, B. A., Hashim, M** (**2010)**. Mapping Hydrothermal Alteration Minerals Associated with Copper Deposits Using ASTER imager with Principal Component Analysis Approach. Proceedings of Map Asia 2010 conference, Kuala Lumpur, Malaysia, July 2010. Page 55.

11) **Pour, B. A., Hashim, M** (**2011)**. "Remote sensing data analysis in the view of geologic mapping applications via ASTER, ALI and Hyperion sensors". Journal of Earth-Science Reviews. Manuscript Number: EARTH1761. **Current status (under review)**. **Impact factor: 5.8.**

12) **Pour, B. A., Hashim, M** (**2011)**. "Detecting hydrothermal alteration zones of porphyry copper mineralization using ASTER, ALI and Hyperion data in the Urumieh-Dokhtar volcanic belt, Iran". Geosphere. Manuscript Number: GS718. **Current status (under review)**. **Impact factor: 2.**

13) **Pour, B. A., Hashim, M** (**2011)**. "Evaluation of Earth Observing-1 (EO1) data for lithological and hydrothermal alteration mapping". Advances in

Space Research. Manuscript Number: ASR-D-11-00698 **.Current status (under review). Impact factor: 1.076.**