Код МРНТИ 36.23.31

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MULTISPECTRAL ANALYSIS OF ASTER DATA FOR REMOTE SENSING OF PORPHYRY COPPER DEPOSITS

Abstract. Porphyry copper deposits are key sources of ***Cu***, ***Mo*** and ***Au***, requiring effective exploration methods. ASTER multispectral data enables mapping ore-bearing zones by identifying hydrothermal alterations. This study explores ***FeOH***, ***AlOH*** and ***MgOH*** indices, along with ASTER thermal channels, to detect minerals linked to ore bodies. The effectiveness of these indices in delineating argillic (sericite-kaolinite) and propylitic (chlorite-epidote) alteration zones is analyzed. A comparative analysis of ASTER data processing approaches and successful applications in various ore-bearing regions is conducted. The results can enhance remote mapping techniques and optimize porphyry copper deposit exploration.

Key words: *porphyry copper deposits, ASTER, remote sensing, hydrothermal alteration, FeOH, AlOH, MgOH, thermal channels.*

ASTER деректерін көпспектрлі талдау арқылы мыс-порфир кен орындарын қашықтан зондтау

Андатпа. Порфирлік мыс кен орындары ***Cu***, ***Mo*** және ***Au***-дың негізгі көздері болып табылады, оларды барлау үшін тиімді әдістер қажет. ASTER көпспектрлі деректері гидротермалдық өзгерістерді анықтау арқылы кенді аймақтарды картаға түсіруге мүмкіндік береді. Бұл зерттеуде кен денелерімен байланысты минералдарды анықтау үшін ***FeOH***, ***AlOH*** және ***MgOH*** индекстері, сондай-ақ ASTER жылулық арналары қарастырылады. Осы индекстердің аргиллиттік (серицит-каолиниттік) және пропилиттік (хлорит-эпидоттық) өзгеру аймақтарын ажыратудағы тиімділігі талданады. ASTER деректерін өңдеу тәсілдері мен олардың әртүрлі кенді аймақтардағы табысты қолдану мысалдары салыстырмалы түрде зерттелді. Алынған нәтижелер қашықтықтан картаға түсіру әдістерін жетілдіруге және порфирлік мыс кен орындарын барлауды оңтайландыруға ықпал ете алады.

Түйінді сөздер: *мыс-порфир кен орындары, ASTER, қашықтан зондтау, гидротермальды өзгеру, FeOH, AlOH, MgOH, жылулық арналары.*

Многоспектральный анализ данных ASTER для дистанционного зондирования медно-порфировых месторождений

Аннотация. Порфировые медные месторождения являются ключевыми источниками ***Cu***, ***Mo*** и ***Au***, требующими эффективных методов разведки. Многоспектральные данные ASTER позволяют картировать рудоносные зоны путем выявления гидротермальных изменений. В данном исследовании рассматриваются индексы ***FeOH***, ***AlOH*** и ***MgOH***, а также термальные каналы ASTER для обнаружения минералов, связанных с рудными телами. Анализируется эффективность этих индексов в выделении аргиллитовой (серицит-каолинитовой) и пропилитовой (хлорит-эпидотовой) зон изменения. Проведен сравнительный анализ методов обработки данных ASTER и успешных примеров их применения в различных рудоносных районах. Полученные результаты могут способствовать совершенствованию методов дистанционного картирования и оптимизации разведки порфировых медных месторождений.

Ключевые слова: *медно-порфировые месторождения, ASTER, дистанционное зондирование, гидротермальная альтерация, FeOH, AlOH, MgOH, термальные каналы.*

Introduction

Porphyry copper deposits (PCDs) are major sources of ***Cu***, ***Mo*** and ***Au***, contributing over 60% of global copper production [1]. Formed through magmatic-hydrothermal processes, they exhibit extensive mineralogical zoning linked to redox and hydrothermal activity [2, 3]. Traditional exploration methods – geochemical, geophysical, and geological – require significant resources, making remote sensing (RS) a valuable alternative for mapping hydrothermal alteration zones [4, 5].

ASTER satellite data, with its 14 spectral bands covering VNIR (0.52–0.86 μm), SWIR (1.6–2.43 μm) and TIR (8.125–11.65 μm) ranges, is widely used in mineral exploration [6, 7]. It facilitates:

• *Identification of argillic (sericite-kaolinite) and propylitic (chlorite-epidote) alteration zones [8].*

• *Mapping of iron oxides (hematite, limonite) via FeOH indices [9].*

• *Analysis of silicate and carbonate distribution using thermal channels [10].*

Studies confirm ASTER's effectiveness in Iran, Australia, Chile, and Mongolia for detecting key mineral alterations [11–12]. Various processing approaches include spectral indices, classification methods, and GIS integration. Despite advances, challenges remain in improving classification accuracy and correlating remote sensing data with field studies.

This study focuses on using ASTER data to identify hydrothermal alteration zones in Kazakhstan's Aktogay ore field. By applying ***FeOH***, ***AlOH***, ***MgOH*** indices and thermal channels, we assess their effectiveness, compare results with field data, and provide recommendations for optimizing porphyry copper exploration. The Aktogay ore field includes large deposits (Aktogay, Aydarly), the small Kyzylkiya deposit, and two poorly studied ore stockworks in the Ayagoz district, 22 km east of the Aktogay railway station.

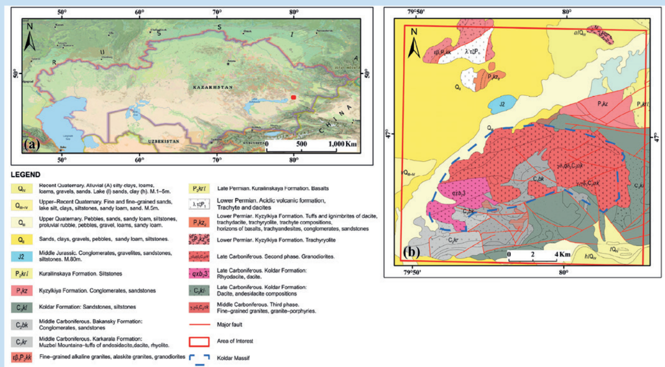


Figure 1. (a) – Geographical location of the study area and surroundings regions. (b) – Simplified geological map of study area (modified from RGF Report 45219 by V.M. Mertenov (sheets L-44-I, II, III), Almaty, 1997).
Сурет 1. (a) – зерттеу аймағы мен оған іргелес аумақтардың географиялық орналасуы. (b) – зерттеу аймағының жеңілдетілген геологиялық картасы (В.М. Мертеновтың РГФ №45219 есебінен өзгертілген, L-44-I, II, III парақтары), Алматы, 1997).
Рис. 1. (a) – географическое расположение района исследования и прилегающих территорий. (b) – упрощенная геологическая карта района исследования (модифицировано из отчета РГФ №45219 В.М. Мертенова (листы L-44-I, II, III), Алматы, 1997).

Methods

This study analyzes ASTER satellite data from the Terra platform, utilizing its 14 spectral bands across VNIR (0.52–0.86 µm), SWIR (1.6–2.43 µm), and TIR (8.125–11.65 µm) for mineral and rock mapping. Standard preprocessing included radiometric correction to remove sensor noise, atmospheric correction using FLAASH, and NDVI-based masking of vegetation and water bodies. To identify hydrothermal alteration zones in porphyry copper deposits, ***FeOH***, ***AlOH*** and ***MgOH*** indices were calculated, along with thermal channels for detecting silicates and carbonates.

The AlOH index was particularly useful for mapping argillic and phyllic alteration minerals linked to ore bodies.

$$\textit{AlOH Group Content} = (B5 + B7) / B6, \qquad (1)$$

where:

This index is based on the spectral characteristics of ***AlOH***-group minerals in the SWIR range (2.1–2.3 µm):

• B5 (2.145–2.185 µm) – sensitive to kaolinite and sericite.

• B7 (2.235–2.285 µm) – also reflects the presence of ***AlOH*** minerals.

• B6 (2.185–2.225 µm) – control channel, where spectral absorption of ***AlOH*** minerals is observed.

High values indicate a high concentration of ***AlOH*** minerals (sericite, kaolinite, alunite) typical of phyllic and argillic alteration zones, while moderate values suggest a mixed clay mineral zone, and low values reflect minimal ***AlOH*** presence. This index identifies sericitized zones in porphyry system cores, differentiates hydrothermal intensity, and, when combined with ***FeOH*** and ***MgOH*** indices, aids in mapping mineralogical zoning.

MgOH Index (magnesium hydroxides: chlorite, epidote, serpentine, talc) – used to identify propylitic alteration zones, which are typical of the peripheral areas of porphyry systems.

$$\textit{MgOH Group Content} = (B6 + B9) / (B7 + B8), \qquad (2)$$

where:

- B6 (2.185–2.225 µm, SWIR) – sensitive to chlorite and epidote.

- B9 (2.360–2.430 µm, SWIR) – used to assess the content of hydrated minerals.

- B7 (2.235–2.285 µm, SWIR) – control channel, showing weak absorption of chlorite and serpentine.

- B8 (2.295–2.365 µm, SWIR) – helps distinguish MgOH minerals from other hydrated phases.

This index is based on the spectral characteristics of magnesium hydroxyl minerals (***MgOH***), such as chlorite, epidote, serpentine and talc. These minerals exhibit distinct spectral features in the shortwave infrared (SWIR) range (2.1–2.4 µm).

- High ***MgOH*** values (> 1.05) – indicate propylitic alteration zones, which are often located on the periphery of porphyry copper deposits.

- Moderate values (0.95–1.05) – may represent transitional zones between propylitic and argillic alteration.

- Low values (< 0.95) – suggest the absence of significant amounts of ***MgOH***-group minerals.

This index is used for identifying propylitic alteration zones characteristic of the peripheral areas of ore bodies, delineating mineralogical zones within porphyry systems, and, when combined with ***FeOH*** and ***AlOH*** indices, for creating comprehensive mineralogical maps to assess the ore-bearing potential of a given area.

FeOH Index (iron oxides and hydroxides) – applied for detecting iron oxides and hydroxides (hematite, limonite, goethite), which are characteristic of oxidation zones and secondary enrichment processes.

$$\textit{FeOH} = B2 / B1, \qquad (3)$$

where:

- B2 – ASTER Band 2 (0.63–0.69 µm, red spectrum) – maximum reflectance of iron oxides.

- B1 – ASTER Band 1 (0.52–0.60 µm, green spectrum) – control channel.

High ***FeOH*** values indicate hematite, limonite, and goethite, typical of oxidized zones, and help map secondary sulfide enrichment crucial for ore exploration. Color composite (RGB) images of ASTER band ratios were used for initial mineralogical interpretation, highlighting ore-related mineral zones. Spectral indices, based on mineral reflectance in different spectrum ranges, are calculated as band ratios to identify anomalies linked to specific mineral groups.

Results and Discussion

The multispectral analysis of ASTER data identified hydrothermally altered rock zones essential for remote sensing of porphyry copper deposits. Color interpretation shows red areas (R: (4+6)/5) correspond to intense hydrothermal alteration minerals like alunite, kaolinite, and pyrophyllite. Green areas (G: (5+7)/6) indicate sericite, muscovite, illite, and smectite, typical of phyllic zones linked to ore formation. Blue areas (B: (7+9)/8) represent carbonates, chlorite, and epidote, associated with peripheral propylitic alteration. The most significant anomalies are red, signaling intense hydrothermal changes, while green anomalies suggest argillic alteration, and blue areas indicate the outer hydrothermal zones (Figure 2).

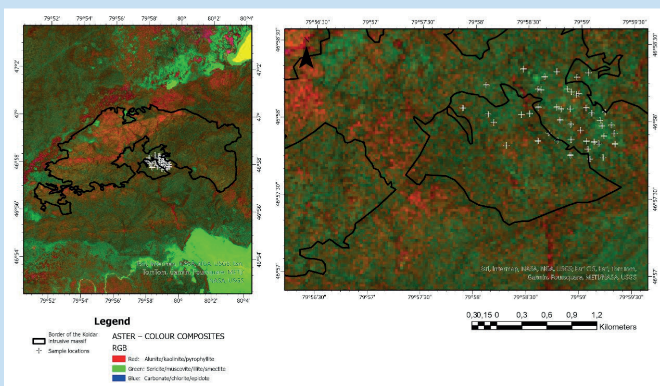


Figure 2. ASTER colour composite.
Сурет 2. ASTER түсті композициясы.
Рис. 2. ASTER цветовой состав (композитное изображение).

Comparison with known mineralized zones showed that areas marked with white crosses align with increased sericite and kaolinite content, confirming the methodology's accuracy.

This highlights the effectiveness of ASTER data for identifying prospective ore zones. The detected anomalies provide a basis for further exploration, detailed mapping, and drilling prioritization. The ***AlOH*** index (Figure 3), derived from ASTER data, reflects aluminosilicate minerals like alunite, kaolinite, and diaspore, which form in intense hydrothermal alteration zones. High values indicate argillic alteration, a key marker of porphyry copper-molybdenum deposits and epithermal systems.

In the image, high ***AlOH*** index values appear in yellow and light blue, while low values are in darker shades. The primary anomaly zone on the right aligns with white crosses, confirming the index's effectiveness in identifying ore-bearing targets. Additional anomalies along tectonic faults suggest secondary alteration, as hydrothermal fluids often migrate along faults, creating favorable conditions for ore deposition.

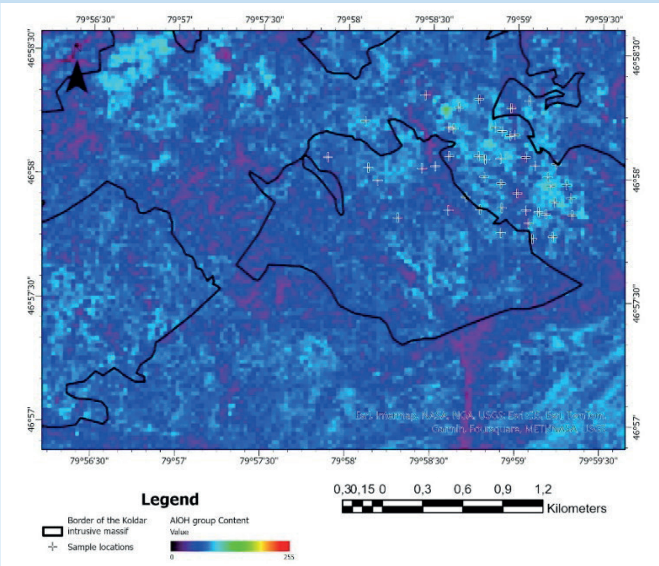


Figure 3. AlOH Group content based on ASTER Data.
Сурет 3. ASTER деректері негізіндегі AlOH тобының мөлшері.
Рис. 3. Содержание группы AlOH по данным ASTER.

Scattered zones of elevated ***AlOH*** values may indicate local kaolinization and argillic alteration, not necessarily linked to ore formation but still worth further study. The ***MgOH*** index, derived from ASTER data, identifies magnesium-hydroxyl minerals like chlorite, serpentine, talc, and smectites (Figure 4). These minerals are common in metamorphic and hydrothermally altered rocks within porphyry copper deposits and ultramafic complexes. High ***MgOH*** values may signal propylitic alteration zones associated with ore-forming processes.

The ***MgOH*** index distribution differs from ***AlOH*** due to distinct hydrothermal alterations. ***AlOH*** anomalies, linked to argillic alteration, concentrate in the central and right parts of the image, aligning with known ore zones. In contrast, ***MgOH*** anomalies are weaker, indicating limited magnesium-bearing minerals in the area. Localized ***MgOH*** anomalies along faults suggest possible metasomatic alterations but are less intense than ***AlOH***, confirming aluminosilicate dominance. Low ***MgOH*** values in mineralized zones indicate weak links to ore formation, aligning with the porphyry deposit model, where argillic alteration (high ***AlOH***) prevails near ore bodies, while ***MgOH*** minerals are peripheral. The ***FeOH*** index (Figure 5) maps iron-hydroxyl minerals like goethite, limonite, and hematite, marking oxidation zones typical of sulfide mineral alteration in porphyry deposits.

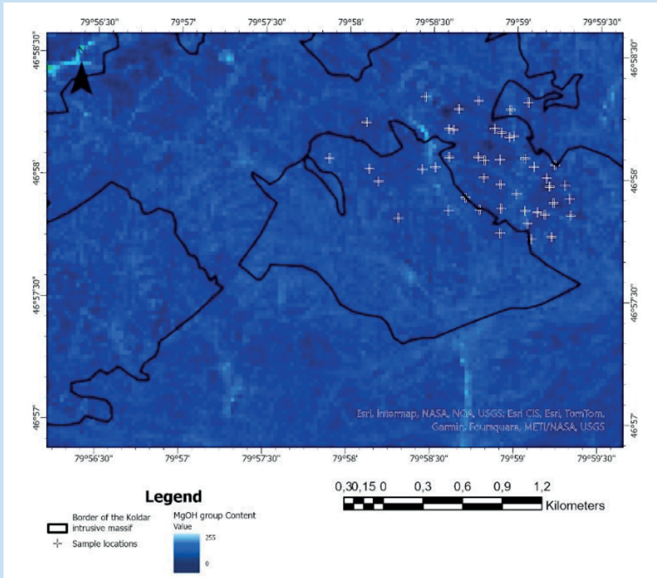
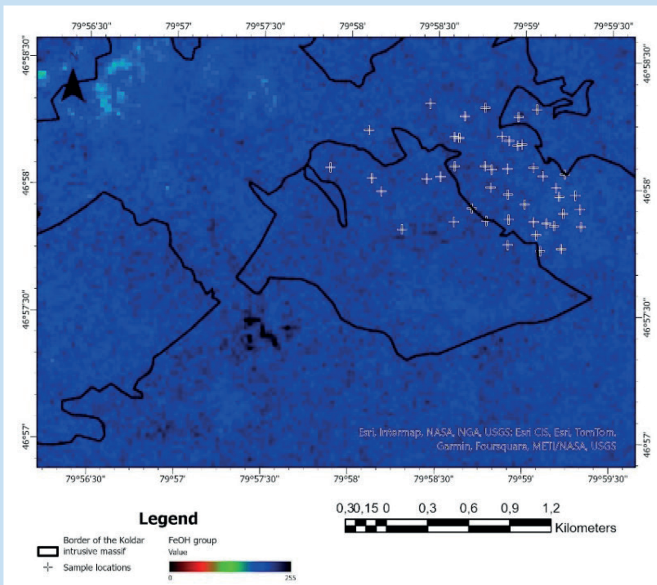


Figure 4. MgOH Group content based on ASTER Data.
Сурет 4. ASTER деректері негізіндегі MgOH тобының мөлшері.
Рис. 4. Содержание группы MgOH по данным ASTER.



Сурет 5. ASTER деректері негізіндегі FeOH тобының мөлшері.
Figure 5. FeOH Group content based on ASTER Data.
Рис. 5. Содержание группы FeOH по данным ASTER.

The ***AlOH*** index identified zones of argillic and kaolinitic alteration, characteristic of acidic hydrothermal processes associated with the leaching of aluminosilicates, with well-defined anomalies concentrated in the central part of the study area. The ***MgOH*** index exhibited less prominent anomalies, indicating weakly developed propylitization, which aligns with the typical model of porphyry systems. The ***FeOH*** index revealed isolated zones of increased concentration, suggesting the localized presence of iron-bearing hydrothermal minerals. However, compared to ***AlOH*** and ***MgOH***, ***FeOH*** anomalies were less distinct and more scattered.

At known mineralized locations (marked with red crosses), ***FeOH*** values do not show a strong correlation, which may indicate weakly developed oxidation zones or deep-seated ore bodies. The low intensity of ***FeOH*** anomalies compared to ***AlOH*** and ***MgOH*** suggests that oxidation processes are weakly expressed, which may imply either the absence of significant weathering and oxidation zones or a low concentration of iron-bearing minerals in the near-surface layers.

Scattered local ***FeOH*** anomalies require further investigation, as they could be related to oxidized sulfide mineralization zones or weathering products. A comprehensive analysis of ***FeOH***, ***AlOH***, and ***MgOH*** indices confirms that the dominant processes in the mineralized zone are argillic alteration and weak propylitization, rather than intense oxidation of sulfide minerals.

The ***FeOH*** index revealed only minor signs of oxidative changes. Unlike ***AlOH*** (argillic alteration) and ***MgOH*** (weak propylitization), iron-bearing minerals did not form significant anomalies, which may indicate deep-seated ore bodies or weakly developed oxidation processes. To refine the findings, additional geochemical and geophysical investigations are recommended in the areas where FeOH anomalies have been identified.

Conclusion

This study analyzed ASTER data to map ore-bearing zones in porphyry copper deposits using ***FeOH***, ***AlOH***, and ***MgOH*** indices. The results showed that the ***AlOH*** index revealed significant anomalies associated with argillic and kaolinitic alterations in the outer zones of porphyry systems. The ***MgOH*** index indicated localized weak propylitic alteration, suggesting the presence of secondary magnesium silicates. The ***FeOH*** index exhibited low anomaly intensity, which may imply weak sulfide oxidation or deep-seated ore bodies. A comparison with known mineralized areas confirmed the effectiveness of these indices for remote sensing of porphyry copper deposits. The findings can be applied for the preliminary assessment of prospective areas and optimization of further exploration activities, while integration with geophysical and geochemical methods is recommended to refine the depth characteristics of ore bodies.

Acknowledgments

The research is funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. BR21882179).

REFERENCES

1. *Sillitoe R.H. Porphyry copper systems // Economic Geology. 2010. V. 105. No. 1. 3–41 pp. (in English)*
2. *Lowell J.D., Guilbert J.M. Lateral and vertical alteration-mineralization zoning in porphyry ore deposits // Economic Geology. 1970. V. 65. No. 4. 373–408 pp. (in English)*
3. *Porphyry deposits: Characteristics and origin of hypogene features. Economic Geology 100th Anniversary Volume / Seedorff E., Dilles J. H., Proffett J.M. [et al.]. Littleton: Society of Economic Geologists. 2005. 251–298 pp. (in English)*
4. *Rajan Girija R., Mayappan S. Mapping of mineral resources and lithological units: A review of remote sensing techniques // International Journal of Image and Data Fusion. 2019. V. 10. No. 2. 79–106 pp. (in English)*
5. *Abubakar A.J.A. Satellite remote sensing for hydrothermal alteration minerals mapping of subtle geothermal system in unexplored aseismic environment: dissertation. Universiti Teknologi Malaysia, 2018 (in English)*
6. *Pour A.B., Hashim M., Marghany M. Characterization of ASTER Data for Mineral Exploration // Proceedings of the MRSS 6th International Remote Sensing & GIS Conference and Exhibition, Kuala Lumpur, Malaysia. 2010. V. 6. 1–8 pp. (in English)*
7. *Abrams M. 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. 2000. V. 21. No. 5. 847–859 pp. (in English)*
8. *Ninomiya Y. A stabilized vegetation index and several mineralogic indices defined for ASTER VNIR and SWIR data // IGARSS 2003. 2003 IEEE International Geoscience and Remote Sensing Symposium. Proceedings (IEEE Cat. No. 03CH37477). IEEE, 2003. V. 3. 1552–1554 pp. (in English)*
9. *Liu L. et al. Gold-copper deposits in Wushitala, Southern Tianshan, Northwest China: Application of ASTER data for mineral exploration //Geological Journal. 2018. V. 53. 362–371 pp. (in English)*
10. *Fatima K. et al. (October 2017). Minerals identification and mapping using ASTER satellite image. https://www.spiedigitallibrary.org/journals/journal-of-applied-remote-sensing/volume-11/issue-4/046006/Minerals-identification-and-mapping-using-ASTER-satellite-image/10.1117/1.JRS.11.046006.short (in English)*

11. *Pour A.B., Hashim M. Hydrothermal alteration mapping from Landsat-8 data, Sar Cheshmeh copper mining district, south-eastern Islamic Republic of Iran // Journal of Taibah University for Science. 2015. V. 9. No. 2. 155–166 pp. (in English)*
12. *Rowan L.C., Schmidt R.G., Mars J.C. Distribution of hydrothermally altered rocks in the Reko Diq, Pakistan mineralized area based on spectral analysis of ASTER data // Remote Sensing of Environment. 2006. V. 104. No. 1. 74–87 pp. (in English)*

ПАЙДАЛАНҒАН ӘДЕБИЕТТЕР ТІЗІМІ

1. *Sillitoe R.H. Порфирлі мыс жүйелері // Economic Geology. 2010. Т. 105. № 1. Б. 3–41 (ағылшын тілінде)*
2. *Lowell J.D., Guilbert J.M. Порфирлі кен орындарындағы минералдану-альтерацияның бүйірлік және тік зоналылығы // Economic Geology. 1970. Т. 65. № 4. Б. 373–408 (ағылшын тілінде)*
3. *Порфирлі кен орындары: гипогендік белгілердің сипаттамасы және шығу тегі. Economic Geology 100th Anniversary Volume / Seedorff E., Dilles J. H., Proffett J. M. [және т. б.]. Литлтон: Society of Economic Geologists. 2005. Б. 251–298 (ағылшын тілінде).*
4. *Rajan Girija R., Mayappan S. Минералдық ресурстар мен литологиялық бірліктерді картаға түсіру: қашықтықтан зондтау әдістеріне шолу // International Journal of Image and Data Fusion. 2019. Т. 10. № 2. Б. 79–106 (ағылшын тілінде)*
5. *Abubakar A.J.A. Гидротермалды альтерация минералдарын картаға түсіру үшін Жерді қашықтықтан зондтау: дис. … техн. ғыл. докт. Universiti Teknologi Malaysia, 2018 (ағылшын тілінде)*
6. *Pour A.B., Hashim M., Marghany M. ASTER деректерінің минералды барлау үшін сипаттамасы // Proceedings of the MRSS 6th International Remote Sensing & GIS Conference and Exhibition, Куала-Лумпур, Малайзия. 2010. Т. 6. Б. 1–8 (ағылшын тілінде)*
7. *Abrams M. ASTER спутниктік сенсоры: NASA Terra платформасындағы жоғары кеңістіктік ажыратымдылыққа ие құрылғының деректер өнімдері // International Journal of Remote Sensing. 2000. Т. 21. № 5. Б. 847–859 (ағылшын тілінде)*
8. *Ninomiya Y. Тұрақтандырылған өсімдіктер индексі және ASTER VNIR мен SWIR деректеріне арналған бірнеше минералогиялық индекстер // IGARSS 2003. 2003 IEEE International Geoscience and Remote Sensing Symposium. Proceedings (IEEE Cat. No. 03CH37477). IEEE, 2003. Т. 3. Б. 1552–1554 (ағылшын тілінде)*
9. *Liu L. және т.б. Солтүстік-Батыс Қытайдың Оңтүстік Тянь-Шань аймағындағы Ушиталадағы алтын-мыс кен орындары: минералды барлауда ASTER деректерін қолдану // Geological Journal. 2018. Т. 53. Б. 362–371 (ағылшын тілінде).*
10. *Fatima K. және т. б. (Қазан 2017). ASTER спутниктік суреттерін пайдалана отырып, минералдарды анықтау және картаға түсіру. https://www.spiedigitallibrary.org/journals/journal-of-applied-remote-sensing/volume-11/issue-4/046006/Minerals-identification-and-mapping-using-ASTER-satellite-image/10.1117/1.JRS.11.046006.short (ағылшын тілінде)*
11. *Pour A.B., Hashim M. Landsat-8 деректерін пайдалана отырып, гидротермалды альтерацияны картаға түсіру, Сар Чешмех мыс кен орны ауданы, Иран Ислам Республикасының оңтүстік-шығысы // Journal of Taibah University for Science. 2015. Т. 9. № 2. Б. 155–166 (ағылшын тілінде)*
12. *Rowan L.C., Schmidt R.G., Mars J.C. ASTER деректерінің спектралдық талдауына негізделген Пәкістанның Реко-Дик минералданған аймағындағы гидротермалды өзгерген жыныстардың таралуы // Remote Sensing of Environment. 2006. Т. 104. № 1. Б. 74–87 (ағылшын тілінде)*

СПИСОК ИСПОЛЬЗОВАННЫХ ИСТОЧНИКОВ

1. *Sillitoe R.H. Порфировые медные системы // Economic Geology. 2010. Т. 105. № 1. С. 3–41 (на английском языке)*
2. *Lowell J.D., Guilbert J.M. Латеральное и вертикальное зонирование минерализации-альтерации в порфировых рудных месторождениях // Economic Geology. 1970. Т. 65. № 4. С. 373–408 (на английском языке)*
3. *Порфировые месторождения: характеристики и происхождение гипогенных признаков. Economic Geology 100th Anniversary Volume / Seedorff E., Dilles J.H., Proffett J.M. [и др.]. Литлтон: Society of Economic Geologists. 2005. С. 251–298 (на англ. яз.).*
4. *Rajan Girija R., Mayappan S. Картирование минеральных ресурсов и литологических единиц: обзор методов дистанционного зондирования // International Journal of Image and Data Fusion. 2019. Т. 10. № 2. С. 79–106 (на английском языке)*

5. *Abubakar A.J.A. Дистанционное зондирование Земли для картирования минералов гидротермальной альтерации в слабоизученных сейсмически стабильных районах: дис. ... д-р техн. наук: Universiti Teknologi Malaysia, 2018 (на английском языке)*
6. *Pour A.B., Hashim M., Marghany M. Характеристика данных ASTER для разведки полезных ископаемых // Proceedings of the MRSS 6th International Remote Sensing & GIS Conference and Exhibition, Куала-Лумпур, Малайзия. 2010. Т. 6. С. 1–8 (на английском языке)*
7. *Abrams M. Спутниковый датчик ASTER: продукты данных для прибора с высоким пространственным разрешением на платформе NASA Terra // International Journal of Remote Sensing. 2000. Т. 21. № 5. С. 847–859 (на английском языке)*
8. *Ninomiya Y. Стабилизированный индекс растительности и несколько минералогических индексов, определенных для VNIR и SWIR данных ASTER // IGARSS 2003. 2003 IEEE International Geoscience and Remote Sensing Symposium. Proceedings (IEEE Cat. No. 03CH37477). IEEE, 2003. Т. 3. С. 1552–1554 (на английском языке)*
9. *Liu L. и др. Золото-медные месторождения в Ушитала, Южный Тянь-Шань, Северо-Западный Китай: применение данных ASTER для поиска полезных ископаемых // Geological Journal. 2018. Т. 53. С. 362–371 (на английском языке)*
10. *Fatima K. и др. (Октябрь 2017). Идентификация и картирование минералов с использованием спутниковых изображений ASTER. https://www.spiedigitallibrary.org/journals/journal-of-applied-remote-sensing/volume-11/issue-4/046006/Minerals-identification-and-mapping-using-ASTER-satellite-image/10.1117/1.JRS.11.046006.short (на английском языке)*
11. *Pour A.B., Hashim M. Картирование гидротермальной альтерации по данным Landsat-8, район медного рудника Сар-Чешмех, юго-восток Исламской Республики Иран // Journal of Taibah University for Science. 2015. Т. 9. № 2. С. 155–166 (на английском языке)*
12. *Rowan L.C., Schmidt R.G., Mars J.C. Распределение гидротермально измененных пород в минерализованной области Реко-Дик, Пакистан, на основе спектрального анализа данных ASTER // Remote Sensing of Environment. 2006. Т. 104. № 1. С. 74–87 (на английском языке)*

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