

### Review

of the dissertation work of YESKALIYEV YERTAY TALGATOVICH

on the topic: “Methodology for prospecting of gold-bearing deposits using modern satellite technologies, case study of the West Kalba gold belt”,  
submitted for the degree of Doctor of Philosophy (PhD)  
in the educational program 8D07201 – Geology and Exploration of Mineral Deposits.

№ п/п	Criteria	Compliance with the criteria (underline one of the answer options)	Justification of the official reviewer’s position (remarks should be written in italics)
1.	The topic of the dissertation (at the date of its approval) corresponds to the priority areas of scientific development and/or state programs.	<p>1.1 Compliance with priority areas of scientific development or state programs:</p> <p>1. <u>The dissertation was carried out within the framework of a project or target program funded from the state budget (indicate the title and number of the project or program).</u></p> <p>2. The dissertation was carried out within the framework of another state program (indicate the name of the program).</p> <p>3. <u>The dissertation corresponds to a priority area of scientific development approved by the Higher Scientific and Technical Commission under the Government of the Republic of Kazakhstan (indicate the priority area).</u></p>	<p>The dissertation was carried out within the framework of the project funded from the state budget: IRN AP25795761 “Development of a combined method for forecasting gold mineral deposits based on satellite technology, geoinformation science and deep learning AI”, funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan.</p> <p>The work corresponds to the priority area of scientific development “Rational use of natural resources, geology and geological exploration.”</p>
2.	Significance for science	The work <u>makes</u> / does not make a significant contribution to science, and its importance is well demonstrated / not demonstrated.	The work makes a significant contribution to the development of remote sensing methods for forecasting gold deposits. The importance of the research is well demonstrated and justified by the need to introduce modern satellite technologies into geological exploration practice in Kazakhstan.
3.	Principle of independence	<p>Level of independence:</p> <p>1. <u>high</u>;</p> <p>2. medium;</p>	The analysis of the dissertation text shows a high level of independence of the author. The author independently carried out the analysis of spectral characteristics of

		<ol style="list-style-type: none"> <li>3. low;</li> <li>4. no independence.</li> </ol>	<p>minerals; developed a scheme for applying ASTER indices (Al–OH, Mg–OH, CO<sub>3</sub>, Fe<sup>2+</sup>, Fe<sup>3+</sup>); proposed an algorithm for vegetation masking based on NDVI; tested the methodology on specific ore fields (Bakyrchik, Bolshevik, etc.); and performed the geological interpretation of the resulting alteration maps. The processing of satellite data within the framework of the grant project was carried out entirely by the author, which confirms a high level of personal contribution.</p>
4.	Principle of internal coherence	<p>4.1 Justification of the relevance of the dissertation:</p> <ol style="list-style-type: none"> <li>1. <u>justified</u>;</li> <li>2. partially justified;</li> <li>3. not justified.</li> </ol>	<p>The relevance of the research is justified by the economic and geological context: depletion of large deposits, the need to expand the exploration base, and the introduction of digital methods for primary screening.</p>
		<p>4.2 The content of the dissertation reflects the topic of the dissertation:</p> <ol style="list-style-type: none"> <li>1. <u>reflects</u>;</li> <li>2. partially reflects;</li> <li>3. does not reflect.</li> </ol>	<p>The content of the work fully corresponds to the stated topic. The theoretical chapters logically lead to the development of the methodology, and the practical chapters demonstrate its application to specific depos</p>
		<p>4.3 The aim and objectives correspond to the topic of the dissertation:</p> <ol style="list-style-type: none"> <li>1. <u>correspond</u>;</li> <li>2. partially correspond;</li> <li>3. do not correspond.</li> </ol>	<p>The aim of the research — to develop a methodology for forecasting gold-bearing zones using satellite data — has been achieved through the consistent solution of the following tasks:</p> <ol style="list-style-type: none"> <li>1. analysis of the spectral characteristics of minerals;</li> <li>2. justification of diagnostic features of hydrothermal alteration;</li> <li>3. development of algorithms for processing ASTER data;</li> </ol>

			4. geological interpretation of the obtained results.
		4.4 All sections and provisions of the dissertation are logically interconnected: 1. <u>fully interconnected</u> ; 2. partially interconnected; 3. no interconnection.	All sections are interconnected and form a unified logical structure: from the physics of spectral processes to the practical mapping of ore-related alteration zones.
		4.5 The new solutions (principles, methods) proposed by the author are substantiated and evaluated in comparison with known solutions: 1. <u>critical analysis is present</u> ; 2. the analysis is partial; 3. the analysis consists of quotations from other authors rather than the author's own opinions; 4. the analysis is absent.	The dissertation presents a critical analysis of existing methods for remote forecasting of gold deposits. The author compares traditional spectral approaches, the capabilities of different satellite sensors, and the limitations of direct sulfide detection, thereby justifying the need for indirect mapping of hydrothermal alteration zones. The selection of ASTER indices, the use of NDVI masking, and the integration of GIS analysis are substantiated with consideration of known solutions and their limitations.
5.	Principle of scientific novelty	5.1 Are the scientific results and provisions new? 1. completely new; 2. <u>partially new (25–75% are new)</u> ; 3. not new (less than 25% are new).	The scientific results of the dissertation are not completely new from a methodological point of view, since the physical foundations of spectroscopy, the principles of applying ASTER spectral indices, the NDVI masking method, and the general logic of mapping hydrothermal alteration zones are well known in international remote sensing practice. At the same time, the novelty of the work is reflected in: • the adaptation of spectral indices to the specific geological and structural conditions of the West Kalba gold belt; • the justification of the informative value of the B05/B04 index for identifying sulfide zones within the studied region;

			<ul style="list-style-type: none"> <li>• the integrated combination of remote sensing data and geological interpretation into a unified exploration scheme;</li> <li>• the regional testing of the methodology on specific gold deposits in Eastern Kazakhstan.</li> </ul>
		<p>5.2 Are the conclusions of the dissertation new?</p> <ol style="list-style-type: none"> <li>1. completely new;</li> <li>2. <u>partially new (25–75% are new)</u>;</li> <li>3. not new (less than 25% are new).</li> </ol>	<p>The conclusions of the dissertation logically follow from the conducted research and have an applied character. The statement about the impossibility of direct gold detection and the need for indirect mapping of alteration zones is well known in remote sensing theory. However, under the geological conditions of the West Kalba region, the author has demonstrated the stability of spectral indicators of hydrothermal alteration and their spatial correlation with gold-bearing structures.</p> <p>The novelty of the conclusions lies in their regional specification and practical verification on ore fields, which gives them applied significance.</p>
		<p>5.3 Are the technical, technological, economic, or managerial solutions new and well substantiated?</p> <ol style="list-style-type: none"> <li>1. completely new;</li> <li>2. <u>partially new (25–75% are new)</u>;</li> <li>3. not new (less than 25% are new).</li> </ol>	<p>The proposed methodology does not include fundamentally new satellite sensors or original processing algorithms; however, it is distinguished by: the development of a structured scheme for the sequential application of spectral indices; the integration of remote sensing data with the geological model of the area; the adaptation of the methodology to gold-sulfide deposits in folded regions; and its practical focus on optimizing exploration costs.</p>
6.	Validity of the main conclusions	All main conclusions <u>are</u> / are not based on scientifically sound evidence or are sufficiently well substantiated (for qualitative research and fields of study in arts and humanities).	The main conclusions of the dissertation are well substantiated and confirmed by the results of satellite data processing and their comparison with geological data from known gold deposits. The spatial correlation between the identified hydrothermal alteration zones and ore bodies confirms the validity of the methodology. The theoretical provisions are logically connected with practical testing, which ensures sufficient scientific reliability of the conclusions.

7.	Main provisions submitted for defense	<p>It is necessary to answer the following questions separately for each provision:</p> <p>7.1 Is the provision proven?</p> <ol style="list-style-type: none"> <li>1. proven;</li> <li>2. rather proven;</li> <li>3. rather not proven;</li> <li>4. not proven;</li> <li>5. in its current wording, it is impossible to verify whether the provision is proven.</li> </ol> <p>7.2 Is it trivial?</p> <ol style="list-style-type: none"> <li>1. yes;</li> <li>2. no;</li> <li>3. in its current wording, it is impossible to assess whether the provision is trivial.</li> </ol> <p>7.3 Is it new?</p> <ol style="list-style-type: none"> <li>1. yes;</li> <li>2. no;</li> <li>3. in its current wording, it is impossible to assess whether the provision is new.</li> </ol> <p>7.4 Level of applicability:</p> <ol style="list-style-type: none"> <li>1. narrow;</li> <li>2. medium;</li> <li>3. broad;</li> <li>4. in its current wording, it is impossible to assess the level of applicability of the provision.</li> </ol> <p>7.5 Is it proven in the published article(s)?</p> <ol style="list-style-type: none"> <li>1. yes;</li> </ol>	<p>Provision 1. A methodology for identifying gold-bearing zones based on ASTER spectral indices and mapping of hydrothermal alteration zones within the West Kalba belt has been developed and tested.</p> <p>The provision is proven, not trivial, has applied novelty, and can be used for regional forecasting of gold-sulfide deposits.</p> <p>7.1 Is the provision proven? → 1) proven  7.2 Is it trivial? → 2) no  7.3 Is it new? → 1) yes  7.4 Level of applicability: → 2) medium  7.5 Is it proven in the article(s)? → 1) yes</p> <p>Provision 2. The possibility of indirect forecasting of gold-bearing zones through spectral indicators of secondary hydrothermal alteration (sericitization, argillization, propylitization) has been demonstrated.</p> <p>The provision is scientifically substantiated, has regional novelty, and shows broad prospects for application in hydrothermal gold systems.</p> <p>7.1 Is the provision proven? → 1) proven  7.2 Is it trivial? → 2) no  7.3 Is it new? → 1) yes  7.4 Level of applicability: → 3) broad  7.5 Is it proven in the article(s)? → 1) yes</p> <p>Provision 3. The effectiveness of integrating remote sensing and geoinformation analysis to improve the reliability of forecasting gold-bearing zones has been substantiated.</p> <p>The provision is confirmed and has applied novelty.</p> <p>7.1 Is the provision proven? → 1) proven</p>
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8.	Principle of reliability. Reliability of sources and the information provided.	<p>8.1 Is the choice of methodology justified or is the methodology described in sufficient detail?</p> <p>1. <u>yes</u>;</p> <p>2. no.</p>	<p>The research methodology in the dissertation is presented in a consistent and logical manner. The author justifies the choice of ASTER satellite data based on their spectral characteristics in the VNIR and SWIR ranges, which are necessary for diagnosing hydrothermal alteration. The stages of data processing are described in detail: atmospheric correction, topographic normalization, calculation of spectral indices, NDVI masking, creation of false-color composites, and subsequent geological interpretation.</p> <p>The selected methodological approaches are aligned with the objectives of the study and meet modern requirements for remote forecasting.</p>
		<p>8.2 Were the results of the dissertation obtained using modern scientific research methods, data processing, and interpretation techniques with the use of computer technologies?</p> <p>1. <u>yes</u>;</p> <p>2. no.</p>	<p>The work uses modern remote sensing methods and digital data processing techniques:</p> <ul style="list-style-type: none"> <li>• ASTER satellite data;</li> <li>• spectral indices (Al–OH, Mg–OH, CO<sub>3</sub>, Fe<sup>2+</sup>/Fe<sup>3+</sup>, etc.);</li> <li>• NDVI filtering;</li> <li>• GIS analysis of spatial structures;</li> <li>• elements of algorithmic data processing.</li> </ul> <p>All results were obtained using computer technologies for processing and interpreting geospatial information, which fully corresponds to the current level of research in geological exploration.</p>

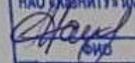
		<p>8.3 Are the theoretical conclusions, models, identified relationships, and patterns proven and confirmed by experimental research (for fields of study in education sciences, the results are proven based on a pedagogical experiment)?</p> <ol style="list-style-type: none"> <li>1. <u>yes</u>;</li> <li>2. no.</li> </ol>	<p>The theoretical provisions presented in the section on spectral fundamentals (mechanisms of electronic and vibrational transitions) are confirmed by the practical testing of the methodology on specific gold deposits within the West Kalba belt. The spatial correlation between the identified alteration zones and known ore bodies demonstrates that the theoretical assumptions are supported by practical results. Thus, the theoretical conclusions are confirmed by the experimental part of the research.</p>
		<p>8.4 Important statements are <u>confirmed</u> / partially confirmed / not confirmed by references to relevant and reliable scientific literature.</p>	<p>The key provisions of the dissertation are based on up-to-date publications in the fields of remote sensing, spectroscopy, and satellite mineralogy. The work includes references to recent studies on the use of ASTER, Sentinel-2, and other sensors for mapping hydrothermal alteration. Most of the important statements are supported by references to scientific literature relevant to the topic of the research.</p>
		<p>8.5 The sources used are <u>sufficient</u> / not sufficient for the literature review.</p>	<p>The literature review covers the main research directions in spectral mineralogy, remote sensing, and geological forecasting. The sources used are sufficient to present the theoretical background and to justify the chosen methodology.</p>
9	Principle of practical significance	<p>9.1 Does the dissertation have theoretical significance?</p> <ol style="list-style-type: none"> <li>1. <u>yes</u>;</li> <li>2. no.</li> </ol>	<p>The work expands the methodological basis of remote forecasting of gold deposits and substantiates the spectral indicators of hydrothermal alteration under the geological conditions of the West Kalba region.</p>
		<p>9.2 Does the dissertation have practical significance, and is there a high probability of applying the obtained results in practice?</p> <ol style="list-style-type: none"> <li>1. <u>yes</u>;</li> </ol>	<p>The methodology can be applied for regional ranking of prospective areas and for optimizing exploration activities. Practical testing confirms its applicability.</p>

		2. no.	
		9.3 Are the recommendations for practice new? 1. completely new; 2. <u>partially new (25–75% are new)</u> ; 3. not new (less than 25% are new).	The methodology is based on known approaches but is distinguished by their integrated application and regional adaptation.
10.	Quality of writing and presentation	Quality of academic writing: 1. <u>high</u> ; 2. medium; 3. below average; 4. low.	The dissertation is presented in a logical and consistent structure, and the terminology is used in accordance with professional standards of geological science. The text follows an academic style, with correct use of specialized terminology and consistent argumentation. The illustrative material (maps, schemes, diagrams) corresponds to the content and helps to clearly present the research results.
11.	Comments on the dissertation	<p>In the theoretical chapter, some sections have a review character and are somewhat overloaded with general descriptions of spectroscopy, which slightly increases the volume of the work without significantly strengthening the applied part.</p> <p>The dissertation does not present a detailed quantitative assessment of the accuracy of the proposed methodology (for example, through statistical indicators comparing the identified alteration zones with the actual distribution of ore bodies).</p> <p>These comments are clarifying in nature and do not reduce the overall scientific and practical value of the dissertation.</p>	
12.	Scientific level of the doctoral candidate's publications on the research topic (in case the dissertation is defended in the form of a series of articles, the official reviewers comment on the scientific level of each article related to the research topic).		

	topic).	
13.	Decision of the official reviewer (in accordance with paragraph 28 of the current Standard Regulations)	<p>The dissertation work of YESKALIYEV YERTAY TALGATOVICH entitled "Methodology for prospecting of gold-bearing deposits using modern satellite technologies, case study of the West Kalba gold belt" meets the requirements for doctoral dissertations established by the Standard Regulations on the Awarding of Degrees of the Republic of Kazakhstan.</p> <p>The work is a completed scientific study and contains scientifically substantiated results and provisions characterized by scientific novelty, theoretical and practical significance, reliability, and internal logical coherence.</p> <p>YESKALIYEV YERTAY TALGATOVICH deserves to be awarded the degree of Doctor of Philosophy (PhD) in the educational program 8D07201 – Geology and Exploration of Mineral Deposits.</p>

**Reviewer**  
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 20.02.2026.

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