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EVALUATION OF LANDSAT-2 (ERTS) IMAGES
APPLIED TO GEOLOGIC STRUCTURES AND
MINERAL RESOURCES OF SOUTH AMERICA

"Made available under NASA sponsorship
in the interest of early and wide dis-
semination of Earth Resources Survey
Program information and without liability
for any use made thereon."

William D. Carter *etc*

and

William S. Kowalik

U. S. Geological Survey

Reston, Virginia 22092

1 July 1976

Type II Progress Report for Period June 30, 1975 - June 30, 1976

Prepared for:

Goddard Space Flight Center

Greenbelt, Maryland 20771

23010

RECEIVED

AUG 19 1976

SIS/902.6

(E76-10460) EVALUATION OF LANDSAT-2 (ERTS)
IMAGES APPLIED TO GEOLOGIC STRUCTURES AND
MINERAL RESOURCES OF SOUTH AMERICA Progress
Report, 30 Jun. 1975 - 30 Jun. 1976
(Geological Survey, Reston, Va.) 23 p HC

G3/43

Unclas
00460

N76-30628
HC #3.50

Landsat-1 -2 Type II Progress Report to NASA

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TYPE II PROGRESS REPORT

LANDSAT-2

A. PROBLEMS

- 1) Image Line Dropouts: This problem, reported in a previous report, has been reduced and has been found only in a few images. For example, of 16 images recently received, only one had a line dropout. Special processing by the Jet Propulsion Laboratory, using their ERTS/FIX program, corrected the line dropout problem in selected CCT's.
- 2) Landsat-2 coverage of the Andes is unusually sparse for the September/October dry period. According to temporal analyses of the Salar of Uyuni and other regions, this period is an optimum time to obtain coverage in many areas. It is suggested that, if at all possible, additional data be collected for this region (Salar of Uyuni, S20°09' W067-31) during the next Sept/Oct period. A coordinated ground sampling and reflectance measurement field experiment will be coordinated with the Landsat-2 overpass, if data collection can be scheduled. See "Significant Results" of this report.

B. Accomplishments

1) Activities and travel:

- a) Three trips by Carter and Kowalik were made to the EROS Data Center, Sioux Falls, S. D. for the purpose of analyzing Landsat CCT's. Emphasis was placed on mapping rock types in northern Chile near Antofagasta and salt deposits in the Chilean Nitrate Fields and unmapped salt deposits of southern Bolivia. Trips were July 7-11, 1975; Feb. 9-13, 1976, and June 28-July 2, 1976. This work was done using the Image 100.
- b) On Sept. 9-15, 1975 W. D. Carter participated in a USIA Space Exhibit in Belgrade, Yugoslavia giving lectures on the uses of Landsat data at several universities. During this trip he also spent 3 days in Zagreb visiting remote sensing-personnel at Industro projekt which is a state-owned development corporation dealing with exploration for petroleum and mineral resources.
- c) L. C. Rowan, during the same period, visited the University of Reading, England, presented a paper by Carter on "Mineral Resources and Structural Geology of the Andes" and discussed a project proposal on "Remote Sensing Applied to Mineral Exploration". This project was jointly proposed by Carter and Rowan to the International Geological Correlation Program (IGCP). The proposal provides for an exchange of information by international participants; approximately 60 countries are now involved and a U. S. National Working Group of 16 scientists has met. The proposal was approved as Project No. 143 by IGCP in March 1976 and is now active. Newsletter No. 1 has been

distributed to key representatives.

- d) During October 6-10, 1975 W. D. Carter attended the 10th International Symposium on Remote Sensing of the Environment and presented a paper entitled "Mineral Resource Investigations in South America Using Landsat Data". A copy of the abstract is attachment "A".
- e) On October 27 - 31, 1975, W. D. Carter attended the W. T. Pecora Memorial Symposium at the EROS Data Center, Sioux Falls, S.D. J. Kutina presented a paper by Kutina and Carter entitled "Landsat Contributions to Studies of Plate Tectonics". A copy of the Abstract is attachment "B".
- f) In November the U. S. Geological Survey began negotiations with the Inter-American Development Bank to provide technical support and guidance on the use of Landsat data in bank-funded development programs. On December 8, 1975, a one day meeting was held at USGS Headquarters to discuss Landsat applications with key IDB personnel.
- g) On December 11, 1975, W. D. Carter and J. Reinemund briefed Science Attaches of Foreign Embassies on Landsat applications and U. S. Geological Survey programs, respectively.
- h) February 18 and 19, 1976, an IGCP/U. S. National Committee on "Remote Sensing applied to Mineral Exploration" was established with 20 people from government, universities and industry attending. W. D. Carter and L. C. Rowan initiated the discussions. It was decided to concentrate mainly on clarifying geologic terminology related to remote sensing from space and improving communication with those around the world interested in mineral exploration. Our first Newsletter No. 1 was distributed to

both U. S. participants and international correspondents.

- i) Between March 9-20, 1976, W. D. Carter accompanied an Inter-American Development Bank team to five Central American countries (Costa Rica, Nicaragua, El Salvador, Guatemala, and Honduras) to design a remote sensing training and applications program aimed at developing a multinational natural resources inventory program based on the use of Landsat and supporting data. The plan has been developed and should be initiated during 1976. Success of the plan will depend heavily on NASA to acquire cloud free Landsat images of unimaged parts of the region. A formal request for such data will be sent to NASA when the plan is implemented.
- j) Between March 29-April 1976 a short course on remote sensing and Landsat applications was conducted at the EROS Data Center for 14 officials of the Inter-American Development Bank. W. D. Carter lectured on "Landsat applications in Latin America" and "Legal Aspects of Remote Sensing and Landsat Data".
- k) From April 18 to May 7, 1976, W. D. Carter visited Bolivia (2 weeks) and Chile (1 week). In Bolivia he conducted a 5 day field trip to the Salar of Uyuni and went on a 2 day overflight of Landsat-detected alteration zones in the western cordillera of the Andes along the Chilean frontier. In Chile, he visited cooperating government agencies and Inter-American Bank officials primarily to check on the status of DCP development in Chile. See significant results for additional information.

- 1) Between June 12-19, 1976, [redacted] attended the Annual COSPAR Meeting in Philadelphia as official representative of the International Union of Geological Sciences. He presented a paper on Landsat studies of the Salar of Uyuni. A copy of the abstract is provided as attachment "C".

2) Image Processing and Analysis -

Research during the period was aimed at developing multidisciplinary examples of automatic image analyses of selected areas of South America. The list of images below indicate the location and types of products that were developed using the Image 100 system at the EROS Data Center, Sioux Falls, S.D.

<u>Image No.</u>	<u>Location</u>	<u>Principal Products</u>
2059-13512	Santiago, Chile	Rio Blanco Mine, Alteration Zone, Land Use-Santiago, Agricultural Vegetation types-San Felipe
2155-14202	Nazca, Peru	Archeological Lines, Rock types
2040-15163	San Jose, Costa Rica	Land Use, Agricultural crops, soil units
1243-13592	Lago Poopo, Bolivia	Geologic units, vegetation, water surfaces
1243-14001	Salar of Ascotan, Chile Bolivia	Salar mapping of Ascotan, Coposa and Laguma Pastos Grandes, alteration zone at San Juan del Abra
1243-14004	Salar of Atacama, Chile	Chuquicamata Copper, Mines Mapping Salar of Atacoma
1243-13595	Salar of Uyuni, Bolivia	Salt surface mapping of Uyuni and nearby salt flats
1244-14062	Antofagasta, Chile	Rock types, soils of Pedro de Valdivia nitrate mines, Mejillones Peninsula

A catalog of reflectance spectra based on these measurements will be developed as part of our Landsat-2 final report.

3) Mosaic Construction -

The Santiago, Chile/Mendoza, Argentina Mosaic covering the area from Latitude 32-35° South and Longitude 60-72° West has been completed in three colors using only Band 5 and 7. A grid and collar annotations are being prepared and it is hoped that a limited edition will be printed in September or October 1976.

C. Significant Results:

1) Salar de Coposa, Chile:

The Salar of Coposa is located in northern Chile ($20^{\circ}45'S$ and $68^{\circ}40'W$) along the frontier with Bolivia. It was mapped by Stoertz and Ericksen (1974) with aerial photography and by field observations. The surface was divided into 6 general classes of materials. Analysis of Landsat image 1243-14001 by use of interactive multispectral computer (Image 100) enabled us to accurately repeat these general classes on the basis of reflectance but also to subdivide some of the larger units. The success of these results encouraged us to extend this work to several other study areas such as Ascotan and Uyuni.

2) Salar of Uyuni, Bolivia:

The Salar of Uyuni is the largest of the South American evaporite deposits. It covers an area of $9,439 \text{ km}^2$ at $20^{\circ}S$ and $68^{\circ}W$ and is exploited for table salt, supplying all of Bolivia's needs. Repetitive images (5) between 1972 and 1975 show that it was driest in October 1972 and wettest in March 1973. Using image 1243-13595, and paralleliped computer classification of reflectance units, we were able to divide the Salar into nine classes ranging from deep to shallow water, water over salt, salt saturated with water and several classes of dry salt. Field work demonstrated that the dry salt classes could be recognized by surface roughness differences. None of these classes had vertical relief greater than 10 cm. The correspondence between the surface roughness and reflectance classes appears

significant. Fourteen samples of the salt crust, collected at 10km intervals across the salt flat, were analyzed and lithium was found to be present and ranging from 30 to 100 ppm. This is 6 to 20 times the average concentration for NaCl.

Samples of brine from two open surface ponds were also found to contain significant concentrations of magnesium, potassium and lithium. Of these, lithium has the greatest potential commercial value because it is an alkaline metal used in long duration storage batteries and as a breeder of tritium in fusion reactors. Potassium has considerable value as a fertilizer. Magnesium, on the other hand, causes problems in the extraction of lithium and, therefore, must be considered carefully in the design of any commercial venture. A summary of the analyses, as determined by atomic absorption methods, is shown below:

<u>LOCATION</u>	<u>Mg</u>	<u>K</u>	<u>Li</u>
Colchani saltworks (SU-2)	36,200	24,100	1510 mg/Kg
Isla de los Pescadores, 100km to west (SU-16)	12,300	10,600	490 mg/Kg

These amounts greatly exceed the concentrations of lithium currently being exploited as a by-product at Searles Lake, Calif. (70 mg/Kg) and at Clayton Valley, Nev. (300 mg/Kg) where lithium is a primary product. The discovery of lithium at the Salar of Uyuni is considered significant and was officially announced by Gen. Zelaya, Minister of Mines, Government of Bolivia on July 10, 1976 crediting the role of the U. S. Geological Survey. Further sampling of the brines and salt, however, will be necessary to fully evaluate the potassium and lithium resources of the Salar of Uyuni evaporites.

Plans are currently being developed to conduct more sampling at Uyuni and neighboring Salar de Coipasa during September 1976 in conjunction with surface spectral reflectance measurements. A request to NASA to collect Landsat data over the region during this period is included under "Recommendations" of this report.

D. Status of Publications:

- 1) Landsat (ERTS-1) Final Report to NASA has been approved by the Director's Office for publication. After typing corrections it will be printed and forwarded to NASA and co-investigators.
- 2) U. S. Geological Survey Professional Paper 929 entitled "ERTS-1, A New Window on Our Planet" by R. S. Williams, Jr. and W. D. Carter, Editors was delivered for public distribution on August 12, 1976.
- 3) Three abstracts on the uses of Landsat data uses have been published. They are:
 - a) Carter, W. D., 1975, Mineral Resource Investigations in South America Using Landsat Data: 10th International Symposium on Remote Sensing of the Environment: Proceedings, Univ. of Michigan, Ann Arbor, Mich. Abstract) p. 1029.
 - b) Kutina, Jan and Carter, W. D., 1975, Landsat Contributions to Studies of Plate Tectonics: Abstracts of the W. T. Pecora Symposium, Sioux Falls, S. D. October 28-31, 1975.
(Full paper to be published in U. S. Geological Survey Professional Paper - Symposium Proceedings)
 - c) Carter, W. D., Kowalik, W. S. and Brockmann, C. E., 1976, "Mapping Andean Salar Deposits by Radiance Values from Landsat Computer Tapes": 19th Plenary Meeting of COSPAR, Philadelphia, Pa. Program Abstracts, p. 414.
- 4) One abstract is in press:
 - a) Kutina, Jan and Carter, W. D., in press, Metallogeny and

Two Major East-West Fracture Zones in the United States: 2nd
Symposium on New Basement Tectonics, Newark, Delaware, July, 1976.

E. Recommendations:

- 1) NASA is hereby requested to collect MSS image data of the Salar of Uyuni during the September/October time frame as close to October 1 as the orbital schedule allows. A joint project involving personnel from U. S. G. S., ERTS/Project Bolivia of GEOBOL, University of San Andres, LaPaz and the French BRGM is planned for more detailed sampling of the salt and brine. Field spectra will also be measured of the surface roughness units within the salar and of some of the more abundant rock types exposed in the vicinity.

F. Funds Expended:

Travel:

5 Trips to EROS Data Center	=1750.00
Yugoslavia (paid by USIA)	=1404.00
Michigan Symposium	=415.00
Central America (paid by IDB)	
Bolivia/Chile Field Trip	=750.00
COSPAR Meeting	=206.00
TOTAL	\$5982.00

G. Data Use:

The following tabulation shows the value of the data allowed for this project and the value of the data received as of May 30, 1975.

	<u>Value of Data</u> <u>Allowed</u>	<u>Value of Data</u> <u>Received</u>	<u>Balance Remaining</u>
Film*	\$38,100.00	\$21,223.00	\$16,877.00
CCTs**	\$1200.00	\$1200.00	0
TOTAL	\$39,300.00	\$22,423.00	\$16,877.00

*Account No. G-23010 Initial amount 16,400 increased 9/8/75 by \$21,700

**Account No. G-E 3010

MINERAL RESOURCE INVESTIGATIONS
IN SOUTH AMERICA USING LANDSAT DATA

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William D. Carter
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SUMMARY

Synoptic, multispectral LANDSAT images of the South American continent are providing a new look at one of the largest under explored areas of the Earth. Mineral resources include vast areas of timber, grasslands for grazing, abundant water supply for hydroelectric power, and a great variety of mineral and petroleum resources that are beginning to be developed to meet world requirements. The surface of the continent is rapidly changing in response to current land use demands; the accelerated industrial development of Brazil and Venezuela is symptomatic of these changes. The oil-rich countries of Ecuador, Peru, and Bolivia are feeling the pressures of world resource needs and are beginning to realize the effects of increased development. Remote sensing by side-looking airborne radar and satellite imaging is playing an important role in this development.

This paper describes a cooperative effort between the U. S. Geological Survey and similar agencies of several South American countries to investigate the applications of satellite data to mineral and energy resource exploration. Informal arrangements for data and information exchange were devised to insure that each country would have an opportunity to participate in the experiment. Venezuela, Colombia, Peru, Chile, Bolivia, Brazil, and Argentina have all participated to varying degrees.

Data collected by the LANDSAT system has been sporadic because of the failure or gradual demise of tape recorders on the satellites. The images obtained, largely of the drier areas of the Andes, have provided an important data base for investigators with which to begin their work. A nucleus of geologists in each country has been formed to work with data sent to them by the project.

Two mosaics (La Paz and Copiapo), each covering 4 degrees of latitude and 6 degrees of longitude (scale 1:1,000,000), a total of 552,000 km², were compiled from band 5 images. These were analyzed for linear features and compared with overlay maps showing the distribution of ore deposits of various types. Revised metallogenic maps showing trends favorable for field investigation were compiled. Mineralized fractured ground containing malachite and chalcocite, along one of these favorable trends has been reported from Bolivia, but the total extent and value of this discovery is not yet known. The use of LANDSAT data for planning an exploration program, however, was clearly demonstrated. In addition, such mosaics and interpretations appear to be of value in helping to define areas of high seismic risk and in studies of plate tectonics.

More detailed studies have been conducted in smaller areas using computer compatible tapes and commercially available multispectral analysis systems. These systems have the capability of distinguishing rock types and other features by differences in their spectral reflectance. Granitic rocks have been differentiated from andesite. Light-colored volcanic rocks, such as rhyolitic tuffs and breccias, can generally be differentiated from darker andesites and basalts and their reflectance values measured. Salt deposits within large salars (playas) have been subdivided, largely on the basis of water content. Hopefully, better knowledge of the distribution and composition of these vast salt deposits will lead to their economic development. The project is attempting to build a catalog of reflectance values for rock types that may serve as guides for studies in lesser known regions.

1079

Presented at the 10th International Symposium on Remote Sensing of the Environment, Univ. of Michigan, Ann Arbor, Mich. Oct. 1975

LANDSAT Contributions to Studies of Plate Tectonics*

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William D. Carter

U. S. Geological Survey, Reston, Va. 22090

ABSTRACT

Tectolinear interpretation of satellite image mosaics has proven to be a powerful method for tracing the course of basement fracture zones which have been propagated upwards through a platform cover and even through orogenic belts. The method has also been applied to locate fracture zones, the orientations of which have been changed by rotation of lithospheric plates.

(1) A tectolinear interpretation map of the United States by W. D. Carter, set in context with structural geological knowledge of the Canadian Shield, suggests that the Hudson Bay Paleolineament (HBP) of J. Kutina may extend into the Precambrian basement of the eastern United States. A spatial correlation of significant ore districts with the HBP and associated structures in Canada (both in the Archean greenstone belt and outside) suggests that important ore concentrations may also exist along the probable extension of the HBP beneath the sedimentary cover of the eastern United States, where it may intersect with an east-west trending fracture zone, distinguished by A. V. Heyl (1972), between 38° and 40° N in central and eastern United States. A number of Mississippi Valley type ore deposits are spatially associated with this east-west fracture zone.

(2) Three major northwest-trending lineaments have also been delineated in South America, and their extension into the Andean Region has been traced by statistical treatment of linears in the LANDSAT mosaics. These NW-lineaments may very well have been E-W fracture zones in the paleogeographic orientation of South America before it was separated from Africa.

*Abstract of a paper presented at the 1st Annual William T. Pecora Symposium "Applications of Remote Sensing to Mineral and Mineral Fuel Exploration," organized by the American Mining Congress, October 28-31, 1975, at Sioux Falls, South Dakota.

Mapping Andean Salar Deposits by Landsat
Radiance Values

by

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and

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ABSTRACT

Large, relatively unexplored, but potentially valuable deposits of salts occur in the high intermontane basins of the central Andes of South America. Because of their vast expanse and apparent uniformity from ground and aerial views, they are extremely difficult to map, appraise, and evaluate using standard techniques. Standard film and prints of Landsat images also tend to show these features as nearly uniform units, generally saturated by tones of white due to extremely high radiance values beyond film capabilities having 16 shades of gray.

Digital processing of Landsat computer compatible tapes, however, enable the investigator to subdivide the salars into at least 9 different classes of surface materials on the basis of radiance values using 128 shades of gray. This was done successfully on a number of Andean salars and the salars of Uyuni in Bolivia and Coposa in Chile and provides excellent examples of this capability. The Coposa results compare favorably with existing maps made by conventional aerial and surface mapping techniques.

For presentation at the XIX Plenary Meeting of COSPAR, Philadelphia, Penna., June 8-19, 1976.

The Salar of Uyuni covers approximately 10,000 square kilometers. The area was subdivided into 9 thematic classes which include deep water areas, shallow water covering salt, moist salt, and several classes that are apparently based on surface roughness characteristics (i.e., pressure ridges and salt hummocks, small salt pans, and uniform salt flats). Recognition of these units enable the investigator to better select the areas for detailed surface and subsurface sampling and thereby reduce the total number of samples required to evaluate the deposit. The relationship of surface features to the distribution of salts is discussed.

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MEETING OF EUROPEAN GEOLOGICAL SOCIETIES

University of Reading, Reading, England Sept. 1975

Author(s)	W. D. Carter	Session of IAGOD's Commission on Tectonics of Ore Deposits (CTOD).
Address	1925 Newton Square East U. S. Geological Survey, Reston, Virginia 22090	
Title of contribution	Use of LANDSAT Images in Studies of Ore Deposits of the Andes Mountains, South America	

Multispectral satellite images acquired by LANDSAT 1 and 2 (formerly ERTS-1 and ERTS-2) provide a new data source on which to study the relationships of ore deposits, mineral districts, and metallogenic provinces to regional geologic features. Several well-known mineral resource areas of the Andes Mountains of southern Peru, western Bolivia, northern Chile, and northwestern Argentina were selected for testing the applications of the imagery to economic geology studies and to develop visual and machine-assisted methods of utilizing the data to its fullest extent.

Mosaics were compiled of three areas (La Paz, Copiapo, Tucuman) using black and white band 6 (near-infrared) images. Each mosaic covers an area of 4° latitude by 6° longitude and were produced at a scale of 1:1,000,000. Overlay maps showing linear features identified on the images, locations of known ore deposits, and known and newly located volcanic centers were constructed to identify areas that may be favorable for mineral exploration. The locations of earthquake epicenters were also plotted on an overlap map to determine areas of greatest hazard. Computer program (AZMAP) and an electronic digitizer were employed to develop histograms which summarized trends and lengths of linear features. This method took only about two hours, whereas hand measuring, recording, and analyzing such data took 20 hours.

Computer enhancement and recognition techniques, such as those provided by the General Electric Image 100 and the Bendix M-DAS systems, were tested to determine their capability to provide cluster analyses of reflectance classes. Several rock types (sandstone, welded tuff, granodiorite) were successfully separated from other rock units such as andesite and basalt. Salt bodies within a small solar (playa) were subdivided. Reflectance values for alteration zones related to known ore deposits were developed and similar features were displayed at other locations within the image. These extremely flexible computer-assisted analytical methods enable the investigator to quickly evaluate images at scales ranging from 1:1,000,000 to about 1:25,000.

Field verification of lineation maps and theme extractions are currently underway by cooperating geologists from several South American countries. Economic geologists of the Geological Service of Bolivia (Servicio Geológico de Bolivia) reported in July 1974 having found a mineralized fracture zone corresponding to a lineation defined on LANDSAT images in the Corocoro Copper District of western Bolivia.

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Metallogeny and Two Major East-West Fracture Zones
in the United States

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ABSTRACT

Visual interpretation of the 1:5,000,000-scale Landsat-1 mosaic of the conterminous United States has defined two rather continuous, roughly parallel major east-west trending lineaments that may be of both tectonic and metallogenic importance. One of them extends for more than 1,000 km through the central and eastern United States between parallels 38° and 40° N. and intersects the Appalachian orogen close to 40° N. where the Precambrian rocks may be displaced in a right-lateral sense. The lineament appears to correspond to the "Cornwall transcurrent fault" postulated by Drake and Woodward and, in part, to Heyl's "38th Parallel lineament," along which lie a number of significant lead, zinc, barite, and fluorite deposits of the Mississippi Valley-type.

The other lineament lies about 550 km to the south and extends east-north easterly between 32° and 36° N. It is well-expressed for about 1,000 km or more in the southeastern United States where it corresponds, in part, to the Towaliga fault zone of north Georgia, part of the Carolina Slate belt west of Columbia, South Carolina. It also extends

(Prepared for 2nd Symposium on New Basement Tectonics, Univ. of Del., Newark, Del. July, 1-76)

northeastward into the Coastal Plain. In Alabama and Mississippi, it turns to the west into the Mississippi embayment, where it is no longer evident. Although not recognized in southern Louisiana or Texas, an equivalent possible extension is visible in southern New Mexico, Arizona, and California, where it has been referred to as the "Texas lineament." For convenience at this time, we refer to this feature as the "34th Parallel lineament." The lineament essentially parallels the boundary between the North American craton and the encircling miogeosynclines on the south, as illustrated by Stewart. In addition, both the 34th and 38th Parallel lineaments lie along the north and south boundaries, respectively, of the east-west trending belt of magnetic highs appearing on the Global Magnetic Anomaly Map by Regan and others. In view of the association of the "38th Parallel lineament" with the location of known ore deposits, a metallogenic study of the "34th Parallel lineament" is recommended.

Such a study would contribute directly to our knowledge of intraplate tectonics of the United States and, perhaps, to the concept of metallogenic provinces and epochs. Under this concept, Rice and Fairbridge suggested the idea of periodic pulses or episodes of endogenic ore formation. Vogt has compiled evidence which suggests some degree of global magmatic synchronism. The relationships between plate rotation, intraplate movement, centers of magmatic activity and their relative ages, as well as the location and age of ore deposits must be considered in the metallogenic model.