TOPOGRAPHIC LINEAMENTS AND THEIR GEOLOGIC SIGNIFICANCE IN CENTRAL NEW ENGLAND AND ADJACENT NEW YORK

Sally N. Shake
J. Gregory McHone

Department of Geological Sciences
University of Kentucky
Lexington, Kentucky 40506

ABSTRACT

Using LANDSAT imagery and a raised relief map, two maps of topographic lineaments in northeastern New York, Vermont, and New Hampshire have been drawn and are compared with geologic maps of the same region. Major lineaments in central New England (longer than 20 km) generally trend in three different directions, and are marked by streams and lakes as well as by straight ridges and valleys. Northeast trends of lineaments on the west are progressively replaced by north-south trends in the central portion and then by northwest trends on the east. A few major lineaments also crosscut these trend groups. The mostly northeast-trending Adirondack lineaments are along high-angle faults and fracture zones. North-south lineaments in the western to central Vermont area follow major lithologic contacts along fold-hinge lines and thrust faults in the Green Mountains. Northwest-trending lineaments in Vermont and New Hampshire are more cryptic but may represent fracture zones aligned with transform zones of the western North Atlantic Ocean. Some circular lineaments formed from lithologic breaks around igneous plutons. A few major lineaments that have no correlation with obvious geologic structures may be high angle faults or fracture zones that are too poorly exposed to be easily recognized or mapped in local field studies.

INTRODUCTION

Lineaments are straight or gently curving features on the Earth's surface that are commonly expressed topographically as ridges, depressions, or aligned depressions. In recent years, interest in lineaments has increased because of the association of hydrocarbons and mineral deposits with such features (e.g. Black, 1986; ch. 8 of Sabins, 1987). Lineament studies are often regarded as a science-based art because the results may be subjective, dependent upon biases or previous knowledge about a specific study area. Wise and others (1985) discuss observation problems inherent in lineament studies.

Nevertheless, major topographic lineaments are often clearly related to structures and rocks as mapped on the Earth's surface, and increasingly, to postulated subsurface fractures (Saunders and Hicks, 1976; Nur, 1982; Onyedim and Norman, 1986). The importance of lineaments to geological studies and applications is becoming more appreciated, and has encouraged the development of relatively inexpensive image analysis methods and equipment. Traditionally, lineament studies have used empirical approaches in which topographic patterns are attributed to geological features that are already familiar to the observer. We attempt more objectivity by cross-referencing lineament patterns of central New England as observed in two independent studies with no simultaneous reference to geologic maps. Only major lineaments (those longer than 20 km) are described, and our subsequent correlation with regional geology is limited to features that are shown on published maps.

Several studies of topographic lineaments have been completed in areas adjacent to or overlapping central New England. Pioneering work by Hobbs (1904) covered much of southern New England. More recent work on lineament patterns in southern New England has been published by Barosh (1976) and by Goldstein and Wise (1982). In his unpublished thesis work, Green (1977) described hundreds of relatively small linear and curvilinear features in New Hampshire. General lineament patterns across New England have been described by Wise (1976) and by Barosh (1986). Isachsen and others (1983), Palmquist and Pees (1984), and Fakundiny (1986) have described topographic lineaments in New York State. With varying degrees of speculation, all of the above studies emphasize correlations of lineaments with faults, fractures, and lithologic contacts.

Northeastern Geology v. 9, no. 3, 1987
pp. 120-128

REGIONAL TOPOGRAPHIC AND GEOLOGIC PROVINCES

Our study area encompasses an important and classic section of the Appalachian orogen between 71 and 74 degrees longitude and between 43 and 45 degrees latitude, covering much of New Hampshire, Vermont, and adjacent New York State. The region contains a great variety of Proterozoic and Paleozoic rock units that have been variably affected by Grenville, Taconic, Acadian, and possibly Alleghanian orogenies. Mesozoic brittle deformation is known locally and may be common across the region (Lyons and Snellenburg, 1971; Isachsen and McKendree, 1977; McHone, 1981 and 1987b).

Given that the Earth's topography is generally related to physical contrasts in regional crustal rocks, it follows that lithotectonic provinces may produce distinctive lineament groups. Denny (1982) has divided the study area into eight physiographic regions based on geomorphology and bedrock groups, as shown by Figures 1 and 2 and summarized as follows:

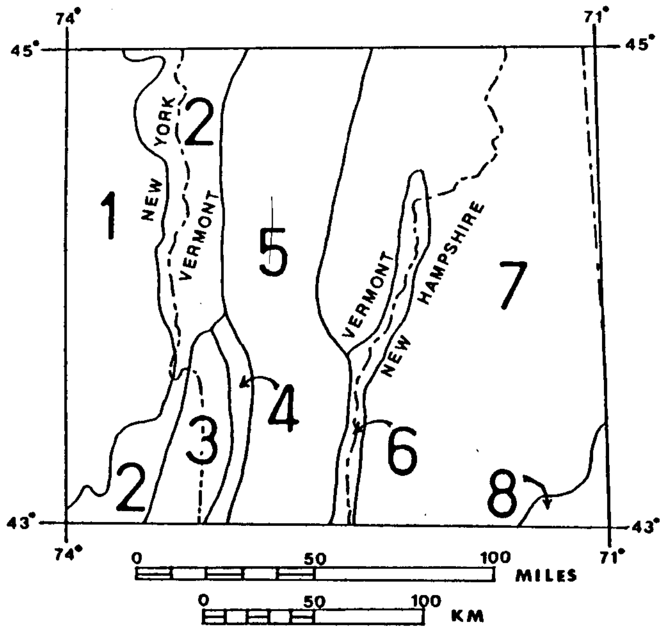


Figure 1. Outline map of physiographic provinces of central New England and adjacent New York, modified from Denny (1982). Numbers refer to discussion in text.

(1) Adirondack Mountains. This anomalous basement dome has undergone uplift in late Proterozoic times, followed by Paleozoic subsidence and renewed uplift during the Mesozoic or possibly Cenozoic Era (Isachsen and others, 1983). The bedrock of the eastern Adirondack Highlands is dominated by Grenvillian gneisses, meta-anorthosite, and other high-grade metamorphic rocks, flanked by onlapping or fault-bounded Paleozoic quartzite and carbonate strata (Isachsen and Fisher, 1971; McHone, 1987a).

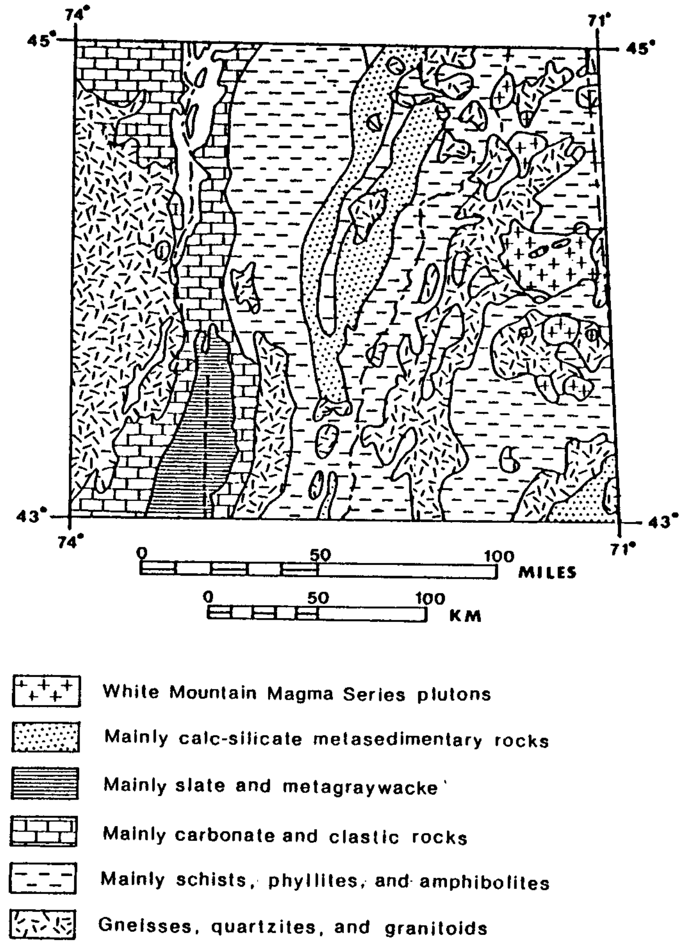


Figure 2. Generalized lithologic map of central New England and adjacent New York, modified from Denny (1982) and Williams (1978). Area with no pattern is Lake Champlain.

(2) Hudson-Champlain Lowlands. The north-south valleys of Lake Champlain and the northern Hudson River are underlain largely by shale, limestone, and dolostone of Cambrian through Ordovician ages. The boundaries of these lowlands are easily defined by marked changes in bedrock and topography to the east and west (McHone, 1987b).

(3) Taconic Highlands. This allochthonous terrane of thrust slices comprises low mountains and hills that gradually decrease in elevation toward the floor of the Hudson Valley to the west. To the east, the Taconics are bounded by an abrupt, narrow valley connected with the Champlain lowlands. The rocks are mostly slate and meta-graywacke that overlie the autochthonous Paleozoic carbonate rocks of region 2 (Zen, 1972).

(4) Vermont Valley. This lowland is a chain of narrow, north-south valleys with carbonate to quartzite bedrock, the margin of the Paleozoic sequence of the Hudson-Champlain lowlands that were exposed by erosion of the eastern Taconics.

(5) Green Mountains Highlands. An anticlinorium of Late Precambrian to early Paleozoic meta-sedimentary rocks is cored by Grenvillian basement exposures in this zone, bounded sharply on the west by regions (2) and (4) but less conspicuously to the east by generally younger eugeosynclinal overthrust belts (Stanley and Ratcliffe, 1985).

(6) Connecticut River Valley. This region is defined mainly by topography, as a narrow north-south valley. The valley in part follows faults that separate Paleozoic sequences of metasedimentary rocks between Vermont and New Hampshire. Lyons and others (1982) described a major tectonic boundary along this zone.

(7) Central Highlands. Meta-igneous and meta-sedimentary Paleozoic rocks are intruded by Paleozoic and Mesozoic plutons in central and northern New Hampshire. The high mountains and monadnocks of this region are generally underlain by igneous bedrock (Billings, 1956). The boundary between the Central and Green Mountains highlands is arbitrary north of region 6.

(8) Coastal Lowlands. Much of the southeastern part of the study area contains metamorphosed calc-alkalic plutons and argillaceous rocks (Billings, 1956). This region has no sharp boundary with the adjacent Central Highlands.

The entire study area has surface features of Wisconsin glaciation. Locally, intensive erosion by the ice sheets was followed by glacially-dammed lakes and inundation by post-glacial seas (Stewart and MacClintock, 1969). Figure 3 illustrates the directions of ice movements shown by surface striations and boulder trains.

METHODS OF STUDY

In a lineament study, biased results may be suspected if the researcher has previous knowledge about geologic features that may produce lineaments. For example, it may be easier to find a lineament that "should" be present along a known fault, or perhaps along a familiar boundary between contrasting lithologies. To minimize these influences, a study area with geology unfamiliar to one of us (Shake) was chosen. Shake used methods employed in a 1979 study (unpublished) of the same area by McHone.

The emphasis of the study was placed on major lineaments, defined as those longer than about 20 km. Lineaments were observed to be marked by straight segments of streams and lakes as well as the edges of shadows cast along straight ridges and depressions. Only those lineaments judged to be continuous and distinct were recorded.

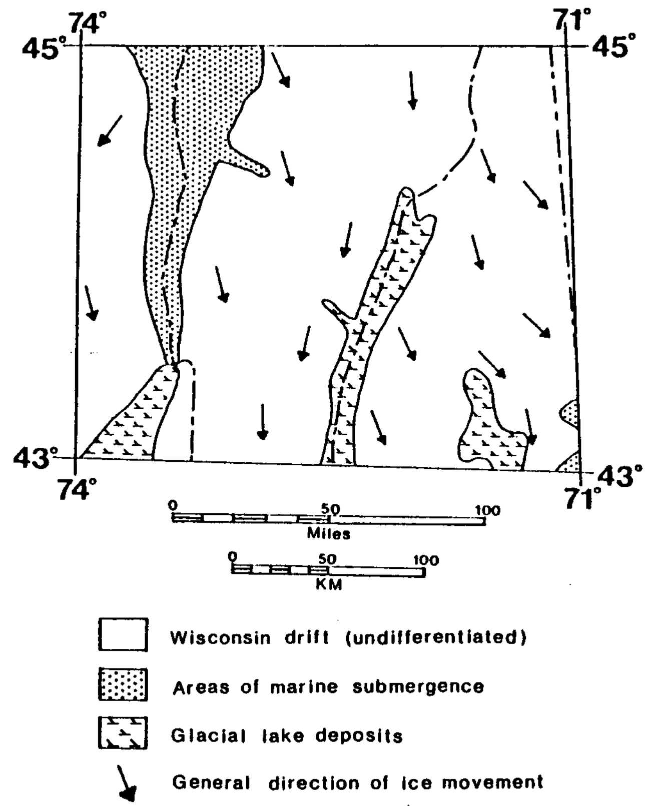
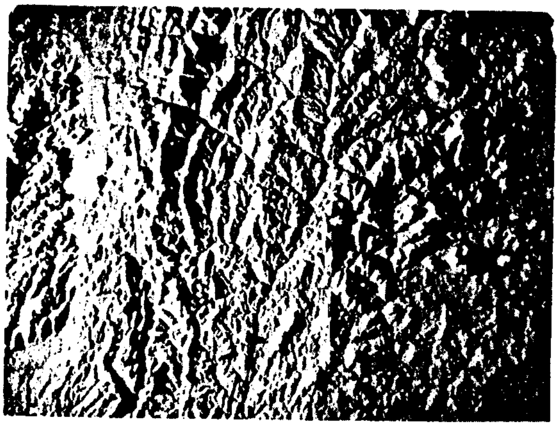


Figure 3. Generalized glacial map of the study area, modified after Flint and committee (1945).

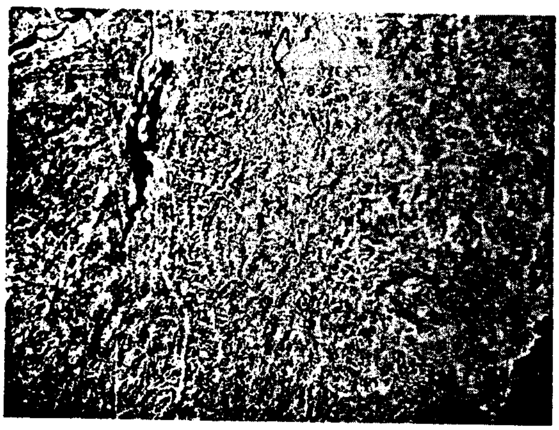
Lineament maps at a scale of 1:1,000,000 were sketched and traced from raised relief maps and from LANDSAT-1 imagery (Earth Resources Technology Satellite-1, later renamed LANDSAT-1). Figure 4 shows examples of the appearance of this map and image. Azimuth-frequency diagrams for various portions of the region were constructed by measuring orientations of straight segments of the lineaments. Especially long lineaments were measured in 50-km segments to keep the measurements more statistically significant.

Lineaments from Raised Relief Maps

Shadow enhancement of raised relief maps was used to identify lineaments, a method developed by Wise (1969). Four plastic 1 x 2 degree quadrangle maps produced by Hubbard of Northbrook, Illinois, at a scale of 1:250,000 were glued together to create a continuous raised relief map of the study area (Fig. 4A). Vertical exaggeration of the maps is 3:1. The quadrangles used are the USGS Lake Champlain, Glens Falls, Lewiston, and Portland sheets. The composite raised relief map was studied in a darkened room using side-illumination from several azimuths. We did not find it necessary to adopt Wise's (1969) technique of reversing a photo image of the back of the map. Observed lineaments were transposed by eye onto a base map with a scale of 1:1,000,000.



A



B

Figure 4. Photographs of portions of (A) raised relief map with oblique illumination, and (B) LANDSAT-1 image used for this study. The vertical line through (A) is a physical join between two sheets. The flat surface for Lake Champlain reflects white in the raised relief map (A), whereas water appears black in the satellite image (B).

Lineaments from LANDSAT Imagery

The second map studied for lineaments was a LANDSAT-1 image taken in October 1972 and produced at a scale of 1:1,000,000 (Fig. 4 B). The area of the image completely overlaps the above mentioned 2-degree quadrangles. The imagery was recorded with visible light energy at wavelengths of 0.6 to 0.7 micrometers, designated as band 5 of the MSS (multi-spectral scanner). The lineaments observed on the imagery are shadowed with radiation from the southeastern sun, and were traced onto 1:1,000,000 base maps similar to those used for raised relief maps.

RESULTS AND DISCUSSION

Major lineaments found by examining the raised relief and LANDSAT maps are summarized by figures 5 and 6. Despite the different media and directions of illumination, the lineament patterns are similar in their trends and placement. The LANDSAT lineament map (Fig. 5) shows greater detail because of the ease of direct tracing from the image, and because the side-illuminated raised relief map has minor parallax from changes in perspective with different viewing angles.

Lineaments on both maps show three general trends that vary in abundance across the study area. In the western portion of the area (region 1, the Adirondack Mountains), lineaments trend generally northeast. In regions 2, 3, 4, 5, and 6 (western and central Vermont), north-south trends are more common. In northeastern Vermont and New Hampshire (regions 7 and 8) lineaments are mixed, but many have northwest orientations. Circular lineaments are scattered across the eastern two-thirds of the study area.

For both lineament maps, azimuth-frequency diagrams (rose diagrams) measured for lineaments of the three trend domains are shown in Figure 7. Obvious trend maxima (10-degree intervals) support the visual assessment of important trend preferences in the three geographic regions.

The lineament maps were compared to published geologic maps of the study area in an attempt to find obvious correlations of rocks and structures with individual lineaments. Important sources include the state geologic maps of New York (Isachsen and Fisher, 1971), Vermont (Doll and others, 1961), and New Hampshire (Billings, 1956). In addition, we examined a basement map of the United States (Bayley and Muehlberger, 1968), a tectonic map of North America (King, 1969), a geologic map of the United States (King and Beikman, 1974), and the tectonic maps of Williams (1978), Lyons and others (1982), and Stanley and Ratcliff (1985). Figures 8 and 9 are coded illustrations of geologic features that are colinear with lineaments from Figures 5 and 6.

Most of the northeast-trending lineaments in the western portion of the study area follow high-angle faults and intense zones of fracturing in the Adirondack Mountains of New York. Isachsen (1976) also noted abundant northeast trends of linear features in the same area, using both remote sensing and ground study. Isachsen (1976) related the trend to reactivation of deep-level Precambrian fractures during doming along a parallel axis of elongation. Fakundiny (1986) has observed E-W to NW-trending lineaments, especially farther west in the Adirondack highlands, that he relates to tectonic slices and fault zones.

The north-south trending lineaments in the central portion of the study area are parallel to fold hinges and some fault traces

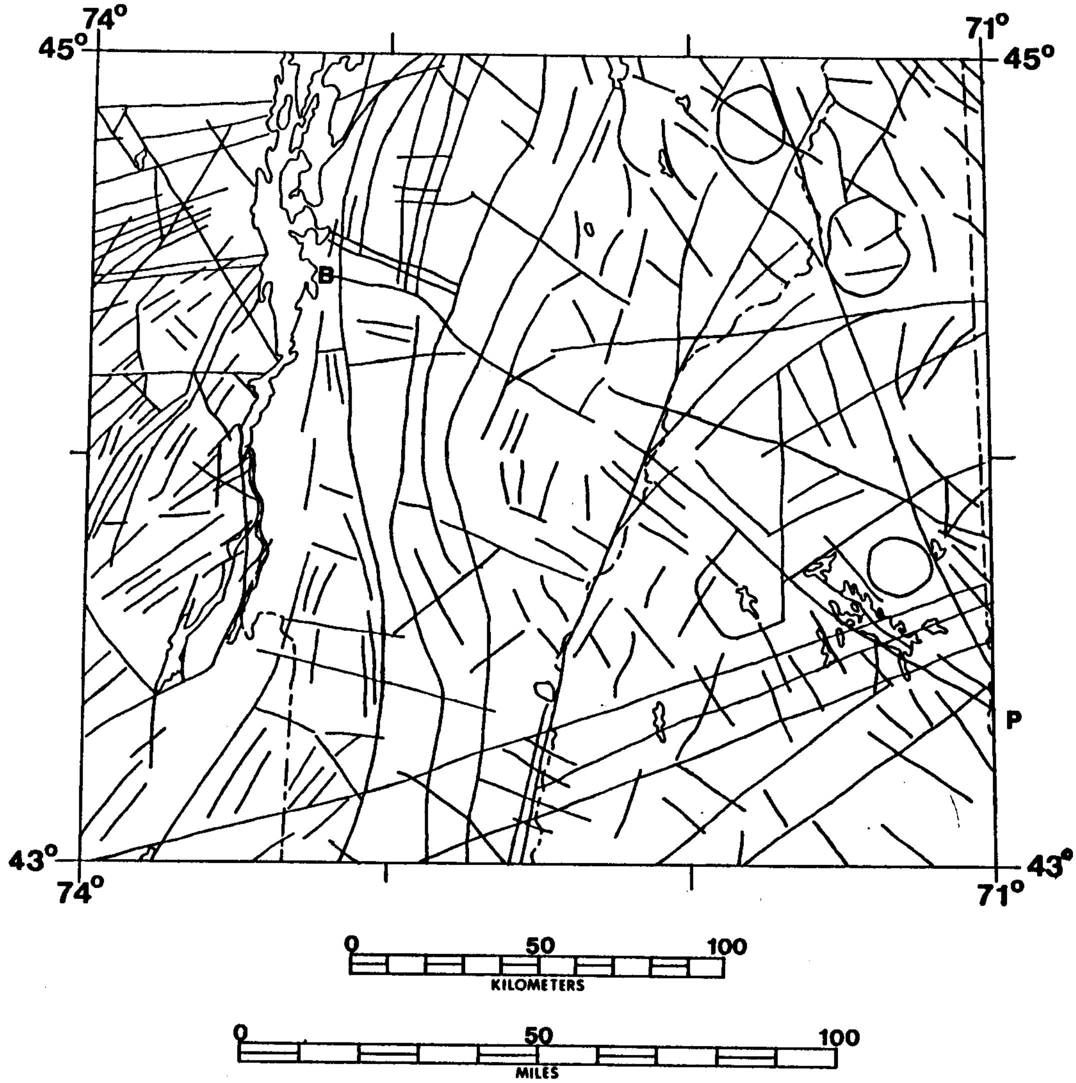


Figure 5. Major lineaments recorded as observed by oblique illumination of the raised relief map of the study area. B and P locate cities at the ends of the Burlington - Portsmouth lineament (see text).

of the Green Mountains, regions 5 and 6 of Figure 1. Many of the lineaments are contacts between rock units on the limbs of folds as mega-lineations along the anticlinoria, and several are along Paleozoic thrust-slice terminations described by Stanley and Ratcliff (1985).

In the eastern portion of the study area, geologic correlations are less easily made. Some appear to be related to differential erosion between igneous intrusions and surrounding metamorphic rocks. A few correspond to faults, but many of the lineaments are not dependent upon obvious mapped features. The predominant structural trend of regions 7 and 8 (most of New Hampshire) is east-northeast, but several major lineaments show east-west and northwest-southeast orientations. Green (1977) also noted this independence of patterns in his study of New Hampshire lineaments.

A very distinct northwest-trending lineament extends across central Vermont and southeastern New Hampshire on both Figures 5 and 6, labeled the Burlington-Portsmouth lineament after major cities near each end. The lineament has also been observed by Wise (1976), Saunders and Hicks (1976), and Barosh (1986). This feature and several smaller NW-SE lineaments in the region are parallel to colinear with geophysical lineaments of the continental interior (Diment and others, 1972) and with oceanic fracture zones of the adjacent North Atlantic (Rona, 1980). Northwesterly orientations are also observed for groups of seismic foci and for the New England seamounts offshore (Sbar and Sykes, 1973).

Nearly all of the circular lineaments of the study area outline plutonic complexes and ring dikes, including a Devonian granitoid in Vermont's Northeast Kingdom and Mesozoic

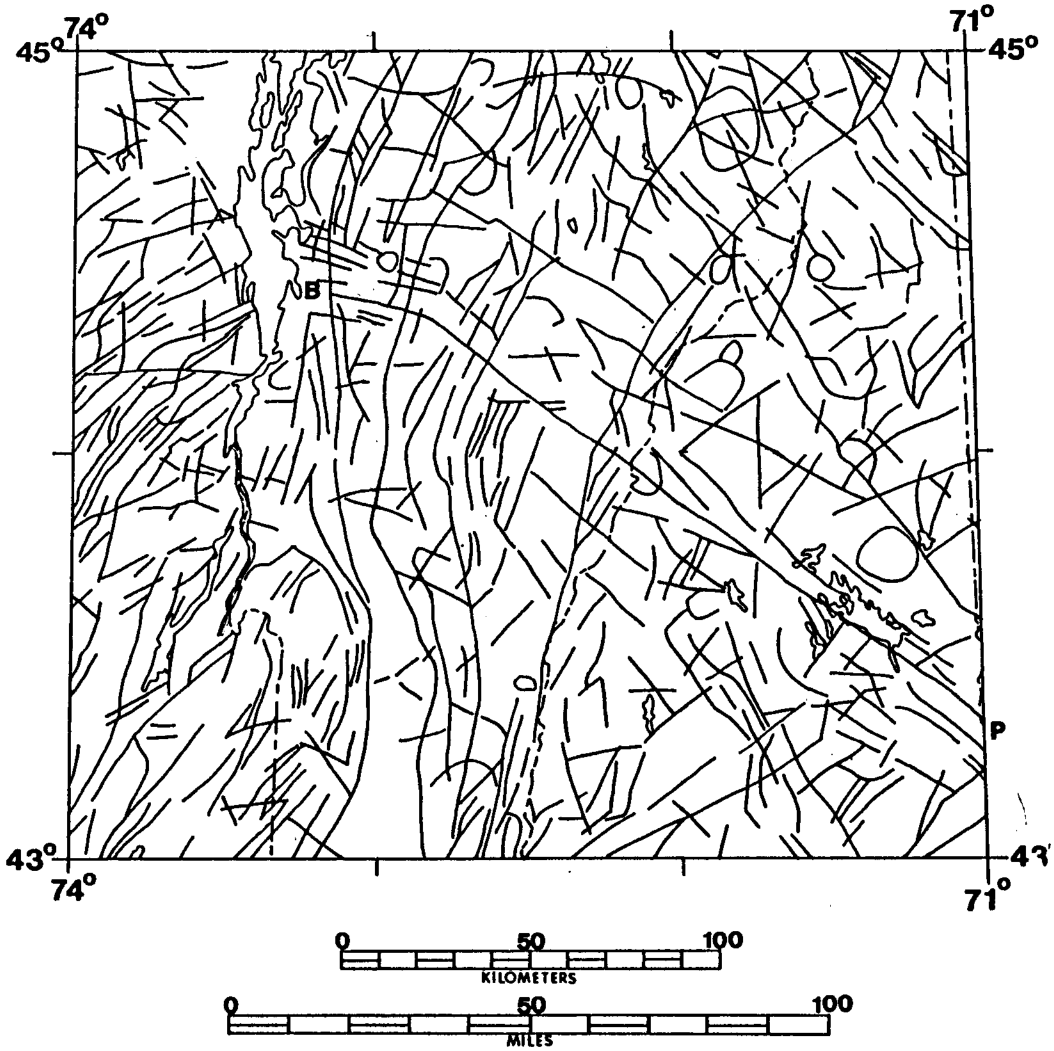


Figure 6. Major lineaments traced from LANDSAT-1 imagery of the study area. B and P as in Fig. 5.

plutons in central New Hampshire. Green (1977) also found circular lineaments associated with plutons of the White Mountain magma series in New Hampshire, but none related to older intrusions.

Wisconsin ice movements (Stewart and MacClintock, 1969) followed some of the lineament trends of central New England (Fig. 3). We believe that the direction of ice flow was controlled by previously-formed topographic lows, some of which were enlarged by glacial erosion and others of which were obscured by sediment fill. These pre-existing topographic lows remain as lineaments. Also, fracture zones both across and along the orogenic trends are likely to have been more easily eroded by glacial ice.

In contrast to the correlations described above, there are other major lineaments that have no obvious structural or lithologic cause. Such anomalous lineaments may follow high-angle fracture zones or faults that have not yet been mapped or recognized in the field. Norman (1976) argued that older fractures can propagate upward into younger unconformable rocks, even when the stresses that produced the older structures ceased activity before deposition of the overlying materials. Thus, lineaments may be perpetuated through time. Subsurface information from gravity and magnetic anomaly maps, seismic surveys, earthquake data, and other sources are needed for additional explanations of lineaments.

CONCLUSIONS

Most topographic lineaments in New England are shown to correlate with faults, fracture zones, and lithologic contrasts along fold belts and in crystalline basement rocks. As might be expected, lineament trends vary according to physiographic provinces that are also geologic terranes, and lineaments that transect several

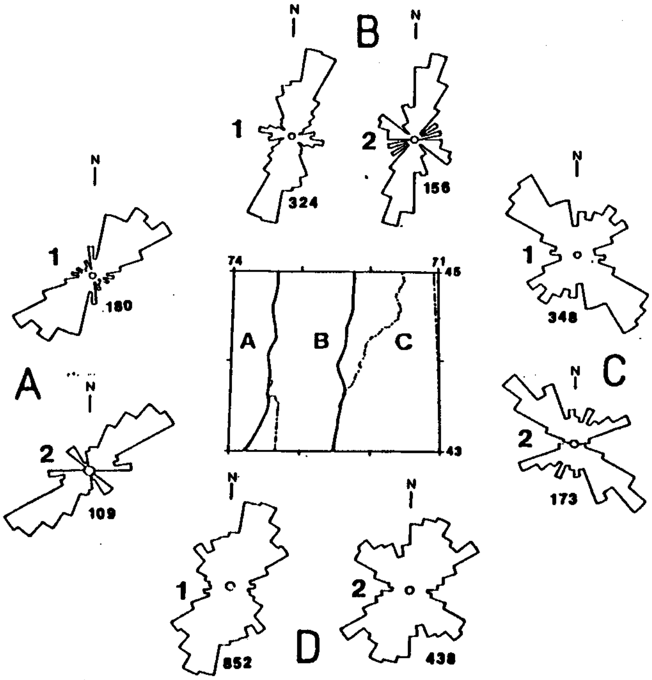


Figure 7. Azimuth - frequency (rose) diagrams for lineaments of the study area, measured from (1) the raised-relief map and (2) the LANDSAT-1 map. Numbers of lineaments are given in parentheses. Letters show combined regions as in the text: A = regions 1 and 2; B = regions 3, 4, and 5; C = regions 6, 7, and 8; and D = all regions combined.

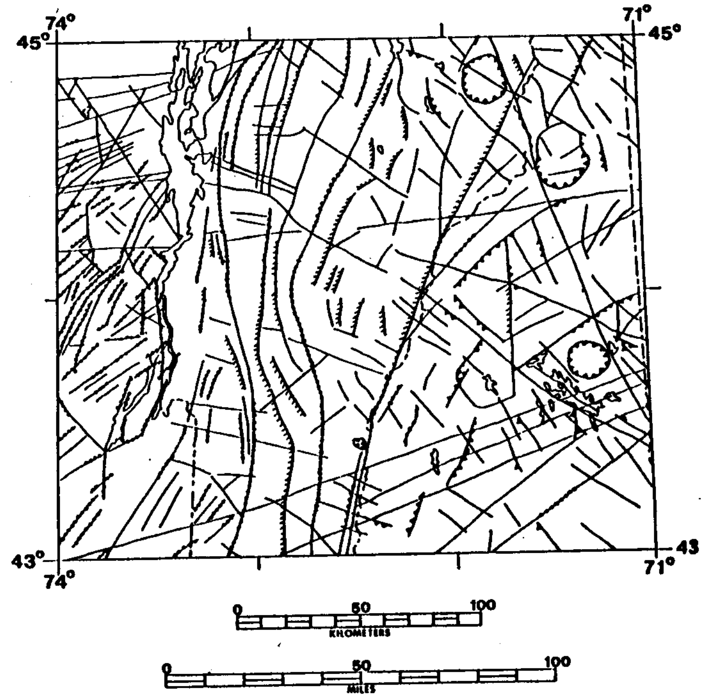


Figure 8. Coded map of lineament - geology correlations for the raised relief map of the study area. Correlation code: dots = faults (both high and low-angle); feather slashes = lithologic units contacts; teeth = pluton borders. Plain lines are uncorrelated lineaments.

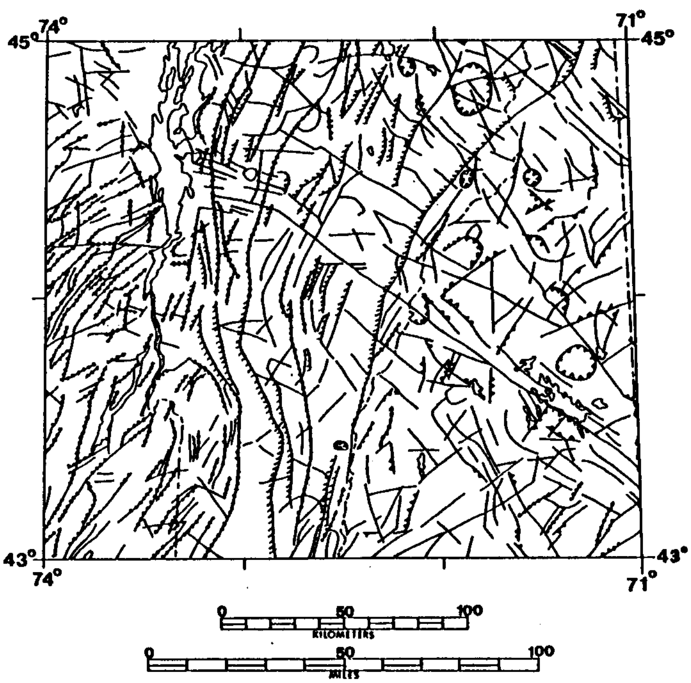


Figure 9. Coded map of the lineament- geology correlations for the LANDSAT-1 map of the study area. Correlation code as in Figure 8.

provinces can be attributed to younger tectonic events. The correlation of topographic lineaments with regional geology is properly addressed only after objective measurement and analysis of the lineaments and their patterns. Lineament maps can be useful tools for studying details of known structures as well as for suggesting locations of unmapped faults.

Relatively long lineaments such as were measured in this project may be useful for showing connections or continuity of faults and other structures that have only sporadic field exposures. In particular, some of the long N-S and NE-trending lineaments of Vermont and New Hampshire probably represent tectonic contacts or faults. It is also clear that fractures that control lineaments in the Grenvillian basement of New York are not well expressed in northwestern New England, even where similar basement is present. Finally, very long lineaments of unknown origin are observed to cross the region in NW-SE and ENE-WSW directions. Additional field work and geophysical studies are needed to explain their significance.

ACKNOWLEDGEMENTS

Shake's work on this project was performed in 1985 at the Department of Geology of Indiana University-Purdue University at Indianapolis. McHone's initial observations of New England lineaments were made in 1979 in connection with the National Uranium Resource Evaluation, while employed by Chiasma Consultants, Inc. of South Portland, Maine. We appreciate helpful comments by Pascal de Caprariis, Yngvar Isachsen, Don Wise, and Robert Fakundiny.

REFERENCES CITED

Barosh, P.J., 1976, Lineament studies in New England and their tectonic implications, in Hodgson, R.A. and others, eds., Proceedings of the First International Conference on the New Basement Tectonics: Utah Geol. Assoc. Pub. No. 5, p.218-235.

Barosh, P.J., 1986, Structural interpretation of magnetic and gravity data of New England - case histories, in Riad, S. and Barrs, D.L., eds., Proceedings of the Fifth International Conference on Basement Tectonics: Salt Lake City, International Basement Tectonics Association, p.245-257.

Bayley, R.W. and Muehlberger, W.R., compilers, 1968, Basement rock map of the United States: U.S. Geological Survey, scale 1:2,500,000.

Billings, M.P., 1956, The geology of New Hampshire, Part II: New Hampshire State Planning Commission, Concord, 203 p. text and map, scale 1:250,000.

Black, D.F.B., 1986, Oil in dolomitized limestone reservoirs in Kentucky, in Aldrich, M.J. and Laughlin, A.W., eds., Proceedings of the Sixth International Conference on Basement Tectonics: Salt Lake City, International Basement Tectonics Association, p.125-139.

Denny, C.S., 1982, Geomorphology of New England: U.S. Geological Survey Prof. Paper 1208, 18 p.

Diment, W.H., Urban, T.C., and Revetta, F.A., 1972, Some geophysical anomalies in the Eastern United States, in Robertson, E., ed., The nature of the solid earth: New York, McGraw Hill, p. 544-574.

Doll, C.G., Cady, W.M., Thompson, J.B., Jr., and Billings, M.P., compilers and editors, 1961, Centennial geologic map of Vermont: Vermont Geological Survey, Montpelier, scale 1:250,000.

Fakundiny, R.H., 1986, Trans-Adirondack Mountains structural discontinuities, in Aldrich, M.J. and Laughlin, A.W., eds., Proceedings of the Sixth International Conference on Basement Tectonics: Salt Lake City, International Basement Tectonics Association, p. 64-75.

Flint, R.F. and committee, compilers, 1945, Glacial map of North America: Geological Society of America, scale 1:4,555,000.

Goldstein, A.G. and Wise, D.U., 1982, W.H. Hobbs revisited: Fracture and lineament studies in southwestern New England: Northeastern Geology, v.4, no.2, p.73-80.

Green, J.W., 1977, The relevance of linear features found on Landsat imagery of New Hampshire: unpub. M.A. thesis, Hanover, Dartmouth College, 71 p.

Hobbs, W.H., 1904, Lineaments of the Atlantic border region: Geological Society of America Bulletin, v.15, p.483-506.

Isachsen, Y.W., 1976, Fracture analysis of New York State using multi-stage remote sensor data and ground study: Possible application to plate tectonic modeling, in Hodgson, R.A. and others, eds., Proceedings of the first international conference on the new basement tectonics: Utah Geological Association Pub. No. 5, p.200-217.

Isachsen, Y.W., and Fisher, D.W., 1971, Geologic map of New York, Adirondack sheet: New York State Museum and Science Service, Map and Chart Series No. 15, scale 1:250,000.

Isachsen, Y.W., Geraghty, E.P., and Wiener, R.W., 1983, Fracture domains associated with a neotectonic, basement-cored dome: the Adirondack Mountains, New York, in Gabrielsen, R.H. and others, eds., Proceedings of the fourth international conference on basement tectonics: International Basement Tectonics Association Pub. No. 4, p.287-306.

Isachsen, Y.W. and McKendree, W.G., 1977, Preliminary brittle structures map of New York: New York State Museum Map and Chart Series 31, scale 1:250,000.

King, P.B., compiler, 1969, Tectonic map of North America: U.S. Geological Survey Prof. Paper 628, scale 1:2,500,000.

King, P.B. and Beikman, H.M., 1974, Geologic map of the United States: U.S. Geological Survey, scale 1:2,500,000.

Lyons, J.B. and Snellenburg, J., 1971, Dating faults: Geological Society of America Bulletin, v.82, p.1749-1752.

Lyons, J.B., Boudette, E.L., and Aleinikoff, J.N., 1982, The Avalonian and Gander Zones in central eastern New England, in St. Julien and Beland, eds., Major structural zones and faults of the Northern Appalachians: Geological Association of Canada, Special Paper 24, p.43-66.

McHone, J.G., 1981, Mesozoic rocks and structures in northern New England: A data compilation: Geological Society of America, Abstracts with Programs, v.13, no. 3, p. 166.

McHone, J.G., 1987a, Geology of the Adirondack-Champlain Valley boundary at the Craig Harbor faultine scarp, Port Henry, New York, in Roy, D.C., ed., Centennial Field Guide Volume 5: Northeastern Section: Geological Society of America, p.151-154.

McHone, J.G., 1987b, Cretaceous intrusions and rift features in the Champlain Valley of Vermont, in Westerman, D. and Larsen, F., eds., New England Intercollegiate Geological Conference Guidebook: Montpelier, in press.

Norman, J.W., 1976, Photogeological fracture trace analysis as a subsurface exploration technique: Institute of Mining and Metallogy (London) Trans., v.85, p.B52-B62.

Nur, Amos, 1982, The origin of tensile fracture lineaments: Journal of Structural Geology, v.4, p.31-40.

Onyedim, G.C. and Norman, J.W., 1986, Some appearances and causes of lineaments seen on Landsat images: Journal of Petroleum Geology, v.9, p.179-194.

Palmquist, J.C. and Pees, S.T., 1984, Lineaments from LANDSAT imagery and topographic maps in the northern Appalachian basin: Northeastern Geology, v.6, no.1, p.65-69.

Rona, P.A., 1980, The central North Atlantic Ocean basin and continental margin: Washington, D.C., National Oceanic and Atmospheric Administration, Atlas No. 3.

Sabins, F.F., Jr., 1987, Remote sensing: Principles and interpretation (2nd ed.): New York, Freeman and Co., 449 p.

Saunders, D.F. and Hicks, D.E., 1976, Regional geomorphic lineaments on satellite imagery - their origins and applications, in Podwysocki, M.H. and Earl, J.L., Proceedings of the second international conference on basement tectonics: Basement Tectonics Committee, p. 326-352.

Sbar, M.L. and Sykes, L.R., 1973, Contemporary compressive stress and seismicity in eastern North America: An example of intraplate tectonics: Geological Society of America Bulletin, v.84, p.1862-1882.

Stanley, R.S. and Ratcliffe, N.M., 1985, Tectonic synthesis of the Taconian orogeny in western New England: Geological Society of America Bulletin, v.96, p.1227-1250.

Stewart, D.P. and MacClintock, P., 1969, The surficial geology and Pleistocene history of Vermont: Vermont Geological Survey Bulletin no. 31, 251 p.

Williams, H., compiler, 1978, Tectonic lithofacies map of the Appalachian orogen: St. John's, Memorial University of Newfoundland, Map No. 1, scale 1:1,000,000.

Wise, D.U., 1969, Regional and subcontinental sized fracture systems detectable by topographic shadow techniques, in Baer, A.J. and Norris, D.K., eds., Geological Society of Canada Paper 68-52, p.175-199.

Wise, D.U., 1976, Sub-continental sized fracture systems etched into the topography of New England, in Hodgson, R.A. and others, Proceedings of the first international conference on the new basement tectonics: Utah Geological Association Pub. No. 5, p.416-422.

Wise, D.U., Funiciello, R., Parotto, M., and Salvini, F., 1985, Topographic lineament swarms: Clues to their origin from domain analysis of Italy: Geological Society of America Bulletin, v.96, p.848-870.

Zen, E-an, 1972, Some revisions in the interpretation of the Taconic allochthon in west-central Vermont: Geological Society of America Bulletin, v.83, p.2573-2588.

Manuscript received
December 24, 1986
Manuscript accepted
July 2, 1987