# Ground magnetic, E-mode VLF, and radiometric surveys at Phillips Mine-Camp Smith uranium prospect, Westchester and Putnam Counties, New York

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Westchester and Putnam Counties, New York. The stations were located at 20 m intervals on lines spaced 40 m apart over an area about 400 by 800 m. About 45 man-days were required to get the data presented here; over half of this time was spent surveying and flagging the base grid through the thick brush which covers much of the study area.

The Phillips Mine-Camp Smith prospect is located in the Hudson Highlands on the border of Westchester and Putnam Counties, New York. Camp Smith is to the south of the line in Westchester County; the long-abandoned Phillips Mine is north of the line in Putnam County. (See location map, Figure 1.) The moderate-to-high-grade metamorphic rocks of the study area display considerable local structure which was mapped in a preliminary manner by Klemic and others (1959). They describe the local geology, some geophysical work, and results of a trenching and coring program performed there in the 1950's. The present study is a follow-up on the work of Klemic and others using modern-day magnetic and radiometric equipment. It also includes a simple resistivity measurement which we anticipated might be sensitive to massive sulfide mineralization. A short abstract of the work described in this report has been given by Grauch and Campbell (1977). Other studies using non-radiometric geophysical methods in exploration for uranium in crystalline terranes have been reported by Collin and others (1958), Campbell and Flanigan (1976), and Flanigan (1976).

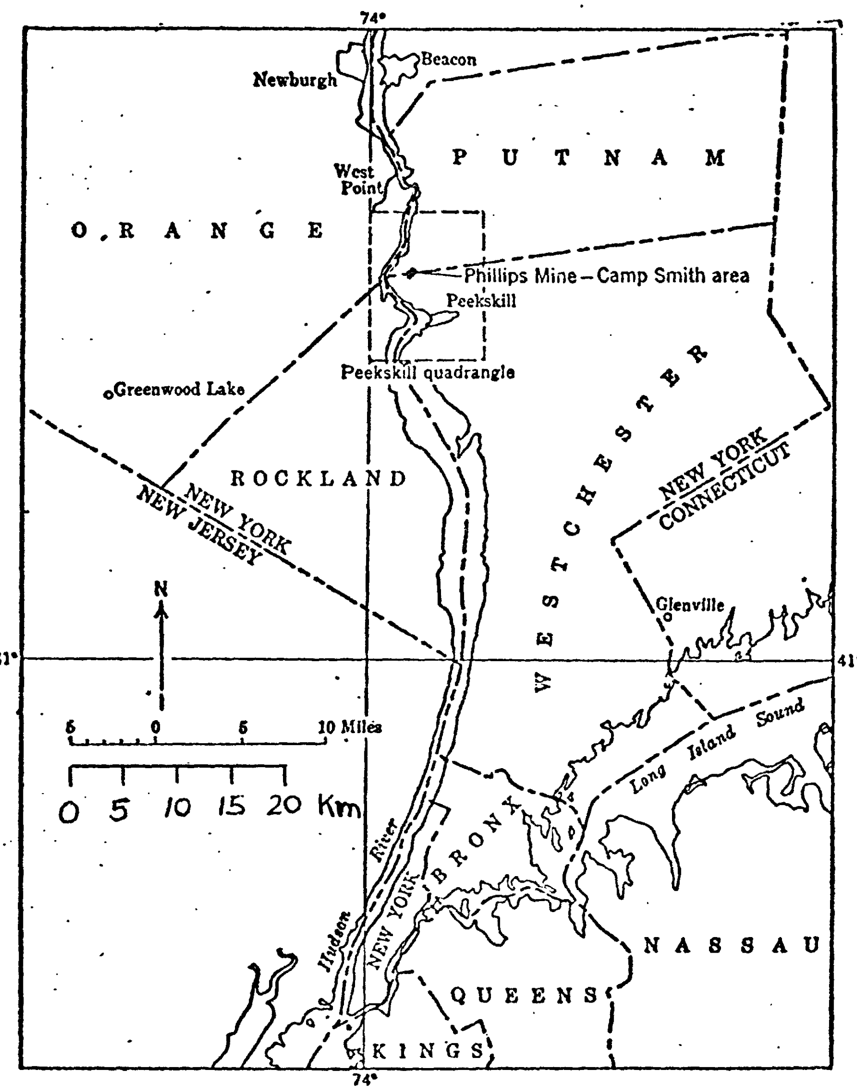



Figure 1.--Index map showing Camp Smith-Phillips Mine location.

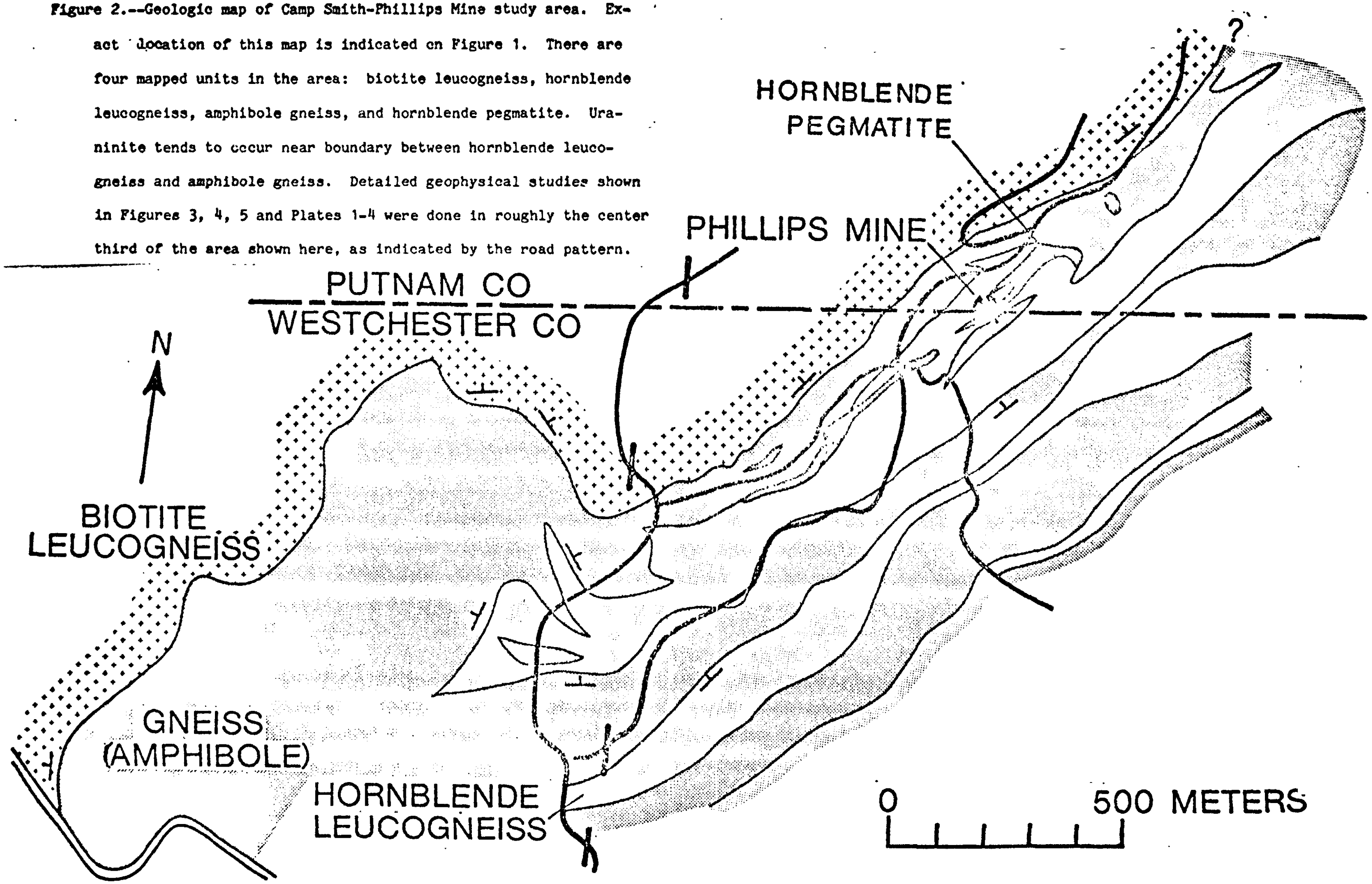
From Klemic and others (1959).

## Geology

The Camp Smith area is underlain by a complexly folded, interlayered sequence of metamorphosed (granulite facies) submarine volcanogenic, carbonate, pelitic rocks, and minor amounts of granitic and pegmatitic material. The three major rock units are amphibolite gneiss, quartz-feldspar-biotite leucogneiss, and quartz-feldspar-hornblende-($\pm$biotite) leucogneiss. These rock units are shown on Figure 2. The amphibolite gneiss unit is variable in composition and appearance, ranging from massive dark-green amphibolite to banded hornblende-quartz-feldspar gneiss. Minor horizons of magnetite-rich amphibolite gneiss and scapolite-rich amphibolite gneiss are included in that unit. The biotite leucogneiss unit includes minor amounts of marble, graphitic calc-silicate gneiss, graphitic metachert, biotite-garnet-quartz-feldspar gneiss, and amphibole-pyroxene-garnet-graphite skarn. Compositional variations within the hornblende leucogneiss are minor and are reflected by variations from 1:0 to 1:1 in the ratio of hornblende to biotite. All three of the major rock units host small amounts of quartz-feldspar pegmatite and hornblende-quartz-feldspar-($\pm$pyroxene) pegmatite.

Uraninite is found in four different rock types: magnetite-rich layers and scapolite-rich layers in amphibolite gneiss; hornblende-pegmatite; and the outer, Cu-Ni-bearing zone of the massive sulfide body. The magnetite-rich and scapolite-rich layers appear to be near the contact between light- and dark-colored gneisses. Hornblende pegmatites, interpreted by us as being anatectic in origin, are also

Figure 2.--Geologic map of Camp Smith-Phillips Mine study area. Exact location of this map is indicated on Figure 1. There are four mapped units in the area: biotite leucogneiss, hornblende leucogneiss, amphibole gneiss, and hornblende pegmatite. Uraninite tends to occur near boundary between hornblende leucogneiss and amphibole gneiss. Detailed geophysical studies shown in Figures 3, 4, 5 and Plates 1-4 were done in roughly the center third of the area shown here, as indicated by the road pattern.




GENERALIZED GEOLOGIC MAP — PHILLIPS MINE AREA most abundant near that contact. In the massive sulfide body uraninite is apparently restricted to the Cu-Ni-bearing zone which in addition contains apatite, pyrrhotite, pyrite, chalcopyrite, marcasite, magnetite, and molybdenite. The core of the sulfide body is apparently massive pyrrhotite with little if any uraninite, pyrite, or chalcopyrite. The uraninite occurrences mentioned above have two features in common: association of uraninite with apatite and proximity to the lithologic break between melanocratic and leucocratic rocks. Minor concentrations of uranium are also found in small, presumably old, fractures near the lithologic break.

## Geophysics

A general discussion of total-field magnetic methods may be found in Breiner (1973). Our magnetic data was acquired using two Geometrics Model G816 proton-precession magnetometers.[1] One of the magnetometers was used to measure the magnetic field at selected stations, while the other recorded background magnetic field at a fixed base station. The sensitivity of the instruments was 1 $\gamma$ (gamma). The base-magnetometer recorded one reading per minute on a strip chart recorder. The base magnetic field changed each day by less than 40 $\gamma$, while the anomalies measured often had amplitudes of several thousand gammas. Measurements at a given station site usually

[1] Manufacturers and model numbers of equipment used in this report are given for descriptive purposes only. This reference does not imply endorsement by the U.S. Geological Survey.

repeated to within $\pm 2\ \gamma$, but in some zones of steep magnetic gradients successive readings at the same site occasionally differed by more than 200 $\gamma$. The difference between station value and base value is shown on Plate 1. All values have also been adjusted by subtracting an arbitrary 1600 $\gamma$ to give both positive and negative regions on the contour map (figure 4).

A general discussion of VLF (very-low-frequency) electromagnetic exploration techniques may be found in Paterson and Ronka (1971). Our E-mode VLF data were taken using a Geotronics Model M16 unit with an R100 attachment.[1] The unit was tuned to NBA, a U.S. Navy navigation station at Annapolis, Md., broadcasting at 21.4 KHz. This particular station was chosen to give maximum coupling with local geologic units, since Annapolis is located approximately on an extension of the direction of local strike. At each site a single apparent resistivity value and a phase-angle was read directly from the unit. The apparent resistivity value is a combination of resistivities of those rocks below the site which are shallower than perhaps one skin-depth for the 21.4 KHz electromagnetic wave. At that frequency, one skin-depth is about 10 m in rocks of 10 ohm-m resistance, and 100 m in rocks of 1000 ohm-m resistance. The measured VLF resistivity values and associated phase angles are shown on Plate 2. Low resistivity values may be indicative, among other things, of massive sulfide mineralization or of wet ground. At Camp Smith, however, very high resistivity values were often measured at stations in marshes and shallow ponds, so that we may discount the latter possibility to an extent.

A general discussion of radiometric techniques may be found in Parasnis (1973). Four-channel radiometric measurements were made using a Geometrics "Exploranium" model scintillometer.[1] Plate 3 shows eU and eTh counts per 2-minute sampling time in the study area. Plate 4 shows eK counts and the ratio of eU counts to eK counts per 2-minute sampling time. The total-count channel on the instrument almost always became saturated during the 2-minute sampling period, and so the total-count measurement is not presented here. Readings taken during the summer repeated to within about 10%, but winter readings were more scattered, possibly due to frozen ground conditions or to a temperature effect in the instrument. (In winter, temperatures below zero degrees Fahrenheit were common.) Most winter radiometric readings were repeated at least once; of these the warmest-day readings tied best to the summer measurements, and so are reported on Plates 3 and 4. The summer measurements, which are thought to be fairly reliable, include stations 160W through 40E on lines 120N through 160S, and stations 100W through 100E on lines 200S through 400S.[2] The remaining stations were measured in winter, and are probably less reliable.

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[2] Station designations are with respect to nominal E-W and N-S directions chosen approximately perpendicular and parallel to local strike, respectively. Nominal west is $40^{\circ}$ west of true north. Station ON-S, OE-W is at the intersection of Mine Road and Iron Mountain Road. Station distances are in meters from this origin point.

Despite this one difficulty, winter field work was generally more efficient than summer field work in the Camp Smith area. In winter the leaves were down and outcrops and grid lines could be seen, the marshes and ponds were frozen, so stations there could be occupied, and the snakes were in their holes and did not bother the field workers.

## Interpretation and discussion

Figures 3, 4, and 5 show contoured maps of the VLF resistivity, magnetic, and eU data, respectively. These figures may be compared with Figure 2, a generalized geologic map of the surveyed area. As expected, there is a general tendency for magnetic highs (magnetite or pyrrhotite?), resistivity lows (massive sulfides?), and radiometric highs (uraninite?) to occur at or near the boundary between hornblende leucogneiss and amphibole gneiss. This correlation is strongest along the northwesternmost such boundary, where many of the geophysical anomalies may be due to hornblende pegmatite units. Proceeding across strike from northwest to southeast, we note the following, generalized, geophysical characteristics:

(1) A zone of high resistivity, low magnetics, and low eU values that probably contains little mineralization. Locally, however, there are some low-resistivity subzones that may be sulfide-or graphite-bearing.

(2) A narrow zone of low resistivity, high magnetics, and high eU, that correlates with a uraniferous hornblende pegmatite.

Figure 3.--Shaded contour map of the VLF resistivity data in Plate 2. Note the logarithmic contour interval. Heavy dark lines are road patterns and can be compared with Figure 2.

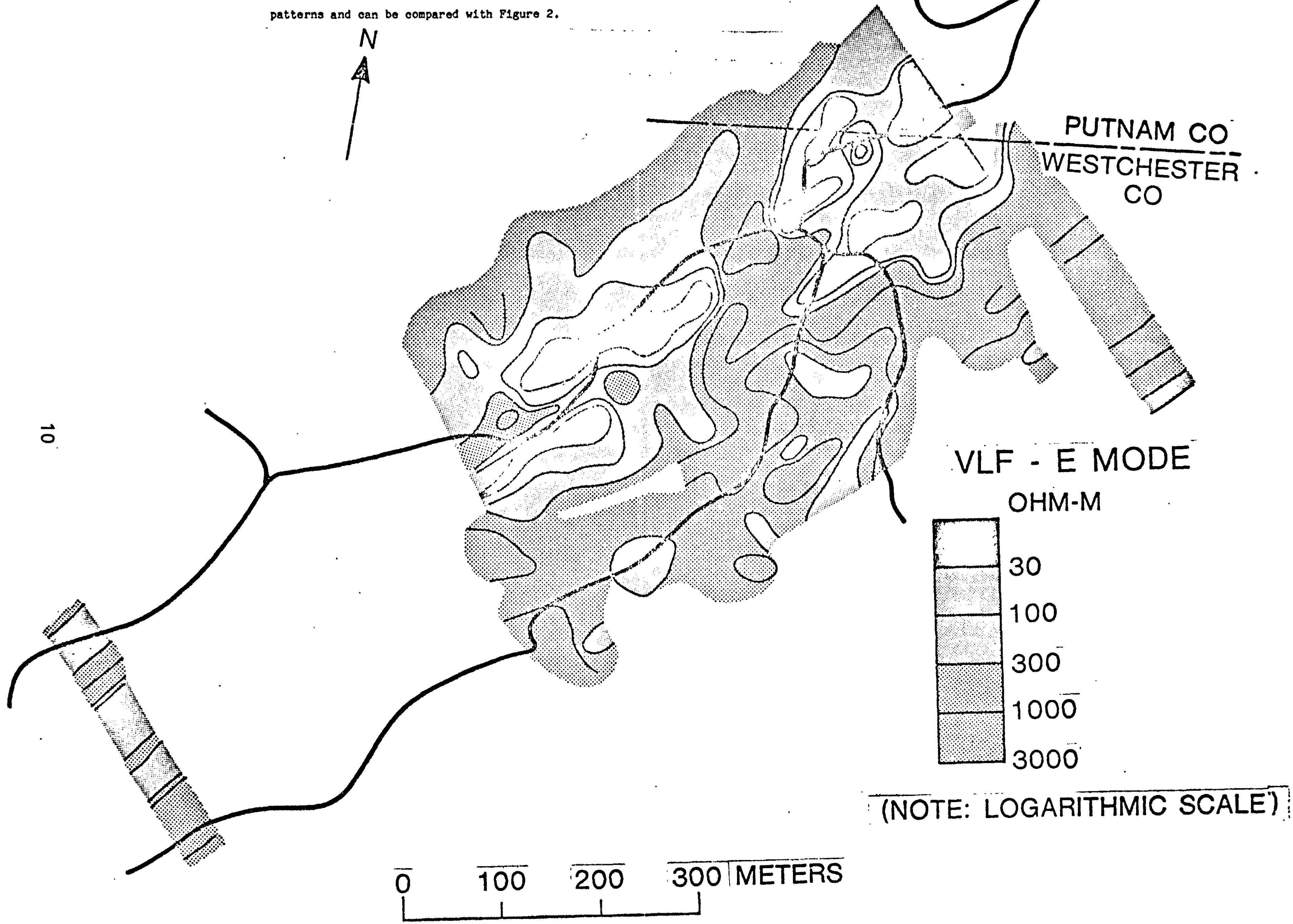


Figure 4.--Shaded contour map of the total-field magnetic data in Plate 1. Note the variable contour interval. Heavy dark lines are road patterns and can be compared with Figure 2.

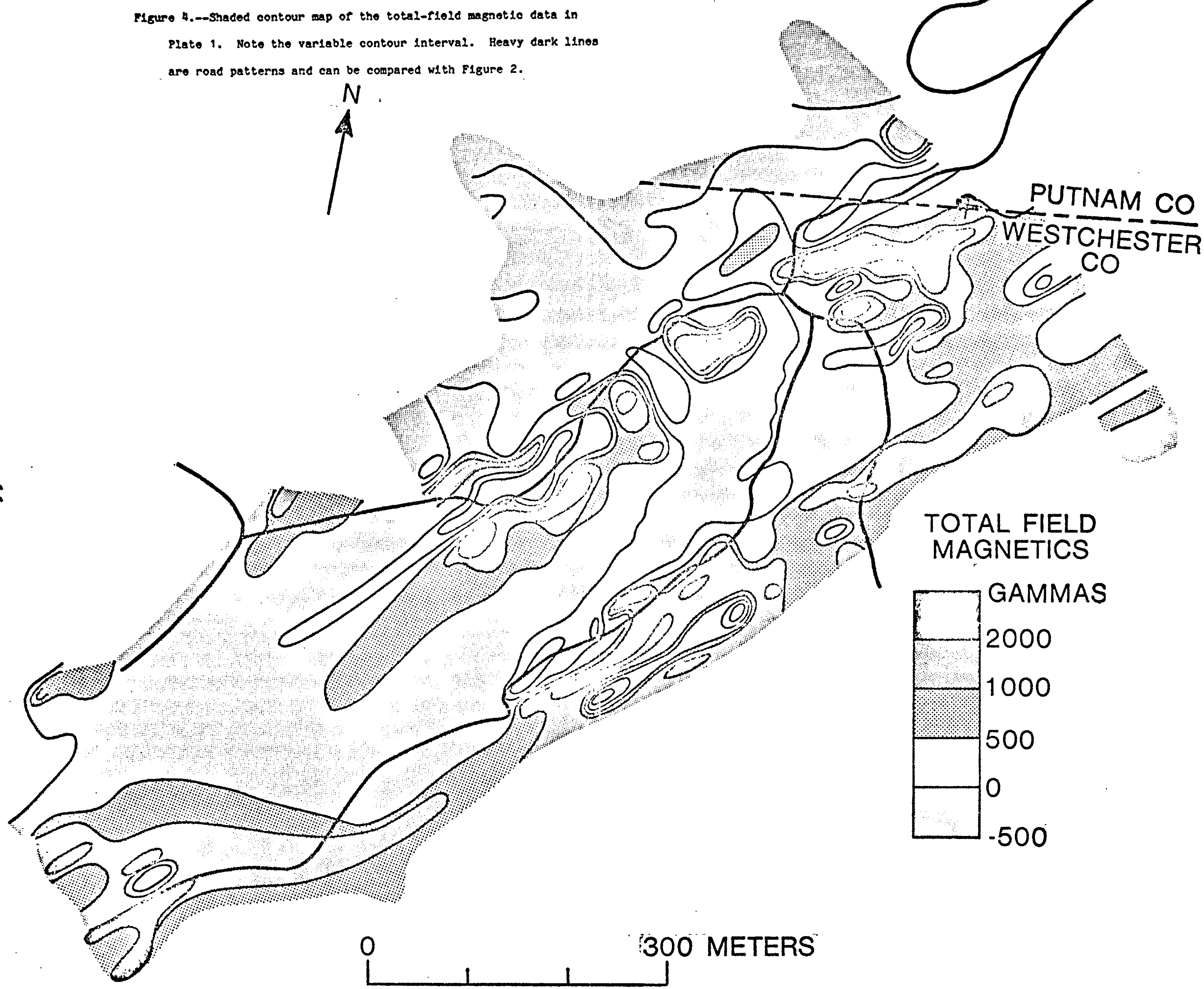
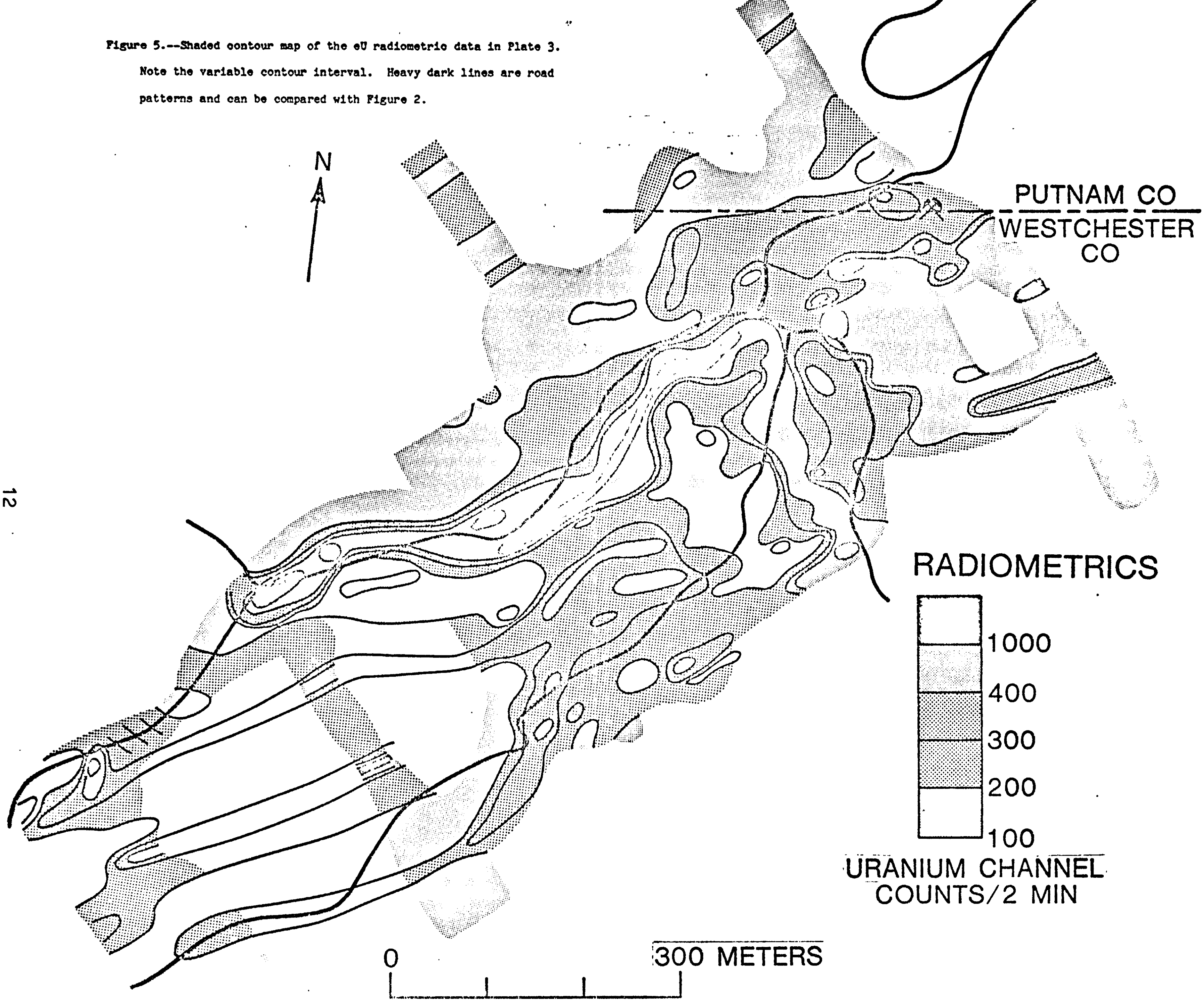


Figure 5.--Shaded contour map of the eU radiometric data in Plate 3. Note the variable contour interval. Heavy dark lines are road patterns and can be compared with Figure 2.



(3) A zone of moderate-to-high resistivity, smooth but low magnetics, and moderate eU content, that seems to typify the hornblende leucogneiss unit.

(4) A zone that shows high resistivity and large variations in magnetic and eU values, which correlates with the amphibolitic gneiss unit. The different magnetic character of this zone, compared to zone 1, indicates that the amphibolitic gneiss unit to the southeast contains some local magnetic material which is largely absent in its northwestern outcrop.

Figure 6 is a cross section along line 280S. The VLF resistivity low and the magnetic and eU highs which correlate with the hornblende pegmatite unit are marked on Figure 6. Analysis using the Stanford Research Institute (Aero Service) catalog (1968?) indicates that the body causing the magnetic signature at this location dips between about $80^{\circ}$ and $90^{\circ}$ to the northwest, and has a susceptibility-thickness product $kt \simeq 0.02d$. Here k is the susceptibility contrast between the unit and the surrounding rocks, t is its thickness, and d is the distance from magnetometer sensor to the top of the unit. If the causative body is the outcropping hornblende pegmatite unit, then d $\backsim$ 2 meters and $t \simeq 10$ meters, so that the calculated value for k is 0.004. This value is quite high, appropriate for a rock containing perhaps 1-4% disseminated magnetite (Balsley and Buddington, 1958). Alternate possibilities are that the hornblende pegmatite unit contains fairly continuous magnetic (magnetite or pyrrhotite) stringers, that the hornblende pegmatite substantially thickens with depth, or

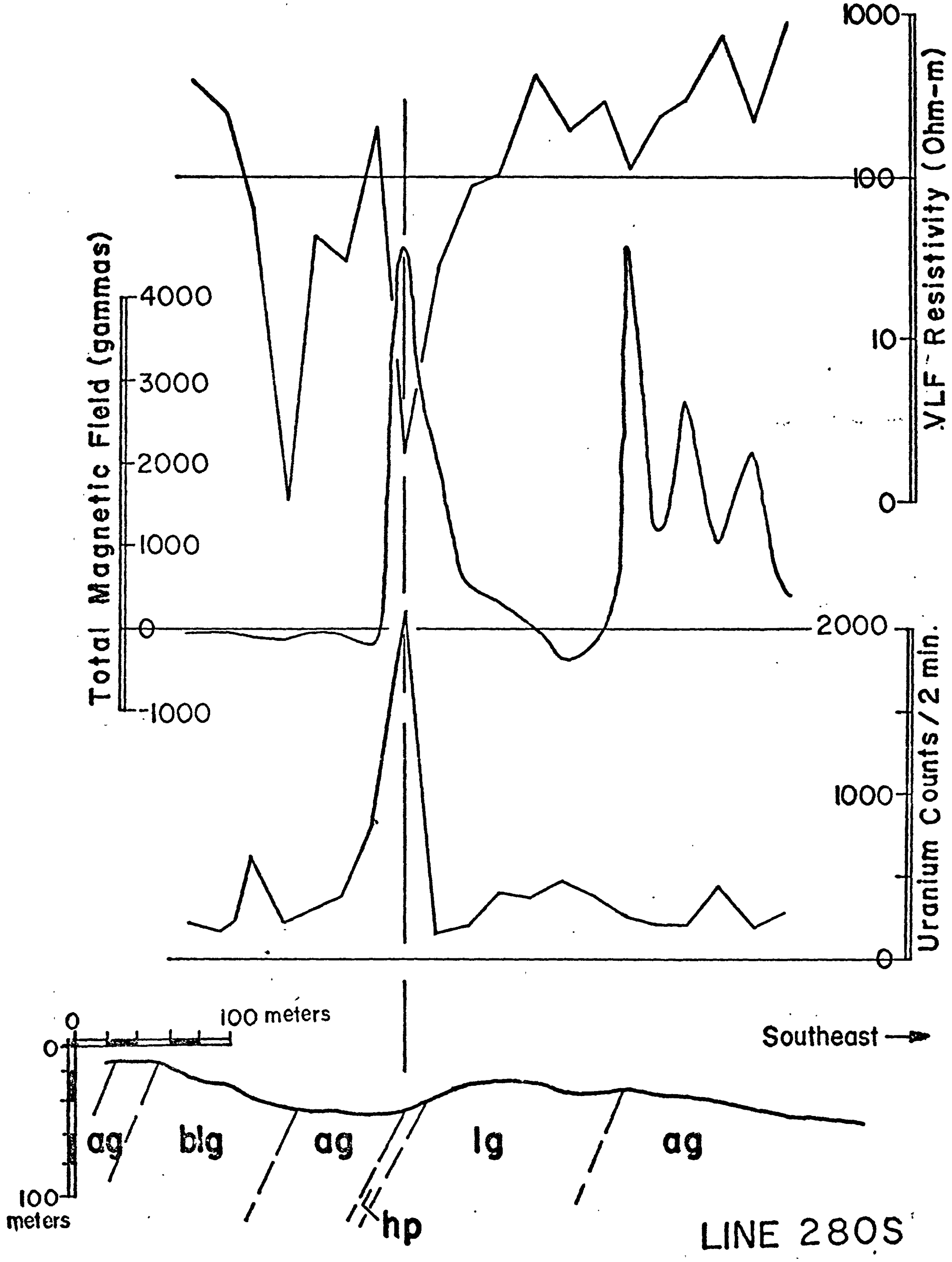



Figure 6.--Geological and geophysical profiles along line 280S. A uraniferous hornblende pegmatite is characterized here by low VLF resistivity, high total-field magnetics, and high eU radiometrics. (ag = amphibole gneiss; blg = biotite leucogneiss; hp = hornblende pegmatite; lg = leucogneiss.)

that the magnetic signature at this location is due to some unit, probably at depth, other than the hornblende pegmatite.

Figure 7 is a cross section along line 120N. Two eU highs are marked. The northwesterly eU high occurs at the boundary between leucogneiss and amphibole gneiss, and is offset from a magnetic high to the northwest, and a resistivity low still further northwest. The southeasterly eU high does not seem to correlate with any mapped geologic boundary, magnetic signature, or VLF resistivity feature. In general, the geophysical anomaly patterns in the northeast third of the mapped area are more complex than those to the southwest, suggesting complicated structural and lithologic relations in this area. In particular, the northwest-dipping sequence of rock units shown on Figure 7 may be over-simplified.

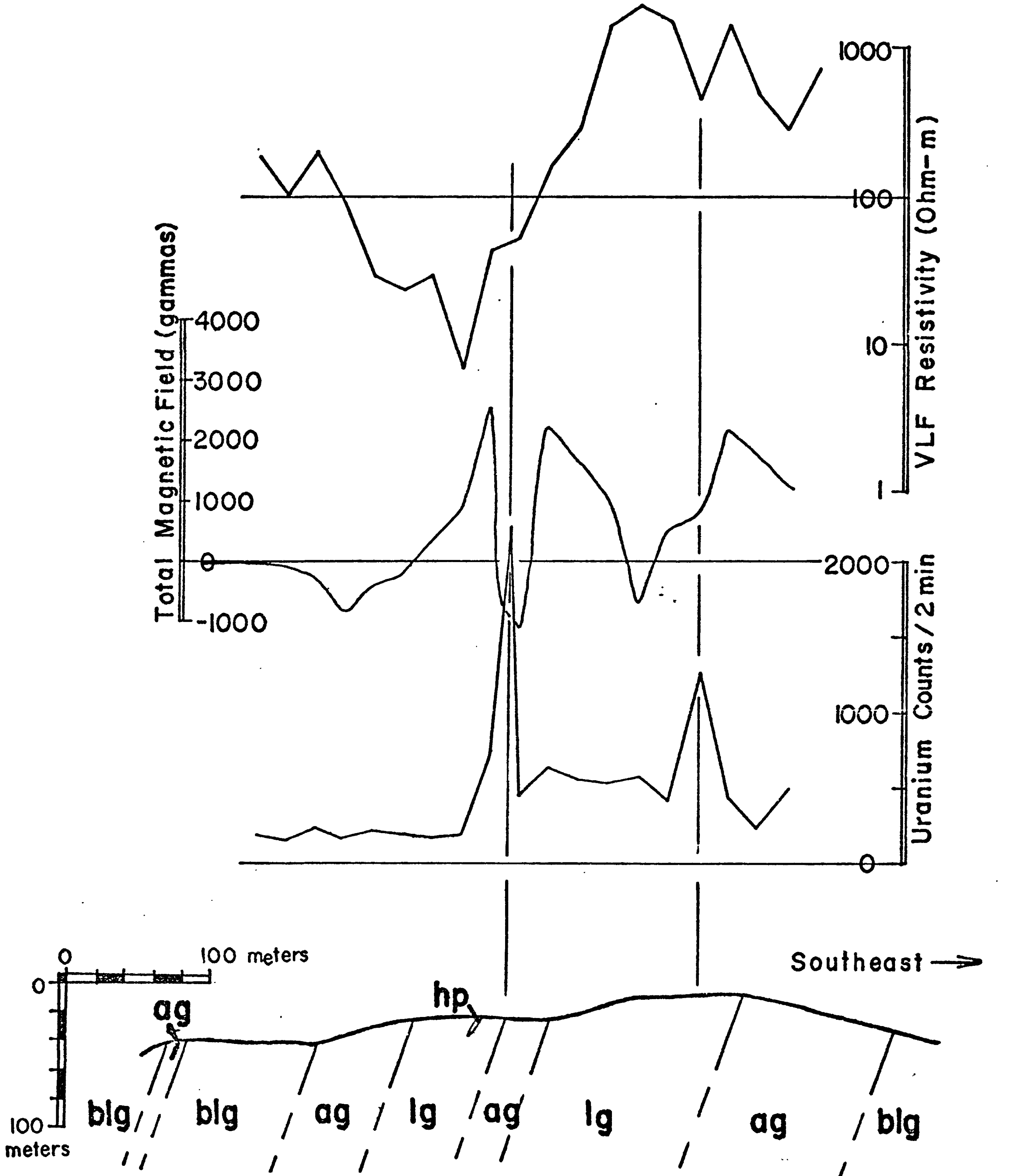



Figure 7.--Geological and geophysical profiles along line 120N. Vertical lines show locations of two eU radiometric highs, which do not clearly correlate with other geophysical signatures or with surface-mapped geological contacts. (ag = amphibole gneiss; blg = biotite leucogneiss; hp = hornblende pegmatite; lg = leucogneiss.)

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