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GEOGRAPHY

Specific Features of the Ice Sheet Dynamics in Eastern Antarctica

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Current ideas on the dynamics of the Antarctic ice sheet are based on geodetic observations that only register the glacier surface flow, whereas theoretical models of dynamic processes inside the ice sheet are of a hypothetical nature due to the lack of actual measurements of parameters of ice flow inside the glacier mass.

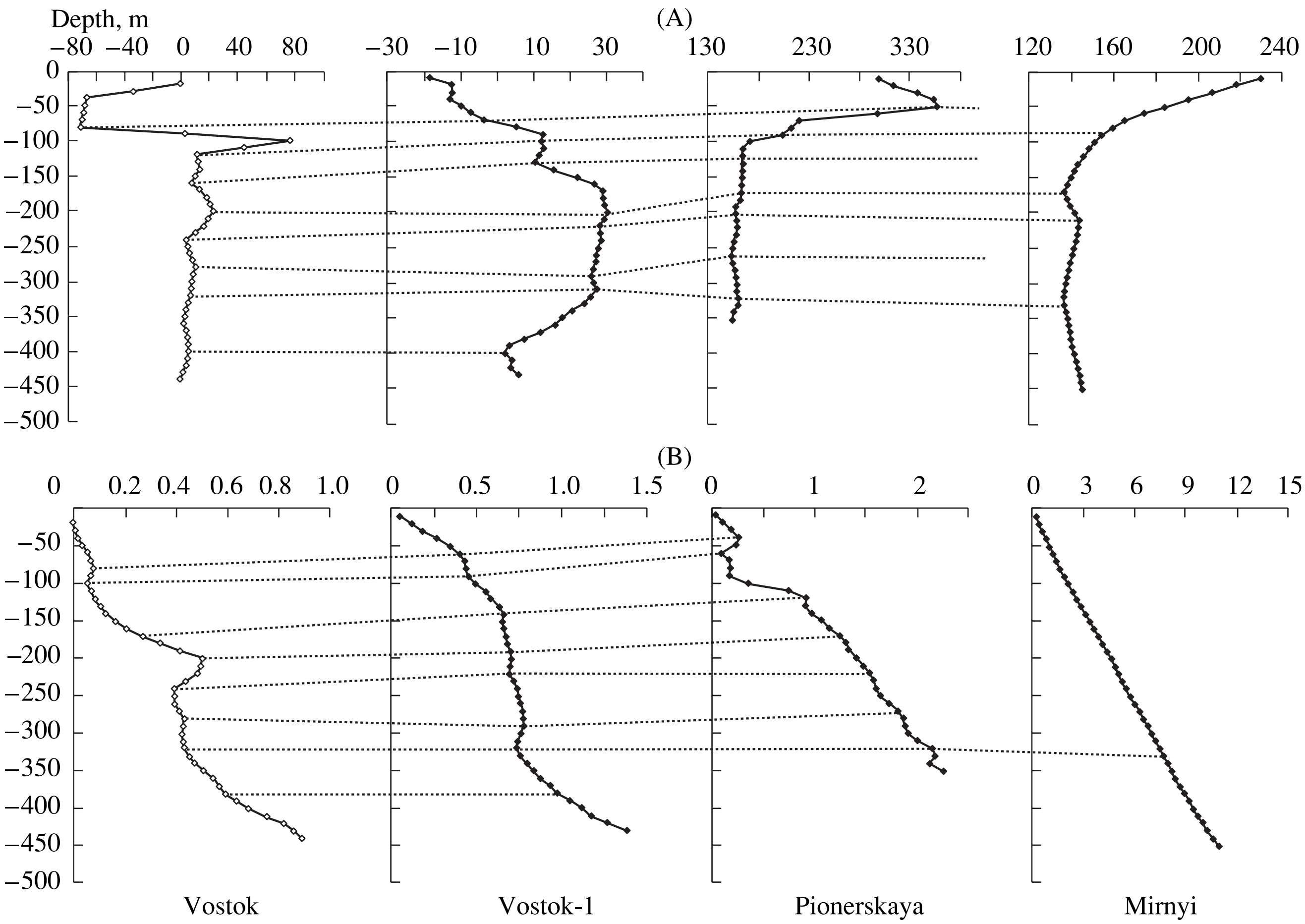

Fig. 1. Parameters of the IFV of layers relative to the ice sheet surface based on measurements in eastern Antarctica. (A) Direction of the IFV of layers relative to the ice sheet surface (magnetic azimuth, degrees); (B) modulus of the IFV of layers relative to the ice sheet surface (m/yr). Dotted lines connect layers based on results of the correlation analysis of velocity vector parameters and individual dynamic characteristics.

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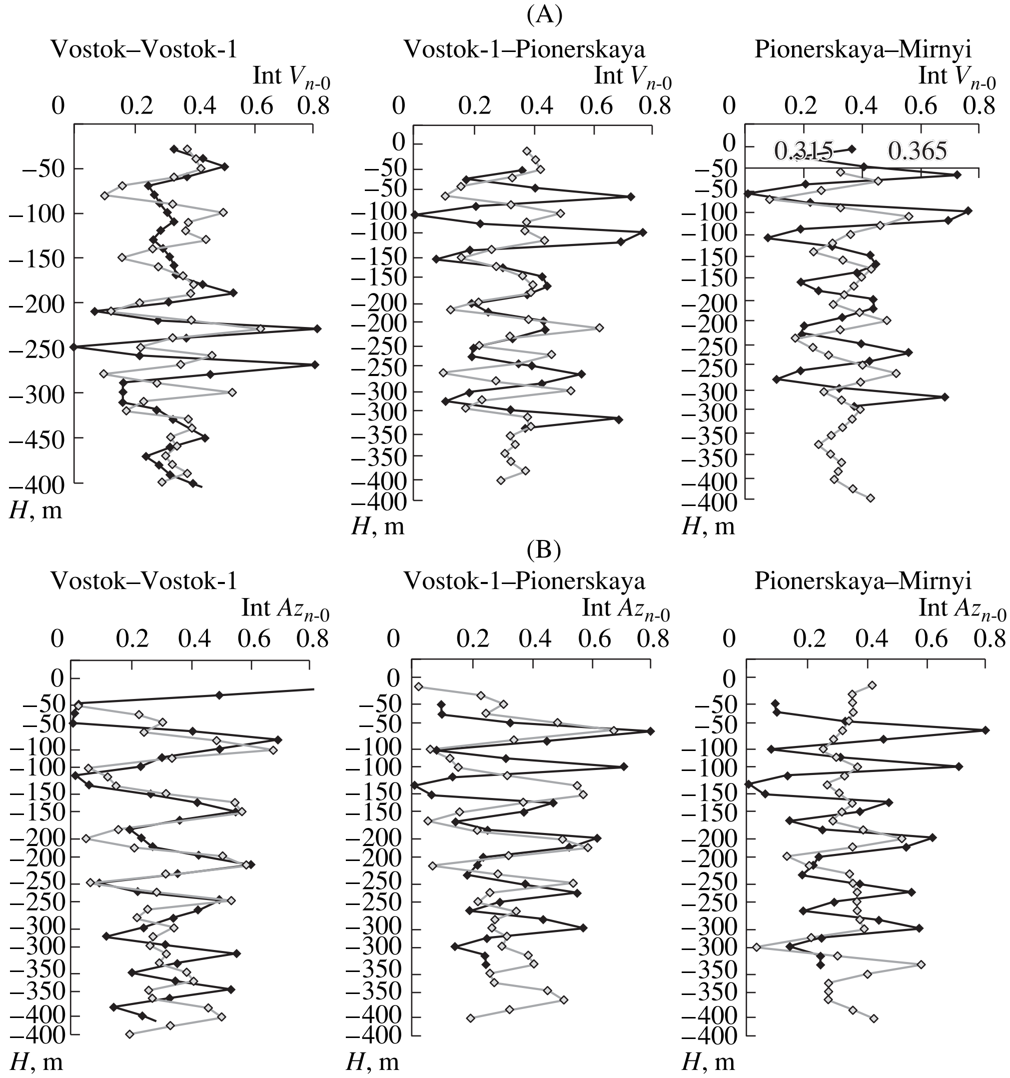

Fig. 2. Comparison of synchronism of depth variations of independent functions of the relative intensity of changes in the IFV in different pairs of regions (Vostok–Vostok-1, Vostok-1–Pionerskaya, and Pionerskaya–Mirnyi) used in subsequent qualitative and quantitative estimates of the correlation degree. Comparison of (A) Int V_{n-0} and (B) Int Az_{n-0} functions of the relative intensity of variations in the (A) modulus or (B) direction of the IFV relative to the surface. In some cases, the depths of actual values of functions of one of the compared regions were shifted by 10–20 m throughout the whole interval to determine the depth variation step of ice layers along the Vostok–Mirnyi profile corresponding to the maximal correlation of parameters. Comparison between different regions of function Int V_{n-0} (A) and Int Az_{n-0} (B) of the relative intensity of variation of module (A) or direction (B) of the vector of flow rate of layers relative to the surface.

The task of this study was to determine the real pattern of the ice mass dynamics inside the ice sheet on the vast territory of eastern Antarctica based on actual measurements in boreholes.

In 1980–1982, the spatial position of axes was measured in four boreholes drilled in the ice sheet of eastern Antarctica in the vicinity of the Vostok, Vostok-1, Pionerskaya, and Mirnyi stations. Using methods described in [1], the direction and modulus of the vector of ice flow velocity (IFV) were established at different depths with the measurement step of 10 or 20 m within the depth interval 0–450 m (up to 2000 m at Vostok Station). In each study region, complicated variations of the IFVs along the depth were revealed relative to the ice sheet surface and relative to each other. The ice dynamics at different depths is variable in both modulus and azimuth of the IFV (Fig. 1).

Based on the correlation analysis of interactions between the observation sites in terms of primary and secondary functions of parameters of the IFV (Fig. 2), eight principal layers with individual dynamic characteristics were outlined (Fig. 1). The results obtained allow us to infer that the ice sheet dynamics along the Vostok–Vostok-1–Pionerskaya–Mirnyi profile within the depth of 0–450 m has a differentiated (in depth) layered structure with a significant (75%) correlation of layers along the strike between all the observation sites.

In the vertical section, the distinguished layers differ in the following criteria: (1) average (for the whole

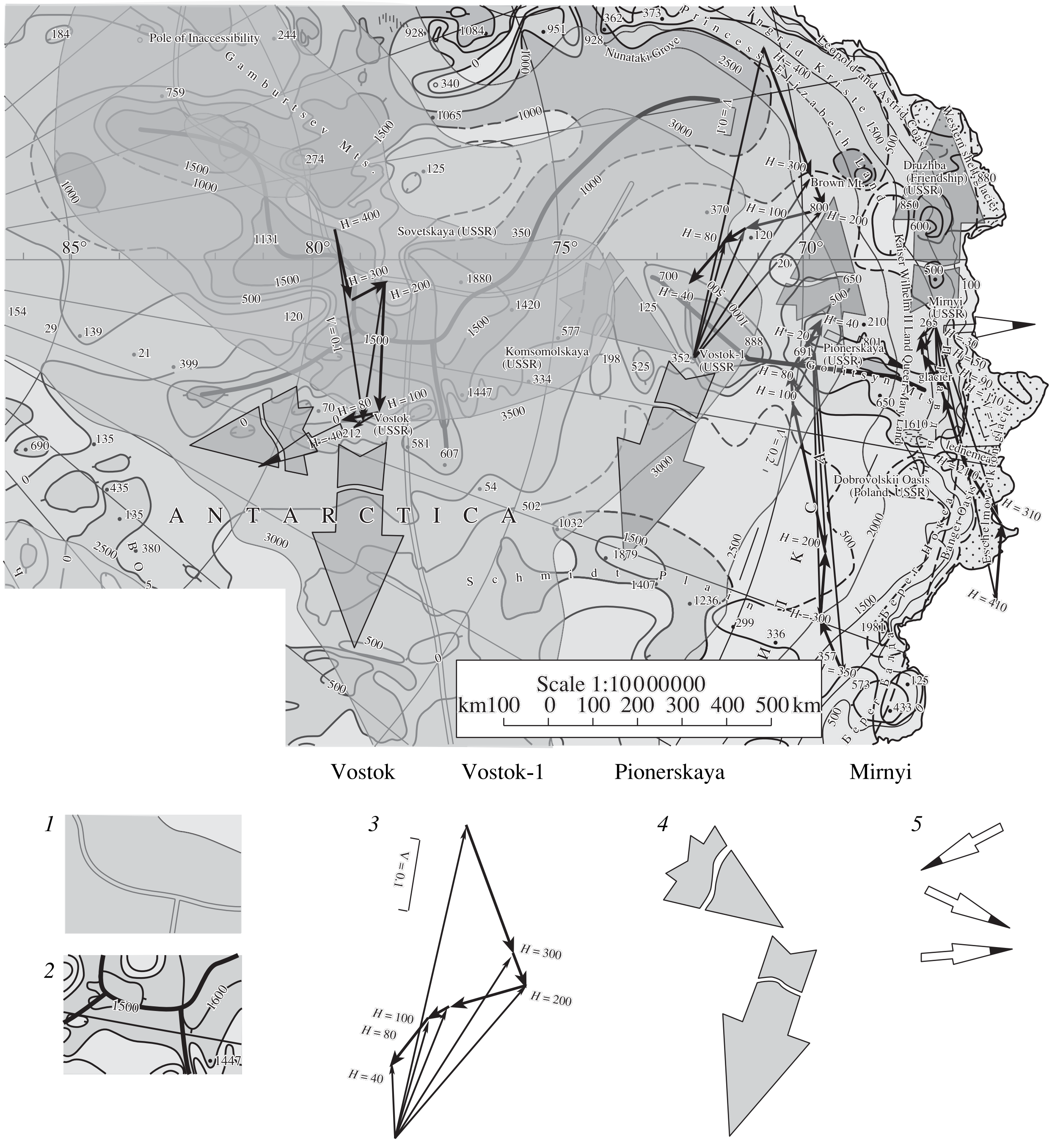

Fig. 3. Comparison of vector diagrams of the IFV inside the glacier sheet with specific features of morphology and direction of the sheet surface flow. Morphological structures of the ice sheet: (1) surface, (2) bedrock floor; vector diagrams of the flow velocity: (3) IFVs relative to the underlying horizon (horizon H= 300 m relative to horizon H = 400 m and so on) based on the results of the study (scale of vectors: 1 : 1 for the Mirnyi Station region; twofold exaggeration for the Pionerskaya Station region; and tenfold exaggeration for the Vostok and Vostok-1 stations; (4) direction of the relative displacement of layers inside the ice sheet established by the results of the study; (5) direction of the ice sheet surface flow determined by geodetic observations.

layer) values of the IFV modulus (i.e., both dynamic and less dynamic layers are distinguished) and direction (differently oriented layers); (2) the intensity of parameter variations with depth inside a layer (with higher or lower variation gradient); and (3) predominating depth variation in the IFV direction inside a layer (layers of the eastern or western torsion).

The distinguished layers are 40–60 m thick. Variations in the ice flow dynamics inside these layers are mostly of an exponential character probably because of

Relative variations in the direction and modulus of the IFV between horizons 40 and 120 m along the Vostok–Mirnyi profile

Parameter	Vostok St.	Vostok-1 St.	Pioner-skaya St.	Mirnyi St.
Ice flow direction, degree	79	25	171	49
Velocity vector modulus, m/yr	0.07	0.34	0.67	1.8

an analogous exponential variation in the rheological properties of ice [2, 3] that are different inside each layer. Maximal gradient variations in the dynamic parameters are recorded at boundaries between the layers.

The occurrence depth of the layers decreases by 20–30 m along the profile from the inland area (Vostok Station) to the coastal area (Mirnyi Station). A wavy rise (by 20–30 m) is recorded near Pionerskaya Station that is likely to be related to the ice sheet spilling over the bedrock elevation into the Golitsyn Mountains.

Comparison of IFV diagrams of the layers with morphological features of the bedrock floor (elevations of the Gamburtsev and Golitsyn Mountains) and the ice sheet surface [4, 5] suggests that variations in the IFV modulus and direction of layers relative to the glacier surface flow depend on the influence of the morphological structure of the bedrock relief. Individual layers inside the glacier are shifted relative to each other in accordance with the influence of local morphological structures in each individual region (Fig. 3).

In particular, the influence of morphology of the Golitsyn Mountains on the layer-by-layer differentiation of ice flow inside the glacier is manifested in the spreading of ice layers in opposite directions along slopes of the massif: eastward (the Vostok-1 region) or westward (the Pionerskaya and Mirnyi regions) with the predominating northward flow of the whole ice sheet mass [6] (Fig. 3).

Variations in parameters of the ice flow at different depths correlate with changes in the ice isotopic composition [1]. This is likely an indicator of the cause-and-effect relationship between variations in the ancient climate, which govern structural and physicochemical properties of ice layers during accumulation, and the subsequent layer-by-layer differentiation of these layers inside the ice sheet provoked by ice flow.

Layers distinguished by flow parameters also correlate with layers based on the radar profiling data, which represent reflecting surfaces [7]. This fact is likely to indicate the structural distinction of ice at the boundaries of layers with different dynamics due to possible dynamic metamorphism.

The table shows that the flow of upper horizons of the glacier at a depth up to 100 m in all of the four studied regions of the profile differs from the flow of the underlying ice mass (especially in direction).

The significant distinction of the upper layer dynamics allows us to consider it as a local dynamic structure on the ice sheet surface. The upper layer differs greatly from the underlying ice mass in the main dynamic properties and flow parameters.

Thus, the results of our study suggest that individual layers inside the ice sheet differ in both the modulus and the direction of the IFV. These distinctions are most prominent in the upper 100-m ice layer. Therefore, the dynamics of the ice sheet of eastern Antarctica should be considered a complicated layered structure subjected to the influence of the glacier mass formation and irregularities in the underlying bedrock relief.

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