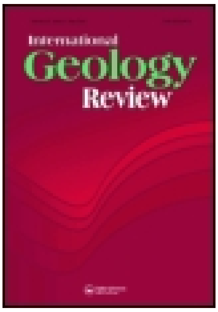

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A REFERENCE SECTION FOR THE EOCENE-OLIGOCENE BOUNDARY IN WESTERN SAKHALIN

V. A. Krasilov [a], I. N. Shmidt [a] & V. I. Remizovskiy [a]
[a] Far Eastern Scientific Section of the USSR Academy of Sciences

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V.A. Krasilov, I.N. Shmidt and *V.I. Remizovskiy*

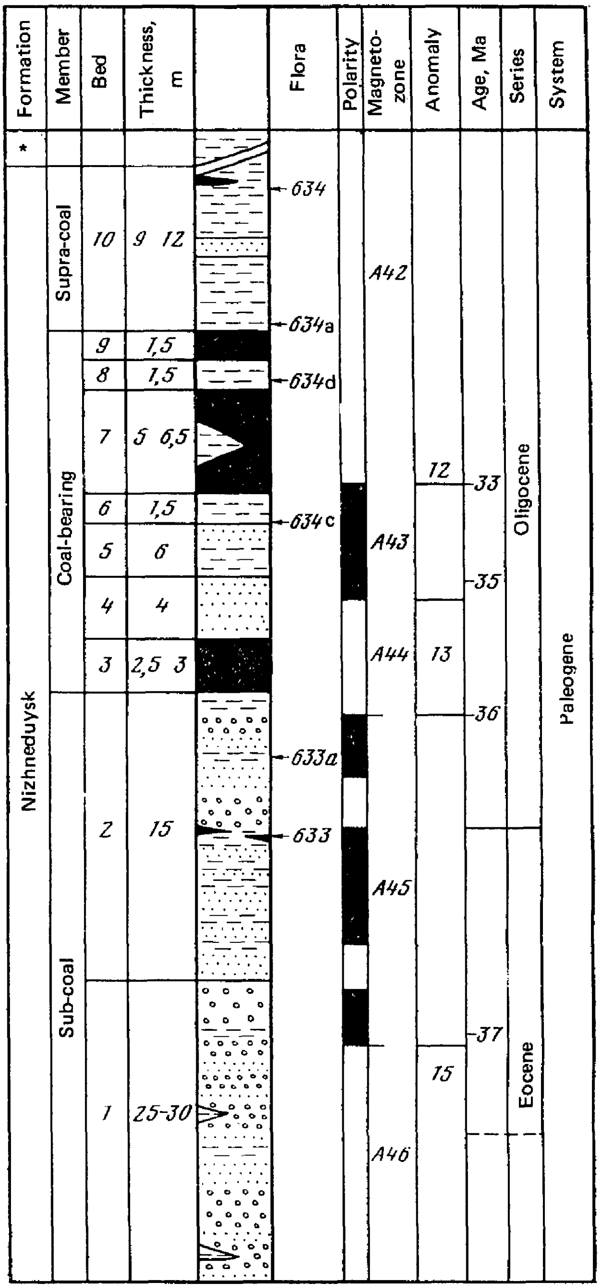
Translated from "Granitsa eotsena i oligotsena v opornom razreze zapadnogo Sakhalina," *Izvestiya AN SSSR, seriya geologicheskaya,* 1986, No. 12, pp. 59-65. The authors are with the Far Eastern Scientific Section of the USSR Academy of Sciences. Their section in continental deposits shows a marked, climatically controlled change in flora, which appears to correlate with the higher placement of the Eocene-Oligocene boundary in marine sections.

A broad range of studies has been carried out under the aegis of the International Geological Correlation Program (IGCP) Project No. 174, "Geological events at the Eocene-Oligocene boundary," but still the position of the boundary itself, especially in continental facies, is by no means always clear. Investigation of reference boundary sections is thus of prime importance. The best such sections are those that contain rich occurrences of fossils, the changes in which may be traced in uniform facies, and thus reflect the changes in the biota, and not in the migration of facies. The accessibility of the section and many years of study are also desirable. Our experience has shown that firm ideas about the nature of a section and its paleo-succession evolve gradually as a result of repeated descriptions.

In the eastern USSR, in spite of the widespread development of Paleogene and Neogene sediments, only a few sections match up to these requirements. The reference section for Primor'ye [Pacific seaboard] is that on Rechnyy Peninsula, which contains rich localities of plant remains in the Oligocene part, essentially above the boundary, whereas the boundary interval itself is relatively weakly defined paleontologically [1]. In the sections in western Kamchatka, on the other hand, an abundant flora is known from the Napan (lower Eocene), Snatol' (basal middle Eocene), and Kovachi (upper Eocene) horizons [2].

The Paleogene section on the west coast of northern Sakhalin, to the south of Cape Khoyndzho, is equally favorable in that the replacement of assemblages of Eocene aspect by Oligocene forms takes place within a relatively thin, facies-uniform coal-bearing member, and here the principal localities are confined to the boundary strata themselves. These circumstances have led us to propose the Khoyndzho section as the regional stratotype for the boundary in continental sequences for the eastern regions of the USSR.

Study of the Khoyndzho section began in the 1870s. It contains the stratotypes of the Kamensk ("conglomeratic"), Nizhneduysk, Gennoyshi, and Verkhneduysk formations, classical subdivisions of the Paleogene and Neogene of northern Sakhalin. The first detailed description of the Nizhneduysk formation was published by Krishtofovich [6], who selected as the stratotype an exposure south of the mouth of the Ogorodnaya Creek, which yields abundant flora (499) from three closely spaced beds (with *Osmunda, Taxodium, Betula, Populus,* and *Juglans*) below the tectonic contact with the Gennoyshi formation (marine Oligocene). The flora from the lower part of the section (Soldatskaya Creek), which has a somewhat different composition, was also studied. Krishtofovich determined the age of the Nizhneduysk formation as a whole to lie within the late Eocene-early Oligocene range. Subsequently, this



*Gennoyshi

FIGURE 1. Stratotype section of the Nizhneduysk formation (description in text). Arrows indicate flora-bearing strata, with paleomagnetic zones on the right (the dashed line marks an alternative of the Eocene-Oligocene boundary in the C16 magnetochron).

formation has most commonly been dated as Eocene. Krasilov and Kundyshev [5] have studied the flora from the upper beds, approximately corresponding to Krishtofovich's point 499, and have concluded that it is Oligocene in age.

During a visit to the section in 1982, we discovered that the exposure of the Nizhneduysk formation had been cleared of colluvium by a typhoon that swept over the island. This has enabled us to compile a more detailed description of the section, to expose several further flora-bearing strata, and to trace the changes in the flora within the coal-bearing member.

As already noted [5], the Kamensk and Nizhneduysk formations form a single megacycle, in which the frequency and thickness of the conglomerate members diminish upwards through the section. We have provisionally placed the boundary between them at the last thick conglomeratic layer, 400 m to the south of Ogorodnaya Creek. Higher up, there follows (Fig. 1):

1. An alternation of conglomerates, gravelstones, and inequigranular sandstones, with beds 1.5-2.5 m thick; the member itself about 25-30 m thick.

2. Coarse- and medium-grained sandstones with lensoid intercalations of fine-pebbly conglomerates, thinly-laminated siltstones, and carbonaceous mudstones, 15 m. In the middle part, in the siltstone bed, there are plant remains at Loc. 633a.

3. First coal seam, 2.5-3 m.

4. Sandstones with intercalations of thinly-bedded siltstones and conchoidal ferruginous mudstones, 4 m.

5. Interstratification of medium- and fine-grained sandstones and siltstones, 6 m.

6. Thinly-bedded mudstone, ferruginized, 1.5 m, with a leafy flora at the base on the boundary with the underlying sandstone, Loc. 634b.

7. Second coal seam of inconstant thickness, 5-6.5 m, with ferruginized mudstones in the splits.

8. Ferruginous mudstone (1.5 m) with remains of ferns (*Osmunda*) and rare dicotyledonous leaves, Loc. 634d.

9. Third coal seam, 1.5 m.

10. Interstratification of siltstones and mudstones, 9-12 m, with intercalations of sandstone up to 1 m in the middle part and with a lensoid coal seam, 0.5 m, in the upper part. At the base of the bed, there are rare plant remains, Loc. 634a, and in the upper part, an intercalation of siltstone with well-preserved leaves, Loc. 634. This member is in fault contact with the Gennoyshi formation, a monotonous sequence of splintery mudstones, containing rare remains of marine mollusks.

The general list of plant species, their distribution through the plant beds, and their quantitative relations, are given in Table 1. Since the percentage of entire leaves in all the strata is very low, it is virtually impossible to use them as a paleoclimatic indicator. Size variations in the leaves of the dominant species are more significant (Table 1; Fig. 2). An analysis of the relations between the leaf size and the climate (temperature and humidity) is given in Krasilov's work [3].

The flora of the Kamensk formation in the Khoyndzho section [4] is marked by the predominance of *Dryophyllum curticellense*. The following assemblages have been recognized in the Nizhneduysk formation:

1. *Magnolia kryshtofovichii–Dryophyllum curticellense*, sub-coal bed of siltstone, Loc. 633a. This is a small assemblage, clearly associated with the flora of the Kamensk formation, and shows that no marked changes in the vegetation took place at its boundary with the Nizhneduysk formation.

2. *Platanus aceroides–Aesculus magnificum*, interseam between coal seams I and II, Bed 5, Loc. 634b. A group of Arcto-Tertiary aspect, virtually without thermophilic elements, and sharply differing in the composition of the dom-

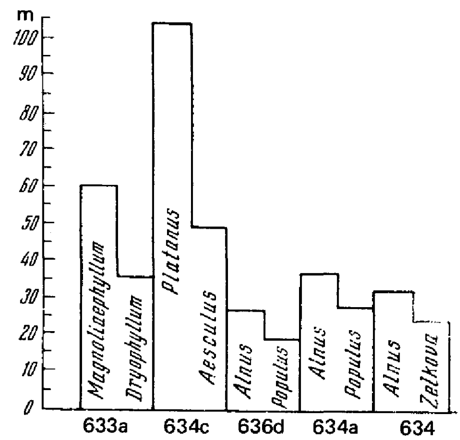


FIGURE 2. Size variations (width, cm) in leaves of dominant plants of five successive assemblages in the Nizhneduysk formation.

inants and the leaf morphology from those of Loc. 633a. It is distinguished from subsequent assemblages by the large-leaf nature.

3. *Alnus onorica–Populus celastrophylla*, Beds 8 and 10, Locs. 634d and 634a. It differs little in species composition from 634b, but other smaller-leaved species come to the fore as dominants. The lower Bed 8 with remains of this assemblage also contains *Osmunda sachalinensis*, and the leaves of the dicotyledons are smaller than in Bed 10.

4. *Zelkova ungeri–Alnus onorica*, Bed 10, Loc. 634. A small-leaved assemblage in which *Metasequoia* and *Trochondendroides* play a leading role.

The most significant change in vegetation, undoubtedly associated with climatic changes, took place during the interval corresponding to the 8.5-9.0-m level in the above-described section, between sub-coal bed 2, containing remains of thermophilic plants of Eocene aspect, and inter-coal bed 5 with remains of the large-leaved assemblage of Arcto-Tertiary aspect. Subsequent events within the 18-m interval (replacement of the large-leaved assemblage by small-leaved forms and then an increase in the content of *Trochodendroides*) reflect progressive cooling, with minor fluctuations of effective temperature and/or humidity affecting the sizes of the leaves.

Thus, the hypothesis of the relative stability of the vegetation during Eocene time and its rapid change near the Eocene-Oligocene boundary, marked by a global cooling, is confirmed.

The boundary may be located with greatest precision by using paleomagnetic data. The sediments of the Nizhneduysk formation, on the basis of their magnetic properties, are clearly divided into two members. The sub-coal member is marked by values close to those for the Kamensk formation: the magnetization is virtually the same, the magnetic susceptibility is about half, and the rock density is somewhat lower. The coal-bearing member is marked by a decrease in magnetization, a marked increase in the magnetic susceptibility (by more than an order of magnitude), and as a consequence of this, very low values for factor *Q*. This is explained by the substantial content of siderite [2]. Siderite is paramagnetic, so that it possesses a comparatively high inductive magnetization, whereas its remanent magnetization is virtually zero. The presence of siderite in the rock is readily diagnosed from factor *Q* (Table 2).

Laboratory studies (thermal cleansing of the entire collection and selective cleansing in a variable magnetic field) have enabled us to recognize five zones of normal (N) and reverse (R) polarity, A-46–A-42. The thick zone of normal polarity A-42 embraces virtually the whole of the Kamensk formation. Within it, there are two small intervals of reverse polarity, but they have been detected only in one specimen each. The sub-coal member of the Nizhneduysk formation belongs to Zone A-45, of predominantly reverse polarity with two short normal intervals, and the first coal seam and the lower part of the inter-seam belong to N-Zone A-44. In the upper part of the inter-seam, including flora-bearing bed 634b, the polarity changes to reverse (R-Zone A-43). Higher up, as far as up to the middle of the Gennoyshi formation, normal polarity predominates.

In comparing this sequence of magnetozones with the standard paleomagnetic scale for the

TABLE 1. Flora in Stratotype of the Nizhneduysk Formation, and Distribution by Localities

Species	Localities				
	633	634b	634d	634a	634
1. *Dryophyllum curticellense* (Watelet) Sap. et Marion	━━━				
2. *Magnolia kryshtofovichii* Borsuk	———	———		———	
3. *Byttneriophyllum tilifolium* (A. Br.) Knobl. et Kvac.	———	———		———	
4. *Osmunda sachalinensis* Krysht.	━━━	———	━━━	———	
5. *Populus calastrophylla* (Borsuk) Suchova	———	———	———	━━━	
6. *Equisetum* sp.		———			
7. *Picea* sp.		———			
8. *Platycarya hokkaidoana* Tanai		———			
9. *Betula nansenii* Budants.		———			
10. *Trochodendrocarpus arcticus* (Heer) Krysht.		———			
11. *Cocculus ezoensis* Tanai		———			
12. *Liquidambar miosinica* Hu et Chaney		———			
13. *Leguminosites* sp.		———			
14. *Acer* sp.		———			
15. *Hibiscus* sp.		———			
16. *Platanus aceroides* Goepp.		━━━		———	
17. *Populus longepetiolata* Brosuk		———		———	
18. *Aesculus magnificum* (Newb.) Iljinskaja		━━━		———	
19. *Carya ezoensis* Tanai		———		———	
20. *Carpinus* sp.		———		———	
21. *Nelumbo nipponicum* Endo		———		———	
22. *Metasequoia disticha* (Heer) Miki		———	———	———	———
23. *Zelkova kushroensis* Oishi et Huzioka		———		———	———
24. *Ginkgo adiantoides* (Unger) Heer			———	———	
25. *Alnus onorica* Borsuk			———	━━━	━━━
26. *Alnus ezoensis* Tanai				———	
27. *Alnus* sp.				———	
28. *Ulmus* sp.				———	
29. *Prunus* sp.				———	
30. *Sphora* sp.				———	
31. *Fraxinus* sp.				———	
32. *Trochodendroides arctica* (Heer) Berry				———	━━━
33. *Smilax* sp.				———	———
34. *Spira a kushiroensis* Tanai					———
35. *Platanus* sp.					———
36. *Acer arcticum* Heer					———

Note. Very thick line — dominant species, thick line — normal species, thin line — rare species.

Eozone and Oligocene epochs [9, 11, 12], we see that during middle and late Eocene time, normal polarity predominated. The interval with very brief inversions occurs between magnetic anomalies 18 and 15, within about 43-37 Ma. The relatively lengthy R-interval (with brief N-intervals) between anomalies 15 and 13 (anomaly 14 has been excluded from the standard succession) has been dated at 37-35 Ma. Anomaly 13 occupies somewhat less than 1 million years on the geochronological scale. Then there also follows a relatively lengthy R-zone, and

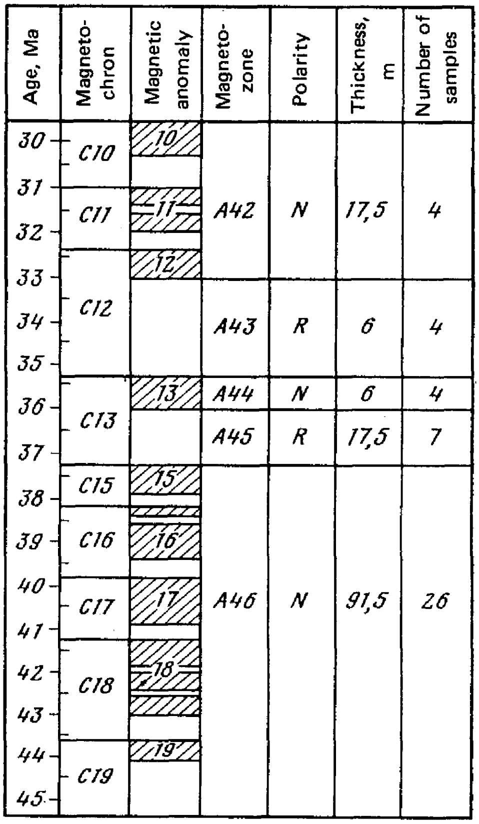


FIGURE 3. Comparison of paleomagnetic zonation in the stratotype of the Nizhneduysk formation and the standard for the late Eocene-early Oligocene interval [12].

higher up, between anomalies 12 and 7, normal polarity predominates (Fig. 3). The single correlation variant, arising from the comparison, is shown in Figures 1 and 3.

The Eocene-Oligocene boundary lies at level 16 [11] or between anomalies 15 and 13. Poore et al. [12], who have analyzed the paleomagnetic and biostratigraphic data through a reference section near Gubbio, Italy, and in core from DSOP site 522, in the mid-latitudes of the South Atlantic Ocean, favor the latter variant. These authors have placed this boundary at the base of Zone OL1, which, according to their data, closely corresponds to the boundary between the *Globorotalia cerroazulensis* (*s.l.*) and *G. chipolensis–P. micra* zones based on Stainforth's planktic foraminifera [13] and coincides with the nannoplankton zones NP_{20}-NP_{21}, and CP15-CP16 [8]. We also have grounds for accepting this variant, since the principal change in the flora takes place in Zone A-44, identified as anomaly 13.

With these correlations, the sedimentation rate during the 37-33-Ma interval (29 m) averaged about 70 cm/million years, which permits an approximate calculation of the periodicity of the climatic fluctuations, reflected in changes in leaf size. The beds with plants in the coal-bearing portion are repeated every 3-7.5 m. The smallest of the intervals which we have identified between points 634d and 634a (3 m) is about $430 \cdot 10^3$ yrs. In the sub-coal portion of the section, this periodicity is not expressed. In the coal-bearing portion, short-period fluctuations are quite clearly expressed, which, as is well known, is typical of a glacial climate. It may be suggested that the boundary that we have recognized actually corresponds to the transition from a non-glacial to a glacial climate, which, according to current hypotheses, took place at the beginning of Oligocene time with the evolving glaciation of Antarctica.

TABLE 2. Petromagnetic Properties of the Paleogene Rocks of the Khoyndzho Section

Formation	Number of samples	Density, g/cm³	Magnetization, $A/m \cdot 10^3$	Magnetic susceptibility, $10^6 \cdot$SI units	Factor
Nizhneduysk					
Coal-bearing part	9	2.64	0.55	1353	0.01
Sub-coal part	9	2.41	1.11	117	0.24
Average per group	18	2.52	0.83	735	0.12
Kamensk	33	2.55	1.16	234	0.12

Conclusions

In the reference section of the Kamensk and Nizhneduysk formations south of Cape Khoyndzho, a marked change in the flora, with the removal of subtropical elements, takes place at the base of the coal-bearing member. According to the paleomagnetic correlation, this boundary occurs within the C13 magnetochron. Two variants of the Eocene-Oligocene boundary exist in the marine sediments: in magnetochrons C16 or C13. Our data favor the latter variant, because the boundary, based on the terrestrial flora, reflecting a significant change in the climate, almost coincides with that based on the oceanic microfauna and nannoflora. The changes in the climatically dependent features of the plant assemblages in the lower Oligocene portion of the section indicate periodicity in the climatic fluctuations. The first appearance of periodicity, imperceptible in the Eocene interval, marks the transition, at the beginning of the Oligocene epoch, from a non-glacial to a glacial climate associated with the evolving glaciation of Antarctica.

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