REFERENCE SECTION OF THE UPPER KAZANIAN SUBSTAGE: CYCLIC REGULARITIES

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ABSTRACT
In the present paper cyclicity of sedimentary rocks was discussed on the example of so called cycles by Noinskyi discovered in reference section of the Upper Kazanian substage near village Pechishchi (river Volga, near Kazan city, Russia). The analysis is based on layers-thickness distributions and isotope ratios of carbon, oxygen and strontium in carbonate component of section. Cycles by Noinskyi are referred to $1*10^5 – 4*10^5$ years cycles of Earth eccentricity.

Keywords: upper Kazanian stage, cycles, noinsky, isotope ratios, carbon, oxygen, strontium.

1. INTRODUCTION
The Kazanian stage is the most studied stratigraphic object within Volga and Kama rivers region because of expressed marine component in its composition. It is considered within Middle+Upper Permian sequence called Upper regional cycle [1].

Common regional palaeogeographical history of the Kazanian stage was characterized in [1]. This history was controlled by Hercynian tectonic movements after the fifth global regressive phase of the Late Paleozoic.

Hercynian Ural mountain structures were actively destroyed, and the eastern marginal area of the Russian plate was provided by a huge amount of clastic and chemogenic sedimentary material. Waters of Boreal Permian Sea penetrated from north to Cisuralian foreland basin. Three megacycles corresponding to the Ufimian, Kazanian and Urzhumian+Severodvinian + Vyatkian regional stages occurred inside the supercycle. Maximum transgression associated with the Early Kazanian.

Terrigenous and carbonate sediments accumulated in the Kazanian paleosea during the Early Kazanian and beginning of the Late Kazanian. Sedimentation during the Late Kazanian has already occurred in increasing evaporate environments when subsequent invasion of the sea became more transient and less ambitious.

We will consider the cycles of Pechishchi that is well-known reference section of the Upper Kazanian substage on the right bank of Volga River in light of historical interpretation and recent geochemical data.

2. DESCRIPTION OF REFERENCE SECTION
The region of the Volga River near Kazan includes the area along the bank of the Volga River from the village of Pechishchi to the town of Tetyushi. The Upper Permian rocks form the right bank of the river and are accessible for studies in the slope of the bank and in numerous gullies.

The stratotype outcrops are exposed on the right bank of the Volga River opposite the city of Kazan. The succession is exposed in the slope of the bank between the village of Pechishchi and Naberezhnye Morkvashi in the bottom and in the slopes of the Kamennyi Gully (Figure-1, outcrop 1). The Kazanian–Urzhumian boundary is the best accessible in the Cheremushka (Figure-1, outcrop 2) and Truba (Figure-1, outcrop 3) gullies.

Pechishchi section’s stratification was firstly made and developed by M.E.Noinskyi in 1899 and 1924 [2]. Section was divided on 52 layers grouped into series with local names. The groups of series were considered by Noinskyi as three cycles.

The first (lower) cycle includes three series from low to up: “Yadrenyi kamen”, “Sloistyi kamen”, “Podboi”. The second (middle) cycle comprises of series from low to up: “Seryi kamen”, “Shikhany”, “Opoki” (lower part). The third (upper) cycle includes series from low to up: “Opoki” (upper part), “Podluzhnik” and “Perekhodnaya”.

Each cycle begins with marine carbonate sediments. Gypsum and dolomite sediments of saline lagoons follow after marine carbonates. The cycle is finished by mud sediments of transition and continental environments.

Main characteristics of section are next:
- dolomites widely spread;
- dolomites altered thinly with limestone and marl;
- limestone with rich marine fauna are rare;
- single layer with oolite carbonates (layer 17) is discovered;
- fine grained sediments mostly present in series “Perekhodnaya”;
- high extent of carbonate rocks weathering.

In [3] the section Pechishechi is described in a grouped form composed of 31 layers with a change in the values of thickness in some layers.

On Figure-2 the distribution of thickness, according to both descriptions, is showed ((by [2, 3])). On thickness plot built using first data (on left) one can see that the thickness (on 52 layers) ranges from 0.04 m (the layer 44 of series “Perekhodnaya”) to 5.48 m (layer 37 of series “podluzhnik”). The thickness of first cycle is 15.6 m (6.8 +5.56 +2.8), second cycle - 11.68 m (5.4 +3.28+3), third cycle - 19.8 (3.27 +9.21+7.32) m. Total thickness is 46.64 m. Mean thickness is 15.69 m. The most thick layers are layers 2 (1.75 m), 9 (2 m), 21 (3 m), 31 (1.57 m), 37 (5.48 m), 38 (3.73m). Second (saline lagoon) component is mostly thick in each cycle. First (marine) and third (lacustrine) components are next. On the Figure-2 bars 9, 21 and 37 point on increasing of continental influence on sedimentation.


In plot by renovated description (Figure-2, on right), the general character of cycles remained unchanged. There are three levels of continental influence increasing marked by layers 9, 21, 28.

Layers descriptions are similar on thickness in the lower (15.45 m) and middle (10.8 m) cycles. The upper cycle (24.3 m) differs and due to the fact that the layers of third cycle were described by researchers at the close, but different points (gully Truba [2] and gullies Kamennyi, Cheremushka and Truba [3]).

We base our consideration on the modern description by [3] that is presented below.

**Prikazanske layers (P2kz21)**

**Series Yadrenyi Kamen**

Dolomite, clayish, yellowish-brown, soft; with vermiculate cavities. The thickness is 0.9 m.

Light-grey, calcareous, thickly bedded, compact, hard dolomite containing the small foraminifers *Ichtyolaria fallax* (K.M.-Maclay), *Ich. longissima* (K.M.-...
Mac.), rare molds and impressions of bivalves and brachiopod shells. The thickness is 1.7 m.

Light-grey, yellowish, compact, moderately hard, solid dolomite. The thickness is 0.7 m.

Light-grey, compact and hard dolomite, sometime cavernous, with Cancrinella cancrici (Vern.). The thickness is 0.7 m.

Grey, calcareous, compact dolomite; sometimes it is replaced by thinly porous softer dolomite with numerous inclusions of celestine. This layer contains the foraminifers Paraglomospira simplicissima (K.M.-Maclay), Ammodiscus sp., Globivalvulina bulboides Brady, Nodosaria suchonensis K.M.-Maclay, Pseudodonosaria lata K.M.-Maclay, Lingulina semivelata Tscherd., Ichthyolaria triangularis (Gerke), and small shells of Cancrinella cancrici (Vern.), Rhynchopora geinitziana (Vern.), Cleiothyridina pectinifera (Sow.). The thickness is 1.4 m.

Yellowish-grey, fine-grained, porous, sometimes cavernous, relatively soft dolomite. These rocks contain the accumulations of small non-sorted bioclasts. The thickness is 0.7 m.

Yellowish-grey with bluish-grey stains, fine-grained, calcareous, solid dolomite containing numerous molds and impressions of bivalves and brachiopod shells. The dolomite contains inclusions of celestine. The thickness is 0.3 m.

Bluish-grey calcareous crypto-grained, lenticular and bedded dolomite, with impressions of vegetative shoots of charophytes, the brachiopods Cancrinella cancrici (Vern.), Aulosteges fragilis (Netsch.), Stenoscisma superstes (Vern.), Crturithyris nuella (Netsch.), and the conodonts Merrillina sp. and Stepanovites sp. The thickness is 0.35 m.

**Series Sloistyi Kamen**

Light-grey, calcareous, fine-grained, sometimes bioclastic dolomite. It is clearly subdivided into four layers. Rocks in the upper part contain gypsum nodules and caverns at places where gypsum was leached. The layer contains the bivalves Nuculana speluncaria (Gein.), Lithophaga consobrina (Eicw.), Pseudobakevella ceratophagaformis Noin., Schizodus rossicus Vern., Permorphus simplex (Keys.), Pseudomonotis sp., Solemya (Janea) cf. biarmica (Vern.), and the brachiopods Cancrinella cancrici (Vern.), Pinegathyris roysiana (Keys.), Beecheria sp., conodonts Merrillina sp., and Stepanovites sp. The thickness is 2 m.

Yellowish-grey, very compact, moderately hard, finely laminated dolomite, with smooth or uneven fractures. The thickness is 0.2 m.

Light-grey, calcareous, thinly porous, fine-grained, medium bedded dolomite. The layer contains small (up to 2.5 mm) bioclasts oriented along the bedding planes. The thickness is 0.6 m.

Dull-grey, fine-grained, medium-grained dolomite, with numerous large cavernous. The rock contains small scattered bioclasts up to 1 mm in size. The thickness is 1.4 m.

Light-grey, fine-grained, thinly wavy laminated very soft, porous, dolomite with numerous celestine nodules and rare gypsum nodules, which are usually leached. The bedding plane at the top of the layer contains desiccation fractures and verruculate branching perforations. The rock contains rare bioclasts (up to 0.5 mm in size), in which calcite is replaced by dolomite. The thickness is 1.2-1.5 m.

**Pechishchinskie layers (P:Kz.2)**

**Series Podboi**

Dark-brown and greenish-brown dolomitic, plastic, thinly wavy laminated clays, with numerous differently orientated gliding planes. Clays contain many coaly remains of the plants Paracalamites katorgae Gein., Sphenophyllum stoukenbergi (Schm.), Callipteris sp., Nucicarpus minutus Easul., etc. and scales of the fish Palaeoniscum sp. The thickness is 0.25-0.35 m.

Greenish-grey, muddy-marly, fine-grained marl with irregular thin lamination, platy, strongly weathered, loose and soft. Rocks are diagonally fractured, the fractures are filled with calcite. Some interbeds are filled with calcite bioclasts (0.5 mm). The thickness is 1.2-2.0 m.

**Series Seriyi Kamen**

Brownish-grey, muddy, thinly and medium bedded, platy dolomite with rhomboidal fractures. Rocks contain many small (2-3 mm) rounded nodules of dark calcite, the bed is sometimes completely replaced by dark-grey, fine-grained limestone. The thickness is 1.0-1.5 m.

Grey, fine-grained, porous, relatively soft, sandy, thickly bedded, bituminous dolomite, sometimes with ooids. The rock contains the gastropods Goniasma sp., Baylea sp., bivalves Schizodus rossicus Vern., and the brachiopods Aulosteges wangenheimi (Vern.), Cleiothyridina pectinifera (Sow.), and Beecheria sp. The thickness is 1.4 m.

Brownish-grey, muddy, thinly porous dolomite, thickly bedded at the bottom and thinly bedded at the top. The dolomite contains inclusions of calcite, celestine, and gypsum. The inarticulate brachiopods Orbiculoidea konincki (Gein.) and the conularid Conulalaria hollebeni (Gein.) are typical. The bed also contains the bivalves Pseudomonotis (Trematiconcha) noinsky (Lich.), Pseudomonotis (Pseudomonotis) perennial Masl., Solemya (Janea) biarmica (Vern.), Parallelodon kingi (Vern.), and the fish Kasanichthys sp., and Acropholis sp. The thickness is 1.2-2 m.

Grey, thickly bedded, fine-grained dolomite, sometimes stained and with ooids. The bed also contains inclusions of calcite, quartz, and calcedony, more rarely celestine and gypsum. The layer contains the foraminifers Glomospira sp., Ammodiscus sp., Globivalvulina bulboides Brady, Pseudodonosaria lata K.M.-Maclay, Nodosaria suchonensis K.M.-Maclay, and Pseudomonotis microsphaericus (K.M.-Maclay), numerous gypsum or siliceous molds of bivalves Pseudomonotis garforthensis (King), Ps. sp., Schizodus rossicus Vern., brachiopods
contains the bivalves
compact, sometimes siliceous dolomite. The lower part
often form bioherms. The thickness is 1 m.

Moroz
Clays and sandstones contain foraminifers
with subdominant interlayers of siltstone and sandstone.
replaced by dolomitic clays and yellowish-grey marls,
hydroxides of iron. Upward in the section dolomites are
laminated dolomites. The thickness is 2.2-3.8 m.

grey, thinly bedded, with rare interlayers of thinly
(0.1-0.2 mm). The thickness is 0.8 m.
laminated, sometimes sandy dolomites with rare bioclasts
(Vern.). The thickness is 1.6-3.2 m.

Grey, clayish, crypto-grained, micro wavy
laminated, sometimes sandy dolomites with rare bioclasts
(0.1-0.2 mm). The thickness is 0.8 m.

Alternation of siltstones and clays, yellowish-greyness,
thinly bedded, with rare interlayers of thinly
laminated dolomites. The thickness is 2.2-3.8 m.

Grey, muddy, fine-grained dolomite fractured by the
intersection of hair-thin fractures filled with hydroxides of iron. Upward in the section dolomites are replaced
by dolomitic clays and yellowish-grey marls, with subdominant interlayers of siltstone and sandstone.
Clays and sandstones contain foraminifers Glomospira sp.,
Ammodiscus sp., Pseudoammodiscus megasphaericus
Gerke, bivalves Pseudobakewellia ceratophagaformis
Noin., Pseudomonotis (Ps.) permianus Masl., brachiopods
Cancrinella cancini (Vern.), Rhynchopora geinitziana
(Vern.), Cleiothyridina pectinifera (Sow.), marls contain
Lingula sp. The thickness is 2.5-4.0 m.

Series Podluzhnik
Light-grey, muddy, fine-grained, thickly bedded
dolomite with cherty nodules. The rock contains imprints of the bivalves Nuculana kasanensis (Vern.),
N.spleuncaria (Gein.), Schizodus rossicus Vern.,
Netschajewia globosa (Netsch.), Pseudomonotis (Ps.)
permianus Masl., the brachiopods Cancrinella cancini
(Vern.), Beecheria netschajewi Grig., Spiriferella
netschajewi (E. Ivan.), Odontospirifer subcristatus
(Netsch.), and fish scales of Platysomus solodouchoi
Munch, Palaeoniscum kasanense Gein. et Vett., and
conodonts Merrillina sp. and Stepanovites sp. The
thickness is 2.3-3.2 m.

Light-grey, fine-grained, medium bedded
dolomite. The thickness is 3 m.

Light-grey, muddy, irregularly layered dolomite
with numerous thin laminas and nodules of white and pink
gypsum. The top of the bed has desiccation fractures. The
thickness is 3.5 m.

Morkvashinskie layers (P:kz²)

Series Perekhodnaya
The rocks of this member unconformably overlie the
underlying rocks.

Yellowish-grey, dolomitic, stained marl with lenses of conglomerates (10–20 cm) at the base. Conglomerates consist of small pebbles of white dolomite. Upward in the section, marls are occasionally replaced by muddy dolomites. Marls contain non-marine ostracodes Palaedarwinuslina onega (Bel.), Prusuchonella belebeica
(Bel.) and others, phyllopoideae, fish scales of
Acentrophorus varians Kirykh, Kasyshchuythys viatkensis
Esin, and Palaeoniscum kasanense Gein. et Vett., and
plant fragments. The thickness is 3-4 m.

Light-grey, muddy, fine-grained, thickly bedded
dolomite. The rock contains numerous foraminifers
Saccammina sp., Ammodiscus sp., Haplophragmoides
opinabilis Ucharsk., Trochammina sp., Verneuilinoides
sp., and Digitina rara Ucharsk., the gastropod
Loxoneoma sp., the bivalves Paralleledon kingi (Vern.),
Pseudobakewellia ceratophagaformis Noin., Lithophaga
(="Modiola) consobrina (Eichw.), Schizodus rossicus
Vern., and Pseudomonotis (Ps.) permianus Masl.,
the brachiopods Cancrinella cancini sp. and Beecheria netschajewi
Grig., and the conodonts Merrillina sp. and Stepanovites
sp. Because of the mass occurrences of Lithophaga (=
"Modiola) consobrina (Eichw.), the layer is known as the
"Modiolyi Horizon". The thickness is 2.5-3.5 m.

Greenish-grey feldspar- quartzite siltstone, with
irregular laminae and lenses of clays and dolomites. The rock
contains the rare remains of the plants Siganularia
noinskii Zal., Paracalamites kutorgae Gein.,
Sphenophyllum stouckenbergii (Schm.), Odontopteris
rossica Zal., and Nucicarpus minutus Esaul., etc. The
thickness is 2–3 m.

These layers are unconformably overlain by the
red-layered Urzhuman siltstone and sandstone.

3. CYCLIC REGULARITIES
On isotopic data, received in [4] three cycles on isotopes were detected, correlated with cycles by Noinskyi
(Figure-3).
Thicknesses of cycles correlate with the number of layers in them (Figure-4, A). The lower cycle has most frequent changes of thicknesses (five short cycles). Each of middle and upper cycles has two ones respectively.

Amplitude of thickness oscillation in short cycles does not exceed 3 m, with a maximum in middle cycle. If we assume that paleobasin during the Late Kazanian was a bay with carbonate sedimentation, the observed thickness fluctuations can be interpreted as relative sea level fluctuations due to accommodation space changes. The increase of thickness can be correlated with level rise. Nine short cycles can be revealed (Figure-4, B). Maximum 1 corresponds to “Yadrenyi kamen”. Group of maximums 2, 3, 4 is referred as “Soisty kamen”. Maximums 5, 6, 7 and 8 correspond to “Podboi”, “Seryi kamen”, lower and upper part of “Opoki” respectively. Maximum 9 includes layers 28 and 29 in series “Podluzhnik” and “Perekhodnaya”.

The hypothesis of correlation of thickness changes with sea accommodation changes can be proved by correlation of thickness changes with the number of fauna species (Figure-4, C).

The zero line is arbitrary and corresponds to the composition of the poor paleontological complex. The resulting graph shows that in zones of marine component of cycle’s thickness maximums 1 and 2, and also 3 (with a
small time lag) correspond to biotic peaks. In middle cycle, the biotic peak accompanies a maximum 6 and still retains its value in a downturn of thickness. In the upper cycle biotic peaks follow the thickness peaks 8 and 9, respectively. Thus, the increase of species of marine biota correlates with an increase of thickness of the layers (sea accommodation increase), and our hypothesis is acceptable.

![Figure-4. Cycles in Pechischki. A - correlation of layers number and thicknesses:long periods. Composition of each cycle: blue - carbonates with fauna, green - carbonates with hypsum without fauna, yellow - carbonate and mud sediments. B - short thickness cycles with maximums 1-9. C - thickness and biota in cycles.](image)

Also reversal correlation was observed between $\delta^{13}$C and the number of marine biota species (Figure-4, C), confirmed by cycles of biota activity in dependence on sea level rise or fall ($\delta^{13}$C increase or decrease respectively).

Three cycles along Pechischki section correspond to cycles with mean thickness 17 m of fifth order (duration of Late Kazanian is ~1-1.5 Ma by ISS, and one cycle duration is ~0.5-0.6 Ma).

Estimation of the rate of the sedimentation obtained by simple dividing of thickness on the time, gives a value of about 0.02-0.04 m/ka for large-scale stratigraphic records. The smaller cycle corresponds to the increased rate of sedimentation. According to [5], the rate of accumulation of "lingula clays" (base layer of Lower Kazanian) is estimated by value of about 0.5-1 mm/year, supposing that the probability of interruption increases with sediment thickness [6]. This estimation is close to the estimated 0.23 - 0.24 m/ka given for the Permian of Australia in [7]. It can be correlated with one or two 100 thousand year cycles of eccentricity.

Supposing a fifth-order cycles were taken in a simplified visual version comparable to 100 thousand year cycles of eccentricity, then on the table [8] we obtain the following simulation model (Table-1).
### Table-1.

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5. CONCLUSIONS

Cycles, determined by M. E. Noinskyi, were considered as effective terms to reconstruct the Upper Kazanian substage history in Volga-Kama rivers region. They can be used for stratigraphic estimations and correlation in regional and global scale.

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