GEOCHEMISTRY OF OILS IN THE TEREK-CASPIAN FOREDEEP AND PRIKUMSK SWELL, NE GREATER CAUCASUS, SOUTHERN RUSSIA

N. Sh. Yandarbiev1, R. F. Sachsenhofer2, S. Ajuaba2, A. Bechtel2 and D. N. Yandarbieva3

Hydrocarbon reserves of the order of 1140 MM bbl of have been identified in the northern foreland of the eastern Greater Caucasus, principally in the Terek-Caspian fold-and-thrust belt and the Prikumsk Swell in the north of the Terek-Caspian foredeep. Despite the great economic significance of these areas and their long exploration history, the origin of the hydrocarbons is still poorly understood. In the present paper, geochemical data from 73 oil samples representing 28 fields are used to investigate the presence of oil families and to correlate the oils with potential source rocks.

Biomarker composition of oils in Cretaceous and Miocene reservoirs in the Terek-Caspian fold-and-thrust belt is mainly controlled by reservoir depth (100-5700 m) and maturity (0.70-1.15 %R), and it is therefore difficult to separate maturity and facies effects. For example, a downward increase in diasterane/sterane ratios may indicate a change in source rock facies or may be attributed to increasing maturity. Some shallow oils are biodegraded. The presence of short-chain n-alkanes in biodegraded oils indicates recent hydrocarbon migration. Biomarker data (e.g. the presence of oleanane) and compound-specific isotope data suggest that the Khadum Formation in the lower part of the Maikop Group is the main source rock. However data from Cretaceous and Paleogene organic-rich rocks, which may also have contributed to the accumulated oils, are urgently needed in order to quantify their possible input.

In the Prikumsk Swell, at least two oil families, characterized by low and high C28/C29 sterane ratios respectively, can be distinguished in reservoir rocks of Triassic to Cretaceous age. Most oils are characterized by low C28/C29 sterane ratios and the absence of oleanane (“Group B oils”). These characteristics suggest a pre-Upper Cretaceous source for the oils, which is also supported by the geological setting. Hierarchical cluster analysis suggests the presence of four sub-groups (Sub-Groups B1 to B4). Typically, biomarker ratios in oils in Cretaceous reservoirs are more uniform than those in Triassic and Jurassic reservoirs. Potential source rocks include Lower Triassic deep-water clayey limestones and shales as well as Middle Jurassic and Aptian-Albian marine shales. Three oil samples from Triassic and Cretaceous reservoirs form a separate oil family (“Group A”), which is genetically related to oils from the Terek-Caspian fold-and-thrust belt. Group A oils have high C28/C29 sterane ratios and in general contain at least some oleanane. A contribution by Cenozoic source rocks to Group A oils is likely.

1Petroleum Geology Department, Lomonosov Moscow State University, Russia, 119234 Moscow, Leninskie gory. 2Chair in Petroleum Geology, Montanuniversitaet Leoben, 8700 Leoben, Austria. 3Moscow, Leninskiy prospekt 60/2, 457, Russia. *corresponding author: yandarbiev@mail.ru

Key words: Greater Caucasus, Russia, Terek-Caspian fold-and-thrust belt, Prikumsk Swell, petroleum, geochemistry, biomarkers, oil families, source rocks, Maikop Group.

©2021 The Authors. Journal of Petroleum Geology published by John Wiley & Sons Ltd on behalf of Scientific Press (SCIPRE). This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
INTRODUCTION

The Terek-Caspian foredeep is located to the NE of the Greater Caucasus (Figs 1, 2). The northern part of the basin comprises the Prikumsk Swell, the East Manych Trough and the Karpinsky Swell. At its southern margin is the Terek-Caspian fold-and-thrust belt which experienced major shortening during Late Cenozoic time (Sobornov, 2021 this issue). The fold-and-thrust belt can be divided from west to east into three structural segments referred to as the Terek-Sunzha Fold Zone, the Dagestan Promontory and the Maritime Zone in Southern Dagestan (Sobornov, 2021; Fig. 1).

According to Boote et al. (2018), 52 oil and gas fields have been identified in the Terek-Caspian fold-and-thrust belt. The largest of these are the giant Starogroznenskoe and Malgobek-V oznesenskoe oil fields; the average field size here (95 MM brl) is remarkably high and cumulative reserves are about 4875 MM brl. Oil and minor gas/condensate occur in Jurassic, Cretaceous and Miocene reservoirs at depths between a few hundred metres and 5800 m.

The Prikumsk Swell contains another 142 fields with oil and gas-condensate. The average field size is 47 MM boe and total reserves are estimated to be 6705 MM boe (Boote et al., 2018). Hydrocarbons are reservoired in Triassic carbonates, in a number of Jurassic and Cretaceous sandstone horizons, and in fractured Oligocene (Lower Maikop) shales (Boote et al., 2018).

Fig. 1. Location map showing structural provinces and oil and gas fields in the Terek-Caspian foredeep to the NE of the Greater Caucasus (after Yandarbiev et al., 2017b). Dashed line shows the profile of the cross-section in Fig. 2. Study areas for this paper are indicated by orange shading: the Terek-Caspian fold-and-thrust belt (see Fig. 4) and the Prikumsk Swell (see Fig. 16). The inset map at bottom left shows the regional location.
Although the NE Caucasus is one of the oldest oil and gas producing regions in the world, geochemical information is limited and the presence of different oil families is still unclear as is the source of the oils (e.g. Yandarbiev et al., 2017a). Potential source rocks include argillaceous limestones and shales in the Triassic succession; thick marine shales of Middle Jurassic (Bajocian) age; and anoxic marine mudstones in the Kuma Formation and the lower (Oligocene) part of the Maikop Group (Ulmishek, 2001; Sachsenhofer et al., 2017; 2018b).

In the present paper, we present geochemical data from oils from the Terek-Sunzha Fold Zone, the Dagestan Promontory and the Maritime Zone (Fig. 1), as well as from the Prikumsk Swell (Figs 1, 2). The investigated oil samples were recovered from carbonate and sandstone reservoirs ranging in age from Jurassic to Neogene (Terek-Caspian fold-and-thrust belt) and from Triassic to Cretaceous (Prikumsk Swell). The depth of the reservoirs varies from 130 m to 5684 m. In addition, source rock data from the Khadum Formation (the Lower Oligocene part of the Maikop Group) in Dagestan are reported. The aims of the paper are therefore to define oil families in the Terek-Caspian fold-and-thrust belt and Prikumsk Swell, to investigate possible stratigraphic and depth trends, and to contribute to oil-to-source correlations.

Geological setting
The Terek-Caspian foredeep, located to the north of the eastern Greater Caucasus, overlies basement rocks of the Scythian Plate. According to the conventional view, the Scythian Plate accreted to the East European Craton in the Late Palaeozoic (e.g. Khain, 1994; Nikishin et al., 1998; 2001) although Saintot et al. (2006) showed that the available data are also consistent with a Neoproterozoic to earliest Palaeozoic accretion. Sobornov (2021 this issue) distinguished four megasequences in the basin succession which reflect the Mesozoic and Cenozoic evolution of the plate (Nikishin et al., 2001; Saintot et al., 2006). The main stratigraphic units in the succession are shown in Fig. 3 together with the distribution of source and reservoir rocks.

Early and Middle Triassic rifting near the southern margin of Eurasia resulted in the formation of a series of graben structures (e.g. the East Manych Trough) in which deep-marine sediments were deposited (Nikishin et al., 2001). Thin-bedded, dark-coloured, clayey limestones and shales may represent a potential source rock in the East Manych Trough and in the Prikumsk Swell (Ulmishek, 2001). Contemporaneously, reef-fringed carbonate platforms developed along graben margins; thus the Lower Triassic Neftekum and Kultay Formations occur along the margin of the Manych Trough and form important reservoirs in the Prikumsk Swell (Ulmishek, 2001). Minor oil is also present in carbonate rocks within the Middle Triassic Kizlyar Formation. Upper Triassic non-marine to shallow marine sediments with a high percentage of volcanic rocks (Nogay Formation) follow unconformably above these sediments, indicating that the rift basins were inverted before the Late Triassic (Nikishin et al., 2001). During the Late Triassic – Early Jurassic Early Cimmerian phase, the Triassic cover of the Scythian Plate was folded and large parts were eroded (Ershov et al., 2003).

Early and Middle Jurassic back-arc extension resulted in the development of a deep-water rift (“Great Caucasus Basin”) at the southern margin of
the Scythian Plate (e.g. Blackbourn et al., 2021 this issue). A braided fluvial-alluvial system supplied clastic material from the East European Platform to large-scale deltas in the northern basin margin, along the eastern part of the present-day Terek-Caspian fold-and-thrust belt. Coal-bearing sediments accumulated during the Aalenian (Blackbourn et al., 2021 this issue and references therein). The Scythian Plate was overstepped by shallow-marine sediments in late Aalenian and Bajocian times (Nikishin et al., 2001).

In the Prikumsk Swell, the Lower Jurassic succession contains a few small hydrocarbon accumulations, but 20 separate sandstone reservoir horizons have been recorded within the Middle Jurassic (Bajocian) section (Ulmishek, 2001). Lower Bajocian dark coloured marine shales, up to 200 m thick, containing ammonites and foraminifera, may represent a source rock horizon in the Prikumsk area (Ulmishek, 2001).

Following the mid-Cimmerian compressional event, Upper Jurassic to Eocene siliciclastics and carbonates accumulated in a south-facing passive margin setting. Upper Jurassic (Tithonian) evaporitic rocks are present in the western part of the Terek-Caspian fold-and-thrust belt (Sobornov, 2021 this issue). An angular unconformity between Jurassic and Cretaceous rocks was caused by Late Cimmerian compression (Nikishin et al., 2001).

The southern part of the Scythian Plate subsided rapidly during the Early Cretaceous, especially during the Aptian and Albian. During Late Cretaceous to Eocene time, the plate was covered by a carbonate platform with southward-increasing water depths. Middle Eocene limestones of the Kuma Formation provide a prolific hydrocarbon source rock (Beniamovski et al., 2003; Sachsenhofer et al., 2018b). It is questionable whether Upper Jurassic rocks beneath the Tithonian...
evaporites, and Aptian-Albian rocks with TOC contents up to 2% in thin layers, may be considered as additional source rocks (Ulmishek, 2001).

Lower Cretaceous siliciclastics contain the most important hydrocarbon reservoirs in the Priukumsk Swell, e.g. layers XIII (Valanginian-Hauterivian), IX (Hauterivian) and VIII (Aptian); a few small oil pools have also been found in Upper Cretaceous carbonates (Ulmishek, 2001). In the Terek-Caspian fold-and-thrust belt by contrast, fractured Upper Cretaceous (and Paleogene) carbonates are the main reservoir units although Aptian and Albian siliciclastics also contain significant reserves.

The overlying Oligocene to Quaternary foredeep succession reflects the orogenic history of the Greater Caucasus as well as a series of sea level falls which resulted in major unconformities. The succession includes the generally fine-grained rocks of the Oligocene to Lower Miocene Maikop Group; the Lower Oligocene part of this Group (Khadum Formation) is generally considered to be the main source rock in the area (Ulmishek, 2001; Sachsenhofer et al., 2107; 2018a,b). Rare overpressured oil pools are also located in fractured reservoirs in the lower part of the Maikop Group, and dry gas has been detected in sandstones in the middle part of the Group in the Prikumsk area (Ulmishek, 2001). The overlying Middle Miocene to Quaternary continental molasse reaches a maximum thickness of 4000-7000 m. Middle Miocene (Sarmatian) and Late Pliocene (Sarmatian) and Late Pliocene (Plioglochenian) compression caused uplift of the Greater Caucasus and shortening with the Terek-Caspian fold-and-thrust belt.

The Terek-Caspian fold-and-thrust belt experienced three main episodes of compression (Sobornov, 2021 this issue). The first episode in the Early Oligocene resulted in the inversion of pre-existing normal faults. Major Late Miocene (Sarmatian) and Late Pliocene (Akchagylian) compressional phases caused uplift of the Greater Caucasus and shortening with the Terek-Caspian fold-and-thrust belt accomodated by wedge-shaped thrusting.

Based on lateral changes in structural style, the Terek-Caspian fold-and-thrust belt can be subdivided from west to east into the Terek-Sunzha Fold Zone,
the Dagestan Promontory and the Maritime Zone (Fig. 4). In the Terek-Sunzha Fold Zone, the Terek and Sunzha anticlines are relatively symmetric, high-amplitude anticlinal structures formed above Tithonian salt which provides a regional detachment. Structural disharmony between the Miocene and Cretaceous intervals complicates exploration of deep Cretaceous hydrocarbon plays.

The frontal part of the Dagestan Promontory is a triangle zone cut by back-thrusts. The lateral extension of the Dagestan Promontory is interpreted to have been controlled by the extent of Early to Middle Jurassic deltaic deposits (Sobornov, 2021 *this issue*), and shale-dominated intervals provide detachment horizons.

The Maritime Zone in Southern Dagestan (Fig. 4) forms the southeastern segment of the Terek-Caspian fold-and-thrust belt, and consists of two sub-parallel, high relief anticlinal zones. Cenozoic deformation here was related to the inversion of pre-existing normal faults and to dextral transpression.

The location of oil and gas fields in the Terek-Caspian fold-and-thrust belt is shown in Fig. 4.

---

**Fig. 5. Stratigraphic distribution of hydrocarbon accumulations in the Terek-Caspian fold-and-thrust belt (after Yandarbiev et al., 2017a).**

| Era          | Period   | Epoch | Age       | Lithology       | Oil & gas fields |
|--------------|----------|-------|-----------|-----------------|-----------------|
| Mesozoic     | Jurassic | Lower | Lower T  | Clay, Argillite | Oil, Gas        |
|              |          |       |           | Argillite       |                 |
|              |          |       |           | Siltstone       |                 |
|              |          |       |           | Sandstone       |                 |
|              |          |       |           | Evaporite       |                 |
|              |          |       |           | Dolostone       |                 |
|              |          |       |           | Limestone       |                 |
|              |          | Upper | Upper T  | Gas             |                 |
|              |          |       |           | Condensate      |                 |
|              |          |       |           | Oil             |                 |
| Cenozoic     | Neogene  | Miocene| Middle T | Clay, Argillite | Oil, Gas        |
|              |          |       |           | Argillite       |                 |
|              |          |       |           | Siltstone       |                 |
|              |          |       |           | Sandstone       |                 |
|              |          |       |           | Evaporite       |                 |
|              |          |       |           | Dolostone       |                 |
|              |          |       |           | Limestone       |                 |
| Paleogene    | Pg       | Cretaceous | Coniacian | Clay, Argillite | Oil, Gas        |
|              |          |       |           | Argillite       |                 |
|              |          |       |           | Siltstone       |                 |
|              |          |       |           | Sandstone       |                 |
|              |          |       |           | Evaporite       |                 |
|              |          |       |           | Dolostone       |                 |
|              |          |       |           | Limestone       |                 |
| Paleogene    | Pg       | Cretaceous | Albian  | Clay, Argillite | Oil, Gas        |
|              |          |       |           | Argillite       |                 |
|              |          |       |           | Siltstone       |                 |
|              |          |       |           | Sandstone       |                 |
|              |          |       |           | Evaporite       |                 |
|              |          |       |           | Dolostone       |                 |
|              |          |       |           | Limestone       |                 |

---

---

Yandarbiev.indd 322
Yandarbiev.indd 322
19/06/2021 12:36:05
while the stratigraphic distribution of hydrocarbon accumulations is presented in Fig. 5. The cross-section in Fig. 6 (Yandarbiev et al., 2014) is a profile through the giant Starogroznenskoe field in the Terek-Sunzha Fold Zone (27, Fig. 4) showing the occurrence of reservoirs at Lower Cretaceous, Upper Cretaceous and Miocene levels. The section illustrates the structural offset of the Miocene anticline from the Upper Cretaceous culmination due to decoupling in the Maikop Group shales.

MATERIALS AND METHODS

Samples
The study is based on the analysis of 52 oil samples. In the Terek-Caspian fold-and-thrust belt (Fig. 4), 19 samples came from the Terek-Sunzha Fold Zone (Kabardino-Balkaria, North Ossetia, Ingushetia, Chechnya), and nine samples from the Dagestan Promontory and Maritime Zone (Dagestan). In addition, 24 oil samples came from the Prikumsk Swell (Fig. 1; see field locations in Fig. 16 below). All samples were taken at the wellhead and were provided by RosNeft. Samples from the Terek-Sunzha Fold Zone were collected about 20 years ago, and the remaining samples were collected in 2012. Since then, the samples have been stored in the archive of Moscow State University in glass bottles under surface conditions.

Rock samples from the Lower Oligocene (Rupelian) part of the Maikop Group (Khadum Formation) were analyzed to provide comparison data for oil-to-source correlation. All rock samples came from the Chirkey outcrop section in Dagestan (blue star in Fig. 4), which has been described in detail by Gavrilov et al. (2017; 2021 this issue) and whose lithostratigraphy is shown in Fig. 7. These authors also provided profiles of bulk geochemical parameters including carbonate and total organic carbon contents (Fig. 7) and reported Rock-Eval parameters for 31 samples. Based on this information, organic matter-rich samples were selected for biomarker and isotope analysis: one sample from the Belaya Glina Formation (Upper Eocene), two samples from the lower marly part of the Pshekh (Pshekha) Member, and three samples from the Solenov (Solenovian) Member. The stratigraphic positions of the samples are shown in Fig. 7.

Methods

Oil samples
Oil samples were analyzed in two separate projects at Moscow State University and at Montanuniversitaet Leoben. At Moscow State University, asphaltenes were precipitated with hexane and the maltanes were separated on a silica gel column (Merck) impregnated with AgNO₃. Gas chromatographic (GC) investigation of n-alkanes and acyclic isoprenoids were performed using a Clarus Perkin Elmer gas chromatograph equipped with silica capillary column (60 m x 0.25 mm). The oven temperature was programmed from 60° to 320°C at 4°C min⁻¹. Helium with a flow rate of 30 cm/sec at 100°C was used as the carrier gas. GC-mass spectrometric studies of the saturated and aromatic fractions were carried out on a Shimazu
GCMS-QP2010NC Ultra instrument with a 30 m ZB-5 MS capillary column (inner diameter 0.25 mm; film thickness 0.25 µm). The oven temperature was programmed from 60° to 180°C at 27°C min⁻¹, and in the temperature range from 180° to 300°C at 6°C min⁻¹, followed by an isothermal period of 50 min. Helium was used as the carrier gas with a flow rate through the column of 0.8 mm³/min. The sample was injected split or splitless depending on the quantity. The injector temperature was set at 275°C.

At Montanuniversitaet Leoben, oil samples were dissolved in dichloromethane. After evaporation of the solvent in a Zymark TurboVap 500 closed cell concentrator, asphaltenes were precipitated from a hexane-dichloromethane solution (80:1) and separated using centrifugation. The hexane-soluble fractions were separated into NSO compounds, saturated hydrocarbons and aromatic hydrocarbons using medium-pressure liquid chromatography (MPLC) with a Köhnen-Willisch instrument (Radke et al., 1980). The saturated and aromatic hydrocarbon fractions were analysed with a gas chromatograph equipped with a 60 m DB-5MS fused silica capillary column (i.e. 0.25 mm; 0.25 µm film thickness) and coupled to a ThermoFisher ISQ quadrupole mass spectrometer. The oven temperature was programmed from 40° to 310°C at 4°C min⁻¹, followed by an isothermal period of 30 min. Helium was used as the carrier gas. The sample was injected splitless, with the injector temperature set at 275°C. The mass spectrometer was operated in the EI (electron ionisation) mode over a scan range from m/z 50 to m/z 650 (0.5 s total scan time). Data were processed with an Xcalibur or Chromeleon data system. Individual compounds were identified on the basis of retention time in the total ion current (TIC) chromatogram and by comparison of the mass spectra with published data. Relative percentages and absolute concentrations of different compound
groups in the saturated and aromatic hydrocarbon fractions were calculated using peak areas in the TIC chromatograms in relation to those of internal standards (deuterated n-tetracosane or squalane and 1,1′-binaphthyl, respectively), or by integration of peak areas in appropriate mass chromatograms using response factors to correct for the intensities of the fragment ion used for quantification of the total ion abundance.

The n-alkanes were separated from branched/cyclic hydrocarbons by an improved 5 Å molecular sieve method (Grice et al., 2008) for the analysis of stable carbon isotope ratios on individual n-alkanes and isoprenoids. Stable C isotope measurements were performed using a Trace GC-ultra gas chromatograph attached to the ThermoFisher Delta-V isotope ratio mass spectrometer (IRMS) via a combustion and high temperature reduction interface, respectively (GC Isolink, ThermoFisher). The GC coupled to the IRMS was equipped with a 30 m DB-5MS fused silica capillary column (i.d. 0.25 mm; 0.25 μm film thickness). The oven temperature was programmed from 70 to 300°C at a rate of 4°C/min followed by an isothermal period of 15 min. Helium was used as the carrier gas. The sample was injected splitless at 275°C. For calibration, a CO standard gas was injected at the beginning and end of each analysis. Isotopic compositions are reported in the δ notation relative to the V-PDB standard. Analytical reproducibility (0.2‰ for δ13C) was controlled by repeated measurements of n-alkane standard mixtures.

Rock samples
Total carbon (TC), total sulphur (S) and total organic carbon (TOC) contents were analysed using an ELTRA Elemental Analyser. Samples for TOC measurements were decarboxylated with concentrated phosphoric acid. TC and TOC were used to calculate calcite equivalent percentages ([TC-TOC]×8.333). Pyrolysis measurements were performed using a Rock-Eval 6 instrument. The S1 and S2 peaks (mg HC/g rock) were used to calculate the petroleum potential (S1+S2), the production index, PI = S1/(S1+S2), and the hydrogen index (HI = S2/ TOC×100 mg HC/g TOC). The temperature of maximum hydrocarbon generation during pyrolysis (Tmax) was used as a maturity indicator. For biomarker and isotope analysis, rock samples were extracted for ca. 1 hour using dichloromethane in a Dionex ASE 200 accelerated solvent extractor at 75 °C and 50 bars. The rock extracts were treated in the same way as the oil samples.

Hierarchical cluster analysis
Hierarchical cluster analysis was performed in order to group the oil samples. The analysis was completed using autoscale preprocessing and Euclidean metric distance following the method of Ward (1963). The analysis included different selected biomarker and isotope parameters.

RESULTS

1. THE TEREK-CASPIAN FOLD-AND-THRUST BELT

(i) Terek-Sunzha Fold Zone
Nineteen samples from eleven oil fields in the Terek-Sunzha Fold Zone in the west of the Terek-Caspian fold-and-thrust belt were investigated (red and orange stars in Fig. 4). Results are presented in Table 1 (page 343). Yandarbiev et al. (2017a) reported data from 21 oil samples (Table 2: page 344) derived both from fields investigated in this study and from six additional fields (white stars in Fig. 4). Hence, analytical data for oil samples from a total of 17 fields was available.

Molecular Data
Gas chromatograms of the saturated hydrocarbon fraction of selected oil samples are shown in Fig. 8 together with sterane and hopane patterns. Most samples are characterized by high amounts of n-alkanes and low Pr/n-C17 and Ph/n-C18 ratios (Tables 1, 2). The position of these oils on a plot of Pr/n-C17 versus Ph/n-C18 ratios (Fig. 9) is mainly controlled by present-day depth. The plot shows that the Lower Cretaceous Eldarovo oil (Eldarovo-99) is characterized by exceptionally low Pr/n-C17 and Ph/n-C18 ratios, and very low ratios are also observed in all the Zamankul oils (Yandarbiev et al., 2017a; Table 2).

By contrast, oils from shallow depths (<1500 m) in the Starogroznenskoe oil field are depleted in n-alkanes (Fig. 8a) resulting in high Pr/n-C17 and Ph/n-C18 ratios (Tables 1, 2, Fig. 9). This indicates light to moderate biodegradation (level 2 on the biodegradation scale of Peters and Moldovan, 1993). Biodegradation affects oil in Neogene (Chokrakian and Karaganian) reservoirs in both supra-thrust (Starogroznenskoe-5-48, 395) and sub-thrust positions (Starogroznenskoe-662).

Although the amount of mid- and long-chain n-alkanes is significantly reduced, short-chain n-alkanes (n-C8 to n-C12) are present in significant amounts in all biodegraded oils (see Yandarbiev et al., 2017a). This may indicate the presence of a non-biodegraded gas cap and/or ongoing migration of a light oil phase from deeper units into the shallow reservoirs.

The carbon preference index (CPI) ranges from 1.0 to 1.2 (Table 1). Pristane/phytane (Pr/Ph) ratios typically range from 1.4 to 2.1, but the Eldarovo-99 oil in Lower Cretaceous reservoir rocks is characterized by a higher value (2.66; Table 1). Relatively low ratios are observed in the Zamankul samples, irrespective of the reservoir age (1.4-1.6; Table 2).
Fig. 8. Variation of the organic geochemical composition of oils from the Terek-Caspian fold-and-thrust belt. Displayed are FID traces of the saturated fraction, the sterane pattern and the hopane pattern of oils from the Terek-Sunzha Fold Zone (a-d), the Dagestan Promontory and the Maritime Zone (e-f). Field locations in Fig. 4.
Highly branched isoprenoids (HBIs) were detected in quantifiable amounts only in biodegraded samples Starogroznenskoe-5-48 and Starogroznenskoe-662. However, they probably also occur in other samples.

The concentration of steranes ranges from 38 to 420 mg/g oil. Relative sterane percentages of “biological” ααα-steranes and “diagenetic” βββ-steranes are similar (Table 1). However because C$_{27}$ ααα-steranes in other samples sets may be biased (see below), only the relative proportions of βββ-steranes are plotted in Fig. 10. This plot shows that relative percentages of C$_{27}$, C$_{28}$ and C$_{29}$ βββ-steranes are similar in all oils. The C$_{28}$/C$_{29}$ sterane ratio varies between 1.01 and 1.39.

Neither a clear depth trend nor a stratigraphic trend can be observed (Fig. 11).

The ratios of C$_{27}$ diasteranes to the corresponding regular steranes vary between 0.56 and 1.47. There is a clear downward increase in this ratio, and oils from Middle Miocene reservoirs have lower ratios than oils from deeper-lying Paleogene and Cretaceous reservoirs (Table 1; Fig. 11).

Isomerisation ratios of C$_{25}$ steranes are at equilibrium (average: 0.53) and the C$_{28}$/C$_{29}$ sterane ratio varies between 0.55 to 0.65 (Fig. 12).

The concentration of hopanes decreases with depth from 280 to 0.5 µg/g oil (Fig. 11). Hence, the steranes/hopanes ratio increases in the same direction. Hopane isomerisation values are close to 0.60, but could not be determined reliably for samples with very low hopane concentrations (e.g. Figs 8c,d).

Oleanane, an angiosperm-derived triterpane (Riva et al., 1988; Nytoft et al., 2002), was found in all the shallow samples from Neogene reservoirs, but is also present in some oils from Paleogene and Cretaceous reservoirs (e.g. Khayan-Kort-54; Fig. 8b). However, it could not be determined with certainty in some samples from greater depths which were characterized by very small peaks in the m/z = 191 fragmentogram and by very low hopane concentrations (Table 1).

The oleanane index (oleanane/[oleanane+hopane]) varies between 0.19 and 0.64 and increases with depth. This suggests that the apparent absence of oleanane in deep samples may be caused by difficulties with peak identification.

The dibenzothiophene (DBT) / phenanthrenes (Phen) ratio is low for all oils (0.06-0.13) showing that the amount of free H$_2$S in the water column was limited (Hughes et al., 1995). Gammacerane could not be detected.

The Ts/(Ts+Tm) ratio (0.58–0.98) increases downwards (Fig. 11). The methylphenanthrene index (Radke and Welte, 1983) was calculated from m/z...
178 and 192 mass chromatograms using the equation of Cassani et al. (1988). Similar to the Ts/(Ts+Tm) ratio, the calculated MPI-1 values (0.62-1.19) increase downwards (Table 1; Fig. 11).

**Carbon Isotope Data**

Isotope ratios of \( n \)-alkanes and isoprenoids are listed in Table 3 (page 344). Isotope ratios of pristane and phytane show a slight increase in \( \delta^{13}C \) values with depth (Fig. 11). In Fig. 13, isotope ratios of \( n \)-alkanes are plotted versus chain length. All samples are characterized by isotope patterns with decreasing \( \delta^{13}C \) values with increasing chain length, but the amount of decrease is different, even in neighbouring fields (e.g. Andreevo and Oktyabrskoe). Oils from Eldarovo (Lower Cretaceous), Khayan Kort (Paleogene) and Mineralnoe (Upper Cretaceous) contain long-chain \( n \)-alkanes (\( n-C_{23-27} \)) with similar isotope ratios. In the Starogroznskoe and Oktyabrskoe fields, Neogene and Cretaceous reservoirs contain oils with similar isotope patterns, but oil in deeper reservoirs is isotopically heavier i.e. with less negative \( \delta^{13}C \) values. At Eldarovo field, isotope patterns in oils from different reservoirs differ significantly.

**Molecular Data**

All the samples contain high amounts of \( n \)-alkanes, and concentrations of \( n \)-alkanes are 4 to 5 times higher than those of isoprenoids (Table 4). The carbon preference index (CPI) is close to unity in all the samples. The Pr/Ph ratio is about 1.7 in Iberbash oils from Chokrakan reservoirs, but higher in oils from Cretaceous reservoirs (2.04–2.23). The Pr/\( n-C_{17} \) ratio (0.40-0.74) and the Ph/\( n-C_{18} \) ratio (0.23-0.40) are typically low and decrease with depth and age of the reservoir rock (Figs 14, 15).

The relative amount of \( C_{20} – C_{29} \) steranes varies from 31.6 to 56.2 %, while \( C_{19} – C_{25} \) pentacyclic triterpanes and tricyclic terpanes range from 20.4 to 52.6 % and from 9.8 to 29.3 %, respectively. The lowest amount of tricyclic terpanes (9.8 %) and the highest amount of pentacyclic triterpanes (56.2 %) were found in the Izberbash-270 oil. The steranes/hopanes ratio is between 0.70 and 2.64 (Table 5). The \( C_{25} \)-diasteranes / steranes ratios vary between 0.59 and 4.37 and are especially high in deep samples from the Izberbash and Dimitrovskoe fields (Table 5; Fig. 15).

A major difference exists between the relative percentages of \( \alpha\alpha\alpha \) and \( \alpha\beta\beta \) steranes (Table 3). Amongst \( \alpha\alpha\alpha \) steranes, \( C_{27} \) steranes prevail in most...
samples (0.37-0.60), probably due to coelution with diasteranes. Steranes show less variability and plot in Fig. 10 close to the samples from the Terek-Sunzha Fold Zone. The C\textsubscript{28}/C\textsubscript{29} steranes ratios are high (0.94-1.07; Fig. 15). Isomerisation ratios of C\textsubscript{29}-steranes range from 0.49 (Izberbash-270) to 0.56 (Dimitrovskoe-42). The C\textsubscript{29}\textsubscript{ββ}/(C\textsubscript{29}\textsubscript{ββ} + C\textsubscript{29}\textsubscript{αα}) steranes ratio varies between 0.56 and 0.70 (Fig. 12). The steranes/hopanes ratio ranges from 0.70 to 2.64 and reaches a maximum in the shallow Izberbash sample which is derived from a Neogene reservoir. Hopane isomerisation values are at equilibrium.

Fig. 11. Depth plot of facies and maturity-related biomarker ratios and concentrations in crude oil samples from the Terek-Sunzha Fold Zone. Symbols with red outer margin are data from Yandarbiev et al. (2017a).

Fig. 12. Cross plot of 20S/(20S+20R) isomer ratios of C\textsubscript{29}-steranes versus C\textsubscript{28}/C\textsubscript{29} steranes for oil samples from the Terek-Sunzha Fold Zone plot in a narrow field (grey shading); by contrast, the data points for oils from the Dagestan Promontory and Maritime Zone are more widely spread. Boundaries between maturity fields are after Peters et al. (2005).
Oleanane was detected in all samples (see Fig. 8e,f). Low DBT/Phen ratios were determined for the Izberbash-270 (0.08) and Dimitrovskoe-22 oils (0.18; Table 5). Gammacerane could not be quantified.

The Ts/(Ts+Tm) ratio varies between 0.51 and 0.74. The MPI-1 index is lower for oil derived from the relatively shallow Neogene reservoir (0.64) than for oil from deeper-lying Cretaceous reservoirs (0.84-1.12).

Carbon Isotope Data
Isotope ratios of n-alkanes and isoprenoids from the Dimitrovskoe-22 (Cretaceous reservoir) and Izberbash-270 (Neogene reservoir) oils are listed in Table 3. Fig. 13b shows that $\delta^{13}$C values of n-alkanes from both oils are similar despite differences in reservoir age and depth.

2. THE PRIKUMSK SWELL

The Prikumsk Swell is represented by 24 oil samples from eight different fields (locations in Fig. 16) with Upper Cretaceous to Triassic reservoirs (Table 6). GC traces of selected samples are displayed in Fig. 17.

Molecular Data
Results of gas chromatography (GC) and GC-MS analyses are listed in Tables 6 and 7 (pages 346 and 347). Some parameters are plotted versus depth in the Prikumsk Swell (letters in circles refer to oil groups defined in the text).
Fig. 18. Pr/n-C_{17} and Ph/n-C_{18} ratios of oils from the Prikumsk Swell are typically very low, but three samples from Triassic (Velichayev-43), Lower Cretaceous (Bezvodnen-84) and Upper Cretaceous (Urozhaynoe-52) reservoirs show significantly higher ratios (Table 6, Fig. 19).

Pr/Ph ratios range from 1.23 to 2.42. Relatively low Pr/Ph ratios (1.23-1.34) are found in two oils from Triassic reservoirs (Sredinnoe-1, Baydzhanov-101) and two oils from Lower Jurassic reservoirs in the Zimnaya Stavka field (Fig. 18). Ratios above 2.0 are observed in oils from Upper Jurassic reservoirs in the

Fig. 14. Position of oil samples from the Dagestan Promontory and Maritime Zone and of rock extracts from the Khadum Formation in the Chirkey section in a correlation diagram of pristane/n-C_{17} ratio versus phytane/n-C_{18} ratio (after Connan and Cassou, 1980).

Fig. 15. Depth plot of facies- and maturity-related biomarker parameters for crude oil samples from fields in the Dagestan Promontory and Maritime Zone (central and SE parts of the Terek-Caspian fold-and-thrust belt; see location map in Fig. 4).
Ozek-Suat field and in an oil from a Lower Jurassic reservoir (Urozhaynoe-92; Fig. 18).

C_{27} diasteranes/steranes ratios are generally low to very low (<0.85), but reach values of 1.44 in the Urozhaynoe-92 oil. As with oils from the Dagestan Promontory and the Maritime Zone, major differences between the relative percentages of ααα and αββ steranes (Table 7) are attributed to co-elution of C_{27} ααα steranes with diasteranes. Hence, relative percentages of αββ steranes are described below and are plotted in Fig. 20. In most samples C_{28} steranes occur in low amounts (Fig. 20). Hence, C_{28}/C_{29} steranes ratio are typically low (<0.7; Fig. 18). Only the Velichayev-43, Bezvodnen-84 and Urozhaynoe-52 oils contain significantly higher amounts of C_{28} steranes (33-36 %) and high C_{28}/C_{29} steranes ratios around 1 (Fig. 20; Table 7). Relatively high amounts of C_{29} steranes were detected in oils from Lower Jurassic
Fig. 18. Depth plot of facies- and maturity-related biomarker ratios in crude oil samples from the Prikumsk Swell area. Group A oils include those from wells Urozhaynoe-52, Baydzhanov-108 and Velichayev-43. Group B oils are characterized by low C_{28}/C_{29} steranes ratios and high Ts/(Ts+Tm) ratios. B1 and B4 are sub-groups within Group B oils characterized by high and low Pr/Ph ratios, respectively.

Fig. 19. Position of Prikumsk Swell samples in a correlation diagram of pristane/n-C_{17} ratio versus phytane/n-C_{18} ratio (after Connan and Cassou, 1980). The plot shows higher pristane/n-C_{17} and phytane/n-C_{18} ratios in Group A oils than in Group B oils. B1 and B4 are sub-groups within Group B.
Geochemistry of oils in the Terek-Caspian foredeep and Prikumsk Swell, NE Greater Caucasus

and Triassic reservoirs in the Zimnyaya Stavka and Baydzhanov fields.

Sterane isomerisation ratios range from 0.38 to 0.53, showing that only some oils are close to equilibrium values. The highest ratios are observed in the Velichayev-43, Bezvodnen-84 and Urozhaynoe-52 oils. The $\alpha\beta\beta/(\alpha\beta\beta + \alpha\alpha\alpha)$ $C_{27}$-steranes ratio varies between 0.58 and 0.75, generally suggesting a higher maturity than the isomerisation values (Fig. 21). Hopane isomerisation ratios range from 0.48 to 0.66. Oleane is typically absent, but occurs in very low amounts in the Urozhaynoe-52 oil. Gammacerane was detected in all the oils analysed, but often in very low amounts. The $T_s/(T_s+T_m)$ ratio varies between 0.48 and 0.86 and does not show a clear depth trend (Fig. 18). The lowest $T_s/(T_s+T_m)$ ratios are determined for the Velichayev-43, Bezvodnen-84 and Urozhaynoe-52 oils. DBT/Phen (0.06-0.40) and MPI-1 ratios (0.39-0.73) were only determined for a subset of the samples (Table 7).

**Carbon Isotope Data**

Isotope ratios of $n$-alkanes and isoprenoids have been determined for seven samples (Table 3). $n$-Alkanes from all samples in the range of $n$-$C_{11}$ to $n$-$C_{22}$ are characterized by decreasing $\delta^{13}C$ values with increasing chain length, whereas $\delta^{13}C$ values for longer chain $n$-alkanes ($n$-$C_{23-29}$) are relatively constant (Fig. 13c). Oils from Lower Cretaceous reservoirs (Russkiy Khutor-77, -98; Zimnyaya Stavka-124) show similar $\delta^{13}C$ values. In comparison, oils from Jurassic reservoirs have either more negative (Ozek-Suat-260; Urozhaynoe-92) or less negative $\delta^{13}C$ values (Bezvodnen-124; Fig. 13c). The Urozhaynoe-52 oil shows a more prominent decrease of $\delta^{13}C$ values in the range $n$-$C_{15}$ to $n$-$C_{22}$ than any other oil from the Prikumsk Swell.

**SOURCE ROCKS FROM THE KHADUM FORMATION (LOWER PART OF THE MAIKOP GROUP)**

Source rock data for samples from the Chirkey section in Dagestan (Gavrilov et al., 2017; see blue star in Fig. 4 for location) are reported in the following section. Six samples came from the Khadum Formation in the Lower Oligocene (Pshekhian and Solenovian) part of the Maikop Group, and a single sample from the underlying Upper Eocene Belaya Glina Formation (Fig. 7).

The Belaya Glina Formation sample is a marl with a very low TOC content (0.14 wt.%; Table 8: page 348). The carbonate content of the overlying Pshekh Member of the the Khadum Formation decreases upwards, and samples from the top of the member are carbonate-free (Fig. 7) (see Gavrilov et al., 2017). The Pshekh Member deposits pass up into the Solenovian part of the Maikop Group, and a single sample from the underneath Upper Eocene Belaya Glina Formation (Fig. 7).

The Belaya Glina Formation sample is a marl with a very low TOC content (0.14 wt.%; Table 8: page 348). The carbonate content of the overlying Pshekh Member of the the Khadum Formation decreases upwards, and samples from the top of the member are carbonate-free (Fig. 7) (see Gavrilov et al., 2017). The Pshekh Member deposits pass up into the Solenovian part of the Maikop Group, and a single sample from the underneath Upper Eocene Belaya Glina Formation (Fig. 7).

The Belaya Glina Formation sample is a marl with a very low TOC content (0.14 wt.%; Table 8: page 348). The carbonate content of the overlying Pshekh Member of the the Khadum Formation decreases upwards, and samples from the top of the member are carbonate-free (Fig. 7) (see Gavrilov et al., 2017). The Pshekh Member deposits pass up into the Solenovian part of the Maikop Group, and a single sample from the underneath Upper Eocene Belaya Glina Formation (Fig. 7).

The Belaya Glina Formation sample is a marl with a very low TOC content (0.14 wt.%; Table 8: page 348). The carbonate content of the overlying Pshekh Member of the the Khadum Formation decreases upwards, and samples from the top of the member are carbonate-free (Fig. 7) (see Gavrilov et al., 2017). The Pshekh Member deposits pass up into the Solenovian part of the Maikop Group, and a single sample from the underneath Upper Eocene Belaya Glina Formation (Fig. 7).
TOC contents of the studied samples from the Pshekh Member are moderately high (1.1-2.5 wt.%, Table 8). Higher TOC contents (up to 4.6 wt.%) occur in samples from the succession overlying the interval representing the “Solenovian Event”. $T_{\text{max}}$ values (437-449°C) indicate oil window maturities, and the low hydrogen index (HI) values (68-182 mgHC/gTOC) are consequently interpreted to reflect the advanced maturity. However, the original HI probably did not significantly exceed 300 mgHC/gTOC (e.g. Sachsenhofer et al., 2018b).

Molecular parameters are summarized in Table 9 (page 348). Pr/n-C$_{17}$ and Ph/n-C$_{18}$ ratios of samples from the Khadum Formation vary significantly (Fig. 14). Pristane/phytane and diasterane/sterane ratios range from 1.2 to 1.7 and from 0.27 and 0.53, respectively. In all samples the relative percentage of C$_{27}$ steranes exceeds those of C$_{28}$ and C$_{29}$ steranes (Table 9; see also Figs 10 and 20). In accordance with the Oligocene age of the rocks, C$_{28}$/C$_{29}$ steranes ratios are high (about 1.0) and oleanane is present in all samples. Gammacerane is present in very low amounts in all samples. C$_{25}$HBI were detected in two Pshekhian samples (dag-517, dag-468) and one Solenovian sample (dag-574: sample positions in Fig. 7). Dibenzothiophene was only detected in the two youngest samples, but DBT/Phen ratios are very low. Sterane- and hopane-based maturity parameters are at equilibrium. The MPI-1 suggests a vitrinite reflectance between 0.6 and 0.8%$R_0$. All samples are characterized by a negative correlation between $\delta^{13}$C values and chain length (Table 10, page 348; Fig. 13d). Moreover, $\delta^{13}$C values decrease upwards.

DISCUSSION

THE TEREK-CASPIAN FOLD-AND-THRUST BELT

Oil maturity

The studied oils cover a wide depth range from 130 m to 5650 m. Therefore, maturity trends can be expected and have to be considered when interpreting facies-related biomarker proxies.

Sterane and hopane related maturity parameters (Tables 1 and 5; Fig. 12) are near to equilibrium in all samples suggesting at least oil window maturity. The $Ts/(Ts+Tm)$ and the MPI-1 ratios show clear depth trends in the samples from the Terek-Sunzha Fold Zone (Fig. 11), the Dagestan Promontory and the Maritime Zone (Fig. 15). The MPI-1 suggests that the oil has been generated at a vitrinite reflectance between 0.75%$R_0$ (shallow oils) and 1.15%$R_0$ (deep oils). However, $R_0$ values calculated from MPI-1 values are often considered unreliable for marine source rocks (e.g. Goncharov et al., 2015). Nevertheless it is interesting to note that calculated $R_0$ values of deep oil samples (>5 km) are similar to measured vitrinite reflectance values from source rocks in the same depth interval (Yandarbiev, 1983). This suggests that oil from deep reservoirs was generated at depths similar to their reservoir depth.

Indications for different oil types

One of the main purposes of this study was to detect the presence of oil families and to decide if oil samples from Mesozoic and Cenozoic reservoirs have the same
Origin. For a first classification, hierarchical cluster analysis (HCA) was performed and considered all the oil samples from the Terek-Caspian fold-and-thrust belt and the Prikumsk Swell with a limited number of key parameters (Pr/Ph ratios, diasterane/sterane ratios, sterane distributions). The HCA dendrogram (Fig. 22a) identifies two main oil groups. All the samples from the Terek-Caspian fold-and-thrust belt belong to Group A.

Oil samples from the Terek-Sunzha Fold Zone are rather similar, despite the strong variation with depth, with moderately high Pr/Ph ratios typically in the range of 1.5 to 2.0, as well as similar sterane patterns (Fig. 10) and very low DBT/Phen ratios (Table 1). Hence, differences between the oils are subtle and sometimes it was difficult to distinguish between maturity and facies effects. For example, there is a clear trend towards higher diasterane/sterane ratios in oils from Paleogene and Mesozoic reservoirs, and this has also been observed by Yandarbiev et al. (2017a).

Oleanane is present in oil samples from Neogene, Paleogene and Upper Cretaceous reservoirs down to ~4200 m depth, both in the Terek-Sunzha Fold Zone (e.g. Fig. 8a,b), the Dagestan Promontory and the Maritime Zone (Fig. 8e,f). In contrast, oleanane could not be detected with any certainty in deeper samples from the Terek-Sunzha Fold Zone, with very small peaks in the m/z = 191 fragmentogram (e.g. Fig. 8c,d). Therefore, the absence of oleanane in deeper samples is probably an effect of increased maturity rather than an indication that different oil families are present.

Furthermore, the relative percentages of \( C_{27} \) and \( C_{29} \) regular steranes are remarkably similar in all samples (Fig. 10) and depth trends of the \( C_{27}/C_{29} \) steranes cannot be observed in samples either from the Terek-Sunzha Fold Zone (Fig. 11) or the Dagestan Promontory / Maritime Zone (Fig. 15).

Whereas Pr/Ph ratios are rather uniform, relatively high ratios (>2.5) are observed in oil from the Lower Cretaceous reservoir in the Eldarovo field, and relatively low ratios (1.4-1.6) are observed in the Zamankul oils (Fig. 11; Yandarbiev et al., 2017a).

Based on Fig. 13a,b, two different isotope patterns can be observed. Most oils are characterized by a constant decrease in \( ^{13} \)C values with increasing chain length. This decrease may be distinct (e.g. Bragunskoe field) or subtle (e.g. Andreevo oil), resulting in relatively high and low \( ^{13} \)C values of long-chain \( n \)-alkanes (e.g. \( n-C_{31} \)), respectively. The remaining oils are characterized by a decrease in \( ^{13} \)C values between \( n-C_{28} \) and \( n-C_{32} \), but relatively constant \( ^{13} \)C values in longer-chain \( n \)-alkanes. The average \( ^{13} \)C values of these longer-chain \( n \)-alkanes is very negative (~32.5 \%o; Eldarovo oil from a Lower Cretaceous reservoir; Mineralnoe; Khayan-Kort), moderately negative (~ -31.5 \%o; Praveoberezhnnoe), or relatively less negative (~ -30.5 \%o; Goryaicheistochenskoe, North Bragunskoe from Paleogene reservoirs).

HCA was repeated for Group A oils considering key molecular parameters (Pr/Ph ratios, diasterane/sterane ratios, sterane distributions) and isolate values of selected \( n \)-alkanes (\( n-C_{15}, n-C_{21}, n-C_{25} \)), pristane and phytane. The resulting dendrogram (Fig. 22b) suggests the presence of three Sub-Groups (A1 to A3). Shallow oil in Neogene reservoirs in the Terek-Sunzha Fold Zone, as well as oil from the deep Bragunskoe field (~4100 m; Paleogene reservoir) cluster in Sub-Group A1. However, most samples from the Terek-Sunzha Fold Zone cluster into Sub-Group A3. Considering the uncertainties caused by the varying oil maturity, it is questionable if the differences between Sub-Groups A1 to A3 are sufficient for the oils to be grouped into their own oil family.

Sub-Group A2 includes only a single sample from the Terek-Sunzha Fold Zone (Khayan-Kort-54), but deep (Dimitrovskoe-22) and shallow (Izberbash-270) oil samples from the Dagestan Promontory and the Maritime Zone, respectively, as well as a sample from the Prikumsk Swell (see below). Hence, Sub-Group A2 may reflect lateral variations of the source rock facies.

Oil-to-source considerations
The ratio of regular \( C_{27} \) steranes can be used to estimate the geological age of a source rock (Grantham and Wakefield, 1988). The increase in the proportion of \( C_{29} \) steranes over time is explained by an expansion of diversity in phytoplankton species. Observed values in this study range from 0.94 to 1.39 (Figs 11, 15). Overall, the ratios agree with a Cenozoic (or Late Cretaceous) age for the source rock, which is also suggested by the presence of oleanane. A possible contribution of oil from an older source rock characterized by low \( C_{28}/C_{29} \) sterane ratios could not be observed.

Within the Cenozoic section, the Lower Oligocene part of the Maikop Group and the Middle Eocene Kuma Formation are the most likely source rocks for the oils in the Terek-Caspian fold-and-thrust belt (e.g. Ulmishek, 2001; Sachsenhofer et al., 2018b).

Lower Oligocene part of the Maikop Group (Khadum Formation)
Pr/Ph ratios of samples from the Chirkey section range from 1.24 to 1.63, while diasterane/sterane ratios vary between 0.24 and 0.53 (Table 9). Oleanane is present in all samples, but highly branched isoprenoids were detected only in a few samples. Sterane percentages fit well with those of accumulated oils (see Fig. 10). Isotope patterns vary significantly for rocks with Pshchikhan and Solenovian ages (see also Bechtel et al. (2013) and Aghayeva et al. (2021 this issue) for

Yandarbiev.indd 336
19/06/2021 12:36:11
Hierarchical cluster analysis dendrograms showing genetic relationships among oil samples.

(a) Dendrogram for non-biodegraded crude oils from the Terek-Caspian fold-and-thrust belt and the Prikumsk Swell. The analysis included Pr/Ph and diasterane/sterane ratios as well as the distribution of ab steranes, and clearly differentiates oil Groups A and B. Group A includes all oils from the Terek-Caspian fold-and-thrust belt and three samples from the Prikumsk Swell. The remaining Prikumsk oils form Group B.

(b) Dendrogram for Group A oils. The analysis is based on biomarker parameters and selected isotope ratios (n-C17, n-C21, n-C27; Pr, Ph).

(c) Dendrogram for Group B oils (see Tables 6 and 7 for applied biomarker parameters). TS FB – Terek-Sunzha Fold Belt (Zone); DP – Dagestan Promontory; MZ – Maritime Zone.
Lower and Upper Oligocene rocks in Azerbaijan). Thus, apart from maturity effects (e.g. Pedentchouk and Turich, 2017) and lateral facies variations, the high variability of isotope patterns observed in oils from the Terek-Caspian fold-and-thrust belt may reflect varying oil contributions from different intervals within the Maikop Group. Clearly, the Khadum Formation in the Chirkey section has limited oil potential (Table 7; Gavrilov et al., 2017). By contrast however, data in Gavrilov et al. (2021 this issue) show that the Khadum Formation in the nearby Miatly section in the Sulak River valley includes layers with good to very good oil potential. Unfortunately biomarker and isotope data from these layers are not available.

Kuma Formation
Biomarker and isotope data are not available for the Kuma Formation in the northern Caucasus foredeep. Pupp et al. (2018) and Mayer et al. (2018) reported biomarker and isotope data for samples from the Martvili section, located in the southern margin of the western Greater Caucasus in the Rioni Basin, Georgia (see Sachsenhofer et al., 2021 this issue). Although this section is located 250 to 300 km away from the Terek-Caspian fold-and-thrust belt, it may serve as an analogue as both areas were located within a continuous basin during the Middle Eocene (Beniamovski et al., 2003; Sachsenhofer et al., 2018b). For samples from Martvili, the sterase percentages differ significantly from those in the Terek-Sunzha oils (Fig. 10). Moreover, compound-specific isotope patterns are characterized by an increase in δ13C values with increasing chain length. This suggests that the Kuma Formation, as present at the analysed location, did not contribute significantly to the Terek-Sunzha oils. However, additional investigations on samples from the Kuma Formation in the Terek-Caspian foredeep are necessary to assess the role of the Kuma Formation in greater detail. Within this context, it should be noted that Oblasov et al. (2020) assumed a predominant Kuma source for oil accumulated along the northern margin of the westernmost Greater Caucasus in the Kuban Basin.

While the Maikop Group is probably the main source rock for oils in the Terek-Caspian foredeep, it is likely that additional source rocks contributed to the accumulated oils. Amongst these are organic-rich rocks deposited during both Cretaceous (e.g. Gavrilov et al., 2013) and Paleogene anoxic events (e.g. the Paleocene – Eocene Thermal Maximum; Gavrilov et al., 2003). These horizons include abundant organic matter with very negative δ13C values and could be responsible for oils with very light n-alkanes such as Eldarovo (Lower Cretaceous) and Khayan-Kort, although additional biomarker studies are required.

THE PRIKUMSK SWELL
Oil maturity
Whereas the ββ/(ββ+ααa) C29-steranes ratios of the oils suggest peak to late oil window maturity, sterane isomerisation ratios and MPI-1 values (0.47-0.54; Table 7) indicate early to peak oil window maturity (0.60-0.85 %R). The Urozhaynoe-52 oil yields the lowermost MPI-1 value (0.47). The low maturity (early oil window) of this oil samples is also indicated by a low Ts/(Ts+Tm) ratio of 0.51 (Fig. 18) and high Pr/n-C17 and Ph/n-C18 ratios (Fig. 19). A similar low maturity is also suggested for the Bezvodnen-84 and Velichayev-43 oils based on low Ts/(Ts+Tm) ratios (Fig. 18) and the position of the samples in a Pr/n-C17 versus Ph/n-C18 plot (Fig. 19). The remaining oil samples were probably generated at peak oil window maturity (0.75-0.85 %R).

Indications for different oil types
The dendrogram in Fig. 22a shows that most oil samples from the Prikumsk Swell belong to Group B, but that samples Urozhaynoe-52, Bezvodnen-84 and Velichayev-43 correspond to Group A.

Group A oils are from Triassic to Upper Cretaceous reservoirs and from depths of 2423 m to 3520 m. Their close relationship is visible in percentages of regular αββ steranes (Figs 18, 20) and is also emphasized in a spider diagram (Fig. 23) which plots maturity parameters (sterane isomerisation, ββ/(ββ+ααa) C29-steranes, C29 18a-norhopane/C29 norhopane [Neo/Nor]) together with facies parameters indicative of carbonate environments (C29 norhopane/ C29 hopane [Nor/Hop]) and organic matter input (steranes/pentacyclic triterpanes [Ster/Pent]; tricyclic/ pentacyclic triterpanes [Tri/Pent]). Group A oils are characterized by very low Tri/Pent and Neo/Nor ratios and moderate Pr/Ph ratios (Fig. 23a). Oleanean is clearly observable, but because of the high amounts of hopanes it is difficult to detect oleanean in the m/z 191 trace (Fig. 17a). Urozhaynoe-52 is the only Group A oil from the Prikumsk Swell for which isotope data are available. Fig. 22b shows that the Urozhaynoe-52 oil forms Sub-Group A2 with oils from the eastern part of the Terek-Caspian fold-and-thrust belt (Dimitrovskoe-22, Izberebash-270) and one oil from the Terek-Sunzha Fold Zone.

Group B oils are characterized by low percentages of C29 steranes and low C29/C29 sterane ratios (Figs 18, 20). Furthermore, in contrast to Group A oils, oleanean is absent. HCA has been applied for Group B oils considering 15 different molecular parameters (see Table 7). The results suggest the presence of four Sub-Groups (B1 to B4).

Oils in Cretaceous reservoirs show similar patterns and cluster into a single Sub-Group (B3). The only...
exception is the Ozek-Suat-50 oil, which has higher Ster/Pent and lower Neo/Nor ratios (Fig. 23d). In contrast, oils in Triassic and Jurassic reservoirs are chemically more variable and cluster into all four sub-groups (including B3). Sub-Group B1 comprises oils in Jurassic reservoirs with high Pr/Ph (>2.0) and often high Neo/Nor ratios (~1.0; Fig. 23b). With the exception of Ozek-Suat-50, Sub-Group B2 oils are also from Jurassic reservoirs, but contain lower Pr/Ph and Neo/Nor ratios than B1 oils (Fig. 23c). Sub-Group B4 includes oils in Triassic and Lower Jurassic reservoirs with low Pr/Ph ratios (1.2-1.4).

Although isotope data are available for only seven oils (Fig. 13c), the isotope patterns strongly support the oil family classification based on molecular data. All investigated oils in Lower Cretaceous reservoirs show similar isotope patterns justifying their grouping into a single oil family (Sub-Group B3). By contrast the only investigated Group A oil (Urozhaynoe-52) displays a unique isotope pattern. In addition, isotope patterns of oils from Jurassic reservoirs classified as Sub-Group B1 (Ozek-Suat-260, Urozhenoe-92) and Sub-Group B3 (Bezvodnen-124) vary significantly.

**Oil-to-source considerations**

Group A oils in the Prikumsk Swell are characterized by high C_{28}/C_{30} sterane ratios and contain at least minor amounts of oleanane. Moreover, HCA showed a clear genetic relationship with Group A oils in the Terek-Caspian fold-and-thrust-belt. Hence, a Cenozoic
source rock (Khadum Formation, Kuma Formation) is very likely for Group A oils.

Group B contains oils with low C_{29}/C_{29} sterane ratios. This suggests a pre-Cenozoic and probably pre-Jurassic source rock for most oils and is supported by the absence of oleanane. HCA shows the presence of four sub-groups (B1-B4; Fig. 22). This indicates contributions by several probably Mesozoic source rocks. According to Ulmishek (2001), potential source rocks in the Mesozoic section include: (i) Lower Triassic thin-bedded, deep-water clayey limestones and shales; (ii) lower Bajocian dark-grey and black marine shales containing Type III-II kerogen; and (iii) thick Aptian-Albian marine clastic rocks with Type II-III kerogen; and (iii) thick Aptian-Albian marine clastic rocks with Type II-III kerogen; and (iii) thick Aptian-Albian marine clastic rocks with Type II-III kerogen. Unfortunately very little is known at present about these source rock intervals. Thus it remains speculative whether oils in Triassic and Lower Jurassic reservoirs with low Pr/Ph ratios (Sub-Group B4; Fig. 23e) were generated by Lower Triassic rocks; whether Jurassic oils with high Pr/Ph ratios (Sub-Group B1; Fig. 23b) were generated by Middle Jurassic rocks with a high contribution of Type III kerogen; and whether Cretaceous oils (Sub-Group B3; Fig. 23d) were generated by Cretaceous source rocks.

Mixing of oils probably occurred. Indications for significant oil migration include the presence of Group A oil in Triassic and Cretaceous reservoirs. In any case, biomarker and isotope studies on potential Mesozoic source rocks are urgently required.

**CONCLUSIONS**

Analysis of geochemical parameters of oils from the Terek-Caspian fold-and-thrust belt and the Prikumsk Swell, together with new data on the Khadam Formation (lower part of the Maikop Group) from the Chirkey outcrop section in Dagestan, provides new insights into the petroleum system of the Terek-Caspian foredeep in the northern foreland of the Eastern Caucasus.

**Terek-Caspian fold-and-thrust belt**

Shallow oils in the Terek-Caspian fold-and-thrust belt are biodegraded. However apart from that, the oils are relatively uniform in spite of their considerable lateral distribution (over >300 km), their great depth variation (between ~100 m and 5700 m), and the wide variety of reservoir rocks (Cretaceous to Miocene). Variations in biomarker compositions are mainly controlled by maturity (0.70-1.15 %R_{o}) and it is therefore difficult to distinguish between maturity and facies effects. For example, a downward increase in diasterane/sterane ratios may indicate a change in source rock facies or may be attributed to higher maturity. Vertical migration is evidenced by the comparison of oil maturity with the maturity-depth trend of the sedimentary succession.

Hierarchical cluster analysis groups all oil samples from the Terek-Caspian fold-and-thrust belt into a single tribe (Group A), which can be subdivided into three sub-groups. Currently, it is not clear if these sub-groups define distinct oil families or reflect maturity variations.

The presence of oleanane in most oils indicates an Upper Cretaceous or Cenozoic source rock. Oil-to-source correlation using biomarker and isotope data suggests that the Lower Oligocene Khadum Formation is the main source rock for oil in the Terek-Caspian fold-and-thrust belt, despite its typically relatively poor oil potential. Based on an extrapolation of data from the Rioni Basin, Georgia, the prolific Middle Eocene Kuma Formation source rock, as present at the analysed location, probably did not contribute significantly to the accumulated oils. Organic-rich rocks deposited during Cretaceous and Paleogene anoxic events may be responsible for some oils with very negative values of δ^{13}C.

**Prikumsk Swell**

Most oils from Triassic to Cretaceous reservoirs in the Prikumsk Swell differ significantly from those in the Terek-Caspian fold-and-thrust belt. They are typically characterized by the absence of oleanane and by low C_{29}/C_{29} sterane ratios (Group B oils). This together with the regional geology suggests a Mesozoic source for the accumulated oils. Several oil families can be defined (Sub-Groups B1 to B4) within a relatively small study area (~500 km²), suggesting that there are several active source rocks within the Triassic to Cretaceous succession. Three oil samples with high C_{29}/C_{29} sterane ratios and minor amounts of oleanane are genetically related to Group A oils in the Terek-Caspian fold-and-thrust belt. A Cenozoic (or Upper Cretaceous) source rock is likely for these oils.

**ACKNOWLEDGEMENTS**

The authors thank Y. Gavrilov for providing the rock samples from the Chirkey section, and RosNeft for providing the oil samples. They also gratefully acknowledge technical support by staff members at Montanuniversitaet Leoben (R. Gratzer, D. Gross, D. Misch, G. Nobis). They warmly thank the JPG reviewers H. I. Petersen (GEUS Copenhagen), N. Oblasov (Tomsk) and G. van Graas (Lysaker) whose comments significantly improved the manuscript.

**REFERENCES**

AGHAIEVA, V., SACHSENHOFER, R. F., VAN BAAK, C.G.C., BECHTEL, A., HOYLE, T., SELBY, D., SHEYANOVA, N. and VINCENT, S., 2021.
New geochemical insights into Cenozoic source rocks in Azerbaijan: Implications for petroleum systems in the South Caspian region. Journal of Petroleum Geology, 44, 3, 349-384, this issue.

BecTeh, A., MoVSuoMova, U., StroBli, S.A.I., SasCheNoHoFeR, R.F., SolSuMan, A., GrAtzEr, R. and PuTtMann, W., 2013. Organofacies and paleoenvironment of the Oligocene Maiakop series of Angharakan (Eastern Azerbaijan). Organic Geochemistry, 56, 51-67.

BeNoMovoVski, N.A.LeeKEr, A.S., OveCheKopa, M.N. and oBeHaNSuLi, H., 2003. Middle to Upper Eocene Eocene dioxane-anoxic Kuma Formation (northeast Peri-Tethys): Biotratigraphy and paleoenvironments. In: WIng, S.L., GiNerCHeR, P.D., SchChtZ, B. and Thomas, E. (Eds.), Causes and Consequences of Globally Warm Climates in the Early Paleogene: Boulder, Colorado, Geological Society of America Special Paper 369, 95-112.

BeCKBoURN, G., TeVzaDzE, N., JannA-VuHVL, E. and AnALia, V., 2021. South Caucasus palaeogeography and prospectivity: elements of petroleum systems from the Black Sea to the Caspian. Journal of Petroleum Geology, 44, 3, 247-298.

BooTe, D.R.D., SasCheNoHoFeR, R.F., TaN, G. and ARBoUille, D. 2018. Petroleum provinces of the Paratethyan region. Journal of Petroleum Geology, 41 (3), 247-298.

CoNNAN, J. and CaSSOU, A.M., 1980. Properties of gases and petroleum lipids derived from terrestrial kerogen at various maturation levels. Geochimica et Cosmochimica Acta, 44, 1-23.

ErshoV, A.V., BrUnET, M.-F., NIKishIN, A.N., BoLoToV, S.N., NaZAREvICh, B.P. and KoroToEvA, M.V. 2003. Northern Caucasus basin: thermal history and synthesis of subsidence models. Sedimentary Geology, 156, 95-118.

GiAVrLoV, Yu.O., SchCHeRBNika, E.A. and oBeHaNSuLi, H., 2003. Paleocene/Eocene boundary events in the Northeastern Peri-Tethys. In: WIng, S.L., GiNerCHeR, P.D. and SchChtZ, B. (Eds.), Causes and Consequences of Globally Warm Climates in the Early Paleogene. Geol. Soc. Am. Spec. Paper 369, 147-168.

GiAVrLoV, Y.O., SchCHeRBNika, E.A., GoLoVoNANoVa, O.V. and PoKROVskiY, B.G., 2013. The Late Cenomanian Paleoeological Event (OAE 2) in the Eastern Caucasus Basin of Northern Peri-Tethys. Lithology and Mineral Resources, 48, 457-488.

GiAVrLoV, Y.O., SchCHeRBNika, E.A., GoLoVoNANoVa, O.V., NEuduN, R.I. and PoKROVskiY, B.G., 2017. Sedimentary environments and geochemistry of Upper Eocene and Lower Oligocene rocks in the NE Caucasus. Lithology and Mineral Resources, 52, 447-466.

GiAVrLoV, Y.O., SchCHeRBNika, E.A., GoLoVoNANoVa, O.V. and PoKROVskiY, B.G., 2021. Stratigraphy, sedimentology and geochemistry of the Oligocene – Lower Miocene Maiakop Group in Dagestan, NE Caucasus. Journal of Petroleum Geology, 44, 3, 385-412 this issue.

GiLmuNOV, I.V., MaLOViclViK, J.P., MoToRoV, A.A. and SEn, B.V., 2004. Regional geology and oil and gas potential of the Caspian Sea. Moscow: Nedra-Biznescentr: 342 p.p (in Russian).

GoNCAnaRoV, I., SaMoLeKoN, V., ObLAsoN, N. and FaDeiVA, S., 2015. MDBT estimation ratio for transformation organic matter ratio in Bazhenov Formation of Western Siberia (Tomsk Basin). In: 3rd International Conference Series: Earth and Environmental Science, 24, 012040, doi:10.1088/1755-1315/24/1/012040.

GrAnThAM, P.J. and WaKeFieLD, L.L., 1988. Variations in the stearic carbon number distributions of marine source rock derived crude oils through geological time. Organic Geochemistry, 12, 61-73.

GiNgR, K., DaMeySY, R., GiLuCNA, A. and WaNG, S., 2008. An improved and rapid 5A molecular sieve method for gas chromatography isotope ratio mass spectrometry of n-alkanes (C29-C35). Organic Geochemistry, 39, 284-288.

HuGHeS, W.B., HoULa, A.G. and Dzou, L.I.P., 1995. The ratios of dibenzothiophene to phenanthrene and pristane to phytane as indicators of depositional environment and lithology of petroleum source rocks. Geochimica et Cosmochimica Acta, 59, 3581-3598.

KhAN, V.E., 1994. Geology of Northern Eurasia (ex-USSR territory). Stuttgart-Berlin: Schweizerbart-Bohrtrager.

Mayer, J., SasCheNoHoFeR, R.F., UNGuReANU, C., BecTeL, A., GrAtzEr, R., SveyDA, M. and TaRi, G., 2018. Petroleum Charge and migration in the Black Sea: Insights from oil and source rock geochemistry. Journal of Petroleum Geology, 41, 337-350.

Nikishin, A.M., ClOttingH, S., BrUnET, M.-F., STEPhoNsoN, R.A., BoLoToV, N. and ErShoV, A., 1998. Sychtian Platform, Caucasus and Black Sea region: Mesozoic–Cenozoic teconnic history and dynamics. In: Crasquin-Soleau, S., Barrier, E. (Eds), Peri-Tethys Memoir 3: Stratigraphy and Evolution of Peri-Tethyan Platforms. Mémoires du Muséum National d’Histoire Naturelle, Paris, 163-176.

Nikishin, A.M., ZieGler, P.A., PaNoV, D.I., NaZarevich, B.P., BrUnET, M.-F., STEPhoNsoN, R.A., BoLoToV, S.N., KoRoToEVA, M.V. and TkhomBoR, P.L., 2001. Mesozoic and Cenozoic evolution of the Syrtanian Platform–Black Sea–Caucasus domain. In: ZieGler, P.A., CrAziWa, W., RoBERTsoN, A. H.F. and CrAsQuin-soLeAU, S. (Eds), Peri-Tethys Memoir 6: Petroleum-Rocks/Wrench Basins and Passive Margins. Mémoires du Muséum National d’Histoire Naturelle, 186, 295–346.

NyToT, H.P., BojesEN-KoefoEd, J.A., ChrisTANSEN, F.G. and FoWler, M.G., 2002. Oleaneane or lupane? Reappraisal of the presence of oleaneane in Cretaceous–Tertiary oils and sediments. Organic Geochemistry, 33, 1225-1240.

ObLAsoN, N.V., GoNCHArOv, I.V., DErDuga, A.V. and KuNiSTyNa, I. V., 2020. Genetic Types of Crude Oil in the Eastern Part of the Crimea–Caucasus Area. Geochemistry International, 58, 1278-1298.

PeDeNCtHoUR, N. and TURICH, C., 2017. Carbon and hydrogen isotopic compositions of methane as a tool in petroleum exploration. In: Lawson, M., ForMolDO, M.J. and ELeR, J. M. (Eds), From Source to Seep: Geochemical Applications in Hydrocarbon Systems. Geol. Soc. Lond., Spec. Publ., 468, 105-125. https://doi.org/10.1144/SP468.1.

PeTeRi, K.E. and MoLDOWAN, J. M., 1993. The Biomarker Guide. Prentice Hall, New Jersey.

PeTeRi, K.E., WaLTeRS, C. C. and MoLDOWAN, J. M., 2005. The Biomarker Guide: Biomarkers and Isotopes in Petroleum Exploration and Earth History, volume 2. 2nd ed., Cambridge University Press.

PoPOV, S.V., ROtT, R., RAZNOv, A.Y., SCHeRCHER, I.G. and KoNaC, M., 2004. Lithological Paleogeographic maps of Paratethys. 10 Maps Late Eocene to Pliocene, Volume 250. Courrier Forschungsinstitut Senckenberg.

PuPP, M., BeCteL, A., CoRIC, S., GrAtzEr, R., RuStAMoV, A. and SasCheNoHoFeR, R.F., 2018. Eocene and Oligo-Miocene source rocks in the Rioni and Kura Basins of Georgia: Depositional environment and petroleum potential. Journal of Petroleum Geology, 41, 367-392. doi:10.1111/jpet.12708.

RaDKe, M. and WELTe, D.H., 1983. The methylphenanthrene index (MPI): a maturity parameter based on aromatic hydrocarbons. In: Bjoroy, M. (Ed.), Advances in Organic Geochemistry. Wiley, Chichester, 504-512.

RaDKe, M., WELTe, C, and WELTe, D.H., 1980. Preparative hydrocarbon gas chromatography. In: CASIA, G., BocK, M. and STEPHAn, T., Advances in Organic Geochemistry 1987 (Proc. 13th Intl. Mtg on Org. Geochem., Venice), Oxford, Pergamon Press, p. 671-676.

SoCHAs, R.F., PoPOV, S.V., ArcH MeTTeV, M.A., BeCteL, A., GrAtzEr, R., GoRSs, D., HORSFieLD, B., RaCHeTTi, A., RuPPReCHT, B.J., SCHaFFMaN, W.B. and ZaPORZhZeTS, N.L., 2017. The type section of the Maiakop Group (Oligocene-Lower Miocene)
at the Belaya River (North Caucasus): Depositional environment and hydrocarbon potential. AAPG Bulletin, 101, 289-319.

Sachsenhofer, R.F., Popov, S.V., Bechtel, A., Coric, S., Francu, J., Gratzer, R., Grunert, P., Kotarba, M., Mayer, J., Pupp, M. and Rupprecht, B.J., 2018a. Oligocene and Lower Miocene source rocks in the Paratethys: Palaeogeographic and stratigraphic controls. In: Simmons, M. (Ed.), Petroleum Geology of the Black Sea. Geol. Soc. Lond., Spec. Publ., 464, 267-306.

Sachsenhofer, R.F., Popov, S.V., Coric, S., Mayer, J., Misch, D., Morton, M.T., Pupp, M., Rauball, J. and Tari, G., 2018b. Paratethyan petroleum source rocks: An overview. Journal of Petroleum Geology, 41, 219-245.

Sachsenhofer, R.F., Bechtel, A., Gratzer, R., Enukidze, O., Janashvili, A., Nachtmann, W., Sanishvili, A., Tievadze, N. and Yukler, M.A., 2021. Petroleum systems in the Rioni and Kura Basins of Georgia. Journal of Petroleum Geology, 44, 3, 287-316, this issue.

Saintot, A., Brunet, M.-f., Yakovlev, F., Sébrier, M., Stephenson, R., Erklov, F., Chalot-Prat, F. and McCann, T., 2006. The Mesozoic-Cenozoic tectonic evolution of the Greater Caucasus. In: D. Gee and R. Stephenson (Eds), European Lithosphere Dynamics. Geol. Soc. London Mem., 32, 277-289, doi:10.1144/GSLMEM.2006.032.01.16.

SoBorov, K., 2021. Structure and evolution of the Terek-Caspian fold-and-thrust belt: New insights from regional seismic data. Journal of Petroleum Geology, 44, 3, 259-286 this issue.

UlmiShek, G.F., 2001. Petroleum Geology and Resources of the Middle Caspian Basin, Former Soviet Union. U.S. Geological Survey Bulletin 2201-A, 38 pp.

Van Kaam-Peters, H.M.E., Koster, J., Van der Gaast, S.J., Derks, M., de Leeuw, J.W. and Shingling-Damste, J.S., 1998. The effect of clay minerals on diasterane/sterane ratios. Geochimica et Cosmochimica Acta, 62, 2923-2929.

Ward, J.H., 1963. Hierarchical grouping to optimize an objective function. Journal of the American Statistical Association, 58, 236-244.

Yandarbiev, N.Sh., 1983. Historical and genetic analysis of the prospects of oil and gas potential of the Mesozoic sediments of the Terek Trough. Ph.D thesis, Moscow State University, 256 pp (in Russian).

Yandarbiev, N.Sh., Krylov, O.V., Kozlova, E.V., Frolov, S.V., Kuranin, D.I., Naumchev, Y.K. and Zavyalova, A.P., 2014. Study of oil and gas generation in regions of activity and interests of Rosneft: South of Russia (Western and Eastern Ciscaucasia). Unpubl. report, Moscow State University, 262 pp. (in Russian).

Yandarbiev, N.Sh., Kozlova, E.V., Fadeeva, N.P., Krylov, O.V. and Naumchev, Yu.V., 2017a. Geochemistry of hydrocarbons of the Terek-Caspian trough. Georesources 2017, Special issue, part 2, 227-239 (in Russian).

Yandarbiev, N.Sh., Fadeeva, N.P., Kozlova, E.V. and Naumchev, Yu.V., 2017b. Khadum Formation of Pre-Caucasus region as potential source of oil shales: geology and geochemistry. Georesources 2017, Special issue, part 2, 208-226 (in Russian).

Yarkhovskii, A. A., Lukanova, O.O. and Bigun, P.V., 2010. Methodical aspects of assessment of organic matter type of the Khadum deposits of Central and Eastern Ciscaucasia region. Georesources 2010, 77-84 (in Russian).
| Borehole | Depth (m) | Age | n-Alkanes (μg/g oil) | Isoprenoids (μg/g oil) | n-C15/16 | n-C17 | C18/C19 | C20/C21 | C22/C23 | Pristane/Phytane | Pentanes | Pristane/Phytane |
|----------|-----------|-----|---------------------|----------------------|----------|-------|--------|---------|---------|-----------------|---------|----------------|
| Starogroznenskoe-5-48 | 125-135 | N.4 kg | 461 | 836 | 1.00 | 0.00 | 0.00 | 4.11 | 4.51 | 4.12 |
| Starogroznenskoe-395 | 690-698 | N.4 ch | 1458 | 2411 | 0.23 | 0.05 | 6.76 | 4.54 | 1.67 |
| Starogroznenskoe-662 | 1453-1463 | N.4 kg | 1407 | 4087 | 0.59 | 0.23 | 0.06 | 6.63 | 4.54 | 1.67 |
| Starogroznenskoe-163 | 1537-1564 | N.4 ch | 40723 | 9737 | 0.51 | 0.27 | 0.09 | 1.12 | 0.83 | 0.55 |
| Starogroznenskoe-692 | 4000-4050 | K.4 | 24487 | 5035 | 0.57 | 0.24 | 0.07 | 1.08 | 0.59 | 0.36 |
| Andreyev-1007 | 5613-5684 | K.4 | 67464 | 12983 | 0.57 | 0.24 | 0.07 | 1.08 | 0.56 | 0.33 |
| Oktyabrskoe-219-20 | 598-618 | N.4 ch | 34406 | 7644 | 0.29 | 0.09 | 1.12 | 0.84 | 0.56 | 1.69 |
| Oktyabrskoe-242 | 4223-4283 | K.4 | 41528 | 7854 | 0.57 | 0.24 | 0.07 | 1.08 | 0.56 | 0.34 |
| Goryachistochenskoe-104 | 4225-4275 | K.4 | 35420 | 7418 | 0.57 | 0.25 | 0.07 | 1.05 | 0.63 | 0.36 |
| Bragunskoe-87 | 4110-4128 | P.4 | 131444 | 27010 | 0.57 | 0.25 | 0.06 | 1.17 | 0.61 | 0.35 |
| Bragunskoe-34 | 4140-4185 | P.4 | 176911 | 35956 | 0.58 | 0.24 | 0.07 | 1.07 | 0.61 | 0.35 |
| North-Bragunskoe-10 | 4915-4933 | P.4 | 88026 | 19804 | 0.58 | 0.24 | 0.07 | 1.07 | 0.63 | 0.35 |
| North-Bragunskoe-80 | 4852-5012 | K.4 | 60945 | 12943 | 0.58 | 0.24 | 0.07 | 1.06 | 0.64 | 0.35 |
| Khayev-Kort-54 | 3118-3250 | K.4 | 60828 | 14248 | 0.56 | 0.26 | 0.05 | 1.08 | 0.62 | 0.38 |
| Pravoberezhnoe-174 | 4586-4597 | K.4 | 69347 | 15247 | 0.57 | 0.24 | 0.07 | 1.09 | 0.63 | 0.37 |
| Eldarov-99 | 4196-4252 | K.4 | 92369 | 13876 | 0.63 | 0.22 | 0.05 | 1.06 | 0.35 | 0.16 |
| Eldarov-98 | 3782-3864 | K.4 | 43833 | 8841 | 0.55 | 0.26 | 0.05 | 1.07 | 0.63 | 0.37 |
| Mineralnoe-25 | 5019-5037 | P.4 | 60381 | 12256 | 0.57 | 0.24 | 0.07 | 1.09 | 0.61 | 0.36 |
| North-Mineralnoe-10 | 5110-5153 | K.4 | 3786 | 13602 | 0.57 | 0.25 | 0.07 | 1.17 | 0.62 | 0.37 |

| Borehole | Depth (m) | Age | Steranes (μg/g oil) | C29 steranes | C22/23 steranes | Pristane/C27/28 steranes | Pristane/C29 steranes | Pristane/Phytane |
|----------|-----------|-----|-------------------|-------------|----------------|------------------------|------------------------|----------------|
| Starogroznenskoe-5-48 | 125-135 | N.4 kg | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Starogroznenskoe-395 | 690-698 | N.4 ch | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Starogroznenskoe-662 | 1453-1463 | N.4 kg | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Starogroznenskoe-163 | 1537-1564 | N.4 ch | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Starogroznenskoe-692 | 4000-4050 | K.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Andreyev-1007 | 5613-5684 | K.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Oktyabrskoe-219-20 | 598-618 | N.4 ch | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Oktyabrskoe-242 | 4223-4283 | K.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Goryachistochenskoe-104 | 4225-4275 | K.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Bragunskoe-87 | 4110-4128 | P.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Bragunskoe-34 | 4140-4185 | P.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| North-Bragunskoe-10 | 4915-4933 | P.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| North-Bragunskoe-80 | 4852-5012 | K.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Khayev-Kort-54 | 3118-3250 | K.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Pravoberezhnoe-174 | 4586-4597 | K.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Eldarov-99 | 4196-4252 | K.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Eldarov-98 | 3782-3864 | K.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| Mineralnoe-25 | 5019-5037 | P.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |
| North-Mineralnoe-10 | 5110-5153 | K.4 | 156.6 | 0.61 | 0.07 | 1.13 | 0.98 | 5.5 |

*Percentages and ratios have been calculated for ax (first value) and β (second value).*
Table 2. Stratigraphic distribution and geochemical characteristics of oils from the Terek-Sunzha Fold Zone studied by Yandarbiev et al. (2017a). Field locations in Fig. 4.
FID: flame ionization detector. CPI: carbon preference index.

Table 3. Carbon isotope ratios (‰ V-PDB) of individual n-alkanes and isoprenoids in oil samples from the Terek-Caspian fold-and-thrust belt (Terek-Sunzha Fold Zone; Dagestan Promontory: Maritime Zone) and the Prikumsk Swell.
Table 4. Geochemical parameters of oils from the central and SE parts of the Terek-Caspian fold-and-thrust belt (Dagestan Promontory, Maritime Zone). FID: flame ionization detector. CPI: carbon preference index.
Field locations in Fig. 4.

| Borehole       | Sampling interval (m) | Reservoir | Pr/n-C_{17} | Ph/n-C_{18} | Pr/Ph | CPI     |
|----------------|-----------------------|-----------|-------------|-------------|-------|---------|
| Shambhal-Bulak | 3874-3904              | K_{1}     | 0.61        | 0.33        | 2.13  | FID     |
| Dimitrovskoe-42 | 3442-3471             | K_{1}     | 0.74        | 0.39        | 2.17  | FID     |
| Dimitrovskoe-38 | 3466-3487             | K_{1}     | 0.74        | 0.40        | 2.13  | FID     |
| Dimitrovskoe-22 | 3795-3861             | K_{1}     | 0.70        | 0.40        | 2.09  | FID     |
| Dimitrovskoe-30 | 3812-3844             | K_{1}     | 0.53        | 0.29        | 2.23  | FID     |
| Dimitrovskoe-25 | 4107-4177             | K_{1}     | 0.40        | 0.23        | 2.04  | FID     |
| Izberbash-190   | 1794-1802              | N_{2} ch  | 0.87        | 0.56        | 1.69  | FID     |
| Izberbash-270   | 1800-1824              | N_{2} ch  | 0.90        | 0.57        | 1.71  | FID     |
| Izberbash-248   | 3630-3748              | K_{1}     | 0.61        | 0.34        | 2.19  | FID     |

Table 5. Biomarker parameters of oils from the eastern Terek-Caspian fold-and-thrust belt (Dagestan Promontory/Mariette Zone). *Percentages and ratios have been calculated for \( \alpha \)α and \( \beta \)β steranes (first and second value, respectively). Field locations in Fig. 4.

| Borehole       | Depth (m) | Age | Triyclic Taran. | Hopanes | Steranes | CPI     |
|----------------|-----------|-----|----------------|---------|----------|---------|
| Shambhal-Bulak | 3874-3904 | K_{1} | 27.1           | 37.4    | 35.5     | FID     |
| Dimitrovskoe-42 | 3442-3471 | K_{1} | 17.1           | 31.9    | 31.0     | FID     |
| Dimitrovskoe-22 | 3795-3861 | K_{1} | 26.3           | 42.1    | 31.6     | FID     |
| Dimitrovskoe-30 | 3812-3844 | K_{1} | 23.4           | 20.4    | 36.3     | FID     |
| Izberbash-270   | 1800-1824 | N_{2} ch | 9.8          | 52.6    | 37.6     | FID     |
| Izberbash-248   | 3630-3748 | K_{1} | 29.3           | 34.9    | 45.8     | FID     |

Table 5. Cont’d

| Borehole       | 21S(21S+21R) | 21R/21S | CPI     |
|----------------|-------------|---------|---------|
| Shambhal-Bulak | 0.59        | 0.92    | 1.10    |
| Dimitrovskoe-42 | 0.58        | 1.55    | 0.86    |
| Dimitrovskoe-22 | 0.65        | 0.74    | 0.84    |
| Dimitrovskoe-30 | 0.61        | 2.64    | 1.00    |
| Izberbash-270   | 0.61        | 0.70    | 0.64    |
| Izberbash-248   | 0.69        | 1.74    | 1.12    |
Table 6. Physico-chemical properties, oil fractions and results of gas chromatographic studies of oils from the Prikumsk Swell. Roman numbers denote reservoir layers.
FID – flame ionization detector. Field locations in Fig. 16. 1Parameters used for hierarchical cluster analysis of Group B oils.

| Borehole          | Age  | Depth, m | Viscosity \(\nu^{0.5}\) cSt | Density \(\rho^{20}\) (kg/m³) | Initial boiling point, °C | Output of gasoline fraction to 200°C % | Hydrocarbons | Fractions (%) | Asphalts | Pristane/ Phytane \(\text{n-C}_{15}\) | Pristane/ Phytane \(\text{n-C}_{20}\) | n-alkanes | Acyclic isoprenoids | n-alkenes |
|-------------------|------|----------|-------------------------------|-------------------------------|--------------------------|-------------------------------------|--------------|--------------|----------|----------------------|----------------------|-----------|----------------------|-----------|
| Ozek-Suat-248     | B II | 3306-3323| 2.54                          | 0.8305                       | 62                       | 15                                  | 71.5         | 22.6         | 3.5       | 1.1                  | 1.3                  | FID       | FID                  | FID       |
| Ozek-Suat-262     | B II-III | 3314-3308| 1.80                          | 0.8138                       | 66                       | 20                                  | 70.8         | 24.6         | 2.0       | 1.9                  | 0.7                  | FID       | FID                  | FID       |
| Ozek-Suat-260     | B IV  | 3314-3310| 1.80                          | 0.8106                       | 67                       | 20                                  | 74.5         | 20.9         | 3.7       | 1.5                  | 0.3                  | 2.08      | 0.34                 | 0.15      |
| Ozek-Suat-158     | K1 VII | 3228-3292| 1.80                          | 0.8106                       | 67                       | 20                                  | 75.2         | 19.1         | 3.3       | 1.7                  | 0.7                  | 1.59      | 0.25                 | 0.14      |
| Ozek-Suat-50      | K1 IX | 3184-3192| 3.60                          | 0.8417                       | 72                       | 13                                  | 74.8         | 19.3         | 3.4       | 1.7                  | 0.8                  | 1.50      | 0.22                 | 0.14      |
| Russky Khutor-76  | K1 XII | 3228-3235| 2.65                          | 0.8297                       | 65                       | 10                                  | 73.7         | 24.4         | 1.7       | 0.2                  | -                    | 1.71      | 0.20                 | 0.13      |
| Russky Khutor-101 | K1 XII | 3162-3165| 1.69                          | 0.8235                       | 68                       | 18                                  | 70.2         | 22.7         | 4.0       | 1.9                  | 1.2                  | 1.70      | 0.19                 | 0.12      |
| Russky Khutor-98  | J III | 3285-3289| 1.06                          | 0.8185                       | 87                       | 26                                  | 71.2         | 26.7         | 0.6       | 1.5                  | -                    | 1.73      | 0.21                 | 0.14      |
| Russky Khutor-77  | K1IX   | 3186-3181| 1.48                          | 0.8420                       | 69                       | 20                                  | 64.2         | 27.8         | 2.7       | 3.5                  | 1.8                  | 1.68      | 0.19                 | 0.13      |
| Russky Khutor-90  | K1 IX  | 3150-3145| 6.03                          | 0.8244                       | 86                       | 20                                  | 74.7         | 22.6         | 2.4       | 0.3                  | -                    | 1.95      | 0.22                 | 0.13      |
| Zimnyaya Stavka-177 | J VII | 3404-3407| -                             | -                            | -                        | -                                  | 72.4         | 20.9         | 1.7       | 1.6                  | 3.4                  | 1.23      | 0.25                 | 0.22      |
| Zimnyaya Stavka-208 | J VII | 3420-3422| -                             | -                            | -                        | -                                  | 71.6         | 21.6         | 2.1       | 2.8                  | 1.9                  | 1.27      | 0.26                 | 0.24      |
| Zimnyaya Stavka-116 | K1 IX | 3034-3096| 5.40                          | 0.8522                       | 65                       | 9                                   | 73.1         | 21.2         | 1.3       | 2.7                  | 1.7                  | 1.69      | 0.20                 | 0.13      |
| Zimnyaya Stavka-124 | K1 VIII | 3090-3091| 5.40                          | 0.8401                       | 65                       | 11                                  | 74.1         | 21.2         | 1.6       | 1.8                  | 1.3                  | 1.59      | 0.23                 | 0.15      |
| Urotnoye-92       | J VII | 3510-3517| 4.34                          | 0.8103                       | 56                       | 21                                  | 73.1         | 21.5         | 1.5       | 1.2                  | 0.7                  | 2.14      | 0.20                 | 0.10      |
| Urotnoye-52       | K2 I  | 2423-2428| 5.08                          | 0.8296                       | 72                       | 12                                  | 59.7         | 26.7         | 6.1       | 4.3                  | 3.4                  | 1.74      | 0.82                 | 0.52      |
| Baylyanov-101 81  | T II f | 4249-4300| -                             | 0.9103                       | -                        | -                                  | 76.3         | 19.4         | 1.1       | 3.2                  | -                    | 1.30      | 0.20                 | 0.17      |
| Baylyanov-108     | K1 VII | 3137-3143| -                             | -                            | -                        | -                                  | 1.55         | 0.25         | 0.17     | 0.17                 | 0.77                 | 1.72      | 0.83                 | 0.53      |
| Bezvodnen-124     | J III | 3246-3251| -                             | -                            | -                        | -                                  | 1.59         | 0.20         | 0.14     | 0.17                 | 0.37                 | 1.63      | 0.26                 | 0.19      |
| Bezvodnen-84      | K1 VII | 3131-3121| -                             | -                            | -                        | -                                  | 1.59         | 0.20         | 0.14     | 0.17                 | 0.37                 | 1.63      | 0.26                 | 0.19      |
| Velichayev-43     | T     | 3512-3520| -                             | -                            | -                        | -                                  | 1.59         | 0.20         | 0.14     | 0.17                 | 0.37                 | 1.63      | 0.26                 | 0.19      |
| Velichayev-20     | J VII | 3427-3431| -                             | -                            | -                        | -                                  | 1.59         | 0.20         | 0.14     | 0.17                 | 0.37                 | 1.63      | 0.26                 | 0.19      |
| Velichayev-16     | K2 VIII | 2525-2529| -                             | -                            | -                        | -                                  | 1.59         | 0.20         | 0.14     | 0.17                 | 0.37                 | 1.63      | 0.26                 | 0.19      |
| Sredinnoe-1       | T II f | 3850-3900| -                             | -                            | -                        | -                                  | 1.59         | 0.20         | 0.14     | 0.17                 | 0.37                 | 1.63      | 0.26                 | 0.19      |
Table 7. Results of GC-MS analysis of oils from the Priukumsk Swell. Roman numbers denote reservoir layers. Field locations in Fig. 4.

| Borehole     | Age  | Tricyclic terpen. % | Pentacyclic terpen. % | Steranes % | C29 Diasteranes/ C27 Steranes* | C27 / Sum Steranes* | C28 / Sum Steranes* | 205/[205+20R] | ββ / (ββ+ααα) | C28 / C29 Steranes* | Tfs / Tsi+m |
|--------------|------|---------------------|-----------------------|------------|-----------------------------|-----------------|-----------------|---------------|----------------|-------------------|-------------|
| Ibid         | 191  | 191                 | 217                   | 217, 218, 259 | 217                         | 217/218         | 217/218         | 217           | 217           | 217               | 217/217     |

*Percentages and ratios have been calculated for ααα (first value) and βββ steranes (second value).

1Parameters used for hierarchical cluster analysis of Group B oils.
Table 8. Source rock parameters of samples from the Chirkey outcrop section, Dagestan. Height is above base-Maikop Group. Location in Fig. 4; sample positions in Fig. 7.

| Sample  | Height (m) | Formation/Subformation | Calc_{S_i} | TOC | S | T_{min} | CPI | HI |
|---------|------------|-------------------------|-----------|-----|---|---------|-----|----|
| dag-607 | 96.0       | Solonov                 | 0.00      | 2.42| 3.54| 0.7    | 0.38| 2.38| 441 |
| dag-574 | 49.9       | Solonov                 | 0.00      | 4.58| 3.42| 1.3    | 1.53| 4.29| 437 |
| dag-561 | 43.5       | Pshikh                  | 0.01      | 3.52| 0.86| 4.1    | 0.21| 4.82| 439 |
| dag-453 | 33.9       | Pshikh                  | 0.01      | 2.46| 0.06| 40.0   | 47.48| 443 |
| dag-466 | 20.7       | Pshikh                  | 30.06     | 1.62| 0.03| 57.6   | 0.16| 1.10| 442 |
| dag-517 | 2.7        | Pshikh                  | 38.54     | 1.15| 0.03| 37.1   | 0.31| 1.43| 449 |
| dag-213 | -13.7      | Belaya Glinka           | 58.48     | 0.14| 0.01| 22.5   | 0.01| 0.04| 29  |

Calc_{S_i}: Calcare equivalent percentages.
TOC: Total organic carbon.
S: Sulphur.
S:S: free hydrocarbons.
S: generated hydrocarbons.
T_{min}: temperature of maximum hydrocarbon generation.
HI: Hydrogen index.

Table 9. Geochemical characteristics of rock samples from the Chirkey outcrop section.

| Sample  | Height (m) | Formation/Subformation | Calc_{S_i} | TOC | S | T_{min} | CPI | HI |
|---------|------------|-------------------------|-----------|-----|---|---------|-----|----|
| dag-607 | 96.0       | Solonov                 | 0.00      | 2.42| 3.54| 0.7    | 0.38| 2.38| 441 |
| dag-574 | 49.9       | Solonov                 | 0.00      | 4.58| 3.42| 1.3    | 1.53| 4.29| 437 |
| dag-561 | 43.5       | Pshikh                  | 0.01      | 3.52| 0.86| 4.1    | 0.21| 4.82| 439 |
| dag-453 | 33.9       | Pshikh                  | 0.01      | 2.46| 0.06| 40.0   | 47.48| 443 |
| dag-466 | 20.7       | Pshikh                  | 30.06     | 1.62| 0.03| 57.6   | 0.16| 1.10| 442 |
| dag-517 | 2.7        | Pshikh                  | 38.54     | 1.15| 0.03| 37.1   | 0.31| 1.43| 449 |
| dag-213 | -13.7      | Belaya Glinka           | 58.48     | 0.14| 0.01| 22.5   | 0.01| 0.04| 29  |

Calc_{S_i}: Calcare equivalent percentages.
TOC: Total organic carbon.
S: Sulphur.
S:S: free hydrocarbons.
S: generated hydrocarbons.
T_{min}: temperature of maximum hydrocarbon generation.
HI: Hydrogen index.

Table 9 (cont.).

| Sample  | Height (m) | Formation/Subformation | Calc_{S_i} | TOC | S | T_{min} | CPI | HI |
|---------|------------|-------------------------|-----------|-----|---|---------|-----|----|
| dag-607 | 96.0       | Solonov                 | 0.00      | 2.42| 3.54| 0.7    | 0.38| 2.38| 441 |
| dag-574 | 49.9       | Solonov                 | 0.00      | 4.58| 3.42| 1.3    | 1.53| 4.29| 437 |
| dag-561 | 43.5       | Pshikh                  | 0.01      | 3.52| 0.86| 4.1    | 0.21| 4.82| 439 |
| dag-453 | 33.9       | Pshikh                  | 0.01      | 2.46| 0.06| 40.0   | 47.48| 443 |
| dag-466 | 20.7       | Pshikh                  | 30.06     | 1.62| 0.03| 57.6   | 0.16| 1.10| 442 |
| dag-517 | 2.7        | Pshikh                  | 38.54     | 1.15| 0.03| 37.1   | 0.31| 1.43| 449 |
| dag-213 | -13.7      | Belaya Glinka           | 58.48     | 0.14| 0.01| 22.5   | 0.01| 0.04| 29  |

Oleanane: Oleanane/(Oleanane + C_{29}hopane).
Gammarocene: Gammarocene/(Gammarocene + C_{29}hopane).
DBT/Phen: Diolbenzophenone/phenanthrene ratio.